EISSN: 2707-0425

East African Journal of Science, Technology and Innovation, Vol. 3 (Special issue): February 2022

Assessing community perceptions and response to climate change in Nyando catchment using geospatial technology

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Abstract

The world is experiencing climate crisis that is threatening lives. Those in low lands are displaced by floods loosing possessions and food crops; while those in hilly areas experience land degradation and vegetation loss leading to poverty. Monitoring such occurrence through time is inevitable as it enables governments to make critical decisions for environmental conservation, enhanced resilience and minimize risks of food insecurity. This study explored the use of geospatial technology to investigate climate risk indicators within Nyando catchment. Geospatial technology provides a platform to monitor occurrences of extreme weather conditions, facilitates the understanding of end to end temporal changes of the environment and provides an environment for modelling future scenarios. We derived indicators of climate change within Nyando catchment over the period 2013 to 2021 and inferred their impact on livelihoods. We collected data on rainfall, vegetation cover and land use from Landsat 8 30m satellite images and *in situ* data using the Mobile mapper global positioning system (GPS) within Nyando catchment. We overlaid these data, characterized them and performed change detection using Erdas Imagine software. Results showed 9.9% reduction in forest cover, 54.1% sedimentation of water areas, 3.9% loss of agricultural land and 2.5% increase in built up areas. The main land use in Nyando catchment is agriculture followed with settlement. We inferred that loss of forest cover is the reason for sedimentation of the water areas, subjecting lowlands to flooding. Moreover, conversion of forest land to agricultural land and settlement were fund to be the main drivers for climate crisis. Indeed agro-ecological approaches to farming will increase forest area while maximizing on vertical farming for increased productivity to meet the ever growing demand for food. We recommend adoption of geospatial technology in monitoring of the landscape for informed decision making to avert risks of climate change.

Keywords: *Geospatial; Remote sensing; Climate; Degradation; Conservation; Floods*

Cite as: *Mulianga and Ng'onyere, (2022)* Assessing community perceptions and response to climate change in Nyando catchment using geospatial technology. *East African Journal of Science, Technology and Innovation 3 (Special Issue).*

Received:	28/10/21
Accepted:	13/12/21
Published:	16/02/22

Introduction

Climate change is rapidly emerging as one of the most serious global problems affecting many sectors in the world today (Eriksen *et al.*, 2008). Africa is particularly vulnerable to the impacts of climate change because of factors such as widespread poverty and emerging diseases, flooding, recurrent droughts, inequitable land distribution and over-dependence on rain-fed agriculture (Change U.N., 2007). Continuous use of this landscape for agriculture without observing mitigative and adoptive measures declines the quality of land, impacting heavily on agricultural productivity of both the degraded (eroded) areas and areas of sediment deposits (Mulianga *et al.*, 2015; Bezuayehu and Sterk, 2010); Mulianga *et al.*, 2012). Researchers have shown that productivity of such eroded landscapes declined by 50% in the 21st century and contributed to a continental mean yield loss of 8.2% (Change U.N., 2007; Andersson, 2010), by 30 to 90% in West Africa (Eriksen *et al.*, 2008) and by 36% in Kenya (Congalton and Green, 2009). Pressure exerted on the already burdened soils to feed the rural communities and ensure food security cannot be wished away and requires mitigation measures for a sustainable system. Soils fundamentally contribute to primary production, through the supply and recycling of nutrients and water to plants and microorganisms in natural ecosystems as well as in agricultural production ecosystems (Jaetzold *et al.*, 2005; Mbagwu *et al.*, 1984).

Pressure on these soils through agricultural activities introduce degradation at varied scales in time and space, depending on the topography, soil characteristics and crop management practices in the landscape. The loss of soils from the sloppy landscape was seen as a critical phenomenon to natural resources, causing sedimentation of basins and water sources (Saavedra, 2005) in the 21st century (Reich *et al.*, 2000; Jaetzold *et al.*, 2013) pausing flooding threats to communities downstream. Soils are lost from areas designated as hot spots (Anejionu, 2013) in the agricultural landscape where poor tillage methods and poor soil conservation measures (Valentin *et al.*, 2005) are observed. Soil erosion leads to land degradation which affects crop production and environmental aesthetics. Landscape degradation therefore remains important among global issues of the 21st century due to its negative effects on agricultural productivity (Eswaran *et al.*, 2001).

