

Use of Remote Sensing and GIS Techniques for Land Use Mapping at Four Selected TaCRI Stations, Tanzania

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Received February 12, 2024; Revised March 14, 2024; Accepted March 21, 2024

Abstract Most major agricultural research stations in Tanzania have adopted the geographic information systems (GIS). Tanzania Coffee Research Institute (TaCRI) was late to come on board because its establishment does not include a cartographic unit. Collaboration with TARI-Mlingano in 2008/09 enabled the initiation of a mini-GIS unit at Lyamungu. One of its tasks was to develop digital maps of the TaCRI substations scattered over major coffee zones in Tanzania. Four substations were chosen to start with. For Lyamungu, a non-georeferenced paper map was scanned and 8 control points selected, whose x-y coordinates were taken with a GPS tool. They were loaded into Excel spreadsheet and saved as a .csv file. The image and the point shapefile were properly aligned in ArcMap 10.7.1 and digitized onscreen. Ugano, Mbimba and Mwayaya maps were digitized from satellite images remotely sensed with Google Earth Pro, saved first as .kmz files, and converted in ArcMap to features and later to shapefiles. Land use was elaborated using expert knowledge. The resultant was the first ever digital maps of the four substations. Created shapefile layers included boundary, rivers, roads and fields (categorized as coffee land, other crops, forest reserve, other reserves, wetlands and waterbodies, nurseries and general infrastructure). Land use per category showed to have a bearing on station history, current land ownership status and staff population. Percentage land assigned to coffee decreased in the order Lyamungu > Mwayaya > Ugano > Mbimba. This work has formally introduced TaCRI to the GIS world – an important step as GIS is becoming ubiquitous in global research, planning and problem solving. It was also a very good starting experience with ArcMap and Google Earth.

Keywords: Digital maps, GIS techniques, land use mapping, remote sensing, TaCRI stations

Cite This Article: Maro G.P., Mbwambo S.G., Monyo H.E., and Mosi E.J., “Use of Remote Sensing and GIS Techniques for Land Use Mapping at Four Selected TaCRI Stations, Tanzania.” *Journal of Geosciences and Geomatics*, vol. 12, no. 1 (2024): 6-11. doi: 10.12691/jgg-12-1-2.

1. Introduction

Geographic information system (GIS) is the type of database containing geographic data (latitude, longitude and altitude), combined with software tools for managing, analyzing, and visualizing those data. In a broader sense, one may consider such a system to also include human users and support staff, procedures and workflows, body of knowledge of relevant concepts and methods, and institutional organizations [1]. Geographic information systems are utilized in multiple technologies, processes, techniques and methods. They are attached to various operations and numerous applications, that relate to: engineering, planning, management, transport/logistics, insurance, telecommunications, business [2] and precision agriculture [3], among others.

GIS is a rather new discipline in Tanzania as compared to the rest of the world, and its usage is picking up pace fast [4]. Many of the research and academic institutions involved in cartography are gradually embracing GIS at

varying intensities depending on the usage of the ensuing maps. For instance, the National Bureau of Statistics maintains a polygon shapefile map of Tanzania at the scale of 1: 2,000,000, down to ward level, for purposes of censuses [5,6]. GIS labs exist in universities like UDSM, ARDHI, SUA, etc. for training purposes [7,8], and in major agricultural research institutes like TARI-Mlingano which harbours the largest and most sophisticated GIS lab in the country. Tanzania Coffee Research Institute (TaCRI), as one of the major research institutions, was late to come on board, likely because its establishment does not include a cartography unit. During the PADEP Collaborative Soils Project that covered Kasulu, Kibondo, Tarime and Rorya Districts in 2008/09 [9], TaCRI borrowed several shapefiles from TARI-Mlingano, which enabled the establishment of a mini-GIS unit at its Soil Fertility Lab. Its first of several tasks was to create digital maps of the TaCRI substations that are scattered in major coffee growing zones of Tanzania; with focus on land use, which would be useful for planning purposes [10]. This paper discusses the efforts done in this regard, milestones achieved so far and the perspectives of GIS usage.

