

LIVESTOCK WATER PRODUCTIVITY: TOWARDS IMPROVING RURAL LIVELIHOODS FROM  
LIVESTOCK IN SEMI-ARID RANGELANDS.

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

In

Science

In the

Department of Environmental Science

Rhodes University

Grahamstown

By

Bukho Gusha

March 2019

## ABSTRACT

Communal rangelands in South Africa mainly occur in the former homelands. The former homelands constitute 13% of the land surface area and support a quarter of the country's human population with a wide range of goods and services, among them, grazing for livestock, mostly reared on communal rangelands. These rangelands are degraded and cannot sustain maximum livestock production because of poor species composition and low standing biomass, however research has been conducted on livestock production at household level (where all livestock goods and services are valued). This provides an opportunity to conduct a study describing livestock water productivity in the north of the Eastern Cape, where livestock production is a primary source of livelihood for rural communities from which many households generate cash but where different practices and factors undermine high livestock production.

Many studies have focused on understanding the water productivity of a natural rangeland system for commercially oriented crop-livestock systems, but the aim of this study is to contribute towards improving rural livelihoods from livestock in the sub-humid rangelands of the north Eastern Cape. Here, unimproved native grasslands are the major source of feed for livestock and people do not have herders to take livestock to the most productive parts of the rangelands.

Households were surveyed using a questionnaire on livestock household contribution, socio-economic characteristics of the household, livestock holdings and livestock production strategies. Rangeland productivity was measured in the field. Experimental animals for livestock grazing distribution were identified and fitted with Global Positioning Systems (GPS) collars to identify the seasonal grazing areas. These activities shed light on the biophysical attributes of the ecosystem and livestock production in a communal rangeland system.

Because continuous grazing in the rangelands of the north Eastern Cape reduces the standing biomass, there is no obvious aboveground biomass to provide a visual perspective of production nor is it possible to determine production without excluding the livestock. Thus, four parallel lines of evidence were employed to measure rangeland productivity: line intercept, grazing exclosures, net photosynthesis from earth observation and disc pasture meter. Earth observation products were used to derive the amount of water used by the

landscape to produce this forage (i.e. evapotranspiration or ET) and these measurements of net primary production and landscape water use were used in preparing a value of livestock water productivity (LWP) for this farming system.

There has been the perception that residents of the study area lack knowledge of technical efficiencies in the large stock sector at household level. The study used stochastic frontier analysis to assess livestock production and followed with a household survey to collect information on socio-economic characteristics and information on livestock practices. The data from the household survey were used to estimate the technical efficiency of households using a stochastic frontier analysis. Productivity and inefficiency variables that increase livestock production or increase technical difficulties were identified. The focus on livestock has mostly been on the direct value of livestock to owners with a poor understanding of their value to non-livestock owners, where cultural activities, such as livestock slaughtering, were documented as the only source of protein for non-livestock owners. However, the value that is available to non-livestock owners has not been quantified. This study assessed livestock-based livelihoods of communal people to improve their livelihoods through a household survey looking at the contribution of livestock to both livestock and non-livestock owners. Earlier work on LWP has focused on systems where animals were on 'fed, cut and carry' and irrigated systems. However, there is a need to describe LWP in a natural grazing system and this study set out to achieve this for these communal rangelands through a household survey that determined the value of livestock goods and services given the amount of water used (ET). Lastly, livestock grazing distribution across the landscape was assessed, using GPS collars that recorded livestock behaviour every five minutes during the daylight. This approach was necessary because livestock grazing patterns in these communal rangelands is poorly controlled by people, and animals are largely free-ranging, grazing selectively, based on their own preferences, which leads to localised overgrazing. This part of the study was achieved through experimental livestock collaring and weighing (both sheep and goats) for the wet and dry seasons. The collared livestock were weighed on the day of putting on collars and the day of removing the collars. The results on livestock grazing distribution were analysed using the R package, T-LoCoH.

The major finding of this study was that communal rangelands of the north Eastern Cape can improve rural livelihoods from livestock if proper interventions for both livestock and

rangeland production and productivity can be implemented. One of these interventions is fencing as it was found that exclosures that were fenced during the study yielded high aboveground productivity comparable to that achieved in commercial rangelands, yielding  $220 \text{ g DM m}^{-2} \text{ yr}^{-1}$ . Surveys using the calibrated disc pasture meter showed the need for proper rotation and resting of the rangeland. Net photosynthesis of  $880.7 \text{ g C m}^{-2} \text{ yr}^{-1}$  for unimproved grassland in good condition was comparable to commercial rangelands in the region. Using the line intercept, vegetation cover was found to be a good predictor of aboveground standing biomass; thus a positive relationship was revealed. Lastly, annual ET of  $270 \text{ mm yr}^{-1}$  was calculated using the Penman Monteith Palmer (PMP) equation, while  $379 \text{ mm yr}^{-1}$  was extracted from the MOD16 product, suggesting that PMP ET may not be accurate in these grassland systems due to the slow response of MODIS Leaf Area Index (LAI).

The average household technical efficiency (TE) score was found to be 0.79 on the study sites, indicating the potential for households to improve outputs from livestock. A range of household categories were identified, based on gender and an index of wealth, and households with lower and higher TE were identified. This analysis revealed that productivity variables such as holding higher livestock numbers and providing additional feed achieved high livestock outputs, suggesting high livestock productivity. However, in terms of inefficiency variables, gender (female-headed households), dwelling type (an index of homestead wealth), kraaling livestock at night and herding livestock during the day were found to improve technical efficiency. It was revealed in this study that households keep livestock to derive different goods and services including offtake, manure, milk, wool and services such as traction. The non-livestock owning households were reported to also benefit from the abovementioned goods and services in the study site and that the value of their contribution could be quantified, thus contributing significantly to rural livelihoods.

The study showed that LWP was comparable with other studies such as those conducted in Ethiopia. This study compared its results with the studies conducted outside South Africa as there were limited comparable South African studies available; however, this does not necessarily mean we can use the same model as the value of livestock outputs varies based on the preferred outputs. This study developed an LWP model for the natural rangeland system. The LWP values were measured in ZAR and later converted in USD and were divided

into three different categories based on the wealth index, such as better-off, middle wealth and poor households.

Lastly, this study showed that livestock (both cattle and sheep) spend a high proportion of their grazing day, during both the wet and dry seasons, in a small physical area, immediately around the homesteads. These are areas where the active green growth occurs throughout the year, suggesting the need for livestock herders to move livestock around the landscape for more effective landscape use. Herding has the potential to improve landscape use and conserve grazing resource and the ability of a household to attain best outputs from livestock. Positive daily weight gains were reported in collared livestock during the wet season. However, both sheep and cattle lost weight during the dry season.

This study recommends interventions such as labour for herding, and other animal husbandry-related activities including milking, handling, and vaccinating animals. Market opportunities for communal rangeland livestock should be facilitated by informing livestock owners about livestock market specifications to improve their livelihoods. Lastly, proper grazing management planning, such as fencing, which enables rotational grazing, and herding which moves animals to the most productive parts of the rangeland, should be implemented so that rangelands can be rested for plant growth, vigour, and improved aboveground net primary productivity. Based on the recommendations made in this study, a research development approach is necessary which prioritises female empowerment in agriculture and poor farmers as female-headed households were reported by this study to be more technically efficient.

Keywords: degradation, households, livestock outputs, livelihoods, technical efficiency, Eastern Cape Province, South Africa

## TABLE OF CONTENTS

ABSTRACT .....	i
LIST OF TABLES .....	x
LIST OF FIGURES .....	xi
ABBREVIATIONS AND ACRONYMS.....	xiii
ACKNOWLEDGMENTS .....	xvi
CHAPTER 1. GENERAL INTRODUCTION .....	1
1.1. Background .....	1
1.2. Overview of water productivity .....	5
1.2.1. Importance of water productivity.....	5
1.2.2. Livestock water productivity: Concept .....	6
1.2.3. Livestock water productivity (LWP) model .....	7
1.2.4. Livestock water productivity (LWP) framework .....	8
1.2.5. Livestock-water interaction .....	11
1.2.6. Factors affecting livestock water productivity .....	12
1.3. Strategies to improve livestock water productivity .....	13
1.3.1. Sourcing of feed and management.....	13
1.3.2. Enhancing animal productivity and herd size management.....	14
1.3.3. Conserving water resources.....	15
1.3.4. Allocation of livestock feed and drinking water .....	15
1.4. Biophysical attributes of the communal rangelands .....	16
1.5. Livestock production in communal rangelands .....	17
1.6. Livestock grazing distribution across the landscape in communal rangelands .....	19
1.7. Rural livelihoods in communal rangelands .....	20
1.8. Scope of the thesis.....	21
1.9. Aim .....	23
1.10. Key questions .....	23
1.11. Thesis outline .....	24
CHAPTER 2. THE BIOPHYSICAL ATTRIBUTES OF THE RANGELAND ECOSYSTEMS IN THE NORTH EASTERN CAPE COMMUNAL AREAS.....	26
ABSTRACT .....	26
2.1. Introduction .....	27
2.1.1. Satellite and ground-based instrument .....	28
2.1.2. The MODIS Leaf Area Index (LAI) .....	29

2.2. Materials and methods .....	32
2.2.1. Characteristics of the study site .....	32
2.2.2. Defining domains within a study site .....	33
2.2.3. MODIS LAI and MODIS ET data .....	34
2.2.4. Penman Monteith Palmer (PMP) equation. ....	34
2.2.5. Estimating vegetation cover and aboveground standing biomass .....	35
2.2.6. Estimating aboveground net primary productivity and calibrating disc pasture meter (DPM) .....	35
2.2.7. Assessment of net photosynthesis (PsnNet) .....	36
2.3. Results .....	37
2.3.1. Evapotranspiration.....	37
2.3.2. Relationship between aboveground standing biomass and vegetation cover.....	38
2.3.3. Calibration of ANPP and disc pasture meter (DPM) .....	39
2.3.4. Relationship between disc pasture meter and line intercept.....	40
2.3.5. Net photosynthesis for the best condition unimproved grassland. ....	41
2.4. Discussion.....	42
2.4.1. Evapotranspiration.....	42
2.4.2. Grass standing biomass and vegetation cover .....	43
2.4.3. Relationship between the disc pasture meter and the predicted ANPP .....	43
2.5. Conclusion and recommendations .....	45
CHAPTER 3. PERFORMANCE OF LIVESTOCK PRODUCTION IN THE NORTH EASTERN CAPE COMMUNAL AREAS, SOUTH AFRICA: A STOCHASTIC FRONTIER ANALYSIS.....	46
ABSTRACT .....	46
3.1. Introduction .....	47
3.2. Methodology.....	52
3.2.1. Sampling and data collection .....	52
3.2.2. Sampling approach: Estimating values of livestock goods and services.....	56
3.2.3. Stochastic frontier production function analysis (SFA).....	58
3.2.4. Technical inefficiency model.....	59
3.2.5. Statistical analysis .....	61
3.3. Results.....	62
3.3.1. Socio-economic characteristics of households .....	62
3.3.2. Parameters of ordinary least square and maximum likelihood estimates .....	63
3.3.3. Wealth status classification criteria .....	65

3.3.4. Distribution of technical efficiency scores among the different households .....	66
3.3.5. Frequency of performance based on the post-analysis performance classification .....	67
3.4. Discussion.....	69
3.4.1. Inefficiency model estimates .....	69
3.4.2. Technical efficiency scores.....	70
3.4.3. Determinants of technical efficiency in different performance profiles .....	71
3.5. Conclusion and recommendations .....	72
CHAPTER 4. ASSESSMENT OF HOUSEHOLD LIVESTOCK-BASED LIVELIHOODS IN THE NORTH EASTERN CAPE COMMUNAL RANGELANDS, SOUTH AFRICA. ....	74
ABSTRACT .....	74
4.1. Introduction .....	75
4.2. Materials and methods .....	78
4.2.1. Sampling approach and data collection.....	78
4.2.2. Statistical analysis .....	79
4.3. Results.....	80
4.3.1. Composition of livestock holdings in Mgwalana and Mahlungulu villages .....	80
4.3.2. Cattle holding in different households and dwelling type.....	81
4.3.3. Sheep holding in different households and dwelling type .....	82
4.3.4. Goat holding in different households and dwelling type .....	83
4.3.5. Contribution of livestock goods and services to livestock owning households.....	84
4.3.6. Contribution of livestock beneficial goods and services to non-livestock owners .....	85
4.3.7. Livestock sales from livestock owning households.....	86
4.3.8. Livestock grazing during the wet and dry seasons in Mgwalana and Mahlungulu village .....	87
4.4. Discussion.....	88
4.4.1. Livestock composition and ownership.....	88
4.4.2. Contribution of livestock to rural livelihoods .....	89
4.4.3. Benefits of livestock to non-livestock owners .....	91
4.4.4. Livestock grazing .....	91
4.5. Conclusion and recommendations .....	93
CHAPTER 5. DERIVING AN EVIDENCE-BASED ESTIMATE OF LIVESTOCK WATER PRODUCTIVITY IN COMMUNAL RANGELANDS IN THE NORTH EASTERN CAPE PROVINCE, SOUTH AFRICA. ....	94
ABSTRACT .....	94
5.1. Introduction .....	95
5.2. Materials and methods.....	97

5.2.1. Study site description.....	97
5.2.2. Farming system .....	98
5.2.3. Livestock water productivity (LWP) model/equation .....	98
5.2.4. Household survey design and data collection .....	99
5.2.5. Sampling approach: Estimating the value of livestock goods and services .....	100
5.2.6. Statistical analysis .....	101
5.3. Results.....	102
5.3.1. Household characteristics in different wealth groups.....	102
5.3.2. Household livestock types in different wealth group categories .....	104
5.3.3. Livestock beneficial goods and services in different wealth groups.....	104
5.3.4. Contribution of livestock goods and services to different wealth groups.....	106
5.4. Discussion.....	107
5.4.1. Household characteristics as the implication for livestock water productivity.....	107
5.4.2. Livestock water productivity.....	107
5.4.3. Livestock beneficial outputs .....	109
5.5. Conclusion and recommendations .....	110
CHAPTER 6. ASSESSING LIVESTOCK DISTRIBUTION IN COMMUNAL RANGELANDS OF THE EASTERN CAPE SOUTH AFRICA: TOWARDS MONITORING LIVESTOCK MOVEMENTS IN RANGELANDS. ....	111
ABSTRACT .....	111
6.1. Introduction .....	113
6.2. Materials and methods.....	117
6.2.1. Site description .....	117
6.2.2. Experimental animals.....	118
6.2.3. Description of the GPS equipment .....	119
6.2.4. Mounting GPS on livestock. ....	119
6.2.5. Data preparation, cleaning and generating Google Earth images.....	120
6.2.6. Time Local Convex Hull (T-LoCoH) R .....	121
6.2.7. Vegetation sampling .....	121
6.2.8. Normalised Difference Vegetation Index (NDVI) .....	122
6.2.9. Assessing animal live weights for daily weight gains.....	123
6.2.10. Data analysis .....	123
6.3. Results.....	125
6.3.1. Wet season cattle movement in the study area.....	125

6.3.2. Wet season movement of sheep in the study area .....	127
6.3.3. Dry season sheep movement in the study area .....	131
6.3.4. Google Earth images of cattle grazing during the wet season .....	134
6.3.5. Google Earth image of sheep grazing during the wet season .....	135
6.3.6. Google Earth images of cattle grazing during the dry season .....	136
6.3.7. Google Earth images of sheep grazing during the dry season.....	137
6.3.8. NDVI of the areas where livestock grazing occurs.....	137
6.3.9. Distribution of livestock by number of locations and time .....	140
6.3.10. Grass species composition in the grazing area .....	142
6.4. Discussion.....	143
6.4.1. Livestock grazing distribution patterns.....	143
6.4.2. Factors affecting grazing distribution .....	145
6.4.3. Livestock grazing distribution and implications for proper grazing management .....	146
6.5. Conclusion and recommendations .....	148
CHAPTER 7. CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH .....	149
7.1. Introduction .....	149
7.2. Key results.....	150
7.3. Implications for possible interventions in rangeland production and rural livelihoods.....	152
7.4. Conclusion.....	153
7.5. Recommendations for future study.....	154
REFERENCES .....	155
Appendix .....	179
Appendix 1. Example R script to sort and re-process raw Catlog collar data to correct time zone, projection and analysis using T-locoh .....	179
Appendix 2. Google Earth Engine script for determining Sentinel 2 NDVI values associated with the livestock grazing patterns. ....	186
Appendix 3. Example of a script for frontiers analysis .....	188

## LIST OF TABLES

TABLE 2.1. RELATIONSHIP IN THE DRY MATTER BETWEEN DISC PASTURE METER AND THE LINE INTERCEPT.....	40
TABLE 3.1(A). HOUSEHOLD INCOME BY DWELLING TYPE IN MGWALANA VILLAGE.....	53
TABLE 3.1(B). HOUSEHOLD DWELLING TYPE BY GENDER OF THE HOUSEHOLD HEAD IN MGWALANA VILLAGE.....	53
TABLE 3.1(C). HOUSEHOLD INCOME BY DWELLING TYPE IN MAHLUNGULU VILLAGE.....	54
TABLE 3.(1D). HOUSEHOLD DWELLING TYPE BY GENDER OF THE HOUSEHOLD HEAD IN MGWALANA VILLAGE.....	54
TABLE 3.2. SOCIO-ECONOMIC CHARACTERISTICS OF THE HOUSEHOLDS THAT WERE INTERVIEWED..	63
TABLE 3.3. A STOCHASTIC FRONTIER PRODUCTION FUNCTION PARAMETER AND ORDINARY LEAST SQUARE (OLS) AND MAXIMUM LIKELIHOOD ESTIMATE (MLE). .....	65
TABLE 3.4. LIVESTOCK WEALTH CLASSIFICATION CRITERIA .....	66
TABLE 4.1. ANNUAL CONTRIBUTION OF LIVESTOCK BENEFICIAL GOODS AND SERVICES TO RURAL HOUSEHOLDS.....	84
TABLE 4.2. CONTRIBUTION OF LIVESTOCK BENEFICIAL GOODS AND SERVICES TO NON-LIVESTOCK OWNERS PER ANNUM.....	85
TABLE 4.3. AVERAGE ANNUAL CONTRIBUTION OF LIVESTOCK OFFTAKE TO LIVESTOCK OWNERS (ZAR).....	86
TABLE 5.1. MEANS OF HOUSEHOLD CHARACTERISTICS AMONG WEALTH GROUPS.....	102
TABLE 5.2. MEAN LIVESTOCK WATER PRODUCTIVITY.....	103
TABLE 5.3. MEANS FOR LIVESTOCK BENEFICIAL GOODS AND SERVICES (ZAR) OF HOUSEHOLDS IN DIFFERENT WEALTH GROUPS.....	105
TABLE 6.1. LIVESTOCK DISTRIBUTION BY THE NUMBER OF LOCATIONS OVER TIME DURING THE WET AND DRY SEASONS IN MGWALANA VILLAGE.....	141
TABLE 6.2. OVERALL, MEAN PERCENTAGE ABUNDANCES OF SPECIES COMPOSITION IN MGWALANA VILLAGE.....	142

## LIST OF FIGURES

FIGURE 1.1. LIVESTOCK WATER PRODUCTIVITY (LWP) DEPENDS ON WATER ACCOUNTING PRINCIPLES AND HELPS IDENTIFY OPPORTUNITIES FOR MORE EFFECTIVE WATER USE. ....	10
FIGURE 2.1. MAP OF THE STUDY SITE REPRESENTING THE THREE RURAL RIVER CATCHMENTS T12A, S50E AND T35B.....	33
FIGURE 2.2. THE LOCATION OF THE AREA FROM WHICH VALUES FOR MODIS PSNET PRODUCTS WERE EXTRACTED AT THE MGWALANA VILLAGE. ....	36
FIGURE 2.3. THE MEAN ANNUAL EVAPOTRANSPIRATION FOR THREE GRAZING DOMAINS IN MGWALANA VILLAGE FOR THE YEAR 2001-2017. UG- UNIMPROVED GRASSLANDS, CL- CULTIVATED LANDS.....	37
FIGURE 2.4. THE RELATIONSHIP BETWEEN ABOVEGROUND GRASS BIOMASS AND GRASS COVER FROM 105 0.2 M <sup>2</sup> SUBPLOTS ALONG TWELVE 100 M LINE TRANSECTS. ....	38
FIGURE 2.5. CALIBRATION OF THE ABOVEGROUND BIOMASS AND THE DISC PASTURE METER READING AT THREE SITES. A) COMMUNAL GRAZING LAND, B) COMMUNAL GRAZING LAND C) COMMERCIAL GRAZING LANDS).....	39
FIGURE 2.6. THE NET PHOTOSYNTHESIS FOR THE UNIMPROVED GRASSLAND IN T12A (MGWALANA VILLAGE).....	41
FIGURE 3.1. LOCATION OF THE STUDY AREA IN QUATERNARY CATCHMENT T12A AND S50E .....	56
FIGURE 3.2. DISTRIBUTION OF TECHNICAL EFFICIENCY IN THE STUDY AREA. ....	67
FIGURE 3.3. FREQUENCY OF PRODUCTIVITY PERFORMANCE BY GENDER OF THE HOUSEHOLD HEAD AT MGWALANA AND MAHLUNGULU VILLAGE.....	68
FIGURE 4.1. LIVESTOCK COMPOSITION IN MGWALANA AND MAHLUNGULU VILLAGES.....	80
FIGURE 4.2. AVERAGE CATTLE HOLDING PER GENDER AND HOUSEHOLD DWELLING. ....	81
FIGURE 4.3. AVERAGE SHEEP HOLDING PER GENDER AND HOUSEHOLD DWELLING .....	82
FIGURE 4.4. AVERAGE GOAT HOLDING PER GENDER AND HOUSEHOLD DWELLING. ....	83
FIGURE 4.5. PERCEPTIONS BY LIVESTOCK OWNERS OF LIVESTOCK GRAZING PATTERNS DURING DRY AND WET SEASONS IN BOTH VILLAGES. ....	87
FIGURE 5.1. PROPORTION OF MEAN LIVESTOCK SPECIES AMONG HOUSEHOLD WEALTH GROUPS.....	104
FIGURE 5.2. PROPORTION OF ESTIMATED MEANS OF LIVESTOCK BENEFICIAL OUTPUTS CONTRIBUTED FROM LIVESTOCK (ZAR).....	106

FIGURE 6.1. STUDY SITE MAP IN THE QUATERNARY RIVE CATCHMENT T12A .....	118
FIGURE 6.2. CATTLE FITTED WITH THE GPS COLLAR IN THE GRAZING AREA. ....	120
FIGURE 6.3. A,B AND C ISOPLETHS CONSTRUCTED IN DIFFERENT HULLS, SORTED BY AREA, INDICATING PROPORTIONS OF THE TOTAL POINTS ENCLOSED BY CATTLE DURING THE WET SEASON.....	126
FIGURE 6.4. A,B AND C ISOPLETHS CONSTRUCTED IN DIFFERENT HULLS SORTED BY AREA INDICATING PROPORTIONS OF THE TOTAL POINTS ENCLOSED BY SHEEP DURING THE WET SEASON. ....	128
FIGURE 6.5. A,B AND C ISOPLETHS CONSTRUCTED IN DIFFERENT HULLS SORTED BY AREA INDICATING PROPORTIONS OF THE TOTAL POINTS ENCLOSED BY CATTLE DURING THE DRY SEASON.....	129
FIGURE 6.6. A,B AND C SOPLETHS CONSTRUCTED IN DIFFERENT HULLS SORTED BY AREA INDICATING PROPORTIONS OF THE TOTAL POINTS ENCLOSED BY SHEEP DURING THE DRY SEASON. ....	133
FIGURE 6.7. GOOGLE EARTH PLOT SHOWING THE DISTRIBUTION OF THREE DIFFERENT CATTLE GRAZING DURING THE WET SEASON IN MGWALANA VILLAGE (T12A) RIVE QUATERNARY CATCHMENT. ....	134
FIGURE 6. 8. GOOGLE EARTH PLOT SHOWING THE DISTRIBUTION OF THREE DIFFERENT SHEEP GRAZING DURING THE WET SEASON IN MGWALANA VILLAGE (T12A) RIVE QUATERNARY CATCHMENT.....	135
FIGURE 6.9. GOOGLE EARTH PLOT SHOWING THE DISTRIBUTION OF THREE DIFFERENT CATTLE GRAZING DURING THE DRY SEASON IN MGWALANA VILLAGE (T12A) RIVE QUATERNARY CATCHMENT .....	136
FIGURE 6.10. GOOGLE EARTH PLOT SHOWING THE DISTRIBUTION OF THREE DIFFERENT SHEEP GRAZING DURING THE DRY SEASON IN MGWALANA VILLAGE (T12A) RIVE QUATERNARY CATCHMENT .....	137
FIGURE 6.11. NDVI FOR THREE GRAZING DOMAINS IN MGWALANA VILLAGE: (A) WET SEASON (B) DRY SEASON.. .....	139

## ABBREVIATIONS AND ACRONYMS

ANOVA- Analysis of variance

ANPP- Above ground net primary productivity/annual net primary productivity

ARC- Agricultural Research Council

ASTER-Advanced space borne thermal emission and reflection radiometer

ETA-Actual evapotranspiration

BP- Blood pressure/hypertension

C-Carbon

CAT- Central African Time

CL- Cultivated land

CO<sub>2</sub>-Carbon dioxide

CSV- Comma separated value

DM- Dry matter

DPM-Disc pasture meter

E-Evaporation

EC- Eddy covariance

ET-Evapotranspiration

ET<sub>0</sub>-Potential evapotranspiration

EPWP-Extended public work programs

FAO-Food and Agriculture Organisation

GDP-Gross Domestic Product

GIS-Geographic information system

GMT- Greenwich Mean Time

GPS-Global positioning system

HIV- Human immune virus

IAP- Invasive alien plants

IGBPC-International geosphere biosphere programme classification

K-Potassium

Kg- Kilograms

LAI-Leaf area index

LSU-Large stock unit

LWP-Livestock water productivity

MAR- Mean annual rainfall

MCP-Minimum convex polygons

MIRS-Multi-angle imaging Spectro radiometer

MLE-Maximum likelihood estimate

MODIS-Moderate resolution imaging Spectro radiometer

N- Nitrogen

NASA-National Aeronautics and Space Administration

NDVI- Normalised difference vegetation index

NPP-Net primary production

OLS-Ordinary least square

P-Phosphorus

PSLSD-Project for Statistics on Living Standards and Development

PsNet- Net photosynthesis

RSME-Root square mean error

RUREC- Rhodes University Research Ethical Committee

SFA-Stochastic frontier analysis

SSA-Sub-Saharan Africa

T- Transpiration

TB-Tuberculoses

TE- Technical efficiency

T-LOCOH- Time local convex hull

TLU-Tropical livestock unit

UD-Utilization distribution

UG- Unimproved grassland

UNDP-United Nation's Developmental Programs

USB-Universal Serial Bus

UTM-Universal transverse Mercator

WP-Water productivity

WRC- Water Research Commission

WUE- Water use efficiency

## ACKNOWLEDGMENTS

First, I would like to thank the Lord Almighty for the strength and courage that He has granted me throughout the study period.

My heartfelt appreciation goes to my supervisor, Dr AR Palmer, for the excellent supervision, support, encouragement and patience throughout this study. You were the foundation of this study; my dream to pursue this PhD would not have been possible without you. I am forever grateful to God for your life. I am also grateful for the financial support that I received from the Agricultural Research Council (Professional Development Programme) and the Water Research Commission through WRC Grant K5/2400/4. It was a wonderful experience to be part of the Department of Environmental Science in Rhodes University. To Dr SK Mantel: it was a pleasure working with you. I would like to recognise the constructive comments I received from my co-supervisor, Dr E Mwendera. Drs J Cockburn and A Gwate deserve special mention for their valuable input in reading the early version of this work.

I would like to thank Mrs Juanita Mclean of the Institute for Water Research for the administrative support and extend special thanks to Ms Thantaswa Zondani from the ARC for her fieldwork assistance. I deeply appreciate the generosity of community members in Mgwalana and Mahlungulu villages who allowed me to work with their livestock and welcomed me into their homes during the survey. Special thanks go to the Tom family for opening their home to me during data collection. Thank you, Mr A Geqeza and Mr A Lekauta for assisting with livestock handling. Thanks, must also go to Mr D Gwapezda for the maps and to Mrs Helen Holleman for proof-reading this work.

To my friends and colleagues, from both Rhodes University and the ARC, thank you for the support and laughter during this time: Pindiwe Ntloko, Xola Nduku, Thuthu Stempa, Noyise Mhlwathika, Nanamhla Gwedla, Hesekia Garakae, Monde Duma, Charles Chakoma, Thoza Yapi, Kwena Muthopi, and Andiswa Finca: you guys are the best.

Special thanks to my family for their support and understanding when I had to be away for a very long time without seeing them: my mother, Nolungile Gusha, who took care of my son; my sister, Lethu Gusha, who became the second mother to my son; my younger siblings, Ziyanda Gusha, Asive Gusha, Ndiphiwe Gusha, Yonelisa Didibani, and specially my son,

Bulumko Gusha. Last, but certainly not least, Mr Loyiso Noveve, whom his support made all the difference.

## CHAPTER 1. GENERAL INTRODUCTION

### 1.1. Background

In arid and semi-arid regions of the world, natural rangelands comprise mostly uncultivated landscapes (Palmer & Bennett, 2013), which occur in two different types of land tenure systems: communal (leasehold) and commercial (freehold) systems (Scogings *et al.*, 1999). This study focuses on communal rangelands, areas of rangeland that belong to the entire community, and to which every member has equal access. In South Africa, communal rangelands mainly occur in the former homelands such as Ciskei, Transkei, KwaZulu-Natal and Venda, constituting 13% of the land and supporting a quarter (25%) of the country's human population (Scogings *et al.*, 1999) through a wide range of goods and services (Palmer & Bennett, 2013). One of these services is providing feed for livestock production which occurs under an extensively managed system, together with several other natural resources that are harvested for rural livelihoods (Reid *et al.*, 2008).

Apart from supporting the livelihoods of communal people and natural resources such as water, rangelands support livestock production. However, due to degradation, there is a decline in their ability to use water efficiently (Palmer & Bennett 2013), with increased water loss through run-off during storm-flow events. The ability of a rangeland to use water is primarily driven by the vegetation standing biomass of the rangeland where in the communally managed rangelands, high stocking rate are prevalent leading to low standing biomass. This leads to a rangeland to be unable to optimally control and use the available water, resulting in high run-off water yields and soil erosion. When the standing biomass is low, water runoff the landscape and cannot be used to drive evapotranspiration and therefore, rangeland production. The process of soil erosion and the inability of the rangeland to optimally use water for rangeland production leads to rangeland being degraded.

The estimates of land degradation vary largely, because of the global increase in human population and industrial activities (Eswaran *et al.*, 2001). The extent of land managed in communal systems amount to 66% of the global land surface with 46% of the land surface reported to be slightly to severely degraded; this degradation is estimated to cost USD\$40 billion annually (FAO, 2010). About 65% of the land in Sub-Saharan Africa (SSA) is degraded, while 42% is slightly to severely degraded (FAO, 2010). The impacts of land degradation are mostly found in the dry land areas of SSA, which have worsened because the ecosystems are susceptible to extreme climate changes, people are poor and socially and politically marginalised (Palmer & Bennett, 2013). The increasing land degradation leads to increased runoff, which cannot be absorbed and used by plants, making it difficult to improve rangeland water use. Thus, suitable management of water is necessary to restore unproductive, degraded lands.

Land degradation has been redefined beyond the vegetation change and loss of soil to include the reduction in the capacity of land to support society and development, or to perform ecosystem functions and services (Tongway & Ludwig, 1996). Land degradation is considered when the landscape functionally declines to be a point where soil nutrients and soil erodes. (Tongway & Ludwig, 1996). The main drivers are improper, unsustainable land use, changes in land cover or vegetation and animal species. However, ineffective management of water and the extent to which land degradation occurs under different land tenure systems and management is still under discussion (Vetter, 2013). Vetter, (2013) describes communal rangelands as degraded based on standing biomass and species composition when compared with commercial properties; these areas look degraded because of continuous grazing and the low standing biomass. Furthermore, compared with commercial farms, which are perceived as sustainable and an ideal benchmark against other land-use practices, research on the challenges faced by communal farmers has been done. However, there has been no adequate assessment of the level of livestock production and associated products at household level to assess rangeland productivity in communally managed rangelands.

Studies conducted in South Africa on land degradation showed both communal and commercial systems as degraded, but much of the discussion has focused on managed areas

(Lloyd *et al.*, 2002). These properties are regarded as the most vulnerable because of the users' inability to collectively and sustainably manage common resources due to lack of incentives; the so-called 'tragedy of the commons' (Hardin, 1968). Furthermore, in South African communal rangelands, degradation can be linked to the inability of land users to respond decisively to environmental indicators that warn of impending state changes, and skew access to resources accompanying the social engineering before 1994 (Beinart, 2000). One can achieve sustainable resource management by linking social and ecological systems and this is possible through collective action management of common resources. The interest has been on the ecological dynamics of semi-arid rangelands as inherently non-equilibrium systems which are mainly driven by rainfall and its influence on vegetation dynamics (Vetter, 2005). Although evidence shows that rainfall is a factor in rangeland vegetation dynamics, animal-induced vegetation changes are also evident. The emerging consensus is that differences of equilibrium and non-equilibrium at different spatial and temporal scale in semi-arid rangelands may exist (Vetter, 2005) that are chiefly evident during dry periods. Other edaphic factors, such as increased surface temperatures, elevated CO<sub>2</sub>, vegetation change, and reduced evapotranspiration (ET) in the longer term cannot be ignored (Palmer & Bennett, 2013).

The discussions relating to land degradation in South Africa are polarised between commercial livestock production and the extensive rangeland management in traditional villages (Vetter, 2013). In the north Eastern Cape of South Africa, communal rangelands exist because of the political history of which designated communal rangelands were established during the 20<sup>th</sup> century with the Native Land Act of 1913 and the Native Trust Land Act of 1930s (Beinart, 2000). In this area, previously commercial farms are now rangelands that were transferred as consolidation of the homelands (Beinart *et al.*, 2017). During the dry season, arable lands become a common grazing area where livestock can feed. A long history of communal grazing has been reported as well as claims associated with land degradation (Beinart, 2003). The Department of Agriculture reported that the rangelands in these areas (that were a part of common property since the 19<sup>th</sup> century) were degraded as a result of overgrazing and soil erosion (Beinart, 2000, 2003).

In the current political environment, land in the north Eastern Cape is being redistributed, and government is committed to improving livelihoods of previously disadvantaged people in

rural areas (Vetter, 2013). The government is looking for a willing seller and a willing buyer for the redistribution of land to the black people living in the former homelands, however, only 5,46 percent of the land has been distributed up to date (Kepe & Hall, 2016). The major focus is on the greater land transferee levels and on improved engagement with smallholder agriculture. A study conducted by Gwate (2018) in the north Eastern Cape communal rangelands provided an interesting opportunity to study the dynamics of ecosystem services related to land degradation, rangeland water use and household livestock production. The ability of these rangelands to support primary ecosystem services, such as grazing by livestock and rangeland water use by both livestock and people, is undermined by the land cover changes taking place, such as the invasion of alien plants, the increase in rural settlements, increased afforestation, reduction in native grassland (Münch *et al.*, 2017) and changes in species composition (Bennett *et al.*, 2012). Thus, it is necessary to better understand rangeland water use and livestock production in order to improve rural livelihoods and optimally manage the landscape. This study seeks to understand rangeland livestock water dynamics by looking at the biophysical components of the ecosystem such as evapotranspiration (ET), aboveground net primary productivity (ANPP) and vegetation cover of livestock grazing lands. Another component of this study is the performance of livestock production in communal rangelands using a stochastic frontier analysis, which as method of economic modelling as an application to provide empirical evidence on livestock productivity and looking at the ability of a household to attain maximum goods and services, given the set of inputs and technology. Household livestock-based livelihoods of communal people were also assessed to understand the contribution of livestock to rural livelihoods. The study also describes livestock water productivity in communal rangelands, productivity which is composed of livestock goods and services, given the amount of water used by the landscape (ET) for aboveground net primary production (Descheemaeker *et al.*, 2011). Finally, the grazing distribution of sheep and cattle in a communal rangeland was assessed and the factors that affect livestock grazing distribution such as normalised difference vegetation index (NDVI) and species composition were assessed. Global positioning systems (GPS) were used to assess livestock landscape use during the wet and dry seasons. Daily weight gains for the collared livestock during the study were calculated to assess livestock performance for both seasons.

## 1.2. Overview of water productivity

The concept of water productivity includes the outputs and their associated costs, given the water used by aquatic and terrestrial ecosystems (Molden & Sakthivadivel, 1999). Water productivity (WP) is defined as water-use efficiency, carbon assimilated and crop yield per unit of transpiration, and later, as the amount of produce per unit of ET (Molden & Sakthivadivel, 1999). Irrigation specialists have used other terms, such as water-use efficiency (WUE) to indicate the amount of water wasted and how effectively it is delivered to the crop. However, the concept does not indicate the outputs produced, or that the water lost through irrigation can be re-used (Seckler *et al.*, 2003). Improving water productivity is most appropriate in water-scarce areas and reasons for water productivity improvement include meeting the increasing food demand from developing regions in the light of water scarcity (Molden *et al.*, 2007a). Another reason is to respond to pressures in relocating water from agriculture to ensure its availability for environmental use (Molden *et al.*, 2007b). Lastly, improved water productivity contributes to poverty alleviation and economic growth for poor rural areas, which leads to better nutrition, productive employment and more income. The investment cost of the amount of water to be drawn can be reduced through targeting high water productivity (Seckler *et al.*, 2003).

### 1.2.1. Importance of water productivity

Increased productivity of water is primarily important in areas where water is a scarce resource and, in agriculture, plays a significant role in facilitating competition for scarce resources, providing food security, and preventing environmental degradation (Bossio *et al.*, 2010). Using less water to grow more food makes water available for other natural and human uses (Sonder *et al.*, 2003). The water consumed by an animal enables optimum and efficient conversion of feed, and ensures maximum milk production and growth throughout its lifetime (Peden *et al.*, 2003). However, scarcity of the water that the animal uses for body cooling through metabolic processes and transpiration results in low production and health problems.

The amount of drinking water required depends on various factors such as dry matter intake, feed composition, feed water content, animal species, live weight of the animal, level of production, climate in which the livestock is managed, and the physiological status of the animal (Sonder *et al.*, 2003). Most of the water consumed by the animal is ingested as drinking

water or as a component of the feed (Sonder *et al.*, 2003). The feed may be highly variable in moisture content, ranging from 5% in dry feeds to 90% or more in moist feeds (Sirohi *et al.*, 1997). Water that is absorbed directly from dry feeds may not be as important as the water intake, while that derived from moist feeds can supply large amounts of the necessary water requirements (Blümmel *et al.*, 2009). However, there are more opportunities to increase WP in the livestock sector under the combined concept of LWP (Peden *et al.*, 2009).

#### 1.2.2. Livestock water productivity: Concept

Livestock water productivity (LWP) is defined as the measure of agricultural outputs (goods and services) derived from livestock against the amount of water consumed in the process of producing these outputs (Hoeve & Koppen, 2005; Breugel *et al.*, 2010; Peden *et al.*, 2009). The concept was introduced by Peden *et al.*, (2007) to investigate interactions and ways to improve livestock production without environmental and water depletion. The system receives, contains, and loses water through various hydrological processes such as precipitation, evapotranspiration, storage, runoff and recharge, and the rates of the movement of water through these processes are affected by degradation and depletion (Descheemaeker *et al.*, 2010a; Breugel *et al.*, 2010). Generally, the amount of water used in a livestock production system consists of not more than 2% of drinking water and only water lost during evapotranspiration of feed production is usually considered in livestock water productivity (Descheemaeker *et al.*, 2010d). However, in sub-Saharan Africa and other arid and semi-arid parts of the world, livestock ranching in a commercial agricultural enterprise, and feeding are the major components of agricultural water use.

Livestock ranching is a significant livelihood strategy for communal farmers in Africa. In land under communal tenure and traditional ownership, livestock's contribution to livelihoods is mainly through providing different products and services; however, their productivity is generally low (Otte & Chilonda, 2003). This low productivity is most often attributed to the poor quality and low quantity of feed, low-yielding breeds, prevalence of indigenous breeds, inadequate water resources, prevalence of disease, and high mortality rates (Salem & Smith, 2008). Other challenges faced by African smallholders are limited access to credit, lack of technology transfer, high transaction costs and poor market access (Pica-Ciamarra *et al.*, 2011). However, the increasing global demand for livestock products, along with increasing global water competition, population growth, and changing nutritional habits (Whaley *et al.*,

2003) have encouraged communal livestock farmers to re-evaluate their management practices.

### 1.2.3. Livestock water productivity (LWP) model

The benefits derived from water use are normally referred to as the productivity of water (Peden *et al.*, 2007). Livestock water productivity depends on the beneficial outputs that are considered and can be expressed in different units: in kilograms per cubic metre ( $\text{kg m}^{-3}$ ) of water, in litres per cubic metre ( $\text{L m}^{-3}$ ) of water, or in the monetary value per cubic metre (US\$ or ZAR  $\text{m}^{-3}$ ) of water if milk or offtake is considered (Peden *et al.*, 2009). It can be more difficult to assess the water used by livestock for non-economic benefits even though they are significant (Burke *et al.*, 2009). This is because they are indirect benefits of the environmental flow (Cook *et al.*, 2009). The water productivity assessment however, includes payment for the environmental services to include non-economic benefits (Falkenmark *et al.*, 2007). When comparing the produced commodity and water flow component, the benefits vary greatly with the scale of the analysis and the interest of stakeholder (Wesseling & Feddes, 2006). The varying scale of analysis and the definitions of water productivity often restrict the discussion (Bouman, 2007).

The value of livestock consists of multiple benefits and services such as offtake, milk, wool/hides, manure, farm power and the preferred means of accumulating wealth (Dovie *et al.*, 2006). The denominator of the ratio represents the amount of water depleted for producing feeds, consumed by the animals (expressed as evapotranspiration), and for drinking over the entire lifetime of the herd being assessed, based on the water foot-printing concept (Hoekstra *et al.*, 2009). This study, however, focuses on the model developed by Hailelassie *et al.*, (2009a) and modified by Kebebe *et al.*, (2015) which is a simplified method that quantifies the annual LWP of the livestock herd being assessed. In a communal livestock production system, livestock husbandry varies significantly compared to a commercial production system: there is a lack of record keeping in terms of animal husbandry activities such as productivity, veterinary services, measurement of drinking water and breeding stock over the lifespan of a livestock herd. The model used in this study includes water used by the landscape for the production of grass/forage to estimate LWP. However, the study acknowledged that during the dry season where animals mostly feed on crop residues, some households afford to pay for baled lucerne. The LWP values were estimated as follows:

$$LWP_i = \frac{\sum_{i=1}^n (O_i * P_i + S_i * P_i)}{\sum_{k=1}^n WD_k} \quad (1.1)$$

Where:

$i$  is the unit of observation;  $LWP$  is livestock water productivity;  $O_i$  is the quantity of the  $i_{th}$  livestock output such as milk, offtake, hides/wool and manure;  $S_i$  is the service type, such as traction of the  $i_{th}$  livestock obtained over a year;  $P_i$  is the local market price (ZAR) of the  $i_{th}$  good or service type;  $WD_k$  is the amount of water used in ET for the production of grass in the rangelands. To assess multiple benefits, monetary equivalents such as ZAR of livestock products are used and later converted to USD. Although non-monetary cultural benefits remain important, they were not included in the computation of monetised benefits of livestock.

Several water accounting techniques have been used to quantify LWP at various agricultural scales and to understand the LWP denominator better (Molden & Sakthivadivel, 1999). The denominator can be applied at many scales of interest and requires the definition of a bounded domain in space and time (Peden *et al.*, 2009). For example, the domain at the field scale starts from the plant canopy to the bottom of the root zone bounded by the edges of the field over a growing season (Descheemaeker *et al.*, 2010). The main task in water accounting is estimating the flows across the boundaries in the specified period (Ritzema, 2014). When estimating the water productivity, the interest is in the water inflows and water depletion. Different water accounting categories in the process of water accounting procedures are classified by the inflow and outflow components (Molden & Sakthivadivel, 1999).

#### 1.2.4. Livestock water productivity (LWP) framework

In a livestock production system, land degradation can be reversed through improved LWP, which contributes to reduced poverty of a smallholder's livelihood (Burke *et al.*, 2009).

Using the composite nature of the livestock system, Peden *et al.*, (2007) developed a conceptual framework to analyse LWP. The framework allows the accounting of the various factors affecting LWP that are involved in various water flows, and the multiple benefits from livestock production. The framework improves the understanding of water use in a mixed farming system, logically evaluates livestock water interactions, and integrates hydrology, economics, ecosystems, production systems, and various natural resources.

However, this study adopts this framework to improve the understanding of livestock production in a communal rangeland system. The major focus of the study in this framework is on livestock production on communal rangelands, on water used by the rangelands, and the net annual beneficial goods produced by livestock.

The water flowing into a system to produce drinking, processing, servicing water and biomass, enables the production of animal outputs using various types of feeds and other natural resources (Peden *et al.*, 2006). The services rendered by livestock play a role in the livelihoods and environmental services (Senda *et al.*, 2011) and thus management of livestock production affects livelihoods. The influence on feed production, water inflow, soil and vegetation are because of environmental services, which creates a feed loop (Duncan *et al.*, 2016). Animal urine and faeces contain less water than the water outflow (Peden *et al.*, 2007). Further, degraded runoff water, transpiration, evaporation and contaminated water cannot be used. Water that has not been lost, such as deep percolation and out-of-the-root zone, can be used by the system downstream or after being recycled (Burke *et al.*, 2009). The concept and framework of LWP can be used to determine the strategies or areas of possible intervention for improving LWP.

Figure 1.1 shows that water occurs in rivers, lakes, ponds, reservoirs, plant tissues (which lock up the soil moisture and water), animals and microorganisms. Water joins the system as rainfall, surface or sub-surface inflow (Kumar *et al.*, 2014) and is lost through transpiration (T), evaporation (E) and downstream discharge (Peden *et al.*, 2007). For sustainable water management, a long-term inflow is required and, in drought conditions, the depletion has to be in balance with sufficient storage to offset short-term scarcity (Amede *et al.*, 2011). When the water is depleted, it is no longer available for the system and adds no value. Depleted water is water that has been used up, making it less valuable to the system for future use, even though it is still within the system (Hoeve & Koppen, 2005). The primary requirement for assessing LWP is estimating livestock-related water inflow, depletion and storage (Peden *et al.*, 2007). Since this study deals mainly on water used by rangelands to produce livestock goods and services, the interventions proposed will focus on rangeland management and animal husbandry.

For plants to grow, water has to be lost through transpiration. Evaporation and transpiration are difficult to separate (and is rarely done), but are normally combined as evapotranspiration (ET) for the purpose of estimating agricultural water use, so shifting the depleted water from discharge and evaporation to transpiration (Keller & Seckler, 2004). The ratio of transpiration to evaporation is important because a high transpiration to evaporation ratio indicates possible higher agricultural water productivity than a lower ratio because evaporation is the non-productive water depletion, and transpiration is the water used for plant growth (Amede *et al.*, 2009).

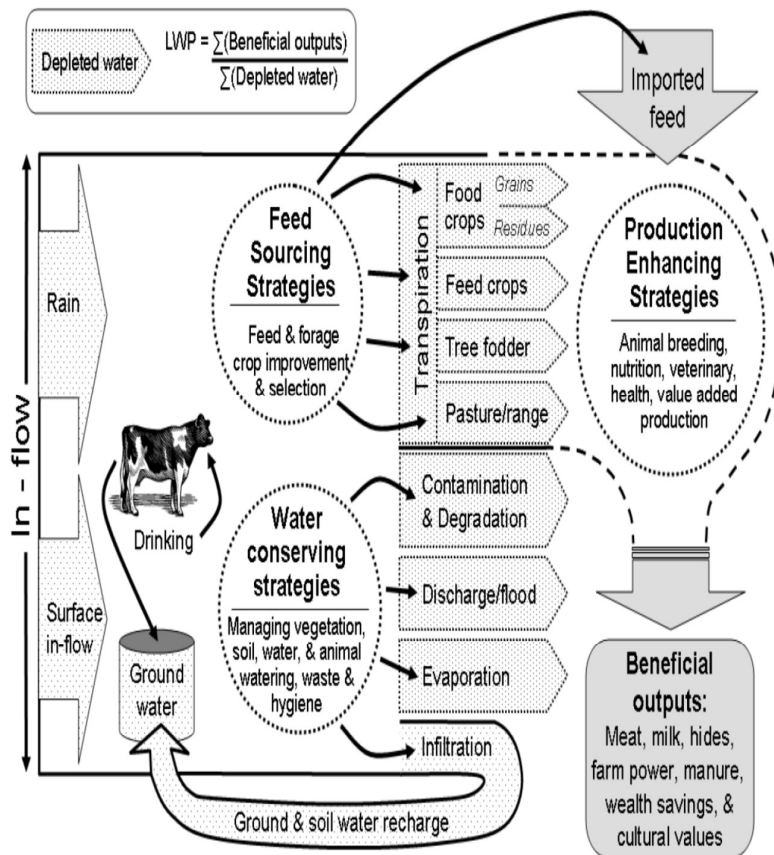


Figure 1. 1. Livestock water productivity (LWP) depends on water accounting principles and helps identify opportunities for more effective water use. The figure has been re-produced from the source (Peden *et al.*, 2007).

