International Journal of Soft Computing and Engineering (IJSCE)
ISSN: 2231-2307 (Online), Volume-15 Issue-1, March 2025

Spatio-Temporal Analysis of Natural Forest Cover Change Utilizing Geographic Information Systems (GIS) and Remote Sensing Technologies: A Case Study

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Abstract: ***Ethiopia's natural forest cover is declining at an alarming rate due to population-growth-induced factors, other human-caused activities, and natural factors. This study aimed at the evaluation of spatiotemporal natural forest change dynamics by using change analysis. For the study (2000 ETM, 2010 ETM, and 2020 OLI-TIRS Landsat images were used) for change detections. Thus, the study result revealed that the major land use types were natural forests by 2000, but by now (2020), most of the natural forest areas are replaced by other land use classes. Thus, 233.76 ha of natural forest were cleared yearly for the last 20 years, mostly converted to farmland and settlement areas. Forest in the study is a source of energy (fuel wood and charcoal productions), substantial economic importance (timber and other construction material productions), and a source of food and domestic and wildlife habitat. Quantification of land use change detection shows us farmland, human settlement, and plantation areas are showing an increasing trend throughout the study period while natural forests are decreasing trend by 12% during 2000-2010 and by 14 % from 2010-2020. The main causes of natural forest degradation are the high demand for farmland, housing, and energy mainly due to population growth, shortage of clean energy provision, and low level of awareness. Natural forests will have high economic, ecological, genetic, and medicinal value. Thus, protecting and conserving natural forests is crucial for the study area.***

Keywords: Geospatial technologies; land use dynamics; Mari-Mansa district; Natural Forest.

Abbreviations:
GIS: Geographic Information System
RS: Remote Sensing
ERDAS: Earth Resource Data Analysis System
DEM: Digital Elevation model
LULC: Land use land cover
UTM: universal traverse mercator
WGS: world geodetic system

Manuscript received on 29 November 2024 | First Revised Manuscript received on 12 December 2024 | Second Revised Manuscript received on 20 Ferbuary 2025 | Manuscript Accepted on 15 March 2025 | Manuscript published on 30 March 2025.

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I. INTRODUCTION

Even though the natural forest is an ecological unit hosting diverse fauna, flora, and other ecosystem services and as a resource unit surviving substantial economic contributions and other social value, globally, natural forests are declining trends in terms of coverage and diversity [1]. Globally, natural forest cover was 4128 million hectares in 1990.

Later, in 2015, it declined by 3%, which was 3999 million hectares. This change in forest cover can alter the number of ecosystem services and functionality and will affect human well-being [2].

In East Africa, Due to high dependency on domestic energy sources on forests (fuel wood), unproductive traditional farming system for food security, provision of construction materials, overgrazing, and other factors, forest cover declined by 1% yearly between 1990 to 2015 [3].Researchers argue that Ethiopia faced rapid land degradation and deforestation due to high population growth, overgrazing, exploitation of forest fuel wood, fodder, and expansion of settlement areas [4]. Furthermore, this will extend its impact on agricultural performance and an obstacle to reforestation for extended periods [5].

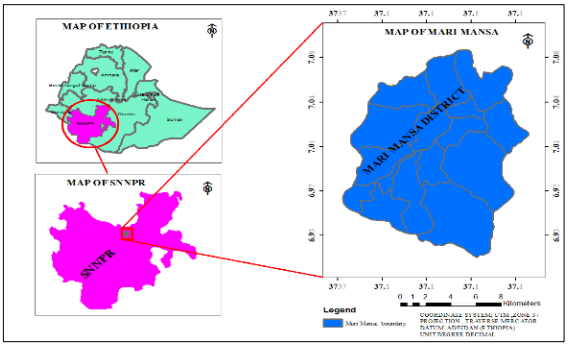
Mari-Mansa District is an area with high natural forest cover, and recent deforestation of natural forest is very common due to the need for energy (fuel wood), agricultural land (food insecurity), other socio-economic purposes (timber production), human settlement area (urbanizations and high need of shelter) and grazing land [6].Thus, those factors are supposed to be one of the reasons for currently observed losses of wildlife, unpredicted extreme weather conditions and climate variability, the lack of productivity of wild honey, and others [12]. Thus, a basic study using GIS, and remote sensing on spatiotemporal natural forest cover change will help decision-makers to develop locally implementable natural forest conservations, protection for wildlife, reforestation, and afforestation programs basically to conserve natural forests and other biodiversity [13].

