Integration of remote sensing in watershed studies: A case study of Chawia & Fururu forested watersheds in Taita Hills, Kenya.

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Abstract

The ever-increasing demand for water due to population growth and the current environmental impacts due to climate change have resulted in the drying up of springs, and a reduction in their discharge volumes in Taita Hills. These impacts necessitated the evaluation and exploration of groundwater resources in Taita Hills. The main objective of the study was to evaluate the potential of integrating both Geographic Information Systems (GIS) and Remote Sensing (RS) in studying the status and spatial distribution of recent springs in the Chawia and Fururu forested watersheds. In this study, physical mapping of the springs was done by demarcating the location using Global Positioning System (GPS). The study identified and delineated the original watersheds in the Chawia and Fururu Forest fragments using GIS and RS using satellite data for watershed mapping.

Remote Sensing data from Landsat 7, 8 and Sentinel 2 were acquired, processed and analyzed. For watershed delineation, the data was examined using the Environmental Systems Research Institute (ESRI) ArcMap GIS hydrology tool, and image classification was done using the Maximum Likelihood algorithm, with classification accuracy verified using the confusion matrix approach. GIS image-processing Arc map program was used to ground truth data and process Digital Elevation Model (DEM) data. From the results, 91 springs were mapped and delineated in Chawia and Fururu forested watersheds. It was found that fifty three (53) springs were in Chawia, of which thirteen (13) were found to be inactive and thirty (30) were still active in Chawia compared to thirty eight (38) springs which were active in Fururu. The study provided information on the LU-LC classes in the study area, and how they influence the functions of the springs in providing water as well as informing environmental managers on watershed management. Six land use classes were identified, including built-up (66.3%), forestland (26.1%), agriculture (7.13%), water bodies (0.23%), grassland (0.04%), and bare land (0.01%). The study also showed that the Chawia forest cover has reduced from the year 1987 by (70%) of Vegetation Index to 2022 (60%) in and Fururu had increased by 10% from 70% in 1987 to 80% in 2022.

Keywords: springs, land use, cover change, watershed, remote sensing, Chawia, Fururu

Introduction

Water is regarded as life and the core of sustainable development.It is indeed very vital for socio-economic development, healthy ecosystems, and human survival. The demand for water around the world has been growing at more than twice the rate of population increase OVER the last century, and although there is no global water scarcity as such, there is an increasing number of regions that are grappling with chronic water shortage (Changwony *et al.*, 2017). This shortage is exacerbated by droughts, which damage surface water resources and generate long-term imbalances, hence reducing water supply and disrupting land cover and biodiversity. There are more than 1.3 billion cubic kilometers of water on earth (USGS, 2019), indicating that most of the planet is covered by water. However, much of water is available in forms unavailable to terrestrial and freshwater ecosystems (Jackson *et al.*, 2001). The rate and intensity at which the global freshwater crisis and the related environmental challenges have been underrated over decadesl, with more than 1 billion people on earth lacking reliable access to water. Addressing this challenge is very critical to the achievement of the United Nations Sustainable Development Goals (Bigas *et al.*, 2012).

According to the United Nations Inter-Action Council (2012), the water crisis' environmental effects are damaging natural water supplies as a result of population increase, which creates competition with nature. The report also shows that many springs and rivers do not make it to sea and there is widespread surface and groundwater contamination and human activities that make water unfit for use while springs are drying up (Bihgas *et al.*, 2012). With a population of 50 million, 32% of Kenyans rely on unimproved water sources, such as springs, ponds, shallow wells, and rivers, while 48% of Kenyans lack access to a steady supply of water (Kanoti *et al.*, 2019). Natural surface water sources in the country are not enough to supplement the vast population and the groundwater is a more important feature of the natural environment (Kagiri, 2005). Mountain springs are the forms in which groundwater provides water security for the rural population. They are the primary and reliable source of water in the hilly and mountainous areas of Taita Taveta County. The livelihood of the community depends on it for provision of clean water for agriculture, households use and beverages (Niraula *et al.*, 2020). Springs are indeed the terminal points of the water tower flow systems, and knowledge of their spatial distribution is essential for getting a better understanding of groundwater flow, vulnerable and water availability (Iván *et al.*, 2020). Chawia and Fururu are known to be among the many of the Taita Hills forest fragments, covering 86.0 ha and 5.0 ha, respectively (Hohenthal *et al.*, 2015).

Unequal and uneven allocation of water distribution and the spatial and temporal drying of springs, present a major problem for the sustainable development of these regions. Many people in Taita Hills live in rural areas, with their main socio-economic activity being farming, agricultural labor, and thus availability of water is essential to their livelihoods (Hohenthal *et al.*, 2015). Therefore, the current status of water suppy that is inadequate for irrigation and domestic usage poses a major problem to the local people in Taita Hills.

Remote sensing plays a vital role in conservation and watershed management and achievement of optimum planning and operation of water resources (Masud and Bastiaanssen, 2017). Satellite data provides readily available and alternative data required by hydrological models and avails spatial information for decision-makers (Ali *et al.*, 2023)). Remote sensing exhibits its presentation quality on worldwide dreary estimation ability including scene investigation, land use grouping, scene environmental change recognition, and landscape demonstration. Therefore, the geographical coverage of remote sensing data is advantageous over ground field data. Additionally, geometrical resolution has substantially advanced over the last decades. Thus it is possible today to investigate small-scale phenomena with satellite-based RS data. The present study aimed at providing much-needed hydrological information on the springs of Chawia and Fururu forested watersheds. It also aimed at providing information on the physical location and status of the springs within the watershed. The information derived from this study will inform the evaluation of watershed conditions through displaying the effects of human exercises to imagining those of elective situations in understanding the danger to water sources to the dynamic cycles; land use planning and backwoods restoration plots in Taita slopes.

Materials and methods

Study area

The Chawia and Fururu forest fragments are among the 12 forest fragments of Taita Hills located approximately 2,000 m above sea level (Fig. 1). The fragments are in Wundanyi around Ngerenyi in Taita Taveta County 86.0 ha (covering Chawia) and Fururu (5.0 ha) (Mkuzi, 2020). Ngerenyi is approximately 291 km (Chemuku, 2018) Southeast of Nairobi, and situated at 38°20’62E”, 3°29’00”S while Fururu is located at 38°20’06.34’’E, and 3°25’54.73”S in the verdant and humid Taita Hills (Wekesa *et al.*, 2020). The hills cover an area of 1,000 km² and are surrounded by semi-arid Acacia/Commiphora shrubland and dry savanna (Erdogan *et al.*, 2011). While the surrounding plains are at an elevation of 600 – 900 m above sea level , the Taita Hills rise abruptly in a series of ridges with the highest peak of Vuria at 2,208 m, although the average elevation of the hills is 1,500 m above sea level (Wekesa *et al.*, 2020).

Data collection

Physical mapping using remote sensing of satellite images

Remote sensing of satellite imagery data collection involved participatory mapping of springs through local knowledge gathered from the elderly people knowledgeable about historic springs and their localities. The springs were then geolocated using GPS device. This enabled the production of a precise map of recent and historic springs and wells, critical for analyzing spatial distribution, identification of former watersheds and determination of pathways consequential to drying up of springs and wells. The prescription of springs, is accessible with pictures and remarks on floristic elements and hints at former land usage in the direct neighborhood (i.e., special trees, like fig trees).

