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# Monitoring Forest Health Using Geographical Information System Based Weighted Overlay Method in Sonaikushi Reserved Forest, Morigaon District, Assam, India

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**ABSTRACT**
Degradation of forest is now a most prevalent global issue. Assessment and monitoring of forest health is considered to be an important aspect for protection and management of forest ecosystem. This study is aimed at evaluating forest health of Sonaikushi reserved forest, Morigaon District, Assam, India. In order to assess forest health of the reserved forest some remote sensing spectral indices namely Normalized Difference Vegetation Index (NDVI), The Green Normalized Difference Vegetation Index (GNDVI), Soil Adjusted Vegetation Index (SAVI) and Normalized Difference Moisture Index (NDMI) have been applied. For this purpose, two multi temporal satellite images have been taken. These maps are prepared using two different spectral bands in raster calculator function of ArcGIS software. The NDVI value ranges from 0.526 to -0.142 in 1992, 0.373-0.049 in 2022 while that of GNDVI value ranges from 0.489 to -0.155 in 1992 and 0.319-0.034 in 2022. SAVI value range in 1992 is 0.786 to -0.212 and 0.559-0.074 in 2022. NDMI value range in 1992 is 0.352 to -0.414 and 0.184 to -0.197 in 2022. Weighted overlay method was used for preparing forest health map where all the indices were overlayed in a single map on the basis of assigned weightage. The results show that unhealthy forest has decreased to -1.89 $km^2$ (-3.71%) and moderately healthy forest has increased to 3.53 $km^2$ (6.92%) during the period 1992-2022. Besides, highly healthy forest has increased to 1.18 $km^2$ (2.32%). But, forest under very highly healthy category has been decreased to -2.82 $km^2$ (-5.53%) from 1992-2022.

**Key words:** NDVI, GNDVI, Soil adjusted vegetation index, NDMI, Spectral bands

## INTRODUCTION

Forest ecosystems constitute the crucial facet of the world's biodiversity. Forests cover about 31% of the earth's land area. Nearly half of the forest area is relatively untouched, with primary forest accounting for more than one-third of the total. Over half of the world's forests are found in just five countries (Russia, Brazil, Canada, USA and China), and two-thirds (66%) of forests are found in just ten countries (Anonymous 2020a). India is a rich country in forest resources. It covers 21.71% of country's total area (Anonymous 2021). But, the forest resources are susceptible to a variety of climatic and human-caused stressors, resulting in their continuous deterioration (Simula 2009). Due to expansion of agriculture land on the earth's surface there is the obvious effect on forest area. Checking and evaluating forest health is thus critical to safeguard and preserve the potential of these resources for long-term beneficial (Smith 2002).

Forests are the vital ecological, economic, artistic, and ethnic resource for the Earth's metabolism. Forest health is a state of an ecological system which allows maintaining its complexity while achieving human needs (O'Laughlin et al. 1994). Plant growth, organisms, climate, insects, and humans all play a role in determining forest health. The condition of forest depends on its age, structure, environmental condition, composition etc. Forests perform numerous ecological functions; hence, it is critical to comprehend the dynamics of forest change influencing forest health and their interconnections with forest structure, type, and history (Dutta et al. 2020)

Remote sensing has provided a method for overcoming the limitations in assessing forest health at various temporal and spatial scales (Lauch et al. 2016). For forest health monitoring, high resolution satellite imagery such as LIDAR and aerial videography are used (Ciesla 2000). Healthy forests, which can be assessed and supervised to use a variety of forest health indicators, are required for aesthetic value, human needs satisfaction, and the long-term viability of ecosystems (Ebinne et al. 2020). Green vegetation has a distinct interaction with energy in the visible and near-infrared wavelengths of the electromagnetic spectrum (John 2018). The portion

of reflected signal in the electromagnetic spectrum's red and near-infrared areas has been the focus of numerous attempts to develop statistical indices of vegetation condition using remotely sensed imagery (John 2018). Vegetation indices allow delineating the distribution of vegetation and soil based on the characteristic reflectance patterns of green vegetation. For measuring various facets of vegetation cover on spatio-temporal context Normalized Difference Vegetation Index (NDVI) has been used. The NDVI, one of the first remote sensing introspective products used to standardize the difficulties and challenges of multi spectral imagery, is now the most prevalently used index for vegetation estimation. It can relate visible and near infrared bands using NDVI. The ultimate aim of using NDVI is to optimize the analysis of vegetation information using remotely sensed data. NDVI has been shown in studies to be effective in distinguishing savannah, dense forest, non-forest, and agricultural (Huang et al. 2020). It is used to study temporal and spatial trends and variation in plant communities, productivity, and dynamics, in addition to monitor environmental loss and segmentation of (Pettorelli et al. 2005). Furthermore, in addition to NDVI, another vegetation index known as Green Normalized Difference Vegetation Index (GNDVI) is used to assess forest health. The GNDVI indices are used to assess photosynthetic activity. Besides that, Soil Adjusted Vegetation Index (SAVI) indices are employed to reduce soil brightness factor in order to assess the same. Water or moisture content has an effect on forest growth. In this study, Normalized Difference Moisture Index (NDMI) indices are used to analyse amount of moisture on forest.

The present study primarily concerned with assessing the spatiotemporal changes of NDVI, SAVI, GNDVI, and NDMI, and a forest health map is created using the weighted overly method based on these indices. It is a method that assigns weightage to each value and performs a single analysis.

