WFL Publisher
Science and Technology

Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.13 (2): 190-196. 2015

www.world-food.net

# Vegetation density assessment in the Upper Molopo River Catchment, South Africa

**Lobina G. Palamuleni * and Agnes K. Turyahikayo**

*North West University, Mafikeng Campus, Department of Geography and Environmental Sciences, P/Bag X2046, Mmabatho, South Africa, 2745. *e-mail: Lobina.Palamuleni@nwu.ac.za*

*Received 22 December 2014, accepted 29 March 2015.*

## Abstract

In arid and semi-arid environments like the rest parts of South Africa, the state of vegetation density in catchments is an important indicator of the state of the environment. Climate variability coupled with different anthropogenic activities could affect vegetation cover at varying levels. The Upper Molopo River Catchment (UMRC) in the North West Province of South Africa is under this combined human use and climatic pressure. This study aimed at assessing long-term changes in vegetation density in the Upper Molopo River Catchment area. Two pairs of bi-seasonal Landsat images, TM 1989 and OLI-8 2013 (autumn) and TM 1996 and TM 2005 (summer) were classified using Maximum Likelihood algorithm. Classification of vegetation density categorised three major classes: low vegetation density (< 0.1), medium vegetation density (>0.1- 0.5) and high vegetation density (>0.5) based in Normalized Difference Vegetation Index (NDVI). For purposes of interpreting the changes identified, ancillary long-term data on anthropogenic factors (human population, number of houses, household use of wood as energy source, livestock populations) were obtained from state sources. The overall accuracy of vegetation density maps generated from post-classification change detection methods and evaluated using field data was 88% with a Kappa coefficient ($K_{hat}$) value of 83%. Results indicated a growth in built up area from 3% in 1989 to 16% in 2013 with a simultaneous decrease of medium vegetation density within 5 km of human settlements. Low vegetation density revealed an increasing trend whereas high and medium vegetation density areas have been declining during the study period. In addition, a significant negative correlation between human population and area of cover by medium vegetation density ($r$ = -0.960, P < 0.01) was obtained. The decline in medium vegetation density in the Upper Molopo River Catchment is of ecological concern. There is therefore, a need for short-term and long-term strategies to ensure sustainable land management in order to preserve vegetation density and biodiversity within the catchment.

***Key words:*** Molopo River, NDVI, vegetation density, South Africa.

## Introduction

Changes in vegetation density have important environmental consequences at local, regional and global scales. At the regional and global scales, these changes have profound implications for global radiation and energy balances, alterations in biogeochemical cycles, perturbations in hydrological cycles and loss of biodiversity at genetic and species levels [1]. At the local scale, changes in vegetation cover affect watershed runoff, micro-climatic resources, groundwater tables, processes of land degradation and landscape level biodiversity. All these have direct impacts onto the livelihoods of local communities. These multifaceted environmental impacts can affect, immensely, food security and sustainable development [2]. Monitoring and analysing vegetation density at a local scale is important to understand drivers of the change and the positive or negative impacts likely at the local scale. Studies at a local scale of land cover can also help to reveal general principles to provide an explanation and a prediction of new land use cover changes (LUCCs) at larger spatial scales especially in semi-arid areas [2]. Land use-derived disturbance to the vegetation in catchments often results in land degradation, defined by Numata [3] as the reduction of land productivity. Therefore, vegetation density can be used as an indicator of land degradation in comparison to the ultimate degradation stage of bare land.

In the Upper Molopo Sub-Management Area, like most other catchment areas in South Africa and the North West Province in particular, vegetation density is continually decreasing. This trend could be attributed to both the climatic and anthropogenic factors such as climate variability, deforestation, erosion due to overgrazing and urbanisation [4]. Most of the impoverished people live in semi-arid mixed farming regions and depend on natural resources for their survival [5]. Removal of forests and woodlands is of ecological concern in the context of among others; biodiversity conservation, groundwater recharge and carbon stock provision in buffering the build-up of $CO_2$ as greenhouse gas [6]. Therefore, the purpose of this study was to assess changes in vegetation density in the study area for the periods 1989, 1996, 2005 and 2013. The specific objectives were to (i) quantify vegetation density trends using multi-temporal Landsat data; (ii) identify and map various land use types and (iii) establish relationships between anthropogenic activities, climate variability and vegetation density change.

## Materials and Methods

***Study area:*** The Upper Molopo River Catchment is located between 25°38' S, 26°10' S and 25°10' E, 26°10'E, in the eastern part of the Molopo catchment in the North West Province of South Africa (Fig. 1). It is located between the Molopo Eye in the East of Mafikeng Town and the Disaneng dam in the West of Mafikeng. The study area also covers the Botsalano game reserve on the North where the Molopo River forms the border between the North West Province and Botswana. The Molopo River is the main supplier of water across the study area with major dams along the river including Disaneng, Modimola (Setumo), Letlamoreng and Cooke's Lake whose flora and fauna form a major tourism industry.

