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Socio-Ecological Dynamics of Deforestation Induced by the Influx of Rohingya: Evidence from Ukhia, Cox's Bazar, Bangladesh

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Abstract: *Cox's Bazar district of Bangladesh is mainly significant in terms of environmental and economic perspective which have been disrupted considerably due to Rohingya influx in 2017. A significant amount of the forest has been cleared for the Rohingya community's refuge. The appearing deforestation of the mega camp (camps in Kutupalong area) and huge anthropogenic activity has made it necessary to perform change detection research in this area. The concept of this research comes from the intention to explore the changes it had experienced in past few years. This study inspected the changes with particular reference to a major theoretical approach named Socio-Ecological System since it incorporates an encroachment of a society and the local environment. The overall aim of this research was to find the changes of forest cover in Rohingya response camp area of Ukhia upazila between 2017 to 2022 using Landsat imageries of the study area. In this secondary data-based quantitative research, Normalized Difference Vegetation Index (NDVI) will be performed on three multi-temporal satellite imageries and total of 4 major land cover classes were identified and mapped followed by inspecting interconnectivity between society and environment. The result of this study revealed the amount of deforestation occurred in this area along with the environmental and societal disruption. The findings analyzed and quantified trends of land cover change in the chosen area. The findings were also be used to quantify the patterns of land cover change in the chosen area and analyze land cover changes within a spatiotemporal framework. This can be used as inputs to land management and policy decisions with regard to varied themes that have link with space such as tourism, water management, deforestation and land degradation.*

Introduction

The forest is a crucial component of the ecology, supporting both vegetation and animals. Forests have crucial functions in preserving equilibrium in environmental and biological systems. The continually growing human population in the country, coupled with limited natural resources, poses a persistent threat to the environment. Deforestation has emerged as a significant global issue. According to the UN FAO, 10

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million hectares of forest are deforested annually due to many factors, including infrastructural development, agriculture, and natural disasters. This results in a concerning annual decline in the proportion of forest cover. However, individuals are beginning to recognize that it may contribute to the extinction of both humans and animals. Recently, reforestation has gained global popularity.

Remote sensing data has demonstrated efficacy in monitoring land cover changes over time. The satellite image facilitates the straightforward detection of temporal changes in forest cover due to its provision of multi-temporal spatial data. Furthermore, data on the spatial representation of land use and land cover, along with the dynamics of landscape patterns and habitat organization, are essential for formulating land use policies, adapting to, and mitigating the impacts of climate change, as well as for proposing conservation areas through nature-based solutions. Spatial data can significantly contribute to the provision of geographically linked or situated information through remote sensing, geographical information systems, and Global Positioning Systems.

The woodlands of Cox's Bazar, Bangladesh, serve as both national resources and crucial components of the local economy. It is also essential for biodiversity and provides habitat for numerous wildlife species. The sudden inflow of Rohingya refugees on August 25, 2017, in Cox's Bazar, particularly in Ukhiya upazila, has significantly impacted the forest region. Bangladesh must furnish a substantial quantity of shelters for 509,000 Rohingya individuals throughout the early phase of the migration. A significant expanse of woodland was deforested by the end of 2017. Upon recognizing the impacts of climate change in this region, humanitarian organizations initiated a replanting effort in the Rohingya camp. To identify alterations in this forest region, it is essential to obtain land cover data.

This project will assess the extent of forest cover conversion to alternative land uses. The results will quantify the patterns of land cover change in the selected area and analyze these changes within a spatio-temporal framework. This study will examine land cover change using the framework of Socio-Ecological System theory. This can serve as input for land management and policy decisions concerning several subjects related to space, including tourism, water management, deforestation, and land degradation.

Research location: Kutupalong mega camp (Figure 1) located in the Ukhia upazila of Cox’s Bazar district. It is now the largest and most densely populated camp in Bangladesh. The Humanitarian Data Exchange reports that the population of Kutupalong mega camp in Ukhia upazila was 725,031 individuals, including 170,887 households. The density reached 42,724.28 individuals per square kilometer in 2018 (Source: NPM Site Assessment Round 11: Baseline Master List as of 14 June 2018, HDX).

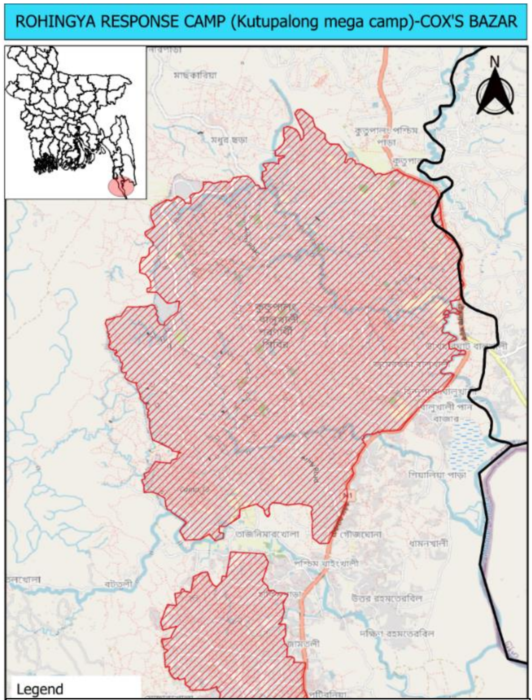

Figure 1: Study area (Kutupalong mega camp of Cox’s Bazar) Source: Authors

Chronology of the Crisis:

- Year: 1991, Approximate population: 250,000
  More than 250,000 Rohingya refugees flee to Bangladesh following increased activities, and reports of human rights abuses, by the Myanmar Army in Maungdaw, Buthidaung and Rathedaung townships of Rakhine State.
- Year: 1993-1997, Approximate population: 230,000
  230,000 refugees return to Rakhine.
- Year: 2012, Approximate population: 140,000
  New violence in June and October 2012, causes hundreds of deaths, injuries, destruction of property and displacement of 140,000 people. Around 120,000 people remain in Internally Displaced Persons (IDP) camps in Rakhine State.
- Year: Aug 2014, Approximate population: 87,000
  UNHCR reports some 87,000 people, mostly Rohingya, fled from Rakhine State by sea from the Bay of Bengal since the June 2012 outbreak of violence, during which at least 200 people died.
- Year: 9 Oct 2016, Attack
  90,000 flee army crackdown in ensuing months after Rohingya militants attack border guard posts killing 9 police officers.
- Year: Nov 2016 - Feb 2017, Approximate population: 74,000

Following the attacks in Rakhine state on the 9th October 2016, between Nov 2016 and Feb 2017, approx 74,000 Rohingya refugees cross from Rakhine state into Cox's Bazar.

- Year: Mar 2017, Report
  The UN human rights council sets up an investigation into alleged human rights abuses by the army against the Rohingya.
- Year: 25 Aug 2017, Attack
  Rohingya insurgents attack 30 police stations, triggering a massive military response. Thousands of Rohingya flee from Rakhine state.
- Year: 25 August 2017, Approximate population: 509,000
  Violence in Rakhine State which began on 25 August 2017 has driven an estimated 509,000 Rohingya across the border into Cox's Bazar, Bangladesh. As of today, there are an estimated 809,000 Rohingya in Bangladesh.
- Total 809,000 Rohingya are staying in Camps of Cox's Bazar
  (As of 1st Oct 2017)

(Data source: Humanitarian Response Plan, October 2017)

Objectives

To ascertain the specific alterations in forest cover resulting from the recent Rohingya migration and to assess these changes through the lens of Socio-Ecological System (SES) theory.

Goals

To identify alterations in forest cover inside the Rohingya response camp region of Ukhia upazila from 2017 to 2022 and to visualize the patterns of forest cover change. Evaluate using SES theory.

Anticipated Results

A quantitative assessment of the alterations in forest cover throughout the specified period.
A graphical representation of the alterations in forest cover from 2017 to 2022.
An assessment of the socioeconomic and ecological conditions of this location.

Review of Literature

Change detection in land cover, as defined by Hoffer (1978), refers to the temporal effects resulting from variations in spectral response, which occur when the spectral features of vegetation or other cover types at a certain place change over time. Change detection, as described by Singh, is the technique of discovering alterations in the state of an object or phenomenon through the observation of photographs captured at different times. Boakye et al. elucidate that alterations in forest cover frequently stem from anthropogenic pressures, such as population development, as well as natural variables like climate fluctuation. Tropical forests are utilized for several reasons, including timber extraction, slash-and-burn agriculture, and pasture establishment.

Change detection analysis has become the standard method for monitoring alterations in land use and development. Change detection analysis has been conducted to ascertain the nature, extent, and rate of land cover change over time and space. It has been conducted for many causes over time.

Miwei saw transient vegetation at Poyang Lake from satellite images. The research examined the alteration in the extent of ephemeral vegetation through the analysis of satellite imaging time series and explored the correlation between this alteration and variations in hydrological conditions. Ahmad employed remote sensing and GIS technologies to map a dry shrub forest for biodiversity conservation planning, utilizing the Salt Range of Pakistan as a case study. Joshi examined the spatial identification and forecasting of Banmara invasion. He assessed the possible hazard of Banmara incursion into forest regions affected by human activity. The study determined that extensive forest exploitation, human intervention, and environmental factors had caused forest degradation, leading to a heightened invasion of Banmara. Adia and Rabiu examined the spatio-temporal alterations in plant cover in Jos and its adjacent regions.

Vegetation indices, among other methodologies, have proven effective in monitoring changes in forest cover. The Normalized Difference Vegetation Index (NDVI) is one of the most commonly utilized indices for monitoring forest cover. There are alternative methods that have also demonstrated efficacy in change detection analysis. Supervised image categorization is employed in numerous research studies.