Land degradation has been reported to be common in Africa due to human induced activities on landscape (Bezuayehu and Sterk, 2010) in the tropical region that has a rainy climate, fragile soils (Claessens *et al.*, 2008) coupled with improper land uses (Metternicht, 2001; Pimetel, 2006; Metternicht and Gonzalez, 2005). Soils washed away from such landscapes carry along nutrients and are deposited in water ways. This erosion is influenced by exogenetic processes such as wind or water flow, exacerbated by human activities. Indicators of soil erosion in agricultural landscapes include rills, gullies, granites and siltation (Okoba and Sterk, 2006), which influence crop production and soil fertility.

It is therefore important to investigate the susceptibility of the landscape to erosion to prevent soil and nutrient loss (Okoba and Sterk, 2008) for a sustainable productivity of any ecosystem. As suggested by (Jaetzold *et al.*, 2013), it is important for farmers in the uplands to embrace erosion control measures such as use of terraces and enhanced natural vegetation for continuous soil cover to minimize downstream flooding (Andersson, 2010). Such a conservation measure will minimize erosion and enhance crop productivity in the uplands. In the low lands, siltation of water streams will be reduced and thus clean water service provided for the ecosystem. In the hilly landscape of western Kenya, the multiple cropping system, planting and harvesting dates introduce spatial heterogeneity in the landscape which contribute at different scales to soil erosion risk. As argued by Jolande and Paul, (2009), variable land preparation practices may introduce different levels of soil degradation in the landscape unless conservation measures are observed. Although effort has been made on soil conservation, the sensitivity of the landscape to erosion risk has limited documentation in western Kenya.

Kenya has made various strides to ensure sustainable agriculture is realized while emphasizing on food security for the rural communities. Sustainable agricultural practices not only boost pasture and crop productivity but also improve soil physical and chemical characteristics, thus reducing pressure on biodiversity and forests while increasing the resilience of communities living in vulnerable ecosystems (Jaetzold *et al.*, 2013).

Remote sensing data have been integrated with rainfall and soil datasets in the past to account for vegetation properties (Mulianga *et al.,* 2015; Cohen *et al.,* 2008; De Jong *et al.,* 1999). Among other studies, De Jong *et al.,* (1999) used Landsat TM data to represent vegetation conditions and developed soil erosion model for Mediterranean regions (SEMMED), which is applicable at regional scale. Cohen *et al.,* (2008) used temporal series of Landsat TM normalized difference vegetation index (NDVI) to represent the annual variations in vegetation growth and integrated it with spatial data sets from the heterogeneous landscape to develop a fuzzy based dynamic soil erosion model at local scale. Remote sensing techniques have therefore proved successful in characterization of heterogeneous landscapes when integrated with spatial dynamic models and expert knowledge to investigate the extent of soil losses in agricultural landscapes (Claessens *et al.,* 2008; Cohen *et al.,* 2008) and risks posed to communities in the low lands where the soils are deposited. This is because remote sensing is able to detect both spatial and temporal characteristics of heterogeneous landscape patterns and processes and identify areas vulnerable to soil erosion (Anejionu *et al.,* 2013). Soil management influences changes in physical, biological and chemical properties of soils in landscapes that produce sugarcane (Panosso *et al.,* 2009). A study on the spatial and temporal variability of these landscapes is therefore crucial in estimation of potential soil erosion from which environmental services that are provided by main land uses to the ecosystem are ascertained (Jolande and Paul, 2009; Saavedra, 2005).

Remote sensing is therefore a technology that facilitates the exploration of spatial and temporal variability in landscapes. (Pettorelli *et al.*, 2005; Zarco-Tejada *et al.,* 2005; Mulianga *et al.,* 2012). Remote sensing provides temporal series datasets that are used in studying the evolution of such landscapes by depicting spatial and temporal changes over the desired study period (Zarco-Tejada *et al.,* 2005).