The most dominant vegetation types in the upper Molopo River catchment area are the open *Acacia tortilis* woodland, open grass plains, thicket closed woodlands, *Acacia karroo*, vlei and floodplain[7]. In general, the vegetation type in the study area can be described as Kalahari bushveld, sourish mixed bushed to a more open tree savanna [8].

***Remote sensing data:*** To map vegetation density in the Upper Molopo River Catchment, multi-temporal Landsat data, obtained from the South African Space Agency were used spanning between 1989 and 2013. Two pairs of biseasonal Landsat cloud-free images were selected for vegetation density analyses: Landsat TM 1989 and Landsat OLI-8 of 2013 (autumn) and Landsat TM 1996 and Landsat TM 2005 (summer). A pixel-based classification process was undertaken using the Maximum Likelihood algorithm. Landsat data (30 m) reveal detailed features of the land surface, which is the scale of the characteristics suitable for this study based on available datasets.

***Ancillary data:*** Contextual information such as source of energy, type of dwelling (house), livestock numbers (livestock census) and the total population within the study area were obtained from state sources for the period 1996, 2001, 2007 and 2011. These data were used to describe the proximate and underlying drivers of vegetation density change and was further correlated with vegetation density. In addition, monthly rainfall data from five weather stations within the UMRCA for the period 1984 to 2012

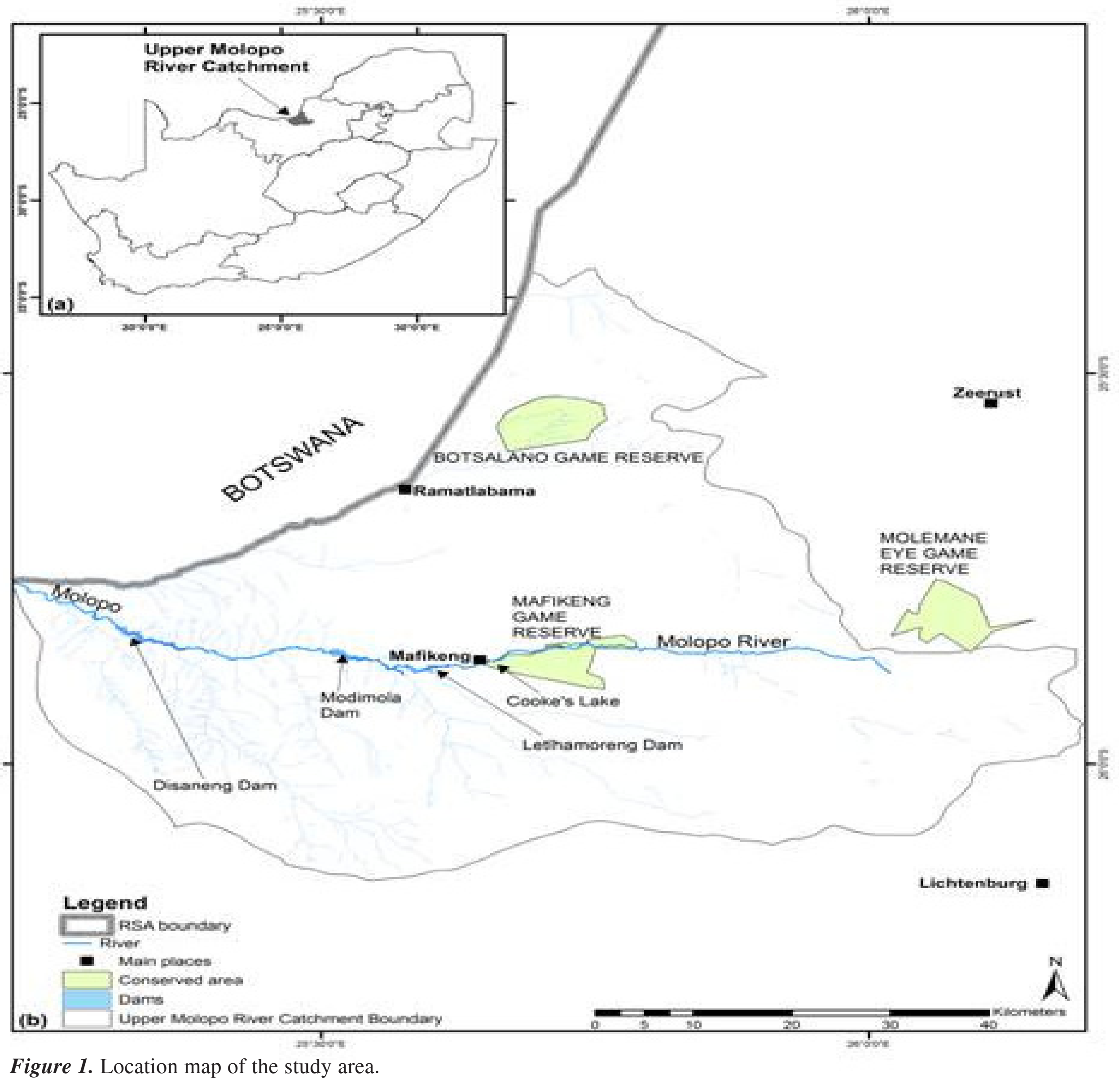


***Figure 1.*** Location map of the study area.

were obtained from the South African Weather Services (SAWS). Standardised Precipitation Index was computed to determine rainfall trend in the study area and was further correlated with vegetation density.