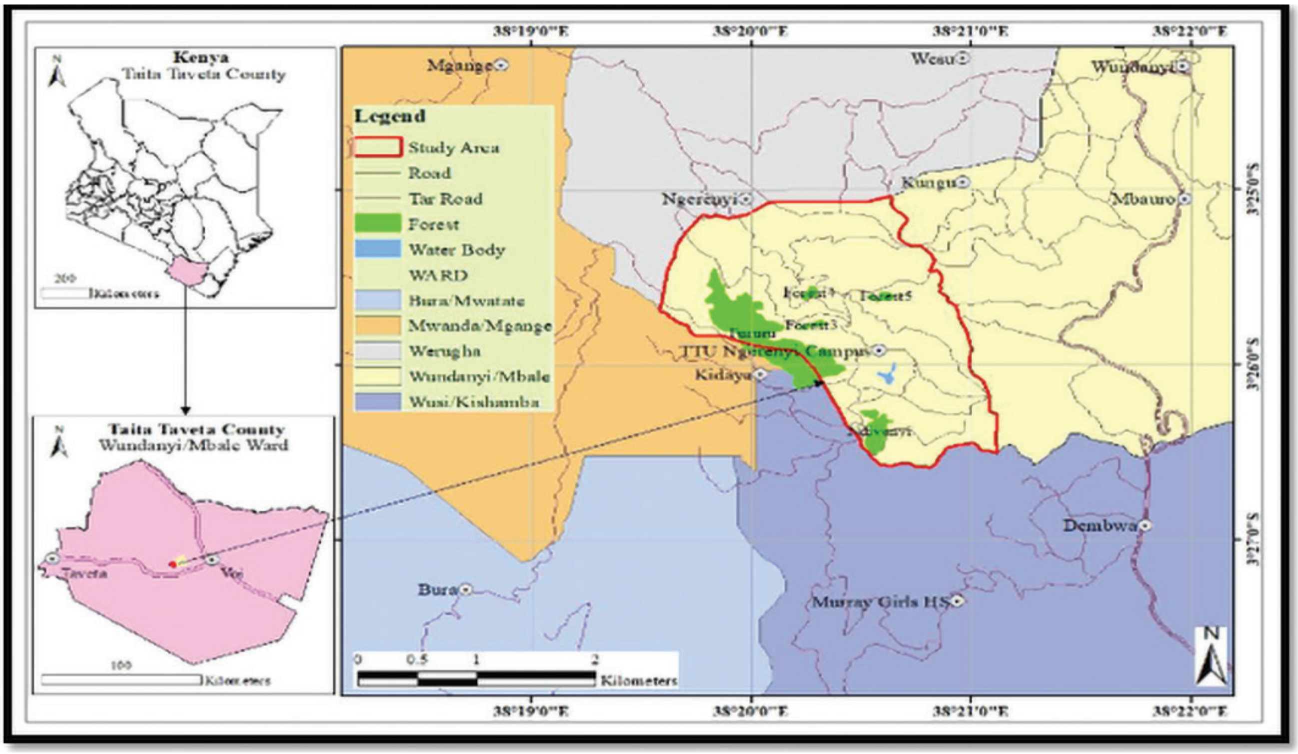


Figure 1. Site map showing Chawia and Fururu fragmented forests within the Taita Hills (Source: Author).

Watershed delineation and hydrological modelling

The study used Landsat images with a ten-year sequence between 1987 and 2019. Remotely sensed data from Landsat and sentinel-2 in digital elevetation model (DEM) format was used to delineate the Chawia and Fururu watersheds. To analyze vegetation change, the use of satellite-based RS data was applied to provide a cost-effective means to develop LC coverages over large geographic regions as described by Mkuzi (2020). Satellite images such as Sentinel-2A, Landsat 8, 4-5 MSS and 1-5 MSS were acquired from the United States Geological Survey website. The Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between Near-Infrared (NIR). Vegetation strongly reflects green and red light (which the vegetation absorbs/has a low reflectance). NDVI values range from -1 to +1. This index accounts for the converse reflectance properties of green vegetation in the near infrared (NIR) and red (R) parts of the solar spectrum and is defined as NDVI =(NIR-RED)/(NIR+RED). Negative values of NDVI corresponds to water. Values close to zero (-0.1 to 0.1) generally corresponds to barren areas of rock, sand, or snow. Tables 1 - 6 describe characteristics of Land sat images used in monitoring dynamics of land cover, images for various bands, and sentinel sensors.

Low positive values represent shrubs and grasslands (approximately 0.2 to 0.4), while high values indicates dense natural/indigineous forest (0.5-1). NDVI calculation formula for Landsat 8 image, cloud cover of 10% = NIR-RED/NIR+RED; where RED is B4, 636-673 nm & NIR is B5, 851-879 nm. This applies for landsat 8 image from 2013 to 2022 using band (B5) and (B4) for computation of NDVI. B5 is NIR & B4 RED. Landsat 1-5 (NIRB04-REDB02)/(NIRB04+REDB02) NDVI calculation formula For Landsat 5 image,cloud cover 10% = NIR-RED/NIR+RED. This applies for landsat 7, 5 image from 1970 to 2013 using band (B4) and (B3) for computation of NDVI. B4 is NIR and B3 RED.

Sentinel-2 A

The combination of different optical wavelength of satellite data provides increased opportunities for more frequent cloud-free surface observations due to variable cloud cover as different satellites overpass time and dates (Li & Roy, 2017). In this study the Landsat-8 images, sentinel-2A and sentinel-2B together provided a summary of revisit intervals and the number of observations that are useful in terrestrial monitoring and assessment.The images came from sentinel-2, NDVI = (NIR-RED)/(NIR+RED) where RED is band B4 (664.5 nm) & NIR is band B8 (835.1 nm).

Table 1. Characteristics of Landsat and Sentinel images used in monitoring land cover change dynamics.

ID Scenes	Satellite sensor	Altitude	Spatial Resolution	Number of bands	Cloud cover level	Date
LM05_L1TP_166062_19870218	MSS	705km	60m	4	Low	1987/02/18
LT04_L1TP_166062_20091113	MSS	705km	60m	4	Low	2009/11/13
S2A_MSIL1C_20170126T073251	MSI	786km	30m	13	Low	2017/01/26
S2A_MSIL1C_20190327T073251	MSI	786km	30m	13	Low	2019/03/27
S2A_MSIL1C_20220209T072619	MSI	786km	30m	13	Low	2022/02/09

Table 2. Landsat 8 image has 11 bands.

Band Name	Bandwith (µm)	Resolution (m)
Band 1 coastal	0.43-0.45	30
Band 2 blue	0.45-0.51	30
Band 3 green	0.53-0.59	30
Band 4 red	0.64-0.67	30
Band 5 NIR	0.85-0.88	30
Band 6 SWIR 1	1.57-1.65	30
Band 7 SWIR 2	2.11-2.29	30
Band 8 pan	0.50-0.68	15
Band 9 Cirrus	1.36-1.38	30
Band 10 TIRS 1	10.6-11.19	100
Band 11 TIRS 2	11.5-12.51	100

Table 3. Landsat 7 image has 9 bands.