In the recent past, information from remote sensing imagery was integrated with spatial data to increase accuracy in monitoring changes in land use (Adami *et al.,* 2012) in (Mulianga *et al.,* 2015) to provide information on the impact of soil quality on this land use. Additionally, satellite images provide temporal information on changes in environmental variables in space and time, and permit to study the impact of vegetation cover type on soil protection for a sustainable ecosystem. In the Nyando context where crops are established among other land uses with multiple planting and harvesting crop dates, time series NDVI from satellite imagery of such landscape facilitated understanding of the seasonal variations in vegetation and the impact of management practices that determine variations in spatial productivity and susceptibility of such landscape to soil degradation.

Recent studies have used NDVI to identify changes in vegetation cover that are presumed to have resulted from crop management practices. Changes studied form climate change indicators that include: increase in soil loss, decreased rainfall, increased dry spells and drying up of water streams due to sedimentation.

Many environmental studies have associated sedimentation of low lands to causes for flooding in most catchments. Satellite image acquired on a specific date was presumed to reflect results of crop management practices as impacted by environmental variables such as soil characteristics for that particular space in time (Blaschke, 2010; Cohen *et al.,* 2018; Rudorff *et al.,* 2010). On the other hand, temporal NDVI captures the different stages of land cover from temporal series when integrated with ground data and expert knowledge. This integration provides spatial and temporal information that is critical in fuzzification of the landscape elements used in modelling the vulnerability of an area to different degrees of erosion in order to quantify potential soil erosion over a heterogeneous landscape (Cohen *et al.*, 2008; Eswaran *et al.*, 2001), and investigate their impact on soil erosion control in space and time. The objective of this study was to explore the use of geospatial technology to investigate climate risk indicators within Nyando catchment. The study laid emphasis on remote sensing and *in situ* data to derive information and determine its conclusions.

Materials and methods

Study area

The study area (Figure 1) stretches over 5651Km2 within Kano plains with an altitude of 1000 m to 1800 m in the escarpment. The area is located between longitude 34.8°E to 35.12°E and latitude 0.01°S to 0.16°S, within a sub humid agro-ecological zone. Rainfall received in the area is between 1400 mm and 1550 mm with a slope rising from 2% in the plains to >18% in the hilly areas (Mulianga *et al.*, 2015). The main crop in the zone is sugarcane, besides maize and horticultural crops. Sugarcane is planted in the months of April and September in accordance with the bimodal rainfall in February to June and September to December (Mulianga *et al.*, 2015). Soils of the plain land are dominantly black cotton cambisols that easily clog with increased rainfall and crack during prolonged drought with temperatures rising to 33°C (Jaetzold *et al.*, 2005). The highlands are dominantly well drained sandy loamy acrisols. It is the spatially heterogeneous terrain, diversified cropping systems, varied soil types and rainfall in this zone that provide an enabling environment for evaluation of a soil service offered by sugarcane crop to the ecosystem.

