UNIVERSITY OF GHANA

ASSESSMENT OF SARGASSUM BEACHING AND IT'S EFFECT ON COMMUNITIES ALONG THE WESTERN COAST OF GHANA

BY

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THIS THESIS IS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILMENT OF THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN ENVIRONMENTAL SCIENCE

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DECLARATION

I, Paul Adu, hereby declare that this thesis is my conceptualized work under supervision. It has never been presented for a degree award, and all sources cited have been acknowledged.

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DEDICATION

This thesis is dedicated to the memory of my beloved father, Daniel Adu, whose enduring spirit and guidance continue to inspire me every day. To my mother, Christiana Awuah, your unconditional love and support have been my greatest strength. I also dedicate this work to Mrs. Pamela Zormelo, for believing in my potential and providing the scholarship that made this journey possible. To everyone who has stood by me, especially Mrs. Doreen Williams and Dr. Joseph Kobina Essibu, this work is a testament to your unwavering support and encouragement.

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I am profoundly grateful to Mrs. Pamela Zormelo, whom I affectionately call Aunty Pamela, for her immense support. Your motivation and generous scholarship made it possible for me to pursue this research, and your motivation guided me through every step of the MPhil program. I owe a great debt of gratitude to Mrs. Doreen Williams and Dr. Joseph Kobina Essibu for their invaluable support, both personally and academically. Your guidance and encouragement have been instrumental in my success.

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Finally, I would like to thank everyone who, in one way or another, contributed to the successful completion of this thesis. Your kindness and support will always be remembered.

ABSTRACT

Sargassum, a genus of the brown macroalgae, plays a crucial role in marine ecosystems but has become an increasing concern due to its massive beaching events globally, particularly along the coastlines of Ghana. This study focuses on assessing the trends in *Sargassum* beaching and its effects on the livelihoods of selected coastal communities in the Western Region of Ghana.

A mixed-methods approach was employed, combining simple random sampling and purposive sampling to select a representative sample of 400 participants, including fishermen, fishmongers, and coastal residents from Beyin, Esiama, and Sanzule. Data were collected through transect walks, field observations, photography, focus groups, and face-to-face interviews, with audio recordings in Nzema dialect transcribed for analysis. An Unmanned Aerial Vehicle (UAV) was used to monitor and evaluate the incidence and distribution of *Sargassum* along the beach.

The UAV data collection was conducted in September and October 2021 and 2023, using a DJI Phantom and processed using Structure-from-Motion (SfM) and Multi-View Stereo (MVS) algorithms in Agisoft Photoscan software. The resulting orthophotos were converted to Normalized Green-Red Difference Index (NGRDI) values using QGIS to detect sargassum on the beach. These images were further segmented and classified using eCognition and ArcMap, allowing for the estimation of *Sargassum* extent and volumes.

The research highlights the temporal variability in *Sargassum* accumulation from 2021 to 2023, revealing a decline in average beach coverage from 17,153 m^2 in 2021 to complete a near-zero range (0–5 m^2) in 2023, indicating complete disappearance in 2023. The estimated *Sargassum* volume also decreased from 11,387 m^3 in 2021 to near-zero levels in 2023, indicating a significant reduction in beaching over the period studied. Fluctuations in accumulation were found to affect local livelihoods with 80.5% of respondents reporting a negative impact on fishing and income, while 49.2% indicated that tourism activities declined during heavy influx periods. Environmental degradation was observed through reduced water quality and shoreline contamination, reported by 72% of participants. Health concerns were also evident, with 18% reporting skin irritation and 7% respiratory discomfort associated with decomposing *Sargassum*. Despite these challenges, 63% of community members adopted sweeping and burning as management practices, while 37% buried *Sargassum* to reduce odor and beach obstruction. Furthermore, only 16% of respondents were aware of its alternative uses, such as composting and fertilizer production, showing untapped potential for sustainable management.

The findings contribute to a deeper understanding of the socio-economic and environmental implications of *Sargassum* beaching in Ghana, providing evidence-based recommendations for policymakers and stakeholders to enhance resilience and sustainability in the region.

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LIST OF ABBREVIATIONS

AMO - Atlantic Multi-decadal Oscillation

CAST - Caribbean Alliance for Sustainable Tourism

DJI - Da-Jiang Innovations

ECBAS - Ethics Committee for Basic and Applied Sciences

ENSO - EI-Nino-Southern Oscillation

EPA - Environmental Protection Agency

FAO - Food and Agriculture Organization of the United Nations

FGDs - Focus Group Discussions

GCPs - Ground Control Points

GIS - Geographical Information System

IBM - International Business Machines Corporation

ITCZ - Intertropical Convergence Zone

MAXQDA - MAX Qualitative Data Analysis

MVS - Multi-View Stereo

NAO - North Atlantic Oscillation

NERR - North Equatorial Recirculation Region

NGRDI - Normalized Green-Red Difference Index

SARTRAC - Teleconnected Sargassum risks across the Atlantic

SFM - Structure-from-Motion

SPSS - Statistical Package for the Social Sciences

SSTs - Sea Surface Temperatures

UAVs - Unmanned Aerial Vehicles

UNEP - United Nations Environment Programme

CHAPTER ONE

INTRODUCTION

1.1Background

Algae are primary producers in aquatic environments and thus make up the base of the food chain. Phaeophyta, also known as "brown algae", is one of the significant subgroups of eukaryotic sea algae and contains various algal life forms, including edible forms. The world consumes brown algae in various forms because they are nutrient-rich. Particular examples include *Sargassum*, *Laminaria*, and *Fucus* species, which are utilized as livestock and poultry feed (Makkar et al., 2016).

The genus *Sargassum* is a seaweed that belongs to the class Phaeophyceae, and has more than 300 species that are found in both tropical and temperate regions of the planet (UNEP, 2021). Unlike other seaweeds that reproduce and start their lives on the ocean floor (benthic phase), *Sargassum* is holopelagic, reproducing vegetatively on the high seas as a free-floating species (Laffoley et al., 2011, Burton, 2018). *Sargassum* species naturally occur in the Sargasso Sea and can be seen floating freely as mats in the Atlantic Ocean. Thus, according to Laffoley et al. (2011), it has been the reason it is referred to as the "golden tide" or the "golden floating rainforest." The only sea without a geographical border is the Sargasso Sea, which is totally contained within the Atlantic Ocean.

