A Review on Remote Sensing Based Forest Vegetation Health Assessment: Bangladesh Perspective

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Manuscript received: 30 June 2023; accepted for publication: 12 October 2023

ABSTRACT: This paper aims to present a critical review of the published scientific papers that have addressed the issue of forest health in Bangladesh using remote sensing techniques. A systematic review approach has been followed in this study where all the available papers on the application of remote sensing to assess the forest health vegetation condition of Bangladesh were considered for review. That search resulted in the selection of 48 papers. The findings indicate that remote-sensing-based studies have focused mostly on forest cover mapping and change, and landcover change detection rather than assessing the overall health condition of those forests. Also, among the major forests of the country, most studies have been conducted on Mangrove (Sundarban) forests whereas the least number of studies were found for the forests in the Chittagong Hill Tracts Forests areas and those studies were mostly conducted after the Rohingya crisis. Landsat satellite products have been most extensively used for their broader temporal resolution and availability while a few studies have worked with other products like MODIS, Sentinel, SPOT, etc. The application of advanced classification approaches incorporating machine learning algorithms and ground validation has shown effectiveness for investigating the forest or overall ecosystem health in a more detailed way. Although the RS techniques are increasingly used to study the forests of Bangladesh, forest health-specific and indicator-based research is yet to be done which can ensure sustainable forest management.

Keywords: Forest Health; Remote Sensing; Vegetation Indices; Bangladesh

INTRODUCTION

Forests are one of the major natural resources of the world that cover nearly 30% of the world's terrestrial area (Keenan et al., 2015) and play a multifarious beneficial role in maintaining ecological functions, regulating climate, and ensuring environmental balance (Roshani et al., 2022). They provide various direct and indirect benefits, including nutritious food, wood for fuel, medicines, employment opportunities for rural communities, supporting livelihoods, and ensuring food security. Forests also play a vital role in regulating climatic components (air and water), facilitating crop pollination, enriching the soil, reducing erosion, maintaining biodiversity, mitigating climate change, and contributing to cultural heritage and socio-economic development (Milad et al., 2011; Sunderland et al., 2013 and Foli et al., 2014). However, forests worldwide are facing diverse natural and human-caused stress factors, including plagues, droughts, nutrient unavailability, and due to the impacts of global climate change (Gentilesca et al., 2017; Wong and Daniels, 2017; Clare et al., 2019; Domínguez-Begines et al., 2019; Hibit and Daehler, 2019; Morcillo et al., 2019). Human-induced stress factors due to their rapid and widespread effects, exacerbating the magnitude of natural disasters and extreme weather events influenced by anthropogenic climate change also pose risks to global forest health (Trumbore et al., 2015). Therefore, conservation and monitoring of forest resources are imperative to ensure enjoying the continued benefits of this resource.

While the definition of forests is quite straightforward considering the size of land, tree characteristics, and major use of that land (UNEP, 2001), the term "forest health" is subjective and the definition varies based on different perspectives. Therefore, the approach to assessing forest health from an ecosystem perspective (functions and resilience) is completely different from the utilitarian perspective where human benefit is the major priority for measurement (Witzell et al., 2022). Forest health assessment is an effective tool of communication for depicting forest conditions as

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DOI: https://doi.org/10.3329/dujees.v12i1.70560

something that people can make sense of and, thus is capable of drawing attention to forest ecosystem management problems (O'Laughlin, et al., 1994). Forest health assessment techniques encompass in-situ field-based assessments and remote sensing-based assessments and each of these techniques has its own benefits. While field data collection offers high-quality information and mostly can focus on the biological and ecosystem health issues, it is resource-intensive and may struggle to capture spatial variability and heterogeneity as it often lacks covering a wider area. In contrast, remote sensing technologies offer diverse capabilities and cost-effective options for assessing forest vegetation health considering the physical-chemical parameters with wider spatial and temporal patterns and overcoming the hindrance of the remoteness of forests making them a valuable choice for forest vegetation status evaluation (Lamber et al., 2013; Navarro-Cerrillo et al., 2014; Pause et al., 2016; Hernández-Clemente et al., 2019 and Orozco-Fuentes et al., 2019).

The diversity of species, extent of forest area, and overall forest environment often make it difficult to carry out extensive field-based investigations of forests. Also, field study and associated analyses in turn demand greater investments of resources and time. Hence, for continuous monitoring of the forests, satellite image-based Remote Sensing techniques are widely being applied globally. The application of remote assessment of forests started using aerial photographs and continued to the latest hyperspectral satellite image-based assessment and has mostly been used for inventories and measurement purposes (Tuominen et al., 2009). The incorporation of sensors to provide information using a wide range of indices has made advancement in incorporating the foliar chemistry too by allowing the remote sensing-based assessment to be useful for biochemical assessment purposes alongside the forest cover extent mapping activities (Solberg, 2005). Although there are numerous benefits of satellite image-based forest health assessment, uncertainties remain in the quality of data and algorithms which need to be validated by extensive in situ measurements (Tuominen et al., 2009). Regardless of these uncertainties, the widespread use of remote sensing for the assessment of forest health has proven its importance in forest management (Kuenzer et al., 2014; Masek et al., 2015).