## MATERIALS AND METHODS

### Study area

Sonaikushi Reserved Forest is located in Morigaon District's southern region. Its latitude and longitude are 26°3'41"N to 26°7'36"N and 92°10'3"E to 92°17'5"E, respectively. Total area of this reserved forest is 50.98 km². Evergreen and deciduous types of vegetation are found in this reserved forest. It creates border between Assam and Meghalaya in Morigaon District.

### Database

To assess the forest health condition in the reserved forest from 1992 to 2022, the study uses two Landsat series satellite imageries from USGS portal (Table 1). These imageries were taken during the time of winter season to avoid cloud coverage.

### Methodology

*Image pre-processing*

Image data enhancement that suppresses unwanted distortions or enhances some image features applicable to subsequent processing and analysis tasks. After acquiring images, it is pre processed for minimizing the effects of atmosphere with the help of brightness corrections, histogram equalization,geometric transformation etc.

*Normalized Difference Vegetation Index(NDVI)*

The NDVI is a simple numerical index that can be used to analyse remote sensing measurements from various platforms and determine whether the objects being observed contain live green vegetation or not. In the case of healthy green vegetation, the NIR band reflects more light and the red band absorbs more. The NDVI scale ranges from -1 to 1. Very low near -1 reflects bare soil, rock, sand, snow, and so on. A moderate value represents shrubs and grasslands, while a high value near 1 represents a healthy dense forest (Gandhi et al. 2015). The NDVI is expressed as:

$$NDVI=NIR-Red/NIR+Red \ldots\ldots\ldots\ldots\ldots(1)$$

*Soil Adjusted Vegetation Index(SAVI)*

A transformation technique is under taken to reduce the effects of spectral vegetation indices involving red and near-infrared (NIR) wavelengths on soil brightness (Huete et al. 2020). The Soil-Adjusted Vegetation Index (SAVI) method is a vegetation index that uses a soil-brightness correction factor to try to minimize soil brightness influences. This is commonly used in arid regions with low vegetative cover, and it produces values ranging from -1.0 to 1.0 (https://pro.arcgis.com/en/pro-app/latest/arcpy/spatial-analyst/savi.htm).In areas with low vegetative cover, SAVI is used to correct the Normalized Difference Vegetation Index (NDVI) for the influence of soil brightness. Surface reflectance from Landsat SAVI is calculated as a ratio of the R and NIR values, with a soil brightness correction factor (L) of 0.5