Sargassum natans and *Sargassum fluitans* are the two species that float freely in the ocean, with the former the most prevalent species (Godínez-Ortega et al., 2021). Historical accounts of *Sargassum* expanding and reaching far from the Sargasso Sea, like the Mexican state of Veracruz in the Gulf of Mexico (Godínez-Ortega et al., 2021). In the central Atlantic Ocean *Sargassum* blooms first appeared in 2011 and expanded to include the West Indies, Mexico, the Gulf of Mexico, Brazil, and the Great Caribbean (Godínez-Ortega et al., 2021).

Once it beaches, *Sargassum* decomposes, invading and harming ecosystems as well as negatively affecting human health and way of life (van Tussenbroek et al., 2017). Thus, beached *Sargassum* can have negative economic implications, such as marine life death, as well as decreased fish catches (UNEP, 2018), and a reduction in tourism activities by 35% due to unpleasant odors and an unattractive visual impact (Chavez et al., 2020).

Since 2011, the Ghanaian coast, especially along the Western Region, has recorded annual Sargassum beaching events, disrupting fishing and tourism activities (Fidai et al., 2020; Marsh et al., 2021). Local news outlets such as Graphic Online (2019) *and* Ghana News Agency (2020) also reported severe Sargassum invasions at Beyin and Axim beaches, describing them as recurring seasonal nuisances affecting livelihoods. However, there has not been a documented assessment of the beaching trends over the years along the coast and how this trend impacts the livelihoods of the coastal communities.

This research thus investigated the impacts of *Sargassum* beaching on livelihoods of selected coastal communities in the Western Region of Ghana using Unmanned aerial vehicles (UAVs) and community engagement.

Figure 1: Sargassum beached along the Western Coast of Ghana (September 2021, SARTRAC Project)

1.2 Problem Statement

Since 2011, Ghana's western coastline has experienced recurring influxes of *Sargassum*, with coastal communities such as Axim, Beyin, and Sanzule being the most affected (*Daily Graphic*, 2019; *Ghana News Agency*, 2020; Fidai et al., 2020). These *Sargassum* beaching events have become an annual phenomenon, often coinciding with the major upwelling season between July and October. Local media reports have reported huge volumes of the brown macroalgae covering beaches, obstructing fishing activities, and creating foul odors along the beaches. Fishermen have complained of damaged nets, clogged outboard motors, and reduced fish catches, while residents have expressed concerns about air pollution and health effects linked to the decomposing sargassum (*MyJoyOnline*, 2021; *Ghana News Agency*, 2020).

Despite these recurring incidents and their growing socio-economic consequences, there remains limited scientific data and systematic monitoring of Sargassum beaching along Ghana's coast.

Unlike the Caribbean and parts of Latin America, where satellite-based monitoring and early warning systems have been developed to forecast *Sargassum* influx, Ghana and the wider West African region lack such mechanisms. This gap in empirical research makes it difficult for coastal planners, local authorities, and environmental managers to understand the magnitude**,** frequency, and spatial distribution of these events.

The absence of quantitative assessments has also hindered the development of effective response strategies for affected communities. As a result, local fishers, traders, and tourism operators continue to suffer economic losses, with little policy support or adaptation guidance. Furthermore, while anecdotal reports and community observations suggest that the problem is worsening, there is no consistent baseline data to verify long-term trends or to evaluate potential mitigation approaches such as composting, collection, or reuse of the biomass.

Therefore, this study seeks to fill this critical research gap by using Unmanned Aerial Vehicles (UAVs), field surveys, and community-based data to assess the spatial extent, temporal trends, and socio-economic impacts of Sargassum beaching along the Western Coast of Ghana. The findings aim to provide evidence-based insights that will support local governments and policymakers in designing sustainable management strategies and improving the resilience of coastal livelihoods.

1.3 Aims and Objectives

Generally, this study aims to investigate the beaching trend of *Sargassum* and its impacts on the livelihoods of selected coastal communities in the Western Region of Ghana.

The specific objectives are:

1. To map *Sargassum* beaching within the selected communities

2. To assess the impacts of *Sargassum* beaching on coastal communities.

3. To evaluate community management strategies for the impacts of *Sargassum* invasion on livelihoods.

1.4 Research Questions

The following research questions are formulated to help achieve the research objectives.

1. What are the temporal and spatial patterns of Sargassum beaching between 2021 and 2023 in the selected communities?
2. How does Sargassum influx affect fishing, tourism, and coastal ecosystem health in the Western Region?
3. What coping and management strategies are being adopted by local communities, and how effective are they?

CHAPTER TWO

LITERATURE REVIEW

2.1 Influx of Sargassum

The brown macroalgae of the family *Phaeophyceae*, including *Sargassum*, have been observed to flourish in the North Atlantic Ocean's Sargasso Sea and the Gulf of Mexico. According to Huffard et al. (2014), *Sargassum* can develop into a variety of sizes, ranging from tiny clumps of only a few centimeters broad to rafts or patches that are large enough to be seen by satellites with a coarse resolution.

The accelerated growth rates of *Sargassum* are influenced by a variety of physical conditions and external nutritional inputs (Carvalho & Granéli, 2010). These factors include changes in regional winds and ocean current patterns, rising sea surface temperatures, an increased supply of iron due to the atmospheric deposition of Saharan dust linked to desertification and climate change, as well as nutrients from rivers, sewage, and nitrogen-based fertilizers (Oxenford & Franks, 2015).

The transfer of floating biomass out of the Sargasso Sea into the tropical Atlantic between West Africa and South America has been facilitated since 2011 by climatological and environmental factors (Putman et al., 2018; Johns et al., 2020). The Atlantic and Caribbean coasts are seriously affected by beach-cast occurrences as a result of huge masses of these seaweeds being dumped on beaches.

According to recent research (Wang et al., 2019; Johns et al., 2020), the availability of nutrients is the primary factor influencing the interannual variability of *Sargassum* blooms in the central tropical North Atlantic. The El Niño–Southern Oscillation (ENSO), North Atlantic Oscillation

(NAO), and Atlantic Multi-decadal Oscillation (AMO) are three climate indices that have also been observed or assessed for potential connections with bloom events (Franks et al., 2014). According to Johnson et al. (2012), the observed fluctuation in the distribution of *Sargassum* has been attributed to the Intertropical Convergence Zone (ITCZ) moving northward, increased air pressure in the North Atlantic, and sea surface heating.

