GIS application in rangeland management in Tanzania: a systematic review

Conference Paper · April 2022

Emmanuel Nzunda
Sokoine University of Agriculture (SUA)

GIS application in rangeland management in Tanzania: a systematic review

Emmanuel F. Nzunda[1] and Amri S. Yusuph[2]

[1]Department of Forest Resources Assessment and Management, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, Morogoro, Tanzania

Email: nzunda@sua.ac.tz, nzundaef@gmail.com

Phone: +255 765 815 265

Permanent address

[2]Tanzania Agricultural Research Institute (TARI), TARI-Kibaha

Phone: +255-783634492/+255-755416438

Email: yusuphay@gmail.com

Temporary address

[2]Department of Crop Science and Horticulture, College of Agriculture, Sokoine University of Agriculture

Phone: +255-783634492/+255-755416438

Email: yusuphay@gmail.com

SUGGESTED CITATION:

Nzunda, E.F. and Yusuph, A.S. (In press). GIS application in rangeland management in Tanzania: a systematic review. *Proceedings of the 5th Conference of the Rangeland Society of Tanzania, 11-12 April 2022, EDEMA Conference Centre, Morogoro, Tanzania.*

Abstract

A good proportion of the aspects of range resource management are amenable to GIS technology because range resource management integrates spatial and non-spatial aspects of data and information for which GIS is best suited. Whether this amenability is exploited was questionable and needed evidence-based research to confirm. The current paper presents the results of a systematic review of the application of GIS in rangeland management in Tanzania. The specific objectives of the study were: (1) to assess the distribution of the publications by year of publication; (2) to examine the distribution of the publications by subject area; (3) to analyse the relationships among key words used in titles and abstracts of the publications; (4) to describe details of a sample of selected publications, and; (5) to evaluation the distribution of publications by institution of the authorship. The study used the PRISMA method in searching, selecting and analysing the publications. Records were retrieved from Google scholar, Scopus, and science direct. We included 80 English language studies done in Tanzania for the first four specific objectives and 136 for the fifth specific objective. There is an increasing trend of application of GIS from 1 study in 1993 and years close by to 11 publications in 2021. About 34%, 31%, 27% and 8% of the publications applied GIS respectively in environmental science, earth and planetary sciences, agricultural and biological sciences and social sciences. The words 'change', 'area' and 'Tanzania' were the most frequently used in titles and abstracts. Furthermore, words in titles and abstracts formed about five clusters representing study area (e.g. Tanzania), method of analysis (e.g. remote sensing, assessment, data), topic of study (e.g. change, land use, land, conservation) and land use (e.g. grassland, woodland, forest). Most words clustered close together forming a meshwork but the word 'conflict' was the most distant from the rest of the meshwork. GIS data sets used included land use land use/cover (LULC) layer, landscape features (e.g. rivers, roads, topographic variables) and socioeconomic data. Most publications came from Sokoine University of Agriculture, University of Dar es Salaam and Nelson Mandela African Institution of Science and Technology while the fewest came from Norwegian University of Life Sciences, Hohenheim University and the University of British Columbia respectively. It is concluded that GIS is increasingly being applied to rangeland management. However, social sciences apply GIS the least. Tanzanian institutions lead in application of GIS technology, which means it is no longer foreign expertise. It is recommended that all fields apply GIS wherever appropriate. In particular, why GIS is least applied in social sciences aspects of rangeland management needs further investigation.

Keywords: Geographical Information System, remote sensing, rangeland, grassland, resource management, land use, land cover.

1.0 Introduction

Rangelands refer to natural ecosystems in the arid or semi-arid areas predominantly occupied by a diversity of vegetation involving grasses, forbs, shrubs, and grass-like plants; and are primarily suited for grazing (Zerga, 2015; Godde *et al.,* 2020) . In Tanzania rangeland resources account for around 74 percent of the country's total land area (Kideghesho *et al.,* 2013). Rangelands in Tanzania extend into Dodoma, Mwanza, Kagera, Shinyanga, Arusha, Kilimanjaro, Singida, Tabora and some parts of Iringa, Lindi, Mtwara, Mbeya and Katavi regions(Kideghesho *et al.,* 2013). In some regions rangelands are patchier but in some regions rangeland are more extensive.

Rangelands provide a wide range of goods and services that are valuable in terms of economics, social, cultural, and biological value. Internal, self-sustaining biological processes such as soil genesis, water and nutrient cycling, energy flow, and the structure and functional dynamics of plant and animal communities all play a role in rangelands' ability to generate commodities and meet societal demands on a long-term basis(Al-bukhari *et al.,* 2018). The rapid increase in human population and livestock in Tanzania has raised a demand of land for grazing and crop production, which inevitably has led to land use conflicts. Large human population in high fertile lands and reliable rainfall areas has motivated in-migration to communal rangelands where people can access land for cultivation (Kideghesho *et al.*, 2013).

Climate change, on the other hand, has impacted all ecosystems, including rangelands. As a result, habitats have been destroyed, biodiversity has been decreased, and water sources have been depleted (Nzunda *et al.,* 2013). Rangeland quality and composition are influenced by temperature, rainfall, and atmospheric CO2 concentrations, as well as grazing and land cover change. Increased temperature increases drought stress and, consequently, affects their digestibility and decomposition rate (Magita and Sangeda, 2017).

Expansion of agricultural production and the increased number of domestic and wildlife which exceed the carrying capacity has exerted the profound impact on the degradation of rangeland(Al-bukhari *et al.,* 2018). This raises concerns about the ongoing sustainability of these rangeland resources. Rangelands require effective management, which is dependent upon accurate and timely monitoring data to support the assessment of rangeland deterioration(Al-bukhari *et al.,* 2018).

A good proportion of the aspects of range resource management are amenable to GIS technology because range resource management integrates spatial and non-spatial aspects of data and information for which GIS is best suited. These data can play a significant role in rangeland monitoring, permitting observation, monitoring and prediction of vegetation changes, productivity assessment, fire extent, vegetation and soil moisture measurement and quantifying the proliferation of invasive plant species (Al-bukhari et al., 2018; Karl et al., 2012)(Khalid Kija et al., 2020a; Kija et al., 2020) Whether this amenability is exploited in Tanzania was questionable and needed evidence-based research to confirm. The current paper presents the results of a systematic review of the application of GIS in rangeland management in Tanzania. The specific objectives of the study were: (1) to assess the distribution of the publications by year of publication; (2) to examine the distribution of the publications by subject area; (3) to analyse the relationships among key words used in titles and abstracts of the publications; (4) to describe details of a sample of selected publications, and; (5) to evaluation the distribution of publications by institution of the authorship.

2.0 Methodology

A systematic literature review is the research method applied in this work. For the article selection, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta- Analyses) method was applied (Moher *et al.,* 2009). Articles were searched from Scopus, Science direct and Google Scholar. Table 1 indicates the keywords used to search and retrieve published articles.