### 1.2.5. Livestock-water interaction

Livestock and water interactions are a crucial challenge as livestock utilise huge amounts of water for feed production and they are responsible for environmental degradation due to overgrazing (Descheemaeker *et al.*, 2011). Water used in livestock rearing through to the livelihoods is either not valued or is undervalued (Mekonnen *et al.*, 2011). Livestock and water managers face the challenge of guaranteeing that livestock rearing minimises water degradation, depletion and contamination of resources, while at the same time maximising the outputs from livestock and other systems (Breugel *et al.*, 2010). There is a need to improve the understanding of LWP and its influences on water resources (Kebebe *et al.*, 2015) and to fully understand the interaction of livestock water in the livelihoods of communal farmers.

The major factor influencing the development of different livestock production systems is access to water; this is probably the most significant link between people, the environment and livestock (Descheemaeker *et al.*, 2011). Herd composition, livelihood strategies for coping mechanics and livestock distribution are mainly dictated by the distribution of water resources and land (Descheemaeker *et al.*, 2011). In areas where water scarcity is the major problem, farmers have adapted to this challenge by adopting a nomadic lifestyle; however, in intensified farming systems, where population is increasing, water competition among the different sectors has increased as the farm size has decreased (Molden *et al.*, 2007). Livestock water interaction differs depending on animal herd composition, production objectives, market links, management system, livestock health and productivity (Peden *et al.*, 2009). In areas where an output, such as draft power is important, oxen are usually given the priority of a high quantity of quality feed, since they are the major users of water and feed, and have important outputs (Bekele *et al.*, 2017).

Livestock drinking and servicing water such as water used in milking and washing the sheds is the most obvious use of water in a livestock production system, but it is only a small proportion of the total water consumption (Peden *et al.*, 2007). Studies show (Peden *et al.*, 2007; Gebreselassie *et al.*, 2009; Descheemaeker *et al.*, 2009) that the main use of water in a livestock system is related to transpiration of water for feed production, which is about 50-

100 times the amount of water needed for livestock drinking, making it understandable that large quantities of water are necessary to produce a kilogram of meat or a litre of milk. A study conducted in India by Chapagain & Hoekstra, (2003) estimated that 1.96-4.6 m<sup>3</sup> of water are depleted mainly to irrigate the feed necessary to produce one litre of milk, while estimates of the amount of water required to produce one kilogram of beef are in the region of 10.0 m<sup>3</sup> to 12.2 m<sup>3</sup>. However, the estimates apply only to intensive livestock production, and these estimates do not consider small ruminants which have a more water efficient metabolism than large ruminants and equines.

Consideration of the influences of livestock keeping on water resources at landscape scale is essential when evaluating livestock water interactions because, if the influences are ignored, low LWP could be the result (Peden *et al.*, 2009). Livestock grazing affects the hydrological response of rangelands and results in soil and vegetation degradation. According to the study conducted by Descheemaeker *et al.*, (2006), high grazing pressure leads to combined interrelated factors such as poor organic soil matter, poor vegetation cover, soil compaction, poor soil structure, increased soil erosion and higher runoffs from low infiltration rates. However, the tendency of attributing all water lost in the rangeland system to livestock might underestimate livestock water productivity (Peden *et al.*, 2007). Land degradation can be severe around the watering points because of the grazing pressure on vegetation cover and the animal trampling effect (Descheemaeker *et al.*, 2009), and contamination of watering points due to mismanagement, such as lack of fencing and faecal excretion inflow, can make water unusable (Wilson, 2007). According to Peden *et al.*, (2007), livestock water interaction has been given insufficient attention, and much focus has been on land degradation due to grazing and livestock water requirements, resulting in a lack of understanding of feed water productivity and feed intake estimates, which have led to variation in LWP. The lack of knowledge of livestock water interactions has obstructed both proper decision making and the development of methods to improve the situation (Peden *et al.*, 2007). Furthermore, this has resulted in lost opportunities to counter low livestock production, smallholder poverty and land degradation.

#### 1.2.6. Factors affecting livestock water productivity

Management of water resources need to improve worldwide, given increasing population and water scarcity (Gebreselassie *et al.*, 2009). According to Molden *et al.*, (2007), the need for

improved water management is especially true when water resources are allocated to different and competing uses. There must be a formula for effective strategies to achieve more productivity while, at the same time, improving the environment. This situation aggravates the risk of worldwide food security as sufficient water available for food production is a challenge (Gebreselassie *et al.*, 2009). The increasing population depends on agriculture for food which competes with household, environmental and industrial use for the limited water supply (Taddese, 2003). Although all the users increasingly demand water, ground water is slowly decreasing, other water ecosystems are degraded and polluted, and the development of new water resources is costly (Descheemaeker *et al.*, 2009). A wide range of pollutants such as human, agricultural and industrial wastes have contributed to the shrinking of quality fresh water resources (Bennett, 2003).

### 1.3. Strategies to improve livestock water productivity

Producing animal feed resources that would consume water more efficiently, as well as selecting livestock species and breeds that have higher feed conversion rates could improve LWP (Sonder *et al.*, 2003) to sustain the agro-ecosystem (Nardone *et al.*, 2010). Improved grazing of livestock and water management could enhance the productive ability of the land through improved water and soil conservation, which has a potential to reduce pollution such as that of water and has positive environmental influences (van Breugel *et al.*, 2010). At the household level, LWP can be quantified, which requires developing a methodology to improve the quality of rangelands. Peden *et al.*, (2007) identified numerous strategies to improve LWP.

#### 1.3.1. Sourcing of feed and management

The primary strategy for improving LWP is managing and sourcing feed (Haileslassie *et al.*, 2009a). The chief water cost in livestock ranching is the photosynthetic production of feed (Sisito *et al.*, 2012). Selecting quality pastures that have high crop water productivity such as feed crops, crop residues and crop by-products help increase LWP (Ganskopp & Bohnert, 2009). Livestock water productivity is increased by any measure that increases crop water productivity. However, the possibilities for reducing the water consumed in producing feed are limited in number and the results are highly inconsistent (Peden *et al.*, 2003). In practice, maximum feed water productivity is often less than 0.5 kg m<sup>-3</sup> but can reach 8 kg m<sup>-3</sup> in rain-fed dry matter (Peden *et al.*, 2007). Many factors, such as different concepts of water

accounting and the reality of particular production, lead to variability (Alemayehu *et al.*, 2012). The important feed choice for improved LWP is the consumption of crop residues and by-products (Burke *et al.*, 2009). Taking advantage of crops grown for human food and their residues imposes less or no additional water cost beyond what the crop itself needs. Low LWP can be achieved by using irrigation water to produce forage which uses high water cost (Descheemaeker *et al.*, 2010). Importing feed successfully transfers the water cost of feed production to far-away areas, thus decreasing local agricultural water demand. If the water is not enough for producing feed, animals must migrate to other feed sources or rely on imported feeds associated with virtual water, which is the hidden water flow (Chapagain & Hoekstra, 2003).

### 1.3.2. Enhancing animal productivity and herd size management.

Higher LWP is mainly possible when one's livestock herds are productive, stress free and are kept healthy (Hailelassie *et al.*, 2009). When the animals are in poor condition, production is reduced to zero benefits. A fixed input for livestock production is the water required to produce maintenance feed (Descheemaeker *et al.*, 2010). Additional water is required by livestock to gain weight, work, reproduce and produce milk (Molden *et al.*, 2007). Energy used for maintenance is less than that required to enhance LWP; however, interventions of genetics, nutrition, health, marketing and animal husbandry help to improve LWP (Peden *et al.*, 2007). The interventions that help to improve LWP include providing quality drinking water (Gebreselassie *et al.*, 2009), selecting breeding stock with improved feed conversion efficiency (Archer *et al.*, 1999), reducing mortality and morbidity through health services (Descheemaeker *et al.*, 2011), and keeping few but highly productive animals.

There are two approaches to increasing LWP: keeping larger herds that require more feed, water and other inputs with no additional water, which is one way that livestock keepers respond to increased LWP (Amede *et al.*, 2009). The other approach is to keep a few livestock that are highly productive. Some limits are ultimately needed for livestock production, such as restricting land use by animals to certain environmental sustainability levels (Keller & Seckler, 2004) which may include the environmental charge of livestock production in the prices of animal goods and services (Cook *et al.*, 2009). Another limit would be to adopt a policy that ensures reasonable access to animal outputs, such as use of milk and meat to levels that improve nutrition, reducing obesity and diabetes (Ebanyat *et al.*, 2010)..

### 1.3.3. Conserving water resources

Conserving water resources is the process of limiting water loss through non-production depletion pathways. Natural sustainability, agro-ecosystems and agricultural production depend on transpiration (Peden *et al.*, 2009). Evaporated water and discharge do not contribute to the production of plant material. One of the effective ways to increase LWP is to manage vegetation, land, and water through converting evaporation (Peden *et al.*, 2007) and water loss through elevated runoff during storm flow events. Livestock water productivity can be improved by maintaining high vegetative ground cover, harvesting water, improving soil-water holding capacity, developing vegetated buffer zones around water surface bodies, and related measures that decrease extreme runoff, increase infiltration (Descheemaeker *et al.*, 2013). Livestock grazing has an impact on water and animals must be managed in ways that maintain vegetation cover. When the vegetation cover is lost, soil erosion increases and infiltration and production in pastures declines (Peden *et al.*, 2003). Moderate grazing pressure has a less negative impact on water, and on the type and density of grazing on species composition of the vegetation (Sonder *et al.*, 2003), while high grazing pressure results in the loss of nutritious palatable species. In other parts of the world, very low grazing pressure stimulates bush encroachment (Dalle *et al.*, 2006), but this is not always the case in South Africa, as the interaction between low grazing pressure and the resultant increase in fires inhibits woody encroachment. The combination of reduced grazing and the prevention of fires does, however, result in an increase in woody biomass. High water productivity can be maintained by having more palatable vegetation and animals that utilise the vegetation effectively (Faki *et al.*, 2008).

### 1.3.4. Allocation of livestock feed and drinking water

How livestock feed and drinking water is allocated across landscape can lead to unreasonably low LWP, and to land and water degradation (Faki *et al.*, 2008). In areas that are near drinking water sources, LWP for cattle is very low because of the morbidity and mortality associated with weight loss and the high risk of disease transmission (Faki *et al.*, 2008). Animal production and water productivity is also low when the animals have to walk long distances from feed to watering sites (Breugel *et al.*, 2010), however, moving water sources creates feed shortage and mortality.

In arid and semi-arid rangelands, livestock such as cattle in particular, depend on water resources. When there is limited or no water available, they die and, even if they live, the stress caused by non-availability of water reduces animal production (Blümmeln *et al.*, 2014). The animal drinking process takes place within the system and the water drunk within the process is not depleted but supports the ecosystem functioning (Peden *et al.*, 2006). Water consumed by the animal and lost through urine and faecal moisture can be deposited on the soil which it may infiltrate or from which it may evaporate (Taddese, 2003). Small amounts of water may also be lost from the pulmonary tissues of the animal as evaporation. Animal drinking water must be available in small but adequate quantities and be of good quality (Wilson, 2007). Although providing a unit of drinking water is costly, the amount of water consumed by livestock is only 2% of that needed to produce feed (Peden *et al.*, 2007).

The amount of water consumed by an animal varies from 20–50 litres per Tropical Livestock Unit (TLU) per day, and the consumption depends on factors such as breed, species, temperature, quality of water, feed intake, feed water content, animal activity, pregnancy and lactation (Peden *et al.*, 2003), with high-producing, lactating cows consuming as much as 85 litres of water per day. Livestock water productivity, weight gains and milk production can be constrained by water deprivation, which also reduces feed intake (Gebreselassie *et al.*, 2009). In areas where poor water and livestock management is practised, watering sites are often contaminated with sediments, and pastures are overgrazed, contaminating domestic water use that then puts human and animal health at risk (Gebreselassie *et al.*, 2009). Providing water in grazing land is an important contribution and it provides an opportunity to distribute livestock for effective forage consumption without overgrazing (Peden *et al.*, 2006).

#### **1.4. Biophysical attributes of the communal rangelands**

Livestock production in semi-arid rangelands can be affected by biotic and abiotic factors such as stocking rate and rainfall (Fynn & Connor, 2000). The concept of Clemensian succession and theoretical underpinning of range management on ecosystem functioning have been challenged for arid and semi-arid rangelands where a potential determinant of change within a system is rainfall (Fynn & Connor, 2000). Stocking rate has traditionally been used as a tool by which range managers can adjust the succession trend of vegetation. However, the current argument is that grazing has a limited influence on the vegetation dynamics because of inter-annual rainfall variability (Fynn & Connor, 2000). However, the relationship between livestock

and rangeland productivity is positively correlated with mean annual rainfall (Fritz & Duncan, 1994). On the other hand, according to Behnke and Scoones, (1993), grazing has a minimal impact on vegetation in semi-arid rangelands. Variable rainfall can have a strong influence on rangeland productivity and species composition, although a slight grazing effect on species composition over time can result in a shrinking effect on rangeland productivity (Milchunas & Lauenroth, 1993).

#### 1.5. Livestock production in communal rangelands

Livestock in communal rangelands provide multiple benefits to their owners: they are a store of wealth, they provide offtake, hides, wool, milk, draft power and manure. Livestock also provide social prestige, local exchange, bride-wealth payment, loans and accumulation through reproduction (Cousins, 1999; Dovie *et al.*, 2006). However, decline in the use of livestock draft power and increase in livestock slaughter remain a central social practice of many communal people (Brown *et al.*, 2013). Currently, livestock production in communal rangelands is not perceived as a thing of the past but is perceived as having economic potential by which household food security can be addressed. It is important to state that rangelands exist on a continuum form and may exhibit different dynamics over different spatial scales such as rangelands that ostensibly appear to be over the larger scale may also contain key resources areas where dynamics are more equilibria because there is much tighter coupling between plants and livestock.

About 84% of the communal land in South Africa has the potential for livestock production, but livestock sales were thought to contribute little to the cash economy in terms of sales for slaughter in abattoirs (Bembridge, 1987). Because of poor management and low nutrition, the efficiency of communal livestock production in terms of offtake, milk, manure, traction and wool/hides is estimated to be only a quarter of that of commercial rangelands (Bembridge & Tampion, 1993). Factors such as topography, climate, and geology can limit crop production and, as a result, most parts of the rangelands are used for livestock grazing, commercial livestock production and game farming (de Wet & van Averbeke, 1995). Nowers *et al.*, (2013) argue that the deterioration of communal rangelands and low livestock productivity are due to the accelerated degradation of the resource base, but there are environmental factors such as drought that have a greater effect on livestock production. While genetic improvement and improved management can boost livestock production to a

certain level, environmental factors cannot be controlled. In the case of commercial livestock production, production is improved by management factors such as vaccination and tick control; in communal livestock production, this is mostly carried out by the government (Nowers *et al.*, 2013). In communal areas, the adoption of technological solutions to the challenges of improving livestock health and productivity has generally been slow, for a number of reasons: the high costs of these interventions, inadequate access to extension services and advice, and reliance on non-efficacious traditional veterinary solutions. The provision of veterinary services in South Africa has been reduced significantly (Brown *et al.*, 2013), leaving livestock owners to their own devices, to a large extent, some of whom use plant-based remedies as one of the animal disease management practices (Beinart & Brown, 2013).

Although livestock production in communal areas has low formal offtake rates to abattoirs, and poor economic returns, it is an important source of income. In most communal areas of Southern Africa, low input livestock husbandry remains a primary land use option (Shackleton *et al.*, 2001). This happens in situations of inconsistent macro-economic policy, changing environmental regimes and labour market policies, where people adopt different livelihood strategies (Cousins, 1999) such as harvesting natural resources and livestock production. In communal economies, livestock herds are regularly multipurpose in character and when all functions are valued, they produce high rates of economic return per hectare (Dovie *et al.*, 2006). The important functions depend on a number of factors, such as selling livestock for cash and may be more important in areas which are arid or semi-arid, where the rainfall is erratic (e.g. high inter-annual coefficient of variation) and the risk of crop failure is very high (Dovie *et al.*, 2002).

The class identity of the owner also influences the function of livestock and can be highly skewed, due to high levels of crop production and other non-rural sources of income (Cousins, 1996). An individual who owns a relatively large number of cattle normally gives some of the livestock to his or her kin unconditionally. This may start with the gift of a chicken to a youngster, to a cow when the young man gets married, in order to start his own household (Ainslie *et al.*, 2002). The people who benefit most from kinship are usually the men (sons, nephews, and brothers), although, in some cases, women benefit too (Bennett *et al.*, 2013). One can motivate to be given livestock by looking after it while one is young, for instance,

where an older brother has inherited livestock from his parents, he may gift some to his younger brother (Cousins, 1996). However, in some cases it is rare for people to gain title to livestock through kinship unless other customs and institutions contribute to such entitlement (Bennett *et al.*, 2010). Livestock also play a role between households such as bride-wealth payment, co-operative arrangements for ploughing and lending, but these roles differ from area to area (Ainslie *et al.*, 2002).

#### 1.6. Livestock grazing distribution across the landscape in communal rangelands

Proper livestock grazing distribution is an integral part of rangeland management (Gillen *et al.*, 1984). Managing livestock grazing distribution aims at maximising forage use within a wide range of landscape without causing serious damage to the land (Gillen *et al.*, 1984). A complex combination of plant community, topographic water distribution, succession stage, time since last fire, aspect, geology and soil, as well as other habitat factors determine grazing distribution. Areas of gently sloping drainage may receive up to 95% of grazing, while steep slopes will receive less grazing (Fuhlendorf & Engle, 2001). A better understanding of the livestock interaction with the natural habitat and of management factors should aim at more effective methods of livestock grazing distribution.

Grazing livestock react to their environment through behavioural actions that result in different distribution over the landscape (Stuth, 1991). Livestock normally graze selectively under continuous grazing in search of local areas that lack accumulation of biomass (Fuhlendorf & Engle, 2001). This behaviour results in small, heavily grazed patches within grazed or un-grazed patches (Bailey *et al.*, 1998). Livestock tend to concentrate their grazing near watering points and along the meadows immediately adjacent to drainage lines, thus leading to increased grazing pressure on areas near watering points and reduced grazing in areas far from the watering points (Fuhlendorf & Engle, 2001). This grazing pattern of livestock associated with distance to watering points masks the small-scale heterogeneity, leading to rangeland deterioration and results in increased runoff (Fuls, 1992)

To maximise livestock distribution across the landscape, grazing systems such as rotational grazing are designed to harvest forage uniformly. Livestock managers believe that rotational grazing can improve the rangeland condition and livestock production more than continuous grazing where livestock are allowed to range freely and select grazing according to their own

preferences. However, studies demonstrate that continuous grazing at light intensity does not degrade species composition and rangeland production (Holecheck *et al.*, 1998). Unlike most commercial rangelands where livestock are rapidly rotated across the landscape through relatively small pastures, communal rangelands allow livestock to graze freely and continuously across the landscape with or without the presence of a herder.

Herding is the activity of keeping animals together as a group while searching for forage to graze or water to drink. Herding involves keeping and guiding the animals to prevent them wandering, fighting or being subject to predators. Samuels *et al.*, (2013) argue that herd mobility is an adaptable, efficient way to manage livestock in communal rangelands as it responds to the environmental and socio-economic variables. On the other hand, livestock grazing in fenced paddocks have limited access to key resources and so the practice breaks down during dry seasons. In South Africa, the long history of colonialism led to the reduction of land available to Africans and significant restrictions on livestock movements. In communal areas, livestock were kept in kraals at night and released in the morning with a herder to move livestock around the rangeland. However, mandatory schooling meant a decrease in the number of households practising traditional herding of livestock which had been drawn mainly from child labour. On the other hand, it is unclear as why currently under-employed men in rural villages are not considered suitable for herding animals. In the Eastern Cape, smallholder farmers can seldom afford to pay for a herder to move their livestock across the landscape. In a rotational grazing management system, the livestock owner aims at uniform utilisation of the rangeland in order to achieve more livestock production. However, in circumstances where livestock are forced to ingest low quality herbage, this may decrease livestock production and sustainability. Furthermore, in the context of the Eastern Cape, the colonial Betterment programmes created grazing paddocks on community rangeland that were inappropriate for managing the large numbers of livestock within the system, particularly during the dry season. The widespread removal of the fences in the post-apartheid has enabled livestock to forage over a larger distances and gain access to key resources, giving them a better chance of survival, particularly during the dry season.

### 1.7. Rural livelihoods in communal rangelands

At national level, South Africa is a middle developing country with adequate per capita income (Mtshali, 2002). However, many households in traditional areas still experience the

depravation and inequality that was shaped by an apartheid government before the establishment of democracy (Mtshali, 2002), resulting in the undesirable situation of poverty. The fundamental inequalities have led to the impoverishment of the rural population in accessing those resources that contribute to livelihood security such as capital, knowledge, land, basic services, and skills (Mtshali, 2002). Deforestation, threats from invasive alien plants, declining land productivity and soil erosion are other environmental factors that negatively affect rural livelihood security (Overton, 1996).

It is evident that rural areas experience the highest rates of poverty (Mtshali, 2002). About 70% of rural dwellers are poor compared to the 17% living in metropolitan areas, and that 95% of the those living below the poverty line are Africans (Mtshali, 2002). As a result, most rural households are unable to satisfy their basic needs. Household assets are prevalent in rural areas and are appropriate as a unit of analysis (Bank & Qambata, 1999). In areas where rural-urban migration is prevalent, the complexity and diversity of households has increased (Smit, 1998), resulting in difficulties in defining the homestead boundaries since household members live in both rural and urban areas, depending on their employment (Ainslie *et al.*, 2002). Members who leave their homesteads to live and work in urban areas do not lose their homestead membership or their responsibility to support the family members in cash or kind (Russell, 1993).

Having links to more than one household is a common practice in rural areas (Ainslie *et al.*, 2002). Thus assets and resources of such an individual are distributed among the households (Kepe, 2002). South African rural people have complex income strategies including wage labour, remittance from household members working in urban areas, social grants (old age pensions, childcare grants and disability grants), farm labour and paid domestic work, other activities associated with village life, to generate income in order to secure their livelihood (Carter & May, 1999) and livestock production. These strategies and activities mean that South African rural livelihoods are complex and agriculture is considered an essential practice by rural livelihoods (Mtshali, 2002).

### 1.8. Scope of the thesis

Several challenges can be identified within the management of communal rangelands, in addition to water use and livestock production. The debate in South Africa is that communal

rangelands are unproductive and are unable to sustain maximum livestock production because they are perceived to be degraded (Vetter, 2013). However, the information about the livestock production in rural livelihoods has focused on the extent of land degradation through biomass production and change in species composition. Furthermore, research has been done on developing management approaches to promote the maximum ecosystem services of communal rangelands, such as livestock grazing and water provision, which in turn, increase livestock production. However, there is limited information regarding finding a satisfactory way to link livestock production to rangeland production in communal systems, thus LWP. This thesis seeks to address this gap, by describing the biophysical attributes of the ecosystem such as rangeland water use (ET) to give a better understanding of the ecosystem functioning and the expected annual NPP of a rangeland. The performance of livestock production at household level was assessed using a stochastic frontier analysis as an application to provide empirical evidence of household performance in the context of rangeland production. This thesis also assessed the household livestock-based strategies that communal people use for their livelihoods, since livestock production contributes significantly to rural livelihoods and provides an alternative way out of poverty where livestock products are shared among households, regardless of the state of ownership (Ainslie *et al.*, 2002).

Livestock production is perceived to use large quantities of water in the production of livestock outputs (Peden *et al.*, 2009), but several assumptions used to calculate the amount of water that livestock use in producing the outputs are questionable (Scholtz *et al.*, 2013). This issue was addressed by describing LWP of communal rangelands and determining the net annual beneficial output derived from livestock with the associated cost at local level, given the amount of water being used by the landscape (ET). Lastly, areas where most grazing occurs during dry and wet seasons were also identified by collaring livestock using GPS. This was very important as livestock tend to graze anywhere, regardless of the state of degradation and because limited resources mean there are no herders to direct livestock to graze in the under-used parts of the rangelands. Assessment of the livestock distribution was also important to help to plan a grazing management in these communal rangelands because areas that were protected during the study achieved maximum growth production (NPP) and improved vegetation cover.

### 1.9. Aim

The main aim of the study is to describe livestock water productivity in the semi-arid rangelands of the north Eastern Cape, South Africa.. The specific objectives of the study were:

- to provide an overview of communal rangelands in South Africa;
- to describe the biophysical attributes of the ecosystem in the north Eastern Cape communal rangelands;
- to assess the performance of livestock production in the north Eastern Cape communal rangelands using a stochastic frontier analysis;
- to assess household livestock-based livelihoods in the north Eastern Cape communal rangelands, South Africa;
- to assess LWP in the north Eastern Cape communal areas;
- to assess distribution of livestock grazing using GPS collars in a communal rangeland;
- To achieve these objectives the following activities were carried out:
- Household surveys were conducted for information on livestock beneficial goods and services.
- Field surveys determined rangeland condition and production using several parallel approaches, including line transects, descending plate measurements/ disk pasture meter, canopy cover measurements, and cage exclosures for annual net aboveground productivity, aboveground biomass and vegetation cover were conducted.
- Livestock were collared using GPS collars to assess livestock grazing distribution and measure livestock weights for wet and dry seasons.
- Earth observation was used to determine evapotranspiration (ET), LAI, net photosynthesis (PsNet) and NDVI.

### 1.10. Key questions

By developing new metrics, is it possible to assess the total water use of producing livestock in communal areas?

Using the results from a survey of all the products provided by livestock, would it be possible to derive a measure of LWP for communal areas?

Using a fully independent assessment of biomass production and landscape scale evapotranspiration, would it be possible to validate the outputs from the LWP model to achieve an independent assessment of the model?

### 1.11. Thesis outline

This thesis consists of seven chapters that describe LWP in communal rangelands of the north Eastern Cape, South Africa. The first part of the thesis addresses communal rangelands and the debates around the extent of rangeland degradation and productivity. It addresses both water productivity and LWP, its factors and the strategies to improve LWP. This part also discusses rural livelihoods in South Africa, and livestock production and landscape use in communal rangelands.

Chapter 2 describes the biophysical attributes of the ecosystem by determining the amount of water received by the landscape and the amount the landscape uses (ET). It also describes the annual NPP of the landscape, biomass production, vegetation cover, and the net photosynthesis of good condition rangeland.

Chapter 3 determines the performance of household livestock production in a communal rangeland context by using a stochastic frontier analysis as an application to provide empirical evidence of communal rangeland production. This chapter assesses the ability of a household to attain maximum outputs, given the set of inputs and technology.

Chapter 4 examines the household livestock-based livelihoods used by communal people as a way out of poverty. This chapter assesses the livestock goods and services that communal people (both livestock and non-livestock owners) use for their livelihood and reveals what livestock owners understand of where their livestock graze during the wet and dry seasons.

Chapter 5 describes LWP in communal rangelands. In this chapter, ET calculated from Chapter 2 and livestock beneficial goods and services reported in Chapter 4 were used to calculate LWP. The numerator of the equation was all the annual net beneficial goods and services identified by communal people, with their local market prices, while the denominator was the ET from the landscape.

Chapter 6 determines the grazing distribution of sheep and cattle in a communal rangeland and explores the factors that affect livestock grazing distribution. Data collected from GPS-

collared livestock were used to assess livestock landscape use for the wet and dry seasons. Daily weight gains for the collared livestock during the time of collaring were calculated to assess livestock performance for both the wet and dry seasons.

Chapter 7 summarises the key results of the study and explains the possible effects of the proposed interventions and the need for more research.

## CHAPTER 2. THE BIOPHYSICAL ATTRIBUTES OF THE RANGELAND ECOSYSTEMS IN THE NORTH EASTERN CAPE COMMUNAL AREAS.

This chapter will be submitted to a suitable journal. BG wrote all the text and interpreted the results of the chapter, Onalenna Gwate (OG) assisted with data collection.

### ABSTRACT

South Africa is a predominantly semi-arid country, experiencing a chronic water crisis which has an impact on the climatic and anthropogenic-driven shifts in the biotic assemblages. Because of increasing pressure on land and water use, there is little unexploited economically viable surface water. The primary driver underpinning sustainable rural agriculture is rangeland production, as it sustains forage for wildlife and domestic livestock production. Wildlife is part of agriculture that mainly deals with farming game animals that use rangelands and a source of feed. This study describes the biophysical attributes of the ecosystem in communal rangelands of the north Eastern Cape. The study uses MODIS ET extracted from Google Earth Engine (GEE) to estimate evapotranspiration of the landscape. Using four parallel lines of evidence, this study also measures rangeland productivity, such as annual aboveground primary productivity through cage exclosures, disc pasture meter, aboveground standing biomass, vegetation cover using line transects and net photosynthesis. The study looked for these parallel lines of evidence to measure the amount of biomass production in the rangeland that showed a highly productive system with extensively grazed grass. This study estimated Penman- Monteith-Palmer Evapotranspiration (PMP ET) of 270 mm for 2016 compared to MODIS ET of 379 mm, while mean annual rainfall was 636 mm for 2001-2017. The study found a positive relationship between vegetation cover and standing biomass, where cover was found to be a good predictor of a standing biomass. A positive relationship between disc pasture meter and annual aboveground primary productivity was also revealed, where  $370 \text{ g DM}^{-2} \text{ yr}^{-1}$  was estimated based on the disc pasture settling height, compared with  $314 \text{ g DM}^{-2} \text{ yr}^{-1}$  and  $288 \text{ g DM}^{-2} \text{ yr}^{-1}$ . Mean canopy cover was 64% while it was 71% and 65% in other sites and, respectively. The mean annual carbon of  $880.7 \text{ g C. m}^{-2}$  showing the grams of carbon produced by the rangelands per meter square for the unimproved area is reported in this study. The measured variables in the study are a presentation of a rangeland that is in good condition when compared to commercial rangeland systems. However, proper grazing management such as resting the rangelands for a full growing season, are needed to improve productivity and rangeland water use efficiency.

Keywords: *Aboveground net primary productivity, Communal rangelands, Penman-Monteith-Palmer.*

## 2.1. Introduction

South Africa is a predominantly semi-arid country experiencing a chronic water crisis. The main concerns in the context of water resource management are the impacts of the climatic- and anthropogenic-driven shifts on the biotic assemblages (Everson *et al.*, 2011), driven by increasing pressure on land and water use, and little unexploited economically viable surface water. South African rangelands provide multiple ecosystem services to human livelihoods, which are valuable in terms of land production and agricultural economy (Palmer *et al.*, 2015). The production and water use efficiency of these landscapes is generally assumed to be poor because they are continuously grazed and perceived as degraded. These rangelands face the challenge of increased human pressure that varies widely with management practice (Palmer *et al.*, 2015). There is also an increase in woody plant encroachment which has been attributed to several drivers, among them a reduction in fire frequency and intensity, and an increase in atmospheric CO<sub>2</sub> concentration (Buitenwerf *et al.*, 2012). The increase in woody plant density is a key factor affecting the rangeland's ability to provide the desired ecosystem services continuously (Palmer *et al.*, 2015).

In all ecosystems, the aboveground net primary production (ANPP) is a fundamental integrating process (Muldavin *et al.*, 2008), making it important to understand the temporal patterns and production control. Aboveground net primary production is mostly linked with annual precipitation (Muldavin *et al.*, 2008) and is important in addressing questions about the availability of forage, stocking rate for livestock and managed wildlife population in rangelands, as well as wood yield in forests and for estimating the global carbon balance. Sala and Austin, (2000) defined ANPP as the rate at which aboveground biomass is produced and is expressed in weight or energy units ( $\text{g m}^{-2} \text{yr}^{-1}$  or  $\text{kJ m}^{-2} \text{yr}^{-1}$ ). According to McNaughton *et al.*, (1989), ANPP can be used as an integrative ecosystem variable because it reflects and influences other trophic levels.

Evapotranspiration (ET) is the key water cycle process in the ecosystem where energy balance is closely linked. Precise and detailed information of regional evapotranspiration is fundamental to a better understanding of the world's carbon and water cycles. Despite the

development of models, highly accurate ET simulation remains a challenge (Palmer *et al.*, 2015). Such challenges include the comparison of 15 model simulations from the global soil wetness project-2 (Dirmeyer, 2011), which revealed that, on average, the annual global land surface ET mean ranged between 272-441 mm per year. The variability and magnitude of a catchment water yield can be strongly influenced by water used by plants (evapotranspiration) and that lost from the soil surface by evaporation. For this reason, the estimates of catchment water yield should be improved through more accurate estimates of evaporation. Remotely sensed data have long been used to estimate spatially distributed ET fluxes, owing to the high temporal and spatial continuity.

During ET, plant physiological and physical processes combine, contributing to the largest component of the terrestrial water balance after rainfall, and leading to approximately 90% of all the precipitation returning to the atmosphere in arid and semi-arid environments (Palmer *et al.*, 2015). Transpiration comprises vapour fluxes, which regularly account for 70-90% of total ET (Williams *et al.*, 2004), influencing the amount of rainfall partitioned to stream flow, ground water components and infiltration. Strongly coupled with production, transpiration is regulated by water availability in dry areas, with strong responses taking place between hydrology, plant biota and climate (Wilcox *et al.*, 2011). Changes in the structure, physiology, nature and amount of ANPP in these systems have a significant implication for the catchment water yield. These changes cause relatively minor variations in ET and often translate into disproportionately substantial changes in ground water and surface flow.

#### 2.1.1. Satellite and ground-based instrument

Micro-meteorological and satellite sensor technology have both undergone several important advances in recent years and present new opportunities to use ground-based instruments combined with remote sensing to obtain evidence-based, verifiable estimates of evapotranspiration over large land surfaces (Glenn *et al.*, 2007). Several sophisticated satellite sensor systems, including the multi-angle Imaging Spectro Radiometer (MISR), the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) and the Moderate Resolution Imaging Spectro Radiometer (MODIS) mounted by NASA's Terra and Aqua satellite, return to the research community high-quality global information on earth's surface spectral and thermal properties, free of charge. With spectral resolution improved, well-characterised radiometric and on-board calibration systems, polarisation and spatial

sensitivities, MODIS characterises significant technical improvements in earth observation capabilities over its predecessors (Justice *et al.*, 2002). Most importantly, MODIS has established biophysical datasets, stratified according to atmosphere, land and ocean products. Specific interest concerning eco-hydrological research objectives are a LAI product which provides critical information on vegetation phenological dynamics.

For several years, methods such as large aperture Scintillometry, Bowen ratio and eddy covariance (EC) have been used to measure ET but have only recently become widespread thanks to improvements in analytical technique, instrumentation and theory. There has been worldwide growing interest of the carbon budget in an ecosystem and landscape production where permanent EC flux systems were being deployed (Glenn *et al.*, 2007)..

### 2.1.2. The MODIS Leaf Area Index (LAI)

Leaf area index (LAI) provides vital information on surface vegetation processes and well-established plant structural characteristics (Palmer *et al.*, 2015). In all models describing fluxes of mass, momentum and energy within the geo-space, LAI is a state parameter. It describes the green leaf area per unit ground area of canopy cover, or projected needle leaf area in coniferous and broad leaf canopies (Zhang *et al.*, 2004). In the MODIS LAI/fpar product (MOD15), an advanced, three-dimensional radiative transfer theory approach is used to solve for LAI, band uncertainties, atmospherically corrected bi-directional reflectance factors for each MODIS band, and an eight-biome cover land class based on the International Geosphere Biosphere Programme Classification (IGBPC) (Knyazikhin *et al.*, 1998).

To minimise the impact of cloud cover and atmospheric contamination on retrieval quality, the standard MOD15A3 LAI product is now generated as a four-day composite at 0.5 km pixel resolution. Over the compositing period, LAI with the highest corresponding fraction of photosynthetically active radiation (fpar) value is returned. In most global vegetation types, the product has been extensively validated against ground-measured LAI. To evaluate production and water use in rangelands, reliable estimates of ET at suitable time and spatial scales are required. The reliable estimates of ET are also important in monitoring changes in the variables in response to climate activities (Palmer *et al.*, 2015). There is a need to evaluate the effects of change on the hydrology of rangelands. According to Glenn *et al.*, (2007), this is one way to acquire spatially resolved estimates of ET continuously over a large landscape unit.

The approach has improved significantly by combining satellite data, high quality ground-based measurements and meteorological data coupled with algorithm performance and sensors.

In South Africa, the primary driver underpinning sustainable rural agriculture is rangeland production, as it sustains forage for wildlife and domestic livestock production. Graziers view it as the most important variable to describe the services provided by the rangelands (Palmer *et al.*, 2010). Degradation in South Africa has traditionally been equated with undesirable changes in forage quantity and quality related to overgrazing (Vetter, 2013). Several key factors such as animal type, rangeland condition and daily nutrition influence the carrying capacity of a rangeland and are built in to several production models (Wight & Skiles, 1987; Richardson *et al.*, 2007) to provide predictions that are realistic for range managers. Alternative approaches, such as water use efficiency (Snyman, 1994) and rainwater use efficiency (Palmer & Ainslie, 2009) have also been used.

Several studies, such as those of Hailelassie *et al.*, (2009), Peden *et al.*, (2007), Descheemaker *et al.*, (2010a) and Amede *et al.*, (2011) have assessed possible ways to improve the water productivity of mixed crop-livestock systems in Ethiopia. However, no evidence of similar studies could be located that measure Livestock water productivity at household level in South African communal rangelands. The fact that communal rangelands are perceived to be in poor condition and unable to sustain maximum livestock production offered an opportunity to conduct this study on LWP to improve livestock water use. Livestock water productivity (LWP) refers to the net beneficial goods and services derived from livestock relative to the amount of water used in the production of those goods and services (Descheemaker *et al.*, 2010d; Amede *et al.*, 2011). The denominator of the LWP equation includes ET from crop residues, rangelands and degraded water (Peden *et al.*, 2006). However, in this study only ET from rangelands (Hailelassie *et al.*, 2009) was considered, using MODIS ET extracted from google earth engine (GEE). It is worth mentioning that, in the study site crop residues do not form much the livestock diet as there are only small gardens available in the study site.

Following Descheemaker *et al.*, (2010), four parallel methods were applied to measure rangeland productivity, measurements of ANPP using exclosures, the disc pasture meter (Bransby & Tainton, 1977), aboveground standing biomass and vegetation cover using line

transects (Flombaum & Sala, 2007), and earth observation models of net photosynthesis. The study looked for parallel lines of evidence to measure the amount of biomass production in the rangeland with and without herbivory. The study attempts to show that these remain highly productive systems, although their visual impression suggests that all the grass is grazed, and they look degraded. The calibration for the line transects took place outside the overgrazed areas. The calibration of the disc pasture meter was used to predict grass production based solely on aboveground grass biomass. The MODIS NPP product (newly renamed PsnNet product) is one of the indicators of rangeland production because it relates to the quantity of carbon accrued or standing biomass over a certain time, such as the growing season. Improving rangeland productivity through grazing management is one possible way of improving LWP. An adaptive stocking density and appropriate herd composition may positively influence vegetation ground cover, species composition and ANPP, and thus improved water use. Other studies, such as that of Saeed and El-Nadi, (1998), estimate ET during the growing season at field level. Following Palmer *et al.*, (2015), this study also explored potential evapotranspiration from a scientific-grade automatic weather station and MODIS LAI to estimate the ET of a rangeland, implying that evaporation and rainfall during the non-growing season is also accounted as one of the input into plant biomass production. This was done because the communal rangelands of the north Eastern Cape provide grazing throughout the year. However, MODIS ET, which was generated from GEE, was used to calculate LWP.

## 2.2. Materials and methods

### 2.2.1. Characteristics of the study site

The study site is in the northern part of the Eastern Cape Province, South Africa, in the former homeland of Transkei. It is in the quaternary river catchment T12A (centred around 31°31'25S; 27°45'27E). Data from other quaternary catchments S50E (centred around 31°40'41S 27°35'12E) and T35B (centred around 31°04'05S; 28°17'34E) were used in this study for comparison (Figure 2.1). The catchments, T12A and S50E, are both communal tenure arrangements while T35B is administered under the commercial tenure system, with relatively small human and livestock populations. The study site is in the Drakensberg foothills moist grassland (Mucina & Rutherford, 2006) which occurs in a broad arc of the Drakensberg Mountains and its surrounding foothills. The topography ranges from steep mountainous escarpments to moderately rolling grassland incised by river gorges. Mudstones and sandstones of the Molteno and Tarkastad formations of the Karoo Super group, as well as intrusive dolerites of the Jurassic period dominate the geology in the study site. Well-drained soils on the sedimentary parent material are mostly dominant, with clay content ranging from 15–55% and a depth of more than 800 mm, representing soil forms such as Hutton, Griffin, Oatsdale and Clovelly (Mucina & Rutherford, 2006). On the dolerites, soil forms include Mispah rock complex, Shortlands, Balmoral and Vimy. There are 26 average frost days, indicating a sub-montane form of warm cooler temperate climate, and the mean annual temperature is 14.6 °C with a mean annual precipitation of 654 mm. The study site comprises important taxa of graminoids and geophytic herbs (Mucina & Rutherford, 2006).

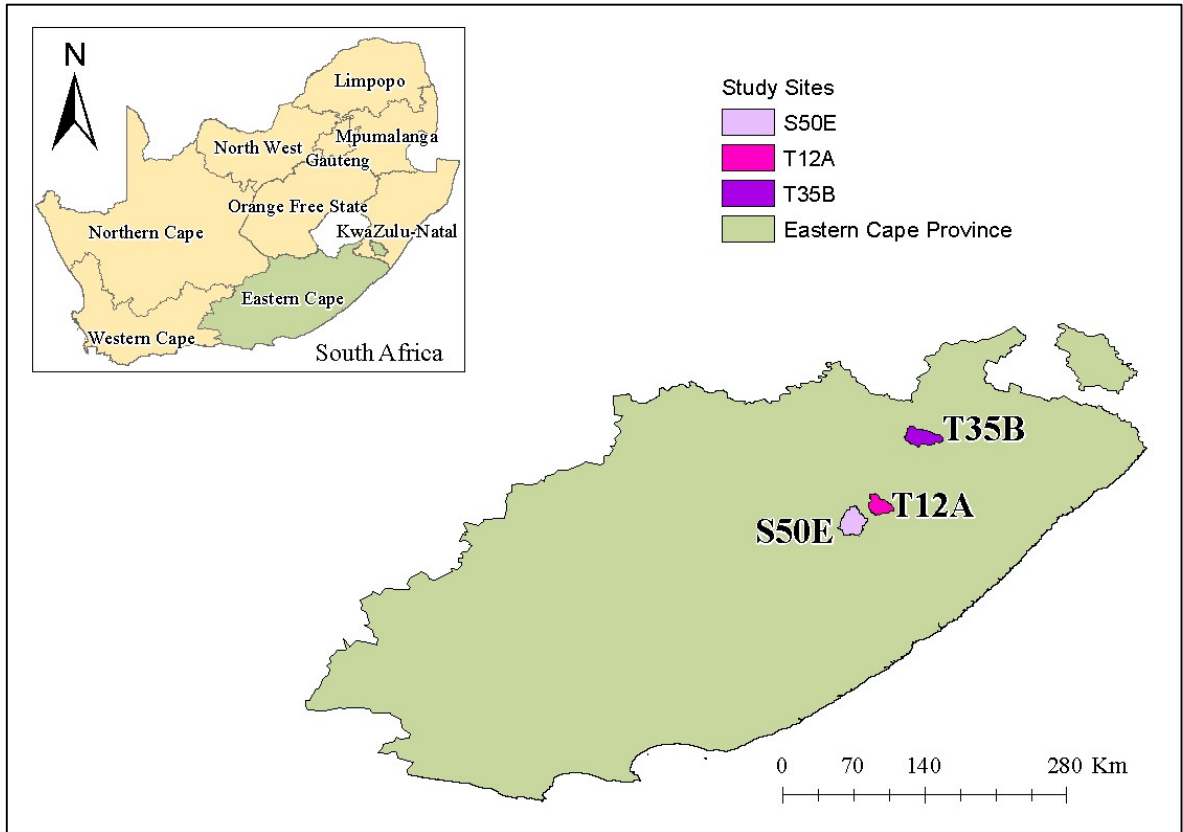


Figure 2. 1. Map of the study site representing the three rural river catchments T12A, S50E and T35B.

### 2.2.2. Defining domains within a study site

Areas where livestock grazing occurred in communal rangelands were identified as domains (Descheemaeker *et al.*, 2010). Identifying the domains of LWP and improving flow efficiency across them offers an opportunity for smallholders to benefit by raising their income and alleviating poverty (Descheemaeker *et al.*, 2010). Livestock derive high value goods and services from water from various sources, such as water consumed by drinking, and water consumed through feeding. The amount of water consumed is determined by several factors related to the animal, feed, and environmental conditions (Giger-Reverdin & Gihad, 1991). Direct water consumption forms only a relatively small part of total water budget. However, livestock ranching has a significant impact on water resources at landscape scale and the watershed. Soil and vegetation degradation may result from the hydrological response of pastures and rangelands which are affected by livestock grazing. Land degradation can be severe around watering points where livestock grazing pressure and trampling of vegetation

can be noticed (Descheemaeker *et al.*, 2010). In this study, areas where most grazing was taking place during the wet and dry seasons were identified and sub-divided into different domains (Descheemaeker *et al.*, 2010) using a combination of earth observations and in-field boundary definition. Possible domains that were identified include a) unimproved grasslands (including riparian zones, wattle groves and areas cleared of wattle), b) cultivated lands and c) areas immediately adjacent to or around homesteads (areas associated with livestock holding, such as kraals). Domain boundaries were determined through GIS mapping techniques using remote sensing.

### 2.2.3. MODIS LAI and MODIS ET data

Both MODIS LAI and MODIS ET were extracted from the three identified grazing domains using pre-processed MODIS imagery (MODIS 15A3) acquired from Land Processes Distributed Data Archive through GEE (Map data 2017 Google, INEGI, ORION-ME, USA). The domains were separated from each other by developing polygons on GEE that matched ground measurements. However, only ET from unimproved grasslands was used in this study to calculate LWP. Maximum LAI values were calculated for each domain. According to Leuning *et al.*, (2009) and Palmer *et al.*, (2015), LAI can be integrated into the Penman-Monteith equation to predict actual evapotranspiration. A Java script with instructions to extract data for the entire length of the MODIS record from 2001–2017 was used for both MODIS ET and MODIS LAI. This provided the baseline of maximum LAI values retrieved for each domain. Rainfall for the entire period (2001–2017) was also extracted. A detailed meteorological record from Cala automatic weather station for the whole 2016 which was relatively a dry year period was used to calculate actual ET for the unimproved grassland. An automatic weather station situated at Cala (-31°52'59S, 27°68'95E) provided records of rainfall, temperature (maximum and minimum), radiation, relative humidity, wind speed direction and potential evapotranspiration at an hourly or daily time step; the station had complete data records for 2016. Daily potential evapotranspiration (ET<sub>0</sub>) returns from the weather station were used to calculate actual evapotranspiration (ET<sub>a</sub>)

### 2.2.4. Penman Monteith Palmer (PMP) equation.

The Penman Monteith Palmer (PMP) equation (Palmer *et al.*, 2015) uses LAI as a proxy for vegetation indices to scale potential evapotranspiration (ET<sub>0</sub>) to actual evapotranspiration (ET<sub>a</sub>). Some form of convergent evolution in terms of strategies and functionality across biomes is shown by vegetation evolution where plants evolve to calibrate light harvesting

ability and leaf area through the availability of resources to optimise carbon fixation. LAI is a main indicator of plant water use and vegetation physiology (Zeppel, 2013). When plant root systems are able to supply water to the atmosphere through stomata at a rate almost corresponding to demand,  $ET_a$  approaches  $ET_0$  under ideal conditions of abundant soil moisture and fertility (Gwate *et al.*, 2016a). However, this relationship degrades to some fraction  $<1$  when there is limited soil moisture. The PMP model was developed to maximum LAI ( $LAI_{max}$ ) which indicates the vegetation functional condition of a landscape relative to its optimum (Palmer *et al.*, 2014). Furthermore, this relationship can be applied to relate  $ET_a$  to  $ET_0$ , assuming that  $ET_0$  represents the upper limit of water use possible within the system when  $\frac{LAI}{LAI_{max}} = 1$ . Maximum LAI can be derived from long-term data sets such as the MOD153A LAI product. The underlying assumption is that under ideal conditions, efficiency levels are possible to the extent that all available energy defined by the  $ET_0$  (Allen *et al.*, 1998) is used for ET. The PMP model is expressed as:

$$ET = \frac{LAI}{LAI_{max}} * ET_0 \quad [2.1]$$

where  $LAI_{max}$  is the maximum LAI and  $ET_0$  is the potential evapotranspiration recorded by the automatic weather station.

#### 2.2.5. Estimating vegetation cover and aboveground standing biomass

A non-destructive method (Flombaum & Sala, 2007) was used to determine aboveground standing biomass in which dry matter biomass was estimated using vegetation cover. Grass canopy cover was measured using the line intercept method from a total of 21 x 100 m transects in the period 2014–2016 during the month of April. The samples were collected on a continuously grazed site. Following Flombaum and Sala, (2007), all aboveground biomass was harvested after every 20 m adjacent to the 100 m transect on a 0.2 m<sup>2</sup> (1.0 x 0.2 m) quadrat. Visual assessment of the cover was estimated based on the area covered in the quadrat. To get the dry matter weight, grass biomass samples from each quadrat were harvested and later dried in an oven at 70 °C for three days. Simple linear regression was constructed to estimate grass dry matter biomass from vegetation cover.