It is still unclear what is causing the sudden *Sargassum* blooms and mass strandings. A number of hypotheses have been put forth; yet due to a lack of information on these changes, anomalous nutrient inputs from the tropical Atlantic large rivers (Amazon, Orinoco, and Congo) as well as equatorial upwelling, African atmospheric dust, and climate change-induced increases in seawater temperature and/or changes in ocean currents (Johnson et al., 2013; Goes et al., 2014; Franks et al., 2014; Oxenford et al., 2015; Guimberteau et al., 2016) have been implicated.

According to Smetacek and Zingone (2013), greater nutrient imports from the Mississippi River in the Gulf of Mexico are associated with an increase in *Sargassum natans* and *Sargassum fluitans*. Tropical Atlantic *Sargassum* blooms may also be caused by warmer sea surface temperatures linked to nutrient-rich waters that are triggered by continental runoff (Sissini et al., 2017). Hinds et al. (2016) indicate that the recent *Sargassum* influxes to the Caribbean Sea and the coast of West Africa have been caused by huge blooms in the North Equatorial Recirculation Region (NERR), an equatorial region of the Atlantic. These masses are carried by currents eastward from the Atlantic Ocean, rising along the Brazilian coast until they reach the Caribbean. Massive *Sargassum* blooms in the NERR have also been blamed for the recent influxes to the Caribbean Sea and the coast of West Africa (Hinds et al., 2016).

In Ghana, the first record of a *Sargassum* sighting was made in 2011, particularly along beaches such as Axim, Beyin, and Sanzule. However, the first major influx was reported between 2011 and 2012 (Ackah-Baidoo, 2013; Fidai et al., 2020; Marsh et al., 2021). Subsequent reports from the Daily Graphic (2019) and Ghana News Agency (2020) confirm periodic *Sargassum* beaching events along Ghana's western coastline, where artisanal fishers reported damaged nets, entangled outboard motors, and decreased fish catches due to seaweed accumulation. The Environmental Protection Agency (EPA, Ghana, 2021) also observed that *Sargassum* accumulation alters nearshore habitats, affecting local biodiversity. These findings emphasize that Ghana is now part of the global *Sargassum* phenomenon, necessitating localized scientific investigations to inform coastal management.

2.2 Impacts of *Sargassum*

Sargassum will blanket the beaches and emit unpleasant odors as it decomposes, imposing a significant impact on the local economy, particularly tourism and its directly or indirectly related industries (Hu et al., 2016). Massive *Sargassum* deposits would obstruct harbors, draw insects, and hence hinder artisanal fishing and raise public health issues (Suida et al., 2016).

Maurer et al. (2015) and Hu et al. (2016) report that *Sargassum* buildup may also affect wildlife, including suffocating sea turtle nesting places, which could have an effect on the population of these animals. Massive Sargassum deposition over an extended period of time can also result in coastal eutrophication (Suida et al., 2016) and provide unfavorable conditions for the development of seagrass and coral communities close to the shore (van Tussenbroek et al., 2018).

Sargassum beaching has accelerated beach erosion, causing coastal dead zones due to biomass decomposition and beach fouling, killing seagrass and mangrove seedlings, eutrophication, altering the species composition of the benthic community, increasing the likelihood of heavy metal contamination of the environment, and altering food webs. *Sargassum* hinders traditional food-finding strategies and blocks sunlight, which prevents other plants from growing (Chavez et al., 2020; Robledo et al., 2021; UNEP, 2018).

Sargassum decomposes almost immediately after beaching and results in the release of toxic gases like hydrogen sulphide and anhydrous ammonia, which can irritate the upper respiratory tract and cause headaches, nausea, and other serious health problems when exposure is repeated (Chavez et al., 2020; Robledo et al., 2021). Due to the abundance of *Sargassum* on beaches, the Caribbean region has seen a significant fall in tourism, with Mexico experiencing a 35% drop of tourists (UNEP, 2018). *Sargassum* prevents visitors from appreciating the beauty of the beaches because matting in the ocean and stacks of seaweed on the shore take up the majority of the space.

Another example of the nuisance caused by *Sargassum* is its unpleasant odor, which most vacationers try to avoid. Due to the lack of beach access, increased cost for consistent removal, and inability to operate tours and ocean-based activities near beach shores, *Sargassum* poses a serious threat to the tourism sector (CAST, 2015). Vacation cancellations and beachside room closures have happened in dire circumstances, which have resulted in staff layoffs and decreased economic gain for the industry and communities (CAST, 2015). Consequently, the *Sargassum* invasion has hurt the tourism industry, which is the main driver of the economy in the Caribbean region (Chavez et al., 2020).

Studies have shown that affected communities have numerous options for recycling and reusing *Sargassum* for various purposes. These include uses for composting and manures, sodium alginate in food, clothing and pharmaceuticals, building materials, manually made paper, cosmetics, crop and livestock production, bioplastics, biogas production and biosorption, all of which have been investigated in the Caribbean region and have created business opportunities (Chavez et al., 2020). As an illustration, Algas Organics, the first Caribbean-based indigenous biotech company, evolved a method to create a plant bio-stimulant from *Sargassum* in 2015. With a quality comparable to leading fertilizer brands, the product can potentially replace synthetic fertilizers in terms of energy (Speede et al., 2024). The company constructed the first *Sargassum* processing facility in the Caribbean with assistance from the government and international organizations and now intends to increase production, add to local employment opportunities, and fund research to enhance its *Sargassum*-based products (UNEP, 2018).

Furthermore, *Sargassum*, on the other hand, has been discovered to improve dune formation on some beaches along the Mexican coastline, perhaps by adding nutrients, organic matter, phytohormones, and alginates that encourage the growth of sand-holding plants (Chavez et al., 2020).

In Ghana, however, limited research exists on the socio-economic and ecological effects of *Sargassum* influxes. Reports from the Daily Graphic (2019) and Ghana News Agency (2020) reveal that fishermen in Axim, Beyin, and Sanzule experienced net damage, reduced catches, and additional fuel costs due to Sargassum entanglement. Sowah et al. (2022) similarly found that artisanal fishers faced income losses of up to 40% during peak influx periods. Local residents also reported skin irritation and respiratory discomfort caused by decaying seaweed, while women involved in fish processing suffered reduced supplies and income. These Ghana-specific challenges highlight the need for targeted mitigation and livelihood adaptation strategies.