Table1: Keyword used in the Scopus and Google scholar databases to search published articles

Key words	Topic Restriction	Area restriction
Grassland OR rangeland OR range application OR assessment OR monitoring) OR “remote sensing” OR GIS OR “spatial data” “temporal data” OR vegetation OR soils OR “water resources” OR wildlife OR “grazing management” OR mapping OR “range condition” OR maps OR “carrying capacity” OR productivity OR ecology OR “habitat types” OR Livestock OR cropland OR “Resource management” National park” OR “Game reserve” OR “Game controlled area” OR “Protected area” OR Reserve OR Maasai OR Pastoralism OR “pastoral Nomadic” OR “nomad Arid” OR “Semi-arid” OR “Dry land” OR Bushland OR Woodland OR Pasture OR Grazing OR graze OR Browse OR browser OR Planning OR Management OR Governance OR “Village Land “Unmanned air ”OR vehicle OR planning OR drone OR uav OR bushland.	AND (Grassland OR rangeland OR range) AND (“Land-use land-cover” OR “Vegetation mapping” OR “Rangeland productivity” OR “Vegetation cover” OR “invasive species” OR “soil moisture” “fire extent” OR “fire extent” OR “Aboveground biomass”) NOT (Forest)	AND (Tanzania)

The Inclusion criteria considered are described in Table 2. Article searching in Google Scholar was done using Harzing's publish or perish software where the primary search returned about 549 articles. Other articles (n=143) were obtained from scopus (n=49) and science direct (n=61). In order to eliminate biasness in searching we also conducted hand searches where 33 articles were obtained. In total 802 records were identified for review. The retrieved literatures were exported into Zotero (reference manager software). During screening phase duplicates records (n=446) were removed. The articles were then exported to Rayyan (a web based program) for screening article titles and abstracts. Articles screened for titles and abstract were 356, records without any of the search terms in their title, abstract and keywords, and study done outside Tanzania and irreverent were excludes. As a result; we selected 138 records were for the subsequent phases. The eligibility phase entailed examining numerous article features in order to select the most relevant articles for further analysis. We screened out records that were not about rangeland, were not accessible, or relied solely on secondary data or case studies. Finally, 80 papers were included in the in-depth analysis[1]. Furthermore, for the analysis of authorship distribution by institution, a different search was done using the same criteria only in Scopus and 136 publications were retrieved. The bibliography was analysed using excel according to a list of indicators, including the year of publication, and the subject area. To obtain the bibliometrics of the records, articles were exported to VOSviewer software to generate item map. Bibliometric methods are currently widely used in scientific research methodologies (Zhang *et al.,* 2017).

[1] These publications can be accessed at: https://docs.google.com/document/d/e/2PACX-1vT1B8DbS2ZjTfdwuPAsiICBg00iNhEMS7QwkK3HpKHT9ghVANtw6fLFBVnPQRktDvYzEX8rq_kw3DT8/pub

Table 2: Inclusion and Exclusion criteria

Inclusion criteria	Exclusion criteria
Text in English	Text in other language other than English
Research articles, or book chapter	Publication type is other than article, review, or book chapter
Addressing GIS application in rangeland	Not addressing GIS application in rangeland
Study done in Tanzania	Study done outside Tanzania
Time frame: 1993 to 2022	Before 1993
Study includes primary data	Study includes secondary data

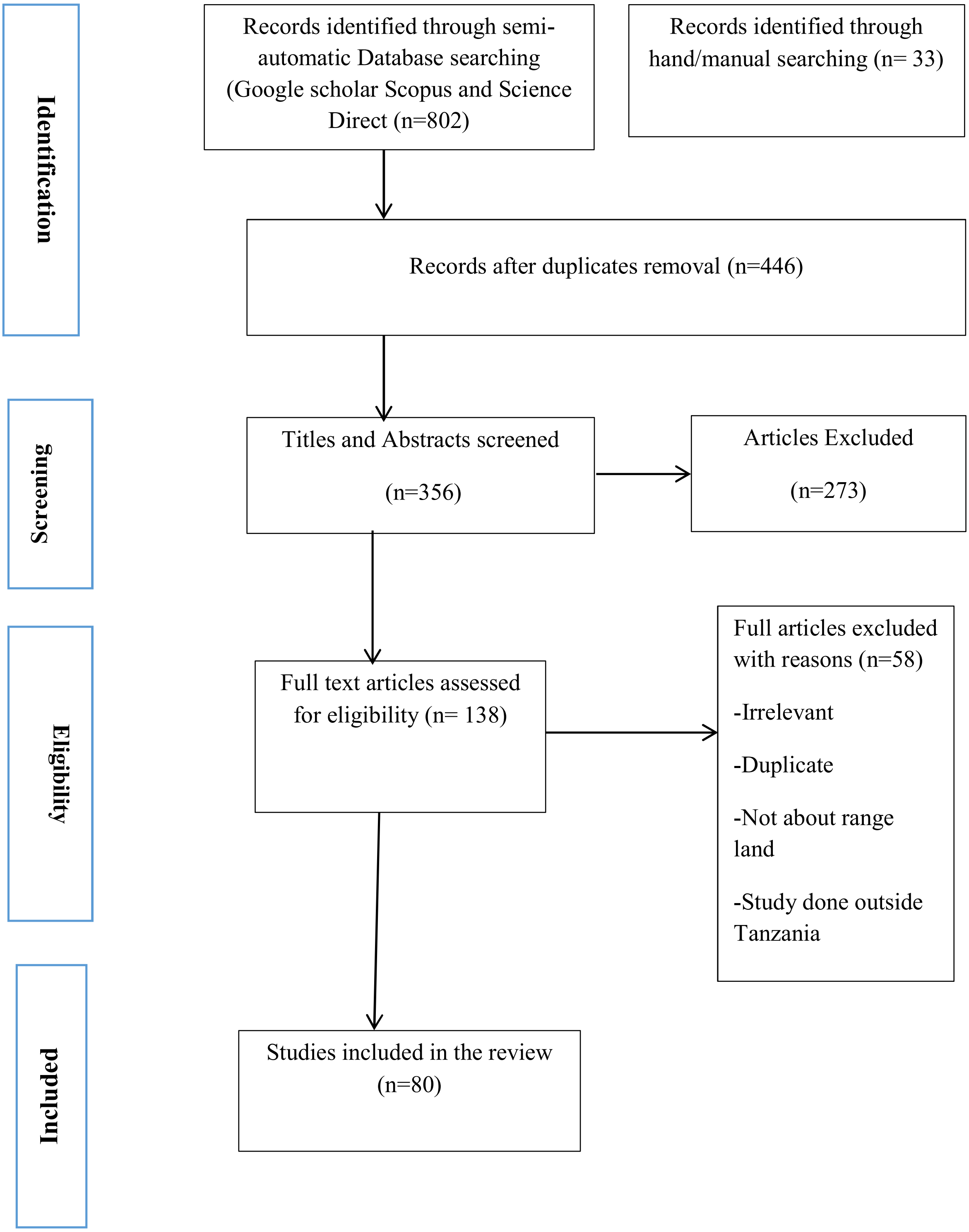


Figure 1. Flow Diagram of article screening to obtain studies that applied GIS in rangeland resource management in Tanzania: the PRISMA framework

3.0 Results and discussion

3.1 Distribution of publications by year of publication

Results in Fig 2 show that the greatest numbers of articles were published in the year 2020 and 2021, whereas from the year 1993 to 2010 there were fewer articles published on studies that applied GIS in rangeland management. This is probably due to the reason that application of GIS in Tanzania was first used in 1990s (Kundi *et al.,* 2003). Higher number of articles from the year 2020 to 2021 indicates that more studies on this topic were done more recently than in the olden days. The great scientific interest in the field, during this time is probably due to availability and simplification of GIS in recent years compared to old days where GIS was not known and not available and extremely difficult to do.