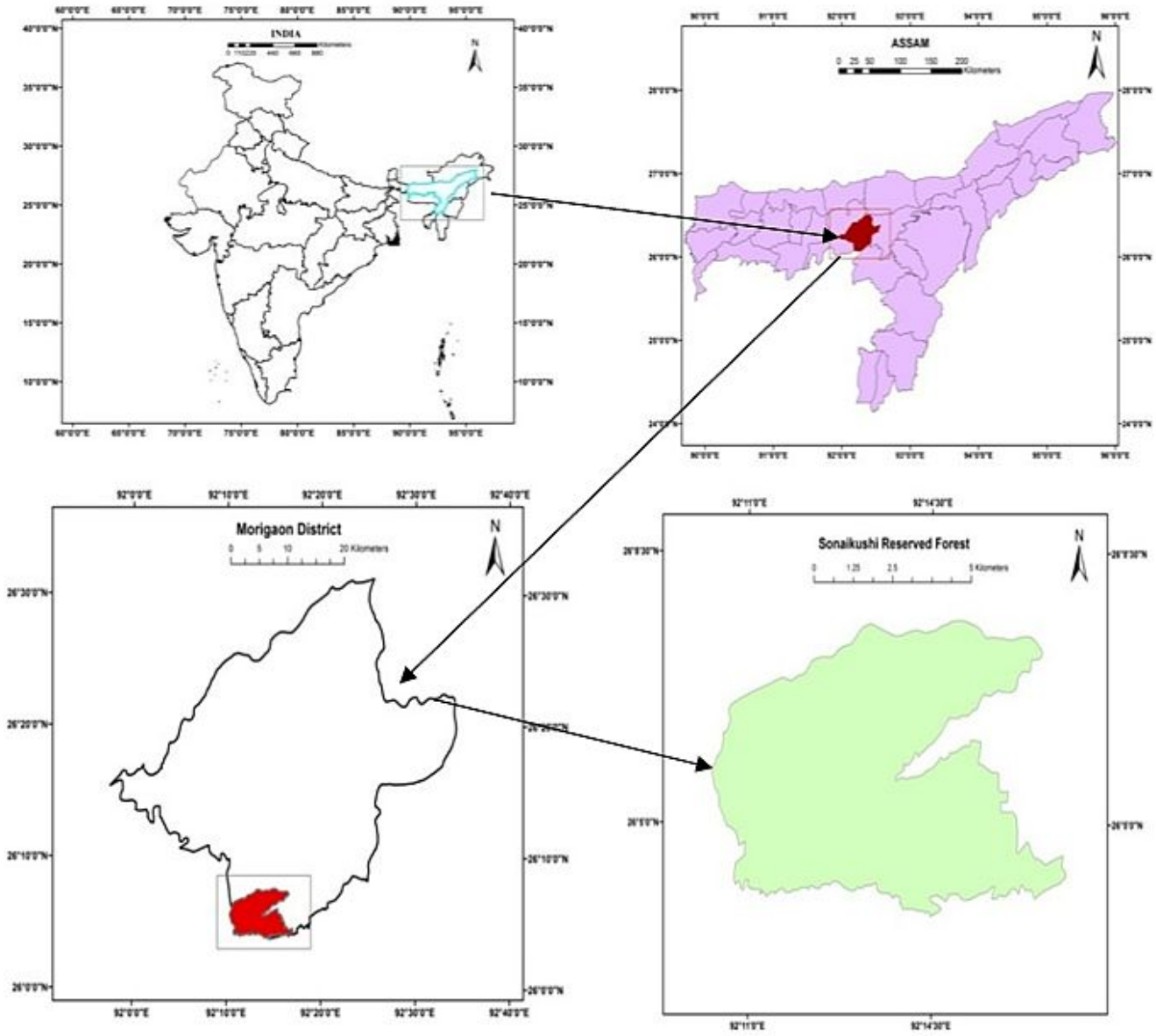


Figure 1. Location map of the study area

Table 1. Characterstics of satellite data used in study

| Satellite | Sensor | Date of acquisition | Path/Row | Resolution |
|---|---|---|---|---|
| Landsat 5 | Thematic Mapper (TM) | 1992/01/06 | 136/42 | 30 m |
| Landsat 9 | Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) | 2022/03/21 | 136/42 | 30 m |

to account for the majority of land cover types (https://www.usgs.gov/landsat-missions/landsat-soil-adjustedvegetation-index).

SAVI = ((NIR – Red)/(NIR + Red + L)) * (1 + L) …(2)

(L—the amount of green vegetation covers)

*The Green Normalized Difference Vegetation Index (GNDVI)*

The Green Normalized Difference Vegetation Index (GNDVI) method is a vegetation index for estimating photosynthetic pigments activity that is extensively used to determine water and nitrogen absorption into the tree canopy (https://pro.arcgis.com/en/pro-app/latest/arcpy/

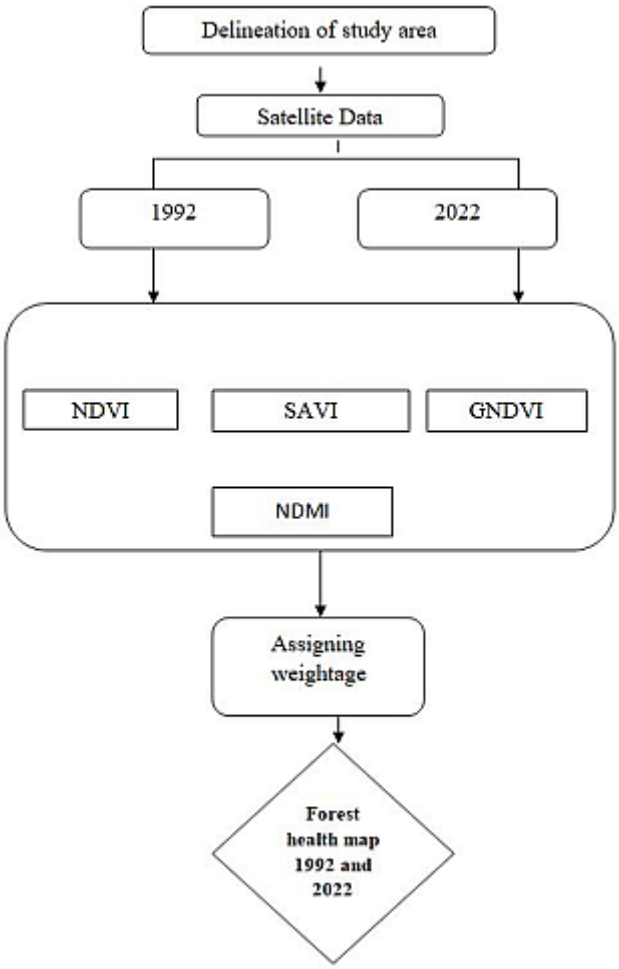


Figure 2. Methodological framework

image- analyst/gnvdi.htm). GNDVI has a higher critical threshold and is more susceptible to chlorophyll alteration in the crop than NDVI. This index, like the NDVI, provides values ranging from -1 to 1. The GNDVI values are estimated as:

GNDVI = (NIR – Green)/(NIR + Green) ….(3)

*Normalized Difference Moisture Index (NDMI)*

The Normalized Difference Moisture Index (NDMI) uses a combination of near-infrared (NIR) and short-wave infrared (SWIR) spectral bands to detect moisture levels in vegetation. It employs NIR and SWIR bands to generate a proportion that is intended to mitigate brightness and atmospheric effects. NDMI value ranges from -1 to 1, which are obtained from the following euation:

NDMI = (NIR – SWIR)/(NIR + SWIR) ……(4)

*Weighted overlay method*

The weighted overlay function is executed through spatial analysis tool in ArcGIS software. This tool applies the reclassified method to classify the indices to a new product and combines them in a single analysis. This analysis is based on multi-criteria support. In the overlay process, each raster is assigned a weight. This method is also used in suitability analysis. In this investigation, NDVI has given more weightage than the other indices, viz. SAVI, GNDVI, and NDMI. NDVI has the ability to segregate the vegetated and non-vegetated areas.