II. METHODOLOGY

A. Study Area Description

MariN-Mansa district is located in Dawro Zone, South West Ethiopia. Based on UTM WGS 1984, it found between*n* 6°54′00" up to 7°05′15"north and 37°00′59.2" up to 37°8′01" east. The population size of the study area projected by the Central Statistical Agency of Ethiopia

by 2020 is 73,158, of which 37,409 are male and 35,749 are female. The economy of Mari Mansa district is largely dominated by subsistence agriculture and livestock farming practices (see Figure 1 for the location map of the study area).



[Fig.1: Study Area Location Map]

B. Data Collection

Detection of Spatiotemporal change was evaluated at the range of 10 years. 2000 and 2010 based on landsat-7-ETM (Enhanced Thematic Mapper) and at 2020 landsat-8-OLI-TIRS (Operational Land Imager-Thematic Infrared Sensor). The resolution of the adopted image is 30*30 meters.

Table 1: Definition of Forest and Classification of Land Use

No.	Major Land Cover	Descriptions
1	Forest	Areas covered by natural forest rather than any man-made forest.
2	Farmland	Areas of land plowed/prepared for growing rain-fed Crops. This category includes areas currently under crop, fallow, and land under preparation were classified as farmlands.
3	Plantation	Areas covered by bamboo trees, inset, and tree plantation
4	Settlement	All urban and rural settlements with road networks

C. Data Processing and Analysis Techniques

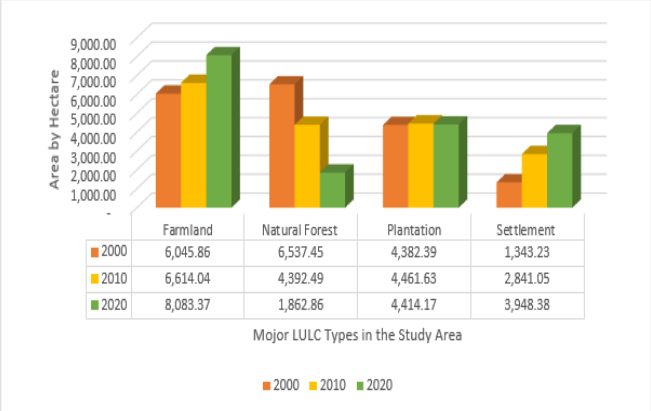
ERDAS Imagine 2014 was pre-processed and supervised by ArcGIS 10.8, and image enhancement was applied and similarly used by other study [7] .Furthermore, researchers' local knowledge was applied to classify local land use (natural forest, farmland, settlement area, and plantations). Band designation was used for interpretation, and classifications were used maximum likelihood algorism, which calculates the highest possibility pixels [14]. Quality assurance was made by generating an error matrix based on 2000, 2010, and 2020 land use land cover classification and area of interest [15]. Thus, the accuracy is measured based on the amount of ground truth pixels. This is based on the kappa value, a measure of the agreement between classification and reference data. It ranked the kappa values, ranging from -1 to 1(if Kappa ≥ 0.80, there is strong agreement between the classification and reference data; for 0.40 ≤ kappa≤ 0.80, moderate agreement; and kappa≤ 0.40 poor agreement [8].

Change matrices were used to detect change by generating quantitative data of spatiotemporal distributions (2000, 2010, and 2020 satellite imageries). Detecting the changes that have occurred, identifying the nature of the change, measuring the temporal and areal extent of the change, and assessing the spatial pattern of the change were investigated. NDVI, which ranges -1, is highly deforested/other than vegetation, while +1 will represent high/dense forest/vegetation) based on reflectance future were applied to triangulate change detections and similarly applied by researchers [9].