Despite these challenges, very few studies have examined the positive reuse potential of *Sargassum* in Ghana. Composting and organic fertilizer trials by local farmers (EPA Ghana, 2021) suggest that *Sargassum* can improve soil texture and moisture retention, but large-scale applications remain unexplored. These gaps justify the focus of this current study on Ghana's Western Region.

2.3 *Sargassum* Beaching Approaches

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2.3.1 Challenges and Limitations of UAVs

Despite their advantages, UAVs face several challenges. Flight restrictions, battery limitations, and weather conditions can significantly affect their utility. UAVs have limited spatial coverage, which restricts their effectiveness in monitoring vast coastal or oceanic areas. Satellite imagery, although less detailed, remains superior for large-scale monitoring due to its wider coverage (Anderson & Gaston, 2013). Additionally, UAV operations are weather-dependent, with factors such as wind, rain, and fog reducing their effectiveness or even halting flights entirely (Koh & Wich, 2012).

Post-processing UAV data also presents challenges. Large amounts of data require extensive computational power for orthorectification and stitching images into cohesive mosaics. While machine learning techniques, such as deep neural networks like ERISNet (Arellano-Verdejo et al., 2019), are increasingly automating this process, these tools often require large training datasets and sophisticated algorithms, which may not be readily available in developing countries.

Satellite remote sensing, particularly through platforms like Sentinel-2 and MODIS (Moderate Resolution Imaging Spectroradiometer), is essential for large-scale monitoring of *Sargassum* blooms (Wang & Hu, 2016). Satellite detection of *Sargassum* depends on the distinctive bio-optical signature of macroalgal mats (Blondeau-Patissier et al., 2014). Satellites provide global coverage and can continuously monitor open waters and coastlines. However, they face several limitations. For instance, the spatial resolution of many satellites, such as MODIS with a resolution of 250–1000 meters per pixel, is often insufficient to detect smaller *Sargassum* patches or to capture detailed data along complex coastlines (Putman et al., 2023). Furthermore, cloud cover can obstruct satellite imagery collection, particularly in tropical regions, creating data gaps (Wang & Hu, 2016). Another limitation is the temporal resolution of satellites; many satellites only revisit the same area every few days or weeks, making it difficult to capture rapid changes in *Sargassum* distribution (García-Sánchez et al., 2020).

LIDAR (Light Detection and Ranging) is another powerful remote sensing tool explored for coastal monitoring. Using laser pulses to create high-resolution 3D maps, LIDAR is particularly useful for assessing coastal topography and erosion caused by *Sargassum* accumulation (Salter et al., 2020). LIDAR's ability to penetrate vegetation makes it advantageous for generating detailed surface models compared to traditional optical remote sensing. However, LIDAR is limited in detecting floating *Sargassum*, as it cannot penetrate water. Additionally, LIDAR systems are expensive, which limits their accessibility compared to more conventional remote sensing technologies (Santos-Romero et al., 2022).

Consequently, the integration of UAV, satellite, and citizen-based monitoring could represent the most viable strategy for regions like Ghana, where resources and technical expertise may be limited but local engagement and observational potential are high. Such hybrid systems could provide continuous and reliable data for early detection, policymaking, and disaster mitigation in coastal communities affected by *Sargassum*.

2.4 Conceptual Framework

The conceptual framework adopted for this research explores the intricate relationships between environmental factors that contribute to *Sargassum* beaching, the strategies implemented by coastal communities to mitigate its adverse effects, the capacity of these communities to adapt and build resilience in the face of *Sargassum*-related challenges, and the subsequent impacts on livelihoods in the Western Region of Ghana (Figure 2). This framework provides a comprehensive understanding of the complex dynamics at play and informs the development of effective strategies for sustainable coastal management.

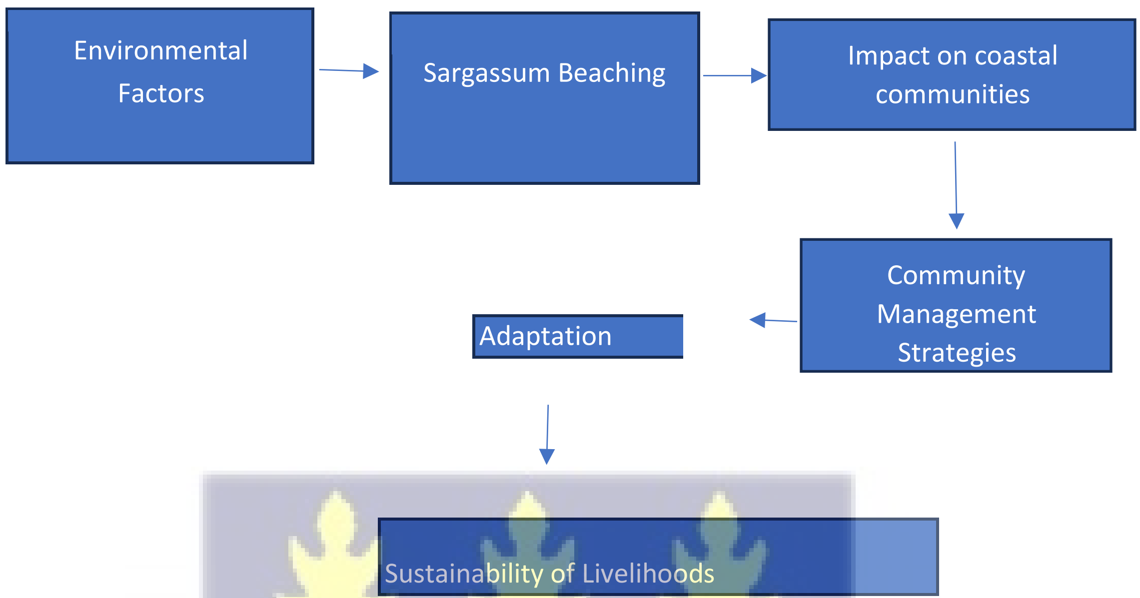

Figure 2: Study Framework

The framework is supported by theories of environmental adaptation and community resilience (Adger, 2000; Folke, 2006), which emphasize the capacity of social–ecological systems to absorb disturbances and reorganize while undergoing change. Environmental factors such as sea surface temperature, nutrient enrichment, and ocean current variability act as initial drivers influencing *Sargassum* proliferation (Wang & Hu, 2016; Carvalho & Granéli, 2010). These physical drivers lead to beaching, which then triggers socio-economic responses within communities. Coastal populations adapt through cleanup activities, innovations in reuse, and collective coping mechanisms (Robledo et al., 2021; UNEP, 2018).