Band Name	Bandwith (µm)	Resolution (m)
Band 1blue	0.45-0.52	30
Band 2 green	0.52-0.60	30
Band 3 red	0.63-0.69	30
Band 4 NIR	0.77-0.90	30
Band 5 SWIR1	1.55-1.75	30
Band 7 SWIR2	2.09-2.35	30
Band 8 pan	0.52-0.90	15
Band 6 TIR	10.40-12.50	30

Table 4. Sentinel-2A – Sensor: MSI.

No.	Band name	Central wavelength (nm)	Bandwidth (nm)	Resolution (m)
1	Coastal aerosol	443.9	27	60
2	Blue	496.6	98	10
3	Green	560	45	10
4	Red	664.5	38	10
5	Vegetation Red Edge	703.9	19	20
6	Vegetation Red Edge	740.2	18	20
7	Vegetation Red Edge	782.5	28	20
8	NIR	835.1	145	10
8a	Narrow NIR	864.8	33	20
9	Water Vapour	945	26	60
10	SWIR – Cirrus	1373.5	75	60
11	SWIR	1613.7	143	20
12	SWIR	2202.4	242	20

Table 5. Sentinel-2B – Sensor: MSI.

No.	Band name	Central wavelength (nm)	Bandwidth (nm)	Resolution (m)
1	Coastal aerosol	442.3	45	60
2	Blue	492.1	98	10
3	Green	559	46	10
4	Red	665	39	10
5	Vegetation Red Edge	703.8	20	20
6	Vegetation Red Edge	739.1	18	20
7	Vegetation Red Edge	779.7	28	20
8	NIR	833	45	10
8a	Narrow NIR	864	32	20
9	Water Vapour	943.2	27	60
10	SWIR – Cirrus	1376.9	76	60
11	SWIR	1610.4	141	20
12	SWIR	2185.7	238	20

Land Use classification using Sentinel 2A Satellite Image

Sentinel 2 images are available since 2015 and with a resolution of 10 meters.

Table 6. List of main band combinations in Sentinel 2.

Combinations	R	G	B
Natural Colors	4	3	2
False color Infrared	8	4	3
False color Urban	12	11	4
Agriculture	11	8	2
Atmospheric penetration	12	11	8a
Healthy vegetation	8	11	2
Land/Water	8	11	4
Natural Colors with Atmospheric Removal	12	8	3
Shortwave Infrared	12	8	4
Vegetation Analysis	11	8	4

Data analysis

Satellite Image processing and analysis

In this study, the Arc GIS Desktop (Version 10.8) was used to perform the data analysis where supervised classification from Landsat/Sentinel_2 was done. The Image classification and processing, watershed delineation using DEM (SRTM) prepared Tiff format.

Confusion matrix/accuracy assessment

The ESRI accuracy evaluation technique was used to quantify how well pixels were sampled into the correct land cover classes. The ESRI ArcGIS software were used to perform this analysis, followed by the classification tab and the accuracy assessment tool. The ground truthing reference data was collected using a stratified random sampling method. Image data can be matched to actual ground-based features and materials through ground truthing, which also. facilitates the calibration of remote sensing data and supports the understanding and analysis of the detected information.

The ground truth points were superimposed on the LU-LC map, and the value was calculated (Sarkar, 2019). A confusion matrix was generated and placed such that class membership determined by image classification was along the y- axis. In this manner, correct values fell along the major diagonal of the matrix (Sarkar, 2018). Time series used herein is a statistical methodology appropriate for longitudinal research designs that involve single subjects that are measured repeatedly at regular intervals over time (Time-Series Study, 2010).

Time series analysis of the study area satellite images

This refers to the processes of removing distortions and anomalies within the images that might hinder image classification, hence affecting the analysis of the results. In the first stage, satellite images from Landsat 7 and 8 between 1987 to 2022 were used to analyze trends of deforestation in the area . This enabled the use of high-resolution Landsat satellite imagery to estimate annual deforestation and degradation simultaneously throughout the entire region for the years 1987–2022 by integrating knowledge-based decision tree classification, normalized difference fraction index, and spectral mixture analysis,

The date and month of data acquisition were all during the dry season allowing the acquisition of cloud-free images (Kaburi and Odera, 2014). Data was divided into bands covering various sceneries on the earth's surface. The image enhancement function was used to improve the image's visual quality to aid image interpretation by increasing visual distinctions between the image's features. Supervised Classification algorithms were used to adjust the contrast, brightness, picture sharpness, and color renderings of features in an image. Two methods of enhancements were applied in this study – brightness, and contrast by using histogram equalization to increase contrast over the whole image and edge enhancement to bring in contrast in linear features, such as river channels. While maintaining the original reflectance values, image enhancement techniques improve the image's visibility, contrast, and edge information (Kaburi and Odera, 2014).

RESULTS

Mapping the physical location of springs and current status

In this study, the physical mapping produced 91 springs visualized in Chawia and Fururu forest ecosystems (Fig. 2). Fifty three (53) springs were located in Chawia, with 13 of them being inactive while 30 were active. In comparison, the 38 springs situated in Fururu were all active.

Past watersheds were also delineated in Chawia and Fururu fragments and the LC-LU were determined as well. In this study the two forested watersheds that form part of the Taita hills forest patches and the study found that Fururu gained at least 10% between 1987 and 2022 as shown in Fig. 2 while Chawia lost at least 10% between 1987 and 2022 as shown in Fig. 3.

Land use land cover analysis from 1987 to 2022

Four different LC classes were determined both within and around the two forested watershed fragments for the period 1987-2022. In Chawia, moderate forest had the highest acreage in terms of cover, which showed a negative decrease from 191 ha (26.09%) to 125 ha (17.08%) between 1987 and 2022 respectively as shown in Table 6. Grasslands increased within the forest from 30 ha (9.93% to 98 ha (32.45%). There is evidence from the LC-LU maps that Chawia land cover decreased from 1987 to 2022 while Fururu land cover maps showed