III. RESULT AND DISCUSSIONS

A. Land use land Cover (LULC) Change Detections

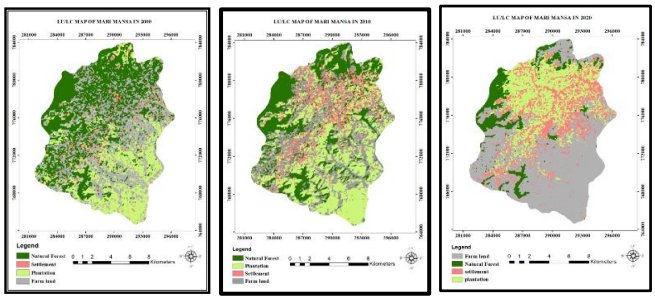
Based on all three-period data, Land use of the study area is majorly categorized into four major categories. This includes natural forests, plantation forests, farmland, and human settlement areas. The result in Figure 2 revealed that all LULC types are increasing trends except natural forest coverage area. Thus, this is an alarming stage to design appropriate mitigation strategies that enable the restoration of degraded areas, preservation of diversity, and protection of available natural forest areas.



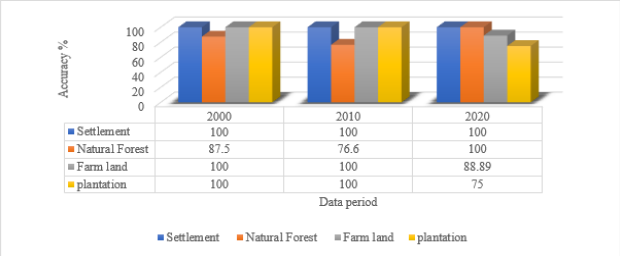
[Fig.1: Quantification of LULC Change Detection (at 200, 2010 and 2020)]

The measured kappa value agreement between classification and reference data is low. The kappa value of classified land classes was 0.9 (90%), 0.86 (86.02%, and 0.91 (91.1%) in 2000, 2010, and 2020, respectively. Better accuracy was achieved. Thus, a strong agreement between classified and collected GCP reference data transformed into a local coordinate system and reported similarly.[8].

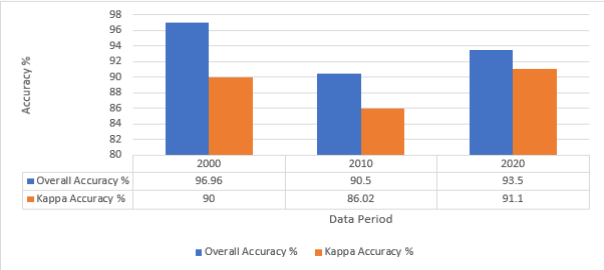
See details in Figures 3 and 4.



[Fig.2: LULC Map of the Study Area (2000, 2010, and 2020)]



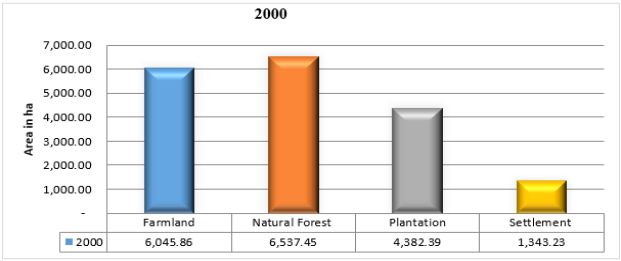
[Fig.3: User Accuracy Measure %]