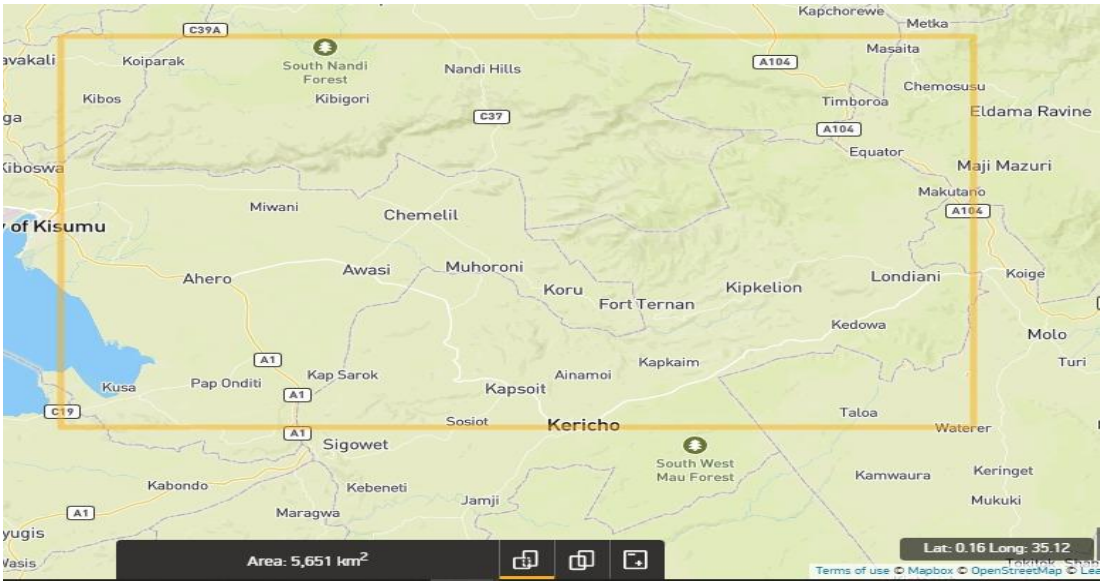

Figure 1. The Nyando Landscape (Source: Mapbox, Open street map)

Indicators of climate change

We used a questionnaire to collect baseline data through an informative survey targeting a population of 300 households. To derive indicators of climate change, descriptive statistics were used. Respondents indicated whether there was increase or decrease in the indicators in each case. These included, increase in soil loss, decreased rainfall, increased dry spells and drying up of water streams. The results section depict these responses.

Landsat 8 satellite Data

Two Landsat 8 (April 2013 and May 2021) of Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images *(Table 1)* were downloaded through the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC: https://lpdaac.usgs.gov/get_data).

Landsat 8 products consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. Landsat 10 and 11 are used to detect clouds. The resolution for Band 8 (panchromatic) is 15 meters. The images were acquired orthorectified, then geo-referenced in WGS84 UTM zone 36S. These images were used to detect any change in land use in the study area. The advantage of satellite images over insitu data is its ability to collect data from end to end (Campbell, 1996; Congalton and Green, 2009) without obstruction of physical features and human errors accosted by fatigue.

Table 1. Landsat 8 bands

Band	Spectral Resolution (m)	Spectral Resolution (μm)
Band 1 - Coastal/Aerosol	30	0.433 - 0.453
Band 2 - Blue	30	0.450 - 0.515
Band 3 - Green	30	0.525 - 0.600
Band 4 - Red	30	0.630 - 0.680
Band 5 - Near Infrared	30	0.845 - 0.885
Band 6 - Short Wavelength Infrared	30	1.560 - 1.660
Band 7 - Short Wavelength Infrared	30	2.100 - 2.300
Band 8 - Panchromatic	15	0.500 - 0.680
Band 9 - Cirrus	30	1.360 - 1.390
Band 10 - Long Wavelength Infrared	100 (resampled to 30)	10.30 – 11.30
Band 11 - Long Wavelength Infrared	100 (resampled to 30)	11.50 - 12.50

Change detection was undertaken using Erdas Imagine software using the following summarized steps:

1. This approach was borrowed from (Blaschke, 2010) as follows:
2. Creating of a composite image using bands 1 to 7;
3. Clipping of the satellite image using the area of interest map (AOI);
4. Classification of the images – Unsupervised classification was undertaken using the Maximum Likelihood classiffier;
5. Conversion of the image from raster to polygon; and
6. Calculation of areas where change has occured

Results

Results *(Figure 2)* show that area under cultivation has increased by about 3.58% over the past 8 years while area under forest has decreased by about 9.94%. The increase in built up areas is illustrated by about 2.52% while it is alarming that water area has been lost by 54%. This signifies a change in socio-economic activities without considering conservation of the environment (Rudorff *et al.,* 2010). *Table 2* illustrates this change.

Loss of forest by 9.94% within Nyando catchment is similar to climate change indicator responses from interviewees *(Table 3)* who indicated 86% increase in flooding. Other responses also reported 66% increase in drying up of water streams as risks (Zarco-Tejada *et al.,* 2005) in Nyando catchment despite increase in rainfall by 76.4%. An indicator on increased dry spells is shown as 65% and increased drying up of water sources as 66.8%. Another climate change indicator is increased temperatures which was reported as 78.1%. Land use change was computed as illustrated in Table 2.