#### 2.2.6. Estimating aboveground net primary productivity and calibrating disc pasture meter (DPM)

To describe the biophysical attributes of the ecosystem in communal rangelands, six grazing exclosures (2.25 m<sup>2</sup>) were established in a communal grazing land (quaternary catchment

T12A). Data from exclosures that were established in another communal grazing land (quaternary catchment S50E) and a commercial grazing land (quaternary catchment T35B) (Gwate, 2018) were also used. During the month of June 2014, the exclosures were established, were clipped to 2 cm above the soil surface, and were protected from grazing. In May 2015 and 2016, nine points were sampled using the DPM (Bransby & Tainton, 1977) within each exclosure, and the grass biomass below the plate (0.166 m<sup>2</sup>) was clipped to 2 cm. The DPM readings were recorded at the settling height for each sample. To determine the dry grass biomass, the clipped samples were oven dried at 70 °C for three days. The DPM was calibrated using a simple linear regression of grass biomass dry matter against settling height.

### 2.2.7. Assessment of net photosynthesis (PsnNet)

The effective measurement of carbon and water fluxes in different land covers is very important as water fluxes differ in their capacity to utilise above and below ground biomass. Figure 2.2 shows the area where net photosynthesis of a un-improved natural grassland was extracted from pre-processed MODIS imagery which was acquired from Land Processes Distributed Data Archive, GEE (Map data 2017 Google, INEGI, ORION-ME, USA). The time series data for MODIS PsnNet were acquired using a Java script with instructions for the period of January 2000 to August 2017. The mean annual carbon produced by the landscape was calculated. The incomplete data set for the year 2015 and 2016 was completed through data gap filling, following Koutsoyiannis, (2003).



Figure 2. 2. The location of the area from which values for MODIS PsNet products were extracted at the Mgwalana village.

## 2.3. Results

### 2.3.1. Evapotranspiration

MODIS LAI was extracted for un-improved grasslands, cultivated lands, and areas around the homesteads in the study area and was then integrated into the PMP equation to predict the actual evapotranspiration (ET<sub>a</sub>). Maximum LAI that were calculated for each domain ranged from 3.84 on un-improved grassland, 4.1 on cultivated lands, and 2.9 around the homesteads. MODIS ET for the three grazing domains is illustrated in Figure 2.3 and shows a mean annual MODIS ET of 428 mm for un-improved grassland, 421 mm for cultivated lands and 425 mm for areas around the homesteads for the entire period 2001–2017. Mean rainfall of 636 mm was also extracted from the study site for the entire 2001–2017 period. The actual ET calculated using the PMP equation for the year 2016 was 270 mm for the communal grasslands, while MODIS ET for unimproved grassland in 2016 was 379 mm, which was used to calculate LWP.

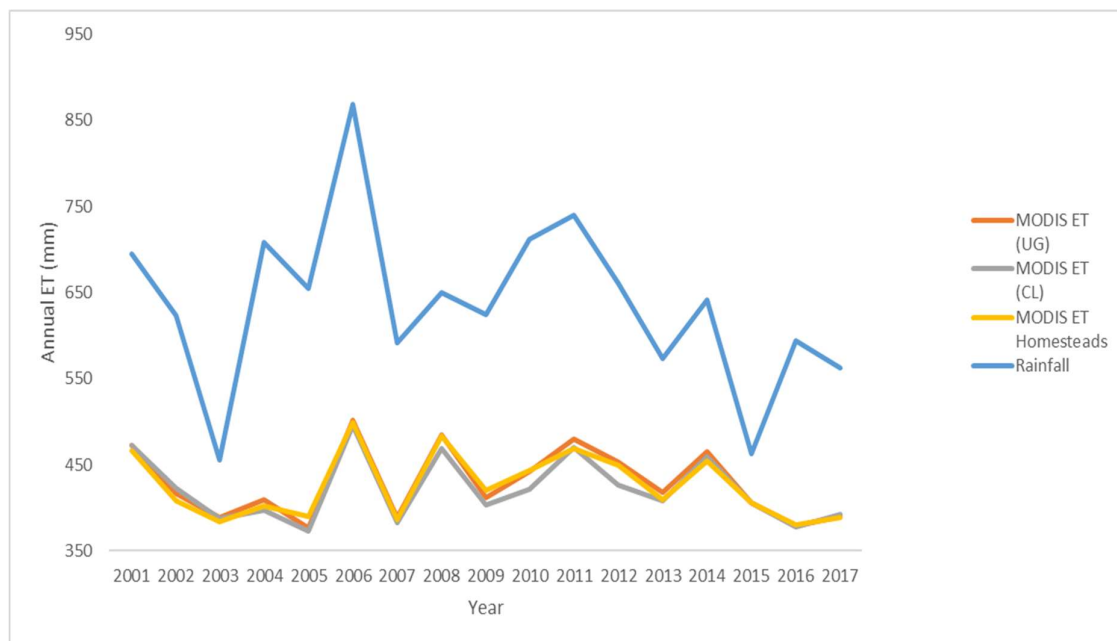


Figure 2. 3. The mean annual evapotranspiration for three grazing domains in Mgwalanta village for the year 2001-2017. UG- unimproved grasslands, CL- cultivated lands.

### 2.3.2. Relationship between aboveground standing biomass and vegetation cover

Figure 2.4 illustrates the relationship between the grass biomass production and the percentage cover of grasses along a 100 m transect. There was a wide range of variation between grass biomass production and vegetation cover. However, the results showed that there was a positive relationship between vegetation cover and grass biomass production. The regression was forced through zero because, in quadrats where there is no grass biomass, the estimated cover was zero. The regression equation revealed a slope of 88.5 with  $R^2$  of 0.96 ( $P < 0.001$ ). The mean canopy cover was 64% in T12A, while canopy cover from other sites (S50E) and (T35B) was 71% and 65% respectively.

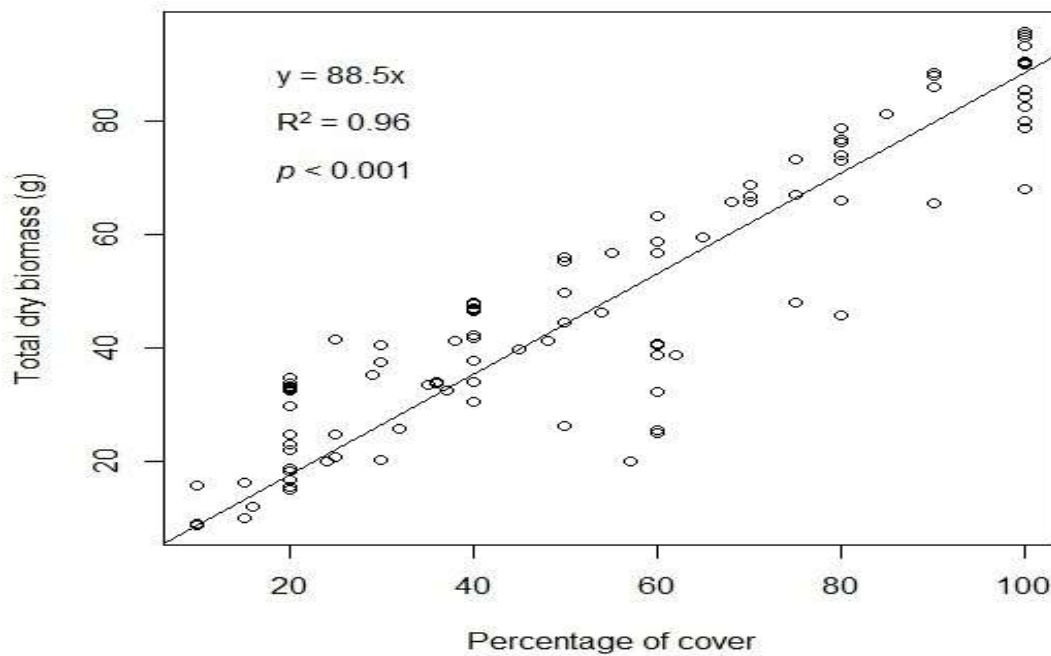


Figure 2. 4. The relationship between aboveground grass biomass and grass cover from 105 0.2 m<sup>2</sup> subplots along twelve 100 m line transects.

### 2.3.3. Calibration of ANPP and disc pasture meter (DPM)

Figure 2.5 (a) illustrates mean DPM settling height and total dry biomass in the study site within the quaternary catchment T12A. Figures 2.5(b) and 2.5(c) also illustrate the mean DPM settling height in two other quaternary catchments which were used for comparison: S50E and T35B respectively. The mean DPM settling height of 16.39 cm was recorded in T12A, followed by 19.53 cm in S50E and 20.93 cm in T35B. Although, the mean DPM readings were significantly different ( $p < 0.001$ ) between the sites, a positive relationship was revealed as the increase in DPM reading increased with the increase in annual ANPP. Figure 2.5 (c), represents disc pasture settling height and total dry biomass estimated in a commercially managed rangeland, which show a great deal of variation in total dry biomass harvested in different disk pasture settling heights.

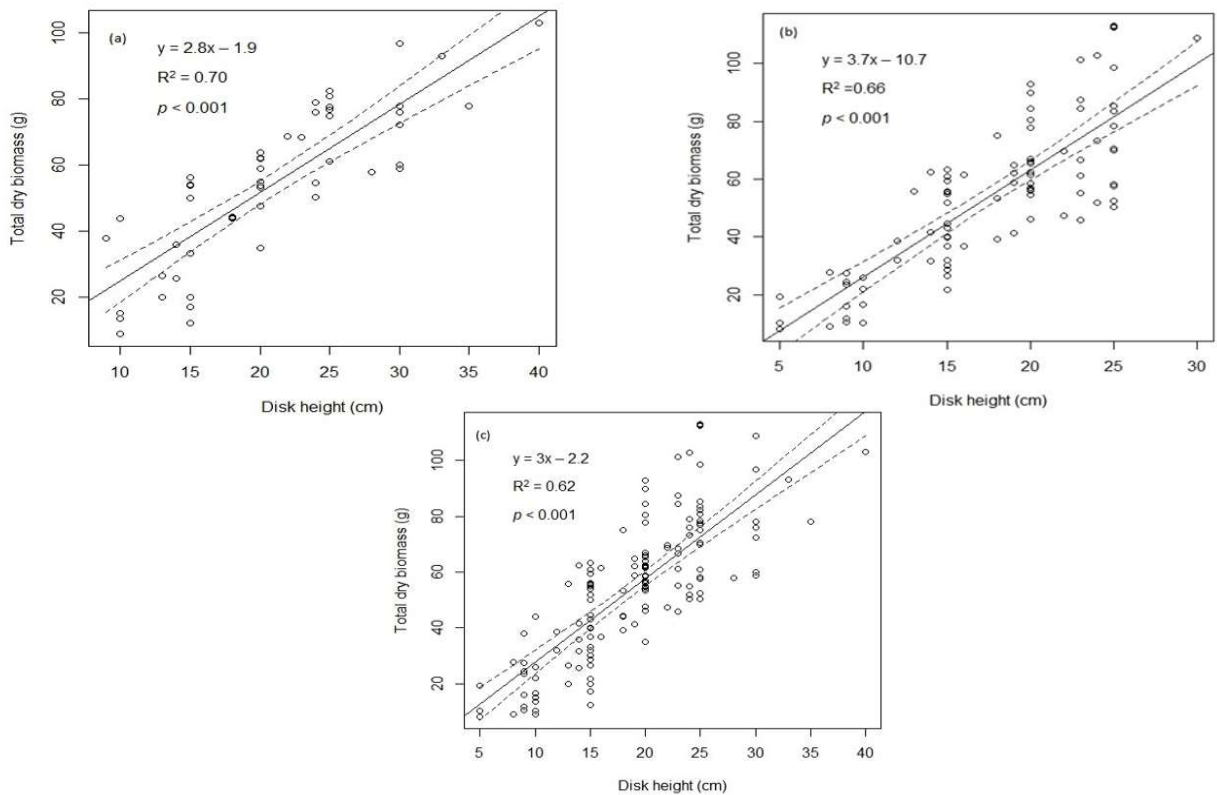


Figure 2. 5. Calibration of the ANPP and the disc pasture meter reading at three sites. a) Communal grazing land, b) Communal grazing land c) Commercial grazing land.

### 2.3.4. Relationship between disc pasture meter and line intercept

Table 2.1 shows the DPM readings and the predicted ANPP using line intercept for the study site. Aboveground net primary productivity of 370 g DM m<sup>-2</sup>yr<sup>-1</sup> was estimated based on the DPM settling height in T12A. The average DPM readings further estimated a line intercept prediction of 220 g DM m<sup>-2</sup>yr<sup>-1</sup> in T12A. Compared to S50E and T35B, the DPM predicted ANPP of 324 g DM m<sup>-2</sup>yr<sup>-1</sup> in S50E and 348 g DM m<sup>-2</sup>yr<sup>-1</sup> in T35B lower than T12A, while the line intercept predicted 314 g DM m<sup>-2</sup>yr<sup>-1</sup> and 288 g DM m<sup>-2</sup>yr<sup>-1</sup> in S50E and T35B, respectively (Table 2.1). This study used results from other studies, such as those conducted by O'Connor, (2008), Everson and Everson, (2016), Danckwerts and Trollope, (1980) for comparison. This comparison was presented to show similar results of the relationship between a disk pasture meter and estimating above ground biomass using line transect in different rangeland systems.

Table 2. 1. Relationship in the dry matter between disc pasture meter and the line intercept.

Site	Location	MAR (mm)	DPM	Line intercept
			Aboveground grass biomass g DM m <sup>-2</sup> yr <sup>-1</sup>	Aboveground grass biomass g DM m <sup>-2</sup> yr <sup>-1</sup>
S50E (Gwate <i>et al.</i> , 2016a)	31°40'41S 27°35'12E	772	324	314
T12A	31°31'25S 27°45'27E	655	370	220
T35B (Gwate <i>et al.</i> , 2016a)	31°04'05S 28°17'34E	786	348	288
Danckwerts & Trollope, (1980)	32°42'05S 26°27'18E	409	252	N/A
O'Connor, (2008)	29°45'01S 29°33'07E	893	292	N/A
	29°49'01S 29°37'57E	862	244	N/A

Everson &	29°56'17S	880	471	N/A
Everson, (2016, biennial burnt)	29°15'41E			

---

### 2.3.5. Net photosynthesis for the best condition unimproved grassland.

Net photosynthesis (PsnNet) extracted from MODIS showed the best condition unimproved grassland at T12A (Figure 2.6). It shows how constant the production of this site has been over the past 17 years (2000–2017). The mean annual carbon of 880.7 g C. m<sup>-2</sup> yr<sup>-1</sup> for the unimproved grassland was calculated from the data presented in Figure 2.6.

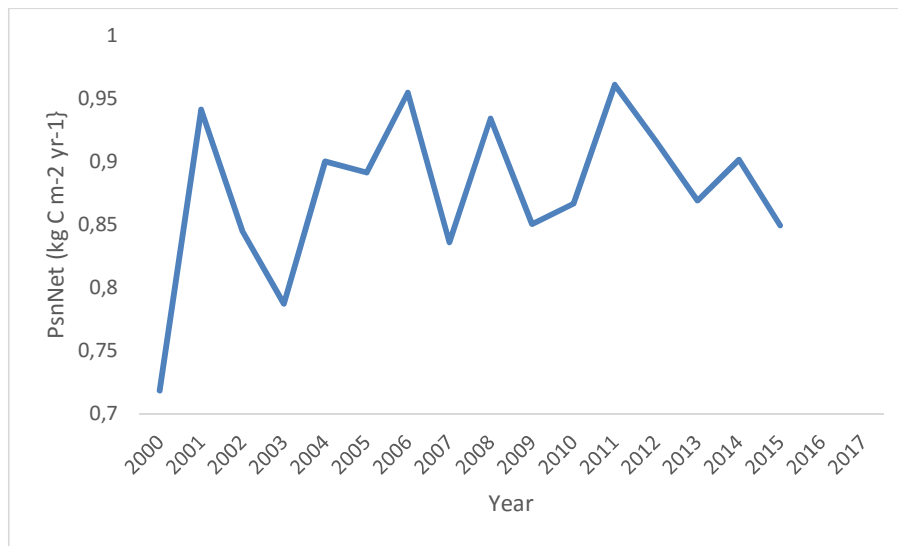


Figure 2. 6. The net photosynthesis (PsNet) for the unimproved grassland in T12A (Mgwalana village).

## 2.4. Discussion

### 2.4.1. Evapotranspiration

Apart from run off and precipitation, the principal part of a hydrological cycle in semi-arid and humid regions is evapotranspiration which affects both environmental and biophysical processes at the interference between vegetation, atmosphere and soil (Mo *et al.*, 2004). The actual evapotranspiration reflects the combined effect of all climatologic factors that can be seen as seasonal variations in different domains, which are caused by the differences in monthly variations of total energy available to drive ET. This study explored the PMP equation to calculate ET<sub>a</sub>, which uses maximum LAI and potential ET to calculate actual ET. Similar to Palmer *et al.*, (2017), a maximum LAI of 3.84 was reported for unimproved grasslands. Maximum LAI for other domains were 4.1 in cultivated lands and 2.9 in areas around the homesteads. On unimproved grassland, a PMP ET<sub>a</sub> of 270 mm was calculated for the year 2016, while MODIS ET for the year 2016 was 379 mm on the unimproved grasslands. MODIS ET further reported a mean ET of 428 mm for the period of 2001–2017. This is because ET<sub>a</sub> depends on water and the amount of energy that is available to drive ET. The study was conducted in a dry land where no irrigation takes place and severe water limitations occur in the dry season. The LAI of vegetation is highly variable both temporally and spatially, depending on seasonality, the prevailing site condition, species composition, the development stage, and management practices (Le Dantec *et al.*, 2000). The Leaf Area Index further characterises energy absorption capacity and canopy function, which is a key parameter in most ecosystem productivity (Sellers *et al.*, 1997).

The amount and timing of precipitation in semi-arid rangelands is an important driving force for evapotranspiration fluxes. A difference between MODIS ET and PMP ET in the study site was found, where MODIS ET was higher than PMP ET. Although maximum LAI in the study area was higher than 2.5, Gwate *et al.*, (2016b) argue that estimating ET from LAI may be reliable when LAI values < 2.5, which applies to most retrievals. This study estimated 56% less ET than the MODIS ET using the PMP. This is possibly due to short grass canopies that can be less effective in capturing energy through the leaf canopy to the soil. Although LAI<sub>max</sub> in the study area was 3.84, the PMP model could not capture changes in ET, and underestimated PMP ET compared to MODIS ET. Similar results were found where PMP ET underestimated ET in the Albany thickets of South Africa (Gwate *et al.*, 2016b), implying that MODIS LAI over grasslands does not respond rapidly to the rainy events, leading to compromised PMP ET

predictions. Even though the PMP model underestimated ET, it was found to perform best in the semi-arid savanna of South Africa (Palmer *et al.*, 2015) where there was a much greater woody component. Furthermore, variations in PMP ET and MODIS ET suggest that the rate of change in ET might not be consistent with that of precipitation because factors such as land cover and changes in land use have a role in the hydrological balance of the landscape. Tian *et al.*, (2010) report a change in ET over time in terrestrial ecosystems of the southern United States during 1995-2007, with semi-arid terrestrial ecosystems using a greater proportion of precipitated water than more mesic ecosystems. Based on the fact that MODIS ET >> PMP ET, and that for these sub-humid grasslands, ET should be closer to precipitation, it was decided that MODIS ET should be used for all further analysis.

#### 2.4.2. Grass standing biomass and vegetation cover

A positive relationship existed between the vegetation cover and dry grass biomass through a 100 m transect. This study used a non-descriptive method to calibrate the estimation of above grass biomass measuring vegetation cover, which can be used to replace the grass harvesting method because it allows for multiple estimates of biomass in the same area and is cost effective (Sala & Austin, 2000). It can be used as an alternative to harvesting grass by estimating it, using the variables that correlate with it, such as vegetation cover. The study results were similar to those found by Flombaum and Sala, (2007) who reported that cover is a good predictor of a standing biomass, vegetation cover and green biomass. Aboveground standing biomass and vegetation cover have inter-annual variation which is affected by the distribution patterns and amount of precipitation (Vandendorj *et al.*, 2015).

#### 2.4.3. Relationship between the disc pasture meter and the predicted ANPP

The amount of herbage available for grazing is crucially important for animal production. The regression equation (Danckwerts & Trollope, 1980) was developed to convert the DPM readings of the standing biomass measurements which expressed the amount of forage at a given time in a rangeland; however, it is not a measure of production of grazeable material through a growing season. In this study, the DPM ANPP of 370 g DM m<sup>-2</sup> yr<sup>-1</sup> was reported on unimproved grasslands, with the line intercept predicting ANPP of 220 g DM m<sup>-2</sup> yr<sup>-1</sup>. The regression equations developed were similar to other studies (Flombaum & Sala, 2007). Using results from Gwate *et al.*, (2017) on other communal (S50E) and commercial (T35B) rangelands, the disc pasture readings were 324 g DM m<sup>-2</sup> yr<sup>-1</sup> and 348 g DM m<sup>-2</sup> yr<sup>-1</sup> respectively, which implies that the lower standing biomass in communal areas does not

equate to lower productivity as communal areas are as productive as commercial areas. The line intercept and the DPM reading revealed a good relationship in validating the ANPP, which provided an easy technique to estimate grass biomass for improved grazing management. The ANPP estimates predicted in this study were similar to other estimates reported in natural grasslands, such as those found by Gwate, (2017) in commercial and communal rangelands of the north Eastern Cape. However, Everson and Everson, (2016) estimated ANPP values ranging from  $190 \text{ g m}^{-2} \text{ yr}^{-1}$  for montane grassland exposed to annual winter burning to  $471 \text{ g m}^{-2} \text{ yr}^{-1}$  for grasslands exposed to two yearly burning using long-term data. Furthermore, Danckwerts and Trollope, (1980) reported ANPP of  $252 \text{ g DM m}^{-2} \text{ yr}^{-1}$ .

Precipitation is the primary constraint on ANPP in grasslands because it is an ecosystem driver of ongoing climatic change (McAuliff, 2003). Results of this study showed the effect of rainfall gradient on ANPP with high rainfall areas reaching higher ANPP than lower rainfall areas. However, this may not always be the case as McAuliff's, (2003) findings which show that shifting patterns in precipitation with an increase in surface temperature have a direct impact on the hydrological cycle of water. Furthermore, studies conducted by O'Connor, (2008) and Everson and Everson, (2016) imply that other factors, such as burning and grazing, play a greater role than precipitation alone. High ANPP in these study sites could possibly be due to the nutrient extraction in the soil due to the removal of invasive alien plants (IAPs) in areas where the exclosures were established (Gwate *et al.*, 2016). This is related to high nitrogen produced by the IAP roots after they have been removed which accumulates in the soil. Net primary production in rangelands is one of the important components of the global carbon cycle. The spatial variability of ANPP over the globe is enormous, ranging from  $1000 \text{ g C m}^{-2}$  for an evergreen tropical rain forest to less than  $30 \text{ g C m}^{-2}$  for desert (Balocchi *et al.*, 2018). In this study there was no discernible trend that could be linked to a continually degrading rangeland as the annual long-term mean PsnNet of  $880.7 \text{ g C m}^{-2}$  was found and the lack of trend retrieved from MOD17A3 indicates that the selected domain represents a healthy grassland showing no signs of degradation.

## 2.5. Conclusion and recommendations

Improving rangeland productivity through rangeland management is one possible way of improving livestock production to improve rural livelihoods. Vegetation ground cover, species composition and ANPP can be improved by adopting judicious rangeland management techniques such as resting rangeland for growth and improved basal cover, thus achieving improved water use. This study supports an estimated annual ET for 2016 over the unimproved grasslands of 379 mm in 2016 (MOD15), which will be used in all further analysis of LWP. We found canopy cover to be a good predictor of aboveground dry grass biomass production in heavily grazed ecosystems. The ANPP was comparable to other studies conducted across South Africa and shows that rangeland production does not depend on the tenure system since communal rangelands were as productive. This implies that many factors other than grazing determine the annual herbage production. Therefore, it is necessary to put proper rangeland management plans in place to prevent excess water loss on communal rangelands; alternatively, excluding animals from certain parts of the rangeland for a certain period of time to allow regrowth is recommended as the exclosures yielded higher biomass. These exclosures were set up as experiments to look at the ability of a rangeland to recover growth if the animals are excluded for grazing over a certain period of time.

### CHAPTER 3. PERFORMANCE OF LIVESTOCK PRODUCTION IN THE NORTH EASTERN CAPE COMMUNAL AREAS, SOUTH AFRICA: A STOCHASTIC FRONTIER ANALYSIS.

This Chapter was published in peer reviewed conference proceeding. BG conducted all the field work and wrote the text in this chapter. RV assisted with the data analysis.

Gusha, B., Palmer, A.R. & Villano, R.A., 2018. "Performance of livestock production in north eastern cape communal areas: a stochastic frontier analysis," 2018 Conference, July 28-August 2, 2018, Vancouver, British Columbia 277555, International Association of Agricultural Economists.

#### **ABSTRACT**

Communal rangelands in South Africa are reported to be on the brink of ecological collapse because they are vastly overstocked compared to those rangelands used by commercial agricultural enterprises. This situation exists because grazing resources are used in a free-for-all environment where there are no incentives to manage common grazing resources. This chapter assesses the performance of households engaged in livestock production in the north Eastern Cape communal areas of South Africa. Survey data from 120 households from Mgwalana and Mahlunqulu villages collected in 2015 and 2016 were used in a stochastic frontier model to estimate technical efficiency scores and evaluate determinants among households in a communal production environment where rangelands are the cheapest source of fodder for livestock. The findings of the study revealed that households use available resources sub-optimally and produce less output compared to the theoretical average. The average technical efficiency score of 0.79 was obtained in this study. These results show that households have a high ability attain livestock beneficial goods and service. These findings suggest that there is significant potential to improve outputs using existing inputs and to address the wide variation in the performance among households. Female-headed households were found to perform better with the help of hired labour. The study provides essential information in understanding the productive performance among households in both villages, and thus provides important policy directions and possible interventions to improve production efficiency.

*Key words: Livestock production, stochastic frontier analysis, technical efficiency*

### 3.1. Introduction

In South Africa, communal rangelands are perceived to be on the brink of ecological collapse because they are vastly overstocked compared to commercial agricultural enterprise (Vetter 2013). This situation exists because grazing resources are used in a free-for-all environment and the free-rider problem inherent in communal areas where there are no incentives to manage common grazing resources. Ainslie *et al.*, (2002) argue that actual offtake which includes officially unrecorded home-slaughter for rituals and intra- and intervillage sales, is typically 20-25% per annum. Livestock production in communal areas is generally unresponsive to extension efforts and technical improvements in disease control or herd improvement. Ainslie *et al.*, (2002) further argue that the low offtake rate in communal areas is mostly related to cultural reasons, such as historical reluctance to sell livestock, the reasons for keeping livestock, and keeping livestock for subsistence. The bigger question is are these areas really facing ecological collapse at all? This has been strongly contested since the 1990s and it is too simplistic to adopt one side of the argument without acknowledging the broader debates these issues are situated in (Vetter 2013). It is clear that these areas are more degraded than commercial ranches but they continue to maintain high levels of livestock over long periods of time and it is rainfall (and thus forage availability) which seems to be the key variable that determines this.

Prior to European colonisation, livestock played a significant role in rural livelihoods. Communal people were agro-pastoralists who owned cattle and goats and were known to cultivate millet, maize, kidney beans, sorghum, melons, pumpkins and tobacco (Elbourne, 1993). For basic protein intake in the form of milk, they relied on their livestock, mainly cattle. They were game hunters and wild plant collectors. Cattle raising was their favourite pastime and cattle were important for subsistence purposes. Meat from dead animals was eaten when an animal died from sickness or old age, and also when an animal was ritually slaughtered. Based on the rules of distribution and criteria for kinship and residential association, consumption of beef was complicated (Ainslie *et al.*, 2002). These agro-pastoralists used cattle hides supplemented by the skin of goats and wild animals to make clothing and war shields (Lewis, 1984). They used dung in their homes for floors, building, and plastering walls. Fines were levied through the medium of exchange of cattle and cattle were accumulated as

wealth, which conferred social importance, maintained a good relationship with ancestral spirits, and ensured health and prosperity.

Currently, the main reasons for keeping livestock in communal areas include a store of wealth, milk, and less frequently meat, draft power, and manure production (Cousins, 1997). Furthermore, livestock ownership confers status and prestige within the community and, in some instances, livestock are used to pay a bride price and provide animals for ritual slaughter. Livestock further underpin social relationships where they serve as social goods in non-market ways. Having said that, a difference exists between holding livestock and owning livestock in communal areas, where an owner may not sell livestock without consulting other family members because they are not inherent goods but are subject to overlapping claims within the family. This phenomenon exists because of rural-urban linkages in these communal areas, where the livestock owner may employ a herder to look after the livestock, or he leaves livestock in the village with relatives but is resident in an urban area where employment opportunities are greater. The combination of birth and residence in communal areas affords one the right to run and own livestock in the rangelands. In some instances, even those who do not belong to the community are allowed to run their stock on the rangelands. This situation has given rise to the argument that the communal tenure system is unfair to the poor who do not own livestock (Cousins, 1996).

Development programmes in South Africa have been implemented to improve animal and rangeland productivity through tenure reform (Behnke & Scoones, 1993). However, to arrive at a more balanced characterisation of the communal tenure system, a historical perspective of pre-colonial forms of land use and tenure system is necessary. The criticism of traditional livestock ownership and land use has a long history in South Africa. Beinart, (1984) states that, in South Africa, the colonials first arrived in the Cape colony during the increasing shortage of grazing land followed by the competition for farmland caused by awarding farms to British settlers. This refers to the spread eastwards from Cape Town of settler-pastoralists into the Zuurveld and what has become known as the Eastern Cape Province.

The boundaries where the African settlers stayed were 'thorns in the side' of the colonists' acquisitive interest. Beinart, (1997) further states that the settler farmers of British and Dutch descent were seen to be directly or indirectly affected by what was happening in the reserve

areas where sheep owned by African farmers were regarded as a threat to colonial farmers' flocks in terms of diseases (e.g. tick-borne diseases, sheep scab and fever). The African farmers were seen as disrespectful of fences and boundaries and they had to be eliminated so that settler livestock could be safe in the future. Communal farmers were restricted to traditional areas by the 1913 Native Land Act in terms of which they could only grow their herds within the limited genetic resources available regionally. This argument of irrational and inefficient African sector first surfaced in the 19<sup>th</sup> century with the growing need for African men for labour in the mines and industries in the diamond fields (McAllister, 1992); men who could only visit their rural homes once a year. Men brought back cash which was best used to purchase cattle as there were no banking facilities available in these areas, and owning cattle was an effective way of securing funds. Young boys were available to herd the livestock as they were not compelled to attend school. The rise of female-headed households in the post-apartheid era was intensified by drivers of male mortality which included diseases such as Human Immuno-Deficiency Virus (HIV), tuberculosis (TB), diabetes and hypertension (BP), as well as the movement of adult men to cities. Fewer adult men remained in the villages, leading to changes in the role of women in the livestock sector and their role in providing payments for large family expenses (e.g. tertiary education). With the introduction of mandatory school attendance in 1996 (South African Schools Act 84 of 1996), there are no longer young boys to herd the livestock all day as they are compelled to attend school. Successful herding to prevent area selective grazing by livestock requires the herder to be present throughout the day. Currently, men and women are now earning much larger salaries in cities and contributing to the herds of the homestead, which leads to unequal distribution of large herd owners in the demographics of the village. Furthermore, these non-residents are generally unwilling to be part of agreements about rangeland management of the grazing commons.

In the traditional areas of the Eastern Cape, livestock continue to supply many different products and services, making a significant contribution to rural livelihoods. People are known to invest heavily in livestock production, and in the small-scale sector cattle production alone accounts for 80–90% of asset value. Both rural and urban-dwelling people continue to have considerable high livestock numbers in these communal areas, which is perhaps mainly related to the absence of other saving methods such as banks, thus leading to thousands of

rural people using livestock to store wealth. However, the apparent excessive number of livestock in these communal areas has had a deleterious effect on the condition of communal grazing resources through overstocking and overgrazing, and this led to mandatory destocking (Vetter, 2013) in some parts of the north Eastern Cape province. This de-stocking was believed to have had a positive effect on the quality of livestock in the communal sector as well as on their reproduction rates, production and their market value. However, there is limited information of any direct evidence that this improved livestock quality and production, and its implementation certainly met with a great deal of resistance.

Livestock ownership provides prestige in many societies, but this varies culturally. There are considerable, unacknowledged cash amounts and unrecorded commercial activities, such as livestock trading, within communal rangelands. The benefits and their importance to rural people during extreme economic uncertainty are well understood and documented (Shackleton *et al.*, 2001). However Vetter (2013) argues that the value of livestock are still underestimated and they are little acknowledged in economic assessment and policy. The role of livestock in communal areas is closely linked to cultural identity. Apart from their contribution to rural household income and food security, they fulfil important spiritual, cultural, and social functions (Ainslie *et al.*, 2002). However, rural people keep livestock for various objectives such as food security, cultural use, or as a form of savings as the perceived relative importance of these benefits differs in areas and with livestock species (Waters-Bayer & Bayer, 2009).

Food security can be improved by maximising the efficiency of livestock production (Otieno *et al.*, 2014). Production inefficiencies limit livestock productivity and sources of inefficiencies are diverse. The most important requirement for improving productivity is to use production inputs more effectively (Otieno *et al.*, 2014) and for farmers to understand the production elasticity of inputs, socio-economic characteristics, and determinants of efficiency. Such understanding would help to improve agricultural policies and programmes, which will, in turn, increase food security (Baha *et al.*, 2013).

Technical efficiency assesses the production of an enterprise's use of resources to produce goods and services (Bahta *et al.*, 2015). According to Battese and Coelli, (1992), technical efficiency is an enterprise's (in this study, a farmer's) ability to increase outputs, given a set

of inputs and technology. The level of technical inefficiency shows the inability of an individual to attain the highest possible outputs from each input used. Extensive studies on technical efficiency of crops, dairy, mixed crop-livestock farms Mlote *et al.*, (2013), Otieno *et al.*, (2014) and Kumbhakar *et al.*, (2014) have been conducted, but there is a paucity of studies on livestock production where all the beneficial livestock goods and services are consolidated and assessed for an individual household. To our knowledge, no studies have been conducted in the north Eastern Cape to assess livestock technical efficiency in communal rangelands where every member has equal access to available resources. The provision of knowledge of production efficiencies is important to improve the potential of a communal livestock system and thus increase economic growth and decrease poverty in livestock-dependent rural households in South Africa.

In the Eastern Cape Province where this study was conducted, livestock production is one of the possible sources of household income and consumption, with the major household livestock holdings being sheep, cattle and goats. The outputs from livestock in this area are chiefly used for household consumption, draft power and wool which is marketed to obtain cash income. People also plant maize during the wet season, which after harvesting is used as animal feed during the dry season. Animals are also used for ploughing and transport, and animal waste is used to improve soil fertility. However, the rangelands are perceived to be poor and unable to sustain maximum livestock production (Bennett *et al.*, 2012) when assessed in terms of species composition and standing biomass. This study provides empirical evidence in the context of a rangeland production perspective as to why it is important to manage rangelands properly for improved productivity and technical efficiency in these communal areas by assessing the performance of livestock production. The study makes a contribution by improving the understanding of the productivity and efficiency of livestock production in the communal area. To achieve this end, the study mainly focuses on identifying the most efficient households who are able to benefit from the possible interventions (access to market, improved labour, improved capital and supplementary feeding) so that they can become more successful at livestock production and improve their food security and be able to provide job opportunities for the less affluent.

## 3.2. Methodology

### 3.2.1. Sampling and data collection

Data for this study were collected from livestock and non-livestock owners in two villages in the Cala communal areas situated in the Eastern Cape Province, South Africa. Cala lies in the north Eastern Cape region of the country (Figure 3.1). Villages were selected on the basis of the presence of a significant population of invasive alien plants (IAPs), and evidence of clearing of these plants to restore the cleared area to grasslands. The tables below were downloaded from Census 2011 prior to conducting the study in order to analyse the dwelling type, annual household income and gender of the household head. Table 3.1(a) shows the annual income from different households, which ranged from no income to those receiving an annual salary of R76 400 in Mgwalana village, with one household earning between R307 601–R614 400. The dwelling type ranged from brick buildings to traditional buildings and apartment flats. Table 3.1 (b) shows that there are 63 male-headed households and 63 female-headed households in Mgwalana village. Table 3.1(c) shows that annual income in Mahlunqulu village ranges from households receiving nothing to households earning between R19 601– R38 200. However, only three households earn up to R307 600 per annum. Table 3.1(d) represents dwelling type by gender of householder in Mahlunqulu village, where 42 households are male-headed households with 18 households living in both traditional and brick buildings for both genders. These tables represent background information on the records of demography of the study sites that will allow us to upscale results from the sample of households. These tables further support the use of the dwelling type as an index of household wealth following Census, (2011).

Table 3. 1(a). Household income by dwelling type in Mgwalana village (Census, 2011).

	House or brick/concrete block structure on a separate stand or yard or on a farm	Traditional dwelling/hut/structure made of traditional materials	Flat or apartment in a block of flats
No income	7	-	4
R 1 - R 4800	1	-	2
R 4801 - R 9600	11	4	7
R 9601 - R 19 600	22	9	12
R 19 601 - R 38 200	15	7	6
R 38 201 - R 76 400	5	3	-
R 76 401 - R 153 800	-	1	-
R 153 801 - R 307 600	-	-	-
R 307 601 - R 614 400	1	-	-
R 614 001 - R 1 228 800	-	-	-
R 1 228 801 - R 2 457 600	-	-	-
R 2 457 601 or more	-	-	-
Unspecified	-	-	-
<b>Total</b>	<b>62</b>	<b>24</b>	<b>31</b>

Table 3. 1(b). Household dwelling type by gender of the household head in Mgwalana village (Census, 2011).

	Male	Female
House or brick/concrete block structure on a separate stand or yard or on a farm	33	30
Traditional dwelling/hut/structure made of traditional materials	12	12
Flat or apartment in a block of flats	15	18
Cluster house in complex	-	-
Townhouse (semi-detached house in a complex)	-	-
Semi-detached house	3	3
House/flat/room in backyard	-	3
Informal dwelling (shack; in backyard)	-	-
Informal dwelling (shack; not in backyard; e.g. in an informal/squatter settlement or on a farm)	-	-
Room/flatlet on a property or larger dwelling/servants quarters/granny flat	-	-
Caravan/tent	-	-
Other	-	-
Unspecified	-	-
Not applicable	-	-
<b>Total</b>	<b>63</b>	<b>60</b>

Table 3. 1(c). Household income by dwelling type in Mahlangu village (Census, 2011).

	House or brick/concrete block structure on a separate stand or yard or on a farm	Traditional dwelling/hut/structure made of traditional materials
No income	1	6
R 1 - R 4800	1	-
R 4801 - R 9600	7	6
R 9601 - R 19 600	14	10
R 19 601 - R 38 200	13	14
R 38 201 - R 76 400	1	3
R 76 401 - R 153 800	1	-
R 153 801 - R 307 600	1	-
R 307 601 - R 614 400	-	-
R 614 001 - R 1 228 800	-	-
R 1 228 801 - R 2 457 600	-	-
R 2 457 601 or more	-	-
Unspecified	-	-
<b>Total</b>	<b>40</b>	<b>39</b>

Table 3.1(d). Household dwelling type by gender of the household head in Mgwalana village (Census, 2011).

	Male	Female
House or brick/concrete block structure on a separate stand or yard or on a farm	21	18
Traditional dwelling/hut/structure made of traditional materials	21	18
Flat or apartment in a block of flats	-	-
Cluster house in complex	-	-
Townhouse (semi-detached house in a complex)	-	-
Semi-detached house	-	-
House/flat/room in backyard	-	-
Informal dwelling (shack; in backyard)	-	-
Informal dwelling (shack; not in backyard; e.g. in an informal/squatter settlement or on a farm)	-	-
Room/flatlet on a property or larger dwelling/servants quarters/granny flat	-	-
Caravan/tent	-	-
Other	-	-
Unspecified	-	-
Not applicable	-	-
<b>Total</b>	<b>42</b>	<b>36</b>

The respondents were selected based on their willingness to participate in the household survey, and included both livestock and non-livestock owners in the two rural villages, Mgwalana and Mahlungulu, located in quaternary catchments T12A and S50E respectively (Figure 3.1). One hundred and twenty (120) households were equally sampled across the two study sites based on their availability and willingness to participate in the survey during November 2015–January 2016, and May 2016–August 2016. In order to achieve a representative sample of different wealth categories, the household dwelling type applied in Census 2011 was used as a surrogate of household wealth, and respondents were selected to represent the range of dwelling types recorded in the National Census. Only one respondent declined to participate in the survey. The household head was interviewed, and in cases where the household head was absent, the most senior person was interviewed. The respondents were given classes of livestock ownership because it is difficult to get an absolute value for livestock ownership it serves as a form of savings. With the help of a local research assistant data was collected using a face-to-face interview during both the dry and wet seasons. The questionnaires were administered in the local language, isiXhosa, which is the language best understood by the respondents, and responses were translated into English. There was one enumerator for each household to conduct the interview. The interviews were conducted during the day and recorded/captured using Kobo collect toolbox that was installed in an Android mobile device.

On the first day of data collection, an introductory workshop with community leaders and community members was held to explain the purpose of the survey and schedule appointments for interviews. Ethical clearance to conduct the survey was obtained from the Rhodes University Ethical Clearance Committee. A consent form was provided prior to the interviews requesting the authorisation of the entire household. Data gathered included information on socio-economic variables of the household such as age, gender, dwelling type, livestock holdings, livestock sales and mortalities, provision of livestock feed, livestock kraaling and herding. Information was also collected on the inputs as well as outputs in terms of livestock beneficial goods and services derived for household use. The input data collected include hired labour, livestock units owned, cost of feed used; output data collected were milk, offtake, wool, hides, mohair, manure and traction.

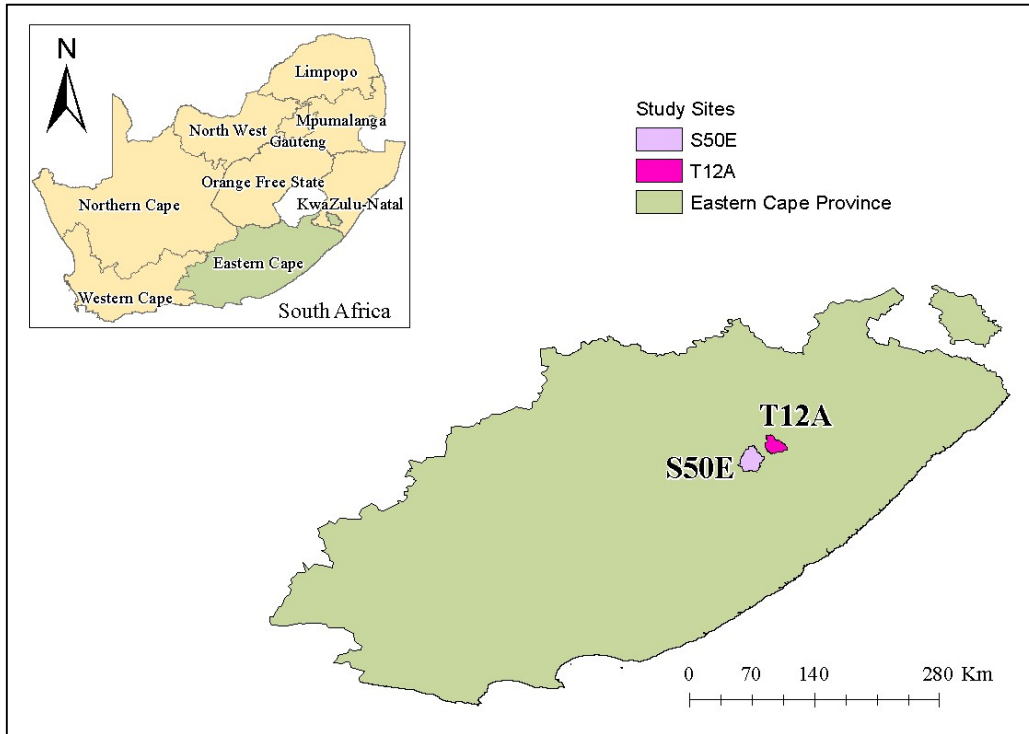


Figure 3. 1. Location of the study area in quaternary catchment T12A and S50E.

### 3.2.2. Sampling approach: Estimating values of livestock goods and services

Livestock form a vital component of agriculture worldwide. They provide ecosystem service output and have cultural value (Haileslassie *et al.*, 2009). However, in this study only offtake, milk, manure, skin, hides, wool and traction were considered. The beneficial outputs and services in this study were estimated as follows:

**Manure:** Manure production was calculated using dry weight, daily dung production of 3.3 kg/day/TLU for large animals and 2.4 kg/day for small ruminants for the annual average livestock holdings (Descheemaeker *et al.*, 2010; Bekele *et al.*, 2017). Nutrient composition was estimated based on nutrient content of 18.3 g N/kg, 4.5 g P/kg and 21.3 g K/kg on a dry weight basis (Bekele *et al.*, 2017). Monetary equivalence of manure to artificial fertiliser was extrapolated from the nutrient contents and price of LAN (28).

**Milk production:** Annual milk production was estimated as a function of: number of lactating cows, lactation period and milk production in litres/day/cow in a household herd per year (Haileslassie *et al.*, 2009). The figures that were used for lactation period and daily milk production were part of the data collected as part of the study. The total milk produced per cow was converted into monetary values based on the value of milk at a farm gate price.

**Offtake:** Livestock offtake was estimated as the proportion of animals sold or slaughtered for household consumption in a year. It was calculated by summing the values of each animal type (Rands) that was sold for consumption or gifted in a year (Kebebe *et al.*, 2015). Number of sold animals, stock fair sales, informal sales and slaughter were also measured as reported by low input farmers (Tada *et al.*, 2012). The low input farmers are farmers that are not investing in livestock production such as health services and livestock feeding.

**Fibre production:** Fibre production was estimated based on the annual income derived from selling hides/wool in formal markets as reported by households. During shearing season, the amount of wool produced per sheep was weighed and animals were sexed.

**Traction power:** Traction power was estimated based on daily hiring cost of draft animals (e.g. oxen) and number of working days/year spent for ploughing and threshing in every sample (Hailelassie *et al.*, 2009).

### 3.2.3. Stochastic frontier production function analysis (SFA)

In this study, household agricultural production is aimed at maximising production. In view of this, the study uses the SFA method (Aigner *et al.*, 1977; Meeusen & Van Den Broeck, 1977) in order to examine input-output relationships and obtain efficiency indicators. The method was extended by Kumbhakar *et al.*, (1991) to introduce the determinants of technical efficiency into the model. The model also proposes that an inefficiency effect  $u_i$  be expressed as a clear function of the vector of a firm specific random error and variables in a single stage stochastic frontier. Battese and Coelli, (1995) provide a frontier model with output-oriented technical efficiency specified as:

$$Y_i = X_i \beta + (\varepsilon = V_i - \mu) \quad (3.1)$$

where  $Y_i$  is a scalar output of the  $i_{th}$  firm;  $X_i$  is a vector of input quantities, and  $\beta$  is a vector of parameters to be estimated;  $\varepsilon$  is the disturbance term comprised of  $V_i$  and  $U_i$  independent components.  $V_i$  is a random variables which are assumed to be i.d.  $N(0, \delta_v^2)$ , and independent of the  $U_i$  and  $U_{is}$  are equal to a non-negative random variable which are assumed to account for technical inefficiency in production and are assumed to be independently distributed as truncations at zero of the  $N(m_i \delta_u^2)$ . The estimation of equation 1 provides variance estimators, estimators for  $\beta_j$  and other relationships as denoted as:

$$\delta^2 = \delta_v^2 + \delta_u^2 \quad (3.2)$$

$$\gamma = \delta_v^2 / \delta^2 \quad (3.3)$$

$$\lambda = \delta_v^2 / \delta_u^2 \quad (3.4)$$

where  $\delta^2, \delta_v^2, \delta_u^2$  are the overall variance of the model, variance of the random error and variance of the technical inefficiencies, respectively. Gamma ( $\gamma$ ) measures the proportion of the total output made on the frontier function, which is attributed to technical efficiency and has a value between zero and one. The lambda ( $\lambda$ ) parameter is expected to be greater than one. This condition indicates a correctly specified error term ( $V_i - U_i$ ) and a good fit for the model. The empirical model is defined as:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + V_i - \mu_i \quad (3.5)$$

where

$\ln$  denotes natural logarithm (base);  $Y_i$  is the total output per cow for the  $i^{th}$  household (1,2,3...n);  $\beta_0$  is an intercept and is constant;  $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5,$  are the parameters of regression coefficients of the  $i_{th}$  variable;  $X_1$  is the total labour hired used in the production of livestock outputs;  $X_2$  is the total livestock household holdings which was a conversion of a livestock unit (LSU) 0.8 for cattle, 0.15 sheep and 0.10 for goats;  $X_3$  is the total cost of livestock feed;  $X_4$  is the dummy for (LSU);  $X_5$  is the dummy for total cost of livestock feed.

$X_1$ = it is expected that households that have more hired labour to look after the animals will have increased livestock productivity. Resources in the communal systems are spatially heterogeneous and that herding enables best access to them, particularly during the dry season when additional resources such as crop residues become available;  $X_2$ = it is expected that a large number of household livestock holdings will increase livestock productivity;  $X_3$ = it is expected that livestock productivity will increase if more money is invested in buying additional feed for livestock and  $V_i$  and  $U_i$  as defined above.