Weighted overlay index =

NDVI+SAVI+GNDVI+NDMI ……..…..(5)

## RESULTS AND DISCUSSION

### Forest health status based on NDVI, GNDVI, SAVI and NDMI indices

NDVI is an important parameter to evaluate forest health condition in the study area. For the year 1992, maximum NDVI value was 0.526 and minimum -0.142. In 2022, maximum value was 0.373 and minimum 0.049. The maximum value signifies moderate vegetation pattern in 1992. However, the maximum NDVI value in 2022 is less than that of 1992 implying moderate vegetation cover is gradually converted to shrubs and grasslands (Fig 3).

The photosynthesis activity of tree is evaluated by using GNDVI index. Maximum GNDVI value in 1992 was 0.489 and minimum 0.155. However in 2002, the maximum GNDVI value decreased to 0.319 and minimum to 0.034. This change in GNDVI values signifies the reduction of toatal photosynthetic activity (Fig. 4).

SAVI, an index that has been used to analyze forest health was maximum (0.786) and minimum (0.212) in 1992 which showed similar pattern that was seen for NDVI and GNDVI in 2022 with maximum value of 0.559 and minimum of 0.074 (Fig. 5).

Water or moisture is an important factor of growing tree. The amount of water content present in tree can be measured by using NDMI index. The maximum NDMI value in 1992 was 0.352 and minimum -0.414. For the year 2022, the maximum value was 0.184 and minimum -0.197. It has been observed from the values that between 1992-2022, the moisture content of the forest has decreased (Fig 6).

### Forest health analysis

Four indices namely NDVI, GNDVI, SAVI and NDMI have been used to monitor forest health in Sonaikushi