According to FAO (2015), forests cover only 11% of land in Bangladesh, compared to the world standard of 25%. BFD (2016) however claims that 17% of the land is occupied by forest. It is assumed that the forest cover of Bangladesh covers 2.6 million ha, where 1.6 million ha is managed by the state-controlled Forest Department (Rahman, 2016). Half of the existing forestlands is natural forest, the majority of which lies in the Sundarbans followed by hill forests in the eastern part. Other than forestlands, Bangladesh has a notable portion of trees outside forests (TOF) in the form of homestead forests and cultivable lands that meet the timber needs of the country.

Despite the widespread practice of applying the Remote Sensing approach for understanding and monitoring the forest dynamics, in Bangladesh, very few studies have been conducted on such ground. In addition, the application of geospatial techniques for forest-related assessment is confined mostly to assessing the forest cover change monitoring with a few exceptions where forest vegetation health issues have been considered. Given the importance of forest health assessment and monitoring and incorporating geospatial techniques especially remote sensing in such cases, this paper aims to portray the overall status of how and to what extent remote sensing has been incorporated in studying the natural forest vegetation health of Bangladesh.

METHODOLOGY

The focus of this paper is twofold, one directs to the understanding of natural forest vegetation health issues and uses of remote sensing as the key tool for assessment and the other one is to elucidate to what extent remote sensing-based forest studies have been carried out in Bangladesh. Therefore, this paper takes a qualitative approach to evaluate the studies using remote sensing-based natural forest health condition assessment of Bangladesh.

- **Literature Search:** Reviewing the relevant literature was the key source of information for this study and the detailed procedure has been explained in the following sections. The literature search was confined to published documents found online. The search was conducted using the Web of Science, (https://www.webofscience.com/wos/woscc/basic-search), which is recognized as a comprehensive database of peer-reviewed research literature. The search technique was "Topic" and the filter "Article and Review Article" was used to search the relevant literature. The eligibility criteria encompassed papers or reviews published between

1971 and the cutoff date of 31/05/2023. A variety of keywords were used to search the suitable papers under the broad topic of "Forest vegetation health of Bangladesh". In addition, to ensure the coverage of the major forest hubs of Bangladesh, three major natural forest types were also incorporated into the search criteria. Thus, the specific search keywords were Forests, Mangrove Forests, Sal forests, Hill Forests, Forest health, Forest condition, Remote Sensing, and Bangladesh (Table 1) in the title, keywords, or abstract. The initial search yielded a total of 392 papers. It is acknowledged that there may be publications that discuss forest health conditions or assessments in Bangladesh without explicitly mentioning the terms specified in the search. Therefore, an extended search for more literature (including gray literature) was made in "Google Scholar" also using broader search keywords (Table 1) that yielded 386 documents. However, the screening process ruled out most of the literature and the very limited number of papers made the authors rethink the selection criteria. The inadequacy of relevant literature, therefore, adopted additional synonymous or indirect indicators such as ecosystem health, vegetation health, forest cover changes, etc. while selecting the papers for review. In addition, to compensate for the insufficiency of relevant literature and to provide a holistic understanding of forest health concept relevant global literature were reviewed to create a background for this study. Thus, a "funnel" approach was applied to describe findings from a global to Bangladesh-specific context. It is to be mentioned that, in this paper forest health and forest vegetation health have been used synonymously.

Table 1: Keywords Used for Searching Relevant Literature from The Two Search Engines

Search Engine	Keywords	No. of Paper
Web of Science	"Forest health" and "Bangladesh"	2
	"Forest condition" and "Bangladesh"	2
	"Mangrove forest" and "forest health" and "Bangladesh"	0
	"Mangrove forest" and "forest condition" and "Bangladesh"	0
	"Mangrove forest" and "Bangladesh"	227
	"Sal forest" and "forest condition" and "Bangladesh"	0
	"Sal forest" and "forest health" and "Bangladesh"	1
	"Sal forest" and "Bangladesh"	26
	"*Shorea robusta*" and "Bangladesh"	25
	"Sal forest" and "forest condition" and "Bangladesh"	0
	"Hill forest" and "forest health" and "Bangladesh"	0
	"Hill forest" and "Bangladesh"	7
	"Hill forest" and "forest condition" and "Bangladesh"	0
	"Remote Sensing" and "forest" and "Bangladesh"	102
Google Scholar	"Mangrove forest" and "forest health" and "Bangladesh"	44
	"Mangrove forest" and "forest condition" and "Bangladesh"	47
	"Sal forest" and "forest health" and "Bangladesh"	64
	"Sal forest" and "forest condition" and "Bangladesh"	61
	"Hill forest" and "forest health" and "Bangladesh"	231
	"Hill forest " and "forest condition" and "Bangladesh"	139

- **Selection Criteria:** The paper selection process for this review involved screening a total of 778 documents. Nearly, 39% of the searches from the two search engines were similar and therefore the initial sorting process ruled out nearly 152 papers and documents. The second phase of screening focused on identifying papers that discussed solely the forests in Bangladesh either in the title or in the abstract, that ruled out another 201 papers. The final screening included the careful investigation of the abstract, and objectives of the study to find the major keywords: forest/vegetation/ecosystem health, forest degradation, forest cover mapping and change, forest landcover change, etc. This final step yielded 48 papers. Although the target was to work specifically on the papers that dealt directly with forest health, later indirect assessment of forest health (forest cover change, forest degradation, vegetation physiological parameters) was also included.