2. Materials and Methods

2.1. Study Areas

Four substations were chosen to start with. Lyamungu lies approximately at Latitude -3.2442 and Longitude 37.2462 in decimal degrees, with altitude 1305 metres above sea level (masl). Soils are classified as Haplic Nitisols (Humic, Dystric) [11]. Mbimba substation lies approximately at Latitude -9.0915 and Longitude 32.9543, with altitude 1400 masl. Soils are classified as Haplic Alisols (hyperdystric, profundic) [12]. Ugano substation lies approximately at latitude -10.9702 and longitude 34.9218, with an altitude of 1460 masl. Soils are classified as Chromi-Ferric Acrisols. Mwayaya substation lies approximately at latitude -4.4742 and longitude 29.8205, with an altitude of 1507 masl. Soils are classified as Haplic Ferralsols and Ferralic Cambisols, all according to the WRB [13].

2.2. Paper Map Digitization

Paper map digitization followed procedures analogous to [14]. A non-georeferenced paper map of TaCRI Lyamungu (Figure 1) was scanned and saved as a picture file which would later serve as a raster base map. The map was carefully scrutinized and a total of 8 points were selected; four of them located at the border to represent the northernmost, westernmost, southernmost and easternmost extent of the map, and the other four strategically located within the map itself. These places, in real world, were visited and their x-y coordinates taken with a GPS tool. They were loaded into Excel spreadsheet and saved as a .csv file. The file was opened in ArcMap 10.7.1, assigned the WGS-84 reference and exported as a point shapefile. On ArcMap, the image and the point shapefile were properly aligned; then the control points were inserted in the image and snapped into the shapefile. Several empty polygon and line shapefiles were created on ArcCatalog, digitized on ArcMap and saved separately as complete map layers. We used expert knowledge to assign different colours to different categories of land use, such as infrastructure (or settlements), coffee farms (fully commercial, partly commercial, fully field experiments, germplasm collections), other annual crops, nurseries, forest and riparian reserves.

2.3. Remote Sensing with Google Earth

Ugano, Mbimba and Mwayaya maps were digitized from raster images remotely sensed with Google Earth Pro (Figure 2), as outlined by [15]. The satellite data were from National Oceanic and Atmospheric Administration (NOAA) and the US Navy; image LANDSAT/Copernicus. Areas were searched by names and, where naming ambiguity was noted (e.g. for Ugano), by decimal degrees earlier read onsite with a GPS tool. The area was zoomed in to fit the screen or to the extent where points, lines and polygons (like buildings, etc.) were clearly visible. Within a folder “my places”, three subfolders were opened and named “placemarks”, “polylines” and “polygons”. With subfolders active, points, lines and polygons were separately digitized and properly named. A folder named

“my kmz files” was created under “documents” and the whole folder saved there as .kmz file. The folder was linked, through ArcCatalog, to ArcMap. Within ArcMap, the subfolders were converted from kmz to features using the conversion tool from ArcToolbox. They were later exported as data to shapefiles. Usual editing proceeded as in any other digital maps, including assigning different colours to categories of features, etc. We assigned different colours to different categories of land use, based on visual observation and expert knowledge.

2.4. Map Finalization

The GIS work in both cases was handled according to [16]. We considered it prudent to show relative location of each substation within the host district, and each district within the country. We therefore made three data frames linked to one another, two insets for the country and district, and the main frame for the study areas. In the layout view, configured to A4 landscape, we separated the three data frames and rearranged them accordingly. Usual map elements (legend, scalebar and north arrow) were affixed as pertaining to the main data frame, together with tick-based graticules. They were then exported as .jpg files for use in other applications. No attempt was made to automatically calculate and compare areas used in different categories as in [17], as this would require reprojection to UTM, thus risking further distortion. As such, the percent coverage was visually estimated.