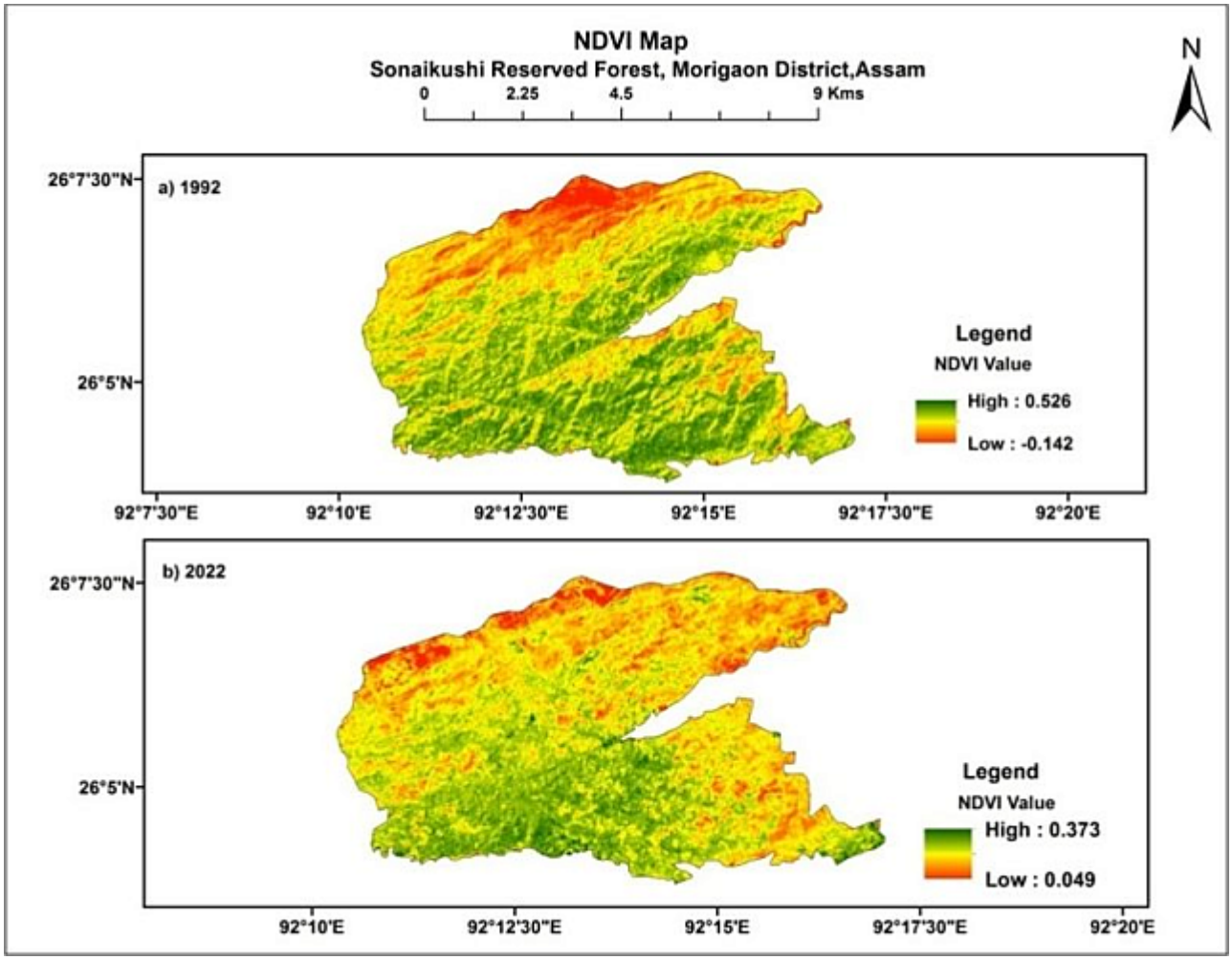


Figure 3. NDVI map (a) 1992 and (b) 2022

Table 2. Area under each forest health category during 1992-2022

| | 1992 | | 2022 | | Change in area (1992-2022) | |
|---|---|---|---|---|---|---|
| Forest health category | $km^2$ | % | $km^2$ | % | $km^2$ | % |
| Unhealthy | 5.61 | 11.00 | 3.72 | 7.29 | -1.89 | -3.71 |
| Moderately healthy | 12.64 | 24.79 | 16.16 | 31.71 | 3.53 | 6.92 |
| Highly healthy | 17.22 | 33.77 | 18.40 | 36.10 | 1.18 | 2.32 |
| Very highly healthy | 15.51 | 30.43 | 12.69 | 24.90 | -2.82 | -5.53 |
| **Total** | **50.98** | | **50.98** | | | |

reserved forest of Morigaon District. It has been proved that single index isn't enough to analyse health status of forest. To understand the several aspects of forest, these indices are used. Forest health map has been prepared by using weighted overlay method in ArcGIS spatial analysis tool. For this purpose, two forest health maps have been prepared for 1992 and 2022. These maps are categorized in 4 classes viz, unhealthy, moderately healthy, highly healthy and very highly healthy forest. Categorization has been done after reclassifying the indices on the basis of range of the values (Fig 7).

NDVI has been identified as an important index for analyzing forest health among the other indices. During the preparation of the forest health map, high priority is given to NDVI. In this index, NIR and Red band is used to analyse the spatio temporal changes of forest area.