### 3.2. 4. Technical inefficiency model

Following Battese and Coelli, (1995), the study uses a function model which has the advantage of allowing simultaneous estimation of the respondent farmer and individual technical efficiency with a one-sided error term specified as follows:

$$\mu_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + \delta_6 Z_{6i} + \omega_{it} \quad (3.6)$$

where:

$\delta_0$ , is the intercept;  $\delta_{1,2,3,4,5,6}$  are unknown parameters to be estimated;  $Z_1$  is the household head age in years;  $Z_2$  is the gender of household head;  $Z_3$  is the type of dwelling that the respondents live in;  $Z_4$  is the proportion of households who provide additional livestock feed;  $Z_5$  is the proportion of households who kraal their animals;  $Z_6$  is the proportion of households who have herders to look after livestock. The  $\omega_{it}$  are the iid variables with variance defined by the truncation of the normal distribution and zero mean. The specific  $Z$  variables in the above model are specified below:

$$U_i = \delta_0 + \sum \sum \delta_{ij} Z_{ij} \quad (3.7)$$

where  $U_i$  is the technical inefficiency of the  $i^{th}$  household for  $i = 1, 2, 3 \dots, N$ ;  $Z_{ij}$  is the  $j^{th}$  socio-economic variable for the  $i^{th}$  household for  $i = 1, 2, 3 \dots, N$  and  $j = 1, 2, 3 \dots, k$   $\delta_0$  is the intercept, and  $\delta_j$  is the coefficient for the  $K^{th}$  variable.

$Z_1$  = age of household head is expected to influence technical efficiency. Older people are not easily convinced to adopt new technology and innovation. As they grow older, they are unable to look after livestock on their own. On the other hand, young household heads are more easily convinced to adopt an innovation and are still active enough to care for the animals. However, with the lack of interest in youth to be involved in agriculture, it is possible that age can have a negative effect on household efficiency.

$Z_2$  = it is expected that gender of a household head may affect technical efficiency positively or negatively, depending on the socio-economic characteristic of a household. Male-headed households are expected to perform better than female-headed households, due to the gender role in livestock production. However, the pressure for women to provide for the household can also lead to female-headed households performing better. However, there are some unidentified reason for this.

$Z_3$  = it is expected that dwelling type, which was used as a proxy for wealth (Bekele *et al.*, 2017), because of rural-urban linkages in rural households, may have an effect on technical efficiency. So, it is expected to increase technical efficiency. However, the study acknowledges that some of the indicators such as inclusion of ownership of consumer white goods, motorcars, tractors, children educated to tertiary/university level, etc. would have strengthened the confidence levels of this variable but were very limited.

$Z_4$  = it is expected that provision of additional feed will have a negative impact on technical efficiency. This is because households can provide feed to livestock to a point where the maximum growth is reached, after which they start losing weight; hence technical efficiency decreases.

$Z_5$  = it is expected that cattle and sheep kraaling will have both negative and positive impacts on technical efficiency. Kraaling reduces the chances of animals being stolen and being exposed to predators overnight in the rangelands, and it allows monitoring livestock numbers and easy access to livestock handling. However, Nowers *et al.*, (2013) state that kraaling

contributes negatively because animals regularly stay confined until mid-morning, so reducing prime early morning grazing.

$Z_6$  = it is expected that livestock herding will increase technical efficiency because herders will move the animals to the most productive parts of the rangelands and will be able to control them when it is time for kraaling at night. However, the decrease in the interest of herding among the youth and mandatory schooling of young children may have a negative effect on technical efficiency.

### 3.2.5. Statistical analysis

Descriptive statistics were used to describe key variables in both villages. Technical efficiency was estimated using Frontier 4.1 programme (Coelli & Battese, 1996) and verified in R, to find the maximum likelihood estimates for parameters of the stochastic frontier production function.

### 3.3. Results

#### 3.3.1. Socio-economic characteristics of households

The results revealed that 65% and 35% of the respondents were females and males, respectively. Of the sampled households (n=120), 14% of the respondents were between 41-50 years old. The youngest respondents (4%) were younger than 30, while 43% of the respondents were over 51 years old. About 39% of the respondents were between the age of 31-40. Of the respondents, 62% lived in houses made of bricks, while 38% lived in houses made of mostly mud, wood, thatch and bits of brick. The results revealed that 82% of the respondents used labour to look after their livestock, while 18% do not employ labour, but look after the animals themselves. Labour employed included both family members and hired people. The results showed that 57% of the respondents provide additional feed during the dry season, but the number of days on which different respondents provide feed to their livestock differs, with 43% of the respondents relying solely on grassland for livestock grazing and feeding. The results also showed that 90% of the respondents kraal their animals at night, while only 10% leave their animals in the field (Table 3.2).

Table 3. 2. Socio-economic characteristics of the households that were interviewed.

<b>Description</b>	<b>Frequency (n=120)</b>	<b>Percentage (%)</b>
<b>Gender</b>		
Females	78	65
Males	42	35
<b>Age</b>		
≤ 30	5	4
31-40	47	39
41-50	17	14
51-60	24	20
≥ 61	27	23
<b>Dwelling type</b>		
Brick building	74	62
Traditional building	46	38
<b>Labour</b>		
Yes	98	82
No	22	18
<b>Additional feed</b>		
Yes	68	57
No	52	43
<b>Kraaling</b>		
Yes	108	90
No	12	10

### 3.3.2. Parameters of ordinary least square and maximum likelihood estimates

The results of ordinary least square (OLS) and maximum likelihood estimate (MLE) are presented in Table 3.3. These results show that the estimated coefficients for main inputs

(livestock unit and cost of feed) are positive. The coefficient for labour was found to be negative and not consistent with our theoretical expectation. However, the coefficient for labour was significant. This result indicates that productivity output decreases with an increase in labour input, suggesting that labour which can affect livestock productivity can be increased to a point of no return where maximum growth has been reached and eventually the outputs decrease. These variables were measured to assess whether they influence livestock productivity. The results suggest that an increase of 1% of both livestock units and feed will increase livestock productivity outputs by 0.25% and 0.06% respectively. The inefficiency variables were included in the analyses to assess whether they influence the technical efficiency of the household. The results reveal inefficiency variables in the analysis of the stochastic frontier which indicate coefficients for age, and provision of feed to be positive, suggesting that increasing these variables will decrease technical efficiency. However, the estimated coefficient for gender, dwelling type, kraaling and herding which were all negative, indicating that an increase in these variables will increase technical efficiency. In this analysis, for the inefficiency variable, the negative means the opposite.

Table 3. 3. A stochastic frontier production function parameter and ordinary least square (OLS) and maximum likelihood estimate (MLE).

Variables	OLS			MLE		
	Co-eff	St. Error	t-ratio	Co-eff	St. Error	t-ratio
Constant	16.903	4.731	3.573	13.700	2.714	5.048
Labour	-0.834	0.545	-1.531	-0.445	0.307	-1.448
Livestock unit (LSU)	0.256	0.109	2.348	0.161	0.091	1.765
Cost of feed	0.066	0.062	1.061	0.070	0.057	1.236
Dummy (LSU)	0.722	0.292	2.469	0.724	0.271	2.672
Dummy (Cost of feed)	0.294	0.193	1.525	0.422	0.219	1.926
Constant				1.153	1.258	0.916
Age				0.491	0.860	0.570
Gender (1= Female)				-1.743	0.760	-2.294
Dwelling type (1= Brick)				-2.580	1.096	-2.355
Additional feed (1=Yes)				1.813	0.765	2.369
Kraaling (Yes= 1)				-1.053	1.286	-0.818
Herding (Yes= 1)				-1.205	0.655	-1.841
Sigma square				0.947	0.268	3.527
Gamma				0.460	0.116	3.982
Log likelihood	-145.68			-136.61		

### 3.3.3. Wealth status classification criteria

A post-analysis of the multiple criteria focused on physical ownership of key assets and their anticipated values at the time of study were used rather than precarious annual cash income (Bekele *et al.*, 2017). Ownership of houses with brick buildings and corrugated iron, thatched roofs, traditional buildings, livestock types and numbers, and technical efficiency were used as indices of wealth (Table 3.4). However, it was not possible to set an absolute cut-off point for each criterion, hence it was evident that overlap in the range of values for set criteria

would occur. The contributions were assessed together as a group of households under one criterion of the three wealth categories following Bekele *et al.*, (2017). The national census data were also used to define the categories of dwelling type (Census, 2011).

Table 3. 4. Livestock wealth classification criteria.

Criteria	Better-off (n=33)	Medium (n=33)	Poor (n=54)
<b>Livestock holdings</b>			
<b>No. of cattle</b>	>8	4-8	<4
<b>No. of Sheep</b>	>15	10-15	1-10
<b>No. of Goats</b>	>15	10-15	1-10
<b>Dwelling type</b>			
<b>Traditional</b>	No	Yes	Yes
<b>Bricks</b>	Yes	Yes	No
<b>Technical efficiency</b>	0.7-0.10	0.4-0.69	0.1-0.39

#### 3.3.4. Distribution of technical efficiency scores among the different households

The frequency distribution of technical efficiency levels is presented below in Figure 3.2. The results show that household livestock production achieve, on average, 79% level of efficiency, ranging from 15% to 93%, with a wide range of efficiency variation among households. About 63% of the households had a technical efficiency level ranging from 81% to 93%. Only 11% of the respondents had a technical efficiency level ranging from 51% to 70%. About 6% of the households were only able to achieve 10% to 50% technical efficiency. The results further reveal that 20% of the households were able to achieve a technical efficiency level between 71% to 80%. These results suggest applying proper interventions has the potential to improve technical efficiency among households.

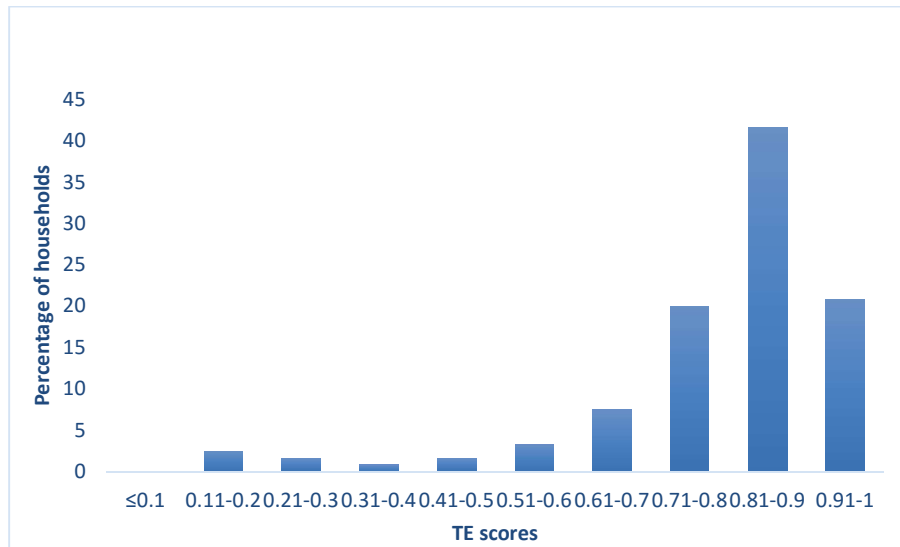


Figure 3. 2. Distribution of technical efficiency in the study area.

### 3.3.5. Frequency of performance based on the post-analysis performance classification

Figure 3.3 shows the results of the post-analysis of performance group categories, based on an individual household's wealth status in terms of livestock holdings, technical efficiency and dwelling type. The poorly performing households numbered 45% (n= 54) of the sampled households. Householders in this group mainly reside in traditional buildings made of wattle and mud and consist of more females (29%) than males (16%). About 27% of households in this group (n=32) have abandoned livestock farming. The poor performing group have a low livestock-derived output and they invest in livestock production through household labour. The middle performing group of 28% obtain moderate outputs with labour and additional feed having been invested. This group of individual households reside in mixed buildings of both traditional and brick houses and have livestock holdings of between 4-8 cattle, and more than four small stock. This group is composed of 18% females and 10% male-headed households. Of the interviewed households that fall into the better-off group (27%), more household heads are females than males (18% and 9%, respectively). According to the results, the better-off group revealed to be positively producing livestock outputs. Householders in this category reside mainly in brick buildings and have more livestock than the other groups.

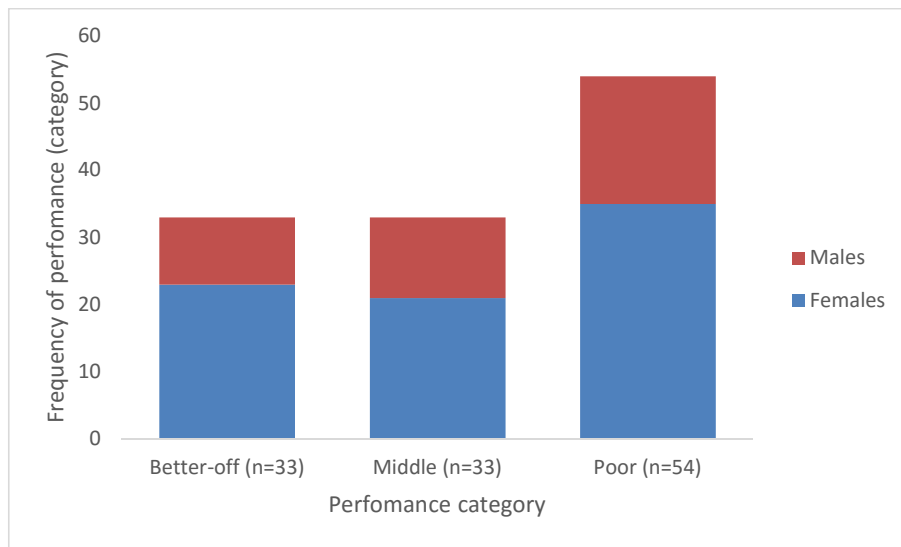


Figure 3. 3. Frequency of productivity performance by gender of the household head at Mgwalana and Mahlungulu village.

### 3.4. Discussion

#### 3.4.1. Inefficiency model estimates

The results of the MLE represent both productivity and inefficiency variables measured in the study. The productivity variables, such as livestock holdings, are variables that have an influence on the livestock productivity. However, inefficiency variables, such as the gender of the household, have an impact on the household technical efficiency. The results indicate that there are gender-based increases in the technical efficiency and that there are more increases in female-headed households, which dominate the highest efficiency group. According to a study conducted by Yisehak, (2008) in Ethiopia, gender is an important component in labour share of livestock production systems. Both males and females have different responsibilities related to animal production, with some level of variation in involvement from household to household. In smallholder livestock production, males are mostly responsible for decision making and general herd management, while females contribute more to labour and feed inputs and manage sick animals and calves (Yisehak, 2008). These results make sense, given that high livestock productivity and technically efficient households are female-headed households. The respondents reported that they provide labour for livestock handling and household members provide most of it. Some of the households use their children to look after cattle, when they come from school. This arrangement, according to Cousins, (1996) also helps an individual to gain livestock ownership because of the experience of animal husbandry he/she gains at a young age. However, mandatory schooling has reduced the number of children who are available to work as herders, so it is mostly elderly people who look after livestock during the school hours. In both villages, 68% of the households provide additional feed for livestock. These households only provide feed during the dry season. The animals that benefit from the feed are only those that are calving and those already in calf. The reason for such a limit could be the fact that these people are unemployed and rely on livestock sales (mostly informal), while their adult children, who are migrant workers, focus on household development (building additions, repairs and maintenance) that is not related to livestock production.

Age was an important criterion with many individuals ranging from 51–60 (20%) to more than 61 (23%) years of age (Table 3.2) in interviewed households. The results (Table 3.3) show that with increasing age (indicated by a positive sign), technical efficiency decreases. This suggests that although older people have more knowledge and interest in livestock keeping, however,

they struggle with the physical responsibilities that come with livestock farming. They also do not easily adapt to new innovation and technology. On the other hand, there is a the likelihood that they have younger people, often grandchildren in their households who can care for livestock. These results were almost the same as those found by Kunene, (2010) in Northern KwaZulu-Natal, and Masuku and Sihlongonyane, (2015) among smallholding farmers in Swaziland, who recorded that most farmers fell into the age group of 50–60 years.

The results of the inefficiency model show that dwelling type, indicated by a negative value (Table 3.3), is associated with increased technical efficiency. In both villages, 62% of the households were brick buildings, while 38% of households were traditional buildings. This may be due to rural-urban linkages, where absent family members who are migrant workers are directly involved in the household development via remittances and kinship contributions. The absent family members become involved in household development by assisting in the building of a household when they start earning an income. Almost every household (90%) kraals their livestock at night. The coefficient for kraaling and livestock herding, indicated by a negative value (Table 3.3), suggests that both kraaling and herding increase technical efficiency. Kraaling and herding are very important in keeping animals away from predation and theft. Kraaling and herding increase technical efficiency but they also cause soil compaction and increase soil erosion and run-off.

#### 3.4.2. Technical efficiency scores

The mean score for both villages was 0.79 of technical efficiency implying that, on average, both villages produce at 79% with given inputs and technology. This study does not exploit the analytical potential of a 'compare and contrast' of the conditions and variables between the two villages because they share similar characteristics. According to the results of technical efficiency, 93% of the households had a score above 0.5. However, there is still more to be done in communal areas to improve technical efficiencies of livestock production. In this study, of the 93% households, 21% obtained more than 91% technical efficiency level. The study showed that factors such as age and provision of additional feed to livestock decreased technical efficiency. According to Tolga *et al.*, (2009), the age of a farmer may have both a positive or negative influence on technical efficiency, depending on whether the experienced older farmers are slower to accept new technologies than young farmers are. Furthermore, when the animal is provided with additional feed, it grows and reaches a point

where there is no further growth, after which weight drops, thus decreasing technical efficiency. The increase in technical efficiency would require improving household interspecific efficiency factors that include proper land use practice, farmers' information days, access to credit, access to markets, increase in extension visits, and close mentoring of the people who are livestock farmers (Bekebe *et al.*, 2017). This can be done by identifying the households that are able to achieve a higher technical efficiency level so that possible interventions can help to uplift them in becoming more successful livestock farmers. Possible options include developing the livestock market value chain where beef suppliers (e.g. abattoirs and feedlots) buy livestock directly from the villages. The government could also assist households who obtain more than 70% technical efficiency level by ensuring better and more reliable support and empowering women farmers.

#### 3.4.3. Determinants of technical efficiency in different performance profiles

According to the results obtained from the performance profile, 45% of households perform poorly in both Mgwana and Mahlangu villages. This group was composed of individual households who have low livestock numbers, live in traditional buildings and obtained low technical efficiency scores. This group consists of households that invest inputs, such as additional labour, but still produce at a loss. The underlying reason for such output can be inefficiency variables such as those documented by Masuku and Sihlongonyane, (2015). Such factors are documented as production constraints affecting production efficiencies of farmers and they include lack of information about livestock farming, poor market information, unavailability of inputs (high feed cost, veterinary services, reliable labour), shortage of water and feed. All these factors apply to these villages. The most frequently observed constraint in these two villages was the fact that people do not have enough information about livestock husbandry because they keep their animals for status or just because the land is freely available to run livestock. They keep the animals for a very long time until they lose their market value. The middle performing group achieved moderate production. This group of households invest both labour and capital in livestock production and reside in brick houses as well as those of wattle and daub.

The better-off performing group obtained positive values and constituted 27% of the sampled population. This group of households comprises individuals who own high livestock numbers and live in brick buildings. In this group, some of the households apparently discontinued and

sold all their livestock production because of disease, theft and drought and have sold all their livestock, converting them into cash for household expenses, such as sending children to school. Better-off performing households are mostly headed by females (18%) rather than males (9%). These were surprising results in view of the fact that men are expected to have more knowledge than women about livestock, and hence are expected to produce more. On the other hand, females in rural areas are under more pressure to provide for their households with the money from livestock sales. These results provide an opportunity for any interventions that may be useful in improving technical efficiencies in these two villages. Women are also better managers of money and the household domestic finances, partly through their greater involvement in clubs and church groups and burial societies.

### 3.5. Conclusion and recommendations

The results of the findings of this study reveal that more women than men participated in the survey, possibly because the men are working or seeking work in urban areas. The mean technical efficiency for the study shows that there is an opportunity for improvement in the households that are performing above 70% at the technical efficiency level. The idea is to uplift all the households in the village – not just the livestock owners – and encourage them into livestock farming. The results also suggest that there is a need for market information and livestock husbandry to reduce the livestock water footprint in the village. However, there is a lack of trust of non-kin herders which could possibly speak to the point of why elderly/female households remain reluctant to hire local unemployed men who they deem to be unreliable wastrels to herd their animals. This will help to improve the availability of feed from the rangelands for those households that cannot afford to buy additional feed during the dry season. The interventions may be more effective in female-headed households by empowering the women in the more affluent category so that they become more successful at food production. The recommended interventions include providing more technical knowledge about livestock production through the Extension Service if the Department of Rural Development and Agrarian Reform. It is important to inform policy makers/government to intervene through Extended Public Work Programmes to possibly provide labour for livestock herding which will improve livestock distribution by providing feed throughout the year, and by increasing advice and support via increased extension visits. Furthermore, non-

profit commodity organisations such as the National Woolgrowers' Association's (NWGA) is another party that could be encouraged to intervene.

#### CHAPTER 4. ASSESSMENT OF HOUSEHOLD LIVESTOCK-BASED LIVELIHOODS IN THE NORTH EASTERN CAPE COMMUNAL RANGELANDS, SOUTH AFRICA.

This Chapter will be published in a suitable journal. BG collected data, analysed the results and wrote all the text in this chapter.

##### ABSTRACT

Agriculture is one of many possible ways to improve food security in rural livelihoods as 75% of people in rural areas derive their income from agriculture. In South Africa, livestock contribute significantly to rural livelihoods through different goods and services such as milk, offtake, manure, wool, hides and traction. In this study, livestock sale, exchange and slaughter (meat) was classified as livestock offtake. However, low input livestock husbandry remains a primary land-use option. This chapter assesses the household livestock-based livelihoods in communal areas of the north Eastern Cape, South Africa. A baseline survey of 120 households was conducted with both livestock and non-livestock owners during the year 2016/2017 to gather information on household demographics including, but not limited to, gender and age of head of household, livestock composition and holding, beneficial livestock goods and services, and livestock grazing during the dry and wet seasons. Information on the household dwelling type was also recorded as an index of wealth other than annual cash income. The results of the study revealed that there are more female- (65%) than male-headed (35%) households in the study site, but more livestock holding was found in male-headed households. Mean cattle holding of seven was found in female-headed households that lived in brick buildings, while ten cattle are the mean held by male-headed households living in brick buildings. The mean sheep holding of 59 was found in brick, male-headed households, while a mean sheep holding of 23 was found in brick, female-headed households. A mean of less than five goats was found in all the households, regardless of the dwelling type and household head gender. Livestock contribution to rural livelihoods varies enormously, where different households keep livestock for different beneficial goods and services such as offtake, manure, milk and traction. This study revealed that non-livestock owning households benefit from livestock beneficial goods and services. Livestock were reported to be spending most of their time grazing on unimproved grasslands, which shows that household heads have a poor understanding of livestock grazing as the animals were often seen grazing in areas around the homesteads due to high nutritious forage. This study shows the need to encourage people to use their animals for improved livestock goods and services. Furthermore, government programmes, which seek to change agrarian and land production systems, should recognise the importance of livestock production in the rural economy.

*Keywords: Beneficial goods and services, Livestock, Livelihoods, Household.*

#### 4.1. Introduction

Globally, 75% of the 1.2 billion people who live in rural areas derive their income from agriculture-related activities (Tarawali *et al.*, 2011). The rate of poverty reduction depends on the ability of a household to participate in agricultural activities, but not on the overall agricultural growth rate (Hadiwidjaja & Suryahadi, 2011). A large population of rural people in South Africa reside in communal lands. Carter and May, (1999) note that there is an overwhelming perception that, in the communal areas, land-based livelihood strategies make an insignificant contribution to the overall livelihood, in contrast to the private sector. Private sector, in this study refers to the commercial agricultural enterprise. Furthermore, communal areas are perceived as being more reliant on government and urban area transfers (Shackleton *et al.*, 2001). Cousins, (1999) argues that, even though government and urban cash income are the primary source of the rural economy, the varied and diverse livelihood base of rural households has been largely ignored. There are diverse strategies that are land based, such as consumption and trade of natural resources, and livestock husbandry. The eagerness of communal people in South Africa to have more land indicates the value of land-based livelihoods in communal areas where people aspire to more land. According to Shackleton *et al.*, (2001), previous studies compared production of staple crops and marketing of livestock to remittances from non-land based and income and have ignored the value of goods and services derived by most households from livestock, which provide a safety net for rural livelihoods during times of need.

Rural people keep livestock such as cattle, sheep and goats as a way of safe-guarding their livelihood portfolio and increasing the returns from their livestock assets to escape from poverty (Delgado, 2005). There is, however, a limited analysis of the livestock-poverty linkages, in contrast to investment plans and formulation of policies intended to have a positive outcome on the livelihoods of the poor livestock dependants. Studies show that an increase in livestock productivity contributes to gross domestic product (GDP) growth and generates huge production linkages and consumption; however, these studies are too crude to deal with policy and investment plans (Ellis & Bahigwa, 2003). Additionally, the analyses tend to focus on a few households, or a sector with livestock, in isolation from other livelihood sources (Barrett & Luseno, 2004).

There is a wide range of reasons for rural people to keep certain types of livestock and, according to Shackleton *et al.*, (2000), over time, these reasons are subject to change. Schmidt-Soltau (2003) maintains that these reasons vary widely and include a form of employment, cash from sales, household consumption, funeral purposes, a form of investment, bride-wealth, sales of skin and wool, transport and draft power. However, every survey of reasons for keeping cattle ranks people's responses differently, such as most important and least important.

Cattle ownership by rural people has officially been considered to be inefficient and wasteful since the 20<sup>th</sup> century due to limited grazing resources (Andrew *et al.*, 2003). Grassland deterioration and occurrence of soil erosion in rural areas are blamed on overgrazing and overstocking and are regarded as impacts of cattle ownership in a modified communal tenure system (Palmer & Bennett, 2013; Vetter, 2013).

According to Shackleton *et al.*, (2001), work that has been done on the value of goods and services derived from livestock is limited and has resulted in the perception that communal rangelands are unproductive and make little contribution towards the national welfare economy. This perception is further fuelled by the relatively small amounts of animal products from communal areas entering the formal market (Shackleton *et al.*, 2001). Cousins, (1996) argues that the role and importance of livestock in the communal system have been investigated in South Africa; however, this work has mainly focused on cattle and reasons for maintaining high numbers in the face of accelerated degradation. The value of small stock has been ignored, with no systematic analysis of the role of livestock to non-livestock owners in communal areas. Furthermore, when productivity of both the commercial and communal system is directly compared, the production in the communal system is low because it is measured on a 'per animal' basis rather than 'per hectare' (Masika, 2004). However, the range of goods and services obtained by households in the communal system is ignored when such comparisons are made although they exhibit higher returns when all goods and services are valued.

The contribution of livestock to rural livelihoods make it an important source of income. In most communal areas of southern Africa, low input livestock husbandry remains a primary land-use option (Shackleton *et al.*, 2002). In the north Eastern Cape, the livestock system is

the result of land issues in which *apartheid* played a significant role in terms of land-use planning, land ownership, farmer support, policies, society and the economy in the 19<sup>th</sup> and 20<sup>th</sup> centuries and which led to a decrease in livestock numbers (Beinart, 2003). However, due to the wide spectrum of benefits livestock provide, households with different income levels have different incentives to keep livestock (Moll, 2005). Some poor farmers, in the absence of formal insurance markets, tend to diversify between potential returns and risks associated with variability of climate and market to achieve a balance. It is difficult to assume generally that richer or poorer households are more likely to keep livestock or to say whether keeping livestock is more important for the poorer or the richer households. This study has therefore taken the opportunity to assess the household livestock-based livelihoods in the north Eastern Cape with particular focus on the beneficial goods and services livestock provide to both livestock and non-livestock owners. This aspect was important as part of the input into livestock water productivity, taking into consideration that the demand for livestock products is increasing and that livestock is only one of many sectors that has the potential to satisfy human demands. This study used a designed questionnaire survey, where each household reported their livestock holdings and composition. Beneficial goods and services such as offtake, milk, wool/hides, manure and traction derived from livestock by livestock owners were also reported. Information on livestock holding was important so that we could upscale/estimate livestock holdings for the whole village following Census, (2011). Non-livestock owners were also interviewed on the annual contribution of livestock products in their livelihoods because livestock are shared among households in rural areas. Lastly, perceptions of livestock grazing distribution during the wet and dry seasons were recorded to assess whether livestock owners know where their animals spend most of the time grazing during the wet and the dry seasons.

## 4.2. Materials and methods

### 4.2.1. Sampling approach and data collection

Data for this study were collected from households in two villages located near Cala, Eastern Cape Province, South Africa. Both villages are located within the Sakhisizwe Local Municipality. The respondents included both livestock and non-livestock owners in two river rural quaternary catchments, T12A and S50E, Mgwalana and Mahlungulu, respectively (Figure 3.1). One hundred and twenty (120) households were sampled during two fieldwork periods: November 2015–January 2016 and May 2016–August 2016. The data were analysed as single data because of the similarities in the farming practises between the two villages. The household head was interviewed, and in cases where the household head was absent, the most senior person was interviewed. Data were collected through a face-to-face interview conducted by the researcher during the dry and wet seasons with the help of a local assistant who accompanied her from one household to the other. The questions were administered in the local language (isiXhosa), which is the language best understood by the respondents, and later translated into English. There was one enumerator for each household to conduct the interviews. The interviews were conducted during the day and recorded/captured using Kobo collect toolbox that was installed on an Android mobile device.

On the first day of data collection, an introductory workshop was held with community leaders and community members to provide clarity on the survey and schedule appointments for interviews. Ethical clearance was obtained from the Rhodes University Ethical Clearance Committee for approval to conduct the survey. Information on household livestock holdings and composition was recorded. Livestock beneficial goods and services such as livestock offtake, milk, manure, wool/hides and traction were also recorded in each household. Livestock owners were interviewed about their perceptions of where their livestock spend most of their time grazing during the wet and dry seasons. The national census data were also used to define the categories of dwelling type and identify the number of households in both villages (Chapter 3). As there were population and household level data from the census, this study scaled up these household-level results to the village as follows:

$$\textit{Livestock population} = \textit{Mean livestock holding} \times \textit{number of households} \quad (4.1)$$

A detailed sampling approach and estimation of values of livestock goods and services is presented in the previous Chapter 3.

#### **4.2.2. Statistical analysis**

R statistical software 3.1.1 was used to generate boxplots and means of different livestock composition in different households and household head gender. Descriptive statistics were also computed for livestock holding, and beneficial goods and services derived from livestock by different households.

### 4.3. Results

#### 4.3.1. Composition of livestock holdings in Mgwalana and Mahlungulu villages

In Mgwalana and Mahlungulu villages combined, only 74% of the interviewed households own livestock. Livestock composition by number (n=3539) in both villages is dominated by sheep (72%), cattle (19%) and goats (9%). The total livestock numbers for the interviewed households are sheep (2530), cattle (701) and goats (308) in both Mgwalana and Mahlungulu villages. The average livestock numbers owned in each household are about 21 sheep, six cattle and three goats. Following Stats SA on population upscaling, the villages together comprise 201 households, suggesting an estimated livestock population of 4221 sheep, 1206 cattle and 603 goats.

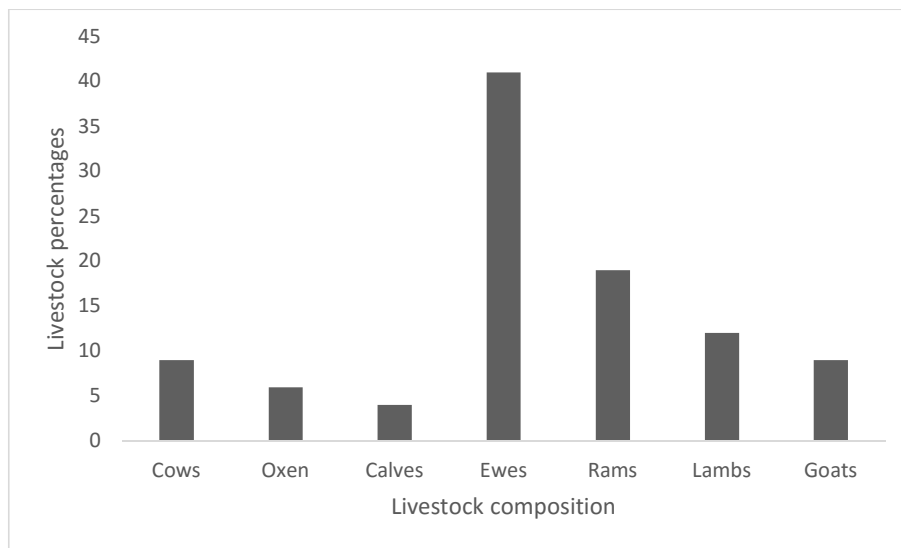


Figure 4. 1. Livestock composition in Mgwalana and Mahlungulu villages.

#### 4.3.2. Cattle holding in different households and dwelling type

The results of the study reveal that male-headed households living in brick buildings own more cattle than female-headed households (Figure 4.2). Male-headed households living in brick buildings have mean cattle holding of (n=10) whereas females living in brick buildings have a mean livestock holding of (n=7), while males and females living in traditional buildings have a mean cattle holding of (n=4).

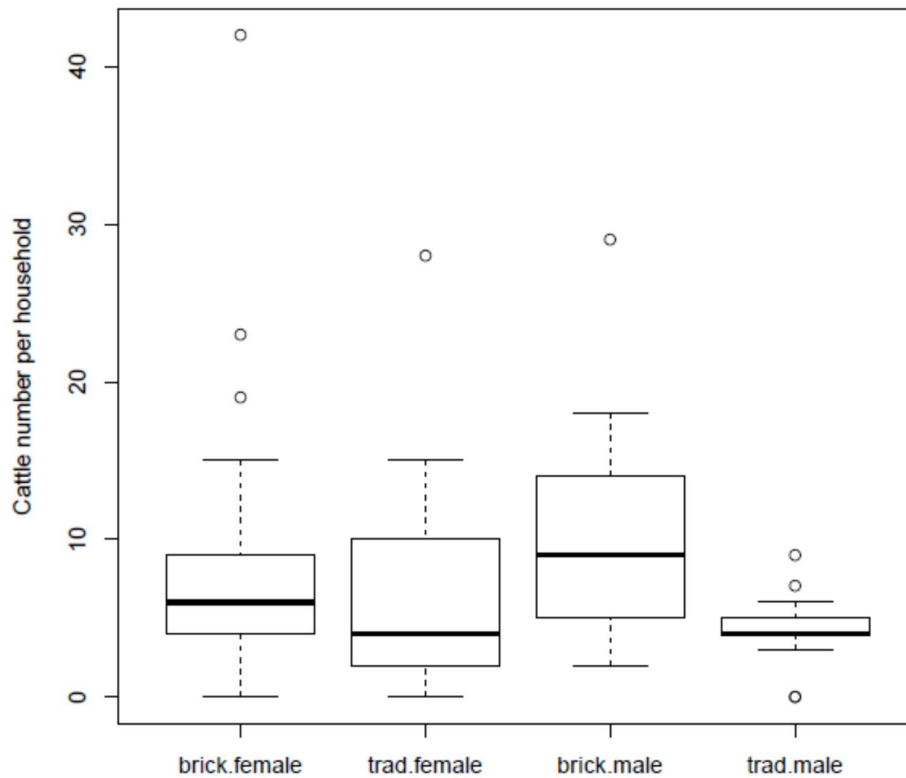


Figure 4. 2. Average cattle holding per gender and household dwelling.

#### 4.3.3. Sheep holding in different households and dwelling type

The results of the study reveal that male-headed households living in brick buildings own more sheep, with the mean holding of (n=59) (Figure 4.3.). Female-headed households in brick buildings have a mean sheep holding of (n=23), while female-headed households in traditional buildings have a mean sheep holding of (n=18) whereas male-headed households in traditional buildings have a mean sheep holding of (n= 20).

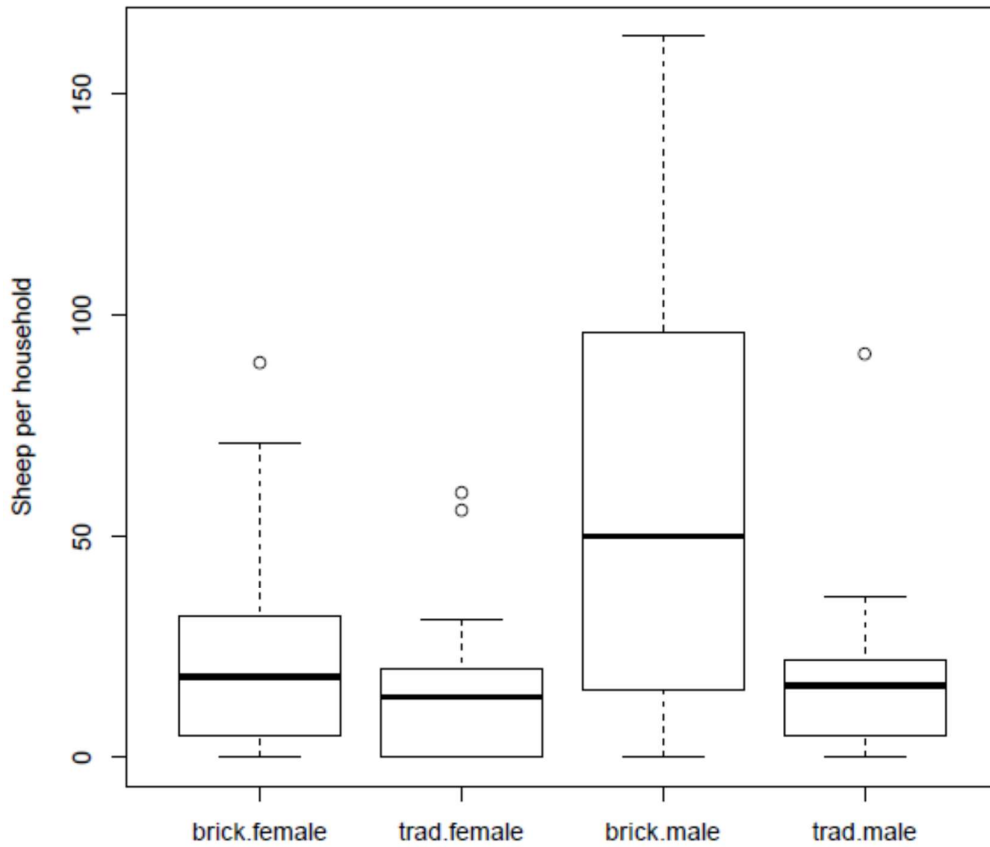


Figure 4. 3. Average sheep holding per gender and household dwelling

#### 4.3.4. Goat holding in different households and dwelling type

The results in Figure 4.4 represent the goat holdings in different dwelling types and household head genders in both Mgwalana and Mahlungulu villages. The results reveal that male-headed households in brick buildings own more goats than male-headed-households living in traditional buildings. Similarly, female-headed households in brick buildings own more goats than female-headed households in traditional buildings. The mean goat holding in all the households for both villages is less than five goats. This mean resulted because many households did not own goats and those who own, own a very small number of goats.

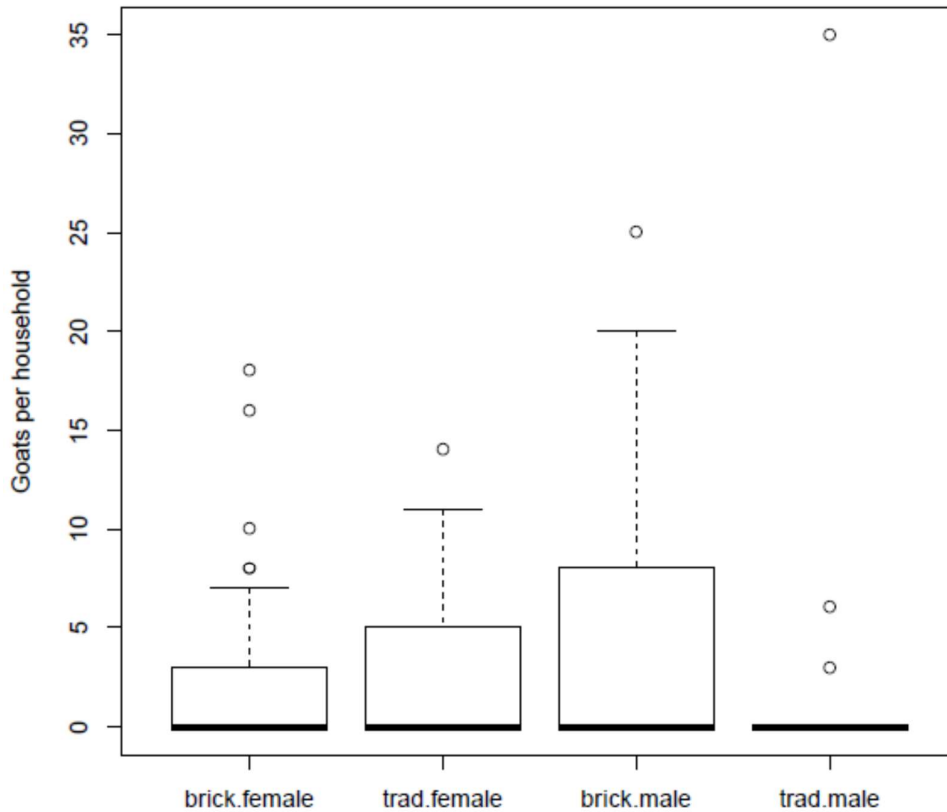


Figure 4. 4. Average goat holding per gender and household dwelling.

#### 4.3.5. Contribution of livestock goods and services to livestock owning households

The results reveal that households benefit significantly from livestock goods and services (Table 4.1). On average, 38% of the households who own livestock use milk as part of their household nutrition. The results indicate that households benefit from livestock through selling hides, wool and mohair for household income. The results also show that 73% of the households use manure. Only 25% of the households reported that they use their animals for traction services. For the purposes of economic analysis, traction is estimated at R300.00 per day. The respondents gave this quote as the average value for hired oxen. Manure is estimated at R50.00 per wheelbarrow. The price of milk is estimated at R6.00 per litre at the farm gate (Farmers Weekly, 2016). In overall, the livestock goods and services were reported to be contributing a mean of R 3208.00 per annum.

Table 4. 1. Annual contribution of livestock beneficial goods and services to rural households

Beneficial goods and services	Mean household outputs (R)	Minimum outputs (R)	Maximum outputs (R)	Percentage of household (%)
Milk	1021.91	732	5940	38
Hides	505.68	500	500	74
Wool	1017.04	500	1500	74
Mohair	502.84	500	500	74
Traction	117.61	150	600	25
Manure	963.07	50	3500	73

#### 4.3.6. Contribution of livestock beneficial goods and services to non-livestock owners

The results reveal that 26% of the sampled households do not own livestock but benefit from livestock goods and services. About 3% of households reported that they benefit from milk from livestock. About 26% of the households in both villages reported livestock contribution from hides, mohair and wool. This contribution is through assisting during sheep shearing and livestock slaughtering when the owner does not want the animal skin or cannot pay shearing costs. Traction (13%) and manure (23%) are also reported to contribute to the livelihoods of non-livestock owners (Table 4.2). The contribution of livestock products to non-livestock owners is through other households paying lesser price for livestock products and contribution through exchange of labour by livestock products. The average annual net was of livestock contribution was R2688.00.

Table 4. 2. Contribution of livestock beneficial goods and services to non-livestock owners per annum.

Beneficial outputs	Average household outputs (R)	Minimum outputs (R)	Maximum outputs (R)	Percentage of household (%)
Milk	205.88	723	3660	3
Hides	554.69	500	1500	26
Wool	648.44	500	1500	26
Mohair	500	500	500	26
Traction	164.06	150	450	13
Manure	617.17	100	3100	23

#### 4.3.7. Livestock sales from livestock owning households

The results of livestock sales are sub-divided into three different categories based on the number of animals sold in each household (Table 4.3). The average number of sales reported by livestock-owning households is between 1-10 animals (cattle, sheep or goats) per year, depending on the household needs. However, this includes confirmed deaths, livestock loss (theft or predation), exchange and traditional slaughter. Livestock loss was included in this study because the study was measuring the value of all livestock owned by a household. About 70% of the sampled households have sold part of their stock but still own livestock, while 24% of the households have sold all their livestock and are left with nothing. Only 6% of the households report that they have not sold their livestock. The net annual average for livestock sales was reported to be R43329,00.

Table 4. 3. Average annual contribution of livestock offtake to livestock owners (ZAR).

<b>Livestock owners</b>	1-5 sales (n=53)	6-10 sales (n=22)	>10 sales (n=9)
	R15 169,00	R50 181,00	R88 666,00

#### 4.3.8. Livestock grazing during the wet and dry seasons in Mgwalana and Mahlungulu village

The results in Figure 4.5 reveal that 92% and 71% of the respondents report that their livestock spend most of their time grazing on unimproved grassland in the wet and dry seasons. The (16%) of the respondents reported that animals spend time grazing on cultivated lands only in winter. Thirteen percent of respondents and eight percent of the respondents report that livestock graze close to the homestead in the winter and summer seasons respectively; however, in reality livestock graze mostly around the homesteads, along the roads, and in abandoned cultivated lands in both seasons.

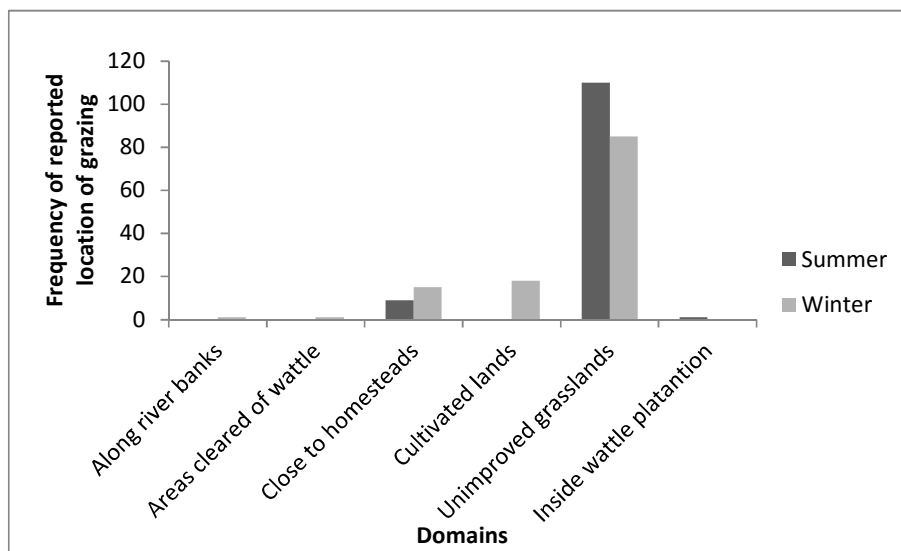


Figure 4. 5. Perceptions by livestock owners of livestock grazing patterns during dry and wet seasons in both villages.

#### 4.4. Discussion

##### 4.4.1. Livestock composition and ownership

In this study, livestock numbers were found to be significantly different from one another. The livestock composition (by number) in both villages is dominated by sheep (72%), followed by cattle (19%) and goats (9%). This ratio of cattle to sheep in the study area is surely related to terrain and the agro-ecology which is better suited to sheep rather than to the cultural practices. The farming system in both villages is composed of multi-species, which Abate *et al.*, (2010) point out is a way to satisfy the farmer's livelihood with different livestock functions. This study did not focus on the micro-livestock component of rural households, but Lahiff, (1997) argues that most rural people in South Africa keep at least some type of micro-livestock such as pigs, chickens, ducks, geese, turkeys and pigeons which constitute a frequently overlooked rural household economy component. The study reveals that livestock production is diverse; sheep production is the major product followed by cattle and very little goat production. However, with regard to animal husbandry practice, differences are known to exist, such as the type of animals kept and the rate of offtake of an animal in each household. Andrew *et al.*, (2003) argue that the type of animals kept in a household is influenced by the composition of household, gender roles, the use of cattle for traction, and the degree of traditional transfer such as bride-wealth. High numbers of sheep dominate the livestock production in this study, possibly because of the Xhosa approach that leads to cattle ownership being dominated by men (Gwelo, 2012) and that sheep production has the advantage of ease of husbandry over cattle and they have no cultural importance. Very few goats are found in the study site, possibly because the rangelands in the villages are mostly grasses with no shrubs, and since goats are browsers, there is insufficient food available for them. Although goats are of significance for cultural ceremonies, people complained of high rates of theft (*pers. comm.*) of goats which may explain the low goat numbers reported.

The study records a high number of female-headed households, but with high livestock numbers recorded in the male-headed households. These results suggest that males keep large numbers of livestock rather than selling them. These numbers are rather connected to cultural constraints to women owning goats, sheep and particularly cattle in the first place as these are seen as male livestock. However, Bank and Qambata, (1999) state that livestock husbandry and ownership follow a largely gendered division of labour which can cause people to ignore the normative roles: women generally keep livestock close to home, such as pigs

and chickens, which were not included in this study. Furthermore, Andrew *et al.*, (2003) argue that female-headed households or widows may be nominal owners of sheep, goats and cattle, a role which is commonly seen as stewardship, and one in which the elder son will formally take over the livestock when the mother dies.

In total, both villages comprise 201 households, regardless of a dwelling type. The average livestock holding of 21 sheep, six cattle and three goats was revealed in the study. Scaling up of the livestock population in this study required working with census data where the number of households were generated, and the mean livestock population was used to estimate livestock population. This is an accepted method, which in this study, was adopted from Stats SA. The estimated livestock population in these villages is 4284 sheep, 1224 cattle and 612 goats. This was important in determining the livestock population.