Supervised classification employs spectral fingerprints derived from training samples to categorize an image. Supervised categorization allows for the identification of specific information classes, such as land cover types, inside the image. These are referred to as "training sites". The image processing software system is utilized to create a statistical characterisation of the reflectance for each information class. This phase is frequently referred to as "signature analysis" and may encompass the formulation of a characterization as elementary as the mean or range of reflectance across each band, or as intricate as comprehensive studies of the mean, variances, and covariance across all bands. After achieving a statistical characterisation for each information class, the image is classed by analyzing the reflectance of each pixel and determining which signature it most closely resembles. Eastman, 1995

Normalized Difference Vegetation Index (NDVI): Researchers must analyze the specific wavelengths of visible and near-infrared sunlight reflected by plants to assess the density of greenery on a land area. The spectrum of sunlight comprises several wavelengths, as demonstrated using a prism. When sunlight encounters objects, specific wavelengths of the spectrum are absorbed while others are reflected. Chlorophyll, the pigment in plant leaves, effectively absorbs visible light (ranging from 0.4 to 0.7 µm) for photosynthesis. The cellular composition of the leaves significantly reflects near-infrared light (ranging from 0.7 to 1.1 µm). An increase in the number of leaves on a plant correlates with a corresponding impact on these wavelengths of light. If reflected energy in near-infrared wavelengths significantly exceeds that in visible wavelengths, the vegetation in that pixel is likely dense and may comprise some form of forest. If the intensity of reflected visible and near-infrared wavelengths is minimal, the flora is likely scarce, maybe comprising grassland, tundra, or desert. The formula is expressed numerically as follows:

NDVI = (NIR - VIS) / (NIR + VIS)
Where NIR= Near-Infrared Radiation, and VIS= Visible Radiation.
(Source: Earth Observatory, NASA)

Table 1: Categories Based on NDVI Values

NDVI Value based Category	NDVI Value	% of Category
No Vegetation	-0.167 - 0.105	5.09
Less Vegetation	0.105 - 0.256	12.27
Moderate Vegetation	0.256 - 0.320	29.14
Dense Vegetation	0.320 - 0.382	35.08
Highly Dense Vegetation	0.382 - 0.544	18.42
Total		100

(Source: Detection of Forest Cover Change Utilizing Normalized Difference Vegetation Index (NDVI): An Examination of the Areas Adjacent to Reingkhyongkine Lake, Rangamati, Bangladesh. 2013)

The NDVI ranged from −1.0 to +1.0. Healthy vegetation exhibits low red-light reflection and high near-infrared reflectance, resulting in elevated NDVI values. The rising levels of positive NDVI values signify an increase in green vegetation. NDVI readings approaching zero and declining into negative territory signify non-vegetated elements, including barren surfaces (rock and soil), water, snow, ice, and clouds.
(Source: Coastal Zone Management, 2019, pp. 471-484)

Regions characterized by barren rock, sand, or snow typically exhibit minimal NDVI values, such as 0.1 or lower. Sparse vegetation, including shrubs and grasslands or dying crops, may yield intermediate NDVI values (about 0.2 to 0.5). Elevated NDVI values (about 0.6 to 0.9) indicate thick vegetation, typical of temperate and tropical forests or crops at their optimal growth phase. Source: Remote Sensing Phenology, United States Geological Survey.

In 2013, a study titled "Forest Cover Change Detection using Normalized Difference Vegetation Index (NDVI): A Study of Reingkhyongkine Lake's Adjoining Areas, Rangamati, Bangladesh" was conducted in the hill tracts of Bangladesh, utilizing the NDVI values presented in Table 1 to categorize five distinct classifications and assign corresponding values to each category.

A study titled "Comparison of NDVI and Supervised Image Classification to Assess Vegetative Land Cover in Ghazi Tehsil, District Haripur, Pakistan, 2012" evaluated the efficacy of Normalized Difference Vegetation Index (NDVI) against supervised image classification for assessing vegetative land cover in Ghazi Tehsil, District Haripur. The area beneath various land cover types have been computed. The analysis indicates that the NDVI-derived vegetative cover is 31,561 hectares, representing 52.68 percent of the whole area, but the image analysis determined the area under vegetation to be 17,599 hectares, or 29.43 percent of the total area. The restriction of NDVI is that the evaluated vegetative cover also encompasses agricultural land.
However, provided the image is captured at an appropriate period relative to crop cultivation, accurate forest cover data can be derived from the NDVI procedure. Moreover, supervised categorization requires prior data (training samples) that is not publicly accessible. Given all the facts, NDVI would be an advantageous method for doing this investigation.

Implications and advantages: Land cover change detection studies often play a crucial role in decision-making and policy formulation. This study will solely identify the patterns of forest cover change; nevertheless, there exists literature regarding the implications of land cover alterations.