***Data processing and image analyses***

*Image pre-processing:* All image processing and subsequent image analysis were carried out using ERDAS Imagine software [9]. Landsat TM, ETM+ and OLI Images were obtained at Level 1 A at which geometric corrections was required. Radiometric rectification was performed to adjust differences in atmospheric conditions, viewing geometry and sensor noise and response [10] using the Zero Minimum Method also called "dark object subtraction technique" embedded in ERDAS software. This method assumes that a zero reflector exists for the given band (that the minimum digital number should be zero) and if not zero, then the minimum value is due to additives effects and the value should be subtracted from each pixel in that band. Mathematically it is a simple method and achieves haze removal better than no correction at all. This process was aimed at minimizing variation due to varying solar zenith angles and incident solar radiation to normalize images to each other so that the images could be compared [11].

***Land cover classification and change detection analysis:*** Supervised classification, using Maximum Likelihood Classifier (MLC), was utilized. Maximum likelihood is a type of classification process that assumes that the data for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class [11] and is based on statistics mean; variance/covariance where a probability function is calculated from the input for classes established from training sites [12]. Training sites were generated by on-screen digitizing of selected areas for each land cover class identified on colour composite. Classification of land cover in the Upper Molopo River Catchment categorized seven major groups namely: woodland; thicket; shrub land/ grassland/pasture; water body/wetland; rainfed agriculture; irrigated agriculture and built up areas. Change detection analysis was done to examine changes in vegetation density over the years using image differencing. A contingency matrix was used to quantify land cover change (LCC) in terms of pixel values, hectares (ha) or percentage of area coverage.

***Determination of vegetation density:*** To assess vegetation density as an indicator of vegetation productivity, NDVI values were calculated separately from each sub-scene using the near infrared and the red bands. Classification of vegetation density categorised three major classes namely: low vegetation density (< 0.1), medium vegetation density (>0.1- 0.5) and high vegetation density (>0.5).

***Field verification:*** Accuracy assessment for the classified images was undertaken in the field with a particular focus on three vegetation classes (high vegetation density, medium vegetation density and low vegetation density). A stratified random sample of 100 field sites was generated for the accuracy assessment. The sample included 17 sites classified as high vegetation density, 25 as medium density, and 58 as low vegetation density which were field checked. However, due to accessibility problems presented by private property restrictions, only sites within 1 km of a road were visited in the field. An error matrix generated for the Upper Molopo River Catchment allowed an assessment of each vegetation density accuracy and error type. The product of the accuracy assessment was a confusion matrix showing errors of omission (producer's accuracy) and commission (user's accuracy), overall classification accuracy and a *k* coefficient [13]. The *k* coefficient of agreement is a measure of the actual agreement minus chance agreement.

## Results and Discussion

***Land cover classification and change detection:*** Table 1 displays the extents of the coverage of land surface features, their respective distributions and changes between 1989 and 2013. Between 1989 and 2013, woodland decreased by 8% while grassland which constituted about 32% in 1989 had decreased to 0.9% by 2013 which is an overall total areal loss of 31% (Table 1). Grassland decreased most due to the grazing patterns taking place in the area associated with overgrazing and overstocking [14]. The areal extent under rain-fed crop gained almost 20% during this period. This could be attributed to the conversion of land for food security since subsistence agriculture has low productivity; hence there has been an inevitable tendency to increase the amount of land being farmed [15].

Table 2 displays the extents of the coverage of land surface features, their respective distributions and changes between 1996 and 2005. During the summer season, the area under irrigated

**Table 1.** Spatial distribution, rate and magnitude of land cover change – summer season (1989 – 2013).

| | 1989 | | 2013 | | Trend cover change | |
|---|---|---|---|---|---|---|
| Land cover | Area (ha) | % | Area (ha) | % | Area (ha) | % |
| Woodland | 143121.3 | 33 | 107159.3 | 2 | -35962.0 | -8 |
| Thicket | 112961.0 | 26 | 159155.8 | 37 | 46194.8 | 11 |
| Grassland | 139037.0 | 32 | 4213.5 | 0.9 | -134823.5 | -31 |
| Water body | 2081.5 | 0.5 | 433.9 | 0.1 | -1647.6 | -0.4 |
| Rainfed agriculture | 2144.8 | 0.5 | 87268.0 | 20 | 85123.2 | 20 |
| Irrigated agriculture | 18533.6 | 4 | 2166.2 | 0.5 | -16367.5 | -4 |
| Built up land | 12553.4 | 3 | 70036.0 | 16 | 57482.6 | 13 |
| Total | 430432.6 | 100.00 | 430432.6 | 100.00 | | |