The framework further draws from the sustainable livelihoods approach (Scoones, 1998), highlighting how human, natural, financial, and institutional capital determine resilience. Livelihood sustainability, therefore, depends on both ecological stability and social adaptability. In the context of Ghana's Western Region, communities that possess diverse livelihood strategies, such as combining fishing, tourism, and small trade, are better positioned to recover from *Sargassum* impacts. The framework thus situates this study within broader environmental governance and coastal management discourses, aligning with FAO (2022) and Sowah et al. (2022) findings on adaptive fisheries and livelihood resilience.

CHAPTER THREE

METHODOLOGY

The location, topography, and socio-economic activities of the study area is discussed in this chapter. The chapter also presents demographic features, including population structure and economic activities. Additionally, the chapter focuses on the research design, methodologies, and procedures employed for data collection and analysis to achieve the study's objectives. Figure 3 shows a summary of the methodology workflow used for this work.

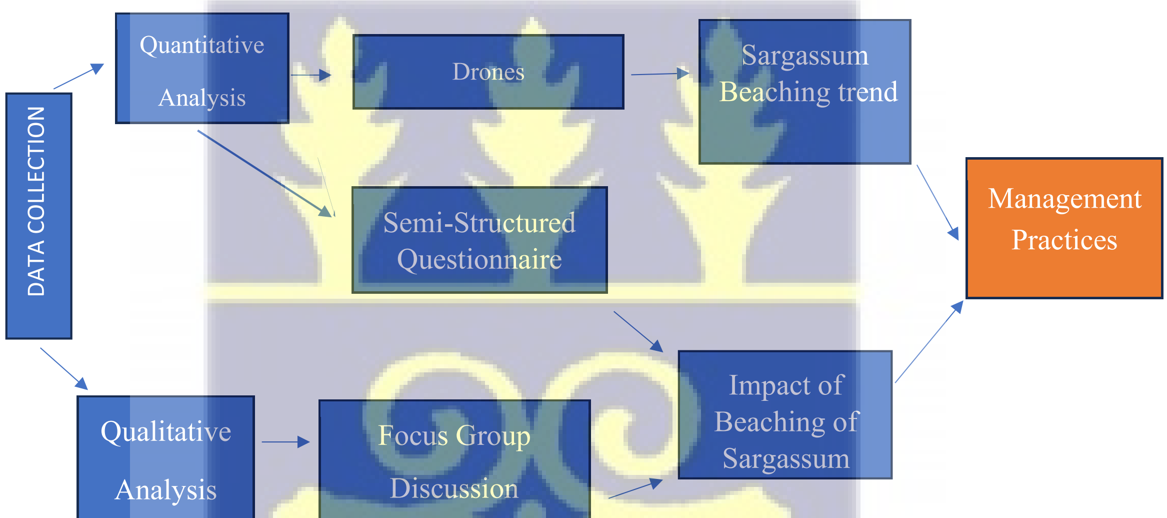

Figure 3: The General workflow to assess the impact of Sargassum beaching on Livelihood along the western coast of Ghana

3.2 Study Area

The study was conducted in two coastal administrative areas of Ghana's Western Region the Ellembelle District and Jomoro Municipality (Figure 4). These areas are characterized by low-lying sandy beaches, numerous lagoons and estuaries, and intensive fishing activities, making them highly vulnerable to *Sargassum* influxes. Jomoro has an estimated population of 126,576 and a population density of 87.7 persons/km², while Ellembelle has 120,893 residents with a density of 124.3 persons/km² (GSS, 2021).

Three communities were purposively selected due to their documented experiences with Sargassum beaching Beyin**,** Esiama and Sanzule (Ackah-Baidoo, 2013; Marsh et al., 2021). Beyin (4.9885°N, 2.5904°W) is a major fishing community; Esiama (4.9387°N, 2.3493°W) combines fishing and small-scale trade; and Sanzule (4.9611°N, 2.4536°W) hosts small tourism establishments and local fish landing sites. These towns depend heavily on artisanal fishing**,** fish processing, and petty trading. Women dominate post-harvest activities such as fish smoking and marketing, while men dominate capture fisheries. Tourism is a growing but vulnerable economic sector due to *Sargassum* accumulation along the beaches.