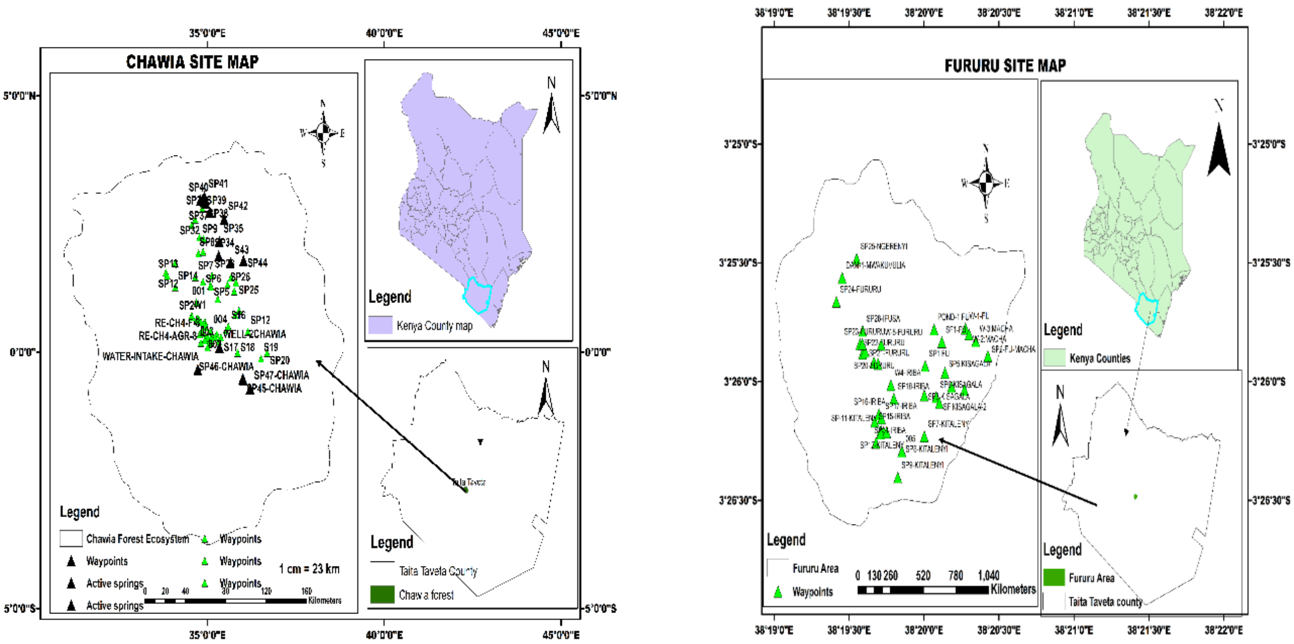


Figure 2. Physical location of the mapped springs in Chawia forest.

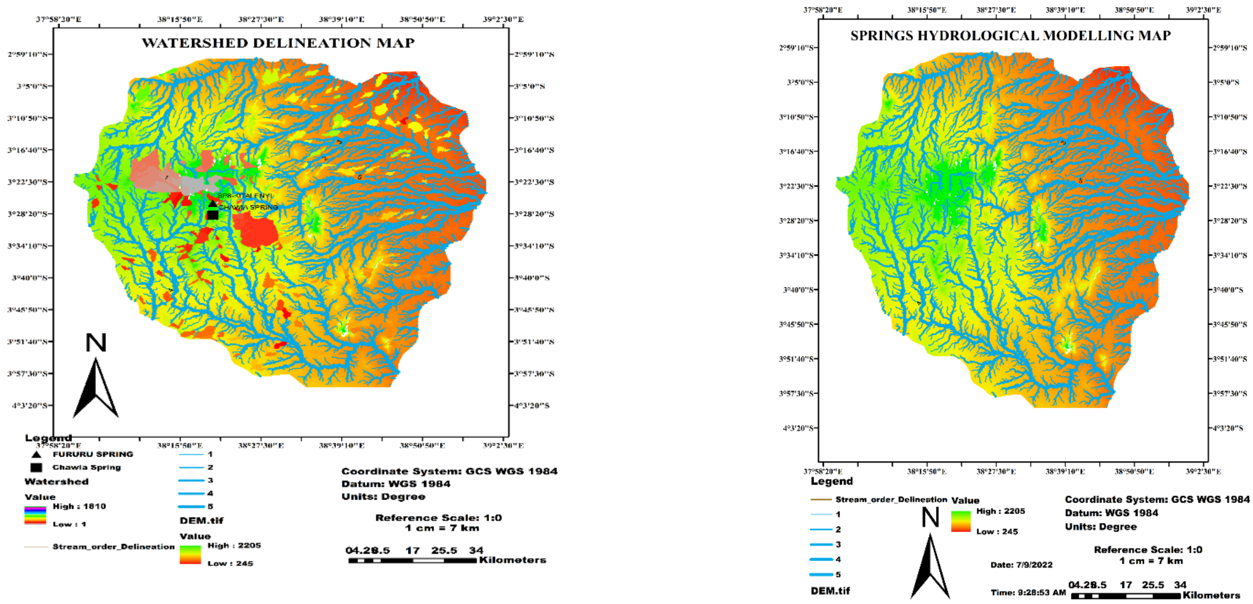


Figure 3. Delineated watersheds in Taita hills.

great increase in the same period as appended in Table 6. The maps show vegetation change and different forms and types. The changes in Chawia could have resulted from forest encroachment or even human disturbance (agriculture, and livestock) as shown in Fig. 4 and 5. From this study, five different LU types were determined namely dense rorest, moderate forest, grasslands, and shrubs in Chawia and Fururu forested watershed as outlined in Table 7.

The observed LU types were found to be impacting the forested watershed and thus reducing the number of springs in the study area, which are essential for human use and ecosystem regulation. The change in LU type caused these springs to dry up and that is the reason why the Chawia forested watershed is degraded and has lost a lot of cover whereas springs found in Fururu forested watershed were found to be active. This is due to the fact that the Fururu watershed is conserved and the forested area is still intact.

Percentage of change detection in land use land cover from 1987-2022

Figure 6 shows the highest NDVI value for each year in percentages. The value range of the NDVI is -1 to 1. Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1).

In this study, the classification accuracy was 80.90%. The study areas were classified into six-land use and land cover classes namely; built up, agricultural, bare land, water bodies, grassland and forest land as defined in the classification scheme.