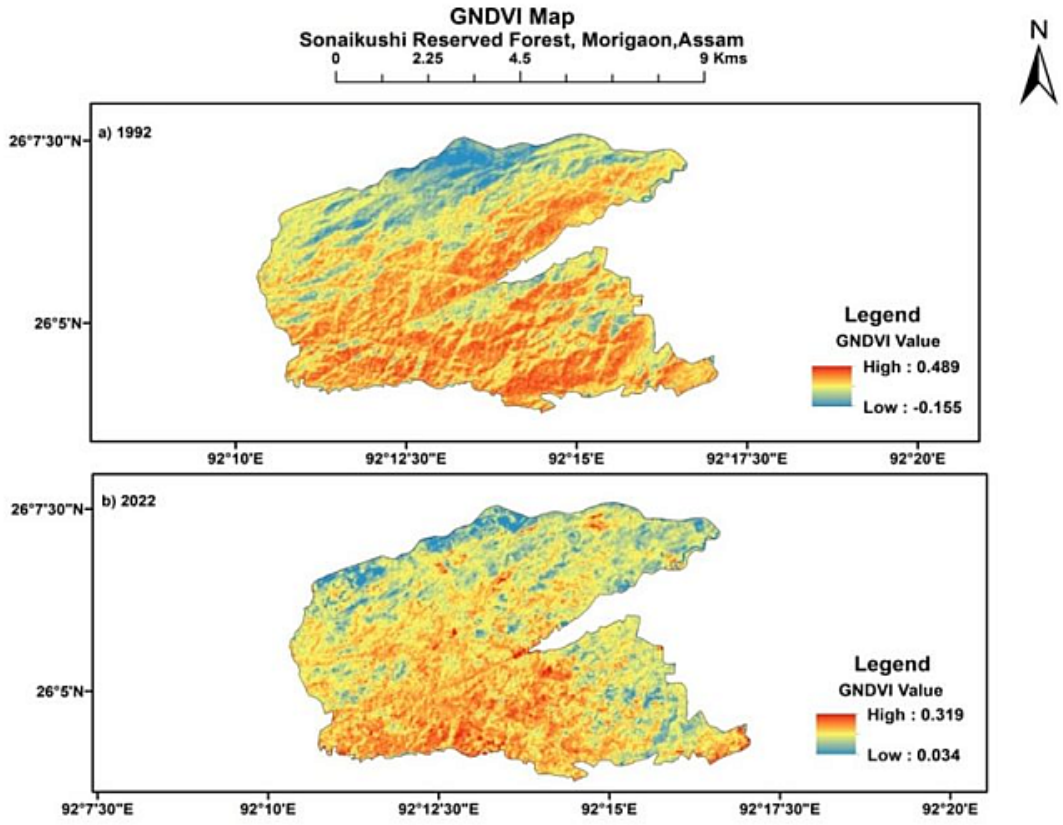


Figure 4. GNDVI map (a) 1992 and (b) 2022

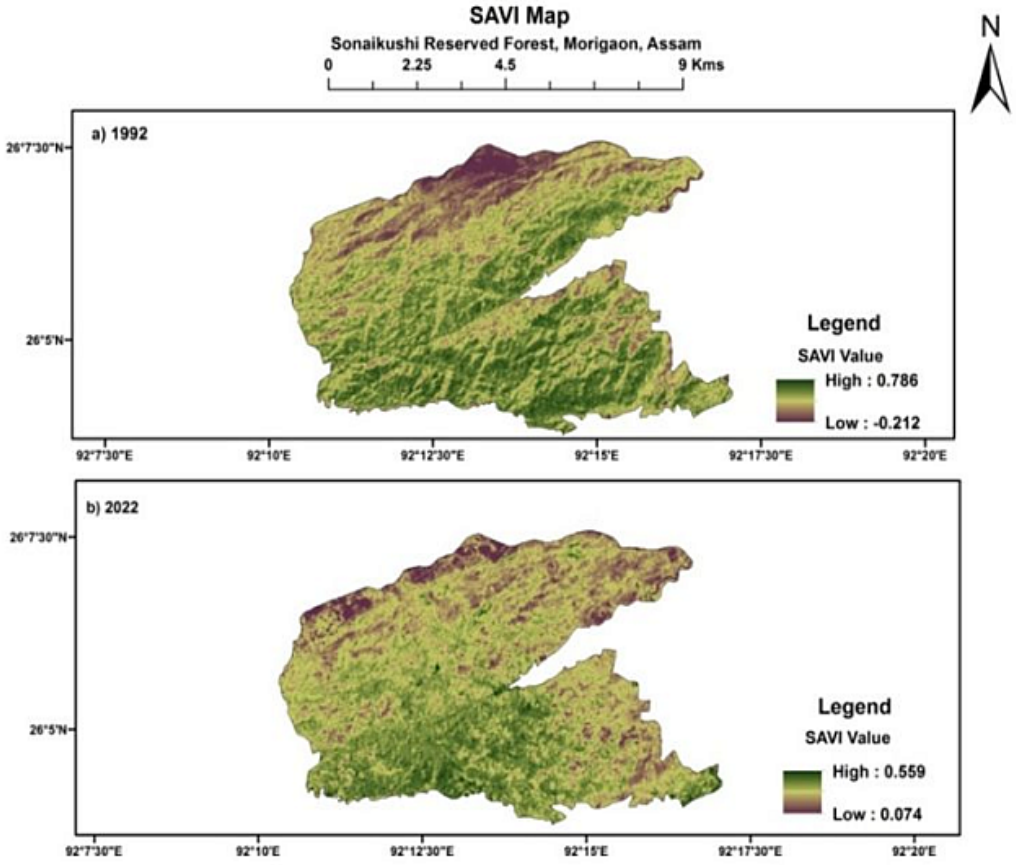


Figure 5. SAVI map (a) 1992 and (b) 2022

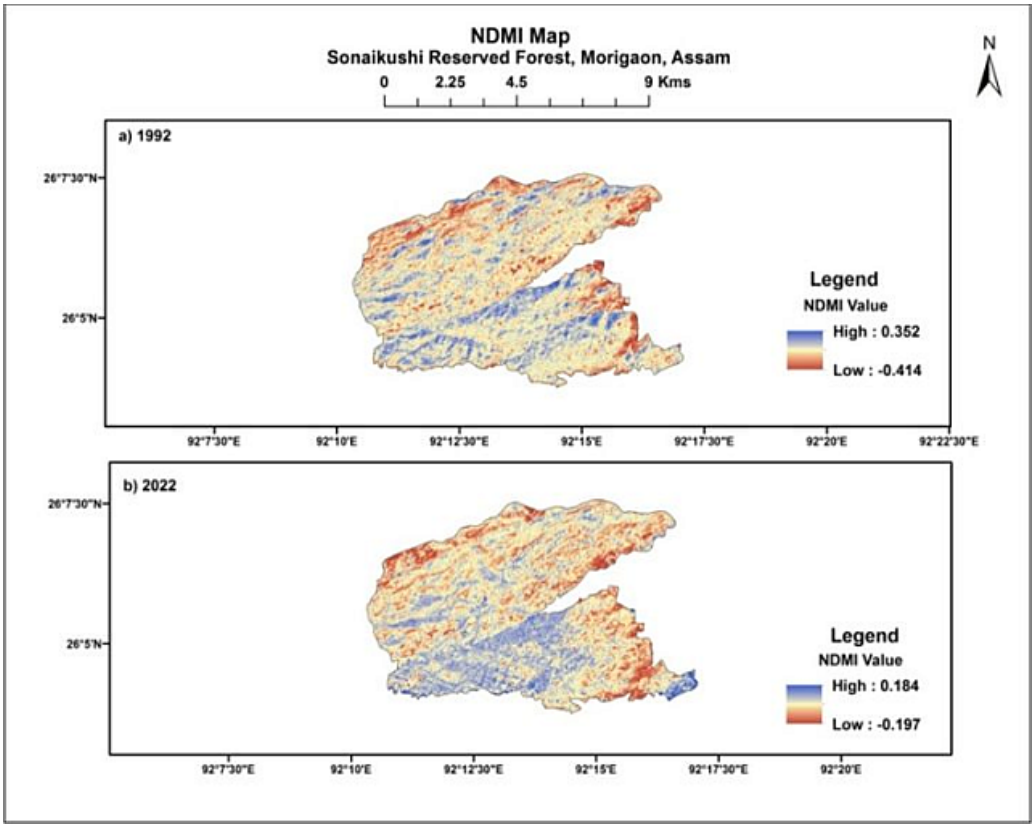


Figure 6. NDMI map a) 1992 and b) 2022

Area of each forest health category is calculated in raster function using spatial analysis tool. The area under unhealthy forest in 1992 was 5.61 km$^2$ which was 11% of the total area of the reserved forest. But, in 2022, the area declined to 3.72% which accounts for 7.29% of the total area of the forest (Table 2). In 1992, moderately healthy forest area was 12.64 km$^2$ representing 24.79% of total area of the forest. In 2022, the area of moderately healthy forest has increased to 16.16 km$^2$, which is 31.71% of total reserved forest area. In case of highly healthy forest status in 1992, the area was 17.22 km$^2$ covering 33.77% of total area of the forest, but in 2022 the area under its category is 18.40 km$^2$ which is 36.14 km$^2$ of total area of the forest. The area under very highly healthy forest is 15.51 km$^2$ and covers 30.43% of total forest area and declining these area in 2022 to 12.69 km$^2$, which covers 24.90% of the total area of the reserved forest.