The physical location of the Meghalaya Plateau is likely adjacent to the Camp region of Cox’s Bazar. A recent study indicates that the Meghalaya Plateau in Northeast India is among the most precipitation-rich inhabited regions on Earth, with over 11,000 mm of annual rainfall recorded in Cherrapunjee. Intense monsoonal precipitation, significant seismic activity, steep hillsides, and superficial soil contribute to the susceptibility of this delicate ecosystem to swift and enduring land-use and land cover (LULC) alterations (Starkel and Singh 2004; Soja and Starkel 2007; Migon´ and Prokop 2013). The predominant characteristic of the LULC system of the Meghalaya Plateau is the extensive presence of grasslands spanning several thousand square kilometers at elevations exceeding 1000 m a.s.l. Concurrently, the remnants of climax vegetation in sacred groves indicate that the plateau was historically forested. These forest sections exhibit dense vegetation and a high species diversity, having been preserved over time by local communities for religious purposes (Bor 1942; Tiwari et al. 1999). The scientific investigation of the Meghalaya Plateau commenced in the early nineteenth century. Historical descriptions from British naturalists indicate that grasslands in the central region of the plateau existed prior to the nineteenth century (Walters 1832; Pemberton 1835; Hooker 1854; Oldham 1854). Initial research conducted by ecologists identified the reduction of the shifting cultivation cycle, attributed to population growth, as the primary factor contributing to deforestation and soil degradation on the plateau (Toky and Ramakrishnan 1981, 1982; Ramakrishnan 1992). Research utilizing satellite imagery from 1975 to 2001 indicates a reduction in forested regions within the Meghalaya Plateau. (Department of Space 1985; Roy and Tomar 2001; Roy and Joshi 2002; Lele and Joshi 2009; Forest Survey of India 2013). The climate is characterized by a monsoonal pattern, featuring a warm rainy season from June to September and a dry, chilly winter. The average annual air temperature correlates significantly with elevation, ranging from 24 degrees Celsius at the Umiew outflow to 16.6 degrees Celsius in Shillong. The average annual precipitation is significantly influenced by the topography, ranging from 6000 mm in the foothills to 11,000–12,000 mm in Cherrapunjee and Mawsynram, situated at the spurs. Rainfall diminishes from the plateau's edge to 2200 mm in Shillong. The soils are acidic and nutrient-poor, attributable to leaching caused by excessive rainfall. Finer grained soils are located in the upper section of the basin, where thicker weathered deposits have been maintained in certain areas. The sedimentary complex soils surrounding Cherrapunjee and Mawsynram are significantly deteriorated, exhibiting a surface armored layer of up to 20 cm or bare rock exposure. The soils in adjacent canyons are typically abundant in humus and shallow due to mass movements. The time series analysis of this region indicates consistently steady ratios between forests and grasslands in the Umiew watershed during the past century. In 1910, these two land cover classes comprised 94% of the study area. The majority of land cover alterations transpired inside the steep plateau encompassing 300 square kilometers. Deforestation has occurred in the densely inhabited top section of the basin, though this has been mitigated by afforestation and natural forest regeneration in less accessible regions. Alterations in forest area and population density indicate that although population density increased from 23 inhabitants per square kilometer in 1901 to 138 residents per square kilometer in 2011, the forest area concurrently expanded from 44.6% in 1910 to 46.1% in 2010. Consequently, the overall forest area has remained relatively unchanged.

Through the investigations on land-use and land cover change, they identified their subsequent appropriate action in the Meghalaya Plateau.

Theory of Socio-Ecological Systems (SES)

Cox's Bazar houses around 2.7 million Bangladeshi residents. The majority of residents rely on natural capital assets and ecosystem services from agriculture, forestry, marine and aquaculture resources, and eco-tourism for their livelihoods (Tallis et al., 2019; Tani & Rahman, 2018).

The world is currently threatened by considerable damage to or losses of many natural resources, including fisheries, lakes, and forests, as well as experiencing major reductions in biodiversity and the threat of massive climatic change. All humanly used resources are embedded in complex, social-ecological systems (SESs). SESs are composed of multiple subsystems and internal variables within these subsystems at multiple levels analogous to organisms composed of organs, organs of tissues, tissues of cells, cells of proteins, etc. In a complex SES, subsystems such as a resource system, resource units, users, and governance systems are relatively separable but interact to produce outcomes at the SES level, which in turn feed back to affect these subsystems and their components, as well other larger or smaller SESs (Ostrom 2009)

Sustainable management necessitates a comprehensive comprehension of the intricacies of various systems (social, biophysical, economic, etc.) and their interrelations (Cumming et al. 2013). The reductionist approach to the interactions between humans and natural resources, coupled with generic advice from managers and regulators, has led to mismanagement and failures (Wyborn and Bixler 2013). The shortcomings of this management approach—characterized by commendable intentions yet inadequate outcomes (Holling and Meffe 1996; Holling 2003)—underscore the necessity for enhancing management policies and strategies via the interconnected analysis of social and ecological systems (Berkes and Folke 1998), alongside the proactive incorporation of local residents' perspectives, knowledge, and aspirations (Carpenter et al. 2012). Knowledge and actions to promote sustainable management of natural resources are particularly essential in contexts where individuals possess the least motivation to contemplate the consequences of their activities (Ostrom 1990, 2005; Agrawal 2001).

Approach

Every title selection is underpinned by a rationale. “Socio-Ecological Dynamics of Deforestation Induced by Rohingya Influx: Evidence from Ukhia, Cox’s Bazar, Bangladesh” This title also elucidates its rationale. Cox's Bazar is a prominent component of the Chittagong Hill Tracts. In 2017, the influx of Rohingya significantly altered the forest cover region. The change detection analysis and SES evaluation could significantly influence decision-making to address emerging issues and contribute to the formulation of essential policies.

The literature review is a crucial and indispensable component of research. This section reviews pertinent research conducted on the topic and identifies the research gap through the review.