- **Data Collection:** At the final stage, information was extracted from 48 papers related to Forest Health issues (direct and indirect) in Bangladesh (Appendix1). The data collection process focused on two main aspects: (1) the overall focus of the paper, and (2) the method of assessment. The following features were extracted:

  - Year of publication: The year when the paper was published.
  - Paper perspective: The major focus of the study.
  - Type of analysis: Categorized as field-based assessment, remote sensing-based assessment, machine learning, or a combination of both.
  - Type of Forest: Major natural forests, Mangroves, hill forests, and Sal forests were identified from the paper as study areas and all other types of study areas were included in the others category.
  - Type of indicators used: Identifying the specific indicators utilized in the assessment.
  - Type of Remote Sensing Data: Types of Satellites from where the images were extracted for the study.

Conceptualization of Forest Health

The Convention on Biological Diversity (2006) defines forests as land areas larger than 0.5 hectares with a tree canopy cover of over 10%, not primarily used for agriculture or other non-forest purposes (Sugden et al., 2015). Despite its widespread use, the term "forest health" lacks a universal definition (Kolb et al., 1994; Xulu et al., 2018), and its definition is often based on subjective judgments from various socioeconomic and ecological viewpoints, leading to the use a wide range of indicators for measuring forest health (Stone and Mohammed, 2017). Additionally, as the unit of scale increases from individual trees to entire forests, assessing forest health indicators becomes more complex (Trumbore et al., 2015). The definition of forest health varies depending on the perspective taken, including social, economic, and ecological perspectives, which can sometimes appear contradictory. The social perspective focuses on the needs of people for a healthy living environment and recreational spaces, reflecting the increasing concern for the environment in many countries. Another categorization presented in the literature is the utilitarian perspective versus the ecosystem perspective (Kolb et al., 1994). According to Aldo Leopold's (1949) proposition, forest health is the land's capacity for self-renewal and conservation efforts aim to understand and preserve this capacity. Although Leopold's definition encompasses more than just forest health, it has served as the foundation for subsequent definitions. Another definition from O'Laughlin et al. (1994) mentioned forest health as the condition of forest ecosystems that maintains their complexity and simultaneously fulfills human needs. However, they also acknowledged that forest health assessments involved subjective value judgments that should be recognized. In contrast, Monnig and Byller (1992) proposed a different definition of forest health, focusing primarily on the ecological perspective. They described a healthy forest as an ecosystem that is in balance, without considering human social and economic needs. Kolb et al. (1994) provided their definition of forest health, which involved examining the role of living and non-living agents in ecosystem processes outlining several characteristics of a healthy forest ecosystem, including the ability to withstand significant changes in important organism populations, maintaining a functional balance between resource supply and demand, and supporting a diversity of stages, cover types, and structures that are essential for native species and crucial processes. At a similar timeframe, Sampson et al. (1994) highlighted both forest properties and service delivery, defining forest health as the condition of forest ecosystems. Later, the Society of American Foresters (SAF) defined forest health as the perceived state of a forest, considering various factors such as age, structure, composition, function, vigor, the presence of insects or diseases, and the ability to recover from disturbances (Helms, 1998, as cited in Ostry and Laflamme, 2009). Coyle and Megalos (2016) prioritized the benefits derived from forests and defined forest health as the ability of a forest to maintain its high-quality provision of products and services.

Use of Remote Sensing in Forest Health Assessment: Global Context

With the rapid advancement of technology, remote sensing (RS) has emerged as a valuable tool for assessing and monitoring forest health (Bera, Saha, and Bhattacharjee, 2020). This approach allows for the examination of forest health indicators across different spatial and temporal scales in a cost-effective, efficient, and objective manner, addressing the limitations of on-site terrestrial monitoring (Lausch et al., 2016). The availability of large satellite data archives, such as Landsat, has further facilitated the use of RS in evaluating forest health (Wulder et al., 2012). While RS signals do not directly measure forest health variables, they offer significant advantages in indirectly capturing forest health indicators for extensive forest areas (Kuenzer et al., 2014; Masek et al., 2015). However, the application of various RS measures in different case studies has led to challenges in comparing results and evaluating the suitability of RS measures for forestry. This lack of standardization impedes a comprehensive assessment of forest health using RS (Petrou et al., 2015). An abridged summary of the Remote Sensing data and associated indicators used for forest health study are presented in Table 2.