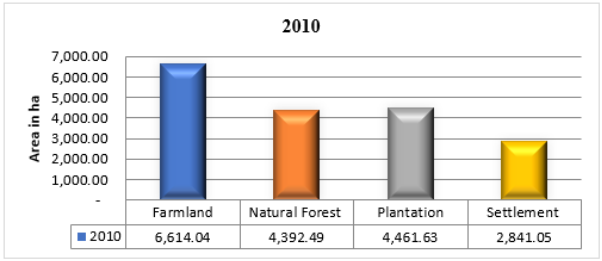
[Fig.4: Overall and Kappa Accuracy Measures in % (Source from Accuracy Assessment Calculation)]

B. Comparative LULC Change Detections Analysis

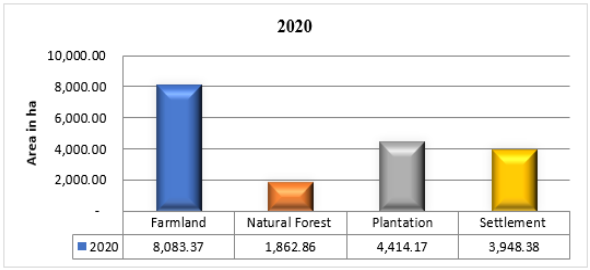
In 2000, about 36% of the study area was covered by natural forest cover, the largest LULC type. Later on, it decreased to 24% of the total LULC type of the study area in 2010, and then in 2020, the smallest LULC type of the study area is Natural Forest cover, which only 10% of the total LULC of the study area is covered by natural forest. However, the plantation area remained constant. This result revealed that there is a good trend of forest protection for plantation areas but not for natural forests. On the other hand, human settlement in the study area, which is leading to urbanization, was the smallest coverage in the area, which was 7% of the total land area in 2000, increased to 16% of the total area in 2010 and reached 22 % of the total area. Similarly, farmland, which is divided by population growth and the struggle to ensure food security, will become the largest land use type of the study area by 2020 which was 33% of the total area becomes 44% of the total area of the land use types of the study area.



[Fig.5: LULC Pattern of the Study Area in 2000 G.C]



[Fig.6: LULC Pattern of the Study Area in 2010 G.C]



[Fig.7: LULC Pattern of the Study Area in 2020 G.C]

Table 2: Change Matrix Table Between 2000 and 2010

Land Class		Area of Land use Class (ha) in 2010 (Final)				
		Farmland	Natural Forest	Plantation	Settlement	Total
Area of Land use class in (ha) in 2000	Farmland	4967.067	0.443	59.52	1018.834	6045.864
	Natural forest	683.852	4241.487	381.538	1230.567	6537.445
	Plantation	267.559	`77.031	3729.466	308.331	4382.388
	Settlement	695.562	73.263	291.1008	283.3029	1343.227
	Total	6614.040	4392.225	4461.625	2841.035	18309
	Change	568. 76	-2145.02	79.237	1497. 0	~0

Table 3: Change the Matrix Table between 2000 and 2010

Land Class		Area of Land use Class in (ha) in 2020 (Final))				
		Farmland	Natural Forest	Plantation	Settlement	Total
Area of Land use class in (ha) in 2010 (initial)	Farmland	5950.76359	0.024091	43.15091	610.201	6614.040
	Natural forest	1118.86222	1862.260088	1105.7642	305.5998	4392.486
	Plantation	322.28633	0.221785	3127.9893	1011.484	4461.625
	Settlement	683.020734	0.005171	137.1833	2020.8387	2841.047
	Total	8083.932	1862.511135	4414.0877	3948.123	18309.
	Change	1469.89	-2529.48	-47.51	1107.076	~0