**Table 2.** Spatial distribution, rate and magnitude of land cover change – autumn season (1996 – 2005).

| Land cover categories | 1996 Area (ha) | % | 2005 Area (ha) | % | Change (ha) | Change (%) |
|---|---|---|---|---|---|---|
| Woodland | 87929.3 | 20 | 122631 | 28 | 34701.7 | 8 |
| Thicket | 76510.4 | 18 | 112895 | 26 | 36384.6 | 8 |
| Grassland | 74885.8 | 17 | 18971.8 | 4 | -55914 | -13 |
| Water body | 617.04 | 0.1 | 728.19 | 0.1 | 111.15 | 0 |
| Rainfed agriculture | 54323.3 | 13 | 20324.2 | 5 | -33999.1 | -8 |
| Irrigated agriculture | 86905 | 20 | 150132 | 35 | 63227 | 15 |
| Built up land | 49261.8 | 11 | 4750.38 | 1 | -44511.42 | -10 |
| Total | 430432.6 | 100 | 430432.6 | 100 | | |

agriculture dominated all other classes by occupying a total area of 86,905 ha (20%) in 1996 and 150,132 (35%) in 2005. The overall increase in this class from 1996 to 2005 was 15%. The plausible explanation for the increase in irrigated agriculture could be due to the above normal precipitation experienced prior to and during image acquisition which filled up the dams and making water for irrigation available. The total area under rainfed agriculture decreased by 8%. Increase in rainfall simultaneously resulted into the increase in woodland (from 20% to 28%) thereby supressing undergrowth which could explain the decrease in grassland by up to 13% [13]. In addition, there was a decrease of 10% in the area occupied by built up land. This could be attributed to the migration of the local people to major towns in search of better job opportunities. The study area experienced substantial net out migration between 1996 and 2001 due to the birth of a democratic South Africa in 1994 which could have opened up opportunities elsewhere in the country for the previously disadvantaged rural population[16].

***Thematic land cover accuracy assessment:*** Accuracy assessment was based on the correlation between ground reference samples collected during field exercise and the satellite image classification to give an indication of the overall agreement between reference data and processed classifications. Based on the ground truth observations and the classification, the error matrix in Table 3 was constructed. The overall mapping accuracy was 88% and an overall Kappa coefficient ($K_{hat}$) value of 83%. Despite the spectral confusion and classification error, the classification scheme that was employed was satisfactory for LULC analysis yielding overall classification accuracy for all land cover classes of 88% and the overall $k$ statistic of 82%. All user's and producer's accuracy for most of the classes were higher than 76% except for grassland and water body which were very dry. The producer's accuracy of built-up areas was 92.3% while the user's accuracy was slightly lower (75%). Although 92.3% of the built-up areas were correctly identified, only 75% of the areas labelled built-up were actually built-up areas, implying misclassification of some pixels in that category.

***Vegetation density change analysis:*** Vegetation density change areal statistics are summarised to express the net vegetation lost and gained in each class over the 24-year period, 1989-2013 (Table 4). The overall total extent lost during this period (1989-2013) from the medium vegetation class is 0.6% while high vegetation density lost 1.0%.

The analysis shows increases in the spatial extent of low

**Table 3.** Error matrix of land cover classes.

| Classified data | Reference data: Woodland | Thicket | Shrub/ grassland | Water | Rainfed | Irrigated | Built up | Totals | User's accuracy % |
|---|---|---|---|---|---|---|---|---|---|
| Woodland | **42** | 0 | 2 | 0 | 3 | 0 | 1 | 48 | 87.5 |
| Thicket | 0 | **13** | 0 | 0 | 1 | 0 | 0 | 14 | 92.9 |
| Shrubs/grassland | 0 | 0 | **1** | 0 | 0 | 0 | 0 | 1 | 100.0 |
| Water | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0.0 |
| Rain fed | 0 | 0 | 0 | 1 | **19** | 0 | 0 | 20 | 95.0 |
| Irrigated | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 1 | 100.0 |
| Built | 1 | 0 | 0 | 1 | 2 | 0 | **12** | 16 | 75.0 |
| Column Total | 43 | 13 | 3 | 2 | 25 | 1 | 13 | 100 | |
| Producer's accuracy % | **97.7** | **100** | **33.3** | **0.0** | **76.0** | **100** | **92.3** | | |
| Overall accuracy % | **88.0** | | | | | | | | |
| Kappa % | **83.0** | | | | | | | | |