#### 4.4.2. Contribution of livestock to rural livelihoods

The average net annual value of livestock goods and services, excluding offtake, is R3208,00 in livestock owning households and R2688,00 in households without livestock. The average net annual value of livestock sales is R43 329, 00 in livestock-owning households. However, a study conducted by Shackleton and Shackleton, (2000) into the direct-use value of secondary goods and services that are attributed to cattle and goats in the Bushbuckridge found that the average net annual value of goods and services to be R2848,00 per cattle-owning household, R415,00 per goat-owning household and R163,00 per household without livestock. Besides livestock sales, milk production forms the highest average net annual output in livestock-owning households. However, other households have stopped milking their animals due to drought and because the animals do not get enough feed in the rangelands (*pers. comm.*). Another reason for not milking their cattle may be the fact that people struggle to buy supplements throughout the year and, when they happen to buy them, the feed is only available for a short period. The estimated annual economic livestock production value in South African Development Trust communal areas is R1200,00 per household (Adams *et al.*, 1999). However, Cousins, (1999) argues that the invisible capital makes a significant contribution to rural livelihoods, which is mostly the livestock value as a wealth store and which observers underestimate.

Livestock also provide meat for household consumption and cash from live animal sales. The animals provide social economic status to their owner; they are considered a means of demonstrating wealth, and are used for traditional rituals, such as bride-wealth payment. Andrew *et al.*, (2003) believe that this livestock contribution component is underestimated and undervalued and very little has been written about it. However, there is a lack of evidence suggesting a decrease in the significance of livestock to rural people, although there are challenges in their livestock ownership. Cousins, (1999) further argues that the decrease in the economic fortunes is fuelled by ever-greater need for livestock in rural households, which can act as a safety net and supplement cash earned in the urban sector.

The survey reveals that traction is the least beneficial output derived from livestock by some communal people, regardless of cattle ownership. The respondents report that the use of tractors has led to the decreased use of cattle for traction (*pers. comm.*). Households who only use animals for traction are those who headed by males and those who have only oxen to do the job. Animal traction is reportedly charged at R300.00 per day, regardless of hours spent on traction. Animal traction may assist households to increase the total production of their crops by increasing the cultivated areas. According to Williams, (1997), animals that are used for traction increase their weight because of their work, which results in significant meat production, which is further influenced by the forage quality and quantity available. Adesina, (1992) further states that oxen are used for traction to reduce the practice of slaughtering young male animals, which leads to larger carcass weights. Castration of the ploughing oxen leads them to add weight/muscle, but the market preferentially wants 18-22 month old steers, so heavy 8-year old oxen don't fetch a particularly good price, for all their size.

Lastly, the results reveal that the average annual value of manure is R1580,00 regardless of livestock ownership, with some households reporting that they use animal dung for fuel. Animal manure supplies the soil with organic matter which improves the soil structure, reduces soil erosion, and increases water-holding capacity; it also has a beneficial effect on soil microorganisms (Makinde & Ayoola, 2012). According to Makinde and Ayoola, (2012), animal manure is an important source of nitrogen for crop production as it helps reduce the input costs and results in increased production and profit. Animal manure contain nutrients that are slowly released into the soil and have a long residual effect because they can be

stored for a longer time in the soil. Dovie *et al.*, (2002) also report animal manure as one of the beneficial outputs derived from livestock in communal areas.

#### 4.4.3. Benefits of livestock to non-livestock owners

Shackleton *et al.*, (2000) state that livestock allow for high degree of sharing of scarce resources with the community members that do not own livestock. This is evident as households who do not own livestock are reported to benefit from livestock goods and services. The average net annual secondary benefit of R2688,00 is reported by non-livestock owning households. Shackleton *et al.*, (2000) estimate 7% of the net annual value of all beneficial outputs is derived from non-livestock owning households and further maintain (Shackleton *et al.*, 2001) that poor households and households that own smaller livestock numbers make greater use of livestock products than better-off households do, and therefore use more alternatives such as tractors, and pasteurised milk instead of fresh milk.

Livestock husbandry also contributes to job creation through employment of livestock herders, livestock handling and maintaining kraals. Tapson, (1997) observes that most rural people have a huge interest in livestock production, even if they do not own any livestock. Furthermore, the value was calculated based on the amount of livestock products non-livestock owner get from livestock owning household through cash or kind.

#### 4.4.4. Livestock grazing

The results of this study reveal that livestock spend most of their time grazing on unimproved grasslands in both the wet and dry seasons. The reason for such grazing patterns could be the fact that these animals are left to graze on their own on the unimproved rangelands without being monitored, following a decline in livestock herding in these communal areas. Andrew *et al.*, (2003) state that livestock herders move livestock to increase the consumption of available resources across the landscape. In other countries such as Lesotho, herding appears to be the main mode for sustainable utilisation of rangelands as it allows for flexible and rapid adaptation to seasonal variations in plant resources and the availability of water. In the north Eastern Cape, herding has declined drastically and few households can afford to hire a herder because young boys are now no longer available as free labour to herd livestock because of mandatory schooling. This is in contrast to Lesotho where there are available herders to look after the animals for the whole day. The herder attends to livestock every morning and evening, particularly since livestock can get lost easily because sheep (unlike cattle) usually

do not return to the kraal at night if left alone and can be vulnerable to predators such as jackals (Allsopp *et al.*, 2007).

Crop residue is very important to livestock in the sourveld of Cala where the natural grassland has a very low nutritional value in winter, and the results reveal that animals spend time (15%) grazing on cultivated lands in winter. Supplements containing nitrogen (fed as urea) improve intake and digestibility. When the crop residue is treated, intake and digestibility is also improved (Palmer & Bennett 2013). The respondents report that animals do not graze in areas cleared of wattle, along riverbanks and inside wattle plantations. These results are at odds and in contrast to the findings of a study conducted by (Gwate, 2018) in the same area which shows that clearing wattle stimulates growth and these areas are more attractive to animals. These results suggest that communal people need better information about the nutrient conversion that takes place in the soil after the eradication of wattle. Gwate, (2018) reports that both sheep and cattle graze intensively in areas cleared of wattle and along the riverbanks, probably due to the greater amount of nitrogen in these areas after clearing of wattle, and to nutrient deposition along riverbanks during floods. This shows that the people interviewed do not have a clear idea of what their livestock should be feeding on, because they generally rely on herders for information about where the animals graze. The reduction in the use of herders by livestock owners further exacerbates this lack of information about livestock grazing patterns.

Livestock spend time in cleared areas because of the presence of nitrogen (Gwate, 2018). Although respondents do not recognise this, it does not mean that livestock do not graze there. The results suggest the importance in distinguishing between what people think the animals do and what they actually do. Furthermore, the people's idea of 'unimproved grassland' may be different from this study's interpretation. However Bennett *et al.*, (2010) argue that poorly resourced farmers in communal areas mostly rely on natural rangelands, which are a valuable, inexpensive resource.

#### 4.5. Conclusion and recommendations

It is evident from the study that uneven distribution of livestock among households remains a critical component of the rural livelihoods of the north Eastern Cape communal rangelands. This is particularly the case for communal areas where severely limited livelihood options prevail, and livestock production will most likely remain the only livelihood option for some households. The study shows that there are numerically more sheep than cattle and goats in the village. The results also reveal that livestock contributes significantly to rural livelihoods, through improved food security and cash income on sales. Even households that do not own livestock benefit from livestock goods and services such as milk, manure and traction.

Livestock are reported to spend most of their time grazing on unimproved grasslands in both the wet and the dry season. This means that communal people need to be better informed about the importance of allowing and herding their animals to feed on areas cleared of wattle, as these are the most productive areas. The study conducted by Gwate (2018) in the same area reported that areas cleared of wattle yielded high grass biomass and that livestock such as sheep and cattle favored those areas.

There is also a need to encourage people to use their animals for traction to improve the amount of muscle when the animal is slaughtered. Provided adequate quality and quantity forage is provided. Additionally, government programmes, which seek to change agrarian and land production system, should recognise the importance of livestock production in the rural economy.

## CHAPTER 5. DERIVING AN EVIDENCE-BASED ESTIMATE OF LIVESTOCK WATER PRODUCTIVITY IN COMMUNAL RANGELANDS IN THE NORTH EASTERN CAPE PROVINCE, SOUTH AFRICA.

This chapter will be published in a suitable journal. BG collected, analysed data and wrote all the text in this chapter

### **ABSTRACT**

Globally, livestock production plays a significant role in satisfying human needs, such as beneficial economic, social, cultural services, and providing nutritious foods. Livestock may be used as a guarantee against inflation and can be converted into cash through sales. However, livestock are considered as the major consumer of fresh water and their influence on global water use is increasing, due to the growing demand for livestock products. Previous studies show a significant variation in livestock water productivity among farming systems, which requires further investigation. The objective of this chapter is to derive an evidence-based estimate of LWP in communal villages of the north Eastern Cape Province in South Africa. The study quantifies LWP for various households in rural villages and assesses the livestock goods and services that benefit rural households. Further, the study focuses on the water used by the rangelands, which is calculated using MODIS ET. There are slight variations in LWP among households in different wealth categories, as better off (0.34 USD.m<sup>-3</sup>) attain a high LWP followed by middle-wealth and poor households (0.29 USD m<sup>-3</sup>). These results could be explained by the differences in livestock ownership, availability of labour, dwelling type and net beneficial goods and services obtained by different household. Livestock holdings, gender of the household head, and labour have a positive impact in improving LWP. The results provide an important direction to influence policy on ways to invest to reduce the livestock water footprint.

*Keywords: Livestock water productivity, Livestock productivity, Livestock products.*

### 5.1. Introduction

Globally, livestock production plays a significant role in satisfying various human needs such as providing highly nutritious food products and beneficial economic, social, cultural and ecological services (Thomas, 2000). Livestock possession may be used as a guarantee against inflation, where livestock can be converted into cash through sales from time to time (Alemayehu *et al.*, 2012). However, this may not be the case during drought years, which may lead to destocking. During drought, animals die because of insufficient forage and water leading to people selling their stock regardless of the need for income. Alemayehu *et al.*, (2012) estimate that about 144 million people in sub-Saharan Africa practise mixed farming and draw their livelihoods from livestock. However, because of health problems such as the animal health problems such as livestock diseases, lack of feed, shortage of capital, degradation of natural resources, the low genetic potential of indigenous breeds, and limited access to improved technology, livestock productivity is generally low. This is refuted by the interest in the Nguni and other Zebu cattle for their ruggedness, adaptability and tick-resistant qualities. Furthermore, livestock production has been widely criticised for its negative impact on water resources and the environment (Descheemaeker *et al.*, 2010). However, evidence suggests that such examples arise from industrial livestock production systems where forage and grains are produced using large quantities of water (Peden *et al.*, 2007).

Livestock production accounts for 20% of agricultural evapotranspiration (ET) worldwide (Peden *et al.*, 2009) and is projected to grow rapidly with the increasing demand for animal products. Future agricultural water needs can be reduced by providing less water for livestock production. The water needed to grow feed is far greater than the water required by livestock for drinking, which accounts for only 2% of the total livestock production need (Peden *et al.*, 2007). The feed that the animal consumes determines the physical water productivity of an animal product. Molden *et al.*, (2007) estimate that an amount of between 3000 and 15 000 litres in ET is required to produce 1 kg of animal product. However, these estimates vary depending on the feed type, management practices, crop residue used, processing and the ability of the animal to convert feed into animal products.

It was further estimated that demand for livestock products increased by 6 to 8% in 2012 (Alemayehu *et al.*, 2012), because of the increase in human population size Thornton, (2010) argues that the rise in income levels, urbanisation and increased population size are possible

drivers of the increased demand for livestock products. According to Steinfeld *et al.*, (2006), people tend to change their eating habits and lifestyle and spend more money on livestock products as their incomes increase. The challenge facing agriculture in attempting to satisfy the changing demand for animal food products is the sustainability of natural resources such as water, soil, air, and biodiversity (Steinfeld, 2004).

In South Africa, high livestock populations have been maintained in the communal areas, significantly in excess of the official recommended stocking rate (Dovie *et al.*, 2006). This has had long-term consequences in rangeland degradation due to the impact livestock have on communal rangelands and has led to the perception that livestock production is unproductive (Vetter, 2013). This evidence is based on rangeland examination of changes in vegetation over time, and of standing biomass. The need for destocking was a result of evidence of rangeland degradation in these communal areas from time series livestock data (McAllister, 1992), who was then the erroneous or at least highly contentious basis for Betterment Planning. Although there have been studies looking at the role and importance of communal livestock in South Africa (Cousins, 1996), attention has been focused mostly on reasons for keeping livestock and their value (Shackleton *et al.*, 2001). However, the quantification of livestock products (goods and services) and the amount of water used in producing those from communal rangelands is lacking, as are the costs associated with livestock production and the value of livestock products (goods and services) to households in a livestock production system.

Against this backdrop of scientific evidence, the study arrives at a concept of LWP which is defined as the ratio of the net beneficial goods such as milk, offtake, manure, skin, hides/wool and services, such as traction, derived from livestock against the amount of water used by the rangeland to produce feed for grazing such as (Kebebe *et al.*, 2015). As this study is in a communal livestock production system, the concept measures the ability of livestock to convert available rainwater into livestock goods and services (Kebebe *et al.*, 2015), which is expressed as a model/equation. The numerator of the equation represents the net annual beneficial outputs and their associated costs at farm gate, while the denominator represents the amount of water used (MODIS ET) from rangelands.

Different studies (Haileslassie *et al.*, 2011; Blümmel *et al.*, 2014; Gebreselassie *et al.*, 2009; Peden *et al.*, 2009; Descheemaeker *et al.*, 2010; Kebebe *et al.*, 2015; Bekele *et al.*, 2017) have

estimated LWP in a mixed crop- livestock system. These studies indicate the scope for improving LWP and show a significant difference in LWP among and within farm households and farming systems. As part of the study aimed at determining whether communal rangelands of the north Eastern Cape can sustain livestock production, LWP was described to identify areas of possible intervention to improve livestock production in communal areas. Livestock products for various households in a diverse livestock production system were reported through a household survey questionnaire. Information such as household demographics, household livestock holdings, net annual beneficial goods and services derived from livestock and their anticipated cost at the time of the study were also recorded. Further, livestock production inputs such as labour/herding availability and supplying additional feed were also gathered. Areas where livestock were reported to be spending most of their time grazing were identified as domains where MODIS ET was extracted (refer to Chapter 2). However, only MODIS ET from unimproved rangelands was used in calculating LWP.

## 5.2. Materials and methods

### 5.2.1. Study site description

The study was conducted in the north Eastern Cape Province, South Africa, in the former homelands of the Transkei. The study sites fall under quaternary river catchments T12A and S50E centered around (31°32'13.80"S, 27°46'42.87"E), (31°42'22.69"S, 27°41'03.80"E) respectively, in the town of Cala (Figure 3.8). Both villages lie on communal land that is traditionally administered under local chiefs. The vegetation is described as *Drakensburg foothill moist grassland* in the mountainous area and is incised by river gorges of dry forest (Mucina & Rutherford, 2006). Dominant and common species in the study sites are *Sporobolus africanus*, *Heteropogon contortus*, *Eragrostis plana* and *Aristida congesta*, which form grass swards (Mucina *et al.*, 2006). The respective study sites receive a long-term mean annual rainfall distribution of 654–786 mm (Schulze *et al.*, 2008) which characterises the wet and dry seasons and coefficient of variation is 25%. The mean annual potential evaporation and mean annual soil moisture stress are 1638 mm and 68% respectively (Schulze *et al.*, 2008). The geology is mostly mudstone and sandstone of the Tarkastard Subgroup and the Molteno Formation, as well as Jurassic Age dolerites. Dominating soils are well drained with more than 800 mm of depth, with sedimentary parent material of 15–55% clay content representing soils from Clovelly, Griffin and Oak Dale (Mucina & Rutherford, 2006).

### 5.2.2. Farming system

A farming system is a group of farms or households which have a common function and structure and are expected to produce at the same level (Hailelassie *et al.*, 2009). According to Ebanyat *et al.*, (2010) a farming system may consist of mostly mixed livestock-crop farming which may result from differences in population densities, climate, diseases, cultural practices and economic opportunities in communal areas. In the study area, households keep cattle, sheep, goats and poultry (Gwate, 2018) to provide meat, milk, manure, traction power and to serve as standing assets (Cousins, 1996) that can be converted into cash at times, and for socio-cultural activities. Manure fulfils a key role through nutrient cycling between and within households which enables the sustainable use of smallholder plots (Garrity *et al.*, 2012). Livestock and crops are both competitive and complementary, because livestock provide traction power and organic fertiliser, while crops provide residues during the dry season (Hailelassie *et al.*, 2009). A nuanced understanding of the nature and direction of this complementarity would be beneficial to livestock and crop intervention strategies. Traditional livestock herding in these areas has slowly gone out of favour, although some households can afford to pay a herder. The loss of herders has been a challenge, especially as fences to control the grazing of livestock have fallen into disrepair. Livestock are moved away from the homesteads but often come back to graze around, resulting in nutrients being transported from the landscape to the homesteads and riparian zones. Highly productive grazing lawns (Palmer & Bennett, 2013) form around the homesteads and areas associated with livestock handling. It is not known what proportion of feed for livestock is derived from crop residues, but livestock and crops do compete for land and water and the crops are grown on, as these could be used for grazing. However, crops seldom compete with livestock for natural grasslands, as much of the natural grassland cannot be cultivated for crops, due to slope, soil depth, rockiness, remoteness etc. In many of the communal areas, all land that can be cultivated has been cultivated at some stage. Households practise low-input rain-fed agriculture, leading to low levels of production.

### 5.2.3. Livestock water productivity (LWP) model/equation

In estimating LWP, the net annual value of livestock goods and services were considered in the numerator. Evapotranspiration (ET), which forms the denominator of the model, was calculated based on MODIS ET extracted from the unimproved rangelands (Chapter 2). The beneficial goods and services from livestock such as milk, manure, livestock offtake, traction

and hides/wool were estimated and converted into monetary values (ZAR) using the communal farm gate value. The communal farm gate value refers to the value of unprocessed animal products at the farm. In calculating these goods and services, all livestock types kept by households were included. Information on livestock herd structure, and the goods and services in a given year were calculated to estimate the value of these products and services, as suggested by Hailelassie *et al.*, (2009) and Descheemaeker *et al.*, (2010). The model was developed in a spread sheet by Hailelassie *et al.*, (2009); however, this study used a modified LWP model by Kebebe *et al.*, (2015) and was used to estimate LWP values that were later converted to USD. The model was used on the basis that the study was conducted in a communal area where there are no records for animal husbandry-related activities as is the case in a commercial livestock production system. There were no records of drinking water, of veterinary services water use, milking water use, or the value of the breeding stock for a livestock lifespan. Hence the study chose the more simplified model which only includes the annual productivity and annual water ET. The model can be mathematically specified as follows.

$$LWP_i = \frac{\sum_{i=1}^n (O_i * P_i + S_i * P_i)}{\sum_{k=1}^n WD_k} \quad (5.1)$$

Where:

$i$  is the unit of observation;  $LWP$  is livestock water productivity;  $O_i$  is the quantity of the  $i_{th}$  livestock output such as milk, offtake, hides/wool and manure;  $S_i$  is the service type such as traction of the  $i_{th}$  livestock obtained over a year;  $P_i$  is the local market price (ZAR) of the  $i_{th}$  good or service type;  $WD_k$  is the amount of water used in ET for the production of grass in the rangelands. To assess multiple benefits, one can monetise and use monetary equivalents such as rand per cubic metre of water depleted. Although non-monetary cultural benefits remain important, they are normally not included in the computation of monetised benefits of livestock.

#### 5.2.4. Household survey design and data collection

An introductory workshop with extension officers, community leaders and community members were held prior to data collection to provide clarity on the survey and to schedule appointments for interviews. Ethical clearance was obtained from Rhodes University for approval to conduct the study. A consent form was provided prior to the interviews for all the

households, requesting their authorisation. Livestock and non-livestock owners were randomly selected for interviews. One hundred and twenty (120) households were interviewed, depending on their availability and willingness to participate in the study. The questionnaire was designed to extract information on annual livestock beneficial goods and services such as milk, offtake, hides/wool, traction and manure. Further information on livestock holdings was also gathered. Information pertaining to livestock production inputs, such as labour, and whether households buy additional feed for livestock was also gathered. Offtake in this study referred to stock sales, stock loss, and animals slaughtered for consumption. This information was important in developing an LWP model for the surveyed households. The interviewed households were further classified into three different wealth categories (better-off, middle and poor), where multiple criteria focused on physical ownership of key assets such as livestock holding, dwelling type and technical efficiency were used rather than precarious annual cash income (Bekele *et al.*, 2017). Furthermore, their anticipated values at the time of study were used to estimate the wealth category of a household (refer to Chapter 3). It is important to acknowledge that the 'three defined income classes' represent a snapshot in time, a 'cross-sectional analysis' of ever-changing categories. In fact, the fortunes of rural households are known to change very suddenly via shocks at for instance, the death of the main breadwinner.

#### 5.2.5. Sampling approach: Estimating the value of livestock goods and services

Livestock form a vital component of agriculture, worldwide. They provide ecosystem service output and have cultural value (Hailelassie *et al.*, 2009). However, in this study only offtake, milk, manure, skin, hides, wool, and traction were considered. To quantify these outputs, total livestock production of each household was estimated through a survey questionnaire administered in 2015–2016. The reported livestock goods and services in each household were converted into monetary values. The livestock holdings were converted to Tropical Livestock Unit (TLU) using a conversion factor of 0.79 for cattle, 0.1 for sheep and goats (Hailelassie *et al.*, 2009). Livestock goods and services were estimated and are well described in Chapter 3. This study used MODIS ET extracted from GEE for the unimproved rangelands. Details of the method are clearly described in Chapter 2.

#### 5.2.6. Statistical analysis

Differences in mean livestock beneficial goods, services and LWP among households and wealth categories were tested using one-way ANOVA. The data were compiled with the assumption of ANOVA when checked for normality and homogeneity of variance. During the data manipulation, where many outliers were captured due to variation and sample size, data were transformed using Log function.

### 5.3. Results

#### 5.3.1. Household characteristics in different wealth groups

The mean household characteristics by wealth groups are presented in Table 5.1. The household wealth categories are calculated using dwelling type, household livestock holding and TE (Chapter 3). Livestock beneficial outputs were similar across different wealth groups, but TLU are significantly different among wealth group categories. Better off households have more livestock holdings than middle and poor households. The results reveal that livestock production input such as the money spent on labour and buying additional feed is not significant between better-off and middle wealth households (Table 5.1).

Table 5. 1. Means of household characteristics among wealth groups.

<b>Household characteristics</b>	<b>Better-off (n=33)</b>	<b>Middle (n=33)</b>	<b>Poor (n=54)</b>
Livestock holding (TLU)	2.04 <sup>a</sup>	1.78 <sup>b</sup>	1.98 <sup>c</sup>
Expenditure (ZAR) (labour and additional feed)	11.58	11.59	11.45
Outputs (ZAR)	13.63	13.27	13.16

Different superscripts <sup>a,b,c</sup> within a row represent significant differences at  $P < 0.05$ . TLU: Tropical livestock unit: 250 kg live weight.

#### 5.3.2. Livestock water productivity in different wealth group categories

Table 5.2 illustrates mean LWP obtained in the study site for the three defined income classes. No variations in mean LWP were obtained by middle and poor household wealth groups. Better-off households obtain a higher LWP (0.34) followed by the middle (0.29) and poor households (0.29). Results from other, similar studies conducted in Ethiopia are reported for comparison. These studies show differences in LWP obtained in different wealth groups. All

these studies show a similar trend, where wealthier households obtain higher LWP compared with middle and poor, although in the case of this study, the differences are not significant between middle and poor households.

Table 5. 2. Mean livestock water productivity.

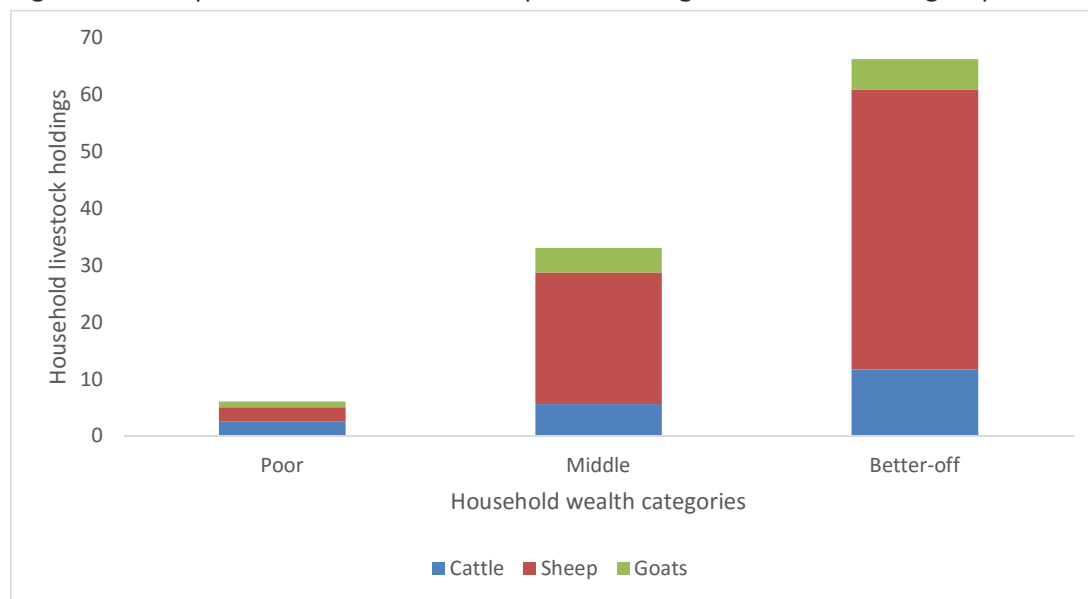
Household characteristics	Better-off (n=33)	Middle (n=33)	Poor (n=54)	Reference
LWP (USD m <sup>-3</sup> )	0.34 <sup>a</sup>	0.29 <sup>b</sup>	0.29 <sup>b</sup>	
LWP (USD m <sup>-3</sup> )	0.26 <sup>a</sup>	0.20 <sup>b</sup>	0.16 <sup>c</sup>	(Kebebe <i>et al.</i> , 2015)
LWP (USD m <sup>-3</sup> )	0.30 <sup>a</sup>	0.24 <sup>b</sup>	0.16 <sup>c</sup>	(Bekele <i>et al.</i> , 2017)

Different superscripts <sup>a,b,c</sup> within a row represent significant differences at P< 0.05.

### 5.3.2. Household livestock types in different wealth group categories

Figure 5.1 illustrates the total household livestock types among different wealth categories. High mean numbers of different livestock species are reported in better-off households, followed by middle-wealth households then poor households. The highest proportion of livestock species found in the village are sheep, irrespective of wealth groups. Goats form the lowest livestock percentage kept in the village by all the wealth group categories. The results reveal a mean sheep holding of better-off (mean=49), middle (mean=23) and poor(mean=2) among wealth groups.

Figure 5. 1. Proportion of mean livestock species among household wealth groups.



### 5.3.3. Livestock beneficial goods and services in different wealth groups

The results of the analysis showing comparisons of mean livestock beneficial goods and services quantified separately on an annual basis and converted into monetary values among the different wealth groups are presented in Table 5.3. The results indicate a variation in terms of individual beneficial goods and services derived from livestock by different wealth groups. However, a significant variation is evident between better-off and poor households, with the exception of wool, which is similar across the three groups. Milk, offtake, and traction are higher in better-off households, while middle and poor are similar. Manure production is different among the wealth groups with better-off households obtaining high manure followed by middle, then poor households. Overall, significant differences in beneficial goods and services correspond with wealth status, being higher in better-off households and lower in poor ones.

Table 5. 3. Means for livestock beneficial goods and services (ZAR) of households in different wealth groups.

Livestock beneficial output	Better-off (n=33)	Middle (n=33)	Poor (n=54)	RMSE
Milk	7.31 <sup>a</sup>	6.24 <sup>b</sup>	6.34 <sup>c</sup>	1.31
Offtake	11.06 <sup>a</sup>	10.50 <sup>b</sup>	10.39 <sup>c</sup>	16.96
Manure	9.68 <sup>a</sup>	8.93 <sup>b</sup>	7.39 <sup>c</sup>	5.80
Hides/wool	7.73	7.57	7.45	3.31
Traction	5.22 <sup>a</sup>	4.40 <sup>b</sup>	4.82 <sup>b</sup>	8.08

Different superscripts <sup>a,b,c</sup> within a row represents significant differences at  $P < 0.05$ . RMSE= root mean square error.

### 5.3.4. Contribution of livestock goods and services to different wealth groups

Figure 5.2 illustrates the contribution of annual goods and services type derived from livestock by different wealth group categories in rand value (ZAR). Irrespective of wealth status, offtake value generates the highest proportion, followed by manure. In terms of South African Rands, offtake is reported to be higher in better-off (mean=R241.39) middle (mean=R173.77) and poor (mean=R182.18) households. Livestock beneficial outputs and services such as traction are the benefits that generate the least, irrespective of wealth group categories, while milk and hides/wool have a similar maximum value.

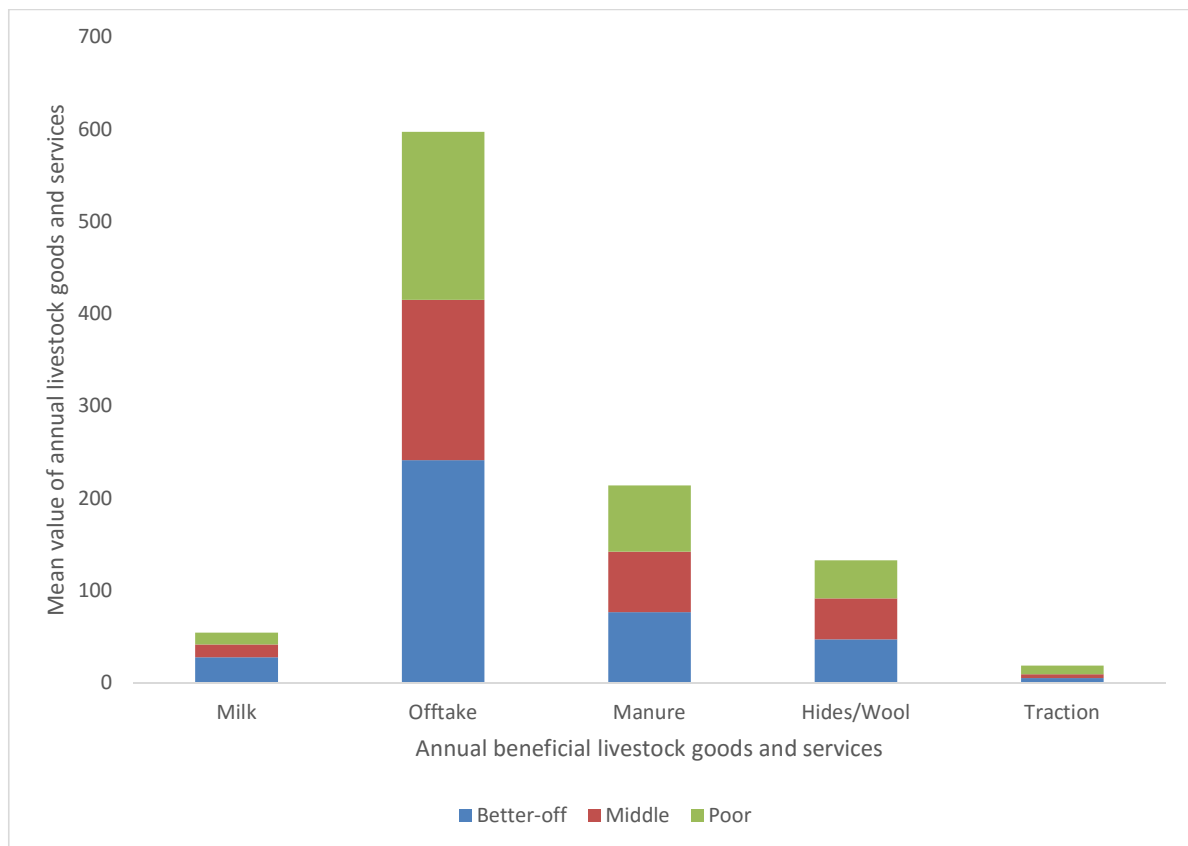


Figure 5. 2. Proportion of estimated means of livestock beneficial outputs contributed from livestock (ZAR).

## 5.4. Discussion

### 5.4.1. Household characteristics as the implication for livestock water productivity

From this study it is evident that the availability of household labour and livestock resources are the pillars of household productivity that stratify villagers into wealth group categories. These results are similar to those found by Kebebe *et al.*, (2015) and Bekele *et al.*, (2017) which show a significant effect of resource legacy of households on the LWP. Wealthier households are better able to hire additional labour and buy supplementary feed than poor households. Furthermore, the high livestock numbers possibly facilitate their ability to generate cash from livestock through sales. According to McDermott *et al.*, (2010), labour is a prerequisite for sound, productive livestock management. The availability of labour is an important positive relationship as it improves production of livestock goods and services. According to Asfaw *et al.*, (2011), family labour plays a significant role, given that it is of a lower rate than wage labour. Although poor households can have family labour invested, it is evident that with the given livestock holdings, they cannot adequately sustain themselves.

TLU was higher in the wealthier households, followed by middle, then poor households. This indicates that wealthier households stand a better chance of cultivating their croplands at the right season with adequate frequency of tillage for better land. Moreover, as described by Bekele *et al.*, (2017), proper agronomic practices are mostly performed when enough family labour is available. The overall beneficial outputs derived from livestock are almost similar across the wealth groups; however, wealthier households are higher than middle-wealth and poor households. Higher overall outputs ultimately contribute to higher LWP. The differences obtained in beneficial outputs among wealth groups reflects the variation in total household livestock holdings among wealth group categories.

### 5.4.2. Livestock water productivity

Although rainwater plays a significant role in livestock production, the increased scarcity of freshwater resources raises concerns about the rainwater conversion efficiency into livestock goods and services (Kebebe *et al.*, 2015). Mean LWP varies significantly among different wealth groups. Better-off households have higher LWP, followed by both middle and poor households. Like other studies Kebebe *et al.*, (2015), Bekele *et al.*, (2017), better-off households obtain higher LWP than middle and poor households. However, middle and poor households obtain similar LWP. This study reveals that wealthier households keep their

livestock as standing assets rather than selling them, while poor households sell their livestock to get cash, and use other livestock products. The numerator of the LWP equation summarises the net annual beneficial goods and services obtained from livestock, while the grouping of the wealth categories uses standing livestock and dwelling type as an index of wealth. These results suggest that being considered a wealthier household does not automatically mean higher LWP. A possible explanation to variations in LWP among wealth groups can be explained by the variations in livestock household holdings, access to labour, and other household assets, which was evident as wealthier households own more livestock than middle and poor households. Kebebe *et al.*, (2015) make the point that wealthier households have the advantage of their high numbers of livestock to be able to convert available feed to higher beneficial outputs such as milk, offtake, manure, traction and wool/hides. Results from other studies, such as those of Kebebe *et al.*, (2015) and Bekele *et al.*, (2017), are used for comparison in this study, which reveal variation in the mean LWP obtained in different studies among different wealth groups. On the other hand, differences in the mean LWP obtained in these studies could be linked to differences in livestock products prioritised and obtained in terms of least and most importance in the different studies.

MODIS ET of 379 mm is reported in this study, which could play a major role in explaining the differences in LWP in different studies. The relatively low ET compared to annual rainfall can be explained by the low leaf area of the vegetation available to livestock. These findings suggest that households with low livestock holdings cannot sufficiently utilise feed from crop residues and grazing lands. Hailelassie *et al.*, (2009) found that, in the Ethiopian highlands, most of the livestock beneficial outputs were from households which own high numbers of livestock. Variations in LWP among different wealth group categories suggest the possibility of improving LWP with the current level of knowledge, given that farmers have better access to land, labour, and oxen for traction. The results on LWP are consistent with those of Hailelassie *et al.*, (2009), who also found that better-off households have higher LWP. Water use in cultivated lands and areas around the homesteads is not included in the analysis; it is difficult to separate the two domains successfully because of the small gardens available in different households. This could possibly be the reason for differences in LWP among different wealth groups.

### 5.4.3. Livestock beneficial outputs

Households use the advantage of keeping different livestock species to derive sustainable outputs and services using available resources. The current study considers outputs such as milk, offtake, manure, hides/wool and traction to estimate the annual beneficial outputs derived from livestock in each household. However, other studies (Behnke, 2010), point out that livestock under mixed crop-livestock system in developing countries like Ethiopia perform economic and social functions that are not easily measured in monetary values. According to the findings of this study, offtake is the prime share of beneficial outputs derived from livestock, followed by manure, but these results vary among wealth groups. The variations in offtake among wealth groups is also found by Bekele *et al.*, (2017) and Behnke, (2010), who reported a low animal offtake rate in a mixed farming system. On the other hand, Kebebe *et al.*, (2015) report manure and traction services as a prime share of the annual beneficial outputs in Ethiopia and Bekele *et al.*, (2017) report milk production followed by traction services and manure as prime beneficial outputs, regardless of wealth status. Manure is very important in replenishing soil fertility and, in the current study, it is the second-highest beneficial output, followed by milk and traction, reported in different wealth groups. Wealthier households possibly have the advantage of being able to replace traction animals because they own more of them.

The differences in milk production among the different wealth groups is possibly because wealthier households are able to retain particular crossbred animals more readily than poor farmers. Even though there is variation in milk production among the wealthy groups, it contributes the least to the overall total annual outputs. However, milk production should be encouraged in this area, with appropriate animal husbandry and management interventions as needed. The primary purpose of keeping livestock in mixed farming is to maintain a continuous livestock herd and complement crop production. Bekele *et al.*, (2017) suggest that an increase in the number of livestock in an individual household could lead to increased LWP in the short term. The study also finds wool/hides as one of the annual beneficial outputs derived from livestock in the study area, which indicates the extent of willingness and different abilities of households to keep sheep.

### 5.5. Conclusion and recommendations

Livestock interact both positively and negatively in the management of natural resources. An example of this positive relationship is that livestock can be used to remove moribund forage during the dry season and re-distribute nutrients across the landscape.. On the other hand, the negative relationship that exists between livestock and the environment is that livestock can selectively and continuously graze the rangeland, causing increased erosion along cattle paths, removing desirable grazing species by continuous grazing, replacing palatable/desirable species with woody shrubs and less palatable/nutritious grasses such as *E. plana*. The positive relationship between livestock holdings and LWP suggests that there is a possibility of improving water use efficiency through increased livestock beneficial outputs. The positive relationship between livestock holdings with LWP and labour with LWP among wealth groups suggests that strategies to improve water use need to focus on providing extra feed and labour.

Considering that the study area is a mixed crop-livestock system, complementary interventions could be suggested to increase water productivity in different households. This will in turn boost the capacity of all household group categories to achieve improved LWP. It is also necessary for research to better understand the role of livestock in the integrated livestock-crop system and to address the implementation of a South African livelihood improvement strategy from livestock. In addition, the findings of this research can help in making a decision on where to invest the resources to achieve increased LWP in a communal production system.

## CHAPTER 6. ASSESSING LIVESTOCK DISTRIBUTION IN COMMUNAL RANGELANDS OF THE EASTERN CAPE SOUTH AFRICA: TOWARDS MONITORING LIVESTOCK MOVEMENTS IN RANGELANDS.

This chapter will be published in a suitable journal. BG wrote all the text in this Chapter, TZ assisted with data collection and analysis.

### ABSTRACT

Rangelands provide ecosystem services to support livelihoods, biodiversity, and livestock production. In the past, rangelands were managed in a semi-nomadic manner, where pastoralists would distribute livestock to different parts of the rangeland depending on the availability of forage. However, the distribution of livestock rangeland use has not been a subject of many studies as the devices to monitor livestock were not available. This study used the global positioning systems to assess livestock distribution in a communal rangeland of the Eastern Cape. Experimental animals (sheep and cattle) were selected randomly from participating households and were fitted with a neck GPS collar, which recorded the geographic position at five-minute intervals during both a wet and dry season in 2016/17 in order to assess the livestock use of the rangeland. Livestock growth rate were also assessed by weighing livestock on the day of collaring using an electronic scale, and again on the day of removing collars for both dry and wet seasons. Three production domains where livestock grazing occurs were identified and grass species composition was surveyed. Lastly, normalised difference vegetation index for the area was downloaded from Landsat imagery using Google Earth Engine to determine the most productive parts of the rangeland. Livestock grazing distribution was analysed using time local convex hull, which is an R package used to analyses movement data. Hull sets were created to identify the areas where livestock spend most of their time during the grazing day. The grass species composition survey revealed that *Hyparrhenia hirta*, a robust perennial C4 grass that is moderately resistant to continuous grazing, was the dominant grass species. This was followed by *Eragrostis plana*, suggesting that rangeland had been disturbed. Furthermore, areas around the homesteads had higher NDVI. In this study, lack of livestock herding might have been the reason why livestock spend most of their time grazing around the homesteads, together with the fact that the animals are saving energy. These results suggest a need for livestock owners to use herders so that

the animals can use rangelands optimally. This is assumed to improve the grazing distribution, species composition and the forage quality and quantity.

Keywords: *GPS, Grazing, Livestock, Rangelands.*

## 6.1. Introduction

Rangelands form an important support system for the livelihoods of millions of people, for livestock production, and biodiversity conservation (Odadi *et al.*, 2018). However, because of climatic and anthropogenic factors, many rangelands are considered severely degraded impacting negatively on people who rely on land for grazing and livestock production (Zhang *et al.*, 2016; Shackleton *et al.*, 2003). Rangeland degradation is chiefly related to poor grazing management, which is often cited as a major contributor to rangeland degradation and reduced rangeland stability (Odadi *et al.*, 2017). In areas where rangeland degradation is severe, such as Africa, communal rangelands are the most degraded ecosystems and sustainable grazing management is important to improve the value of a rangeland in terms of socio-economic and ecological systems (Odadi *et al.*, 2017).

South African communal rangelands make up only 13% of agricultural land on account of colonialism under which the indigenous people were restricted to small areas, and land rights were delineated along racial lines through the 1913 Native Land Act (Samuels *et al.*, 2007). These communal rangelands were administered by the local chiefs or village headmen who determined who could own livestock on the common rangeland or ‘amadlelo’, how many livestock were permitted per household, and where the livestock should graze at different times of the year. With the implementation of the restrictive legislation after 1913, and the “Betterment Planning” following the recommendations of the Tomlinson Commission in 1954, traditional livestock management governance became fractured. Villages could no longer practise the principles embedded in a herding culture as camps (or paddocks), gates and fences replaced the decisions of herders under whose care livestock had roamed freely and had been able to select daily grazing areas based on their own preferences (Bailey, 2004). Household livestock herds are generally quite small (5–10 animals per household) (See Chapter 4), and individual owners influence decisions about where animals are left to forage. At the household level, farmers seldom have the resources to employ a herder to guide livestock to different grazing areas throughout the year. However, the loss of herding skills, as well as the recent mandatory school attendance laws, has further eroded the role of herders in determining where livestock should graze in different seasons. Many parts of the rural Transkei and other dry land regions have been subjected to ploughing, followed by large-scale abandonment, leading to substantial changes in the species composition of the

rangeland (Palmer and Ainslie, 2009), favouring more robust, less palatable grasses such as *Eragrostis plana*, *Hyparrhenia hirta* and *Sporobolus africanus*.

Livestock grazing in past years was managed in a semi-nomadic manner in pastoral rangelands, with frequent changes for pasture regeneration (Ellis & Galvin, 1994). Unlike other parts of Africa, such as Kenya, the nomadic pastoralists would move from places following a drying trend, and cultivation only occurred under irrigation or in areas where water could be sequestered or stored (Ellis & Galvin, 1994). However, now land-use practices have changed from nomadic pastoralism to commercial farming, and rangelands that were traditionally managed with animals spread individually with the presence of the herders, is in contrast with sedentary pastoralism where animals are un-herded during grazing, but are controlled by fences (Odadi *et al.*, 2018). Veblen *et al.*, (2016) state that in this system of grazing management, livestock are typically allowed to graze for a period of time across a general grazing area, depending on the available forage and utilisation, then later moved to a new area to allow for regrowth. Nomadic people use herding to regulate animal movement while sedentary people use fences to control and move the livestock regularly.

Currently, two distinctive grazing management systems to sustain livestock and manage natural resources have long been employed: commercial and communal farming systems (Samuels *et al.*, 2007). The 'white' owned farming system is referred to as commercial and uses a method which adopts rotational grazing management, where camps are grazed for different periods. It is perceived to be ideal for managing livestock (Archer, 2004). However, O'Reagain and Turner, (1992) argue that there is not enough information to justify such claims. The commercial farming system aims at sustained maximum production of livestock products where plants are mostly used for animal forage and livestock are grazed in fenced paddocks and left unattended. Although perceived as productive and beneficial for livestock resource utilisation, this method has shown that resources are selectively grazed where animals may restrict themselves to certain parts of the camp (Baumont *et al.*, 2000). By contrast, communal rangelands are regarded as completely uncontrolled as farmers are interested at maximising immediate benefits at the expense of natural resources (Hardin, 1968). This theory maintains that communal farmers are only interested in increased profits, regardless of the impacts of livestock on natural resources. However, Allsopp *et al.*, (2007) argue that it is the effect of too many people concentrated on a small piece of land rather

than the traditional grazing management practice that poses a threat to the natural resources. On the other hand, the reality on the ground has changed where now, communal farmers have started to recognise the need of managing the common resources

The distribution of livestock in communal areas of South Africa has not been the subject of many studies as the technology was not available to determine when and where the animals have been grazing. However, interest in the distribution of livestock grazing has recently become a major concern for livestock managers (Turner *et al.*, 2000), resulting in observations of general grazing behaviour by both human and different automatic recording devices. Living and non-living factors influence livestock preference of some sites over others, as well as animal behaviour. According to Lyons and Machen, (2001) in a free ranging situation, livestock selectivity is driven by several factors such as plant types (grass, forbs, and shrubs), forage quality, quantity and palatability, plant species composition, shade and shelter, human activities, insects, pests, soil, weather, topography, and water. However, in a controlled livestock production system (rotational grazing), graziers are able to control some of these factors in the activity of the livestock through timing and managing the duration of stay in a paddock. It is important to understand livestock grazing distribution in these systems because livestock in natural grazing systems try to make use of patchy mosaic of available forage in time and space in order to maximize intake. Understanding this and importantly what might limit their ability to do this effectively (such as fencing, lack of water ) enables graziers to think about ways to maximise forage utilisation and potentially how to improve livestock production.

Studies looking at animal location and walking speed have been conducted in past years (Frost *et al.*, 1997) using GPS which has rapidly advanced to become a standard method since the mid-1990s. These systems, mounted on neck collars, are used to track habitat use and behaviour routes of wild ungulates (Schlecht *et al.*, 2004). Dorrrough *et al.*, (2004) used GPS technology to track pasture use of cattle and study grazing areas of hill sheep. Independent information generated from remote sensing images is used to determine the relationship between vegetation characteristics and animal landscape preferences. The improved developments of GPS technology now make it possible to track free-ranging animals using

radio transceivers and positioning data (Tomkins & O'Reagain, 2007).

This study assesses the grazing distribution of cattle and sheep under a continuous grazing system, using GPS collars to identify patterns of rangeland use where interventions would be most beneficial to improving livestock production. Factors such as vegetation composition were determined and the NDVI was used as a proxy for plant production as well as 'active greenness' associated with a concentration of nutrients such as N and P. The animal weight during collaring was recorded to assess livestock performance without herding. The study area was then divided into different domains following Schieltz *et al.*, (2017), to identify where most grazing occurred since animals can select grazing sites based on the nutritional and forage quality preferences to improve their productivity (Lyons & Machen, 2001). In the north Eastern Cape, where the study was conducted, livestock herds are mostly dominated by sheep and cattle, with some herds including a few goats (Chapter 4).

## 6.2. Materials and methods

### 6.2.1. Site description

The study site is in the northern part of the Eastern Cape Province, South Africa, in the former Transkei homelands. It is in the quaternary river catchment T12A (centred around 31°31'25S; 27°45'27E) that is administered under communal tenure arrangement (Figure 6.1). The study site comprises vegetation of the *Drakensberg foothills moist grassland* (Mucina & Rutherford, 2006) which is a broad arc of Drakensberg mountain and its surroundings. The topography ranges from steep mountainous escarpments to moderately rolling grassland incised by river gorges. Mudstones and sandstones of the Molteno formation and Tarkastad, as well as intrusive dolerites of Jurassic Age, dominate the geology in the study site. Well-drained soils on the sedimentary parent material dominate, with clay content ranging from 15–55% and a depth of more than 800 mm represent the soil forms such as Hutton, Griffin, Oakdale and Clovelly. On the dolerites, soil forms include Mispah rock complex, Short-lands, Balmoral and Vimy. The study site receives 654 mm (2000–2017) of mean annual precipitation during the summer rainfall period (Mucina & Rutherford, 2006). There are 26 frost days, indicative of a sub-montane form of a warm cool temperate climate, and the mean annual temperature is 14.6 °C. The study site is composed of important taxa of graminoids and geophytic herbs (Mucina & Rutherford, 2006).

