

GIS application in rangeland management in Tanzania: a systematic review

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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.*

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, rangelands 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.

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	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)

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.

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). The article search was done between 20 February 2022 and 25 February 2022. 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 irrelevant were excluded. As a result; we selected 138 records were for the subsequent phases. The eligibility phase entailed examining numerous articles 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 analysis¹. 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).

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

¹ These publications can be accessed at: https://docs.google.com/document/d/e/2PACX-1vT1B8DbS2ZjTfdwuPAAsiICBg00iNhEMS7QwkK3HpKHT9ghVANtw6lFBVnPQRktDvYzEX8rq_kw3DT8/pub

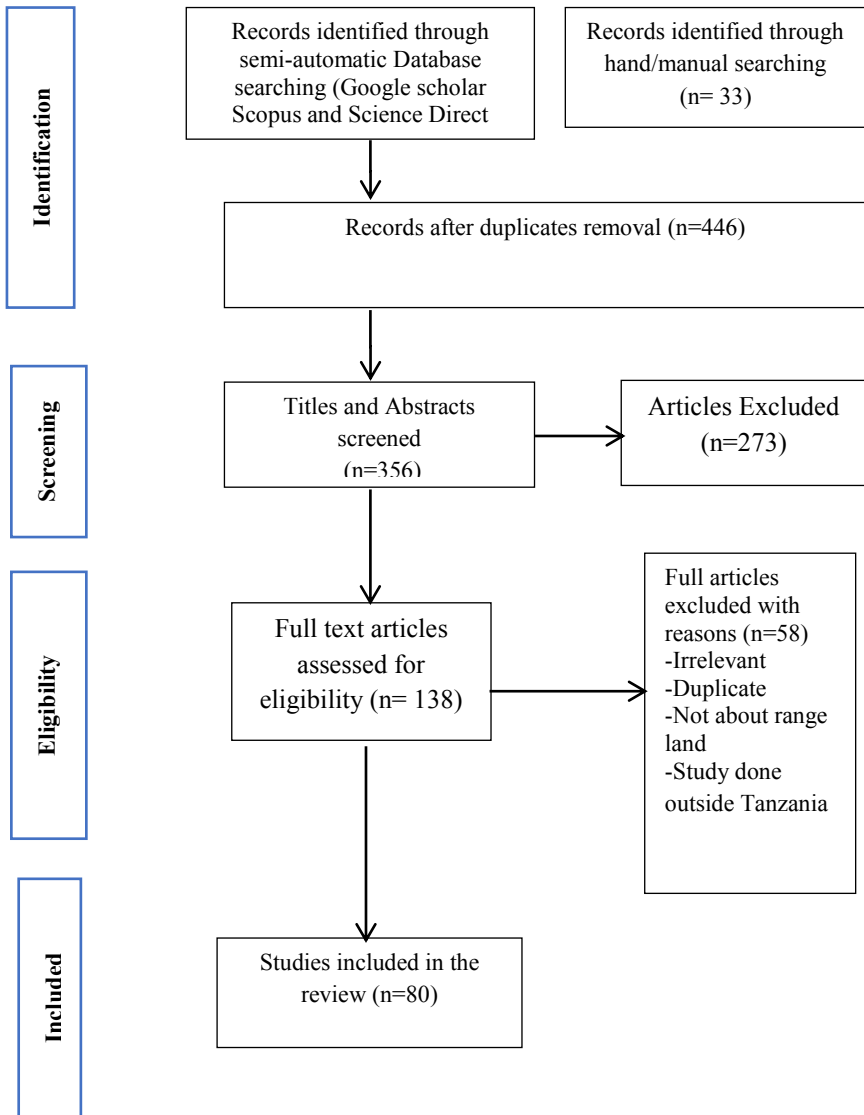


Figure 1. Flow Diagram of article screening to obtain studies that applied GIS in rangeland resource management in Tanzania: the PRISMA framework

Results and discussion

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.