Table 2: Use of RS Data-based Indicators for Forest Health Assessment

Type of RS data	Satel-lite	Forest health indicators	Definition
HYPERSPECTRAL	HYPERION	NDWI (Normalized Difference Water Index)	Assesses the moisture level of plants by analyzing their spectral reflectance in the near-infrared (NIR) and short-wave infrared (SWIR) ranges.
		CRI1 (Carotenoid Reflectance Index 1)	Analyzes the spectral signature of plant leaves, which is responsive to carotenoids.
		NDVI (Normalized Difference Vegetation Index)	Measures the health and abundance of green vegetation by quantifying the difference in reflectance between near-infrared (NIR) and red-light wavelengths.
		PSRI (Plant Senescence Reflectance Index)	Quantifies the degree of senescence or aging in plants measured by the ratio of bulk carotenoids (such as alpha- and beta-carotene) to chlorophyll.
		PRI (Photochemical Reflectance Index)	quantifies the efficiency of photosynthesis and provides information about the physiological status of plants.

MULTISPECTRAL	LANDSAT	AVI (Advanced Vegetation Index)	Determines the presence of healthy vegetation based on the reflectance measured in red and near-infrared spectral bands
		NDVI (Normalized Difference Vegetation Index)	Measures healthy and green vegetation
		NDMI (Normalized Difference Moisture Index)	Evaluate the moisture content of vegetation by comparing near-infrared (NIR) and short-wave infrared (SWIR) reflectance values.
		ARVI (Atmospherically Resistant Vegetation Index)	An enhancement to the NDVI that is relatively resistant to atmospheric factors (such as aerosol)
		SIPI (Structure Insensitive Pigment Index)	A reflectance measurement engineered to optimize the sensitivity of the index towards the proportion of bulk carotenoids (such as alpha-carotene and beta-carotene) in relation to chlorophyll.
		SARVI (Soil and Atmospherically Resistant Vegetation Index)	Incorporates a self-correction mechanism that accounts for the atmospheric impact on the red channel by utilizing the disparity in radiance between the blue and red channels. This approach enables the correction of red reflectance values for atmospheric scattering.
		MCARI (Modified Chlorophyll Absorption Ratio Index)	Indicates the relative abundance of chlorophyll
		MSI (Moisture Stress Index)	Calculates water content in the leaf
		GCI (Green Chlorophyll Index)	Shows chlorophyll content and canopy structure
		GI (Greenness Index)	Distinguishes green vegetation from non-vegetative components
		GNDVI (Green Normalized Difference Vegetation Index)	Shows more accurate chlorophyll content compared to NDVI
		GRVI (Green Ration Vegetation Index)	Indicates photosynthetic rates and leaf pigment state
		RDVI (Renormalized Difference Vegetation Index)	Able to solve saturation problems
	MODIS	NDVI (Normalized Difference Vegetation Index)	A measure of healthy, green vegetation
		PTC (Percent Tree Cover)	Indicates the total area covered by tree canopies
		EVI (Enhanced Vegetation Index)	A remote sensing technique implemented on satellite images to assess the level of greenness in surface vegetation also indicates the biomass abundance within a forest.
		NPP (Net Primary Productivity)	The quantity of carbon assimilated and incorporated into plant biomass within a specific spatial and temporal unit.
		LAI (Leaf Area Index)	The green leaf area per unit ground surface area in broadleaf canopies is measured on one side only and as the maximum projected green leaf area per unit ground surface area in coniferous canopies.
		ET (Evapotranspiration)	The amount of water evaporated to the atmosphere from the soil and transpired from plant tissues

	SPOT	Brightness	(Red+Green+NIR+SWIR)/4
		Maximum Difference	Max (Ri –Rj)/ Brightness
		NDVI (Normalized Difference Vegetation Index)	A measure of healthy, green vegetation
		Simple Ratio	NIR/Red
		The ratio of NIR to Green	NIR/Green
		The ratio of Green to Red	Green/Red
		SAVI (Soil Adjusted Vegetation Index)	Used for correcting Normalized Difference Vegetation Index (NDVI) considering the influence of soil brightness in areas where vegetative cover is low
		MSI (Moisture Stress Index)	A measure of reflectance, sensitive to increases in leaf water content
		SVI (Standardized Vegetation Index)	Characterizes the likelihood of deviation from the "normal" vegetation condition, using calculations derived from weekly Normalized Difference Vegetation Index (NDVI) values.
		GEMI (Global Environment Monitoring Index)	A vegetation index used for global environmental monitoring from satellite imagery

[Source: Compiled from Kamran and Khorrami, 2022; Roshani et al., 2022; Kumari and Asok, 2017; Mahato et al., 2020; Mitra et al., 2021; Ebinne et al., 2020; Ishtiaque et al., 2016; Meng et al., 2016; Mandal et al., 2022.*]*

RESULTS

Forest Health Related Studies in Bangladesh

Major Focus of the Studies

Considering the two keywords remote-sensing and forest came up with studies where mostly the focus was on mapping the forest-covered area and investigating the changes in aerial extent and landcover types of those forests Among the reviewed papers, only one paper dealt directly with forest health issues while nearly 30% of the total paper focused on mapping the forest cover and another 18% focused on the over landcover change of the forests (Fig. 1). Forest degradation was studied in several research where the degradation was assessed based on the analyses of physical and chemical properties (vegetation greenness, evapotranspiration, moisture content, etc.) of forest vegetation using remote sensing.