The change in area from 1992 to 2022 for the unhealthy forest category is -1.89 km$^2$ which is about -3.71%. A positive change can be seen in moderately healthy forest in the order of 3.53 km$^2$ corresponding to 6.92%. Highly healthy forest with progressing growth can be seen as 1.18 km$^2$ which represents 2.32% area change between 1992 and 2022. The area with very highly healthy forest has changed negatively, i.e. reduced by-2.82 km$^2$ which is about -5.53% of forest area change (Table 2).

According to the present study, the protected forest is developing in a positive way. The health of the reserved forest is better than that of the majority of the world's reserved forests (Anonymous 2000b). The area of unhealthy forest has been decreasing, resulting in an increase in the area of highly healthy and moderately healthy forest. However, the occurrence of forest fires in the reserved forest causes the area under very healthy vegetation to diminish.

## CONCLUSIONS

Humans require regular medical checkups to determine their health, similarly forests and vegetation require forest health assessments. Remote sensing and GIS technology play a crucial role in assessment of forest health using multi- spectral bands. Several underlying factors influence forest health. Throughout this study, assessment has been done in Sonaikushi reserved forest, Morigaon district,

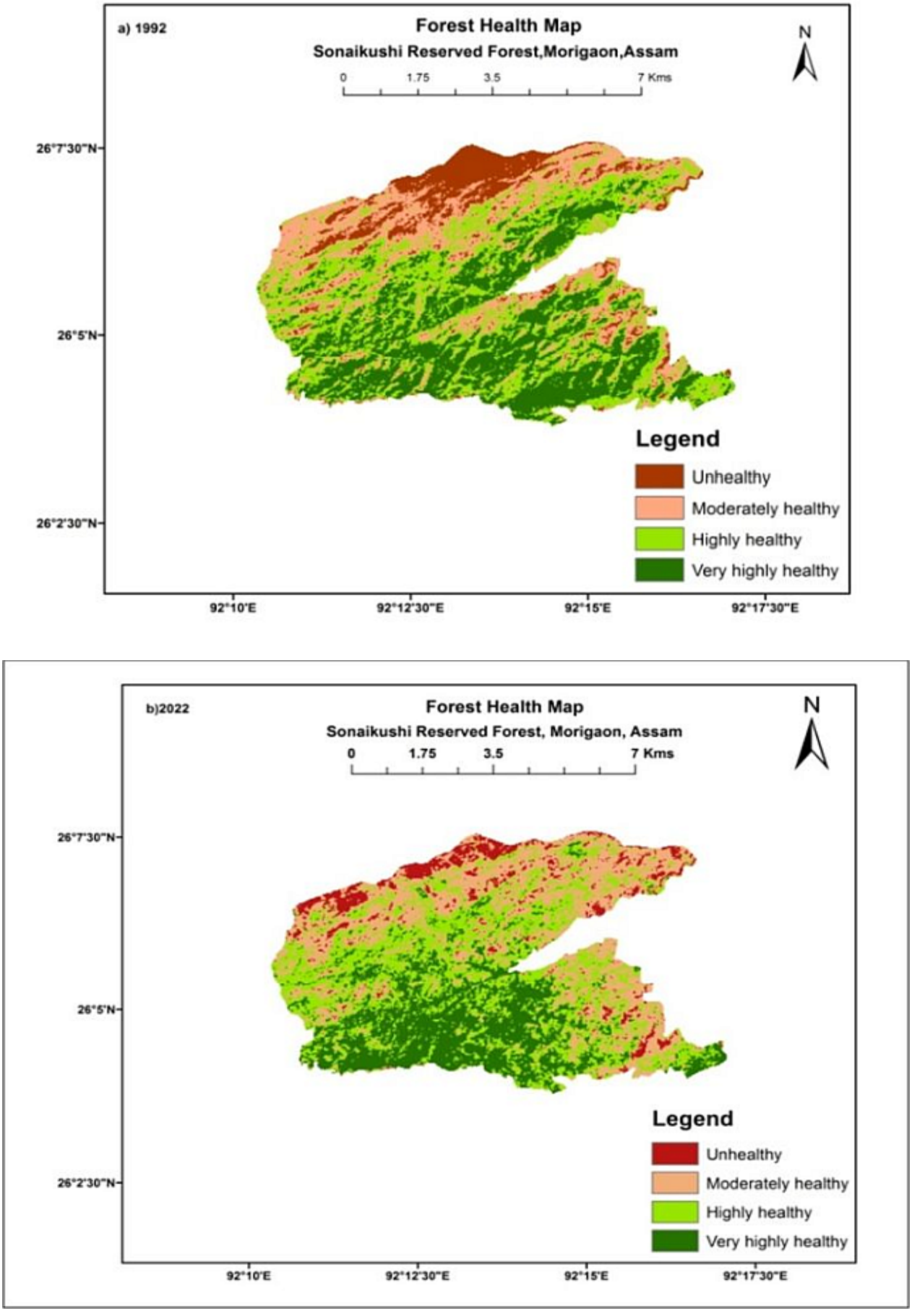


Figure 7. Forest health map (a) 1992, (b) 2022

Assam using Landsat data. During the period 1992-2022, the NDVI, GNDVI, SAVI, and NDMI indices are used to assess the state of forest health. The indices are found to be useful in assessing the health of the vegetation. Vegetation health is found positive in the reserved forest after applying weighted overlay. The amount of moderately healthy and highly healthy forests in the reserved forest have expanded, which has a positive effect on the photosynthetic activity of the study area. However, the area of very highly healthy forest in the reserved forest has been decreasing and converted into moderately healthy and highly healthy forest area. Though the findings of the study reveal the good health condition of the reserved forest based on the 30 years of spatio-temporal vegetation dynamics, for long-term benefit, conservation for future generations necessitates frequent monitoring and management of forest health of the reserved forest.

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**Authors' contribution:** Both the authors contributed equally.

**Conflict of interest:** The author declares that there is no conflict of interest.

## REFERENCES

Anonymous. 2020a. The State of the World's Forests: Forest, Biodiversity and People. Food and Agriculture Organization and United Nations Environment Programme, Nairobi. Anonymous. Anonymous. 2000b. Remote Sensing in Forest Health Protection. United States Department of Agriculture. Remote Sensing Applications Center Salt Lake City, UT and Forest Health Technology Enterprise Team Fort Collins, Vols. 00–03, 276 pages