**Table 4.** Vegetation density change.

| Classes | 1989 Area(ha) | 2013 Area (ha) | 1989-2013 change % | 1996 Area (ha) | 2005 Area(ha) | 1996-2005 change % |
|---|---|---|---|---|---|---|
| Low vegetation density | 17476.0 | 146356.1 | 7.4 | 21074.0 | 78889 | 2.7 |
| Medium veg. density | 190558.4 | 84081 | -0.6 | 117633.3 | 113462.1 | 0.0 |
| High veg. density | 23932.8 | 1092.6 | -1.0 | 92976.1 | 39368.9 | -0.6 |
| Total area | 232439.3 | 232439.3 | | 232439.3 | 232439.3 | |

vegetation density while medium and high vegetation decreased in extent (Fig. 2). In 1989, medium vegetation density and high vegetation density categories occupied 82% and 10.3% respectively, but by 2013, the same classes occupied 36% and 0.5%, respectively, which represents a total decline of 34% for medium vegetation density and 9.8% for high vegetation density. The very low vegetation density was mainly around settlements and dense vegetation in low settlement areas. Noticeable was the composition of vegetation where the low density vegetation mainly comprised vegetation of grassland and thorn tree in association with rock outcrops.

In general, low vegetation density is increasing while medium and high vegetation densities have decreased throughout the study period with the exception of 1996 where vegetation was dense throughout the study area proportionally corresponds with the recorded above normal rainfall. In addition, NDVI and Mean Average Rainfall (MAR) were positively correlated ($r$ = 0.47) indicating that vegetation activity in the area is highly dependent on the amount of rainfall. Classification results in Fig. 3 indicate high to medium NDVI values on the eastern part of the study area and low NDVI values on the western side. This trend corresponds with privately owned farms in the central and north eastern parts and very low rainfall and low humidity in the communal western side (Fig. 3). During this period, medium vegetation density occupied the largest extent of about 49% of the total area. Low vegetation density reflects an increasing trend of 25% from 1996 to 2005 while medium vegetation density class shows a slight decline from 51% in 1996 to 49% in 2005. On the contrary, high vegetation density reflects a decreasing trend throughout the study period. From 1996 to 2005, this class decreased from 40% to 17% which is a total decrease of 23% (Table 4). Drivers of vegetation density change

Analysis of vegetation density within 5 km of settlements showed a pronounced reduction in medium density vegetation and an increase in low density vegetation (Fig. 4). This trend could be attributed to several human activities, for example, settlement expansions (indicated by increase in number of residential houses), trees cutting for fuel-wood and construction, increase in grazing and browsing intensity and expansion of farm area. Although the livestock numbers have been decreasing, the estimated carrying capacity of the study area (48.5 ha/livestock unit (LSU)) exceeds the recommended capacity of 17 ha/livestock unit [17]. Consequently, overgrazing is contributing to loss of vegetation density within the catchment. In addition, the population figures of the area shows an increasing trend from 1996 to 2011 (Fig. 5). High population growth has translated into rapidly increasing demands from the land in terms of food, shelter and energy (fuel-wood) and in comparison with a decrease in high and medium vegetation density. Results of correlation analysis between population data and medium vegetation density revealed a statistically strong significant negative correlation between human population and medium density vegetation ($r$ = -0.960, $P < 0.01$).The livestock data available indicates a constant decrease in the number of animals (Fig. 5).