The study location has been chosen based on the observation that the Rohingya camp in Ukhia upazila is predominantly located on former forest land and is currently the most densely populated region, potentially leading to substantial environmental changes.

This study utilized the camp border shapefile of Ukhia Upazila from the “HUMANITARIAN DATA EXCHANGE” and satellite pictures with a 30-meter resolution (Landsat 8) of the Rohingya response camp from March 2017, March 2018, and March 2022, obtained from “USGS Earth Explorer.”

Landsat 8 comprises nine spectral bands, including a panchromatic band. These are:

Band 1 Coastal Aerosol (0.43 - 0.45 µm) at 30 meters
Band 2 Blue (0.450 - 0.510 µm) 30 m
Band 3 Green (0.53 - 0.59 µm) 30 meters
Band 4 Red (0.64 - 0.67 µm) 30 meters
Band 5 Near-Infrared (0.85 - 0.88 µm) with a spatial resolution of 30 meters
Band 6 SWIR 1 (1.57 - 1.65 µm) with a spatial resolution of 30 meters
Band 7 SWIR 2 (2.11 - 2.29 µm) with a spatial resolution of 30 meters
Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) with a resolution of 15 meters
Band 9 Cirrus (1.36 - 1.38 µm) with a resolution of 30 m
(Source: USGS Earth Explorer)

Table 2: Categories Based on NDVI Values

NDVI Value based Category	**NDVI Value**
Absence of vegetation	-0.167 - 0.105
Less vegetation	0.105 - 0.256
Moderate vegetation	0.256 - 0.320
Dense forest cover	0.320 - 0.544
(Source: Adapted from "Forest Cover Change Detection using Normalized Difference Vegetation Index (NDVI): A Study of the Areas Adjacent to Reingkhyongkine Lake, Rangamati, Bangladesh." 2013)	

The data for assessing the region with socioeconomic status has been obtained from "Rohingya Refugee Response Bangladesh," "Joint Data Center on Forced Displacement," and "ReliefWeb."
Data processing entails the systematic structuring of information into novel and constructive frameworks. Secondary data are not always suitable for contemporary research. The data must be systematically organized to get improved representation. Table 2 will be utilized for categorization based on NDVI values.

The conceptual framework of a Social-Ecological System (SES) proposed by Ostrom (2009) and later modified by McGinnis & Ostrom (2014). The RS and the RUs that complement each other in the natural component; the governance system (GS) and the actors (A) that constitute the social component. These components interact through a focal action situation to produce the interactions (I) and outcomes (O) from either natural or social components. Palomo and Flores (2019)

The subsequent table will be utilized to assess the socioeconomic status of this region.

Table 3: Variables of Social-Ecological System

Source: First And Second-tier variables of social-ecological system adapted from McGinnis & Ostrom (2014).	
First-tier variables	Second-tier variables
Actors (A)	A1-Number of relevant actors

	A2-Socioeconomic attributes*
	A3-History or past experiences
	A4-Location
	A5-Leadership/entrepreneurship*
	A6-Norms (trust-reciprocity)/social capital*
	A7-Knowledge of SES/mental models*
	A8-Importance of resource (dependence)
	A9-Technologies available*
Resource systems (RS)	RS1-Sectors
	RS2-Clarity of system boundaries*
	RS3-Size of resource system
	RS4-Human-constructed facilities*
	RS5-Productivity of system
	RS6-Equilibrium properties
	RS7-Predictability of system dynamics*
	RS8-Storage characteristics*
	RS9-Location*
Resource units (RU)	RU1-Resource unit mobility
	RU2-Growth or replacement rate*
	RU3-Interaction among resource units
	RU4-Economic value
	RU5-Number of units*
	RU6-Distinctive characteristics
	RU7-Spatial and temporal distribution*
Governance system (GS)	GS1-Government organizations
	GS2-Nongovernment organizations
	GS3-Network structure*
	GS4-Property-rights systems*
	GS5-Operational-choice rules
	GS6-Collective-choice rules*
	GS7-Constitutional-choice rules*
	GS8-Monitoring and sanctioning rules*
Interactions (I)	I1-Harvesting
	I2-Information sharing*
	I3-Deliberation processes*
	I4-Conflicts
	I5-Investment activities
	I6-Lobbying activities*
	I7-Self-organizing activities*
	I8-Networking activities*
	I9-Monitoring activities*
	I10-Evaluative activities*
Outcomes (O)	O1-Social performance measures
	O2-Ecological performance measures
	O3-Externalities to other SESs*
Note: *The information on these variables is partial or does not exist;	

Data analysis and interpretation: Data analysis is the systematic application of logical methodologies to explain, illustrate, condense, summarize, and assess data. Data can be examined through multiple methodologies. This research will analyze data using QGIS. Microsoft Word and Excel can be utilized for interpretation. The subsequent analyses will be conducted in this research.