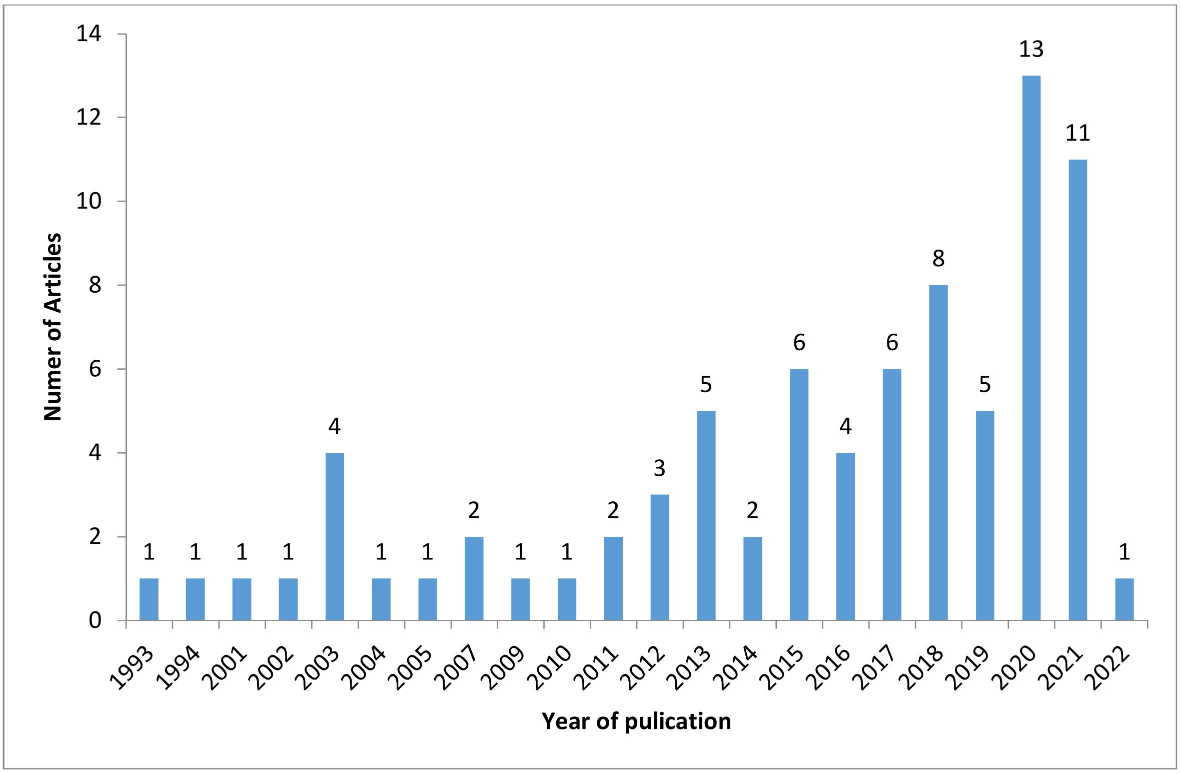
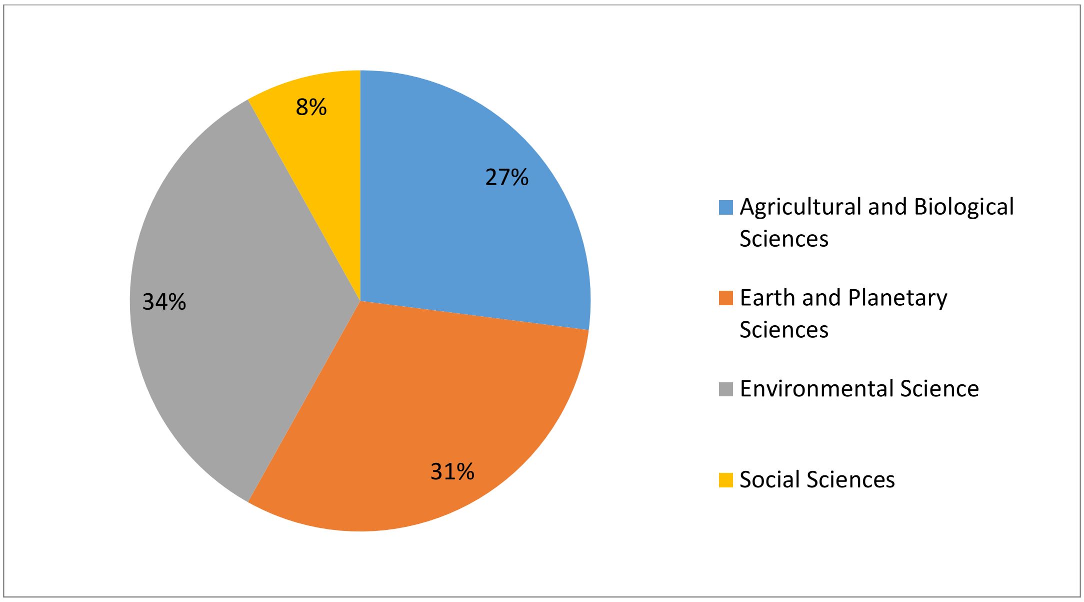


Figure 2: Publications on studies that applied GIS in rangeland management by year of publication

3.2 Distribution of publications by subject area

Results in Fig 3 shows the records obtained in Scopus where by 34% of articles were obtained from the field of environmental science, 34% from earth and planetary science, 27% from Agricultural and Biological science, and 8% from social science



,

Figure 3: Percentage of records retrieved by subject area covered by studies that applied GIS in rangeland resource management in Tanzania

3.3. Relationships among key words used in titles and abstracts of publications

Words in titles and abstracts formed about five clusters representing study area (e.g. Tanzania), method of analysis (e.g. remote sensing, assessment, data), topic of study (e.g. change, land use, land, conservation) and land use (e.g. grassland, woodland, forest). Most words clustered close together forming a meshwork but the word 'conflict' was the most distant from the rest of the meshwork.