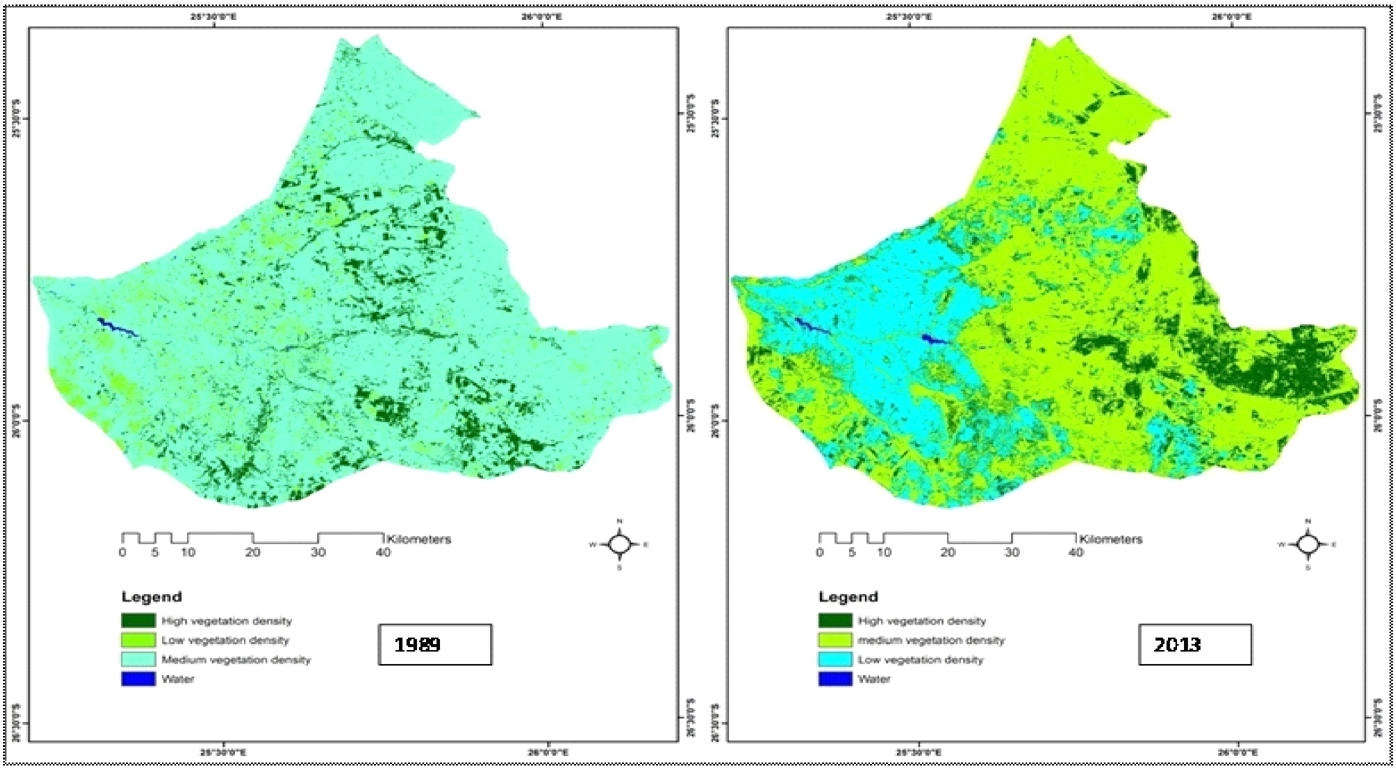


***Figure 2.*** Vegetation density between 1989 and 2003.

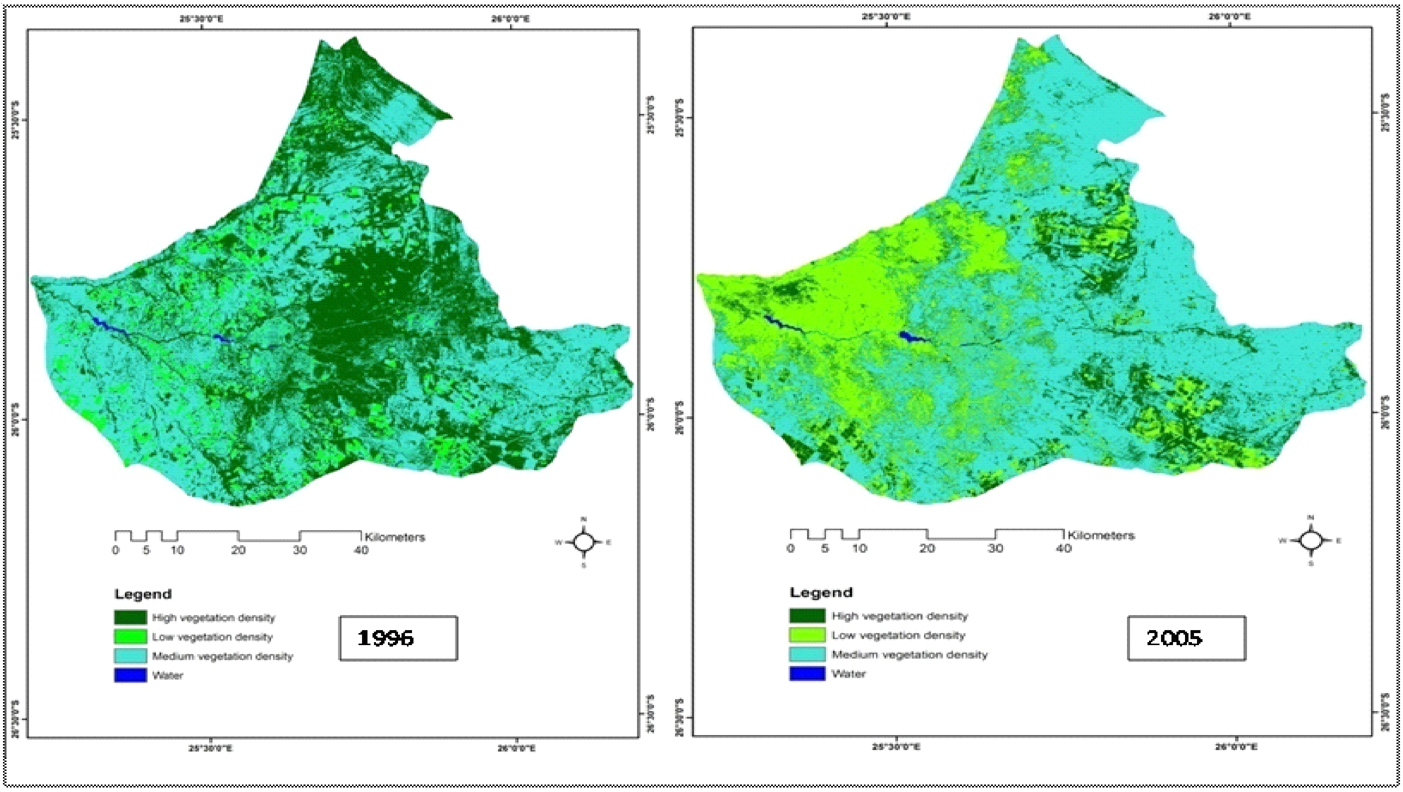