- Performing the NDVI (Normalized Difference Vegetation Index) analysis on three distinct pictures using QGIS, utilizing just Bands 4 and 5 of the Landsat 8 imagery. The equation is as follows-

$$\text{NDVI} = \frac{Band\ 5(Near\ infrared) - Band\ 4(Red)}{Band\ 5(Near\ infrared) + Band4\ (Red)}$$

- Reclassify the NDVI raster file to assign a pixel value to each individual pixel.
- Generating a report in QGIS that calculates the area for each category of the reclassified raster.
- Determine the percentage of land cover for each category using Microsoft Excel.
- Analyzing the pattern of forest cover alteration after the Rohingya migration and identifying changes in the extent of forested areas.
- Evaluating the socioeconomic status of the Rohingya refugee camp area via secondary data from published sources.

Examination and Elucidation

Analysis of the alterations in forest cover patterns and identification of changes in forest cover.

The land cover of the Rohingya response camp region in 2017 (before to the Rohingya immigration) is depicted through a land cover map (Figure 2) and accompanying data table (Table 4).

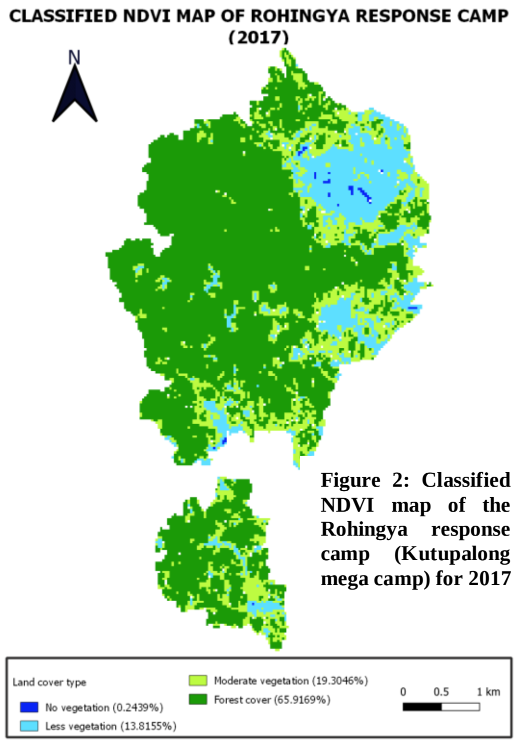

Figure 2: Classified NDVI map of the Rohingya response camp (Kutupalong mega camp) for 2017

(Source: Authors)

Table 4: Land Cover Area Categorized by NDVI Values for the year 2017 (Before to the Rohingya Migration)

Based on NDVI value Classification	NDVI Value	Land cover area in square kilometers	Percentage of land cover area
Absence of vegetation	-0.167 - 0.105	0.0414	0.2439%
Less vegetation	0.105 - 0.256	2.3445	13.8155%
Moderate vegetation	0.256 - 0.320	3.2760	19.3046%
Dense forest cover	0.320 - 0.544	11.1861	65.9169%
Total area		**16.97**	**100%**

(Source: Authors)

The land cover of the Rohingya response camp region in 2018, immediately following the Rohingya inflow, is illustrated with a land cover map (Figure 3) and accompanying data table (Table 5).

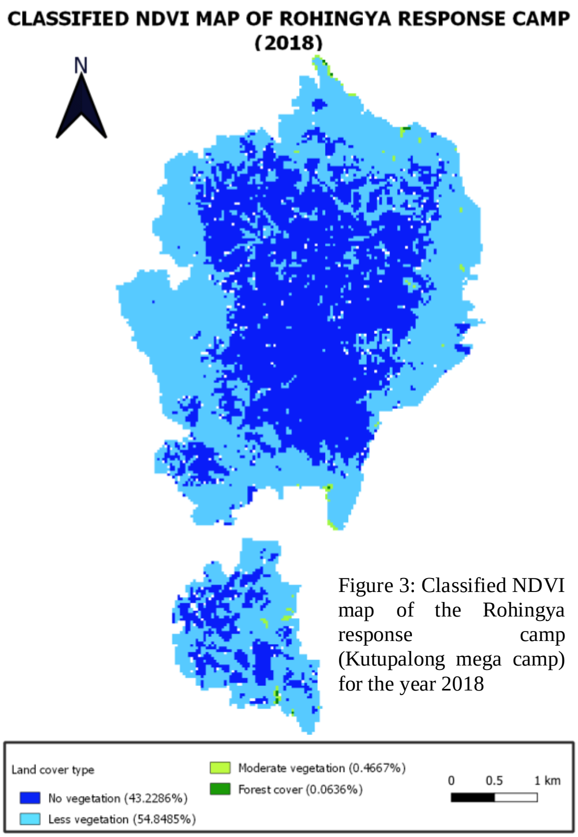

Figure 3: Classified NDVI map of the Rohingya response camp (Kutupalong mega camp) for the year 2018

(Source: Authors)

Table 5: Land Cover Area Categorized by NDVI Values for the year 2018 (Immediately following the Rohingya Immigration)

Based on NDVI value Classification	NDVI Value	Land cover area in square kilometers	Percentage of land cover area
Absence of vegetation	-0.167 - 0.105	7.3359	43.2286%
Less vegetation	0.105 - 0.256	9.3078	54.8485%
Moderate vegetation	0.256 - 0.320	0.0792	0.4667%
Dense forest cover	0.320 - 0.544	0.0108	0.0636%
Total area		16.97	100%

(Source: Authors)

The land cover of the Rohingya response camp area in 2022, following a reforestation initiative implemented by over 40 national, international, and UN organizations, is illustrated with a land cover map (Figure 4) and accompanying data table (Table 6).