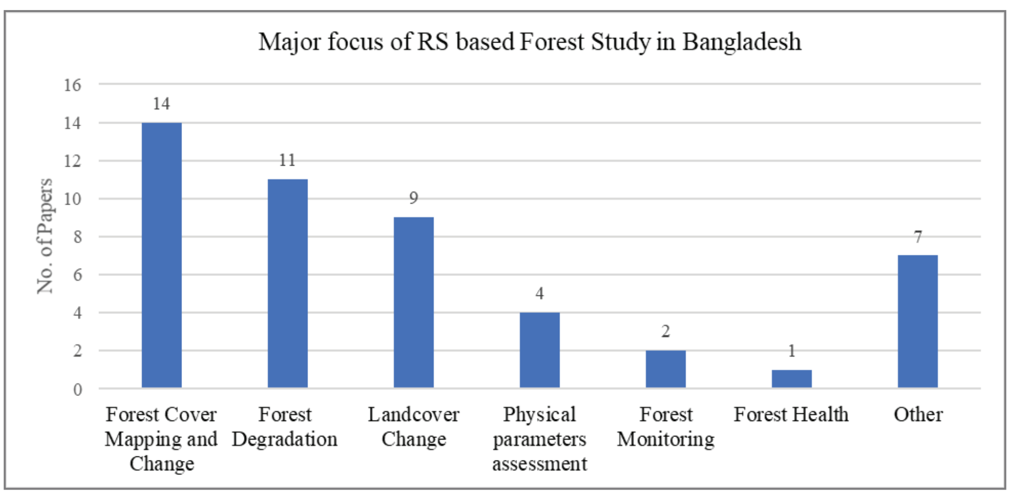

Figure 1: Number of Papers for Each Category of Research Focus

(Source: Reviewed papers)

The temporal cross-section of the reviewed paper shows that nearly 52% of the selected papers were published within the timespan of the last 5 years covering 2018-2023 (Fig. 2).

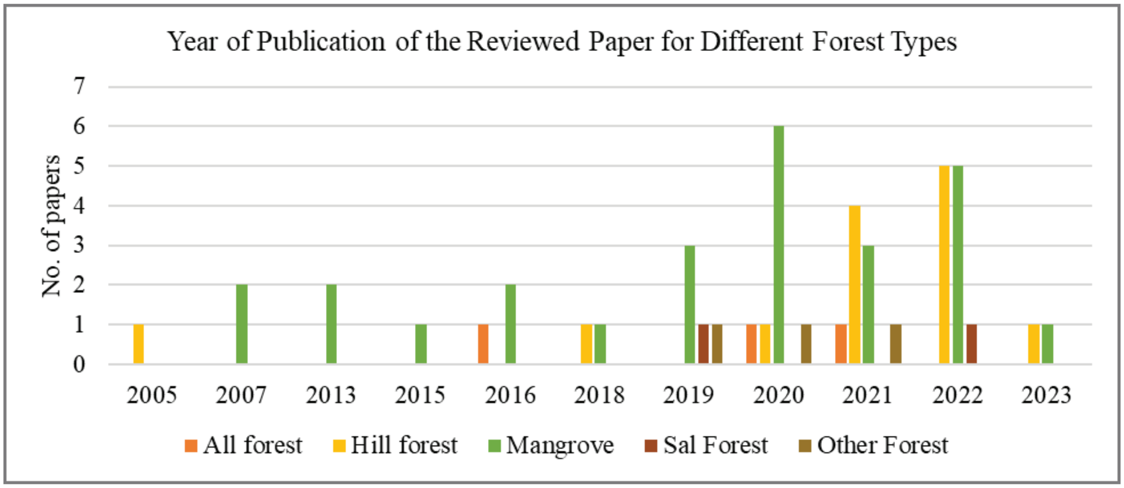

Figure 2: Year of Publication of the Selected Papers and Their Focused Study Area

(Source: Reviewed papers)

Forest Area Covered in the Studies

Among the 48 papers that were reviewed, more than half (nearly 54%) of the papers were about the Mangrove Forest (Sundarbans) of Bangladesh followed by the forests in Chattogram (hill forest covering 27%) (Fig 3). For hill forests, the studies mostly covered the change in the areal extent of forest, especially after the Rohingya influx, and therefore, the hill forest areas represent entirely the forests located in the hilly region of Chattogram division.