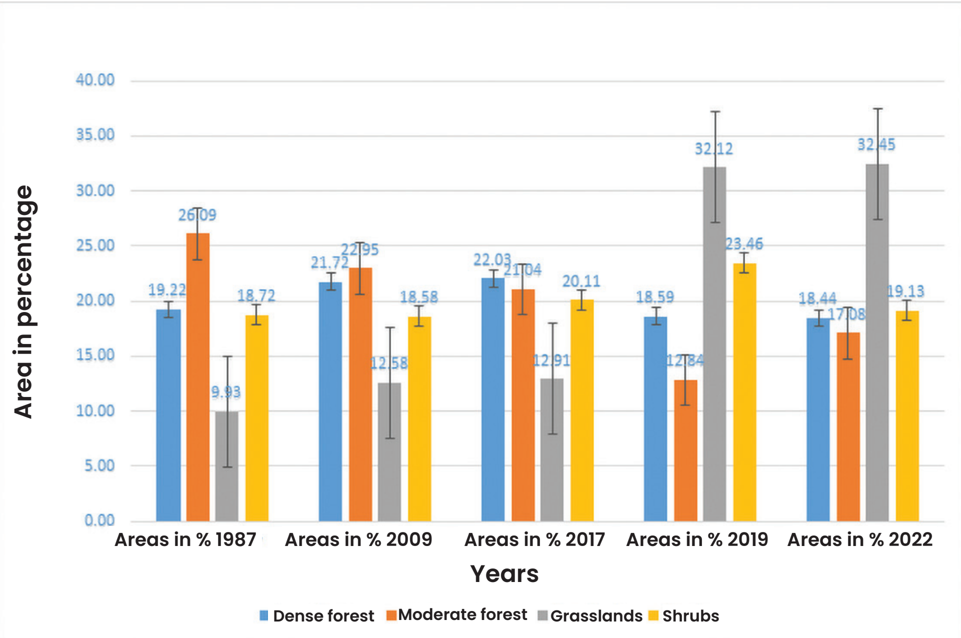


Figure 4: The phenological land cover changes in Chawia from 1987-2022

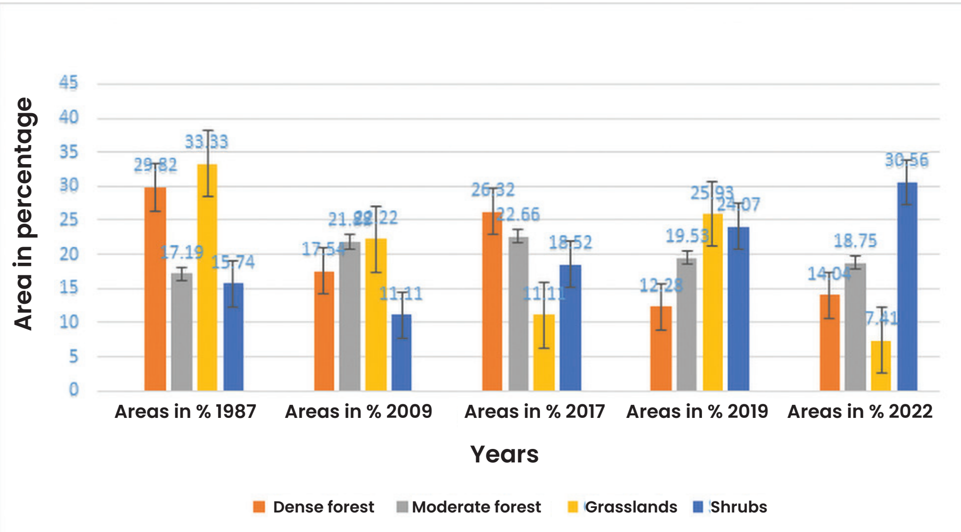


Figure 5. The phenological land cover changes in Chawia from 1987-2022.

Table 7. Land Cover change (Ha) from 1987 to 2022.

Land use type	Area in (ha) 1987	Area in (ha) 2009	Area in (ha)2017	Area in (ha) 2019	Area in (ha) 2022
Chawia					
Dense Forest	123	139	141	119	118
Moderate forest	191	168	154	94	125
Grasslands					
Shrubs	30	38	39	97	98
	134	133	144	168	137
Fururu					
Dense Forest	17	10	15	7	8
Moderate forest	22	28	29	25	24
Grasslands					
Shrubs	9	6	3	7	2
	17	12	20	26	33

Table 6 above where the most changes occurred large with increasing built up areas, forest land and agricultural land. From this study, the changes are attributed to large scale run off and erosion events that may be due to the decreased infiltration capacities associated with LU-LC changes. Chawia forested watershed experienced significant LU-LC changes between 2019 and 2022 while Fururu forested watershed experienced significant changes between 2009 and 2019 with the dominant changes happening within the dense forest and grasslands as shown in Fig. 4 and 5, respectively.

Some 91 springs were mapped and visualized in Chawia and Fururu forest ecosystems, where their respective watersheds were delineated and the hydrological, stream network and flow direction were developed based on the DEM method that was used. The results also showed that Chawia land cover has decreased over the years as follows: 123 ha (1987), 139 ha (2009), 141 ha (2017), 119 ha (2019), and 118 ha (2022). Whereas Fururu dense forest decreased from 17 ha in 1987, 10 ha (2009), 15 ha (2017), 7 ha, and 8 ha (2022).

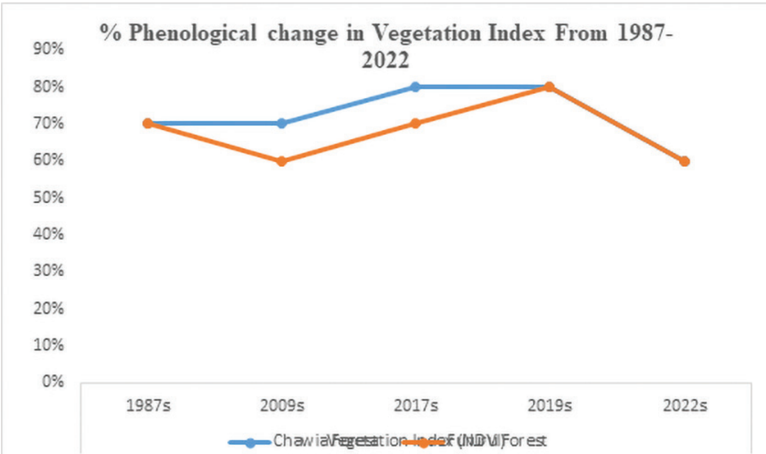


Figure 6. Normalized difference in vegetation Index (NVDI) in percentages.

From this study, six LC and LU classes were identified that is; Built up area dominating 66.3%, Forest land at 26.29%, Agriculture at 7.13%, Grass lands at 0.04%, water Bodies at 0.23% and Bare lands at 0.01%. Generally, the study indicate that the indigenous forest in the Taita Hills decreased by 66.3% due to the establishment of exotic plantations and more built up areas. Significant land use changes have taken place in Chawia and Fururu forested watersheds between 1987 and 2022 showing a relative matrix change within each land use/land cover class for different time scenes as shown in

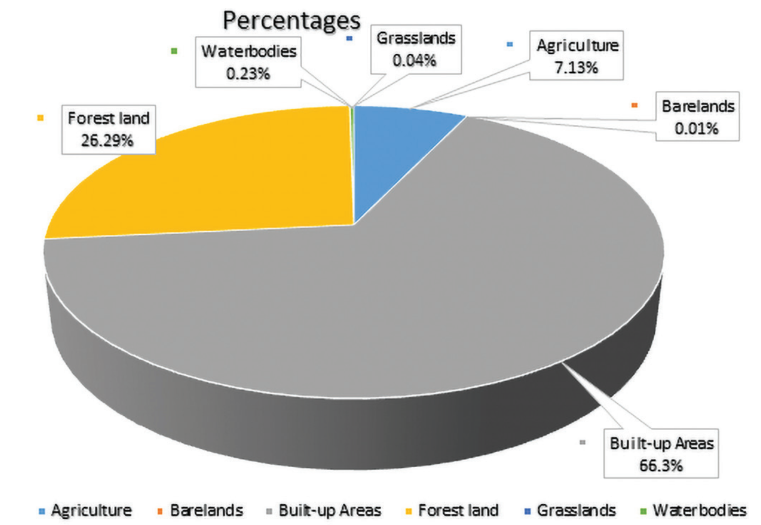


Figure 7. Land use status in Chawia and Fururu forest ecosystems.

Given that it offers guidance for the ensuing two decades and beyond, the Land Use Plan Map is long-term. Because it covers land usage across the Bowl, it is thorough. The following are its goals:

- Indicate the future distribution and general placement of land uses, including parks, mixed-use town centers, residential, commercial, and industrial development;
- Discuss the intended level of intensity, density, and overall nature of the land use designations shown on the map;
- Assist in guaranteeing that the expanding populace has sufficient housing, work, and leisure options;

Trends in forest cover change for dense forest, moderate forest, grassland, and shrubs forest areas varied among the forested watersheds (Table 6). The dense forest area in Chawia decreased between 2009 and 2022 while the moderate forest decreased between the year 2009 and 2019 before increasing in 2022 again. In Fururu, the dense forest area decreased between 1987 and 2009 before increasing in 2017; but decreased again in 2019 and 2022. The moderate forest area increased between 1987 and 2017 but reduced in 2019 and 2022 as shown in Tabel 6 and Fig. 4 and 5, respectively.