Figure 1. The non-georeferenced paper map, Lyamungu



Figure 2. An extract map of Tanzania from Google Earth

3. Results

3.1. Digital Maps

Figures 3, 4, 5 and 6 are the first ever digital maps of the four TaCRI substations. The maps consist of the boundary shapefile layers which are single polygon features covering the whole station areas. These show the true extent of the stations, and serve as base maps within which any point-based data over the stations can be interpolated. There are also rivers shapefile layers whose orientation can give a clue on the terrain structure, the roads shapefile layers which have three line features (main roads/highways, access roads and feeder roads), and whose networks (implying traffic) give the map a “touch” of life. The infrastructural shapefile layer shows all infrastructures (residential houses, factories, stores, etc.), and their relative distance from one another, information that may be needed when addressing issues of placement of new infrastructures. The land use shapefile layers show individual farms and blocks as separate polygons, categorized as coffee farms (commercial, semi-commercial, research and germplasm) other crops (mainly annual food crops grown by substation staff), nursery, forest, riparian and other reserves. This serves to direct any visitor with interest on certain land use types, like environmentalists interested in forest areas and their contribution towards mitigation of climate change.

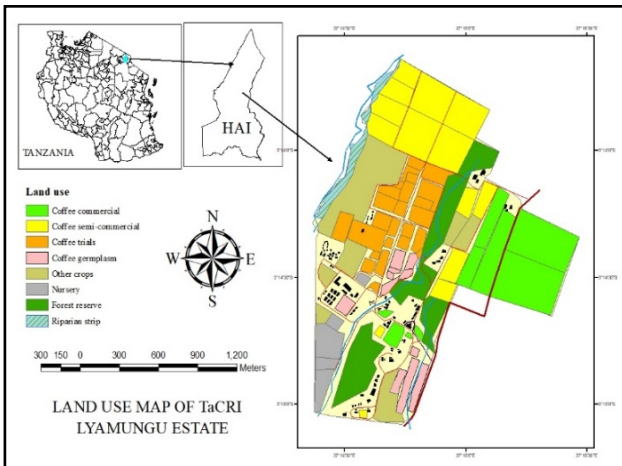


Figure 3. Land use map of TaCRI Lyamungu station

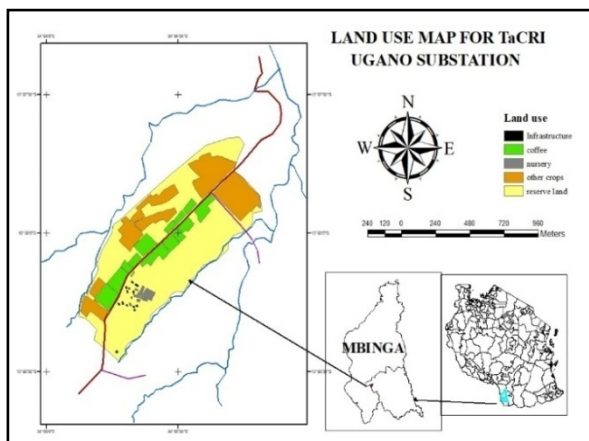


Figure 4. Land use map of TaCRI Ugano station

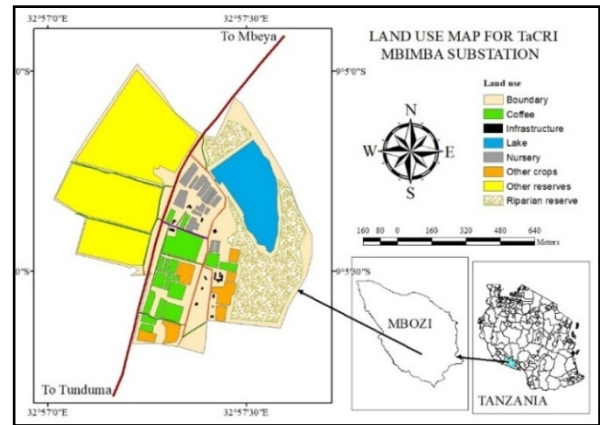


Figure 5. Land use map for TaCRI Mbimba station

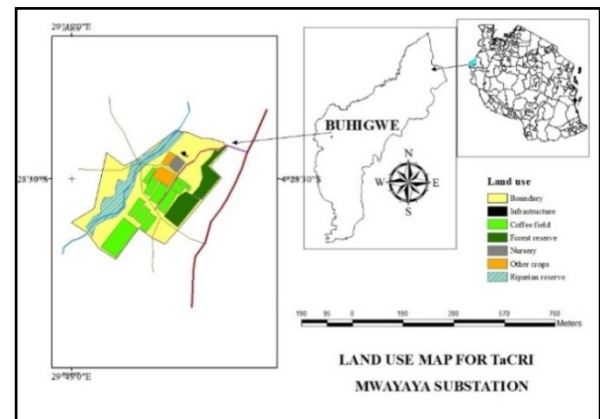


Figure 6. Land use map for TaCRI Mwayaya station

3.2. Land Use Distribution

Table 1 shows the percent distribution of different land use categories across the four substations. At Lyamungu station, the bulk of the land (65%) is allocated to coffee, further categorized as commercial (20%), semi-commercial (20%), field experiments (20%) and germplasm blocks (5%). Another coffee-related land use is the nursery (5%), but this is treated differently since its output is seedlings rather than coffee yields. In the other three stations, the coffee land use was not sub-categorized as the data source did not provide for that. Ugano had 22% and Mbimba had 15%, while Mwayaya had 35%.