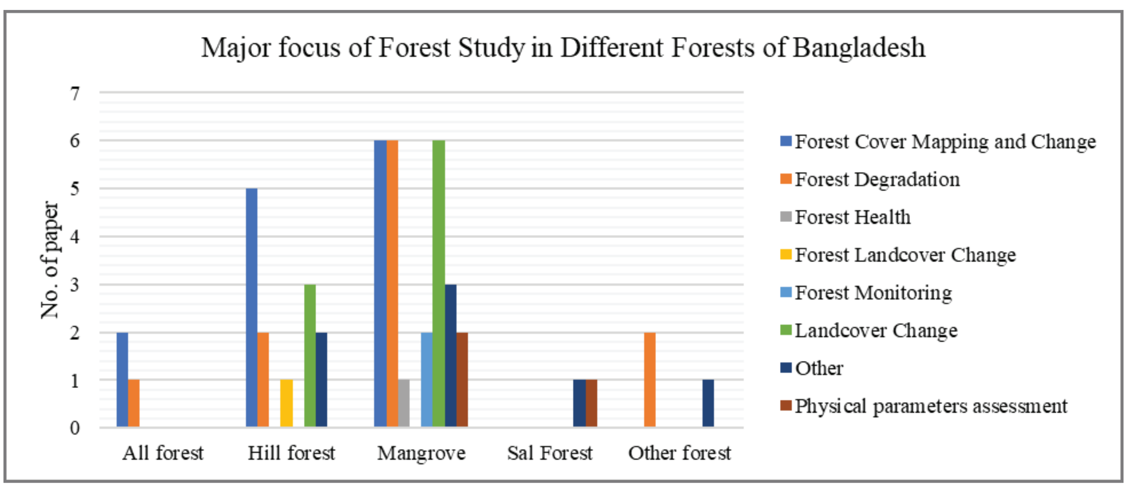

Figure 3: Major Focus of the Scientific Papers to Study the Forests of Bangladesh

(Source: Reviewed papers)

Approach of the Forest Health Study

Among the reviewed papers, most of the papers (90%) applied remote sensing techniques for the assessment of forest attributes (Table 3). Most of the papers (77%) used passive sensor-based data to extract desired information about the forests (Table 3).

Table 3: Approach of Forest-Related Studies in Bangladesh

<table>
<tr><td>Study Approach</td><td>No. of Papers</td><td rowspan="5">Sensor types in RS-based studies</td><td></td><td>No. of Papers</td></tr>
<tr><td>Remote Sensing based</td><td>27</td><td rowspan="2">Active</td><td rowspan="2">3</td></tr>
<tr><td>Remote Sensing and GIS</td><td>7</td></tr>
<tr><td>Machine Learning and Remote Sensing</td><td>3</td><td rowspan="2">Passive</td><td rowspan="2">37</td></tr>
<tr><td>Field survey and Remote Sensing</td><td>2</td></tr>
<tr><td>Field-based</td><td>4</td><td></td><td></td><td></td></tr>
<tr><td>Others</td><td>5</td><td></td><td></td><td></td></tr>
</table>

Sources of RS Data Used in the Studies

All the studies considered here for review had extensively used freely available satellite image sources of which the majority (nearly 63%) of the studies used Landsat satellite products followed by MODIS data (Fig. 4). Among the Landsat products, the most used one was Landsat 5 TM and 8 which indicates its effective application for trend analysis. With the advantage of having several built-in indices, MODIS products were also quite extensively used for understanding the forest components including the vegetation dynamics. Providing a higher-resolution image from Sentinel paved the way to investigate the forest dynamics intensively yet those investigations were limited to assessing forest degradation and forest cover mapping (Hasan et al., 2021; Mandal et al., 2022 and Akhtar et al., 2022). In some studies, a combination of these three types of satellite images has been analyzed to understand the forest cover change dynamics and used the changes in forest cover extent as an indicator for forest degradation (Akhtar et al., 2022).