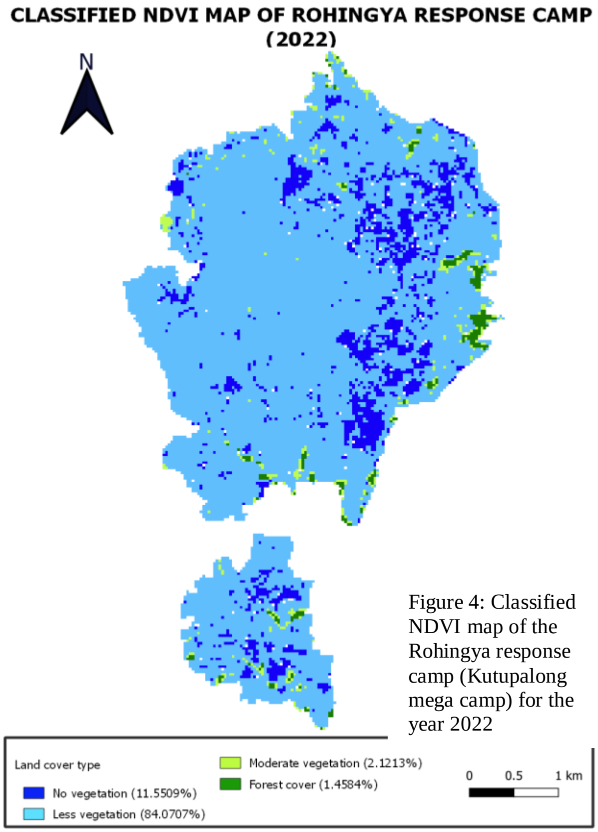

Figure 4: Classified NDVI map of the Rohingya response camp (Kutupalong mega camp) for the year 2022

(Source: Authors)

Table 6: Land Cover Area Categorized by NDVI Values for the Year 2022

Based on NDVI value Classification	NDVI Value	Land cover area in square kilometers	Percentage of land cover area
Absence of vegetation	-0.167 - 0.105	1.9602	11.5509%
Less vegetation	0.105 - 0.256	14.2668	84.0707%
Moderate vegetation	0.256 - 0.320	0.3600	2.1213%
Dense forest cover	0.320 - 0.544	0.2475	1.4584%
Total area		16.97	100%

(Source: Authors)

Comparative examination of forest cover change in 2017 (before to the Rohingya immigration), 2018 (immediately following the Rohingya influx), and 2022 (during the current regeneration program):

Table 7: Comparative analysis of land cover change categorized by NDVI values for the years 2017, 2018, and 2022

Based on NDVI value Classification	NDVI Value	Percentage of land cover area (2017)	Percentage of land cover area (2018)	Percentage of land cover area (2022)
Absence of vegetation	-0.167 - 0.105	0.2439%	43.2286%	11.5509%
Less vegetation	0.105 - 0.256	13.8155%	54.8485%	84.0707%
Moderate vegetation	0.256 - 0.320	19.3046%	0.4667%	2.1213%
Dense forest cover	0.320 - 0.544	65.9169%	0.0636%	1.4584%
Total area		100%	100%	100%

(Source: Authors)

Table 7 indicates that from 2017 to 2018, the " Absence of vegetation " climbed by 43%, the "Less vegetation area" rose by 41%, while the "Moderate vegetation area" declined by 19%, and the "Dense forest cover area" plummeted by 66%. The comparison between the years 2018 and 2022 revealed that the "No vegetation area" fell by 32%, the "Less vegetation area" increased by 30%, the "Moderate vegetation area" climbed by 2%, and the "Dense forest cover area" increased by 1%.

Examination of Socio-Ecological Systems (SES)

The SES is delineated with the primary and secondary variables.

The actors [A1] are the residents of the Maga camp (Kutupalong-Balukhali) in Ukhiya. The human settlement in the camp region was founded prior to 1989, and from 1991 to 2017, around 809,000 Rohingya sought refuge in this area, with 509,000 fleeing over a three-month period (Humanitarian Response Plan, October 2017). On 14 September, the Government designated 2,000 acres for a new camp in Ukhia Upazila. Since mid-September 2017, there has been a trend of individuals relocating from transit points, smaller new sites, and makeshift settlements to the area designated for a potential new camp (Humanitarian response plan, October 2017). A survey conducted before to the 2017 refugee inflow indicates that 57 percent of households, including those of refugees in the region, are entirely reliant on forests for their livelihoods (Uddin & Khan, 2007). Consequently, the migration resulted in significant reliance on the forest. To alleviate strain on adjacent forests and enhance the health and well-being of Rohingyas in the refugee camps, the UNHCR and its partners commenced the distribution of liquefied petroleum gas (LPG) cylinders to refugees and subsequently to select houses in the host community. In 2019, 75 percent of Rohingya households reported utilizing the LPG cylinders supplied by UNHCR for cooking (Inter-Sector Coordination Group, 2019). The LPG initiative has diminished refugees' reliance on forests for fuelwood procurement. Nonetheless, there remains a growing demand for bamboo extraction, a forest product utilized in shelter construction (Dampha, Salemi & Polasky, 2022).