*Figure 3.* Vegetation density between 1996 and 2005.

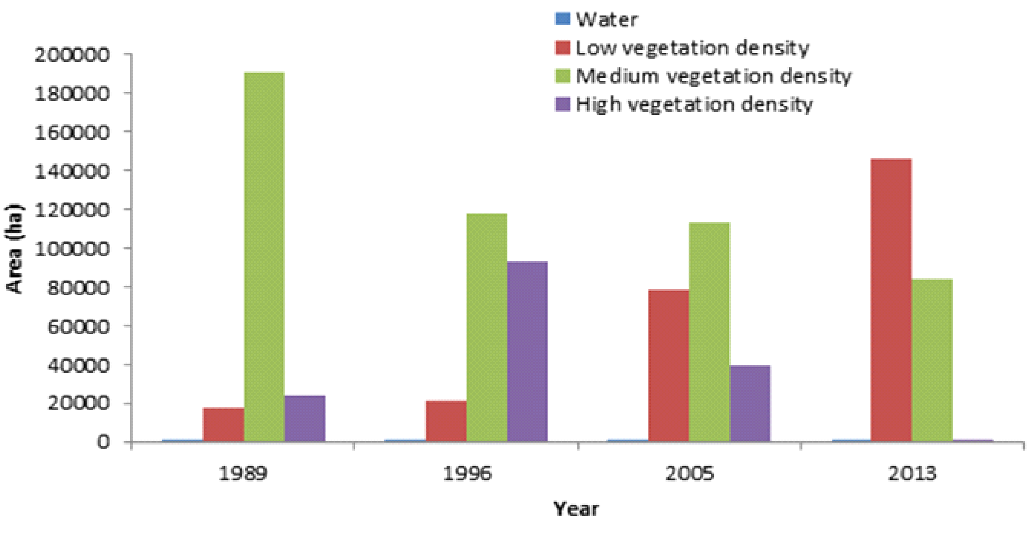


*Figure 4.* Vegetation density within five km settlement buffer.