Lyamungu and Mwayaya had 10% each as forest reserves, though the former is larger, more natural and more attractive. It once earned Lyamungu a “Presidential Environmental Protection Trophy” as the only spot of its kind, natural, unaltered at its altitudinal range (1200-1300 masl) in the entire Kilimanjaro Region. What is referred to as forest reserve at Mwayaya is, in fact, not a forest; but rather a woodland of scattered eucalyptus trees and tufted grasses. The category “other reserves” missing at Lyamungu, showed to be substantial in the other stations. Whereas Ugano and Mbimba are in the process of settling issues of ownership of some land in this category, Mwayaya was delineated quite recently, and is yet to utilize its full potential. Wetlands and water bodies are more in Mbimba (30%, including a lake), and Mwayaya (19%). The rest have 2% each. As for infrastructural developments and their immediate neighbourhood, stations differ widely, even though Ugano and Mwayaya

are given 1% each. Mwayaya infrastructures are just being developed, and appear to be concentrated in a very small area. Lyamungu is an outlier here with as much as 8% of infrastructures. This explains its status as TaCRI Headquarters harbouring over 50% of the entire TaCRI staff. The next in the list is Mbimba, with 5% of land allocated to infrastructural development.

Table 1. Land use distribution across TaCRI stations

S/ No	Category	Percentage land use per category			
		Lyamungu	Ugano	Mbimba	Mwayaya
1	Coffee land	65	20	15	35
2	Other crops	10	24	10	5
3	Forest reserve	10	0	0	10
4	Other reserves	0	51	30	28
5	Wetlands and water bodies	2	2	30	19
6	Nursery	5	2	10	2
7	General infrastructure	8	1	5	1

4. Discussion

4.1. Background to GIS

A detailed history of GIS is given by [18]. The first computerized GIS in the world was developed in Canada by Roger Tomlinson, who even coined the name GIS; and is rightfully referred to as the “father of GIS”. Commercial GIS started with the Environmental Systems Research Institute (ESRI) which released ArcInfo in 1981 [19,20], ArcView in 1996 [21] and ArcGIS in 1999 [22,23]. There are many other commercial GIS software products nowadays. For instance, [1], in his lectures on land information systems, introduced CartaLinx and IDRISI, sister software developed by experts at Clark University's Labs. The two work in complementarity, the former having strength with vector files while the latter is stronger with raster data. Others include the Integrated Land and Water Information System (ILWIS) developed in the University of Twente, Enschede, the Netherlands, and MapInfo developed by Pitney Bowes Software. The two can handle both vector and raster data. More recently, a growing number of free, open-source GIS packages run on a range of operating systems and can be customized to perform specific tasks; the commonest being QGIS [24].