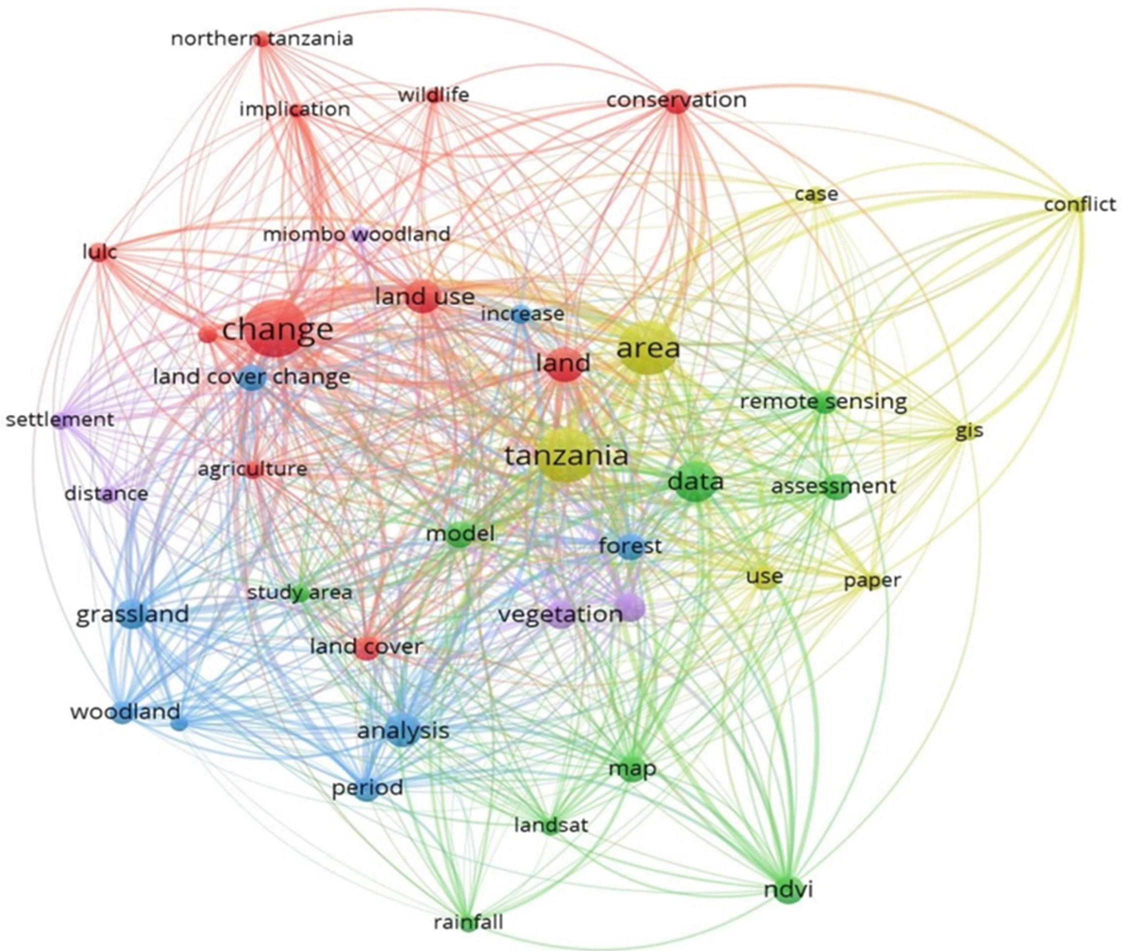


Figure 4: Mostly used terms in the articles indicating clusters in studies that applied GIS in rangeland resource management in Tanzania. Words with same colour belong to the same cluster. The farther apart the words the less their frequency of co-occurrence. The bigger the circle the more frequently used the word, and vice versa. Note that the clustering was not 100% clear and thus some words may appear to belong to the wrong cluster.

3.4 Details of a sample of selected publications

The details of the publications are given in terms of GIS data sets used (Table 3) and topics of GIS applications (Table 4). The topics are further discussed in the next sections.

Table 3: GIS data set commonly used in studies that applied GIS in rangeland resource management in Tanzania

GIS Data set	References
Land use land cover (LULC) layer	(Kitalika and Mlengule, 2021; Mambo and Makunga, 2017; Mtui *et al.,* 2017; S. Makero and J. Kashaigili, 2016)
Landscape features (rivers, roads, boundaries etc)	(Mmbaga *et al., 2*017.)
Socioeconomic data	(Kariuki et al., 2021; Lupala et al., 2015; Macharia et al., 2020; Naiposha et al., 2021; Twisa & Buchroithner, 2019)

Table 4: Application of GIS Applications in rangeland resource management in Tanzania

Topics of GIS applications in rangeland resource management	**Reference**
Land-use and land-cover changes analysis	(Kashaigili and Majaliwa - 2010*;* Kija *et al.,* 2020a, 2020b; Kitalika and Mlengule, 2021; Nzunda and Midtgaard, 2019)
Mapping of invasive species	(Ojija and Marco Manyanza, 2021)
Monitoring of soil erosion	(Lufafa *et al.,* 2003)
Mapping fire extent	(Tarimo *et al.,* 2015)
Aboveground biomass	(Gizachew *et al.,* 2016b)
Vegetation cover assessment	(Kayombo *et al.,* 2020)

3.4.1 Land-use and land-cover changes analysis

Remote sensing and GIS tools are being widely used in analysing and modelling land use land cover dynamics, both quantitatively and qualitatively (Kitalika *et al.,* 2018). GIS techniques like normalised difference vegetation index (NDVI), image differencing, classification analysis (supervised and unsupervised), cross-classification, as well as cross-tabulation have been widely used by various researchers (Kwan *et al.,* 2020).

Most of our selected studies used RS and GIS in assessment of land use land cover changes. Results in Appendix I indicate that majority of studies used Landsat TM in combination with other socio economic approaches such as participatory rural appraisal, questionnaires and interview to assess land use/cover changes. For instance Kashaigili and Majaliwa, (2010) did a study on the dynamics of land use and cover in the Malagarasi river catchment, they investigated long-term and seasonal changes that have occurred as a result of human activities in the area for the periods between 1984 and 2001. Landsat TM and ETM+ images were used in their study to locate and quantify the changes. Kitalika and Mlengule, (2021) employed historical data search, which include Landsat 5 Thematic Mapper and Landsat 8 Operational Land Imager collected from the United States Geological Survey.

Misana (2012) analysed land use and cover change, their driving forces and the socio-economic implications on the southern and eastern slopes of Mount Kilimanjaro. This study is based on data extracted from remote sensing techniques using 1973, 1984 and 1999/2000 satellite images and household interviews. The major change detected in the study area from satellite images was expansion of cultivation at the expense of natural vegetation. These changes led to changes in cropping patterns and crop diversification, declined productivity of land and food insecurity.

Naiposha *et al*. (2021) identified land use implementation problems and suggest solutions relevant to the land users, the government, planners and other stakeholders. Most of their results indicated grassland has been decreasing with time because they have been converted to other land uses such as agriculture and settlement.