2021. India State of Forest Survey. Forest Survey of India. Ministry of Environment Forest and Climate Change. https://fsi.nic.in/forest-report-2021-details.

Dutta, S., Rehman, S., Sahana, M. and Sajjad, H. 2020. Assessing forest health using geographical information system based analytical hierarchy process: Evidences from southern West Bengal, India. Pp. 71–102. In: Shit, P.K., Pourghasemi, H.R., Das, P. and Bhunia, G.S. (Eds.) Spatial Modeling in Forest Resources Management, Springer Nature, Switzerland. https://doi.org/10.1007/978-3-030-56542-8_3

Ebinne, E.S., Apeh, O.I., Ndukwu, R.I. and Abah, E.J. 2020. Assessing the health of Akamkpa Forest Reserves in southeastern part of Nigeria using remote sensing techniques. International Journal of Forestry Research, 2020, art 8739864. https://doi.org/10.1155/2020/8739864

Gandhi, G.M., Parthiban, S., Thummalu, N. and Christy, A. 2015. NDVI: Vegetation change detection using remote sensing and GIS – A case study of vellore district. Procedia Computer Science, 57, 1199–1210. doi:10.1016/j.procs.2015.07.415

GNDVI—ArcGIS Pro Documentation. https://pro.arcgis.com/en/pro-app/latest/arcpy/image-analyst/gnvdi.htm

Huang, S., Tang, L., Hupy, J.P., Wang, Y. and Shao, G. 2020. A commentary review on the use of Normalized Difference Vegetation Index (NDVI) in the era of popular remote sensing. Journal of Forestry Research, 32(1), 1–6. doi:10.1007/s11676-020-01155-1

Huete, A.R. 1988. A soil-adjusted vegetation index (SAVI). Remote Sensing of Environment, 25(3), 295–309. https://doi.org/10.1016/0034-4257(88)90106-x

John, A.O. 2018. Forest Health Analysis, Using Remote Sensing and GIS Techniques: A Case Study of Omo Forest Reserve, Ogun State Nigeria. Continental J. Sustainable Development, 9 (2), 35–45. https://doi.org/10.5281/zenodo.2528982

Landsat Soil Adjusted Vegetation Index. U.S. Geological Survey. https://www.usgs.gov/landsat-missions/landsat-soil-adjusted-vegetation-index

Lausch, A., Erasmi, S., King, D., Magdon, P. and Heurich, M. 2016. Understanding Forest Health with remote sensing - part I—a review of spectral traits, processes and remote-sensing characteristics. Remote Sensing, 8(12), 1029. https://doi.org/10.3390/rs8121029

O'Laughlin, J., Livingston, R.L., Their, R., Thornton, J.P., Toweill, D.E. and Morelan, L. 1994. Defining and measuring Forest Health. Journal of Sustainable Forestry, 2(1-2), 65–85.

Pettorelli, N., Vik J.O., Mysterud, A., Gaillard, J.M., Tucker, C.J. and Stenseth, N.C. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology & Evolution, 20(9), 503–510. https://doi.org/10.1016/j.tree.2005.05.011

SAVI—ArcGIS Pro Documentation. https://pro.arcgis.com/en/pro-app/latest/arcpy/spatial-analyst/savi.htm

Simula, M. 2009. Towards Defining Forest Degradation: Comparative Analysis of Existing

Definitions. Forest Resources Assessment Working Paper, 154.

Smith, W.B. 2002.Forest Inventory and analysis: A national inventory and monitoring program. Environmental Pollution, 116, S233-S242. https://doi.org/10.1016/S0269-7491(01)00255-X

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