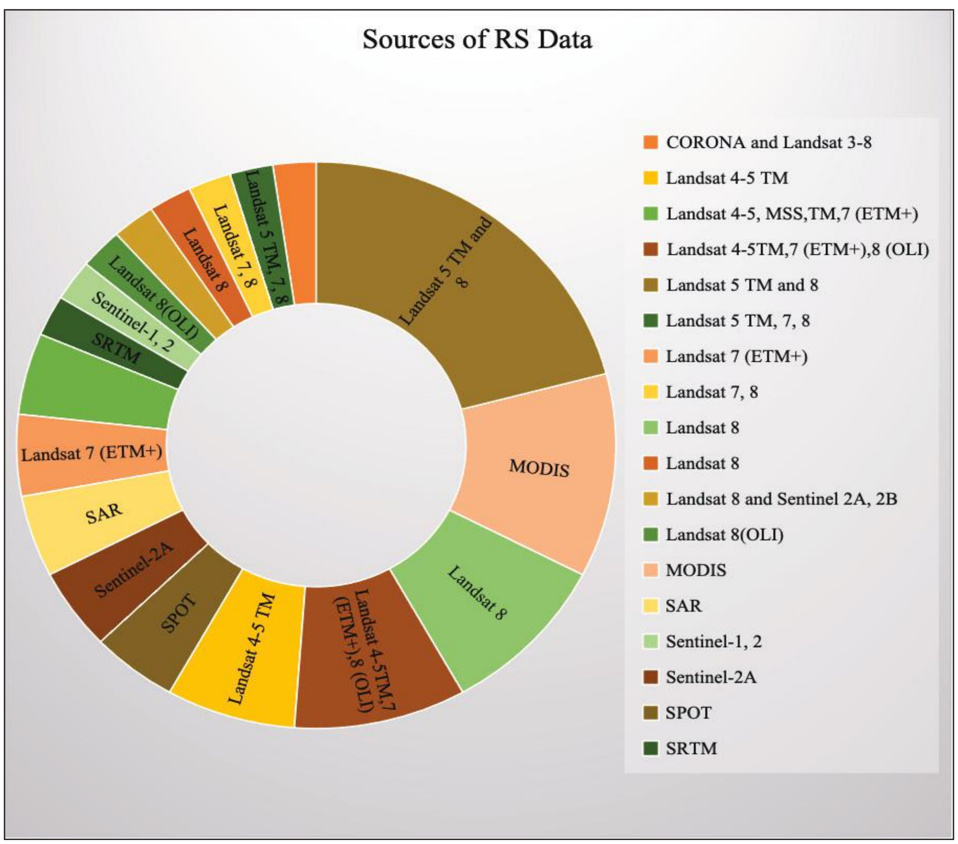

Figure 4: Most Frequently Used Sources of Remote Sensing Data in the Reviewed Scientific Papers

(Source: Reviewed papers)

Methods of Analyses Used in the Studies

The most common method of analyzing the satellite images (Fig. 5) was the supervised classification method (Giri et al., 2007; Islam et al., 2018; Abdullah et al., 2019; Mandal and Hosaka, 2020**;** Bappa et al., 2022, Chowdhury and Hafsa, 2022; Hossain et al., 2022) either was as an individual scheme of analyses or used in support of other vegetation indices. Maximum likelihood approach was the most popular classification approach used in supervised classification to assess the forest cover extent (Giri et al., 2007, Islam et al., 2018, Kumar et al., 2021; Akhtar et al., 2022); and for assessing forest degradation (Abdullah et al., 2019; Mandal and Hosaka, 2020). Alongside supervised classification, unsupervised classification, and vegetation indices especially NDVI (as a single index or part of a composite index) were extensively used for forest degradation (Reddy et al., 2016; Sharma et al., 2022), monitoring assessment (Islam et al., 2019; Awty-Carroll., 2019) and ecosystem health assessment (Ishtiaque et al., 2016). In addition, the application of machine learning to analyze satellite data was also observed in several studies to study forest cover mapping and change detection (Redowan et al., 2020; Hussain and Islam, 2020) and forest degradation (Hasan et al., 2021; Rahaman et al., 2022). The algorithms used in those studies include CLASlite (Redowan et al., 2020), Stochastic Gradient Boosting (SGB), Random Forest (RF), Support Vector Machine (SVM), Partial Least Square Regression (PLSR) for leaf carbon ratio analysis (Rahman et al., 2020); Maximum likelihood classification (MLC), support vector machine (SVM), random forest (RF) and artificial neural network (ANN) to assess vegetation degradation (Rahaman et al., 2022); Random Forest (RF) for forest degradation mapping (Hasan et al., 2021).