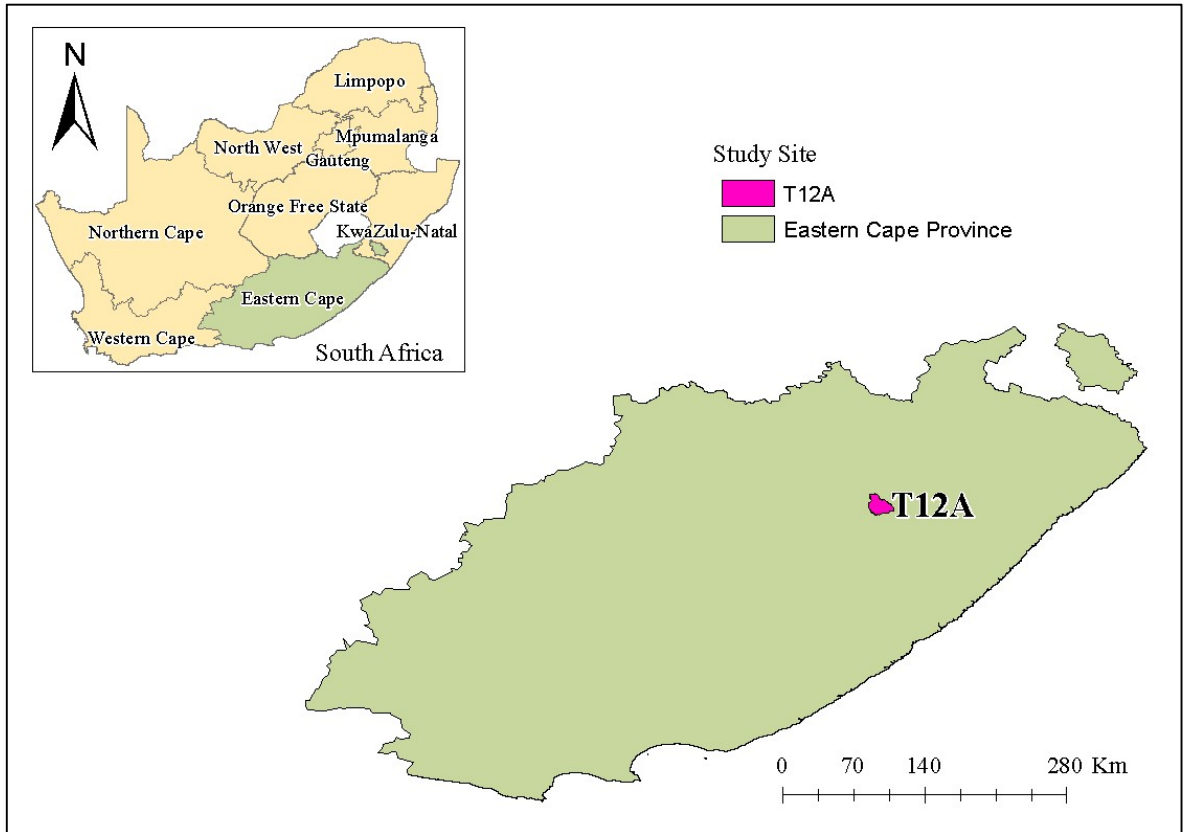


Figure 6. 1. Study site map in the quaternary river catchment T12A.

### 6.2.2. Experimental animals

Prior to embarking on this aspect of the research, ethical approval was obtained from the Rhodes University Research Ethics Committee (RUREC) to undertake the research with live animals. In addition, community collaboration was obtained after a workshop with the villagers of the community detailing the nature of the planned interaction with the livestock and the necessary sensitivity to cultural norms associated with livestock handling. This was necessary as there are cultural sensitivities with regard to a female handling livestock in the communal areas. Following approval from RUREC and the community, two data collection expeditions were conducted during the wet (November to February) and dry season (July to September). A total of 14 local Zebu-type cattle (*Bos indicus*) and 10 sheep were selected from herds of collaborating homesteads and were each fitted with a CatLog GPS tracking device inserted in a waterproof collar.

### 6.2.3. Description of the GPS equipment

The CatLog Gen2 recorder is 4.4 X 2.7 X 1.3 cm with a low weight of 22 g. It is equipped with a ceramic patch antenna (GPS antenna) with three control status elements: the magnetic switch (to switch it on and off), micro USB interface (used for charging and communicating with the computer), status light (green) and charge light (red). To communicate with the device, an interface serial communication cable and micro USB adapter is connected to a computer USB port. The CatLog Gen2 device driver and control centre need to be downloaded for communication with the device. The GPS recorder was set to capture intervals of five minutes, to log if there was no satellite position available, capture a second chance after a ten-second delay, and to log temperature and speed.

The recorder consists of a small chip recorder with an interface for data exchange, a charging USB port and GPS chipset. The battery capacity is 5200 m A (runtime approx. 2160 hours with five-minute intervals) with an accuracy of 5-10 m, depending on signal strength (position jitter is expected in low satellite signal reception conditions). The storage capacity of the equipment is up to 64 000 waypoints. It operates in temperatures between -10 to +50 °C. After downloading, data are exported in a GPX, CSV (Excel) format. The equipment records time, date, position (latitude and longitude coordinates), speed, height, and direction.

### 6.2.4. Mounting GPS on livestock.

The selected animals were fitted with cotton collar belts individually adjusted to their neck size to carry the GPS equipment (Figure 6.2). The devices were inserted in a secure, waterproof pouch attached to a robust neck collar belt. The pouch was closed and sealed with silicon to prevent water damage. Collar belts were placed on the animals on 22 November 2016 and were retrieved on 18 February 2017 for the wet season and were again fitted on the 4 July 2017 and retrieved on the 5 September 2017 for the dry season. After retrieving the collars, the position data were extracted from the GPS receiver using the CatLog Software. Data quality varied enormously, as data from 12 collars (five cattle and seven sheep) were unavailable for analysis, for several reasons, such as GPS failure to collect data for the whole period, battery life, or chip malfunctioning due to water contamination. Furthermore, six GPS collars from cattle did not have a full data set for the whole periods.



Figure 6. 2. Cattle fitted with the GPS collar in the grazing area.

#### 6.2.5. Data preparation, cleaning and generating Google Earth images

Data from the GPS collars were downloaded using the CatLog Data Centre and stored in comma delimited ASCII text format (\*.csv). Data files were renamed to follow a unique numerical convention starting with ARC01S, for the first collar activated in summer, and ARC01W for the same collar in winter. All animals were weighed and sexed at the time of collar attachment, and these data were stored in a database linked to the collar number. The time-stamp on data from the CatLog GPS receivers is in Greenwich Mean Time (GMT) and for use in South Africa, the time stamp was changed. Using the R packages *lubridate* and *plyr*, data from each collar were converted into Central African Time (CAT) and day/time segments. The day/time segments for the summer data were 6 am to 6 pm and described as *day* and *night*. This process was facilitated with R code provided by Zander Venter (*pers. comm.*). The location data from the CatLog GPS receivers is in a geographic projection (latitude longitude), but as this is a pseudo-projection, it is not possible to calculate area or distance, and conversion to recognised projection is required. In this study, the universal transverse Mercator (UTM) was selected as it is required for further analysis T-LoCoH (Dougherty *et al.*, 2018). Once again, this conversion to UTM was undertaken in R using packages *rgdal* and *sp*.

In order to reduce the incidence of collar failure, all GPS collars had been activated in the laboratory prior to placing them inside the waterproof containers. This meant that all collars contained some data not associated with livestock movement. All these data points were removed by sorting: firstly, by date and time, and removing all data prior to and after actual collar attachment, and also by defining the geographic limits of the village and removing all data points that did not fall within these geographic boundaries. As the CatLog data file also contains a speed estimate, data points that had recorded excessive speed (>5m sec) were removed. In this analysis, three cattle and three sheep were randomly selected from the experimental animals that had a full GPS data set for both wet and dry seasons. Google Earth Pro was used to plot livestock distribution movements from the kml files generated by T-LoCoH in the study area.

#### 6.2.6. Time Local Convex Hull (T-LoCoH) R

T-LoCoH is a package for analysing location data developed in the R system for statistical computation and graphics. It is used for constructing home ranges in movement data and explaining spatial-temporal patterns (Lyons *et al.*, 2013). It generalises the non-parametric utilisation construction method and integrates time with space through a scaling that relates distance and time in the construction of local hulls in reference to the velocity of the animal. In both space and time, resulting hulls are local, enabling metrics for multiple dimensions and movement phase of time use including visitation and duration. As a sample for analysis, T-LoCoH produces utilisation distributions (UDs) with high fidelity to temporal partitions of space by taking hulls rather than individual points and can differentiate various behaviour with internal space. T-LoCoH is also used to construct the UD from a set of locations by combining minimum convex polygons (MCP) around each point (Getz & Wilmer, 2004). The T-LoCoH package contains analytical functions for data that have time values attached, such as movement data, and can analyse any set of points. However, it has been developed for data collected at regular intervals from a GPS device such as GPS collar. In each location, time information is used to produce the space used by the animal (Lyons *et al.*, 2013).

#### 6.2.7. Vegetation sampling

At the study site, 12 X 100 m transects were laid to determine the herbaceous species composition which was then assessed using a step point method as described by Trollope *et al.*, (1989). A total of 100 individual species were recorded along the 100 m transect at every

1 m interval (Yapi *et al.*, 2018). One herbaceous species at or nearest to the pointer was identified and recorded within the 1 m interval. If the pointer hit the ground, the nearest plant was identified and recorded. The grass species were grouped into Increaser and Decreaser species, depending on their response to grazing (Bransby & Tainton, 1977). The location of the transects were randomly allocated using a google earth engine which had a pointer in the area where animals were recorded to be spending most of their time grazing during both the wet and dry season, and the samples were taken during the months of April and May. Increaser species are divided into three classes: Increaser I, II and III, and are indicators of poor rangeland. Increaser I is mostly dominant in under-utilised rangeland and in conditions where little or no herbivory is taking place; they are generally unpalatable. Grass species that dominate in over-utilised rangelands are referred to as Increaser II, such as sub-climax and pioneer species that produce highly viable seeds and can quickly establish when exposed to the ground. Lastly, Increaser III are generally unpalatable and increase when selective grazing occurs. They are common in over-utilised rangelands (Yapi *et al.*, 2018). By contrast, Decreaser species are an indicator of good rangeland and dominate in rangelands that are optimally grazed; however, they decrease in abundance in over- or under-utilised rangelands. These grass species were further classified according to whether they are perennial or annual grasses, depending on their longevity (Milton, 2004). Perennial grasses can live for more than two years, while annual grasses cannot.

#### 6.2.8. Normalised Difference Vegetation Index (NDVI)

The presence of 'actively green' patches in the rangelands was determined using NDVI, which is an index that uses visible and near-infrared sunlight absorbed and reflected by the plant to explore green standing aboveground biomass. NDVI is used to estimate pasture performance, crop yield, and rangeland carrying capacity (Donald *et al.*, 2010). It is chiefly directed to the ground parameters such as photosynthetic activity of the plant, ground cover, LAI, surface water and the amount of biomass (La *et al.*, 1987). Healthy vegetation will generally absorb most of the visible light (400–700 nm) that falls on it, reflecting a large portion of the near-infrared light when there is moisture present in the leaves. On the other hand, unhealthy vegetation reflects more visible light and less near-infrared light. Bare soils reflect moderately both the infrared and red portions of the electromagnetic spectrum. This study focused on the satellite band that is most sensitive to vegetation information. NDVI was produced from

the European Space Agency's Sentinel 2 sensor using a Java script (Appendix 2) in GEE with an instruction during both wet and dry seasons while the collared animals were being monitored. The NDVIs were created using the GEE script (Appendix 2), and the images were annotated in PowerPoint to indicate the location of different domains.

#### 6.2.9. Assessing animal live weights for daily weight gains

Animals that were to be collared were captured on the day of collaring, weighed using an electrical weighing scale and ear-tagged for identification. The animals were weighed twice, once on the day of collaring and once the day of removing the collars to measure daily weight gain for both season. The same animals that were used as focal animals. The study randomly selected three cattle and three sheep as focal animals to measure daily weight gains for performance. The animals were weighed in the morning after an overnight stay in the kraal without water or feed. The average initial weight of 284 kg and the average final weight of 376 kg for cattle was recorded for the wet season, and an average initial weight of 38 kg and average final weight of 44 kg was recorded for sheep in the wet season. In the dry season, the average initial weight for cattle was 330 kg and average final weight of 290 kg. For sheep, the average initial weight was 44 kg and the average final weight was 40 kg. The daily weight gain of each animal was calculated using the difference between initial and final weight divided by the number of days on feed during collaring. The initial weight referred to the weight of an animal recorded on the day of collaring, while final weight referred to the weight of an animal recorded on the day of removing the GPS collar.

#### 6.2.10. Data analysis

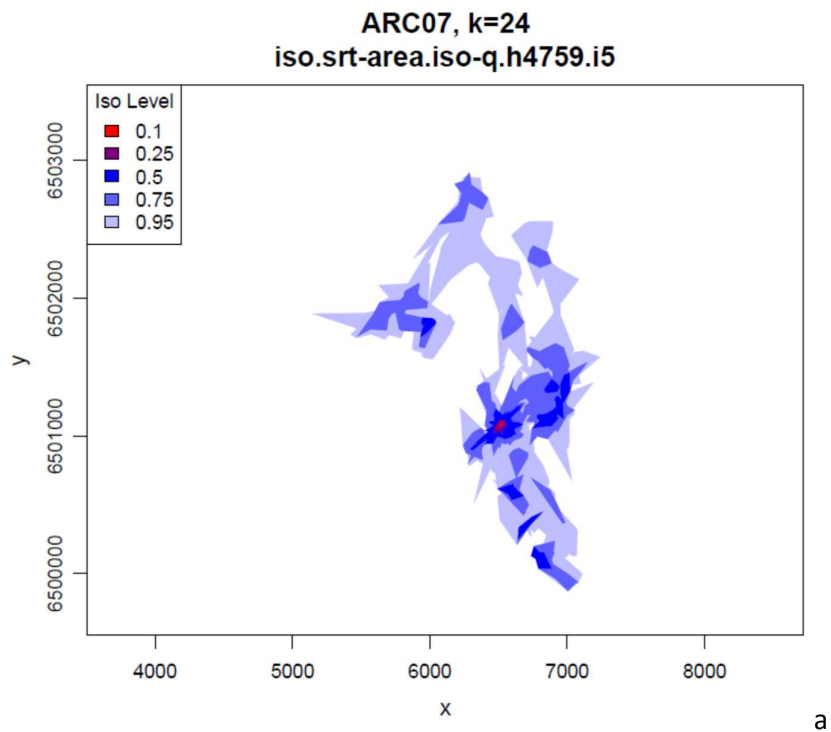
All data were analysed using T-LoCoH software in an R environment (Lyons *et al.*, 2013; Lyons, 2014). T-LoCoH initially facilitates the processing of raw position data into the correct time zone (all raw GPS data are collected using GMT time zone), followed by sorting into daytime and night time periods. T-LoCoH allows for conversion of the geographic projection of GPS system (latitude, longitude) to a UTM projection. This conversion is necessary to correctly calculate distance and area. Using T-LoCoH, the time stamps on the raw data were corrected to Central African Time. Data were cleaned up for GPS positions that did not occur within the study area, or where the speed was  $> 3\text{m/s}$ . These errors mainly arose as the GPS receivers were activated in the laboratory to avoid complications with in-field activation. Poor data points (where the positions had  $< 3$  satellites for triangulation) were also deleted from further

analysis. All activities between 08h00 and 18h00 were regarded as grazing. It is acknowledged that livestock have other activities such as drinking, chewing the cud or walking during daylight hours; however, there was no mechanism on the GPS collar for discriminating these different activities, and further analysis assumes all animals were grazing.

### 6.3. Results

#### 6.3.1. Wet season cattle movement in the study area

The animals represented here include two cows (ARC4 and ARC7) and one castrated male (ARC10) animal (Figure 6.3). T-Locoh provided isopleths constructed from hulls that revealed that the animals spent time grazing on a 10% (iso level=0.1) of all recorded points in an extremely small area during the wet season. This is shown by the area in red (Figure 6.3). Although the animals did move to other grazing areas, they did not spend much time there. The edges of the animal distribution that are shown in purple reveal that the animals roamed around the rangelands even though they did not spend much time.



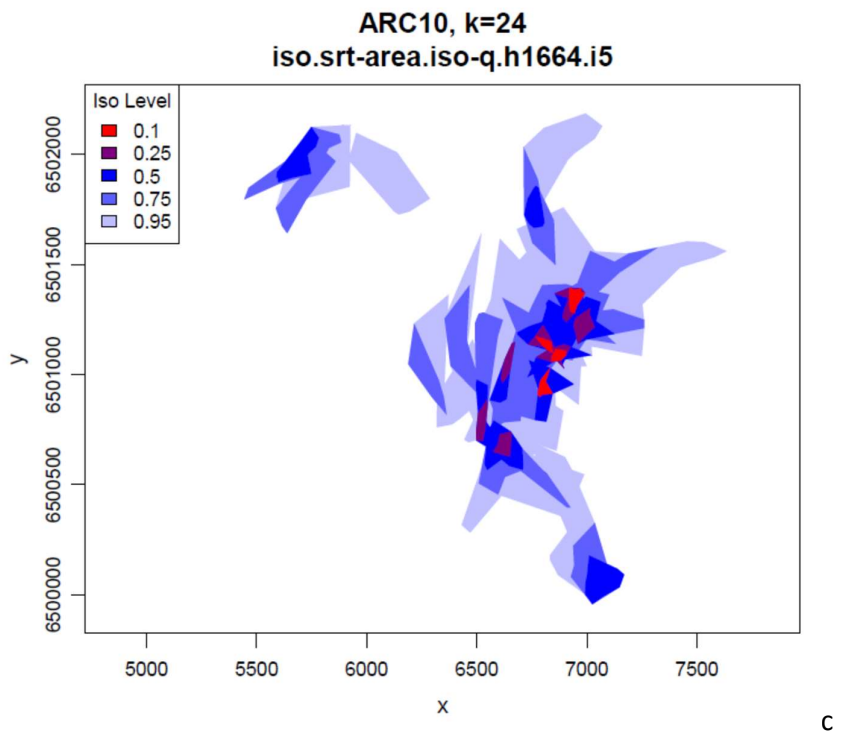
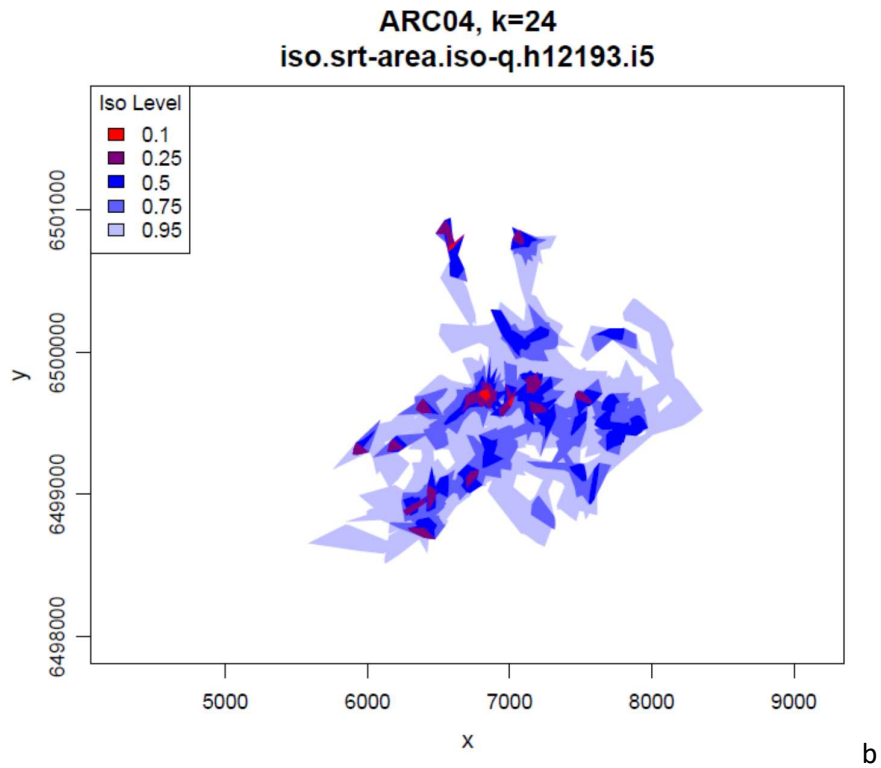
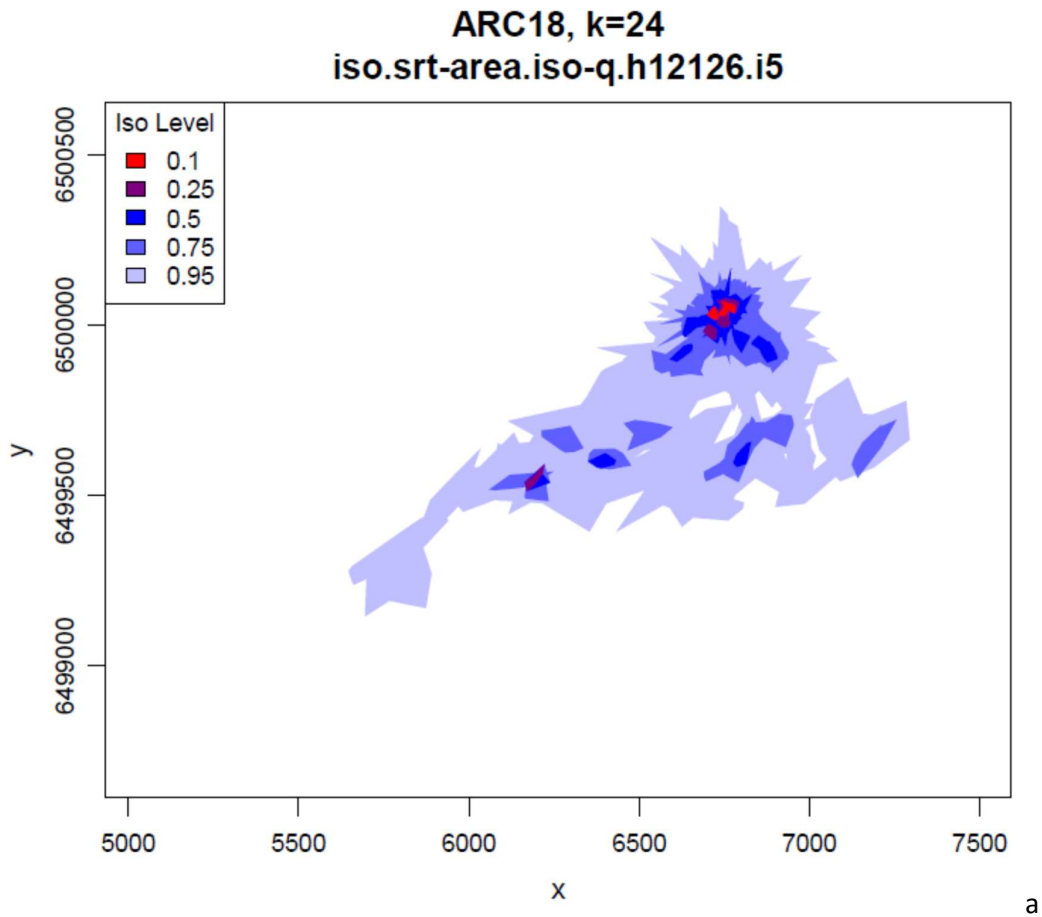


Figure 6. 3a, b and c. Isopleths constructed in different hulls, sorted by area, indicating proportions of the total points enclosed by three focal cattle during the wet season.

### 6.3.2. Wet season movement of sheep in the study area

The representative animals included two female (ARC18 and ARC19) sheep (ewe) and one ram (ARC21) (Figure 6.4) grazing during the wet season. The outputs from the analysis that provided the isopleths constructed from hulls revealed that most of the grazing occurred in only 10% of the available grazing area during the wet season. The greatest elongation (red) around the homestead represents the areas in which most grazing occurred. The edges (purple) at which the animal moved around were also revealed for the duration of the study, even though the animals did not spend much time grazing.



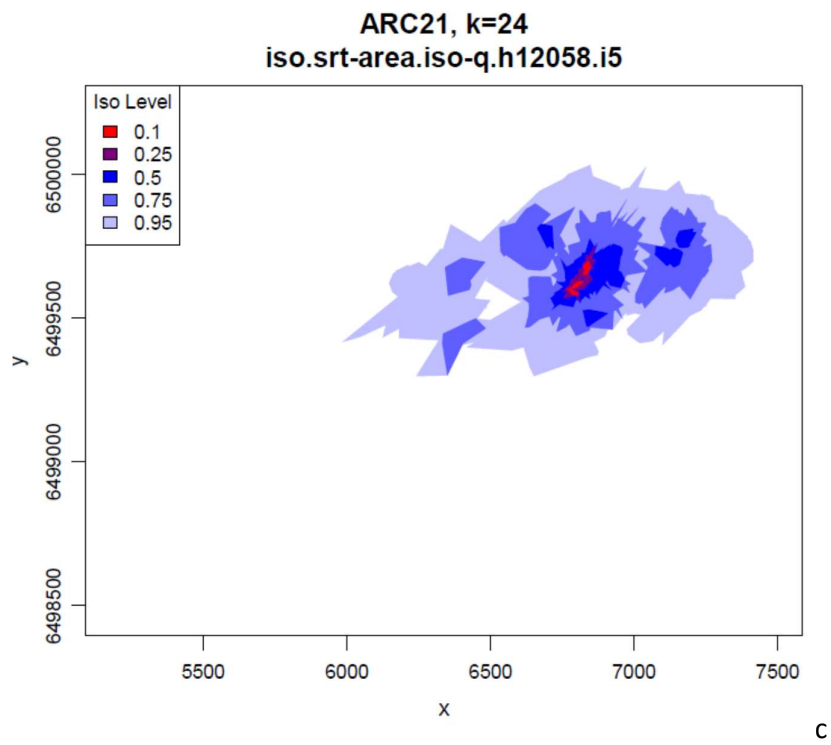
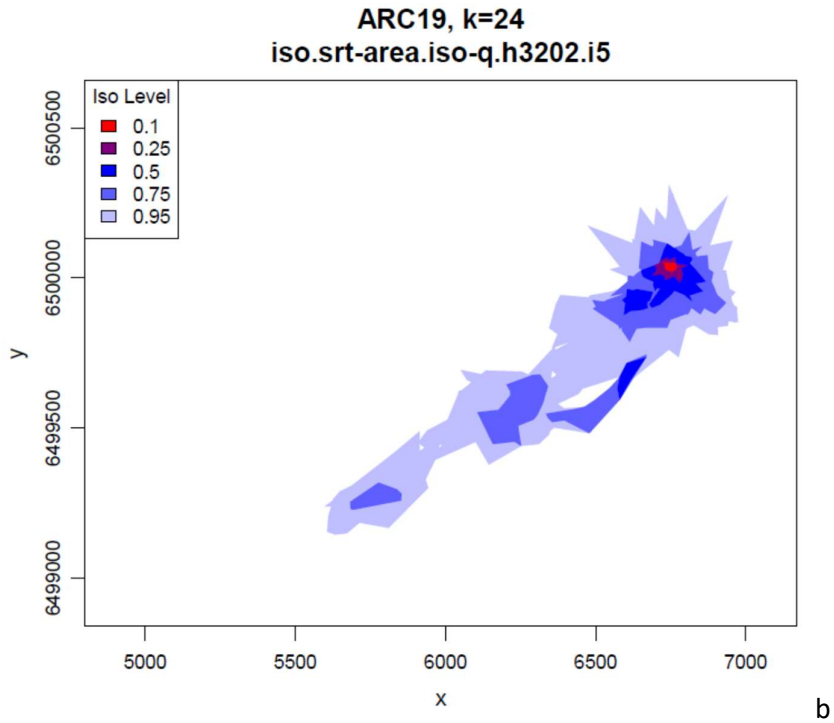
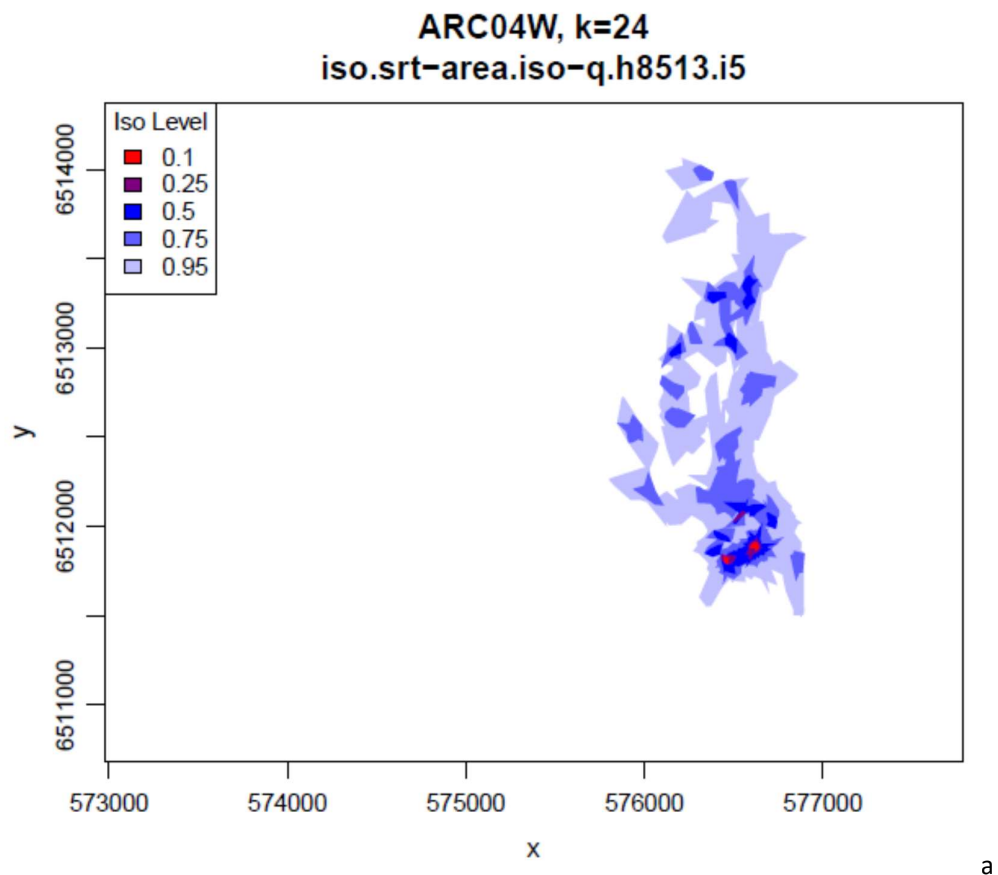
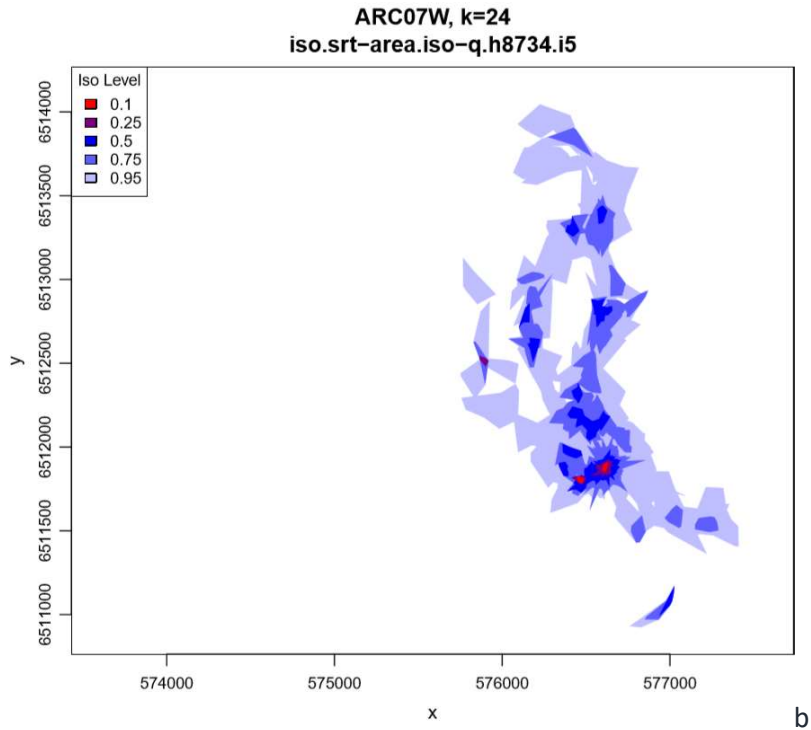


Figure 6. 4 a, b and c. Isopleths constructed in different hulls sorted by area indicating proportions of the total points enclosed by three focal sheep during the wet season.

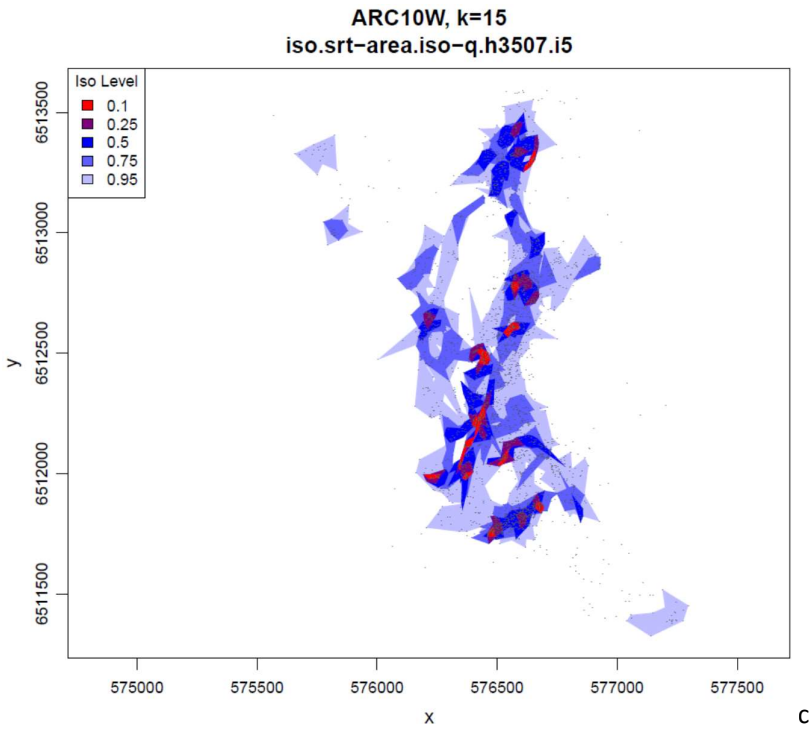
### 6.3.3. Dry season cattle movement in the study area

The outputs from the T-LoCoH analysis show isopleths for mature cattle during the dry season in Mgwalana village. The results revealed that the animals (ARC04W, ARC07W and ARC10W) spent most of their time grazing around the homesteads and along the riparian zones (10%) of the grazing land available for livestock grazing (Figure 6.5). This is shown by the area with greatest elongation (red). The edges of the animal distribution that are shown in purple reveal that the animals roamed around the rangelands even though they did not spend much time grazing.





b



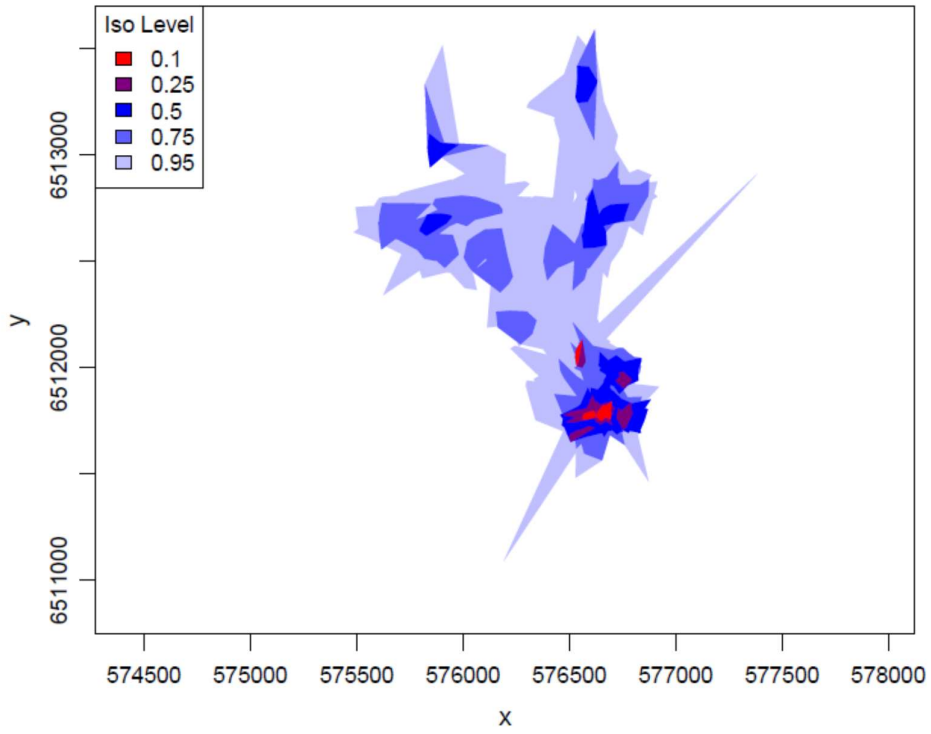
c

Figure 6. 5a, b and c. Isopleths constructed in different hulls sorted by area indicating proportions of the total points enclosed by cattle during the dry season.

### 6.3.3. Dry season sheep movement in the study area

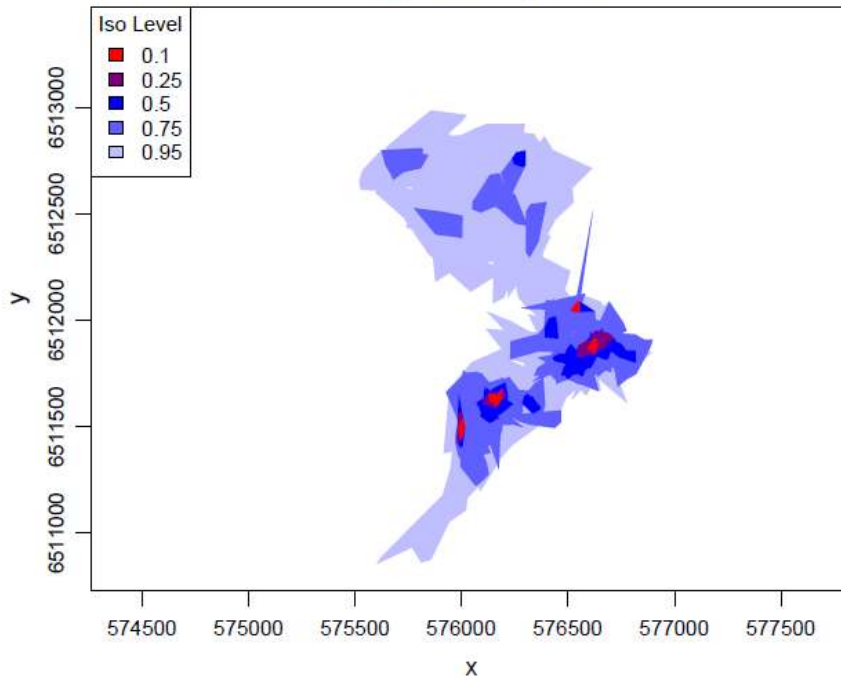
The outputs from the T-LoCoH show isopleth levels for mature sheep (ARC18W, ARC19W and ARC21W), which were constructed from hulls sorted by an area during the dry season. The analyses revealed that most of the grazing occurred in only 10% of the available grazing area around homesteads (Figure 6.6). The greatest elongation (red) around the homestead represents the areas at which grazing occurred the most. The edges (purple) at which the animal moved around were also revealed for the duration of the study, even though the animals did not spend much time grazing.

**ARC21W, k=24**  
**iso.srt-area.iso-q.h4758.i5**

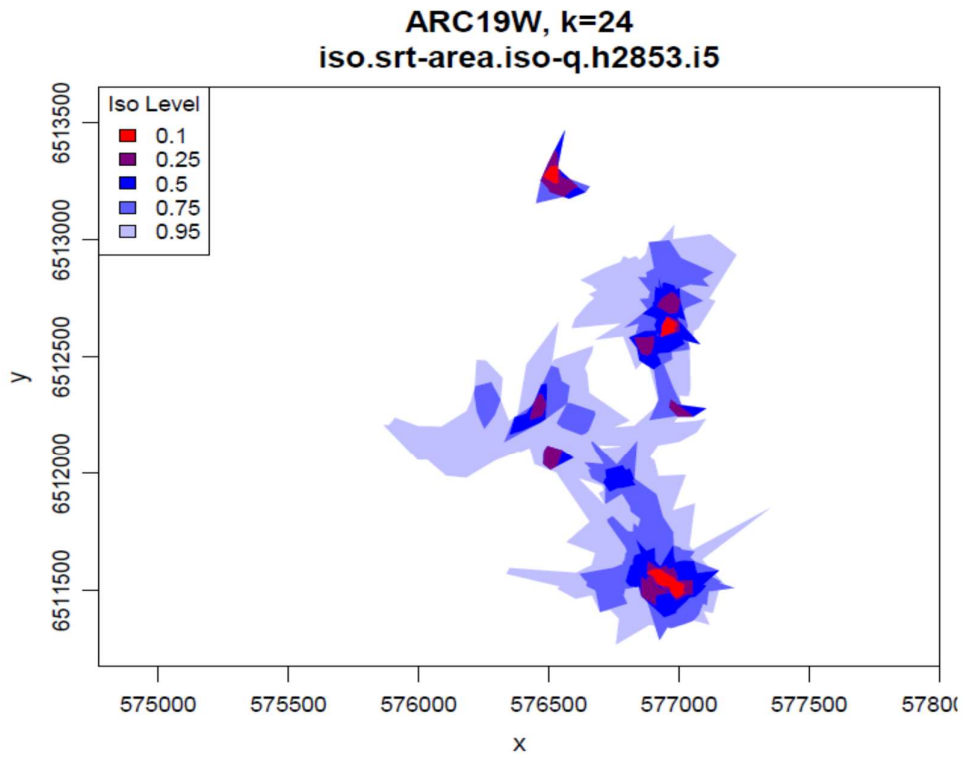


a

**ARC18W, k=24**  
**iso.srt-area.iso-q.h4945.i5**



b



c

Figure 6.6a, b and c. Isopleths constructed in different hulls sorted by area indicating proportions of the total points enclosed by sheep during the dry season.

#### 6.3.4. Google Earth images of cattle grazing during the wet season

The Google Earth image (Figure 6.7) shows the grazing distribution of three cattle during the wet season in Mgwalana village. The red, green and blue colours represent different animals and show that the animals spent most of their time grazing around the homesteads, around the riparian zones and unimproved grasslands. Grazing occurred during the day as the night time points were removed from the analysis. However, the animal shown by the green colour did move and graze on unimproved rangelands during the day in the wet season.

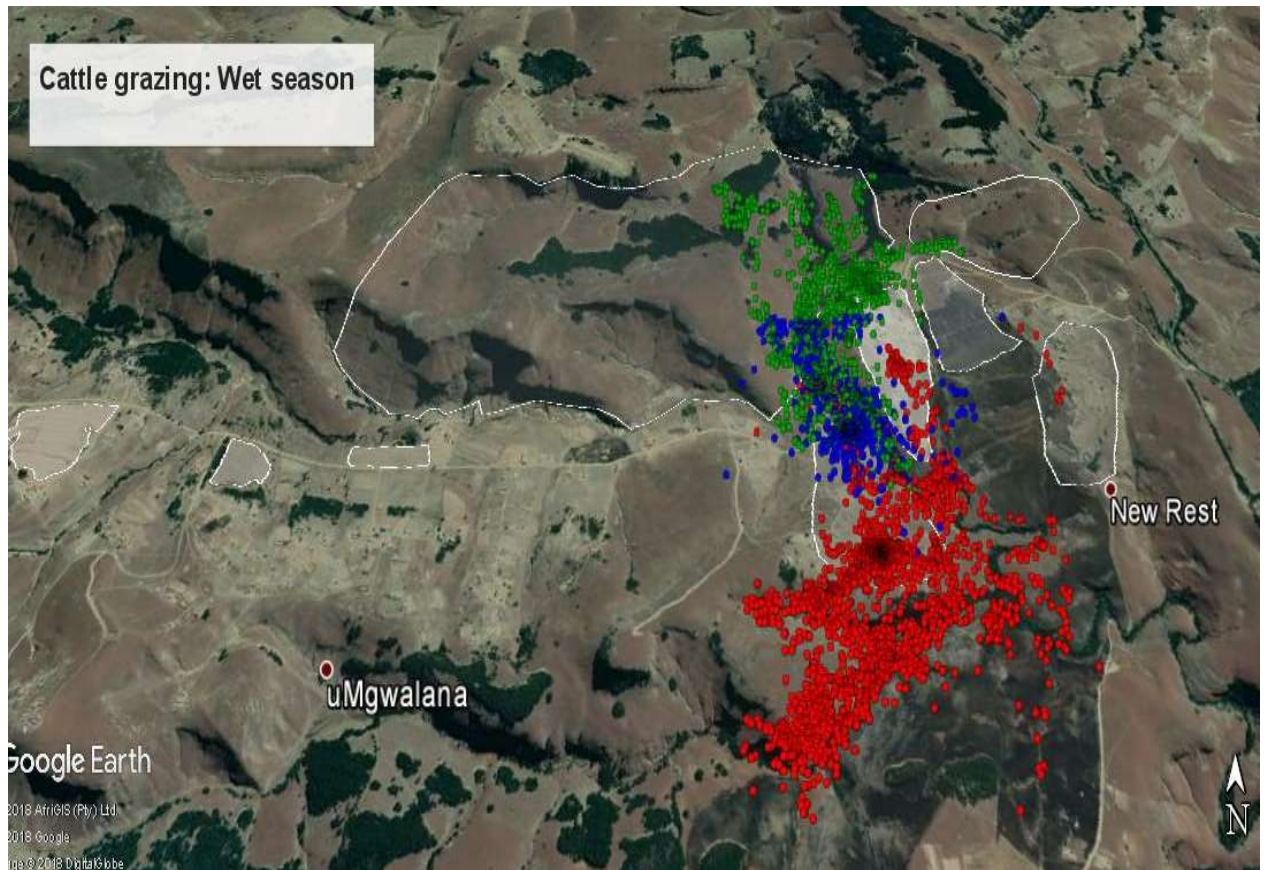


Figure 6. 7. Google Earth plot showing the distribution of three different cattle grazing during the wet season in Mgwalana village (T12A) river quaternary catchment.

### 6.3.5. Google Earth image of sheep grazing during the wet season

The Google Earth image for three mature sheep during the wet season shows that the animals spent almost all their time grazing around homesteads (Figure 6.8). Most of the time was spent in only one domain, with few points on the unimproved grasslands. There were very few points that were recorded along the roads and riparian zones during the whole time of collaring.

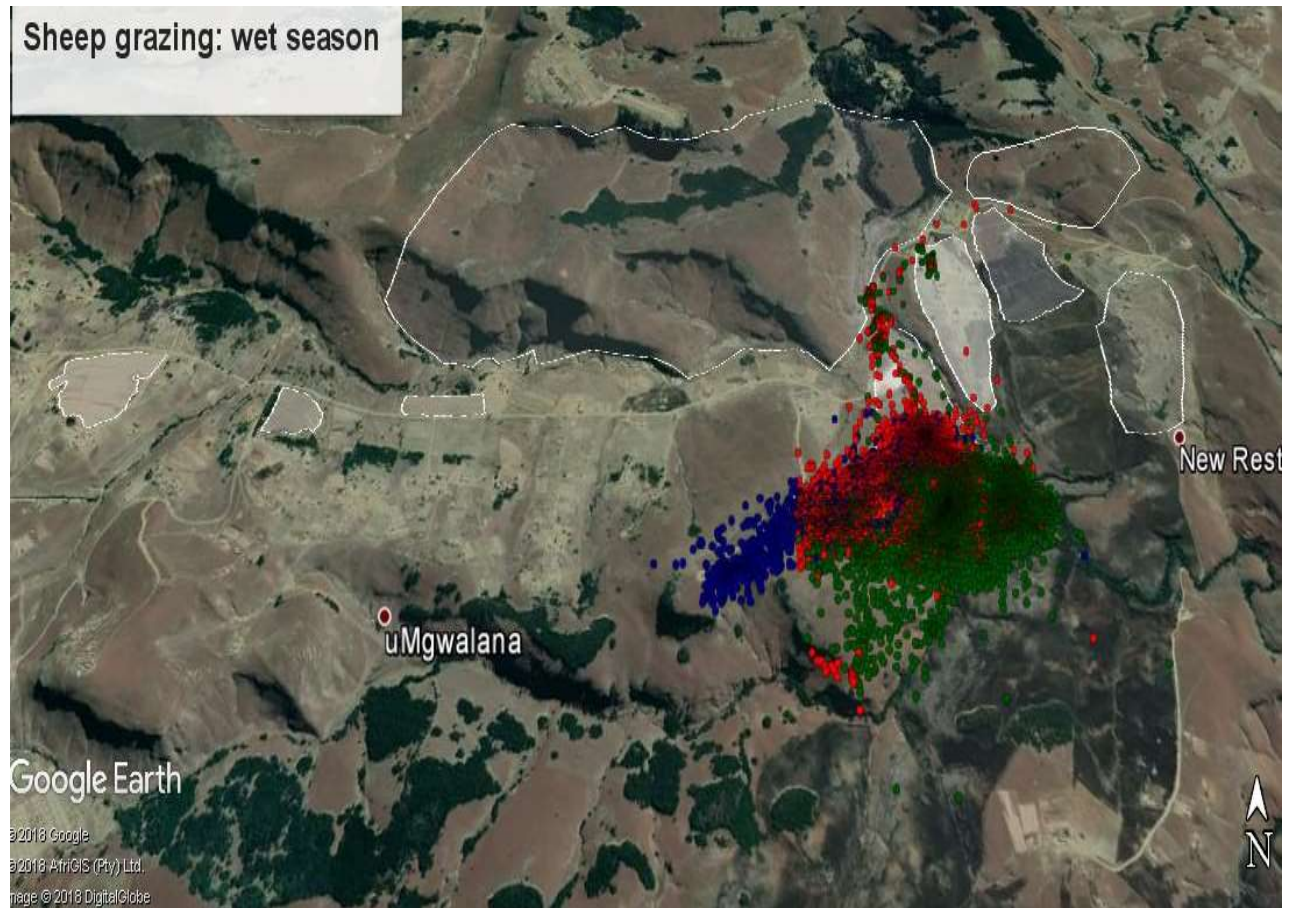


Figure 6. 8. Google Earth plot showing the distribution of three different sheep grazing during the wet season in Mgwalana village (T12A) river quaternary catchment.