Land Cover Analysis from 1987 to 2022

Accuracy summary

As shown in Table 8, the overall accuracy of the data is 80.90%.

Table 8. Accuracy summary.

Accuracy summary					
Class name	**Reference**	**Classified**	**Number**	**Producers**	**Users**
Forestland	71	70	55	84.0%	86.3%
Grassland	21	19	17	90.96%	92.29%
Agriculture	16	19	15	96.4%	95.37%
Built-up	2	2	2	100%	100%
Totals	**110**	**110**	**89**		

Overall Classification Accuracy = 80.90%

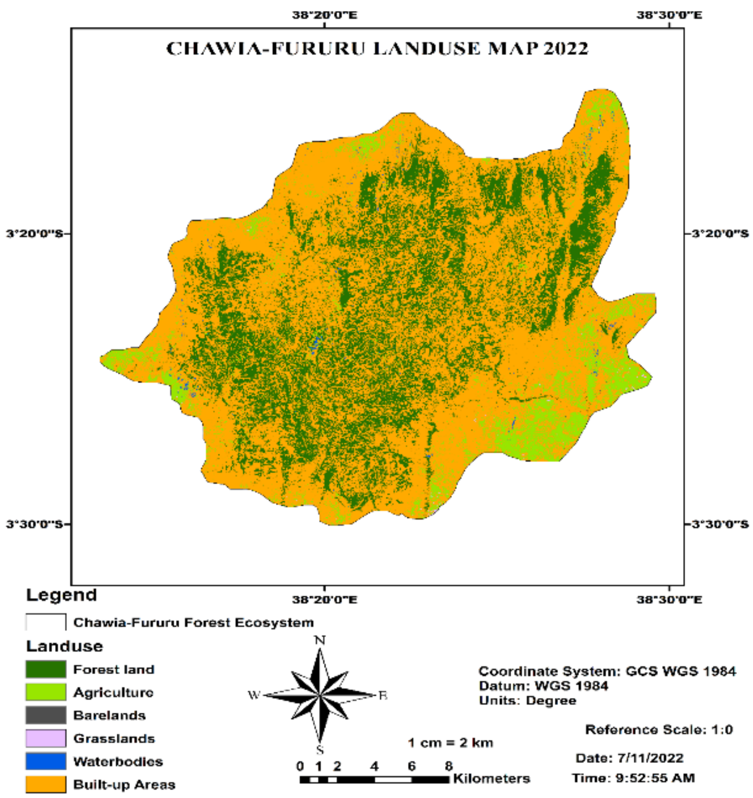
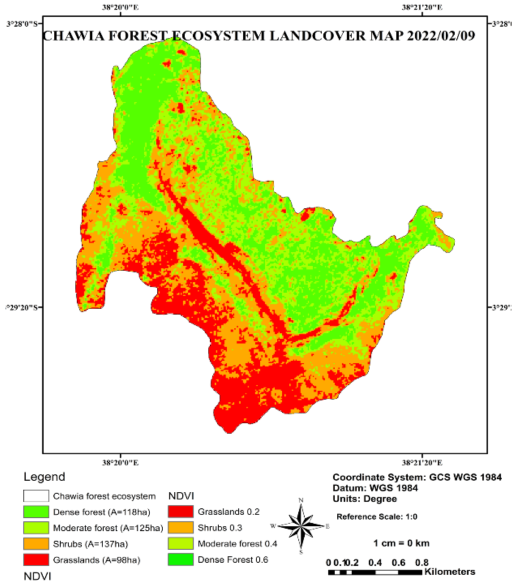


Figure 8. The Chawia-Fururu Land use status and characteristics in 2022.



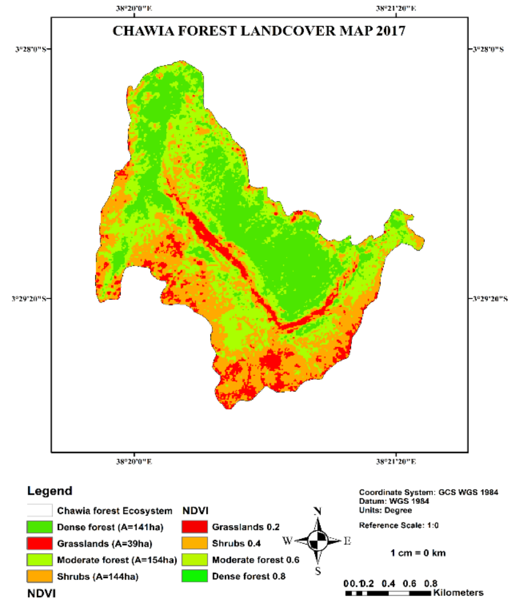
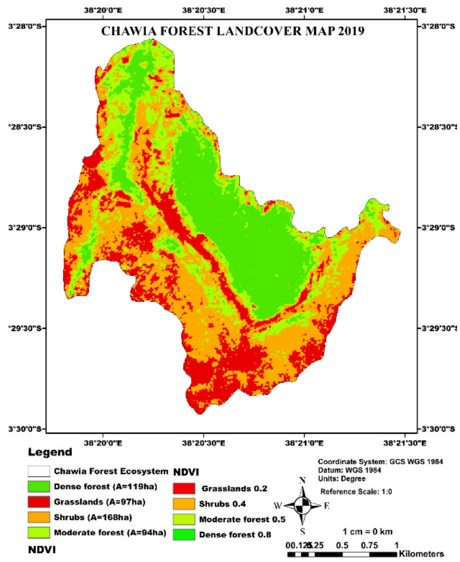


Figure 9. The Chawia land cover characteristics in 2022 and 2017.



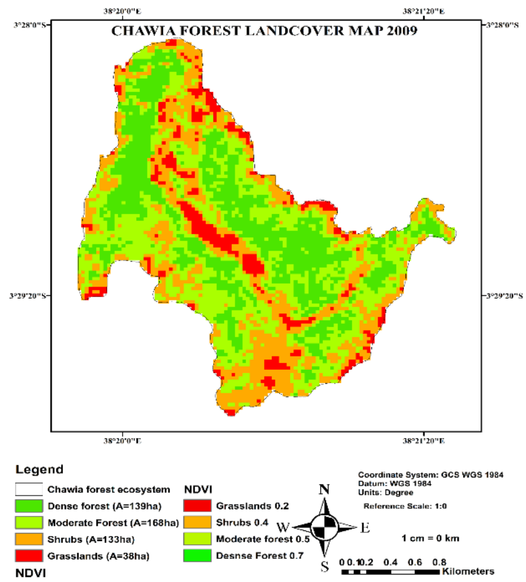


Figure 10. The Chawia Land cover characteristics in 2019 and 2009.