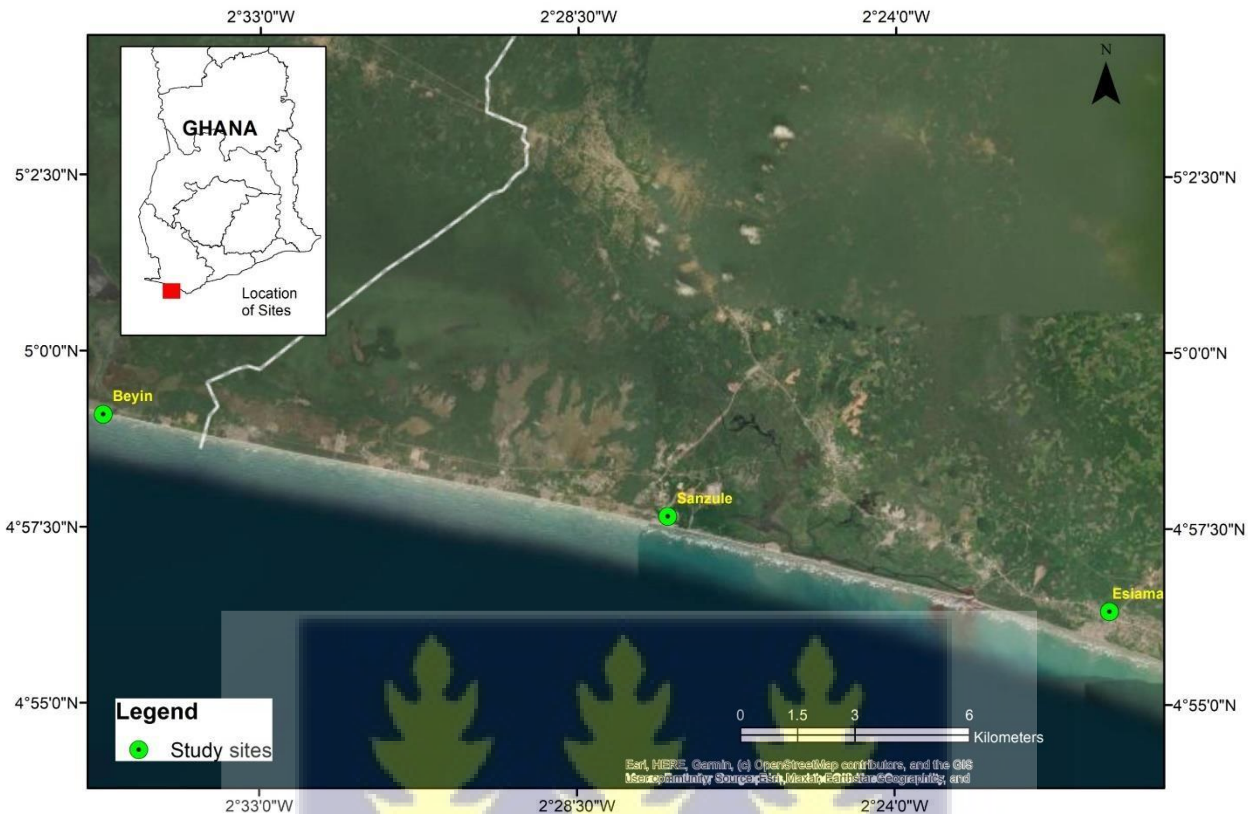

Figure 4: Map of the study area in the Western Region of Ghana showing the three coastal communities

3.3 Socio-Economic Activities of Study Communities

Fish processing, fish selling, and artisanal fishing provide the majority of the Western Region's economic livelihoods. In these gendered occupations, women predominate in the trade and processing of fish while males dominate the actual fishing. Inland, alongside other trading activities, subsistence agricultural practices include crop cultivation and livestock rearing. Furthermore, there are other resorts in the area that cater to visitors. Colonial forts, beaches, and ecotourism destinations are essential to tourism, even though it don't employ as many people as farming and fishing do.

3.4 Research Design

In order to integrate the many study components coherently and logically, and to ensure that the research problem will be successfully addressed. The mixed research approach is the design chosen for this investigation.

According to Creswell (2014), a mixed approach or strategy offers a comprehensive grasp of the problems being investigated. Further, it adds valuable insight into a discrepancy between quantitative findings (sample size) and qualitative outcomes on the research's impact on the general population. It is also helpful because it provides all of the pertinent data to support the study's findings. The mixed-method also produces comprehensive results that might aid in addressing the topic.

3.5 Sources of Data

Data for this study were obtained from primary and secondary sources.

3.5.1 Primary Source

Primary data sources included those gathered from the field through community surveys, interviews, and on-the-ground observation and drone flight surveys. On-site observation and case studies were used to carry out the tasks. Focus group discussions were employed, and this allowed for the organised collection of data and information from stakeholders.

3.5.2 Secondary Data Source

Measured data from Teleconnected *Sargassum* risks across the Atlantic: building capacity for TRansformational Adaptation in the Caribbean and West Africa (SARTRAC) project was used.

The measured data are from drone surveys undertaken with DJI PHANTOM 4 drones. The data spans September and October for 2021 and 2022, respectively.

3.6 Sampling Technique

A simple random sampling procedure was used in this study to determine the participants of the social survey. This method enabled the selection of a more representative sample from a larger population and drew general conclusions about the group.

3.7 Sample Size Determination and Distribution

The sample size of 385 respondents was determined using Cochran's (1977) formula at a 95% confidence level and a 5% margin of error, assuming a maximum variability (p = 0.5). To ensure proportional representation, the total sample was distributed according to the population sizes of the study communities, with Esiama having 154 respondents (40%), Beyin having 115 respondents (30%), and Sanzule having 116 respondents (30%).

3.8 Data Collection/Instruments

3.9.1 Beach Mapping Using UAVs

For each community, a 500-metre stretch of coastline was selected for detailed mapping based on accessibility and local recommendations. UAV flights were conducted in September and October, the peak *Sargassum* months (Adjeroud et al., 2019). Data for 2021 and 2022 were collected under the SARTRAC project, and a follow-up flight was conducted in 2023.

Flights were executed using a DJI Phantom 4 drone at 60 metres altitude during low tide to ensure high-resolution imagery (≤5 cm ground sampling distance). Orthophotos were processed in Agisoft

Photoscan, and vegetation indices (NGRDI) were computed in QGIS to delineate Sargassum patches.

3.9.2 Questionnaire Administration

Structured questionnaires were administered face-to-face using Google Forms to facilitate electronic data entry and export (Raju & Harinarayana, 2016). The questionnaire covered respondents' demographics, fishing practices, economic losses, and perceptions of *Sargassum* impacts.

3.9.3 Focus Group Discussions (FGDs)

FGDs were conducted in each community with seven participants representing fishermen, fishmongers, boat repairers, and hotel operators. Discussions, lasting 20–30 minutes, were held in the Nzema language with assistance from interpreters. Audio recordings were transcribed into English for thematic analysis.

3.8.1 Beach Mapping

For each of the communities, about a 500 m stretch alongshore of the beach was selected for regular mapping based on accessibility and community recommendations. Flights were preplanned to cover the beach, and drone flights were carried out during September and October each year (considered the peak season). The 2021 and 2022 data were collected during a previous project with a follow-up flight in 2023. The flight was taken at a height of 60 m to ensure high ground sampling distance (less than 5 cm), and surveys were carried out as much as possible during low tide.

The months of September and October were selected for this study based on findings from Adjeoud et al. (2019),, which explicitly identified *Sargassum* in Ghanaian waters using satellite images and ground truthing. According to the study, *Sargassum* was present in the waterways from July to November, with the highest concentrations occurring in September and October. These peak periods are crucial as they represent the time when *Sargassum* is most likely to have significant economic and ecological impacts on coastal communities. Therefore, focusing on these months allows for a more targeted and relevant assessment of its effects.