3.4.2 Mapping of invasive species

Invasive species dominate the vegetation of many rangeland plant communities and frequently pose the primary deterrent to effective management of these areas (Raymond *et al.,* 2003). More accurate measurements of area infested and canopy cover are essential to estimating the amount of damage or ecological impact caused by invading brush and weeds. Remote sensing techniques offer rapid acquisition of data with generally short turnaround time at costs lower than ground surveys Ojija and Marco Manyanza, (2021) assessed the current distribution of Parthenium hysterophorus and its associated soil properties within the Arusha National Park (ANP) and in adjacent villages at the park's border zones using road surveys. Mwendwa *et al.,* (2020) assessed spatio-temporal invasion dynamics using forest inventory data collected in 1998 and resurveyed 60 (20 m × 50 m) sample plots in 2018. However, there are limited researches on mapping invasive species in rangeland management in Tanzania. The available studies were concentrated in forest and other woodland.

3.4.2 Assessment of vegetation cover

Vegetation plays an important role in supporting the lives of people and it act as homes of wildlife habitat and tourism. It also act as a source of rainfall, water and medicines; for spiritual purposes; as a better place for carbon storage; for grazing livestock, and as a good source of fertile soil for crop production (Kwan *et al.*, 2020). Vegetation land cover/land use change is a function of interactions between and among humans and the natural environment such as population growth, urbanisation, drought and economic reform policies (Muna and Hussein, 2017). Land Resources are easily interpreted by computing their Normalized Difference Vegetation Index for Land Cover classification. Remote Sensing data from Landsat TM image along with NDVI and DEM data layers have been used to perform multi-source classification(Gandhi *et al.,* 2015)..

(Kisoza, (2013) did a spatial temporal study involving analysis of satellite imageries and range surveys to determine the effects of high stocking levels on savannah vegetation cover types in Mkata plains. The GIS data sources include MSS satellite image of 1975, Landsat TM images of 1991 and 2000. Information obtained during community mapping and timeline trend analysis with local communities formed a local knowledge integrated into GIS analysis. (Chidodo et al., 2020) on their study, aimed at evaluating the potential use of normalized difference vegetation index (NDVI) from satellite- derived remote sensing data for monitoring rodent abundance in semi-arid areas of Tanzania. We hypothesized that NDVI could potentially complement rainfall in predicting rodent abundance spatially and temporally. NDVI. (Machiwa *et al.,* 2021) investigated the relationship between vegetation dynamics in response to climate variations and human activities using Moderate Resolution Imaging Spectro- radiometer (MODIS), Normalized Difference Vegetation Index (NDVI), meteorological, and Globe land Landsat data sets. Spatio-temporal trends and the relationship of NDVI to selected meteorological variables were statistically analysed for the period 2000–2018 using the Mann- Kendall test and Pearson correlation respectively.

3.5 Distribution of publications by institution of authorship

Most publications came from Sokoine University of Agriculture, University of Dar es Salaam and Nelson Mandela African Institution of Science and Technology while the fewest came from Norwegian University of Life Sciences, Hohenheim University and the University of British Columbia respectively (Figure 5). The three Tanzanian universities have many research aspects that are amenable to GIS application. Over the years, the universities have acquired many experts who are comfortable applying GIS. The experts focus mainly in applying the expertise to studies in Tanzania. On the other hand, foreign universities have many other places on the globe to apply their GIS expertise to and not only Tanzania.

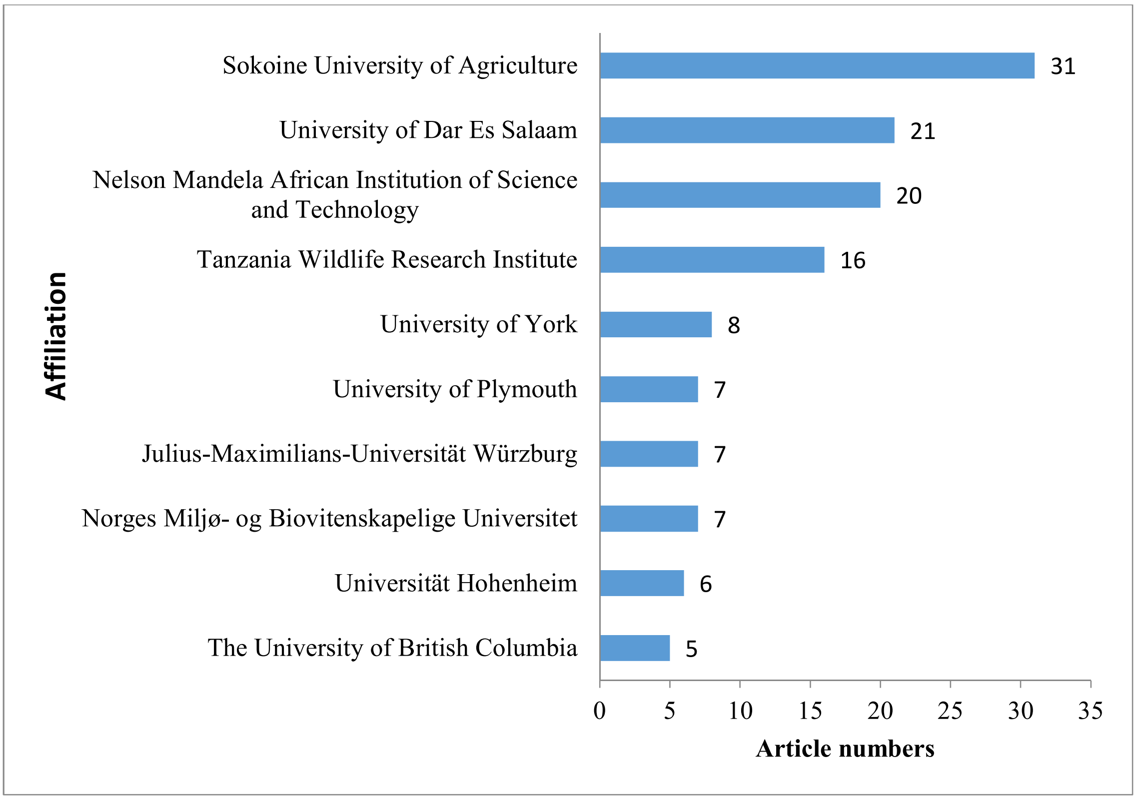


Figure 5. Distribution of publications by institution of authorship

4.0 Conclusions and recommendations

There is an increasing trend of application of GIS from 1 study in 1993 and years close by to 11 publications in 2021. The increase is due to better availability of expertise, tools and data needed for application of GIS. About 34%, 31%, 27% and 8% of the publications applied GIS respectively in environmental science, earth and planetary sciences, agricultural and biological sciences and social sciences. This is partly because the field applying GIS focus on the resource which are land based and more amenable to GIS than social sciences which focus on people whose link to land and hence application of GIS techniques is more complicated. On the other hand, there may be other reasons for least application of GIS in social sciences based studies. The words 'change', 'area' and 'Tanzania' were the most frequently used in titles and abstracts. This is because in most cases GIS is applied to assess change and all the studies were from