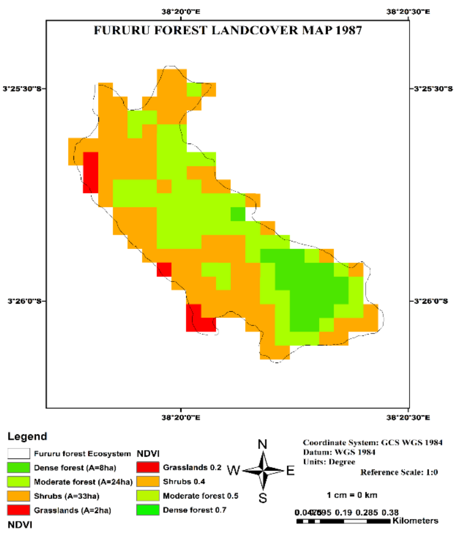


Figure 11.The Fururu Land cover characteristics in 1987.

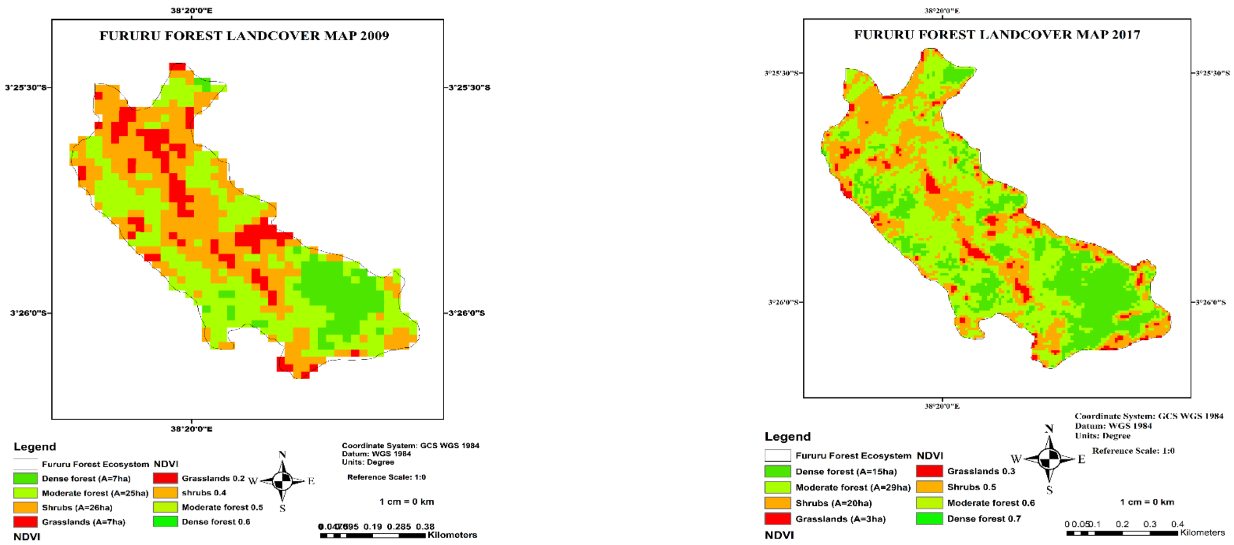


Figure 12. Fururu Land cover characteristics in 2009/2017.

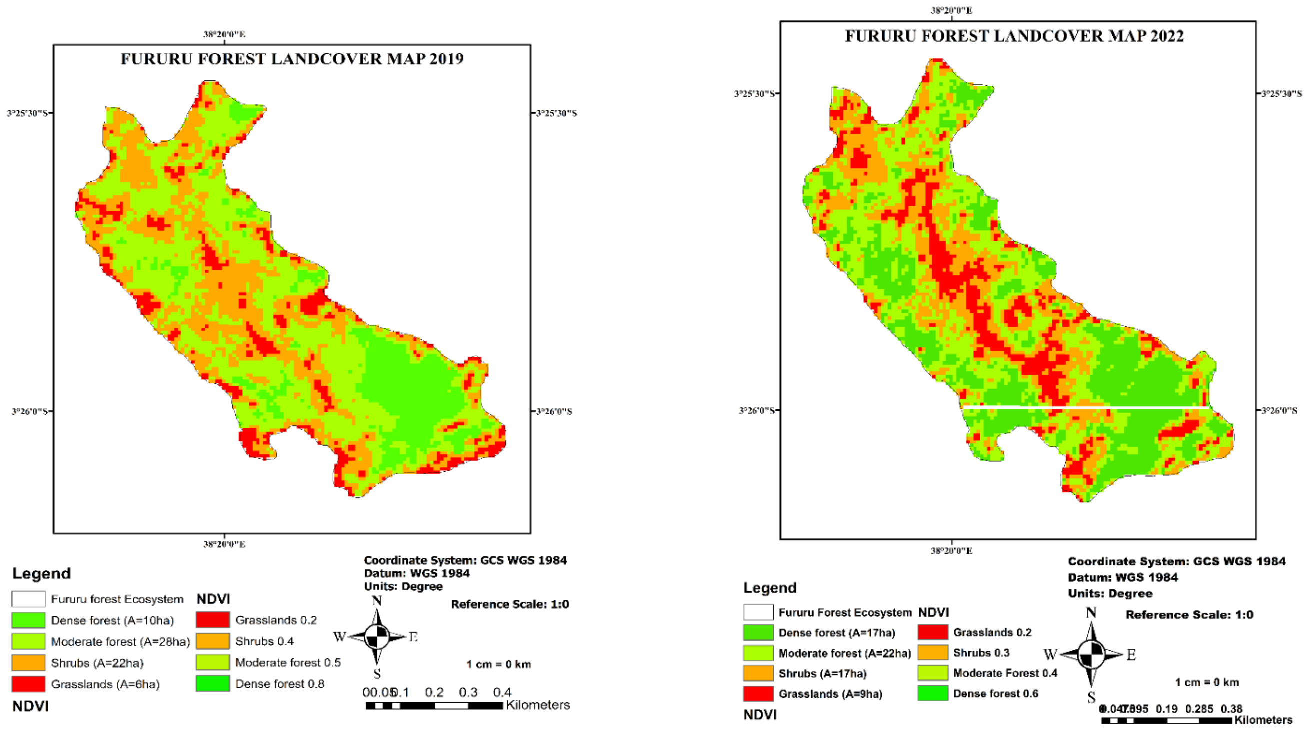


Figure 13. The Fururu Land cover characteristics in 2019/2022.

Table 9. Error matrix.

	Reference				
Classified	**Forestland**	**Grassland**	**Agriculture**	**Built-up**	**Total**
Forestland	55	14	1	0	70
Grassland	12	7	0	0	19
Agriculture	4	0	15	0	19
Built-up	0	0	0	2	2
Totals	71	21	16	2	110

Discussion

On the global scale, springs are a major source of water in the mountainous and hilly areas of the earth's surface and are important to terrestrial ecosystems. However springs are drying up at a rapid rate thus threatening livelihood globally (Dhakal *et al.,* 2020.). The Taita Hills' ability to supply water has been lessened due to deforestation of indigenous trees leading to decreased catchments' ability to retain water. Over the past 50 years, the water levels in numerous springs, rivers, and streams have plummeted, and some have almost entirely dried up. Local and historical knowledge shows that the exponential decrease in water levels peaked in the 1980s and 1990s (Thapa, 2021). Historically, particular areas in the steep upper zones of the the Chawia/Fururu forested watershed, used to remain rainy all year long (Hohenthal *et al*., 2015). Additionally, according to local accounts, residents once frequented the springs and rivers of the Taita Hills for fishing purposes. However, this is no longer the case, as the water quality and quantity have deteriorated, resulting in the absence of fish in these waters.