### 6.3.6. Google Earth images of cattle grazing during the dry season

The Google Earth image shows cattle grazing distribution during the dry season in Mgwalana village. These animals roamed around looking for grazing, as they were not herded (Figure 6.9). The image shows that the distribution was concentrated on areas around the homesteads, followed by riparian zones and unimproved rangelands. The image shows that the animals are not using the available grazing land effectively as they repeatedly grazed in one area throughout the period of collaring.

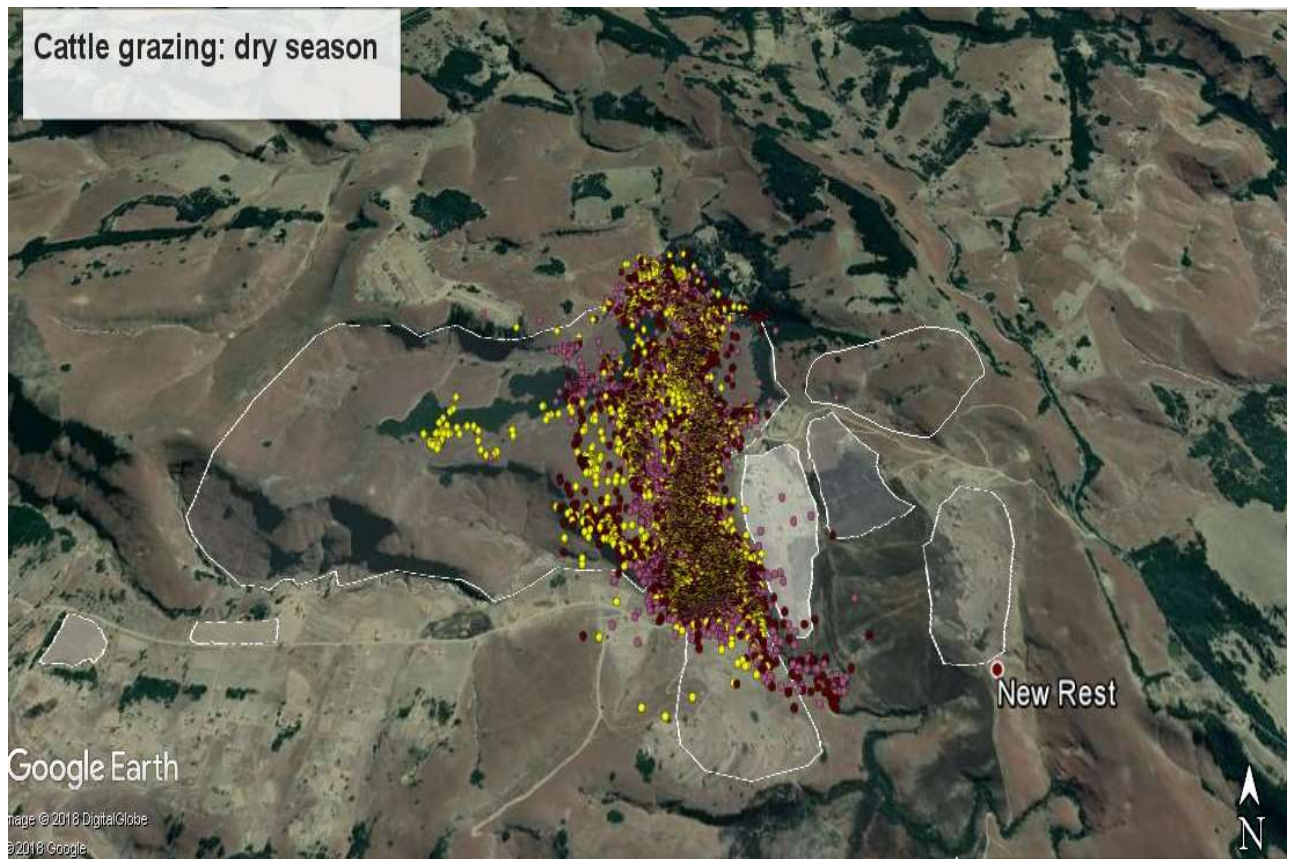


Figure 6.9. Google Earth plot showing the distribution of three different cattle grazing during the dry season in Mgwalana village (T12A) river quaternary catchment.

### 6.3.7. Google Earth images of sheep grazing during the dry season

Figure 6.10 shows the grazing distribution of three mature sheep in Mgwalana village during the dry season. The image shows that the animals spent most of their time grazing around the homesteads, on unimproved lands and river banks to the extent of crossing their grazing border to other areas where they do not belong.

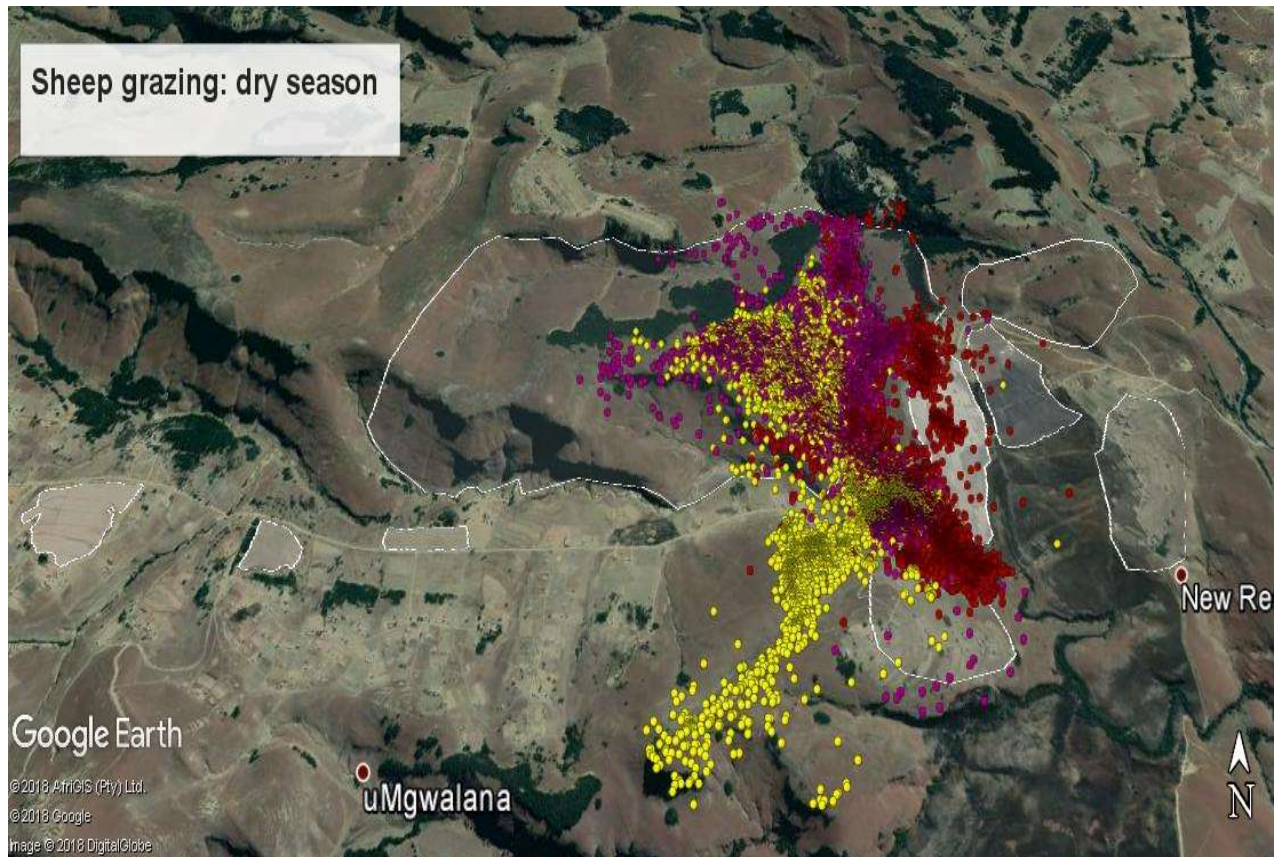


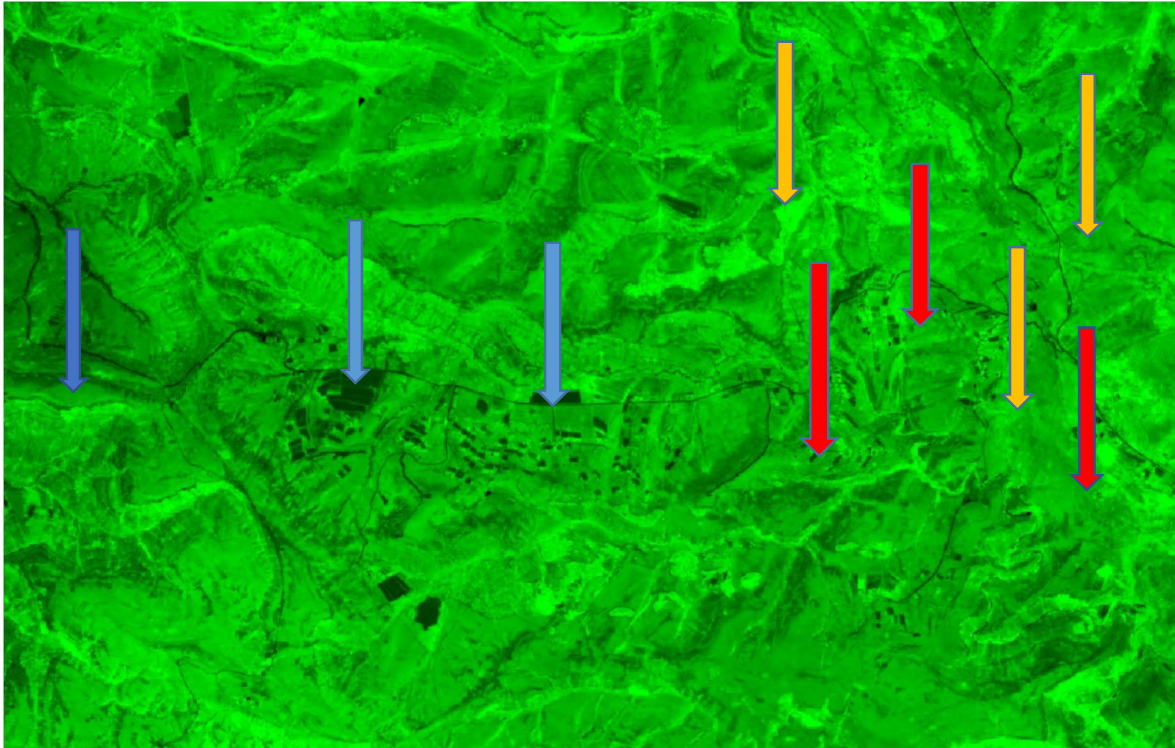
Figure 6.10. Google Earth plot showing the distribution of three different sheep grazing during the dry season in Mgwalana village (T12A) river quaternary catchment.

### 6.3.8. NDVI of the areas where livestock grazing occurs

The normalised difference vegetation index from GEE product based on MODIS Terra surface reflectance for the period of livestock collaring was extracted to determine the active green growth of the areas where most grazing (domain) occurred in both wet (Figure 6.11a) and dry (Figure 6.11b) seasons. In both Figures a and b, the blue arrows show cultivated lands, the orange show the unimproved grasslands, and the red arrows show areas around the

homesteads. NDVI for the wet and dry seasons were different, with the wet season showing more active green areas than the dry season (Figure 6.11). In Figure 11a, which represents the wet season, a high NDVI is represented by bright green, with dark green showing low NDVI. However, Figure 11b represents the dry season, which shows low NDVI values represented by dark green. The bright green during the dry season is the wattle plantation.

a)



b)

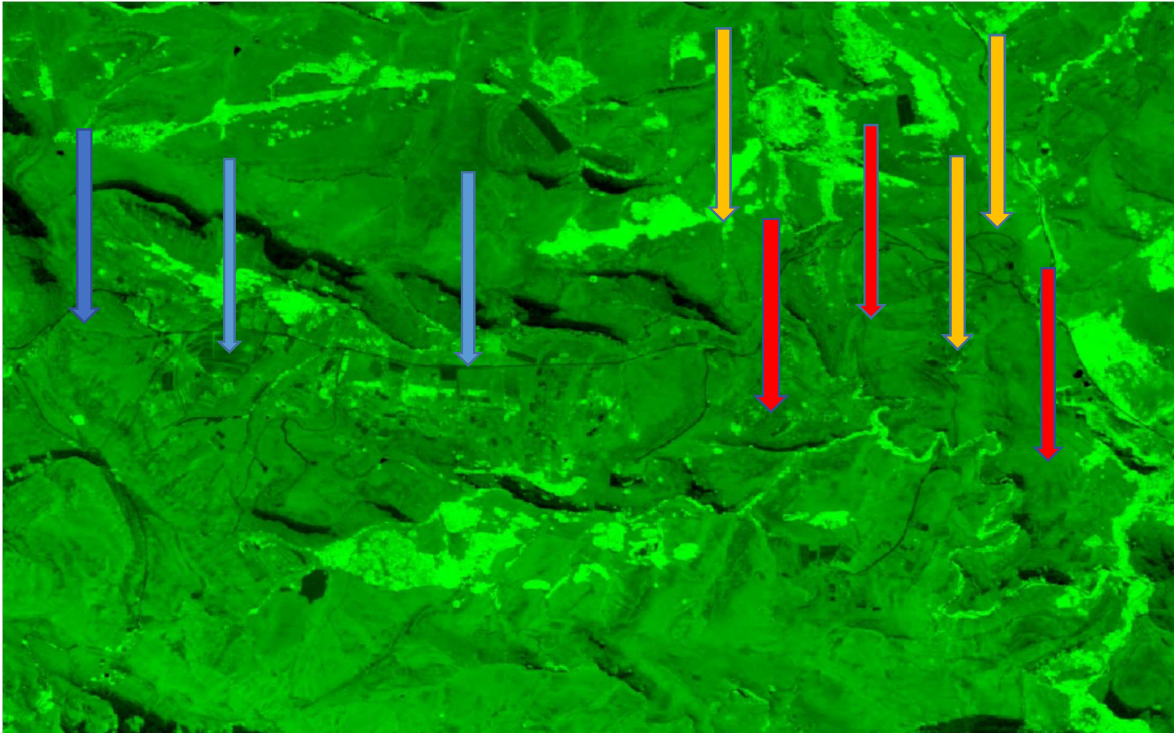


Figure 6 11. NDVI for three grazing domains in Mgwalana village: (a) wet season (b) dry season. Bright green represents the active green growth in the study site, while dark green represents inactive green growth in the study site. In both figures, blue arrows show cultivated lands, orange show unimproved grasslands, and red show areas around homesteads.

### 6.3.9. Distribution of livestock by number of locations and time

Table 6.1 shows the distribution of the grazing livestock by number of locations, steps taken per day, animal weight gain and area covered during grazing in the wet and dry seasons. There is a difference in the number of locations covered by different grazing livestock in both seasons. The total area covered by cattle is much greater than the total area covered by sheep in the wet season, but in the dry season, the total area covered by both grazing livestock does not differ. However, the area covered by sheep during the dry season is greater than the area covered in summer; grazing occurred in a very small proportion of the land (0.05-0.08 ha). Over time, the sampling is not consistent as both cattle and sheep moved location. For both seasons, the number of steps taken per day by both grazing livestock does not differ. The analysis reveals that, even though there is a shift in location, it still occurs within a relatively a small area. The distance (10–50 m) all the animals travel in a short time at low speed indicates that the animal spends most of its time during the day grazing. This is the same for all the animals, regardless of gender. However, in the dry season, both cattle and sheep register a higher number of locations than in the wet season. The results show that distance covered within the location over time occurs in the same area and the animal spends most of its time during the day grazing. During the wet season, both sheep and cattle gained weight. The daily weight gain for cattle ranges between 0.29 to 0.57 kg/day while the daily weight gain for sheep ranges from 0.06 to 0.10 kg/ day during the wet season. Although one of the cattle gained 0.31 kg/day, both sheep and cattle lost weight during the dry season (Table 6.1).

Table 6. 1. Livestock distribution by the number of locations over time during the wet and dry seasons in Mgwalana village.

<b>Wet season</b>										
Animal type	Animal No. analysed	Total number of locations	Av. Distance travelled (steps)	Number of locations per day	10 % area covered (ha)	Total No. of points used	Total area covered (ha)	Length of the recording period (days)	Speed (km/hour)	Growth rate (kg/day)
Cattle	ARC04	3911	2600	90	0,02	7347	126,69	79	0,70	0,38
Cattle	ARC07	1741	1500	93	0,01	7254	397,8	78	0,74	0,57
Cattle	ARC10	2900	1500	94	0,01	7238	122,80	77	0,85	0,29
Sheep	ARC18	10176	7000	93	0,18	7254	48,79	78	1,35	0,06
Sheep	ARC19	3189	1900	90	0,09	2160	39,48	24	0,07	0,10
Sheep	ARC21	2052	8000	69	0,18	1035	59,58	15	0,87	0,10
<b>Dry season</b>										
Cattle	ARC04W	8513	5200	94	0,20	6016	160,50	64	2,94	0,31
Cattle	ARC07W	8734	5200	93	0,26	6720	119,71	64	0,81	-1,03
Cattle	ARC10W	6242	5800	93	0,11	4185	107,39	45	0,81	-0,57
Sheep	ARC18W	8659	5300	93	0,05	5952	111,54	64	1,24	-0,04
Sheep	ARC19W	8850	5300	94	0,11	6016	72,52	64	0,52	-0,11
Sheep	ARC21W	8702	5200	92	0,07	5888	141,03	64	1,00	-0,06

### 6.3.10. Grass species composition in the grazing area

Eight dominant herbaceous species were found in the study site, together with seven grass species and forbs (Table 6.2). The composition comprises 57% Increaser II species, 26% Increaser I species, 17% invader species and 11% forbs. Of the eight-species found in the study area, 50% are of low grazing value, 25% are of moderate grazing value and another 25% are of high grazing value. All the species found were perennial grasses except for the forb, which was unknown.

Table 6.2. Overall, mean percentage abundances of species composition in Mgwalana village.

Plant species	Ecological status	Grazing value	Plant form	Abundance (%)
<i>Eragrostis plana</i>	Increaser II	Low	Perennial	23
<i>Hyparrhenia hirta</i>	Increaser I	Moderate	Perennial	26
<i>Sporobolus africanus</i>	Increaser II	Low	Perennial	10
Forb	Increaser II	Low	Unknown	11
<i>Paspalum dilatatum</i>	Invader	High	Perennial	17
<i>Microchloa cafra</i>	Increaser II	Moderate	Perennial	11
<i>Cynodon dactylon</i>	Increaser II	High	Perennial	2
<i>Cymbopogon plurinodis</i>	Increaser II	Low	Perennial	0,25
<b>Total</b>				100

## 6.4. Discussion

### 6.4.1. Livestock grazing distribution patterns

The results of the livestock distribution patterns for the wet and dry seasons are presented in several ways and all show that, during the daytime grazing periods, livestock spend a great deal of their time strongly associated with human features. The preparation of hull sets presented for three cattle and three sheep using T-LoCoH shows that, in both seasons, the animals spend most of their time grazing on 10%, very small area (1-5ha) near anthropogenic features, for example, homesteads, along roadsides, in abandoned cultivated lands and riparian zones. This strong association is possibly due to the active green growth around these areas; even though the grazing resource is very limited, the grass is generally very short, and is mainly stoloniferous species such as couch grass (*Cynodon dactylon*) and kikuyu (*Pennisetum clandestinum*) and does not offer much bulk forage (Palmer & Ainslie, 2009). However, livestock are able to 'learn the landscape' (Launchbaugh & Howery, 2005) and know that they have to come home, which may be one of the reasons for the strong association with anthropogenic features.

The photosynthetically active green growing grasses generally indicate high-nutrient enriched sites and are adjacent to stockades and houses, riparian zones and soil conservation structures (Palmer & Ainslie, 2009). These represent the classic grazing lawns of the natural African rangelands (McNaughton, 1985), on which most of the grazing occurs. The presence of these plant species may be facilitated by the combination of high stocking rates and continuous grazing around the homesteads. On the other hand, the difference in the NDVI values for different seasons could be linked to cold weather that does not allow plants to absorb more light. The decrease in NDVI could also be associated with the decrease in the amount of plant cover during the dry season.

The cleared surfaces associated with human habitation (roads, footpaths, cultivated areas) create larger runoff areas that provide water to small patches (run-on areas). These patches, akin to the patch dynamics described by Ludwig *et al.*, (2005) provide short, green, nutrient-rich grass throughout the year. Continued revisiting to these sites replenishes the nitrogen and other nutrients on a daily basis through dunging and urination. According to Cid and Brizuela, (1998), livestock avoid grazing near faeces, but when decomposed and highly

nutritious biomass is available later, they will prefer such grazing, resulting in limited grass growth at a later stage. This daily enrichment is similar in nature to the effect of resident indigenous antelope that create and occupy grazing lawns (bontebok, blesbok and black wildebeest). Although there is limited understanding about the sustainability and dynamic of these lawns, Augustine and McNaughton, (2004) show that “periods of positive plant growth following the onset of rains coincide with periods of low N turnover rates, whereas higher rates occur late in the wet season following plant senescence and throughout the dry season”. These higher rates may be what attract herbivores to stay on these sites, even when the alternative grazing in the natural grasslands may be of better quality.

More extensive free-range grazing on upland grasslands did occur, but the density of animals was very light. This may be associated with the small livestock numbers which, according to Stephenson *et al.*, (2016), tend to function as a single unit. Harris *et al.*, (2007) found that small herds usually graze close to one another and Stephenson *et al.*, (2016) argue that cattle are social animals and tend to associate in groups when grazing and normally behave similarly, moving to watering points, grazing and resting together. The analysis of the information provided on location changes over time; the distance travelled and the speed at which both sheep and cattle moved shows that they spend most time during the day grazing. According to Schlecht *et al.*, (2004), the speed for resting animals should be zero, high for a moving animal, and low for a grazing animal. In this study, cattle travel in search of grazing because they are not monitored, unlike a study by Odadi *et al.*, (2018) who found cattle that were monitored travelled less distance in the wet season, so saving energy which resulted in weight gains. However, in the wet season, both cattle and sheep travelled long distances in search for food and lost weight in the dry season. Odadi and Rubenstein, (2015) state that the number of locations covered by the animal looking for grazing during the dry season contributes to weight loss. Lyons and Machen, (2001) argue that animals decide where to graze based on their perception and knowledge of consumed plants in the area and their potential choice memory which later develops a map-like representation of the different areas within the rangeland. The animals have a long-term memory (Lyons & Machen, 2001), which makes them return repeatedly to the areas where they previously grazed in search of forage until the forage is exhausted.

#### 6.4.2. Factors affecting grazing distribution

The livestock distribution across the landscape suggests that there are several factors that affect how livestock use the landscape as some of the grazing land was not used by free-ranging animals. The factors observed in this study include topography, distance from water, and plant composition and were also found by Lyons and Machen, (2001). Another reason for conducting this study was to validate the responses gathered from the interviewed households (Chapter 4) on where their animals spend most of the time grazing during the wet and dry seasons. The responses revealed a poor understanding of about where their animals spent most their time grazing. They reported that their animals spent most time grazing on the unimproved grassland, but this is not the case as the livestock distribution patterns show that the animals spent most time grazing around the homesteads. These grazing patterns, according to Bailey, (2004), may reduce stream bank stability, reduce vegetation cover and increase soil erosion. Areas located along the steep slope received less grazing in this study, possibly because the steep slope was far from the watering point and there was no available shade for rest; shade being one of the factors affecting livestock distribution (Bailey, 2004). It is posited that, during the dry season, animals move further in search of grazing if the resource is limited. However, this study reveals the opposite. Possibly, the animals do not move far in search of forage in order to conserve energy. The patterns of animal distribution in this study show that unrestrained domestic livestock will only move to natural grasslands areas (usually at higher elevation) for short periods during the wet and dry season grazing cycle. Lyons and Machen, (2001) state that topography is one of the causes for poor grazing distribution, because cattle prefer flat and gently rolling terrain, such as valley bottoms, level benches and low areas between drainage. The fact that cattle were seen grazing on a steep slope during collaring suggests that they may be unwilling rather than unable to graze on a sleeper slope. However, sheep which are smaller, surefooted and more agile can make more use of steeper slopes but are limited where rugged terrain can limit their landscape use (Lyons & Machen, 2001). The collared animals demonstrated that livestock prefer certain grazing sites to others because of the terrain. In addition, roads play a role as the study reveals that animals grazed along the road, which according to Bailey (2004), enables the animals to travel and graze on the vegetation alongside.

Distance to water (the river, in this case) may be a strong motivator of grazing distribution for both cattle and sheep. Water acts as a limitation at which the mechanism for foraging operates. According to Lyons and Machen, (2001), livestock need free access to water for improved production. Distant water sources decrease livestock production efficiency because they use energy to travel from the grazing area to watering points, thus making availability a major source of poor grazing distribution across the rangeland. However, plants that are near the watering points are heavily grazed, which results in reduced forage production. In their study, in which animals were fitted with GPS collars, Lyons and Machen, (2001) found that watering points are the main factors determining the distribution, movement and concentration of grazing animals. Their results reveal that areas that are close to watering points receive more grazing than areas that are far from the watering points.

Different livestock species have different forage preferences, strongly influencing grazing distribution. Cattle prefer grazing on grasses and tend to avoid bushes; however, sheep prefer short green grass. The species composition also plays a major role in grazing distribution. Although different plants may be found in the rangeland, they receive different grazing pressure because of their chemical composition (Lyons & Machen, 2001). In this study, the most abundant species in the area was *H. hirta*, a robust perennial C4 grass moderately resistant to continuous grazing. It grows along the road verge and in disturbed soils or abandoned arable lands. Another species that was abundant in the study area was *E. plana*, which grows in disturbed and overgrazed soils. Although this species tolerates overgrazing because of its strong root production, succession ability, drought tolerance and its ability to compete for resources (Scheffer-Basso *et al.*, 2016), it has low forage value and can result in livestock economic losses.

#### **6.4.3. Livestock grazing distribution and implications for proper grazing management**

The results of livestock grazing distribution and the impacts on species composition call for the development of a proper grazing management to monitor livestock movements in communal rangelands. Some of the results this study reveals suggest that livestock herding, which was found to improve livestock technical efficiency (Chapter 3), would be ideal if it was introduced as one of the management tools for livestock monitoring in rangeland utilisation. Livestock herding is a process whereby people move livestock in a rangeland from one place to another for even rangeland utilisation. As the fences in the study sites have fallen into

disrepair, livestock herding could be one possible way to manage rangelands. Norton *et al.*, (2013) argue that proper grazing management can improve grazing distribution of livestock. In this study animals were not herded but they were left on their own to select their preferred grazing sites. Herding is more effective and is a proven tool for controlling livestock distribution, especially when livestock behaviour is considered. In the over-utilised areas of the rangelands, improved grazing distribution could result in an increased stocking rate because of more available forage in the rangeland (Samuels *et al.*, 2007). A herder in communal rangelands could move livestock to different grazing areas for improved, even grazing distribution as the herder purposely relocates animals to alternative sites without harassing them from their preferred sites; harassment often makes them return on their preferred site. According to Norton *et al.*, (2013), the herder should remain with the animals in the rangelands until they get used to the area. Bailey, (2004) states that livestock herding where people move livestock on horseback from one location to another has long been recommended as a management tool to modify grazing patterns of cattle for even utilisation of grasses. Although livestock herding is too costly as it needs labour, over-utilisation of preferred areas such riparian zones and around the homesteads make herding necessary to reduce the negative impacts caused by heavy grazing. For improved livestock grazing distribution, rangeland management in communal areas is often difficult because of the topography and the annual variation in standing biomass.

## 6.5. Conclusion and recommendations

Analysis of the livestock grazing distribution on the landscape reveals that the animals in Mgwana village spend most time grazing around the homesteads and along riparian zones, in both the wet and the dry seasons. The possible motivation for this grazing habit in both sheep and cattle is linked to repeated revisiting areas that are actively green for the most part of the year. Species grazed had moderate grazing value, which is also a strong motivation for continuous grazing in these areas. An abundance of couch grass (*Cynodon dactylon*) and kikuyu (*Pennisetum clandestinum*) between the homesteads and on the run-on areas near roadways was also observed which animals favoured than other grasses in the rangelands.

Livestock owners or herders need to observe where their animals spend most time grazing as the bulk of the rangeland is not used. Extending grazing areas will improve grazing distribution, improve species composition, and forage quality and quantity. It is important to inform owners and herders about the implications of the current grazing distribution for the rangeland condition, and for households to have herders who will move livestock into the areas that are lightly grazed for even grazing distribution. It is also important to encourage and advise livestock owners to fix their fences and gates so that they can rest some camps during the growing season, allowing the species composition to improve by reducing overgrazing on continuously grazed lands. Alternatively, there must a committee set by the local people to at the rangeland use.

## CHAPTER 7. CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

### 7.1. Introduction

Rangelands are important for biodiversity and need to be conserved as they are also a home to people worldwide (Vetter, 2013). Further, biodiversity and ecosystem health are recognised as significant for production, physical and spiritual human well-being, and sustained harvesting of natural resources. However, in many areas under communal tenure, these services are threatened by degradation (Millennium Ecosystem Assessment, 2005). For the purpose of managing communal rangelands, acceptable and feasible ecologically appropriate ways need to be identified (Vetter, 2013), such as livestock rangeland use. Rangeland ecosystem services, such as grazing, are influenced by many factors, both global and local. In South Africa, there is an ongoing debate about the state of communal rangelands, which are believed to be at the point of ecological collapse when they are assessed in terms of standing biomass and species composition (Vetter, 2013). The Eastern Cape Province in South Africa is reported to be among the worst degraded provinces, with rangelands under the communal tenure system being dramatically degraded compared to their commercial counterparts (Meadows & Hoffman, 2002). Livestock mortality is high because severe degradation promotes detrimental shortages of feed for livestock, leading to reduction in the performance of animal production and reproduction (Zerfu *et al.*, 2010). In the former homelands of the Eastern Cape, where rangeland degradation takes place in the form of overgrazing, rangelands are perceived to be unproductive and unable to sustain livestock production. This has an implication on the rangeland's ability to provide feed for livestock, upon which most people depend for their livelihood. However, household livestock production has not been quantified, which poses a challenge in ensuring proper water use efficiency by the landscape. On the other hand, Molden *et al.*, (2007) emphasise the importance of managing water and resources to enhance food security. In communal rangelands, people depend on livestock that feed on rangelands, and thus, increasing LWP has the potential to improve livelihoods. For this reason, there is a need to describe LWP in communal rangelands of the north Eastern Cape in order to improve rural livelihoods from livestock. To address this challenge, this thesis refers back to Chapter 1, which addresses the challenges in communal rangelands and livestock production in the north Eastern Cape. This

study aims to contribute towards a better way of managing rangelands for improved water use and livestock production in communal rangelands. The objectives of this study were to

- provide an overview of the state of communal rangelands in the Eastern Cape Province, South Africa;
- describe the biophysical attributes of the ecosystem in the north Eastern Cape communal rangelands;
- assess the performance of livestock production in the north Eastern Cape communal rangelands using a stochastic frontier analysis as an application;
- assess household livestock-based livelihood strategies in the north Eastern Cape communal areas, South Africa;
- describe LWP in the north Eastern Cape communal areas;
- assess distribution of livestock grazing using GPS collars in a communal rangeland.

## 7.2. Key results

The results described in this thesis show that an increase in LWP can be achieved if interventions are applied at the appropriate entry point. Firstly, this study described the biophysical attributes of the ecosystem such as ET, ANPP, cover and PsNet in a communal rangeland where everyone has an equal access and no obvious, conventional grazing management is practised. Results of this study show an estimated amount of MODIS ET of 379 mm in communal rangelands, which is approximately 50% of the total annual precipitation. Vegetation cover was found to be a good predictor of the potential green biomass production. The aboveground net primary production (ANPP) and carbon produced was comparable with other studies in communal rangelands, implying that many factors exist that determine the annual herbage production other than grazing pressure. However, proper rangeland management, such as proper resting of rangelands to improve basal cover, productivity and production, is necessary. The rangeland production was measured by fencing exclosures to determine ANPP and measuring the amount of carbon occurring in the rangeland. This study revealed that the rangelands of the north Eastern Cape are good rangelands. The study further assessed the performance of livestock production at household level which averaged 79% of technical efficiency, suggesting that there is an opportunity for improvement in the households that are performing above 70% technical efficiency level. When looking at the household practices in livestock rearing, livestock herding is another very

important intervention which this study recommends for improved livestock productivity. The results of the technical efficiency analysis reveal that livestock herding allows for effective utilisation of the rangeland where a herder moves livestock to the most productive parts of the rangelands. The results also suggest that further knowledge about market information and livestock husbandry at the household level is necessary so that the livestock water footprint can be reduced, thus improving production. Household livestock-based livelihoods, such as beneficial goods and services obtained from livestock, suggest that livestock contribute significantly to rural livelihoods. There was also evidence that households who do not own livestock benefitted significantly from livestock beneficial goods and services. It is evident from the study that the uneven distribution of livestock ownership among households remains a critical shortcoming in securing food and services in communal rangelands, most particularly for communal areas where severely limited livelihood options prevail and livestock production will most likely remain a livelihood option only for some households. The study reveals that there are numerically more sheep than cattle and goats in the village, and that interventions should focus on both sheep and cattle in this area.

This study further showed that an increase in LWP is possible if more effective grazing management (e.g. herding and rotational grazing) and supplementary feeding is practised. One way to achieve this is through better management of natural grassland for improved water use (e.g. higher basal cover, a reduction in non-palatable shrubs and the removal of invasive alien plants), thus enhancing rangeland productivity for improved livestock production. The positive relationship between livestock holdings and LWP suggests that it is possible to improve WUE through increased livestock beneficial outputs. The positive relationship between livestock holdings with LWP, and labour with LWP among wealth groups suggests that strategies to improve water use need to focus on feed (e.g. rangeland management for improved herbage) and additional labour for animal husbandry activities such as milking, herding, caring for young and sick animals, and collecting supplementary feed. We expected to find that livestock spend most of their time grazing on areas cleared of wattle, but the results showed that livestock spent most of their time grazing on areas around the homesteads in both the wet and dry seasons. These areas represent highly productive grazing lawn where nutrients are transferred from the landscape by livestock. On the other hand, areas cleared of wattle have a high nitrogen content, enabling the regrowth of highly

nutritious grass (Gwate 2018). Livestock owners need to be informed about the importance of controlling their animals when feeding in areas cleared of wattle, as these areas are the most productive, but subject to rapid deterioration after the N levels are depleted. The study recommends excluding these areas from grazing immediately after clearing, and to apply remedial actions that increase soil pH (e.g. addition of agricultural lime) to allow robust perennial grasses to re-establish in the cleared areas. Finally, in most cases, livestock are not herded, leading to selective grazing, which in turn, leads to changes in species composition, with species such as the unpalatable *Eragrostis plana* becoming abundant.

Animals that were weighed during the study revealed positive performance (i.e. a weight increase) in both male and female cattle during the wet season, but poor performance in the dry season (i.e. animals lost weight). The performance of livestock during the wet season was positive, given the fact that these animals were only grazing and receiving no additional feed.. Finally, government programmes which seek to change agrarian and land production systems should recognise the importance of livestock production in the rural economy.

### 7.3. Implications for possible interventions in rangeland production and rural livelihoods

In areas where water scarcity is a major problem for livestock production, a great opportunity exists to improve rural livelihoods and decrease land degradation through increasing LWP (Descheemaeker *et al.*, 2010). Exclosures (e.g. temporary fencing of areas cleared of wattle as well as nutrient hot-spots) will encourage vegetation restoration and enable water resources to be more effectively used to increase biomass production and to restore ecosystem services such as grazing. Better vegetation cover can lead to reduced storm flows and channel more water to productive evapotranspiration (Descheemaeker *et al.*, 2009). Combined with increased total biomass, higher water use efficiency can be achieved, thus increasing LWP. This could further improve livestock production and productivity, which might encourage people to keep fewer productive animals and reduce land degradation. Improved market access and the availability of more animal products would lead to increased water productivity, thus improving rural livelihoods from livestock in communal rangelands. In rural households, the adoption of possible interventions for improving water productivity is likely to be governed by socio-economic conditions, making it important to understand gender and wealth dynamics. Communal people are likely to adopt interventions if incentives

to invest in water management and land empower them to make appropriate decisions in managing livestock, water and land.

Livestock production is an effective, practical way out of poverty in rural livelihoods and opportunities exist to improve LWP at scales of household levels, such as labour and providing additional livestock feed. However, little research has been carried out on the subject, or existing knowledge being translated into policy and technology to improve livelihoods. Chapter 3 has shown that improved labour following Frontiers Analysis can improve livestock efficiency. Better training of household labour (up-skilling) to actively carry out livestock husbandry and improve skills in the activities mentioned above can also improve LWP.

#### 7.4. Conclusion

The main achievement of this study was to contribute towards improved rural livelihoods from livestock in communal rangelands of the north Eastern Cape. Rules and regulations on rangeland resource use such as livestock grazing, and rangeland use such as resting, are possible ways to manage rangeland production on the communally owned rangeland of the north Eastern Cape.

1. Firstly, it is recommended that community leaders should have the authority to govern livestock grazing. Proper resting for a full growing season of the areas that are grazed by livestock is recommended to improve basal cover, productivity and water use by rangelands. Improving rangeland productivity through grazing management is a possible way of improving LWP. Adaptive stocking density and appropriate herd composition so that a herd can be moved to different grazing areas may positively influence vegetation ground cover, species composition and ANPP, thus improving water use. The disc pasture meter can be a useful and important management tool for poorly resourced farmers, which will allow them to measure the grass growth and allowing them to graze and rest their rangelands at an appropriate time for the next growing season. It is a very non-technical tool which can be easily used by the local farmers.
2. Each household should have a herder to move livestock to areas that are not being grazed to enable more rangeland use by livestock. This will enable households to pool resources and manage livestock and grazing together. Thus, improving the decision

making in communal areas. Furthermore, policy/government should intervene through the Extended Public Work Programmes (EPWP) to provide labour for livestock herding which will, in turn, improve livestock distribution, as will providing feed throughout the year and increasing the frequency of visits by extension services.

3. These interventions should be targeted at more affluent female-headed households so that they become more successful at food production. This is because the more affluent households own more livestock and were found in this study to be producing more than the less affluent. So this study will intervene on them so that they can employ the less affluent households. In so doing, the more affluent households will be able to produce more and be able to create jobs for the poor households.
4. Owners should be encouraged to use their animals for traction to improve the amount of muscle before the animal is slaughtered

#### 7.5. Recommendations for future study

Possible interventions to improve LWP require further research where the interventions are applied to selected households and monitored with other households as controls. This should be followed by another household survey to assess the effect of the interventions. Since livestock and crops complement each other, research that assesses LWP in a crop-livestock system is necessary so that production from cultivated lands can be measured, as crop residue is used as livestock feed in the dry season. Research is needed to better understand the role of livestock in an integrated water management system because critical human health issues are linked to water and livestock management through food security. This has to be addressed in the United Nations Development Plans (UNDP) Sustainable Development Goal (DSG) 1, which calls for a reduction in poverty. An integrated developmental research strategy needs to focus on improving water productivity in crop-livestock enterprises to enable communal people to improve efficiency in enhancing food security and adapting to climate change. Research for a development approach which prioritises empowering women in agriculture and poor farmers is needed as this study reports female-headed households as being more technically efficient.

## REFERENCES

Abate T, Ebro A & Nigatu L 2010 Traditional rangeland resource utilisation practices and pastoralists' perceptions on land degradation in south-east Ethiopia. *Tropical Grasslands* 44 202–212.

Abel, NOJ 1993. Reducing cattle numbers on Southern African communal range: is it worth it? *Range Ecology at Disequilibrium* (eds R.H. Behnke, I. Scoones & C. Kerven), pp. 173±195. Overseas Dev Institute, London

Adams M, Cousins B & Manona S 1999 Land Tenure and Economic Development. In *Rural South Africa: Constraints And Opportunities*. Proceedings of a conference “At the crossroads: land and agrarian reform in South Africa into the 21<sup>st</sup> Century”. Pretoria.....

Adesina AA 1992 Oxen cultivation in semi-arid West Africa: Profitability analysis in Mali. *Journal of Agricultural Systems* 38 131–147.

Aigner D, Lovell CAK & Schmidt P 1977 Formulation And estimation Of Stochastic Frontier Production Function Models. *Journal of Econometrics* 6 21–37.

Ainslie A, Kepe T, Ntebeza L, Ntshona Z & Turner S 2002 Cattle Ownership and Production in The Communal Areas of The Eastern Cape, South Africa. *Programme for Land and Agrarian Studies* 41 1475–1485.

Alemayehu M, Amede T, Böhme M & Peters KJ 2012 Increasing Livestock Water Productivity under Rain Fed Mixed Crop/Livestock Farming Scenarios of Sub-Saharan Africa: A Review. *Journal of Sustainable Development* 5 1–10.

Allen, Richard G., Pereria Luis S., Raes, Dirk., Smith M 1998 in *FAO Irrigation and Drainage Paper No. 56: Crop Evapotranspiration (Guidelines for Computing Crop Requirements)*. FAO, Rome.

Allsopp N, Laurent C, Debeaudoin LMC & Samuels MI 2007 Environmental perceptions and practices of livestock keepers on the Namaqualand Commons challenge conventional rangeland management. *Journal of Arid Environments* 70 740–754.

Amede T, Descheemaeker K, Everisto M, Peden D, Breugel P van, Awulachew SB & Hailelassie A 2011 Livestock-Water Productivity in Nile Basin: Solutions for Emerging Challenges. In Melesse AM. Ed. Nile River Basin: Hydrology, Climate and Water Use, pp 297–320.

Amede T, Descheemaeker K, Peden D & Van Rooyen A 2009 Harnessing benefits from improved livestock water productivity in crop livestock systems of sub-Saharan Africa: Synthesis. *Rangeland Journal* 31 169–178.

Andrew M, Ainslie A & Shackleton C 2003 Land Use and rural livelihoods: Have they been Enhanced Through Land Reform. Policy Brief. Institute for Poverty, Land and Agrarian Studies No. 5, School of Government, University of the Western Cape.

Archer AD JA, Richardson AC EC, Herd B RM & Arthur PF 1999 Potential for selection to improve efficiency of feed use in beef cattle: a review. *Australian Journal of Agricultural Resource* 50 147–161.

Archer ERM 2004 Beyond the 'climate versus grazing' impasse: Using remote sensing to investigate the effects of grazing system choice on vegetation cover in the eastern Karoo. *Journal of Arid Environments* 57 381–408.

Asfaw S, Shiferaw B, Simtowe F & Haile MG 2011 Agricultural technology adoption, seed access constraints and commercialization in Ethiopia. *Journal of Development and Agricultural Economics* 3(9) 536-447.

Augustine DJ & McNaughton SJ 2004 Temporal Asynchrony in Soil Nutrient Dynamics and Plant Production in a Semiarid Ecosystem. *Ecosystems* 7 829–840.

Baha M, Temu A & Philip D 2013 Sources of Technical Efficiency Among Smallholder Maize Farmers in Babati District , Tanzania. *African Journal of Economic Review* 1 34–41.

Bahta S, Baker D, Malope P & Katjiuongua H 2015 A metafrontier analysis of determinants of technical efficiency in beef farm types: an application to Botswana. *International Conference of Agricultural Economists* 1–32.

Bailey DW 2004 Management strategies for optimal grazing distribution and use of arid rangelands. *Journal of Animal Science*. 82 E-Suppl 147–153.

Bailey DW, Dumont B & Wallis DeVries MF 1998 Utilization of heterogeneous grasslands by domestic herbivores: Theory to management. *Annales de Zootechnie* 47 321–333.

Baldocchi D, Chu H & Reichstein M 2018 Inter-annual variability of net and gross ecosystem carbon fluxes: A review. *Agricultural and Forest Meteorology* 249 520–533.

Bank L & Qambata L 1999 No Visible Means of Subsistence: Rural Livelihoods, Gender and Social Change in Mooiplaas, Eastern Cape 1950-1998. African Studies Centre Working Paper 34. Institute for Social and Economic Research, Grahamstown, South Africa

Barrett CB & Luseno WK 2004 Decomposing producer price risk: A policy analysis tool with an application to northern Kenyan livestock markets. *Food Policy* 29 393–405.

Battese GE & Coelli TJ 1992 Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis* 3 153–169.

Battese GE & Coelli TJ 1995 A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics* 20 325–332.

Baumont R, Prache S, Meuret M & Morand-Fehr P 2000 How forage characteristics influence behaviour and intake in small ruminants: A review. *Livestock Production Science* 64(1) 15–28.

Behnke R 2010 The Contribution of Livestock to the Economies of IGAD Member States: Study Findings, Application of the Methodology in Ethiopia and Recommendations for Further Work. IGAD LPI Working Paper No 2 1–45.

Behnke RH & Scoones I 1993 Rethinking Range Ecology: Implications for Rangeland Management in Africa. In *Range Ecology at Disequilibrium*, eds R.H. Behnke, I. Scoones & C. Kerven), pp. 1-30. Overseas Dev Institute, London

Beinart W 1984 Soil Erosion, Conservationism and Ideas about Development: A Southern African Exploration, 1900–1960. *Journal of Southern African Studies* 11 52–83.

Beinart W 2000 African history and environmental history. *African Affairs* 99 269–302.

Beinart W 2003 *The Rise of Conservation in South Africa: Settlers, Livestock and the Environment 1770-1950*. Oxford University Press, oxford, UK.

Beinart W, Ainslie A & Brown W 2013 Animal disease and the limits of local knowledge: dealing with ticks and tick-borne diseases in South Africa. *Journal of the Royal Anthropological Institute* 19 319–337.

Beinart W, McGregor J, Storey WK & Taylor P 2017 Environment, 1770-1950 by William Beinart; Social History and African Environments by Book Reviews. 1–4.

Bekele M, Mengistu A & Tamir B 2017 Livestock and feed water productivity in the mixed crop-livestock system. *Animal Production Science* 1–9.

Bembridge TJ 1987 Some aspects of household diet and family income problems in Transkei. *South African Medical Journal* 72 425–428.

Bembridge, T & Tapson, D., 1993. Communal livestock systems. In: *Livestock Production Systems – Principles and Practice*. Eds. Maree, C. and Casey N.H., Agri-Development Foundation, Brooklyn, Pretoria. pp. 361-373.

Bennett J 2003 Opportunities for Increasing Water Productivity of CGIAR Crops through Plant Breeding and Molecular Biology *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. *Water Productivity in Agriculture: Limits and Opportunities for Improvement* 1–24.

Bennett J, Ainslie A & Davis J 2010 Fenced in: Common property struggles in the management of communal rangelands in central Eastern Cape Province, South Africa. *Land Use Policy* 27 340–350.

Bennett J, Ainslie A & Davis J 2013 Contested institutions? Traditional leaders and land access and control in communal areas of Eastern Cape Province, South Africa. *Land Use Policy* 32 27–38.

Bennett JE, Palmer AR & Blackett MA 2012 Range degradation and land tenure change: insights from a ‘released’ communal area of Eastern Cape province, South Africa. *Land Degradation & Development* 23 557–568.

Blümmel M, Hailelassie A, Samireddypalle A, Vadez V & Notenbaert A 2014 Livestock water productivity: Feed resourcing, feeding and coupled feed-water resource data bases. *Animal Production Science* 54 1584–1593.

Blümmel M, Samad M, Singh OP & Amede T 2009 Opportunities and limitations of foodfeed crops for livestock feeding and implications for livestock water productivity. *Rangeland Journal* 31 207–212.

Bossio D, Geheb K & Critchley W v2010 Managing water by managing land: Addressing land degradation to improve water productivity and rural livelihoods. *Agricultural Water Management* 97 536–542.

Bouman BAM 2007 A conceptual framework for the improvement of crop water productivity at different spatial scales. *Agricultural Systems* 93 43–60.

Bransby DI & Tainton NM 1977 The disc pasture meter: Possible applications in grazing management. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa* 12 115–118.

Brown K, Ainslie A & Beinart W 2013 Animal disease and the limits of local knowledge: Dealing with ticks and tick-borne diseases in South Africa. *Journal of the Royal Anthropological Institute*.

Buitenwerf R, Bond WJ, Stevens N & Trollope WSW 2012 Increased tree densities in South African savannas: 50 years of data suggests CO<sub>2</sub> as a driver. *Global Change Biology* 18 675–684.

Burke M, Oleson K, McCullough E & Gaskell J 2009 A global model tracking water, nitrogen, and land inputs and Virtual transfers from industrialized meat production and trade. *Environmental Modelling and Assessment* 14 179–193.

Carter MR & May J 1999 Poverty, livelihood and class in rural South Africa. *World Development* 27 1–20.

Census 2011. Statistics South Africa. Government Printer, Pretoria.

Chapagain AK & Hoekstra AY 2003 Virtual water flows between nations in relation to trade in livestock and livestock products. *Water Science and Technology* 49 203–209.

Cid MS & Brizuela M A 1998 Heterogeneity in tall fescue pastures created and sustained by cattle grazing. *Journal of Range Management* 51 644–649.

Coelli TJ & Battese GE 1996 Identification of factors which influence the technical inefficiency of Indian farmers. *Australian Journal of Agricultural Economics* 40 103–128.

Cook SE, Andersson MS & Fisher MJ 2009 Assessing the importance of livestock water use in basins. *Rangeland Journal* 31 195–205.

Cousins B 1996 Livestock production and common property struggles in South Africa's agrarian reform. *Journal of Peasant Studies* 23 166–208.