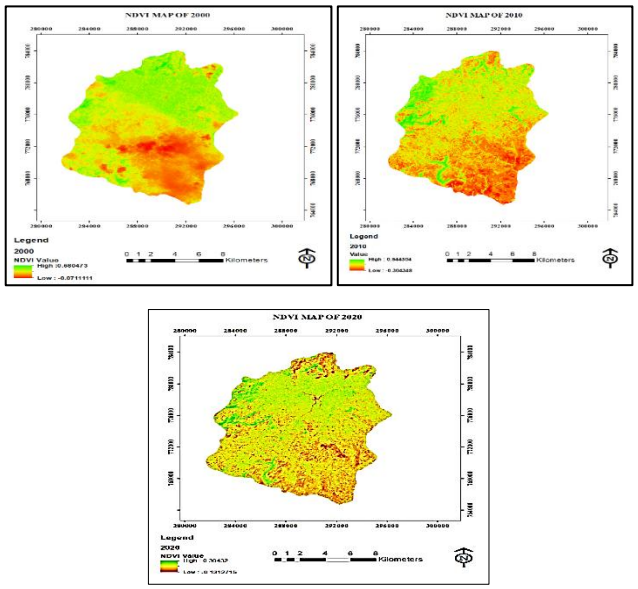
C. Comparative LULC Change Detections Analysis Based on NDVI Data

An increment of NDVI value indicates that the change in vegetation cover is not to the specified vegetation types. Thus, from NDVI, we can see that the area's total green cover is under change. This will confirm e declining trends in natural forests and the increase in human settlement and farmlands. NDVI ranges -1, representing other than vegetation coverage, while +1 represents dense or healthy vegetation area coverages. Similarly, reported by other reports [10]. This means that vegetation status is under changing scenarios from 2000 when compared with the 2010 and 2020 satellite images based on NDVI. Hence, the rate of vegetation change was higher in the 2020 satellite image than

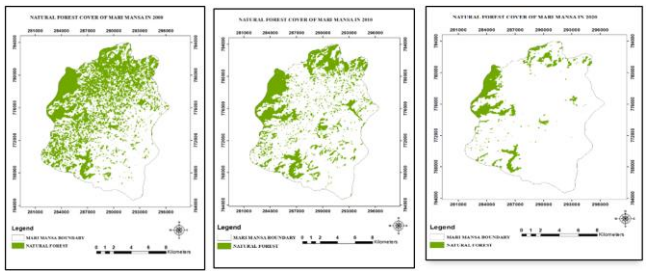
the change of vegetation in 2010 and 2000. The result of the NDVI values showed that the density of vegetation cover was reduced/declining, and the result of inferred data showed continuous deforestation and forest degradation.

D. Natural Forest Data Extraction and Mapping

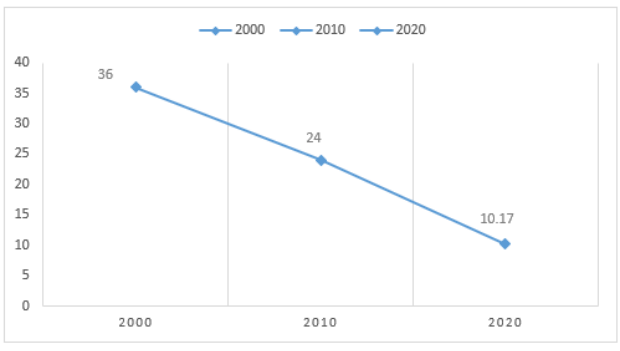
Data extraction was made to map natural forest detection over the study period to confirm the quantified data in Figure 6-8. Extracted natural forest map is used to visualize spatiotemporal distribution and rate of natural forest cover change within selected time series. The mapping revealed that most of the west, northwest, and southwest of the study area was covered by dense forest, and with time, it was cleared, and by now, natural forest cover is diminished highly.



[Fig.8: NDVI Value Mapping Change over Time of Study Area in 2000, 2010, and 2020]



[Fig.9: Natural Forest Mapping of the study Area in 2000, 2010, and 2020]



[Fig.10: Natural Forest Cover Change Trends]