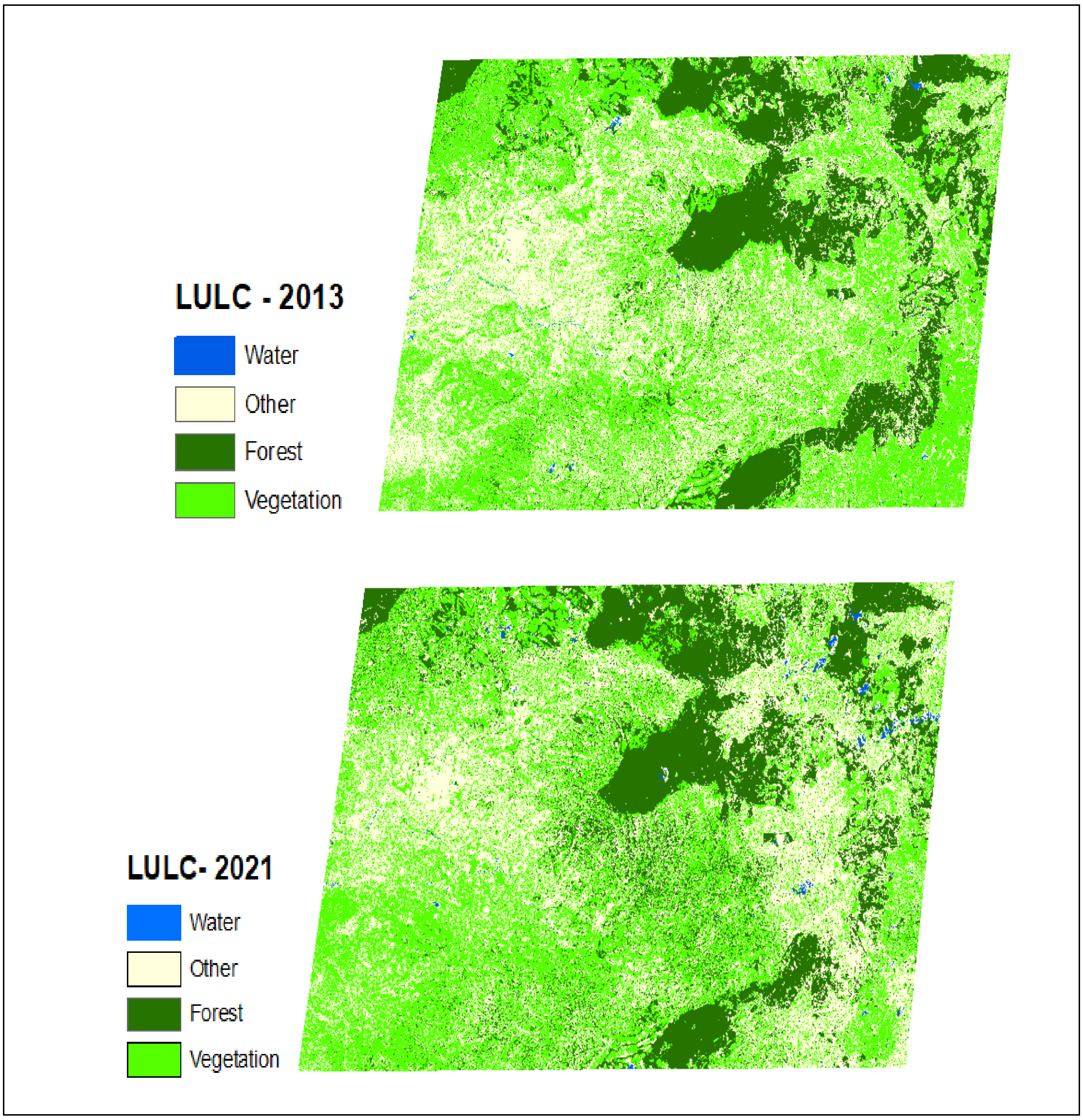

Figure 2. Change detection in land use (2013-2021)

Table 2: Change in land use (2013-2021)

Land Cover	**Area in 2013 (SqKM)**	**Area in 2021 (SqKM)**	**Change in 2013-2021**	**% Change**
Vegetation (Cultivated)	1,769.12	1,832.43	63.31	3.58
Forest land	931.48	838.87	-92.61	-9.94
Water area	18.07	8.30	-9.77	-54.07
Other (Built up; Bare land)	1,552.36	1,591.43	39.07	2.52
TOTAL Area	4,271.03	4,271.03		