The terrain in this district is primarily characterized by its deep forests, encompassing protected regions, nature reserves, and national parks (Hassan et al., 2018; UNDP & UN Women, 2018). Over 25 percent of the district is covered by forests, with approximately 10,849 hectares designated as protected forest (Hossen et al., 2019) and 11,615 hectares classified as a wildlife sanctuary (e.g., Teknaf Wildlife Sanctuary) (UNDP & UN Women, 2018). The Meag camp occupies 1,697 hectares (15.64%) of the forested area (HDX, 2018). The natural system exhibited great productivity, characterized by a forest environment that hosts hundreds of plant and animal species, including birds, monkeys, snakes, bats, and many vertebrate and invertebrate species. It includes threatened and severely endangered species, including the wild Asian elephant (Hassan et al., 2018; Tallis et al., 2019; UNDP & UN Women, 2018). However, following the influx of 2017, there was a dramatic reduction in the Rohingya camp area (Dampha, Salemi & Polasky, 2022).

The forest constitutes the RU, as it is the objective. Only the forest land within the boundaries of the Rohingya camp is regarded as RUs for analytical purposes. The link between forest land and the creatures inhabiting it is symbiotic, with both components being essential for the ecosystem. The historical data series from Table 6 indicates that the "dense forest cover" in the Mega camp region diminished from 65.9169% (2017, prior to the Rohingya influx) to 0.0636% (2018, immediately following the largest Rohingya influx). In 2022, the "dense forest cover" climbed to 1.4584% due to the efforts of the agencies operating in the refugee camps. The forested ground in the camp region has been cleared following the recent influx and converted into residential space for the Rohingya people.

At the national level, the Cox's Bazar North Forest Division, the Cox’s Bazar district office, and the office of the Refugee Relief and Repatriation Commission (RRRC) are accountable for the designated refugee camp. As per ISCG, 45 international non-governmental organizations and UN agencies have been engaged in offering various forms of assistance to refugees since the surge in 2017. Shortly after the influx, they initiated a replanting campaign in the camp area. The Government has established regulations to confine refugees to the camp area and limit their mobility.

The primary contact between refugees and the forest region was the utilization of the latter for fuelwood at the onset of the inflow in 2017. There is a substantial number of conflicts within the Rohingya communities that have resulted in violent warfare. Refugees are resorting to extreme actions, including aligning with criminal organizations and undertaking perilous migrations, solely for the sake of survival. In February 2019, approximately 1,242,995 LPG cylinders (initial and refill) were distributed to Rohingya homes by 2020, along with 46,694 LPG cylinders provided to host community households in Cox’s Bazar (UNHCR, 2020). In 2019, 75 percent of Rohingya households reported utilizing the LPG cylinders supplied by UNHCR for cooking (Inter-Sector Coordination Group, 2019). The LPG initiative has diminished refugees' reliance on forests for fuelwood procurement. A reforestation initiative was initiated in the camp area to provide green space and restore the forest (Dampha, Salemi & Polasky, 2022).

The social performance of this activity is suboptimal. For instance, it references the armed fighting among the refugees. It also notes the significant reliance on nature, although this has diminished with the support of humanitarian organizations. Significant loss of deep forest cover has been observed, rendering the camp area unfriendly for other species; consequently, the ecological performance in the Rohingya refugee camp in Cox's Bazar has deteriorated.

Conclusion

From 2017 to 2022, the Rohingya response camp had significant alterations in land cover, particularly a reduction in forest cover, leading to deforestation. Three Landsat 8 images were utilized to delineate and extract land cover data for the Camp region from 2017 to 2022. The land-cover maps indicate a significant rise in areas classified as “No vegetation” and “Less vegetation” compared to “Dense forest cover” in 2018, following the Rohingya migration at the end of 2017. Following the initiation of the reforestation campaign in the camp area, the 2022 satellite imagery indicates a substantial rise in the "Less vegetation" zone compared to the "No vegetation" zone. However, the region with "dense forest cover" has yet to be restored. The quick inflow of the Rohingya community in 2017 has led to increased land utilization to meet their demands, resulting in numerous areas devoid of vegetation, replacing croplands, bushes, and forests.

While it does not precisely mirror the conditions of the Meghalaya Plateau study, it has some similarities. The Meghalaya Plateau has undergone urbanization and had an increase in population density from 23 to 138 individuals. The Rohingya response camp area experienced an increase in population density from 100 to 42,724.28 individuals per square kilometer. However, the population density in the camp region is far greater than that of the Meghalaya Plateau. It is evident that the reforestation strategy here would differ from that of the other region. However, it cannot be asserted that the deep forest cover can be completely restored, akin to the Meghalaya Plateau. From the perspective of SES theory, the social structure of the Rohingya community has deteriorated, and significant population pressure is disrupting the ecology by deforesting the land.

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