Cousins B 1997 Conditions of Entry into the Red Meat Industry for Black Livestock Producers. Draft Report for Research Project on 'Restructuring Agriculture in South Africa': University of Natal.

Cousins B 1999 Invisible capital: The contribution of communal rangelands to rural livelihoods in South Africa. *Development Southern Africa* 16 299–318.

Dalle G, Maass BL & Isselstein J 2006 Encroachment of woody plants and its impact on pastoral livestock production in the Borana lowlands, southern Oromia, Ethiopia. *African Journal of Ecology* 44 237–246.

Danckwerts JE & Trollope WSW 1980 Assessment of the disc pasture meter on natural veld in the false thornveld of the eastern province. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa* 15 47–52.

De Wet, C. & Van Averbek, W 1995. Regional overview of land reform related issues in the Eastern Cape province. ARDRI/BRC/ISER, University of Fort Hare, Alice and Rhodes University, Grahamstown.

Delgado C 2005 Rising demand for meat and milk in developing countries: implications for grasslands-based livestock production. *Grassland: A Global Resource* 29–39.

Descheemaeker K, Amede T & Hailelassie A 2010 Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. *Agricultural Water Management* 97 579–586.

Descheemaeker K, Amede T, Hailelassie A & Bossio D 2011 Analysis of Gaps and Possible Interventions for Improving Water Productivity in Crop Livestock Systems of Ethiopia. *Experimental Agriculture* 47 21–38.

Descheemaeker K, Bunting SW, Bindraban P, Muthuri C, Molden D, Beveridge M, van Brakel M, Herrero M, Clement F, Boelee E et al. 2013 Increasing Water Productivity in Agriculture. *Managing Water and Agroecosystems for Food Security* 10 104–123.

Descheemaeker K, Mapedza E, Amede T & Ayalneh W 2010d Effects of integrated watershed management on livestock water productivity in water scarce areas in Ethiopia. *Physics and Chemistry of the Earth* 35 723–729.

Descheemaeker K, Nyssen J, Poesen J, Raes D, Haile M, Muys B & Deckers S 2006 Runoff on slopes with restoring vegetation: A case study from the Tigray highlands, Ethiopia. *Journal of Hydrology* 331 219–241.

Descheemaeker K, Raes D, Nyssen J, Poesen J, Haile M & Deckers J 2009 Changes in water flows and water productivity upon vegetation regeneration on degraded hillslopes in northern Ethiopia: A water balance modelling exercise. *Rangeland Journal* 31 237–249.

Descheemaeker K. b, Amede T. b & Hailelassie A. 2010c Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. *Agricultural Water Management* 97 579–586.

Dirmeyer PA 2011 A History and Review of the Global Soil Wetness Project (GSWP). *Journal of Hydrometeorology* 12 (5) 729-749

Donald GE, Trotter MG & Lamb DW 2010 Precision Livestock Management: An Example of Pasture Monitoring In Eastern Australian Pastures Using Proximal And Remote Sensing Tools Graham E. Donald 1,2. 10th International Conference on Precision Agriculture.

Dorrrough J, Yen A, Turner V, Clark SG, Crosthwaite J, & Hirth JR 2004. Livestock grazing management and biodiversity conservation in Australian temperate grassy landscapes. *Australian Journal of Agricultural Research* 55 (3) 279–295.

Dougherty ER, de Valpine P, Carlson CJ, Blackburn JK & Getz WM 2018 Commentary to: A cross-validation-based approach for delimiting reliable home range estimates. *Movement Ecology*.6 (1) 10

Dovie DBK, Shackleton CM & Witkowski ETF 2006 Valuation of communal area livestock benefits, rural livelihoods and related policy issues. *Land Use Policy* 23 260–271.

Dovie DBK, Shackleton CM & Witkowski TF 2002 Direct-use values of woodland resources consumed and traded in a South African village. *International Journal of Sustainable Development & World Ecology* 9 269–283.

Duncan AJ, Bachewe F, Mekonnen K, Valbuena D, Rachier G, Lule D, Bahta M & Erenstein O 2016 Crop residue allocation to livestock feed, soil improvement and other uses along a productivity gradient in Eastern Africa. *Agriculture, Ecosystems and Environment* 228 101–110.

Ebanyat P, de Ridder N, de Jager A, Delve RJ, Bekunda MA & Giller KE 2010 Drivers of land use change and household determinants of sustainability in smallholder farming systems of Eastern Uganda. *Population and Environment* 31 474–506.

Elbourne E 1993 White Supremacy and black resistance in pre-industrial South Africa: The making of the colonial order in the eastern cape. *Journal of Southern African Studies* 19 338–341.

Ellis F & Bahigwa G 2003 Livelihoods and rural poverty reduction in Uganda. *World Development* 31 997–1013.

Ellis J & Galvin KA 1994 Climate Patterns and Land-Use Practices in the Dry Zones of Africa. *Bio Science* 44 340–349.

Eswaran H, Lal R & Reich PF 2001 Land degradation: An overview. *Response to Land Degradation* 20–35.

Everson CS & Everson T 2016 The long-term effects of fire regime on primary production of montane grasslands in South Africa. *African Journal of Range and Forage Science* 33 33–41.

Everson CS, Dye PJ, Gush MB & Everson TM 2011 Water use of grasslands, agroforestry systems and indigenous forests. *Water SA* 37 781–788.

Falkenmark M, Finlayson CM & Gordon LJ 2007 Agriculture, water, and ecosystems: avoiding the costs of going too far. *Water for Food, Water for Life - A Comprehensive Assessment of Water Management in Agriculture* 233–277.

FAO 2011 Part 1: Principles of Farmer Field School. In *Farmer Field School Implementation Guide: Farm Forestry and Livelihood Development*, pp 25–38.

Flombaum P & Sala OE 2007 A non-destructive and rapid method to estimate biomass and aboveground net primary production in arid environments. *Journal of Arid Environments* 69 352–358.

Fritz H & Duncan P 1994 On the carrying capacity for large ungulates of African savanna ecosystems. *Proceedings of the Royal Society: Biological Sciences* 256 77–82.

Frost AR, Schofield CP, Beulah A, Mottram TT, Lines JA, Wathes CM 1997 A review of livestock monitoring and the need for integrated systems *Computers and Electronics in Agriculture* 17 (1997) 139-159

Fuhlendorf SD & Engle DM 2001 Restoring Heterogeneity on Rangelands: Ecosystem Management Based on Evolutionary Grazing Patterns. *Bio Science* 51 625.

Fuls ER 1992 Semi-arid and arid rangelands: a resource under siege due to patch-selective grazing. *Journal of Arid Environments* 22 191–193.

Fynn RWS & O' Connor TGO 2000 Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. 491–507.

Ganskopp DC & Bohnert DW 2009 Landscape nutritional patterns and cattle distribution in rangeland pastures. *Applied Animal Behaviour Science* 116 110–119.

Garrity D, Dixon J & Boffa J-M 2012 Understanding African Farming Systems. *Science and Policy Implications. Food Security in Africa. Bridging Research and Practice.*

Gebreselassie S, Peden D, Haileslassie A & Mpairwe D 2009 Factors affecting livestock water productivity: Animal scale analysis using previous cattle feeding trials in Ethiopia. *Rangeland Journal* 31 251–258.

Getz WM & Wilmers CC 2004 A local nearest-neighbour convex-hull construction of home ranges and utilization distributions. *Ecography* 27 489–505.

Giger-Reverdin S & Gihad EA 1991 Water metabolism and intake in goats. *Goat Nutrition* 37 4-27

Gillen RL, Krueger WC & Miller RF 1984 Cattle Distribution on Mountain Rangeland in Northeastern Oregon. *Journal of Range Management* 37 549.

Glenn EP, Huete AR, Nagler PL, Hirschboeck KK & Brown P 2007 Integrating Remote Sensing and Ground Methods to Estimate Evapotranspiration. *Critical Reviews in Plant Sciences* 26 139–168.

Groenewald, JA, Machete, CL and Sartorius Von Bach, HJ. 1992. Government and agriculture in the new South Africa. *Development Southern Africa*, 9 383–90.

Gwate O 2018 Modelling Plant Water Use of the Grassland and Thicket Biomes in the Eastern Cape, South Africa: Towards an Improved Understanding of the Impact of Invasive Alien Plants on Soil Chemistry, Biomass Production and Evapotranspiration. PhD Thesis. Rhodes University. 304.

Gwate O, Mantel S. K., Palmer, A. R. GL. 2016 Measuring evapotranspiration using an eddy covariance system over a subtropical thicket of the Eastern Cape, South Africa, SPIE draft paper. In SPIE Remote Sensing for Agriculture, Ecosystems, and Hydrology XVIII, p 99980S.

Gwate O, Mantel SK, Palmer AR & Gibson LA 2016b Measuring evapotranspiration using an eddy covariance system over the Albany Thicket of the Eastern Cape, South Africa. 9998 99980S.

Gwelo FA 2012 Farmers' perceptions of livestock feeding and rangeland management; dynamics of soil , forage and cattle blood serum mineral levels in two communal areas of the

Eastern Cape , South Africa By Farmers ' perceptions of livestock feeding and rangeland management. Msc Thesis. University of Fort Hare.

Hadiwidjaja G & Suryahadi A 2011 The Role of Agriculture in Poverty Reduction in Indonesia. SMERU Research Institute.

Hailelassie A, Blümmel M, Clement F, Descheemaeker K, Amede T, Samireddypalle A, Acharya NS, Radha A. V, Ishaq S, Samad M 2011 Assessment of the Livestock-Feed and Water Nexus Across a Mixed Crop-Livestock System's Intensification Gradient: An Example From the Indo-Ganga Basin. *Experimental Agriculture* 47 113–132.

Hailelassie A, Peden D, Gebreselassie S, Amede T & Descheemaeker K 2009a Livestock water productivity in mixed crop-livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement. *Agricultural Systems* 102 33–40

Hailelassie A, Peden D, Gebreselassie S, Amede T, Wagnew A & Tadesse G 2009b Livestock water productivity in the Blue Nile Basin: Assessment of farm scale heterogeneity. *Rangeland Journal* 31 213–222.

Hardin G 1968 The tragedy of the commons. *Science (New York, N.Y.)* 162 1243–1248.

Harris NR, Johnson DE, McDougald NK & George MR 2007 Social Associations and Dominance of Individuals in Small Herds of Cattle. *Rangeland Ecology & Management* 60 339–349.

Hoekstra AY, Chapagain AK, Aldaya MM & Mekonnen MM 2009 Water Footprint Manual State of the Art 2009. Water Footprint Network 131.

Hoeve E V. & Koppen B Van 2005 Beyond fetching water for livestock: A gendered sustainable livelihood framework to assess livestock-water productivity. Nile Basin Water Productivity: Developing a Shared Vision for Livestock Production, a Workshop of the CGIAR Challenge Program on Water & Food (CPWF) 1–27.

Holechek JL, RD Pieper, Herbel CH. 1998. Range management principles and practices. Upper Saddle River (NJ): Prentice Hall, New Jersey.

Justice CO, Townshend JRG, Vermote EF, Masuoka E, Wolfe RE, Saleous N, Roy DP & Morisette JT 2002 An overview of MODIS Land data processing and product status. *Remote Sensing of Environment* 83 3–15.

Kebebe EG, Oosting SJ, Hailelassie A, Duncan AJ & de Boer IJM 2015a Strategies for improving water use efficiency of livestock production in rain-fed systems. *Animal* 9 908–916.

Kebebe EG, Oosting SJ, Hailelassie A, Duncan AJ & de Boer IJM 2015b Strategies for improving water use efficiency of livestock production in rain-fed systems. *Animal: An International Journal of Animal Bioscience* 9 908–916.

Keller A & Seckler D 2004 Limits to Increasing the Productivity of Water in Crop Production. Winrock Water, Arlington 1–20.

Kepe T 2002 The dynamics of cattle production and government intervention in communal areas of Lusikisiki district. In *Cattle Ownership and Production in the Communal Areas of the Eastern Cape, South Africa*, pp 59–79. Ed A Ainslie. Cape Town: Programme for Land and Agrarian Studies, University of the Western Cape.

Knyazikhin Y, Martonchik J V., Myneni RB, Diner DJ & Running SW 1998 Synergistic algorithm for estimating vegetation canopy leaf area index and fraction of absorbed photosynthetically active radiation from MODIS and MISR data. *Journal of Geophysical Research* 103 32257.

Koutsoyiannis D 2003 Climate change, the Hurst phenomenon, and hydrological statistics. *Hydrological Sciences Journal* 48 3–24.

Kumar S, Ansari MQ, Naresh RK & Kumar V 2014 Integrating crop and livestock management for enhanced productivity, profitability and sustainability of the rice-wheat system in North West India. *International Journal of Life Sciences Biotechnology and Pharma Research* 3 74–84.

Kumbhakar SC, Ghosh S & McGuckin TJ 1991 A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Dairy Farms. *Journal of Business and Economic Statistics* 9 279–286.

Kumbhakar SC, Lien G & Hardaker JB 2014 Technical efficiency in competing panel data models: A study of Norwegian grain farming. *Journal of Productivity Analysis* 41 321–337.

Kunene NW 2010 Characterisation of indigenous Zulu (Nguni) sheep for utilisation, improvement and conservation. 132.

La S, Del B & Hamsom M 1987 Understanding the normalized difference vegetation index (NDVI). *Physical Oceanography* 2–5.

Lahiff EL 1997 Agriculture and rural livelihoods in a South African 'homeland': A case study from Venda. Unpublished PhD Thesis. Department of Development Studies, School of Oriental and African Studies, London.

Launchbaugh KL & Howery LD 2005 Understanding landscape use patterns of livestock as a consequence of foraging behaviour. *Rangeland Ecology and Management* 58 99–108.

Le Dantec V, Dufrêne E & Saugier B 2000 Interannual and spatial variation in maximum leaf area index of temperate deciduous stands. *Forest Ecology and Management* 134 71–81.

Leuning R, Zhang YQ, Rajaud A, Cleugh H & Tu K 2009 A simple surface conductance model to estimate regional evaporation using MODIS leaf area index and the Penman-Monteith equation (vol 45, W10419, 2008). *Water Resources Research* 45.

Lewis J 1984 The rise and fall of the south african peasantry: A critique and reassessment. *Journal of Southern African Studies* 11 1–24.

Lloyd JW, van den Berg E. & Palmer A. 2002 Patterns of transformation and degradation in the Thicket Biome, South Africa. *Terrestrial Ecology Research Unit* 1–88.

Ludwig JA, Wilcox BP, Breshears DD, Tongway DJ & Imeson AC 2005 Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology* 86 288–297.

Lyons A 2014 T-LoCoH for R Tutorial and Users Guide. In *Source Forge*, pp 1–55.

Lyons A, Turner WC & Getz W 2013a Home range plus: A space-time characterization of movement over real landscape *Movement Ecology* 1 1–10.

Lyons AJ, Turner WC & Getz WM 2013b Home range plus: a space-time characterization of movement over real landscapes. *Movement Ecology* 1 2.

Lyons RK & Machen R V. 2001 Livestock Grazing Distribution: Considerations and Management. *System* 1–6.

Makinde EA & Ayoola OT 2012 Comparative growth and yield of okra with cowdung and poultry manure. *American-Eurasian Journal of Sustainable Agriculture* 6 18–23.

Masika P 2004 Aspects of goat farming in the communal farming systems of the central Eastern Cape, South Africa. *Small Ruminant Research* 52 161–164.

Masuku MB & Sihlongonyane MD 2015 Economic Analysis of the Milk Supply Chain in Swaziland. *Food Science and Quality Management* 45.

McAllister MP 1992 Comic Books and AIDS. *Journal of Popular Culture* 26 1–24 ST–Comic Books and AIDS.

McAuliffe JR. 2003. The atmosphere-biosphere interface: the importance of soils in arid and semi-arid environments. In: Weltzin JF, McPherson GR (eds) *Changing precipitation regimes and terrestrial ecosystems: A North American Perspective*. University of Arizona Press, Tucson.

McDermott JJ, Staal SJ, Freeman HA, Herrero M & de Steeg JA Van 2010 Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science* 130 95–109.

McNaughton SJ 1985 Ecology of a grazing ecosystem: The Serengeti. *Ecological Monographs* 55 259–294.

McNaughton SJ, Oesterheld M, Frank DA & Williams KJ 1989 Ecosystem-level patterns of primary productivity and herbivory in terrestrial habitats. *Nature* 341 142–144.

Meadows ME & Hoffman MT 2002 The nature, extent and causes of land degradation in South Africa: Legacy of the past, lessons for the future. *Area* 34 428–437.

Meeusen & Julien Van Den Broeck 1977 Efficiency Estimation from Cobb-Douglas Production Functions With Composed Error. *International Economic Review* 18 23 435–444.

Mekonnen S, Descheemaeker K, Tolera A & Amede T 2011 Livestock Water Productivity in a Water Stressed Environment in Northern Ethiopia. *Experimental Agriculture* 47 85–98.

Milchunas DG & Lauenroth WK 1993 Quantitative Effects of Grazing on Vegetation and Soils Over a Global Range of: *Ecological Monographs* Ecological Monographs Lauenroth Ecological Monographs 63 327–366.

Millennium Ecosystem Assessment, 2005. *Assessments: Global Environment Facility; United Nations Foundation; The David and Lucile Packard Foundation, New York.*

Milton SJ 2004 Grasses as invasive alien plants in South Africa. *South African Journal of Science* 100 69–75.

Mlote S, Mdoe N, Isinika A & Mtenga L 2013 Estimating Technical Efficiency of Small Scale Beef Cattle Fattening in the Lake Zone in Tanzania. *Journal of Development and Agricultural Economics* 5 197–207.

Mo X, Liu S, Lin Z & Zhao W 2004 Simulating temporal and spatial variation of evapotranspiration over the Lushi basin. *Journal of Hydrology* 285 125–142.

Molden D & Sakthivadivel R 1999 Water Accounting to Assess Use and Productivity of Water. *International Journal of Water Resources Development* 15 55–71.

Molden D, De Fraiture C & Rijsbfrman F 2007a Water scarcity: The food factor. *Issues in Science and Technology* 23 39–48.

Molden D, Oweis T, Steduto P, Kijne JW, Hanjra MA & Bindraban PS 2007b Pathways for increasing agricultural water productivity. *Water for Food, Water for Life. A Comprehensive Assessment of Water Management in Agriculture* 21 278–310.

Moll H a J 2005 Costs and benefits of livestock systems and the role of market and nonmarket relationships. *Agricultural Economics* 32 181–193.

Mtshali SM 2002 Household Livelihood Security in Rural KwaZulu-Natal, South Africa.

Mucina L & Rutherford MC 2006 Vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19 1–807.

Muldavin EH, Moore DI, Collins SL, Wetherill KR & Lightfoot DC 2008 Aboveground net primary production dynamics in a northern Chihuahuan Desert ecosystem. *Oecologia* 155 123–132.

Münch Z, Okoye P, Gibson L, Mantel S & Palmer A 2017 Characterizing Degradation Gradients through Land Cover Change Analysis in Rural Eastern Cape, South Africa. *Geosciences*.

Nardone a., Ronchi B, Lacetera N, Ranieri MS & Bernabucci U 2010 Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science* 130 57–69.

Norton BE, Barnes M & Teague R 2013 Grazing Management Can Improve Livestock Distribution. *Rangelands* 35 45–51.

Nowers CB, Nobumba LM & Welgemoed J 2013 Reproduction and production potential of communal cattle on sourveld in the Eastern Cape Province, South Africa. *Applied Animal Husbandry & Rural Development* 6 48–54.

O'Connor TG 2008 Influence of land use on plant community composition and diversity in Highland Sourveld grassland in the southern Drakensberg, South Africa. *African Journal of Range and Forage Science* 25 17–27.

O'Reagain PJ & Turner JR 1992 An evaluation of the empirical basis for grazing management recommendations for Rangeland in Southern Africa. *Journal of the Grassland Society of Southern Africa* 9 38–49.

Odadi WO & Rubenstein DI 2015 Herd Size-Dependent Effects of Restricted Foraging Time Allowance on Cattle Behavior, Nutrition, and Performance. *Rangeland Ecology and Management* 68 341–348.

Odadi WO, Fargione J & Rubenstein DI 2017 Vegetation, Wildlife, and Livestock Responses to Planned Grazing Management in an African Pastoral Landscape. *Land Degradation and Development* 28 2030–2038.

Odadi WO, Riginos C & Rubenstein DI 2018 Tightly Bunched Herding Improves Cattle Performance in African Savanna Rangeland. *Rangeland Ecology and Management*.

Otieno DJ, Hubbard L & Ruto E 2014 Assessment of technical efficiency and its determinants in beef cattle production in Kenya. *Journal of Development and Agricultural Economics* 6 267–278.

Otte J & Chilonda P 2003 Classification of cattle and small ruminant production systems in Sub-Saharan Africa. *Outlook on Agriculture* 32 183–190.

Overton J 1996 An introduction to sustainable development: The developing world. *Journal of Rural Studies* 12 89–90.

Palmer AR & Ainslie A 2009 Using rain-use efficiency to explore livestock production trends in rangelands in the Transkei, South Africa. *African Journal of Range & Forage Science* 24 43–49.

Palmer AR & Bennett JE 2013 Degradation of communal rangelands in South Africa: towards an improved understanding to inform policy. *African Journal of Range & Forage Science* 30 57–63.

Palmer AR, Finca A, Mantel SK, Gwate O, Münch Z & Gibson LA 2017 Determining fPAR and leaf area index of several land cover classes in the Pot River and Tsitsa River catchments of the Eastern Cape, South Africa. *African Journal of Range and Forage Science* 34 33–37.

Palmer AR, Short A & Yunusa IAM 2010 Biomass production and water use efficiency of grassland in KwaZulu-Natal, South Africa. *African Journal of Range & Forage Science* 27 163–169.

Palmer AR, Weideman C, Finca A, Everson CS, Hanan N & Ellery W 2014 Modelling annual evapotranspiration in a semi-arid, African savanna: functional convergence theory, MODIS LAI and the Penman-Monteith equation. *African Journal of Range & Forage Science*, 32(1), 33-39.

Palmer AR, Weideman C, Finca A, Everson CS, Hanan N & Ellery W 2015 Modelling annual evapotranspiration in a semi-arid, African savanna: functional convergence theory, MODIS LAI and the Penman–Monteith equation. *African Journal of Range & Forage Science* 32 33–39.

Peden D, Freeman A, Astatke A & Notenbaert A 2006 Investment Options for Integrated Water-Livestock-Crop Production in Sub-Saharan Africa. In ILRI Research Paper.

Peden D, Tadesse G & Hailelassie A 2009 Livestock water productivity: Implications for sub-Saharan Africa. *Rangeland Journal* 31 187–193.

Peden D, Tadesse G & Mammo M 2003 Improving the water productivity of livestock: an opportunity for poverty reduction. IN: In *Integrated Water and Land Management Research and Capacity Building Priorities for Ethiopia.*, pp 57–65.

Peden D, Tadesse G, Misra a. K, Ahmed F a., Astatke A, Ayalneh W, Herrero M, Kiwuwa G, Kumsa T, Mati B et al. 2007 Water and livestock for human development. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* 485–514.

Pica-Ciamarra U, Tasciotti L, Otte J & Zezza A 2011 Livestock Assets, Livestock Income and Rural Households: Cross-Country Evidence from Household Surveys. In *World Bank*.

Reid RS, Galvin KA & Kruska RS 2008 Global significance of extensive grazing lands and pastoral societies: An introduction. *Fragmentation in Semi-Arid and Arid Landscapes: Consequences for Human and Natural Systems* 1–24.

Richardson FD, Hahn BD & Hoffman MT 2007 Modelling the sustainability and productivity of pastoral systems in the communal areas of Namaqualand. *Journal of Arid Environments* 70 701–717.

Ritzema RS 2014 Aqueous Productivity: An enhanced productivity indicator for water. *Journal of Hydrology* 517 628–642.

Russell M 1993 Are Households Universal? On Misunderstanding Domestic Groups in Swaziland. *Development and Change* 24 755–785.

Saeed I a. M & El-Nadi a. H 1998 Forage sorghum yield and water use efficiency under variable irrigation. *Irrigation Science* 18 67–71.

Sala OE & Austin AT 2000 Methods of estimating aboveground net primary productivity. *Methods in Ecosystem Science* 31–43.

Salem HB, Smith T. 2008 Feeding strategies to increase small ruminant production in dry environments. *Small ruminant research*. 77(2-3) 174-94.

Samuels I, Allsopp N & Hoffman MT 2013 How could herd mobility be used to manage resources and livestock grazing in semi-arid rangeland commons? *African Journal of Range and Forage Science*. 30 (1-2) 85-89.

Samuels MI, Allsopp N & Knight RS 2007 Patterns of resource use by livestock during and after drought on the commons of Namaqualand, South Africa. *Journal of Arid Environments* 70 728–739.

Scheffer-Basso SM, Cecchin K & Favaretto A 2016 Dynamic of dominance, growth and bromatology of *Eragrostis plana* Nees in secondary vegetation area1. *Revista Ciencia Agronomica* 47 582–588.

Schieltz JM, Okanga S, Allan BF & Rubenstein DI 2017 GPS tracking cattle as a monitoring tool for conservation and management. *African Journal of Range & Forage Science* 34 173–177.

Schlecht E, Hülsebusch C, Mahler F & Becker K 2004 The use of differentially corrected global positioning system to monitor activities of cattle at pasture. *Applied Animal Behaviour Science* 85 185–202.

Schmidt–Soltau K, 2003 Conservation–related Resettlement in Central Africa: Environmental and Social Risks. *Development and Change*, 34: 525-551.

Schulze RE, Maharaj M, Warburton ML, Gers CJ, Horan MJC, Kunz RP & Clark DJ 2008 South African atlas of climatology and agrohydrology. Water Research Commission, Pretoria, RSA. WRC Report 1489 8.

Scogings P, de Bruyn T & Vetter S 1999 Grazing into the future: Policy making for South African communal rangelands. In *Development Southern Africa*, pp 403–414.

Scoones I 1992 Coping with drought: Responses of herders and livestock in contrasting savanna environments in Southern Zimbabwe. *Human Ecology* 20 293–314.

Seckler D, Molden D & Sakthivadivel R 2003 The Concept of Efficiency in Water- resources Management and Policy. *Water Productivity in Agriculture: Limits and Opportunities for Improvement* 1 37–51.

Sellers PJ, Dickinson RE, Randall DA, Betts AK, Hall FG, Berry JA, Collatz GJ, Denning AS, Mooney HA, Nobre CA et al. 1997 Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. *Science* 275 502–509.

Senda TS, Peden D, Tui SH-K, Sisito G, Van Rooyen AF & Sikosana JLN 2011 Gendered Livelihood Implications For Improvements Of Livestock Water Productivity In Zimbabwe. *Experimental Agriculture* 47 169–181.

Shackleton CM & Shackleton SE 2000 Direct use values of secondary resources harvested from communal savannas in the Bushbuckridge lowveld, South Africa. *Journal of Tropical Forest Products* 6 28–47.

Shackleton CM, Shackleton SE & Cousins B 2001 The role of land-based strategies in rural livelihoods: The contribution of arable production, animal husbandry and natural resource harvesting in communal areas in South Africa. *Development Southern Africa* 18 581–604.

Shackleton S, Shackleton C & Cousins B 2000 Re-valuing the Communal Lands of Southern Africa: New Understandings of Rural Livelihoods. *Natural Resource Perspectives* 1–4.

Shackleton S, Shackleton C, Mander M, Wynberg R, Sullivan C & Leakey R 2003 Diversifying communal rangeland use and benefits: the case of Marula (*Sclerocarya birrea*) in Bushbuckridge, South Africa. In *International Rangeland Congress: Rangelands in the New Millennium*, pp 1–7.

Shackleton SE, Shackleton CM, Netshiluvhi TR, Geach BS, Ballance A & Fairbanks DHK 2002 Use Patterns and Value of Savanna Resources in Three Rural Villages in South Africa. *Econ.Bot.* 56 130–146.

Sirohi SK, Karim SA & Misra AK 1997 Nutrient intake and utilisation in sheep fed with prickly pear cactus. *Journal of Arid Environments* 36 161–166.

Sisito G, Chinofunga PT, Sikosana J, Govere WD, Rooyen AF Van & Charumbira WF 2012 Farmer's Resource Flow Decisions on Farm-Level Interventions on Livestock Water Productivity: A Conceptual Model Approach. *International Journal of Mathematical Archive* 3 1336–1341.

Smit W 1998 The rural linkages of urban households in Durban, South Africa. *Environment and Urbanization* 10 77–88.

Snyman HA 1994 Evapotranspiration, water-use efficiency and quality of six dryland planted pasture species and natural vegetation, in a semi-arid rangeland. *African Journal of Range and Forage Science* 11 82–88.

Sonder K, Abiye A, Ahmed EW, David M, Don P, Astatke A, El Wakeel A, Molden D & Peden D 2003 Strategies for increasing livestock water productivity in water stressed agricultural systems. *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. CAB International: Wallingford, UK.

Steinfeld H 2004 The livestock revolution - A global veterinary mission. In *Veterinary Parasitology*, pp 19–41.

Steinfeld H, Gerberm P, Wassenaar T, Castel V, Rosales M & de Haan C 2006 Livestock's long shadow - environmental issues and options. *Food and Agriculture Organization of the United Nations* 3 1–377.

Stephenson MB, Bailey DW & Jensen D 2016 Association patterns of visually-observed cattle on Montana, USA foothill rangelands. *Applied Animal Behaviour Science* 178 7–15.

Stuth JW. 1991. Foraging behavior. Pages 65–83 in Stuth JW, Heitschmidt RK, eds. *Grazing Management: An Ecological Perspective*. Portland (OR): Timber Press/Elmhurst Institute, London, UK.

Tada O, Muchenje V & Dzama K 2012 Monetary value, current roles, marketing options, and farmer concerns of communal Nguni cattle in the Eastern Cape Province, South Africa. *African Journal of Business Management* 6 11304–11311.

Taddese G 2003 Increasing Water Productivity: Livestock for food security and poverty alleviation. *International Livestock Research Institute (IRLI)* 2050 1–23.

Tapson D 1997 Livestock production and services. In Unpublished Submission to the National Department of Agriculture Green Paper on Agricultural Policy.

Tarawali S, Herrero M, Descheemaeker K, Grings E & Blmmel M 2011 Pathways for sustainable development of mixed crop livestock systems: Taking a livestock and pro-poor approach. *Livestock Science* 139 11–21.

Thomas D 2000 Increasing livestock productivity in mixed crop-livestock systems in south Asia. In *Proceedings of a Planning Workshop of Regional Stakeholders, ICRISAT, Patancheru, India, 15-17 Nov 1999.*, p 185 pp.

Thornton PK 2010 Livestock production: recent trends, future prospects. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 365 2853–2867.

Tian H, Chen G, Liu M, Zhang C, Sun G, Lu C, Xu X, Ren W, Pan S & Chappelka A 2010 Model estimates of net primary productivity, evapotranspiration, and water use efficiency in the terrestrial ecosystems of the southern United States during 1895-2007. *Forest Ecology and Management* 259 1311–1327.

Tolga T, Nural Y, Mehmet N & Bahattin Ç 2009 Measuring the technical efficiency and determinants of efficiency of rice (*Oryza sativa*) farms in Marmara region, Turkey. *New Zealand Journal of Crop and Horticultural Science* 37 121–129.

Tomkin N and O'Reagain P 2007 Global positioning systems indicate landscape preferences of cattle in the subtropical savannas *Rangeland Journal* 29 217–222

Tomkins N 2015 Global positioning systems indicate landscape preferences of cattle in the subtropical savannas (January 2007)

Tongway, David J.; Ludwig J a. 1996 Rehabilitation of Semiarid Landscape in Australia I. Restoring Productive Soil Patches. *Restoration Ecology* 4 388–397.

Trollope WSW, Potgieter ALF & Zambatis N 1989 Assessing veld condition in the Kruger National Park using key grass species. *Koedoe* 32 67–93.

Turner LW, Udal MC, Larson BT, & Shearer SA 2000 Monitoring cattle behavior and pasture use with GPS and GIS. *Canadian Journal of Animal Science* 80 (3) 405–413.

van Breugel P, Herrero M, van de Steeg J & Peden D 2010 Livestock water use and productivity in the Nile basin. *Ecosystems* 13 205–221.

Vandandorj S, Gantsetseg B & Boldgiv B 2015 Spatial and temporal variability in vegetation cover of Mongolia and its implications. *Journal of Arid Land* 7 450–461.

Veblen KE, Porensky LM, Riginos C & Young TP 2016 Are cattle surrogate wildlife? Savanna plant community composition explained by total herbivory more than herbivore type. *Ecological Applications* 26 1610–1623.

Vetter S 2005 Rangelands at equilibrium and non-equilibrium: recent developments in the debate. *Journal of Arid Environments* 62 321–341.

Vetter S 2013a Development and sustainable management of rangeland commons: aligning policy with the realities of South Africa's rural landscape. *African Journal of Range & Forage Science* 30 1–9.

Waters-Bayer A & Bayer W 2009 Enhancing local innovation to improve water productivity in croplivestock systems. *Rangeland Journal* 31 231–235.

Wesseling JG & Feddes RA 2006 Assessing crop water productivity from field to regional scale. *Agricultural Water Management* 86 30–39.

Whaley SE, Sigman M, Neumann C, Bwibo N, Guthrie D, Weiss RE, Alber S & Murphy SP 2003 Animal Source Foods to Improve Micronutrient Nutrition and Human Function in Developing Countries. *Journal of Nutrition* 133 3965–3971.

Wight JR, Skiles JW (eds). 1987. SPUR: Simulation of production and utilization of rangelands: documentation and user guide, ARS-63. Washington, DC: Agricultural Research Service, US Department of Agriculture.

Wilcox BP, Sorice MG & Young MH 2011 Dryland Ecohydrology in the Anthropocene: Taking Stock of Human-Ecological Interactions. *Geography Compass* 5 112–127.

Williams DG, Cable W, Hultine K, Hoedjes JCB, Yopez EA, Simonneaux V, Er-Raki S, Boulet G, De Bruin HAR, Chehbouni A et al. 2004 Evapotranspiration components determined by stable isotope, sap flow and eddy covariance techniques. *Agricultural and Forest Meteorology* 125 241–258.

Williams TO 1997 Problems and prospects in the utilization of animal traction in semi-arid west Africa: Evidence from Niger. *Soil and Tillage Research* 42 295–311.

Wilson RT 2007 Perceptions, practices, principles and policies in provision of livestock water in Africa. *Agricultural Water Management* 90 1–12.

Yapi TS, O’Farrell PJ, Dziba LE & Esler KJ 2018 Alien tree invasion into a South African montane grassland ecosystem: impact of *Acacia* species on rangeland condition and livestock carrying capacity. *International Journal of Biodiversity Science, Ecosystem Services & Management* 14 105–116.

Yisehak K 2008 Gender responsibility in smallholder mixed crop-livestock production systems of Jimma zone, South West Ethiopia. *Livestock Research for Rural Development* 20.

Zeppel M 2013 Convergence of tree water use and hydraulic architecture in water-limited regions: A review and synthesis. *Ecohydrology* 6(5) 889-900.

Zerfu, F., Mohhamed, S., Led, A (eds). 2010. *Community based rangeland management: A Manual*. Somali Region Livestock, Crop and Rural development Bureau, Jijiga, Ethiopia.

Zhang P, Anderson B, Barlow M, Tan B & Myneni RB 2004 Climate-related vegetation characteristics derived from Moderate Resolution Imaging Spectroradiometer (MODIS) leaf area index and normalized difference vegetation index. *Journal of Geophysical Research D: Atmospheres* 109.

Zhang Y, Peña-Arancibia JL, McVicar TR, Chiew FHS, Vaze J, Liu C, Lu X, Zheng H, Wang Y, Liu YY et al. 2016 Multi-decadal trends in global terrestrial evapotranspiration and its components. *Scientific Reports* 6 1–12.

## Appendix

### Appendix 1. Example R script to sort and re-process raw Catlog collar data to correct time zone, projection and analysis using T-locoh

```
#This R application has been put together to import the logging data from the CatLog  
GPS sensor
```

```
#into the t-locoh package.
```

```
#Some of the most important first steps are to get the data from the logger into a  
*.TAB file
```

```
#which is placed in the following directory c:/Program  
Files/R/R3.1.1/libraries/datasets/data.
```

```
#Alternatively, you can use the R command
```

```
#setwd ("c:\\Users\\gushab\\Documents\\catlog\\data\\R")
```

```
#Installing t-locoh
```

```
local({pkg <- select.list(sort(.packages(all.available = TRUE)),graphics=TRUE)
```

```
+ if(nchar(pkg)) library(pkg, character.only=TRUE)})
```

```
utils:::menuInstallPkgs()
```

```
dep.pkg <- c("pbapply", "sp", "FNN", "rgeos", "rgdal", "maptools", "png")
```

```
pkgs.not.installed <- dep.pkg[!sapply(dep.pkg, function(p) require(p,  
character.only=T)]]
```

```
install.packages(pkgs.not.installed, dependencies=TRUE)
```

```
#The downloaded binary packages are in
```

```
### C:\Users\gushab\AppData\Local\Temp\RtmpQJyPit\downloaded_packages
```

```
#utils:::menuInstallLocal()
```

```
#Sorting Catlog GPS collar data (in TAB format) into new time zone and day/time  
segments
```

```
library(lubridate)
```

```
library(plyr)
```

#If you want to use a separate directory for all your work, then you need to edit the line

#beginning 'setwd' and make sure the path is correct. If you don't want to do that and just use

#the default 'R' directory make sure \*.TAB file in c:/Program Files/R/R3.1.3/library/datasets/data

#Import TAB file with GPS points and attributes created by Catlog Software

```
catlog01<-
```

```
read.table("c:/Users/gushab/Documents/catlog/data/R/ARC03/ARC03.tab",
```

```
header=TRUE, sep="\t", na.strings="NA", dec=".", strip.white=TRUE)
```

```
head(catlog01, 200)
```

```
tail(catlog01)
```

#Remove missing (zero) GPS positions. This selects only those Latitudes with #values < 0, in other words all negative Latitudes.

```
catlog01 = catlog01[catlog01$Latitude < -31.521,]
```

```
catlog01 = catlog01[catlog01$Latitude > -31.5413,]
```

```
catlog01 = catlog01[catlog01$Longitude < 27.819,]
```

```
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/lat_long.pdf")
```

```
plot(catlog01[, c("Longitude", "Latitude")], pch=20)
```

```
dev.off()
```

#Remove any high speed values (while the GPS was in a moving car)

```
#catlog01 = catlog01[catlog01$Speed < 5.0,]
```

#Merge data and time columns and convert to POSIXct

```

catlog01$datetime <- paste(catlog01$Date,catlog01$Time)
catlog01$datetime <- as.POSIXct(strptime(as.character(catlog01$datetime), format =
"%m/%d/%Y %H:%M:%S", tz = "GMT"))
head(catlog01, 200)
tail(catlog01)

# Convert GMT to Africa time
catlog01.gmt <- as.POSIXct(catlog01$datetime, tz="GMT")
catlog01.gmt[1:3]
local.tz <- "Africa/Johannesburg"
catlog01$localtime <- as.POSIXct(format(catlog01.gmt, tz=local.tz), tz=local.tz)
head(catlog01, 200)
tail(catlog01)

class(catlog01$localtime)

catlog01$localtime[1:6]

#Segment time series into desired segments
#Separate into night and day
day <- with(catlog01, catlog01[hour(localtime) >= 6 & hour(localtime) < 18 , ])
head(day, 200)

#night1 <- with(catlog01, catlog01[hour(localtime) >= 18, ])
#night2 <- with(catlog01, catlog01[hour(localtime) <= 6, ])
#night<- rbind(night1, night2)
#night<- arrange(night, TEMP)
#night<- arrange(night, localtime)
#night<- arrange(night, TEMP)
#head(night, 30)

```

```

#Now you can write both the 'day' and 'night' files in csv format that can be
#imported into QGIS.

#write.csv(night, file = "Nov2016_all_clipped_night.csv")

#NB NB NB, Read the output file 'ARC03_Nov16_Feb17_day.csv'.
#Separate by weeks. If you have lots of data points (which you will have), it will be
#necessary to split them into weekly sets that are easier to work with. Here you will
need to specify
#the dates of the weeks that you will deal with.
#date1 <- as.POSIXct("2016-11-18 12:00:00")
#date2 <- as.POSIXct("2016-11-28 12:00:00")

#int1 <- interval(date1, date2)

#week1<- catlog01[catlog01$datetime %within% int1,]
##week2<- catlog01[catlog01$datetime %within% int2,]

write.csv(day,                file                =
"c:/Users/gushab/Documents/catlog/data/R/ARC03/ARC03_Nov16_Feb17_day.csv")

head(day)
tail(day)

#Write outputs to file
#write.csv(week1, file = "Nov2016_all_clipped_week1.csv")
#write.csv(week2, file = "Nov2016_all_clipped_week2.csv")

library(lubridate)
library(plyr)

```

```

catlog01<-
read.table("c:/Users/gushab/Documents/catlog/data/R/ARC03/ARC03_Nov16_Feb1
7_day.csv", header=TRUE, sep=",", na.strings="NA", dec=".", strip.white=TRUE)
require(tlocoh)

```

#To work in t-locoh, you will need to re-project the latlong data into UTM.

```

class(catlog01)
head(catlog01)
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/tlocoh_lat_long.pdf")
plot(catlog01[, c("Longitude","Latitude")], pch=20)
dev.off()

```

```

require(sp)
require(rgdal)
catlog01.sp.latlong <- SpatialPoints(catlog01[, c("Longitude","Latitude")],
proj4string=CRS("+proj=longlat +ellps=WGS84"))
catlog01.sp.utm <- spTransform(catlog01.sp.latlong, CRS("+proj=utm +south
+zone=35 +ellps=WGS84"))
catlog01.mat.utm <- coordinates(catlog01.sp.utm)
head(catlog01.mat.utm)
colnames(catlog01.mat.utm) <- c("x","y")
head(catlog01.mat.utm)
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/tlocoh_utm.pdf")
plot(catlog01.mat.utm)
dev.off()

```

```

#setting up the locoh xy object with the UTM co-ordinates and the new local time
catlog01.lxy <- xyt.lxy(xy=catlog01.mat.utm, dt=catlog01$localtime, id="ARC03",
proj4string=CRS("+proj=utm +south +zone=35 +ellps=WGS84"))

```

```
### NB NB NB Wait until the y/n prompt before proceedings
```

```
#summary of the data in that object
```

```
summary(catlog01.lxy)
```

```
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/tlocoh_lxy.pdf")
```

```
plot(catlog01.lxy)
```

```
dev.off()
```

```
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/hist_lxy.pdf")
```

```
hist(catlog01.lxy)
```

```
dev.off()
```

```
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/freq_lxy.pdf")
```

```
lxy.plot.freq(catlog01.lxy, deltat.by.date=T)
```

```
dev.off()
```

```
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/freq_lxy_T.pdf")
```

```
lxy.plot.freq(catlog01.lxy, cp=T)
```

```
dev.off()
```

```
catlog01.lxy <- lxy.thin.bursts(catlog01.lxy, thresh=0.2)
```

```
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/lxy_ptsh_add.pdf")
```

```
catlog01.lxy <- lxy.ptsh.add(catlog01.lxy)
```

```
dev.off()
```

```
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/freq_sfnder_lxy.pdf")
```

```
lxy.plot.sfnder(catlog01.lxy)
```

```
dev.off()
```

```

pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/freq_sfindex.pdf")
lxy.plot.sfindex(catlog01.lxy, delta.t=3600*c(12,24,36,48,54,60))
dev.off()

#identify nearest neighbour
catlog01.lxy <- lxy.nn.add(catlog01.lxy, s=0.003, k=25)

summary(catlog01.lxy)

catlog01.lxy <- lxy.nn.add(catlog01.lxy, s=c(0.0003, 0.003, 0.03, 0.3), k=25)
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/lxy_mtdr.pdf")
lxy.plot.mtdr(catlog01.lxy, k=10)
dev.off()

pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/tspan_lxy.pdf")
lxy.plot.tspan(catlog01.lxy, k=10)
dev.off()

lxy.exp.kml (catlog01.lxy,
'c:/Users/gushab/Documents/catlog/data/R/ARC03/ARC03_kml')

#save your work
lxy.save(catlog01.lxy, dir=".")

#creating hull sets
catlog01.lhs <- lxy.lhs(catlog01.lxy, k=3*2:8, s=0.003)

summary(catlog01.lhs, compact=T)

#create isopleths

catlog01.lhs <- lhs.iso.add(catlog01.lhs)

```

```

#plot isopleths
pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/iso_utm.pdf")
plot(catlog01.lhs, iso=T, record=T, ufipt=F)
dev.off()

pdf("c:/Users/gushab/Documents/catlog/data/R/ARC03/iso_utm_08.pdf")
plot(catlog01.lhs, iso=T, k=15, allpts=T, cex.allpts=0.1, col.allpts="gray30", ufipt=F)
dev.off()

print(catlog01.lhs)

#please extract table of areas of isopleths from the print out on the screen

#export isopleth to kml for Google Earth

lhs.exp.shp                                     (catlog01.lhs,
'c:/Users/gushab/Documents/catlog/data/R/ARC03/ARC03_shp',      iso=TRUE,
id='ARC03.pts3926.k24.s0.003.kmin0',    s=0.003,    k    =    24,    hs.names    =
'ARC03.pts3926.k24.s0.003.kmin0')

lhs.iso.rast                                     (catlog01.lhs,
'c:/Users/gushab/Documents/catlog/data/R/ARC03/ARC03_img')

```

**Appendix 2. Google Earth Engine script for determining Sentinel 2 NDVI values associated with the livestock grazing patterns.**

```

////////////////////Sentinel 2 section////////////////////
//Data availability for Sentinel 2 is Aug, 2017 - 2018

```

//SENTINEL-2 data contain 13 UIN16 spectral bands representing TOA reflectance scaled by 10000:

//Band	Use	Wavelength	Resolution
//B1	Aerosols	443nm	60m
//B2	Blue	490nm	10m
//B3	Green	560nm	10m
//B4	Red	665nm	10m
//B5	Red Edge 1	705nm	20m
//B6	Red Edge 2	740nm	20m
//B7	Red Edge 3	783nm	20m
//B8	NIR	842nm	10m
//B8a	Red Edge 4	865nm	20m
//B9	Water vapor	940nm	60m
//B10	Cirrus	1375nm	60m
//B11	SWIR 1	1610nm	20m
//B12	SWIR 2	2190nm	20m

///Bring up the collection imagery by date. These can be turned on an off as needed.

/\*Sentinel-2 maximum NDVI composite

/source: <https://groups.google.com/d/msg/google-earth-engine-developers/GBhCHMclAng/ltX8WbhwAAAJ>

\*/

```
var mgwalana = /* color: #98ff00 */ee.Geometry.Polygon(  
  [[[27.795238494873047, -31.533463627254644],  
    [27.80013084411621, -31.529933760027777],  
    [27.800045013427734, -31.526989053684495],  
    [27.794272899627686, -31.527921858908748]]]);
```

```
Map.setCenter(27.8,-31.5, 10);
```

```
var s2 = ee.ImageCollection("COPERNICUS/S2")  
.filterDate('2016-11-01', '2017-01-28')
```

```

.filter(ee.Filter.lte('CLOUDY_PIXEL_PERCENTAGE', 70))
.filterBounds(mgwalana);

var rgb_viz = {min:0, max:2000, bands:['R','G','B']};
var ndvi_viz = {bands:'NDVI', min:0, max:0.7, palette:'000000,00FF00'};
s2 = s2.select(['B2','B3','B4','B8'], ['B','G','R','N']);

function addNdvi(img) {
  var nd = img.normalizedDifference(['N', 'R']);
  return img.addBands(nd.rename('NDVI'));
}

var ndvi = s2.map(addNdvi);
var ndvi_composite = ndvi.mosaic().clip(mgwalana);
print(ndvi_composite)
var greenest = ndvi.qualityMosaic('NDVI');
Map.addLayer(s2.median(), rgb_viz, 'RGB (median)', false);
Map.addLayer(ndvi, ndvi_viz, 'NDVI');
Map.addLayer(greenest, rgb_viz, 'RGB (greenest pixel)', false);
Map.addLayer(s2.select('N','R','G'), {min:0, max:3500}, 'VNIR', false);
Map.addLayer(mgwalana);
Export.image.toDrive(ndvi_composite);

```

### Appendix 3. Example of a script for frontiers analysis

```

1      1=ERROR COMPONENTS MODEL, 2=TE EFFECTS MODEL

buk-dat  DATA FILE NAME

buk-out.txt  OUTPUT FILE NAME

1      1=PRODUCTION FUNCTION, 2=COST FUNCTION

y      LOGGED DEPENDENT VARIABLE (Y/N)

120    NUMBER OF CROSS-SECTIONS

1      NUMBER OF TIME PERIODS

```

120      NUMBER OF OBSERVATIONS IN TOTAL

2        NUMBER OF REGRESSOR VARIABLES ( $X_s$ )

n        MU (Y/N) [OR DELTA0 (Y/N) IF USING TE EFFECTS MODEL]

n        ETA (Y/N) [OR NUMBER OF TE EFFECTS REGRESSORS ( $Z_s$ )]

n        STARTING VALUES (Y/N)

IF YES THEN    BETA0

              BETA1 TO

              BETAK

              SIGMA SQUARED

              GAMMA

              MU        [OR DELTA0

              ETA        DELTA1 TO

                          DELTAP]

NOTE: IF YOU ARE SUPPLYING STARTING VALUES  
 AND YOU HAVE RESTRICTED MU [OR DELTA0] TO BE  
 ZERO THEN YOU SHOULD NOT SUPPLY A STARTING  
 VALUE FOR THIS PARAMETER.