3.8.2 Questionnaire Survey

Face-to-face interviews were employed in the collection of data for this study. Both closed-ended and open-ended questions was created. Additionally, spaces were offered for an extra response option for respondents who wish to state their responses if they do not agree with the interviewer's suggested responses.

3.8.3 Focus Group Discussion Sessions

The community survey targeted individuals aged 18 and above, using a carefully selected sampling frame. Most interviews were conducted in the local Nzema language, with the assistance of an interpreter to ensure clear and accurate communication. Focus group discussions (FGDs), lasting 20 to 30 minutes, involved a diverse range of participants, including chief fishermen, fishermen, hotel managers, and other key stakeholders. The FGDs followed a structured guide, ensuring that all participants had an opportunity to contribute. At the end of each thematic discussion, the moderator asked if anyone had additional comments before proceeding to the next topic. Once participants confirmed they had nothing further to add, the discussion moved forward. An audio recorder was used throughout the session to capture the entire discussion for accuracy and future reference. This approach provided a better comprehensive understanding of the perspectives and experiences of those most affected by *Sargassum* beaching.

3.9 Ethical Considerations

Ethical clearance was obtained from the Ethics Committee of the College of Basic and Applied Sciences of the University of Ghana with reference number: ECBAS 077/22-23. The University's research code of conduct regarding ethical issues was strictly adhered to, ensuring voluntary participation of the respondents and clear purpose communication of the study to establish informed consent of the respondents. The participants were assured of their confidentiality and, most importantly, the principle of anonymity.

Individuals below the age of 18 years were excluded from partaking in the exercise. All responses and answers remained anonymous and confidential; respondents were assured. The research subjects received no payment or financial assistance. However, after the brief interview, water was available to encourage the replies.

3.10 Data processing

3.10.1 Trend of Beaching of *Sargassum*

On average, 300 images were captured during each flight and were manually filtered to remove blurred shots. A 3D scene reconstruction was performed using SFM and MVS algorithms (Smith et al., 2015; Snavely, 2011) implemented in Agisoft Photoscan software (Agisoft, 2023).

The SFM analyses included image alignment, which involves detection and matching of image features, providing the basic image structure (Mancini et al.,2013), pixel-based dense stereo reconstruction using the aligned data and the GCPs, and finally the building of orthophotos.

To determine the threshold at which the NGRDI value can be classified as *Sargassum*, a profile of the values was generated across the beach. This was then overlaid on the orthophoto to visually inspect which range of values matches with *Sargassum* on the beach. This was carried out for three (3) profiles for each study site, and an average range was determined to be 0.65-1.00. The determined range was then used to classify all the segments for each site.

The area of *Sargassum* cover was estimated from the classified segments and multiplied by the average beach depth at each study site to compute total Sargassum volume. The measured average beach depth was 0.5 metres at Beyin**,** 0.8 metres at Esiama, and 0.5 metres at Sanzule. The depth was measured by sticking a measuring ruler into the pile of sargassum across the beach on pre-determined profiles. These depth values served as the basis for estimating the volume of accumulated *Sargassum* along the beaches.

3.10.1 Accuracy Assessment

To assess the accuracy of the classification, regular points were generated across the beach at 5m intervals across the beach. The points were used to extract NGRDI values, which were manually validated using the high-resolution orthophotos and knowledge base on field visit. The final output was compared with the classification results, and the percentage of agreement was calculated to represent accuracy.

3.10.2 Focus Group and Questionnaire Analysis

The data from the interviews were analyzed using descriptive analysis and were represented using charts and tables. The audio recording files from the recorder were transferred to the computer. The audio was transcribed with the help of a trained transcriber from Nzema Language to English text. The transcribed text file was imported into MAXQDA for further analysis.

A coding system based on the research questions and themes was developed based on emerging themes from the discussions. Relevant codes were applied to the transcript segments. MAXQDA's functionalities were used to explore the coded data. Based on the queries, co-occurrence analysis, and overall coding patterns, emerging themes and insights from the focus group discussions were identified.

CHAPTER FOUR

RESULTS

Findings of the study gathered from the Beyin, Esiama and Sanzule communities with the use of drone surveys, interviews and focus group discussions are presented.

4.1 Spatial extent and trend of *Sargassum* beaching in the study area

Figures 5 and 6 are classified beach profiles of *Sargassum* influx along Beyin coast in 2021 and 2022 for the months of September and October respectively. The brown coloration represents the beach, and the yellow coloration the *Sargassum* strands. The maps depict the extent of *Sargassum* beaching for the field visits in the two months. In 2021, a large area of the central beach was covered by *Sargassum* during September, with a slight decline in October (Figure 5a and b). The following year, 2022, recorded a gradual reduction in both area and volume, indicating lower accumulation levels (Figure 6) with slightly higher beaching in October than September (Figure 6a and b).

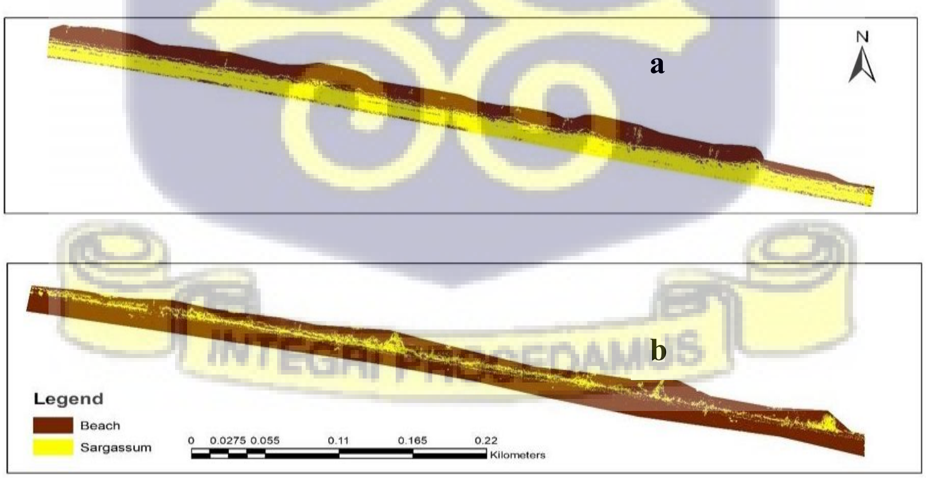

Figure 5: Sargassum beaching in Beyin in the year 2021 (September (a), October (b)