Table 3. Indicators of climate change

	Rainfall amount	Rainfall reliability	Rainfall early onset	Rainfall late cessation	Length of cropping season	Dry spells	Droughts	Floods	Temp	Water sources drying	Thunder and lightning
Increase	76.4	48.3	69.4	59.1	65.5	64.9	33.9	86.4	78.1	66.8	55.8
Decrease	23.6	51.7	30.6	40.9	34.5	35.1	66.1	13.6	21.9	33.2	44.2
Total	100	100	100	100	100	100	100	100	100	100	100

Discussion

Results computed using geospatial technology in Table 2 and from insitu data in Table 3 demonstrates similar characteristics of a change that has occurred within the catchment over 8 years (2013-2021). The close to 10% decrease in forest land is attributed to the increased demand for food and housing as advocated for by the Government of Kenya in its big 4 agenda. This loss is indirectly related to the global climate change indicator of increased soil loss of 8% (Andersson, 2010). We infer that when forest area is lost, bare soils are exposed to agents of soil erosion such as rainfall (Zarco-Tejada *et al.*, 2005) which is reported to have increased within the catchmnet during the study period.

Moreover, we associate such soil losses with increased deposits within river basins as reported by other studies (Rudorff *et al.*, 2010) where the displaced water is observed flooding its river banks and displacing families within the Nyando basin at onset of rains. These results are similar to responses from interviewees *(Table 3)* who indicated over 80% increase in flooding. Other responses also reported over 60% increase in drying up of water streams as risks (Zarco-Tejada *et al.*, 2005) in Nyando catchment. It is expected the increase in rainfall by 76.4% would increase water areas but this is not the case for Nyando. As other researchers have stipulated, sedimentation of water areas is the reason for flooding (Rudorff *et al.*, 2010).

In this study, sedimentation is associated with the results of change detection which show a decrease in water streams by over 50% over the study period. We infer that the increased deposits (Rudorff *et al.*, 2010) in the water streams from soil erosion upstream (Saavedra, 2005) displaces water which quickly dries up with increased dry spells (65%) and increased temperatures.

The increase in built up areas by close to 3% signifies population increase and demand for land for settlement. We associate soil loss and sedimentation of water streams with a change in socio-economic activities hence risks of more flooding (Cohen *et al.*, 2008; De Jong *et al.*, 1999) if mitigation measures are not undertaken. We infer that deforestation exacerbates the sedimentation of water streams (Pettorelli *et al.*, 2005; Pimetel, 2006) in the catchment. These changes in the study area have been quickly captured and analyzed using remote sensing technology which Campbell, (2006) attributes to cover the landscape spatially from end to end and encode temporal data for validation by sampled insitu data.

We are in agreement with other studies which proved that sedimentation destroys habitats for animals and thus loss of grazing land (Reich *et al.*, 2000; Valentin *et al.*, 2005) for livestock. There is need for the decision makers both at County and National levels to determine mitigation measures to salvage the water streams, mitigate impacts of deforestation in Nyando and other catchments with similar characteristics and conserve the environment.

Conclusion and recommendation

Results of this study contribute to information generated using geospatial technology to study farmer responses to indicators of climate change within their agricultural landscapes. This study has used remote sensing data to study temporal changes over an 8-year period (2013 to 2021) to facilitate extraction of information on climate change indicators (Zarco-Tejada *et al.,* 2005) for Nyando catchment in Kenya. The derived indicators point to land use changes and variations in weather elements (rainfall and temperature) as main drivers to climate change risks within the catchment. This information is necessary for organizations to make quick and informed decisions to mitigate risks of climate change associated with land use. Areas where land use has changed over the 8 years period were detected using satellite imagery and area of such change computed within geospatial tools. Insitu data gathered during the physical survey was used to identify indicators of climate change which offered an opportunity for verification of the detected changes within Nyando catchment. It is evident that satellte images recorded end to end data of the catchment over the 8 years period to facilitate temporal analysis while the insitu data provided select data for this verification. This scenario is in agreement with remote sensing articles which advocate for importance of remote sensing technology in environmental modelling and management. Quick and timely identification of climate change risks in the landscape is key to timely decision making to save communities from climate change risks. We recommend the use of geospatial technologies in climate change studies to inform decision making in order to fast track mitigative measures and where possible, devise early warning systems to save ecosystems.

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