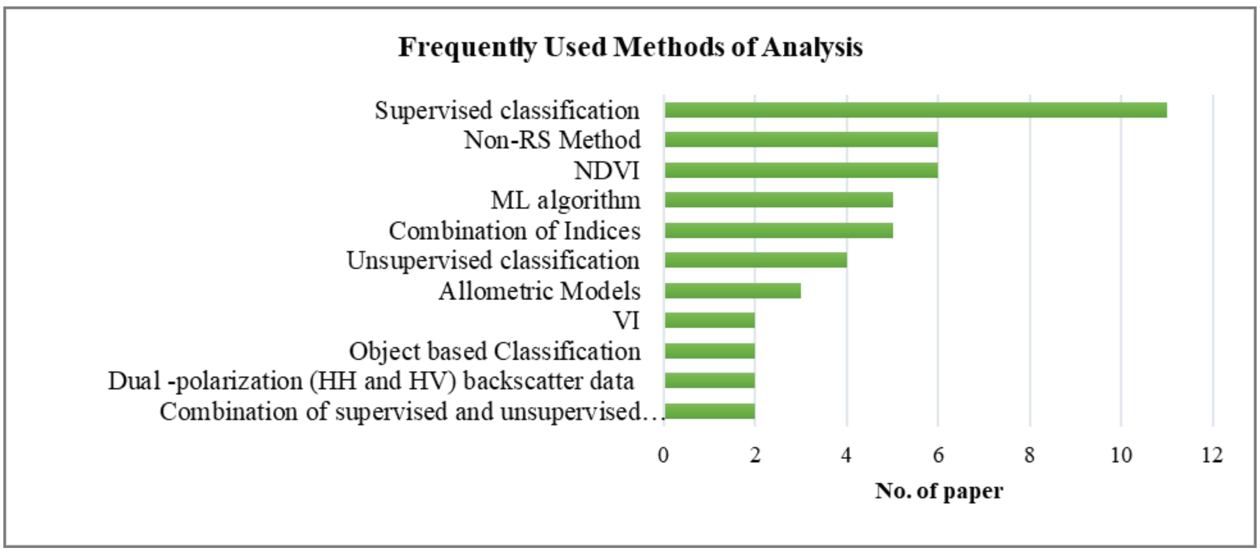

Figure 5: Most Frequently Used Methods of Study in the Reviewed Scientific Papers

(Source: Reviewed paper)

DISCUSSION

Anthropogenic stress and disturbance in forest ecosystems have increased globally which has made monitoring of forest resources inevitable. In-situ monitoring approaches for forest health have improved, but they are labor and resource-intensive and time-consuming. For effective monitoring and management of forests, forest managers and scientists lack access to comprehensive information necessary for understanding and assessing the various factors that affect forest health (Lausch et al., 2016). They require accurate and timely data on forest health, covering a wide spatial and temporal range, and collected at a low cost. Globally there is now a growing availability of forest health data from national inventories (McRoberts et al., 2012) monitoring programs (Traub et al., 2017), experimental studies (Henttonen et al., 2017), and remote sensing technologies (White et al., 2016 and Wulder et al., 2016). However, the combination of field plots and remote sensing data is increasingly recognized as crucial for assessing forest health, although only a limited number of countries and programs currently employ this approach where most obviously the position of Bangladesh is in the least quartile.

Remote sensing addresses these limitations by objectively monitoring forest health indicators across different scales, in a cost-effective and rapid manner (Wang et al., 2010; Lausch et al., 2016). While standardized forest health inventory approaches are incorporating remote sensing widely, current monitoring and data processing methods fall short of future requirements which is particularly severe in the context of Bangladesh. The reviewing process of the literature for this study has clearly depicted that most of the forest-related research has been focused on the use of specific contexts (social and ecosystem service approach) whereas very limited studies have specifically focused on forest health issues. The incorporation of Remote sensing techniques in forest studies has significantly increased in the last decades but most of its application is confined to understanding forest cover mapping, change analyses, and landcover change studies. Only a few studies have explored forest vegetation health conditions using remote sensing techniques, mainly focusing on mangrove forests, and there is a lack of research combining multiple indices to assess forest vegetation health in the form of ecosystem health. Another finding demonstrates that these RS-based studies skewedly selected the study area mostly to be the mangrove forests of Bangladesh while Sal Forest or Hill Forest were least studied. The recent Rohingya influx has drawn little attention to conduct studies on the forests near Rohingya refugee camps, but no explicit study has been found on the entire hill forests in Chattogram that focuses on the forest vegetation health condition.

In general, the application of Remote sensing in forest studies in Bangladesh has increased. The availability of Landsat images with the highest temporal resolution made it the most common source of satellite images to study the changes in forest cover, and with the availability of Sentinel images, more detailed research opportunities were widened. As the research in the domain of forest issues in Bangladesh largely focused on analyzing the trend of changes, the uses of Sentinel images are also being used along with Landsat images. On the other hand, the built-in indices (related to vegetation) of MODIS products could be a good option to assess the forest vegetation health condition despite having comparatively lower spatial resolution than Landsat and Sentinel products. Overall, considering the context of Bangladesh, a combination of satellite image-based (including all high spatial and temporal resolution images) vegetation health detection and validation with intensive in-situ ground truthing will be the best approach to understanding the natural forest vegetation health of Bangladesh.

CONCLUSIONS

This research paper intends to provide a comprehensive review of remote sensing-based forest health studies conducted on the major forests of Bangladesh. A very limited number of papers were found in such context based on the keywords used for searching relevant published papers, yet those provided valuable insights into the direction of forest health-related research in Bangladesh, particularly the incorporation of remote sensing. Considering the major forests of Bangladesh, for understanding and assessing the total resource bases of these forests and continuous monitoring of health and physical parameters, disease, and structural changes, remote sending-based studies could be proven effective alongside the in-situ assessment. In fact, the use of multiple satellite images having diversity in spatial and temporal resolution and validation with ground truth data will significantly facilitate the overall forest health monitoring activities here. The outcomes from such research will enable us to ensure sustainable forest management and will eventually contribute to achieving the Sustainable Development Goals (SDGs).

ACKNOWLEDGEMENT

This study was a part of the research project titled “Remote Sensing-based Approach to Analyze the Change of Health Status of the Forest Areas of the Southeastern Region of Bangladesh”, funded by the University of Dhaka Centennial Research Grant (Phase II). The authors extend their sincere gratitude to the funding authority, the University of Dhaka.

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