4.2. Remote Sensing and Use of Google Earth

According to [25], remote sensing, in the geographical perspective, is looking at the earth while outside it, like in an airplane. The two authors also give a detailed history of remote sensing, from rocket-propelled camera systems way back in 1891, through the Corona military system in 1960, followed by Mercury, Gemini and Apollo systems soon afterwards. In 1972, the ERTS system was launched, a precursor to what we now call the LANDSAT system. Several other satellite systems exist, such as SPOT (developed by France in 1978), RESURS (Russia, 1985), IRS (India, 1988) and IKONOS (US, 1999), among others. Google Earth was launched in 2005 [26]. It is a “virtual

globe”, mapping and geographical information platform that superimposes images remotely sensed from satellite imagery, aerial photography and GIS 3D globe. Google Earth uses digital elevation model (DEM) data collected by NASA's Shuttle Radar Topography Mission (SRTM). Its internal coordinate system is geographic coordinates (latitude/longitude) on the WGS84 datum i.e., the same datum configured to GPS. Via satellite imagery, maps, terrain, 3D buildings and other locational data, Google provides viewers with “a more realistic view of the world”. It is free for download and installation on every computer system, and is widely used for different projects such as photogrammetry [27], accident reconstruction [28], library settings [29] and land use, especially in the urban areas [30,31]. Its use in this work is justified, even though the areas are not exactly urban.

4.3. The Concept of Map Processing

According to [32], digital map processing (or simply map processing) is defined as computational procedures aimed at the automatic or semi-automatic extraction and/or recognition of geographic features contained in scanned images of maps. Its aim is to extract and recognize geographic information results in spatially referenced data (i.e., map data) that can then be accessed, processed, and maintained in a GIS environment (in other words, “unlocking” geographic information from map documents). It can also expedite the processes of comparing map contents from different map series/editions (e.g., contemporary maps vs. historical maps), to update current map series, and to create thematic maps or new map series.

Paper maps can be georeferenced, like in standard topo sheets; whereby the x-y coordinates serve as ground control points. These can be easily digitized on a digitizing tablet using a robust software like ArcInfo, as used by [3] in evaluating land for sugarcane at TPC Estate. On the other hand, there are cases where the paper maps are just sketches (not georeferenced), like in this particular case, whereby one has to rely on permanent addresses like road intersections, sharp corners, permanent structures, trees etc. In case these are labelled in the sketch map, you need to physically visit them with a GPS tool to record their x-y coordinates. Then the whole process of georeferencing and digitization can be done onscreen with software like ArcGIS or QGIS.

Once you have a digital image of the paper map ready for digitization, the process is quite easy because you can clearly see boundaries. With Google Earth it is much more difficult because you will be digitizing from a “real” world, with live impediments such as trees blocking your way, so you won't be seeing boundaries correctly. As a result, polygons end up larger, or smaller, than they should normally be. Lyamungu, for instance, is so full of such impediments as to become virtually impossible to digitize on Google Earth. The three maps (Ugano, Mbimba and Mwayaya) are therefore rough estimates, and should not be relied upon entirely when making serious decisions about the land. They should only serve as sketches on basis of which to plan an actual land survey, in order to correctly delineate the land parcels. This view is supported by [26], even though [17] and [31] appreciated its accuracy with

small urban areas having minimum plant interference. The ground interference issue has been touched by many authors, and a number of mitigation measures suggested like Laplacian pyramids [33] and Wavelet/QMF pyramids [34], both currently under evaluation.

4.4. Implication of the Results

Transformation from an old paper map, archived and literally useless, to a digital map that can be stored indefinitely without losing its usability, and which can be maneuvered and updated appropriately, is itself a big achievement [35]. So is the discovery and use of existing online mapping engines such as Google Earth and Google Map [26]. The following describe the importance of the created maps: Knowledge of land use distribution in an area provides information to decision makers on how to better, and more sustainably, utilize the land. There has been pressure from TaCRI stakeholders to allocate more land for coffee, so as to boost the internal coffee output, thereby leveraging their contributions in seasons of low world coffee prices [36]. We see, from the maps, that at Lyamungu (with only 10% of land servicing over 50% of staff population), the only approach in increasing production is intensification in existing coffee farms rather than expansion. Avenues for expansion exist in the other substations, and efforts should focus on spearheading the settlement of land issues at Ugano and Mbimba; and investing more at Mwayaya where the title deed process was concluded recently.

Mapping also helps in making rational decisions on sustainable use of environmental hotspot areas such as forest reserves, wetlands and water bodies [24]. The lowland ones at Mbimba should be protected against encroaching neighbours aiming at producing wetland crops like paddy; whereas the sloppy ones at Mwayaya should be (re)afforested with short-stature shrubs to conserve the soil against erosion. Mapping also helps in deciding where to install a new infrastructural facility based on the distribution of existing infrastructures [4]. For instance, if we have a new pulper to install at Mwayaya, we will try to get as far away as possible from the already congested office-residence complex for aesthetic reasons.