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusions

- According to the result of the study, every year, about 233.76 ha of Natural Forest were cleared on average in the last 20 years. This result will strengthen previous studies by other researchers [11].
- NDVI, survey made and extracted mapping revealed that natural forest is declining highly at an alarming rate and may cause biodiversity loss.
- This study revealed that not only declining trends of natural forest cover but also the rate of forest cover change is higher in the second ten years (14%) as compared to the first ten years (12%).
- Initiatives taken to protect plantation forests are encouraging and fruitful; thus, plantation forest cover remained constant. This is because commercial plantations enforce re-afforestation for business sustainability.
- Farmland expansion is one of the major role players for natural forest degradation. This is due to high population growth in the study area, triggering high demand for housing and food insecurity impediments with an unproductive farming system, which is traditional and rain feed. On the other hand, the fertility of land under natural forests is highly demanded by local landowners, leading to deforestation. This confirms the general study made at the country level by another researcher With the local context.
- High demand for new settlements resulted from high population growth and urbanization, local awareness for natural forest protections, and values other reasons for natural forest declinations.
- According to the findings, expansion of farmland, timber production, overgrazing, cutting trees for house construction material, firewood, and charcoal extraction were the main factors identified in the study area for deforestation practice and similarly reported by other researchers.

B. Recommendations

- The local and federal government, as well as any concerned governmental and governmental body, has to take initiatives in the provision of green energy supply to protect deforestation of Natural forests. The lack of alternative energy sources of grid power is a major factor in natural forest deforestation.
- The Current need for housing with increasing population trends has to get attention not only from the point of view of citizen rights and conventional development but also from environmental and biodiversity protection.
- Currently, the intervention of wildlife like hyenas, monkeys, baboons, tigers, Impala, and apes with residents is very critical, and it shows us a high distraction in the natural habitat of wildlife. Thus, wildlife habitat protection needs to be planned and implemented.
- Implementing carbon value/ carbon credit in the form of community-based support at the grassroots level,energy-saving appliance provisions, and

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awareness rise may help to reduce the deforestation rate by large.

- Currently, local population growth trends, rate of urbanization and need for industrialization, consumption trends of goods in the community, and other factors are highly affecting indigenous species, and natural forests are going to be lost. Thus, the concerned body of the Mari-Mansa district should work on community empowerment of environmental protections in addition to the current trend of tree plantations as a green legacy.
- The Mari-Mansa district micro and small enterprise, natural resource management, and mineral and energy offices should create other job opportunities for people who are engaged in their lives by selling forest products like charcoal, fuel wood, and timber.
- Local communities should participate in different natural forest conservation mechanisms like afforestation, reforestation, and agro-forestry programs and also the management of planted trees by considering their benefit.
- Since the policy of Ethiopia declares that land is not individual property, it is a good opportunity to enhance land use productivity, not to convert to other land use types. Thus, the land use change has to be controlled by local government, and society has to be encouraged to enhance the productivity of land use types without conversion to other land use types.
- Eco-tourism is one of the important motivational factors for the local community to value natural forests. Natural forest, particularly in the study area, contains diverse fauna and flora species, historical caves, and a very attractive natural waterfall.

ACKNOWLEDGMENTS

First of all, we would like to thank our Almighty God for his tireless protection. We express our deepest gratitude to Wachemo University for allowing us to conduct our research. Without their generous support, this research project would not have been possible. Lastly, we would like to express our gratitude to all those who have directly or indirectly contributed to the completion of this research project.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible. The data and materials used for analysis in this manuscript are available at the corresponding author. It is possible to reasonably request the corresponding author. Also, all secondary and primary data used for the research are available in the hands of researchers.
- **Authors Contributions:** Each author has individually contributed to the article. Tariku Kebede Tofu contributed by conducting research and writing the manuscript and contributed by, arranging, organizing, and directing the manuscript's full write-up. Adamu Dessalegn Taddesse contributed to editing the manuscript. Thus, all authors reviewed the results and agreed on the final version of the manuscript.