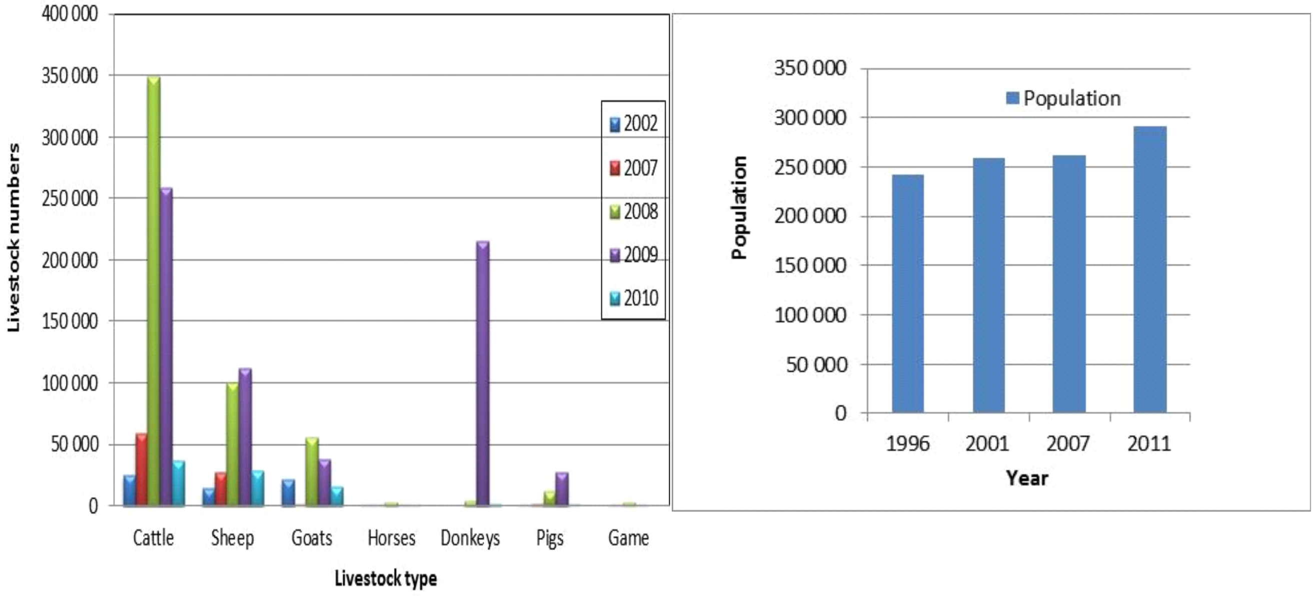


***Figure 5.*** Livestock and population statistics.

## Conclusions

A substantial change in vegetation densities from 1989 to 2013 have occurred in the area as high and medium vegetation density has shown decreasing trends with a simultaneous increase in low vegetation density extent. The results ascertain that the spatial distributions of vegetation density change during the different years and seasons in this region are a result of mainly anthropogenic activities and climatic factors. The decline in vegetation density in the area has occurred mainly within 5 km of human settlements. Decline in vegetation density has implications for the loss of biodiversity in both flora and fauna in the study area. The study recommends short-term and long-term strategies be developed to ensure sustainable land management in the catchment area since the structure and distribution of vegetation vis-à-vis density is critical in the functioning of catchments that provide many important ecosystem services in arid regions.

## References

[1]Steffen, W., Sanderson, A., Tyson, P. D., Jäger, J., Matson, P. A., Moore III, B., Oldfield, F., Richardson, K., Turner II, B. L. and Wasson, R. J. 2004. Global Change and the Earth System: A Planet under Pressure. The IGBP book series, Springer, Berlin, Germany, 336 p.

[2]Lambin, E. F. and Geist, H. J. 2006. Land-use and Land-cover Change: Local Processes and Global Impacts. Springer, Berlin, Heidelberg, Germany, 204 p.

[3]Numata, I., Roberts, D. A., Chadwick, O. A., Schimel, J. P., Sampaio,F. R., Leonidas, F. C. and Soares, J. V. 2007. Characterization of pasture biophysical properties and the impact of grazing intensity using remotely sensed data. Remote Sensing of Environment **109**(3):314–327.

[4]Taylor, J. C., Prygiel, J., Vosloo, A., Pieter, A. and Van Rensburg, L. 2007. Can diatom-based pollution indices be used for biomonitoring in South Africa? A case study of the Crocodile West and Marico water management area. Hydrobiologia **592**:455-464.

[5]Wessels, K. J., Prince, S. D., Frost, P. E. and van Zyl, D. 2004. Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1km VHRR NDVI time-series. Remote Sensing of Environment **91**:47–67.

[6]Bucini, G. and Hanan, N. P. 2007. A continental scale analysis of tree cover in African savannas. Global Ecology and Biogeography **16**:593-605.

[7]Mahikeng Spatial Development Framework & Related Products 2005. Status Quo Report. Mafikeng Local Municipality, Mafikeng, North West Province.

[8]Department of Water Affairs and Forestry (DWAF) 2004. Forestry and Poverty in SA. Working Paper 3. Department of Water Affairs and Forestry, Pretoria.

[9]ERDAS 2010. Fundamentals of Erdas Imagine, Georgia, USA.

[10]Culf, A.D., Fisch, G. and Hodnett, M.G. 1995. The albedo of Amazonian forest and ranchland. Journal of Climate **8**:1544–1554.

[11]Lillesand, T. M., Kiefer, R. W. and Chipman, J. W. 2008. Remote Sensing and Image Interpretation. 6th edn. Wiley, New York.

[12]Sallaba, F. 2009. Potential of a Post-Classification Change Detection Analysis to Identify Land Use and Land Cover Changes. A Case Study in Northern Greece. Geobiosphere Science Centre, Physical Geography and Ecosystems Analysis, Lund University.

[13]Story, M. and Congalton, R.G., 1986. Accuracy assessment: A user's perspective. Photogrammetric Engineering and Remote Sensing **52**: 397–399.

[14]Hammad, A. A. and Tumeizi, A. 2012. Land degradation:Socioeconomic and environmental causes and consequences in the eastern Mediterranean. Land Degradation and Development **23**:216-223.

[15]Palamuleni, M. E. 2010. Some patterns of internal migration in the North West Province, South Africa, 1996-2001. The Journal for Transdisciplinary Research in Southern Africa **6**(1):225–240.

[16]Tilman, D. 1987. Secondary succession and pattern of plant dominance along experimental nitrogen gradients. Ecological Monographs **57**(3):189-214.

[17]State of the Environment Report 2002. North West Province, South Africa.