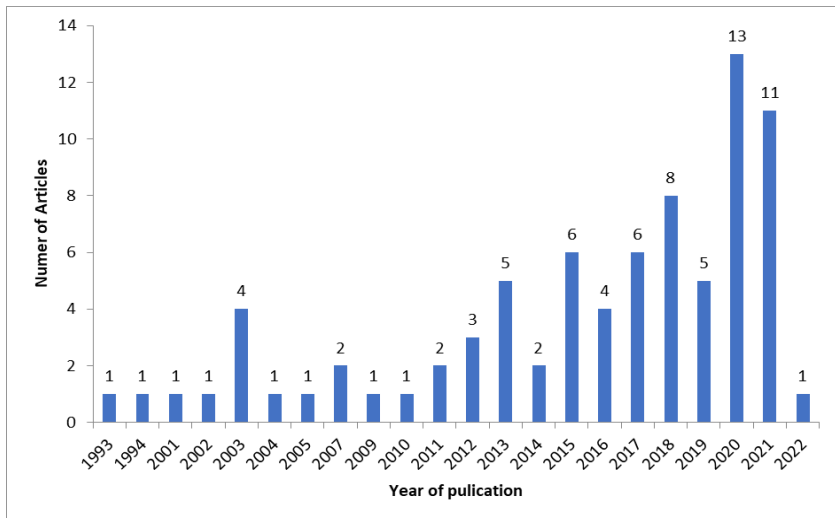


Figure 2: Publications on studies that applied GIS in rangeland management by year of publication

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

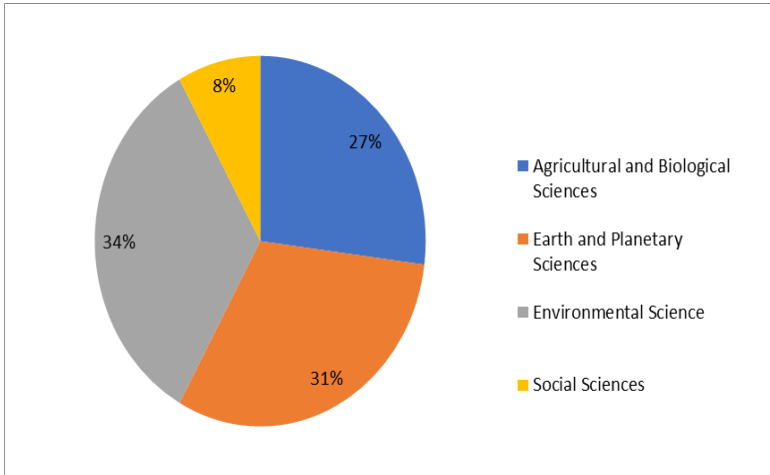


Figure 3: Percentage of records retrieved by subject area covered by studies that applied GIS in rangeland resource management in Tanzania

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. It is also worth noting that words that denote more details of rangeland management activities such as

grazing management, planned grazing, rotational grazing, forage biomass, water resources monitoring, livestock carrying capacity and forage conservation plans are missing from the keywords of the studies. This suggests that there is no documentation of GIS application in rangeland management with regards to those activities.