REFERENCES

1. FAO & JRC, Global forest land-use change 1990–2005 (FAO Forestry Paper No. 169). 2012. DOI: https://doi.org/10.1126/science.1244693
2. M. Shiferaw, Z. Kebebew, and D. O. Gemeda, 'Effect of forest cover change on ecosystem services in central highlands of Ethiopia: A case of Wof-Washa forest', Heliyon, vol. 9, no. 7, p. e18173, 2023, DOI: https://doi.org/10.1016/j.heliyon.2023.e18173
3. N. Berhanu, H. Debela, and B. Jiru, 'Fuel wood utilization impacts on forest resources of Gechi District, South Western Ethiopia', J. Ecol. Nat. Environ., vol. 9, pp. 140–150, Aug. 2017, DOI: https://doi.org/10.5897/JENE2017.0642
4. G. Gidey and A. Gebre, 'Rapid Population Growth as Foremost Cause of Land Degradation in Ethiopia: A Review', Oct. 2021. https://pdfs.semanticscholar.org/f43d/7340449466a8299cc31dd0b49cad5ceef781.pdf
5. O. I. Ollinaho and M. Kröger, 'Agroforestry transitions: The good, the bad and the ugly', J. Rural Stud., vol. 82, pp. 210–221, 2021, DOI: https://doi.org/10.1016/j.jrurstud.2021.01.016
6. S. B. Wassie, 'Natural resource degradation tendencies in Ethiopia: a review', Environ. Syst. Res., vol. 9, no. 1, pp. 1–29, 2020, DOI: https://doi.org/10.1186/s40068-020-00194-1
7. A. Razafinimaro, A. Richard Hajalalaina, Z. Tantely Reziky, E. Delaitre, and A. Andrianarivo, 'Landsat8 Satellite Image Classification with ERDAS for Mapping the Kalambatritra Special Reserve', Am. J. Remote Sens., vol. 9, no. 1, p. 16, 2021, DOI: https://doi.org/10.11648/j.ajrs.20210901.12
8. J. R. Landis and G. G. Koch, 'An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers', Biometrics, pp. 363–374, 1977, doi: https://doi.org/10.2307/2529786
9. A. de la I. Martinez and S. M. Labib, 'Demystifying normalized difference vegetation index (NDVI) for greenness exposure assessments and policy interventions in urban greening', Environ. Res., vol. 220, p. 115155, 2023, DOI: https://doi.org/10.1016/j.envres.2022.115155
10. R. R. Muskett, 'Arctic Diurnal Land-Surface Temperature Range Changes Derived by NASA MODIS-Terra and -Aqua 2000 through 2012', Atmos. Clim. Sci., vol. 04, no. 02, pp. 231–240, 2014, DOI: https://doi.org/10.4236/acs.2014.42026
11. A. Eshetu, 'Forest resource management systems in Ethiopia: Historical perspective', Int. J. Biodivers. Conserv., vol. 6, pp. 121–131, Feb. 2014, DOI: https://doi.org/10.5897/IJBC2013.0645
12. V E, S., Moorthy, U., Park, J., Shin, C., & Cho, Y. (2019). Internet Role in Remote Sensing and Geo Informatics System. In International Journal of Innovative Technology and Exploring Engineering (Vol. 9, Issue 2, pp. 57–64). DOI: https://doi.org/10.35940/ijitee.A4859.129219
13. Gotekar, Mr. R. K., Shaw, Dr. K., & Rout, Dr. M. (2020). Spatial Information System Architecture for the Geographic Information System. In International Journal of Recent Technology and Engineering (IJRTE) (Vol. 8, Issue 5, pp. 2769–2776). DOI: https://doi.org/10.35940/ijrte.D7567.018520
14. Ramesh, G. (2021). Importance and Applications of GIS in Engineering. In Indian Journal of Structure Engineering (Vol. 1, Issue 1, pp. 4–8). DOI: https://doi.org/10.54105/ijse.B8008.051121
15. Srikanth, Dr. L., Srikanth, I., & Arockiasamy, Dr. M. (2019). Identification of Traffic Accident Hotspots using Geographical Information System (GIS). In International Journal of Engineering and Advanced Technology (Vol. 9, Issue 2, pp. 4429–4438). DOI: https://doi.org/10.35940/ijeat.B3848.129219

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