Tanzania and thus most of them must have used the word ‘Tanzania’ in their titles. Words in titles and abstracts formed about five clusters representing study area (e.g. Tanzania), method of analysis (e.g. remote sensing, assessment, data), topic of study (e.g. change, land use, land, conservation) and land use (e.g. grassland, woodland, forest). Most words clustered close together forming a meshwork but the word ‘conflict’ was the most distant from the rest of the meshwork. This is because the word ‘conflict’ is from social sciences while the rest of the words are from the other subject areas. GIS data sets used included land use land use/cover (LULC) layer, landscape features (e.g. rivers, roads, topographic variables) and socioeconomic data. Most publications came from Sokoine University of Agriculture, University of Dar es Salaam and Nelson Mandela African Institution of Science and Technology while the fewest came from Norwegian University of Life Sciences, Hohenheim University and the University of British Columbia respectively. This means that GIS technology is no longer foreign expertise. It is recommended that all fields apply GIS wherever appropriate. In particular, why GIS is least applied in social sciences aspects of rangeland management needs further investigation.

5.0 References

Al-bukhari, A., Hallett, S., & Brewer, T. (2018). A review of potential methods for monitoring rangeland degradation in Libya. *Pastoralism*, *8*(1), 13.

Chidodo, D. J., Kimaro, D. N., Hieronimo, P., Makundi, R. H., Isabirye, M., Leirs, H., Massawe, A. W., Mdangi, M. E., Kifumba, D., & Mulungu, L. S. (2020). Application of normalized difference vegetation index (NDVI) to forecast rodent population abundance in smallholder agro-ecosystems in semi-arid areas in Tanzania. *Mammalia*, *84*(2), 136–143.

Chitayat, A. B., Wich, S. A., Lewis, M., Stewart, F. A., & Piel, A. K. (2021). Ecological correlates of chimpanzee (Pan troglodytes schweinfurthii) density in Mahale Mountains National Park, Tanzania. In *PloS one*. journals.plos.org.

Gandhi, G. M., Parthiban, S., Thummalu, N., & Christy, A. (2015). Ndvi: Vegetation Change Detection Using Remote Sensing and Gis – A Case Study of Vellore District. *Procedia Computer Science*, *57*, 1199–1210.

Gizachew, B., Solberg, S., Næsset, E., Gobakken, T., Bollandsås, O. M., Breidenbach, J., Zahabu, E., & Mauya, E. W. (2016a). Mapping and estimating the total living biomass and carbon in low-biomass woodlands using Landsat 8 CDR data. *Carbon Balance and Management*, *11*(1).

Gizachew, B., Solberg, S., Næsset, E., Gobakken, T., Bollandsås, O. M., Breidenbach, J., Zahabu, E., & Mauya, E. W. (2016b). Mapping and estimating the total living biomass and carbon in low-biomass woodlands using Landsat 8 CDR data. *Carbon Balance and Management*, *11*(1), 13.

Godde, C. M., Boone, R. B., Ash, A. J., Waha, K., Sloat, L. L., Thornton, P. K., & Herrero, M. (2020). Global rangeland production systems and livelihoods at threat under climate change and variability. *Environmental Research Letters*, *15*(4), 044021.

Hunt E. Raymond, Jr., Everitt, J. H., Ritchie, J. C., Moran, M. S., Booth, D. T., Anderson, G. L., Clark, P. E., & Seyfried, M. S. (2003). Applications and Research Using Remote Sensing for Rangeland Management. *Photogrammetric Engineering & Remote Sensing*, *69*(6), 675–693.

Kariuki, R. W., Munishi, L. K., Courtney-Mustaphi, C. J., Capitani, C., Shoemaker, A., Lane, P. J., & Marchant, R. (2021). Integrating stakeholders' perspectives and spatial modelling to develop scenarios of future land use and land cover change in northern Tanzania. *PLoS ONE*, *16*(2).

Karl, J. W., Herrick, J. E., & Browning, D. M. (2012). A Strategy for Rangeland Management Based on Best Available Knowledge and Information. *Rangeland Ecology & Management*, *65*(6), 638–646.

Kayombo, C. J., Ndangalasi, H. J., Mligo, C., & Giliba, R. A. (2020). Analysis of Land Cover Changes in Afromontane Vegetation of Image Forest Reserve, Southern Highlands of Tanzania. *The Scientific World Journal*, *2020*, 1–13.

Khalid Kija, H., Ochieng Ogutu, J., Johana Mangewa, L., Bukombe, J., Verones, F., Jessen Graae, B., Ramadhani Kideghesho, J., Yahya Said, M., & Fred Nzunda, E. (2020a). Land

Use and Land Cover Change Within and Around the Greater Serengeti Ecosystem, Tanzania. *American Journal of Remote Sensing*, *8*(1), 1.

Khalid Kija, H., Ochieng Ogutu, J., Johana Mangewa, L., Bukombe, J., Verones, F., Jessen Graae, B., Ramadhani Kideghesho, J., Yahya Said, M., & Fred Nzunda, E. (2020b). Land Use and Land Cover Change Within and Around the Greater Serengeti Ecosystem, Tanzania. *American Journal of Remote Sensing*, *8*(1), 1.

Kideghesho, J., Rija, A., Mwamende, K., & Selemani, I. (2013). Emerging issues and challenges in conservation of biodiversity in the rangelands of Tanzania. *Nature Conservation*, *6*, 1–29.

Kija, H. K., Ogutu, J. O., Mangewa, L. J., Bukombe, J., Verones, F., Graae, B. J., Kideghesho, J. R., Said, M. Y., & Nzunda, E. F. (2020). Spatio-Temporal Changes in Wildlife Habitat Quality in the Greater Serengeti Ecosystem. *Sustainability*, *12*(6), 2440.

Kisoza, L. J. A. (2013). *Vegetation Cover Changes in Selected Pastoral Villages in Mkata Plains, Kilosa District Eastern Tanzania*. *15*(1), 71–91.

Kitalika, I. J., & Mlengule, D. W. (2021). *Assessing 30 Years of Land Use Dynamics in Usangu Catchment, Tanzania*. *41*(1), 18.

Kundi, B. B. A. T., Ngereja, Z., & Studies, A. (2003). Exploring GIS in Tanzania: Addressing Bottlenecks in GIS Development. *ISPRS Highlights*, *8*(December), 43–46.

Kwan, C., Gribben, D., Ayhan, B., Li, J., Bernabe, S., & Plaza, A. (2020). An Accurate Vegetation and Non-Vegetation Differentiation Approach Based on Land Cover Classification. *Remote Sensing*, *12*(23), 3880.

Lufafa, A., Tenywa, M. M., Isabirye, M., Majaliwa, M. J. G., & Woomer, P. L. (2003). Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. *Agricultural Systems*, *76*(3), 883–894.