4.5. The GIS Perspective in Tanzania

Most district councils in Tanzania, especially those that have been in existence for at least 20 years, used to have hard copies of their respective topo sheets. Because of age, misuse and neglect, these, where they still exist as in Mbozi, are in so bad a shape as to be useless. No such maps could be traced for Ugano or Mwayaya, the latter case even further complicated by the fact that Buhigwe is a new district. In this work therefore, reliance on Google Earth [26] came as alternative strategy, after failure to get paper maps from those districts. The Government is now turning to the GIS technology, and considerable investments have been committed in facilitating local government authorities to embrace the same, a move observed to be slower than expected. According to [37], the government has issued guidelines which literally instruct all regional and district offices to establish GIS desks for preparation of general planning schemes. This means that, in the near future, GIS will be ubiquitous in

the Tanzanian LGAs. Research institutions, and especially soil laboratories, which are sources of soil fertility information to the LGAs, need to brace themselves up for that. LGAs will soon start demanding georeferenced data in soft form to feed into their systems for their own manipulations. It is therefore imperative for soil laboratories in the country, whether on a stand-alone basis or in collaboration with cartography units where available, to establish or strengthen their GIS units. This work is an indication that TaCRI is in the right course.

5. Conclusion

The first ever digital maps of four TaCRI substations (Lyamungu, Ugano, Mbimba and Mwayaya) are now in place. They were developed by the Soil Fertility Laboratory through georeferencing and digitization of an old, non-georeferenced paper map (Lyamungu), and through online digitization of satellite images from Google Earth Pro (the rest). The pilot undertaking was to describe land use distribution in the four substations, which would have a bearing on future decisions. Categories included coffee (further categorized as fully commercial and semi-commercial farming, field experiments, germplasm maintenance), other crops, nurseries, forest reserves and riparian reserves. The maps show that at Lyamungu (with only 10% of land servicing over 50% of staff population), efforts to increase production should focus on intensification rather than expansion. On the other hand, the expansion potential is still there for the other substations. The maps also showed wetland areas at Mbimba that should be protected against encroaching neighbours and the sloppy ones at Mwayaya that should be (re)afforested with short-stature shrubs to conserve the soil against erosion. They can also be used in deciding where to install a new infrastructural facility based on the distribution of existing infrastructures. Our next plan is to collect georeferenced point-based soil fertility data and perform spatial interpolation to visualize their trends. This has been tried successfully at Lyamungu and in Kagera Region, and is planned for the other estates as and when resources allow. This work has formally introduced TaCRI to the GIS world - an important step as GIS is becoming ubiquitous in Tanzania and globally, especially in research, resource management and problem solving. It has also given us a good start-up experience with both ArcGIS and Google Earth.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support from the European Commission in establishing the soil fertility lab, TARI-Mlingano for their collaboration which gave rise to the mini-GIS unit, TaCRI management for authorization and the lab staff for support and data collection.

Conflicts of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Abbreviations

ARDHI: Ardhi University (University of Land and Architectural Sciences); **CRS:** Coordinate Reference System, **DEM:** Digital Elevation Model, **ESRI:** Environmental Systems Research Institute, **GIS:** Geographic Information System, **GPS:** Global Positioning System, **IUSS:** International Union of Soil Science; **LGA:** Local Government Authority; **NBS** National Bureau of Statistics (in Tanzania); **NOAA:** National Oceanic and Atmospheric Administration (of the US); **SRTM:** Shuttle Radar Topography Mission; **SUA:** Sokoine University of Agriculture; **TaCRI:** Tanzania Coffee Research Institute; **TARI:** Tanzania Agricultural Research Institute; **TPC:** Tanganyika Planting Company (a sugar estate); **UDSM:** University of Dar es Salaam; **URT:** United Republic of Tanzania; **UTM:** Universe Transverse Mercator; **WGS:** World Geodetic Society; **WRB:** World Reference Base for Soil Resources.

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