This study establishedthat most of the springs have dried up and thus the local communities cannot access the terrestrial water supply.

Ninety one (91) springs were mapped and visualized in Chawia and Fururu forest ecosystems. They were delineated and the hydrological, stream network and flow direction were developed based on the DEM method. The excessive exploitation and misuse of natural resources, along with environmental degradation, are placing significant pressure on water resources (Hohenthal *et al*., 2015). According to Hohenthal *et al*. (2015), indigenous forest cover has been reducing drastically since the 1960s due to population increase, expansion of intensive agriculture, planting of exotic tree species, and road construction. The drying up of the springs can be attributed to three major factors including anthropogenic factors, climate change, seisimic events and infrastructure development, such as building highways, hydropower tunnels, and cement irrigation canals as explained in similar situation by Dhakal *et al*. (2020). Water scarcity is also a result of unplanned urbanization and population growth, which increases consumption and increases reliance on springs and other water sources.

On forest management, satellite imagery has almost exclusively been used by GIS and geospatial practitioners. The emergence of new forest management solutions is creating new use cases for satellite imagery, addressing previously unanticipated needs, and ultimately driving value outside of GIS departments (Swift Geospatial, 2021). A study conducted by Uddin *et al*. (2015), aimed to assess and monitor natural resources, focusing on forests, within the Lorpa watershed in the Jumla district of Nepal. The research revealed that the cutting of trees, especially larger and older ones, remains a significant concern in the watershed.

Jasrotia *et al*. (2016), evaluated integrated remote sensing and GIS approach for delineation of groundwater potential zones in Devak and Rui watersheds of Jammu and Kashmir, India. Remote sensing, GIS, and fieldwork techniques were combined and used to delineate the groundwater sources map of Devak and Rui watersheds and the results from the study revealed that the excellent zone covers 13.5%, good zone 22.7%, moderate zone 15.8%, low zone 18.5% and run off zone 29.5% of the total study area. The results depicted the groundwater potential zone found to be helpful in better planning and management of groundwater resources in the study area(Jasrotia *et al*., 2016). In this study the Chawia and Fururu forested watersheds were delineated from data acquired from Sentinel_2 and Landsat8 satellites.

Globally, the majority of people on earth (approx 5 billion) live in cities. The urban population is predicted to exceed 6.5 billion within a decade. Terrestrial ecosystems will be impacted by urban growth, which will result in higher demands for the services they supply. The United Nations (UN) highlights the value of ecosystems and environmental services to people as natural products and services, on which social progress and economic growth directly depend, and which are currently disappearing globally at an alarming rate (Abad-Segura *et al*., 2020).

LU-LC classification was performed and although species-level classification was not possible, 10 optimum LC classes were mapped and contrasted in this study without affecting the precision of each class. Rangeland predominates throughout the study region; there are just a few patches of forest and agricultural land. Water, fuelwood, and other forest resources are in short supply, and the three nearby communities' rising demand further reduces their availability. The watershed is progressively being used at unsustainable levels for agricultural production, while overgrazing and overharvesting of fuelwood and lumber are contributing to the destruction of the environment(Uddin *et al*., 2015). Therefore in this study, it was similarly found that the four LC classes were determined and shrubland seemed to dominate the study area of Chawia watershed and there just a few patches of the dense forest in Chawia and Fururu as well but had an increase of the grassland forest.

As a result, therefore, the utilization of remotely sensed data and the integration of GIS and their techniques provide accurate and timely information for detecting and monitoring the land cover and land use. In this study, the classification accuracy was 80.90% where the study areas were classified into six-land use and Land cover classes namely built up, agriculture, bare land, water bodies, grassland and forest land as defined in the classification scheme. The results also showed that Chawia land cover has reduced by 10% from 123 ha in 1987 to 118 ha 2022. . This may be attributed to the increase in population and the increased built up areas in the study sites. Therefore, Chawia has lost 10% of its forest cover compared to reported global rates of a net annual loss of 4.7 million ha (Ritchie and Roser, 2021). The earth's cover has changed over the past 10,000 years shortly after the end of the great ice age up to the present. The loss of 10% cover for Chawia may be as a result of change in the land use activities where most people are encroaching towards the forest and participating more on agricultural activities that has made the forested ecosystem lose its cover whereas Fururu from this study gained a cover by 10% due to more conservation efforts.

According to the estimates of Winkler *et al*. (2021), at least 17% of the Earth's land surface moved between the six land types between 1960 and 2019. The total land change extent, which accounts for all individual change events (as well as areas of multiple change), is 43 million km^2, or almost a third of the world's land area. This indicates that, since 1960, an area of land that is roughly twice the size of Germany (720,000 km^2) has changed annually on average and it has been most evident in Africa and South America, regions of the tropics and sub tropics. They also found out that 0.8 million km^2 net loss of forest area globally, but an increase in world agriculture. However, in this study, land use changes were noticed to have shifted from forested land to agricultural and built up areas and the land use change has not been constant. It is also argued that in addition to globalized trade, climate change and its effects, such as extreme occurrences, droughts, and floods, are other significant drivers of land change dynamics that have increasingly affected the rate of land use change throughout the deceleration phase (Winkler *et al*., 2021). Droughts in West and East Africa have an impact on the utilization of agricultural land which in most parts of Kenya has affected agriculture and vegetation due to the rise in demand for land and poverty levels in Taita hills has made the local people to change their land use types which further contributes to vegetation change and index.

Conclusion and recommendations

Land use in Chawia and Fururu has been swamped by increased horticulture and brushing as a result of the rapid growth of the population, and this has forced the neighboring local area to encroach the slopes, creating actual erosion, soil disintegration, and lowering water tables in the slopes by ploughing the slopes and thus cutting down a lot of trees in the fragmented forests. Consequently, the incorporation of GIS and RS techniques advances watershed depiction and the land cover characterization from DEM information and from Landsat. The use of GIS and RS in Chawia and Fururu watersheds would assist in information securing on the hydrological foundation of the two watersheds, group the land uses, and land cover changes in the catchments. As a result, therefore, the utilization of remotely sensed data and the integration of GIS and their techniques provide accurate and timely information for detecting and monitoring the land cover and land use changes. From this study, there is need for urgent efforts to be done for Chawia forested watershed conservation to avoid its degradation and drying up of most springs. And the conservation efforts should be maintained for Fururu forested watershed in order to prevent drying up of the springs and reduction of the watershed size. As from the study results it is recommended that the Land Use Act should be enacted and enforced to put more conservation strategies to the forested areas of Chawia and more conservation efforts be done on Fururu forested watershed. The study also recommends that due to the higher rate of drying up springs, the Kenya Government and other stakeholders should develop more plans and strategies on the construction of more dams to act as water reservoirs to store water for irrigation and domestic use to meet the demand of the the increasing population in the forested areas of Taita Hills.

Acknowledgments

The authors strongly acknowledge the funding of the Deutscher Akademischer Austauschdienst (DAAD) during this study.

Ethical statement

This study was carried out in accordance with the recommendations of the Pwani University ethics review committee (PUERC) with written informed consent from all subjects. All subjects gave written informed consent in accordance with the declaration of Pwani university committee.

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