Lupala, Z. J., Lusambo, L. P., Ngaga, Y. M., & Makatta, A. A. (2015). The Land Use and Cover Change in Miombo Woodlands under Community Based Forest Management and Its Implication to Climate Change Mitigation: A Case of Southern Highlands of Tanzania. *International Journal of Forestry Research*, *2015*, 1–11.

Macharia, D., Kaijage, E., Kindberg, L., Koech, G., Ndungu, L., Wahome, A., & Mugo, R. (2020). Mapping Climate Vulnerability of River Basin Communities in Tanzania to Inform Resilience Interventions. *Sustainability*, *12*(10), 4102. https://doi.org/10.3390/su12104102

Machiwa, H., Tian, B., Sengupta, D., Chen, Q., Meadows, M., & Zhou, Y. (2021). Vegetation dynamics in response to human and climatic factors in the Tanzanian Coast. *Frontiers of Earth Science*, *15*(3), 595–605. https://doi.org/10.1007/s11707-021-0916-7

Magita, S. Y., & Sangeda, A. Z. (2017). *Effects of climate stress to pastoral communities in Tanzania: A case of Mvomero District*. 6.

Mambo, P. W., & Makunga, J. E. (2017). APPLICATION OF REMOTE SENSING AND GIS FOR ASSESSING LAND COVER RESOURCES VARIABILITY IN THE SELOUS GAME RESERVE, TANZANIA. *European Journal of Technology*.

Misana, S. B. (2012). Land-use/cover changes and their drivers on the slopes of Mount Kilimanjaro, Tanzania. *Journal of Geography and Regional Planning*, *5*(6).

Mmbaga, N. E. (2017). How dynamics and drivers of land use/land cover change impact elephant conservation and agricultural. *Journal of Land Use Science*, *12*, 2–3.

Mmbaga, N. E., Munishi, L. K., & Treydte, A. C. (2017). How dynamics and drivers of land use/land cover change impact elephant conservation and agricultural livelihood development in Rombo, Tanzania. *Journal of Land Use Science*, *12*(2–3), 168–181.

Msofe, N., Sheng, L., & Lyimo, J. (2019). Land Use Change Trends and Their Driving Forces in the Kilombero Valley Floodplain, Southeastern Tanzania. *Sustainability*, *11*(2), 505.

Mtui, D. T., Lepczyk, C. A., Chen, Q., Miura, T., & Cox, L. J. (2017). Assessing multi-decadal land-cover – land-use change in two wildlife protected areas in Tanzania using Landsat imagery. *PLoS ONE*, *12*(9). https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0185468

Muna, M. E. and Hussein, M. S. (2017) Rainfall Erosivity, Land-Use and Land-Cover Change Analysis for Gadarif Region, Sudan. International *Journal of Water Resources and Arid Environments* 6(2): 252-260

Mwendwa, B. A., Kaaya, O. E., Kilawe, C. J., & Treydte, A. C. (2020). Spatio-temporal invasion dynamics of Maesopsis eminii in Amani Nature Forest Reserve, Tanzania. *Forest Ecology and Management*, *465*, 118102.

Naiposha, M. N., Nzunda, E. F., & Kashaigili, J. J. (2021). Participatory Land Use Planning Policy Implementation in Ulanga District, Tanzania: Assessment of Zones Sufficiency. In *Asian J. Environ. Ecol.*

Ojija, F., & Marco Manyanza, N. (2021). Distribution and Impact of Invasive <i>Parthenium hysterophorus</i> on Soil Around Arusha National Park, Tanzania. *Ecology and Evolutionary Biology*, *6*(1), 8. https://doi.org/10.11648/j.eeb.20210601.13

Raphael, L. J. (2018). *Vegetation Land Cover/Use Dynamics and Their Effects in Mbulu and Karatu Districts in the North-Eastern Highlands of Tanzania*. 25.

Rwetabula, J., & Smedt, F. D. (2005). *LANDUSE AND LAND COVER MAPPING OF THE SIMIYU CATCHMENT (TANZANIA) USING REMOTE SENSING TECHNIQUES*. 13.

Tarimo, B., Dick, Ø. B., Gobakken, T., & Totland, Ø. (2015). Spatial distribution of temporal dynamics in anthropogenic fires in miombo savanna woodlands of Tanzania. *Carbon Balance and Management*, *10*(1), 18.

Twisa, S., & Buchroithner, M. F. (2019). Land-Use and Land-Cover (LULC) Change Detection in Wami River Basin, Tanzania. *Land*, *8*(9), 136.

Winowiecki, L., Vågen, T. G., Massawe, B., Jelinski, N. A., Lyamchai, C., Sayula, G., & Msoka, E. (2016). Landscape-scale variability of soil health indicators: Effects of cultivation on soil organic carbon in the Usambara Mountains of Tanzania. *Nutrient Cycling in Agroecosystems*, *105*(3), 263–274.

Zhang, H., Huang, M., Qing, X., Li, G., & Tian, C. (2017). Bibliometric Analysis of Global Remote Sensing Research during 2010–2015. *ISPRS International Journal of Geo-Information*, *6*(11), 332. https://doi.org/10.3390/ijgi6110332

Appendix I: Methodological approach of GIS Applications in rangeland resource Management in Tanzania

GIS Applications in rangeland resource Management	Reference	Method of analysis	Key findings
Land use/land cover	Kija *et al.,* 2020	Used random forest classification algorithm to classify Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (+ETM) and Operational Land Imager (OLI) into eight main classes	Grassland, shrub land and woodland were the major LULC types throughout 1975-2015 with percentage coverages of 50.6%, 23.7% and 20.9% for 1975; 54.2%, 23.5% and 15.9% for 1995; and 57.0%, 23.8% and 8.9% for 2015, respectively. “Overall, woodland cover (-11.1%) was converted to most of the other cover types during 1975-2015. The loss of woodland cover is due to increasing human population size, agriculture, settlements and policy changes fires and elephant browsing.
	(Nzunda & Midtgaard, 2019)	Assesses LUCC for the whole of the mainland Tanzania. The analyses were done using land use and cover maps covering the whole of mainland Tanzania for 1995 and 2010.	For 1995, forest, bushland, grassland, cultivation and other land use and cover (built up areas, bare land, etc.) covered 43.5%, 19.8%, 23.5%, 11.2%, and 2.0% of the study area, respectively. For 2010, the same land use and cover classes covered 38.0%, 14.5%, 6.9%, 36.5%, and 4.1% of the study area, respectively. The annual rate of deforestation was 320,067 ha, which is equivalent to 0.9%. Bushland and grassland were lost at 313,745 and 969,982 ha/year, respectively.
	Mmbaga *et al.,* 2017	Used remote sensing and geographical information system techniques, questionnaires and village meetings to assess spatio-temporal patterns of the LULC changes in the study area. Using Landsat imagery, digital elevation model (DEM) and ground truthing, they classified and monitored changes in LULC from the years 1987 to 2015.	Found that within Rombo, settlements were increasing, while agricultural and agroforestry lands were decreasing and respondents’ perceptions varied along the altitudinal gradient. Patterns of LULC were observed to change along the gradient and the later threatened the agricultural land and ecological integrity for elephant habitat, leading to high tension and competition between elephants and people.
	Misana, 2012	Data extracted from remote sensing techniques using 1973, 1984 and 1999/2000 satellite images and household interviews.	The area under cultivation increased from 54% in 1973 to 62 and 63% in 1984 and 2000, respectively. Expansion and intensification of cultivation were noted particularly in the lowlands