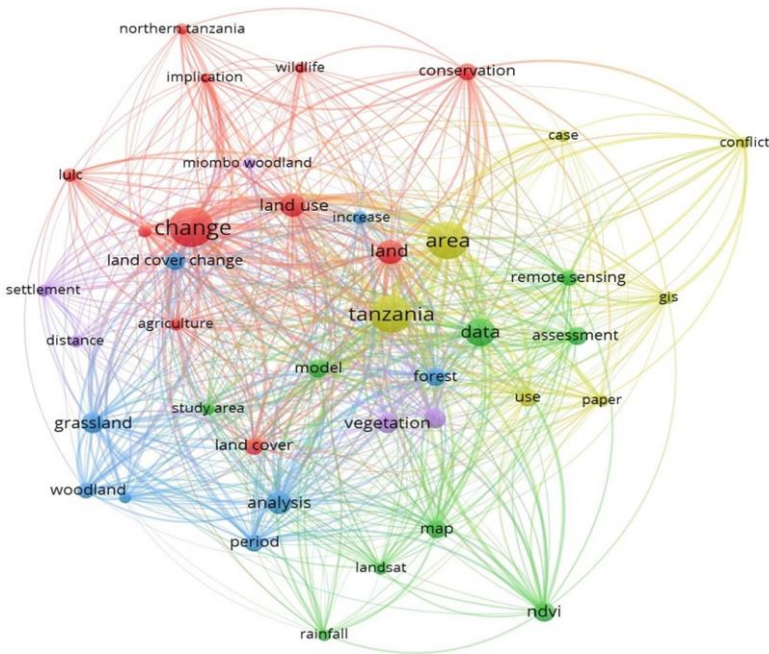


Figure 4: Mostly used terms in the articles indicating clusters in studies that applied GIS in rangeland resource management in Tanzania. Words with same colour belong to the same cluster. The farther apart the words the less their frequency of co-occurrence. The bigger the circle the more frequently 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.

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 <i>et al.</i> , 2017; S. Makero and J. Kashaigili, 2016)
Landscape features (rivers, roads, boundaries etc)	(Mmbaga <i>et al.</i> , 2017.)
Socioeconomic data	(Kariuki <i>et al.</i> , 2021; Lupala <i>et al.</i> , 2015; Macharia <i>et al.</i> , 2020; Naiposha <i>et al.</i> , 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 <i>et al.</i> , 2020a, 2020b; Kitalika and Mlengule, 2021; Nzunda and Midtgaard, 2019)
Mapping of invasive species	(Ojija and Marco Manyanza, 2021)
Monitoring of soil erosion	(Lufafa <i>et al.</i> , 2003)
Mapping fire extent	(Tarimo <i>et al.</i> , 2015)
Aboveground biomass	(Gizachew <i>et al.</i> , 2016b)
Vegetation cover assessment	(Kayombo <i>et al.</i> , 2020)

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.

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.

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.

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.

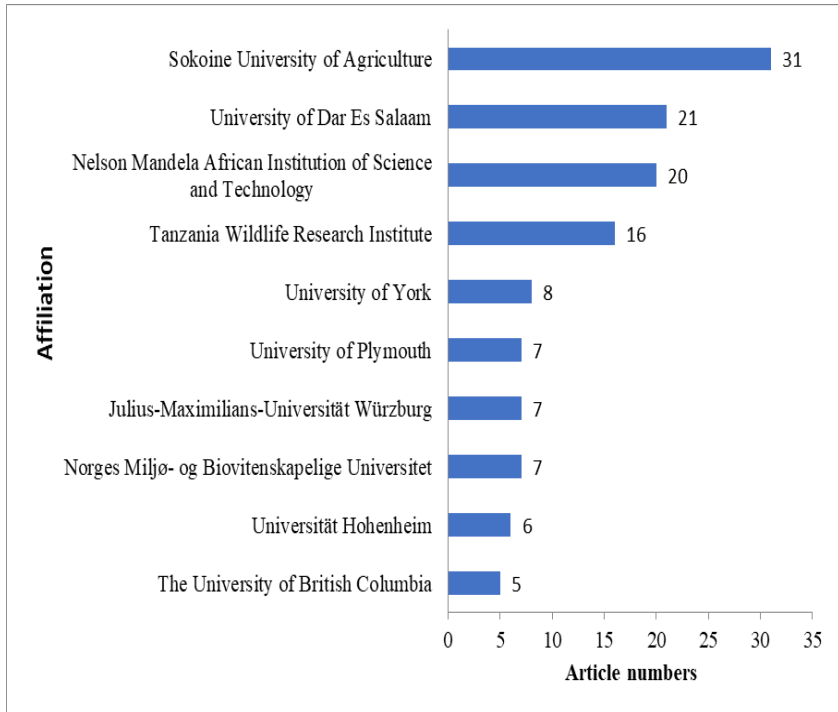


Figure 5. Distribution of publications by institution of authorship

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 and

for such rangeland management activities as grazing management, planned grazing, rotational grazing, forage biomass, water resources monitoring, livestock carrying capacity and forage conservation plans needs further investigation.

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