			while some forest areas in the highlands had become degraded.
	Kitalika and Mlengule, 2021	Employed historical data search, which include Landsat 5 Thematic Mapper and Landsat 8 Operational Land Imager collected from the United States Geological Survey. Additional data were generated from field observation in specific GPS points for classification accuracy assessment. In-depth interview with key informants served as a useful means of collecting land use information.	The results suggest that land use and land cover had a remarkable transformation during the 30 years of the study period. Open bush land gained 4.34% of land from mixed forest in 2006-2017. Water bodies area decreased by 2.4% between 1986 and 1996 due to an increase in bare land by 1.2% in the catchment. Land for agriculture rose by 2.6% in 1996-2006, but declined by 4.5% in 2006-2017
	Kashaigili and Majaliwa, 2010	Investigated long-term and seasonal changes that have occurred as a result of human activities in the area for the periods between 1984 and 2001. Landsat TM and ETM+ images were used to locate and quantify the changes. Perceptions of local people on historical changes and drivers for the changes were also collected and integrated in the assessment.	The study revealed a significant change in land use and cover within a period of 18 year. Between 1984 and 2001, the woodland and wetland vegetation covers declined by 0.09% and 2.51% per year. Areas with settlements and cultivation increased by 1.05% annually while bushed grassland increased at 1.93% annually.
	Rwetabula and Smedt, 2005	Combined remote sensing, Idrisi32 release 2 image processing software, GIS and extensive and detailed ground information to map land use and land cover of the Simiyu catchment.	The Simiyu catchment is by far dominated by mixed short grasses and open land (46.5%). This suggests that the Simiyu catchment is highly subjected to erosion.
	Msofe *et al.*, 2019	Moderate resolution Landsat images were freely downloaded from the United States Geological Survey (USGS) archives, analysed using the random forest (RF) algorithm and mapped in ArcGIS 10.2 software to examine the LUC trends from 1990 to 2016 in the Kilombero valley floodplain (KVFP). Participatory rural appraisals (PRA) and household questionnaire surveys were also used to assess the potential drivers of LUC.	The results show that, from 1990 to 2016, the agricultural land and grassland increased by 11.3% and 13.3%, respectively, while the floodplain wetland area decreased from 4.6% in 1990 to 0.9% in 2016.

Vegetation composition	Mtui et al., 2017	Used Maximum Likelihood classification procedures we derived eight land-cover classes from Landsat TM and ETM+ images, including: woody savannah, savannah, grassland, open and closed shrub land, swamp and water, and bare land.	The results show declines in woody savannah and increases in barren land and swamps inside and outside Tarangire National Park and increases in woody savannah and savannah, and declines of shrubland and grassland inside and outside Katavi National Park.
	Komba et al., 2021	Used LandTrendr algorithm and Google Earth Engine to access satellite data and explore the vegetation dynamics history across the Ruaha–Rungwa landscape, Tanzania	Between 2000 and 2019, 36% of the vegetation was significantly disturbed by anthropogenic activities. The results of this study show that the disturbance trends, severity, and patterns are highly variable and strongly depend on the management approaches implemented in the heterogeneous landscape: Ruaha National Park (RNP), Rungwa–Kizigo–Muhesi Game Reserves (RKMGR), and the surrounding zones.
	Kisoza, 2013)	The GIS data sources include MSS satellite image of 1975, Landsat TM images of 1991 and 2000.	The main vegetation cover types in the study area include: wooded grassland (23.5%), bush grassland (20.12%), bush land (15.15%), woodland (11.65%), open grassland (5.2%), and cultivation area (18.64%). Net area cover changes between 1975 and 2000 include: 4 times increase in bush land, – 66.7% loss of open grassland and + 95.3% increase of wooded grass lands.
	(Raphael, 2018)	The present study assesses the spatial distribution of VLC/LU dynamics from 1987 to 2015 in the North-Eastern highlands of Tanzania using both qualitative (in-depth interviews and focus group discussions) and quantitative techniques (spatio-temporal analysis through GIS). T	The results identified the presence of forest, woodland, bush land, grassland, wetland, cultivated land, bare soil, water, and settlements (built up area). Throughout the period 1987-2015, wetland, settlement (built-up area), cultivated land and bare soil expanded at an average rate of 42.15%, 15.66%, 12.09% and 6.41% per year at the expense of grassland, woodland, water, forest and bush land which declined by 2.68%, 2.5%, 2.04%, 1.36% and 0.12% per year, respectively. The vegetation land cover/use dynamics of 1987-

			2015 resulted in the reduction/loss of plant species, occurrence of soil erosion and ramification of gullies.
Mapping of invasive species	Ojija and Marco Manyanza, 2021	Parthenium hysterophorus density was visually estimated as high, medium, and low when the invasive individuals were > 4, 3–4, and 1–2 in 1 m2 quadrats, respectively. The results showed that albeit some adjacent villages are invaded,	The results showed that albeit some adjacent villages are invaded. Parthenium hysterophorus was observed growing in grazing areas, maize and banana fields in villages, and along road verges, with particularly high densities in maize fields, along roadsides, and at lower altitudes.
	Mwendwa *et al.,* 2020	Assessed spatio-temporal invasion dynamics using forest inventory data collected in 1998 and resurveyed 60 (20 m × 50 m) sample plots in 2018. We also assessed vegetation cover change over a 20 year period between 1998 and 2018 using Landsat satellite images.	Among resurveyed plots, 30 had been invaded by M. eminii in 1998 and other 30 sample plots as control, which had no M. eminii in the year 1998. Over the last 20 years, 23% of control plots were newly invaded by M. eminii.
Mapping soil carbon	(Winowiecki et al., 2016)	Biophysical field surveys were conducted in a 100 km^2 landscape near Lushoto, Tanzania, with composite soil samples collected from 160 sampling plots. Maps of SOC were generated using RapidEye imagery with good performance.	The results of the study showed a decline in SOC as a result of cultivation, with cultivated plots (n = 105) having mean topsoil OC of 30.6 g kg-1, while semi-natural plots (n = 55) had 71 g OC kg-1 in topsoil. Cultivated areas were also less variable in SOC than semi- natural systems.
Aboveground biomass	(Gizachew et al., 2016a)	Inventory data consisted of tree measurements from 500 plots in 63 clusters in a 15,700 km2 study area, in miombo woodlands of Tanzania.	Found a linear relationship between TLB and Landsat 8 derived spectral variables, and there was no clear evidence of spectral data saturation at higher biomass values.