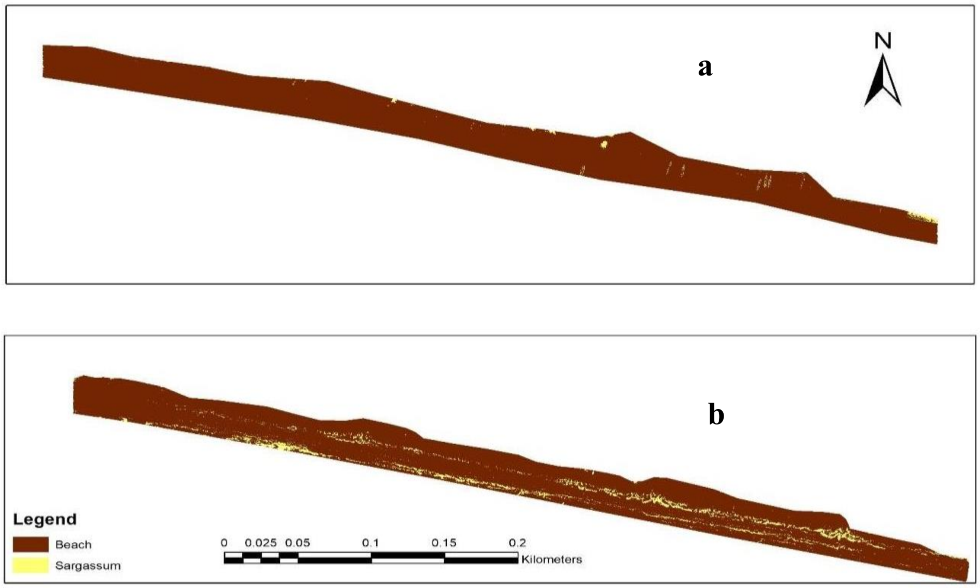

Figure 6: Sargassum beaching in Beyin in the year 2022 (September (a), October (b))

Figures 7 and 8 show *Sargassum* distribution along the Esiama beach. Similar to Beyin, the 2021 season recorded the highest accumulation on this beach, with a higher beaching in October than in September for this site. There was less beaching in 2022, confirming a declining trend over the period.

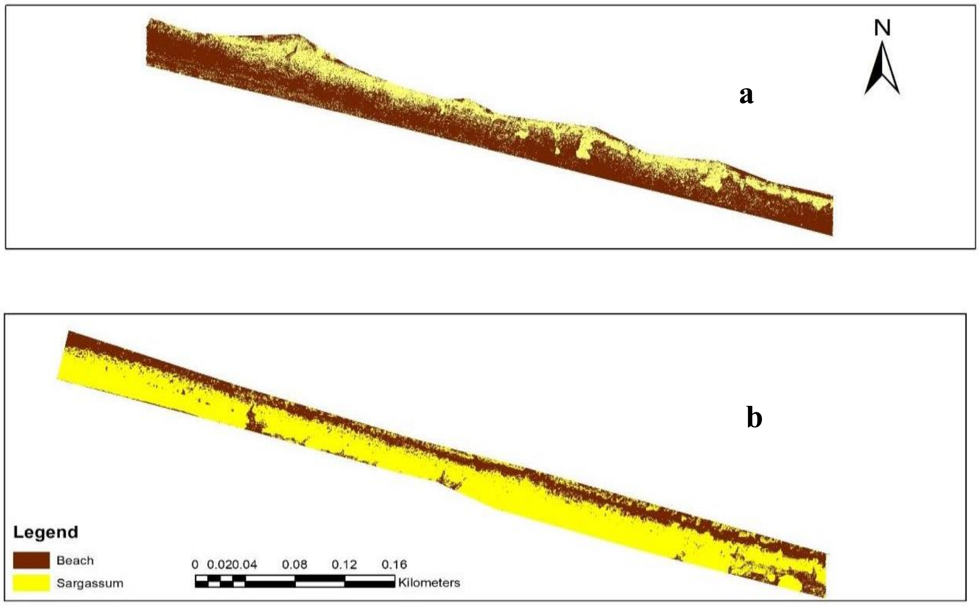

Figure 7: Maps showing Sargassum beaching in Esiama in **September 2021** (a) **and** October **2021** (b)

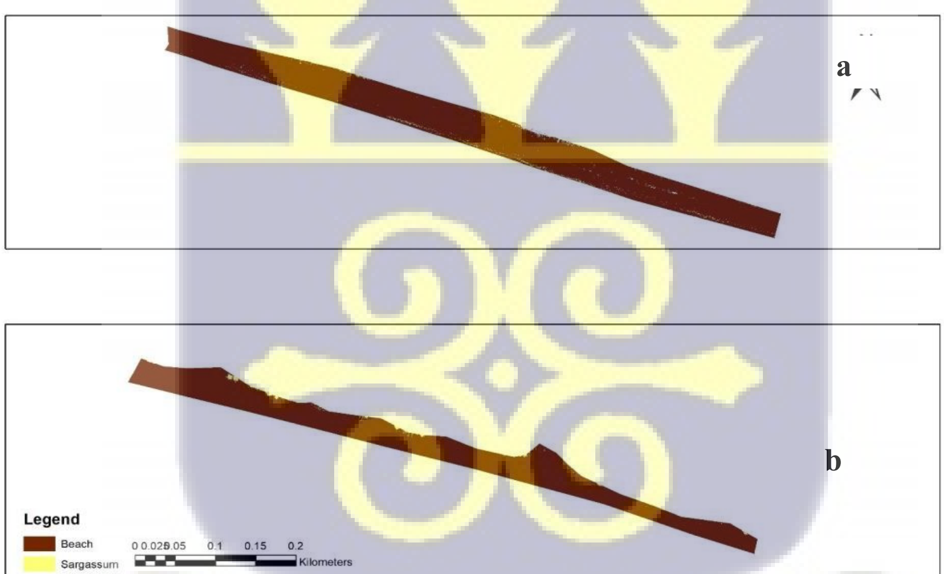

Figure 8: Map of Sargassum beaching in Esiama in the year 2022 (September (a), October (b))

Sanzule recorded a similar pattern of variation as shown in Figures 9 and 10. Relatively higher Sargassum coverage was observed in September and October 2021 (Figure 9a and b), followed by a noticeable decrease in October 2022 (Figure 10). There was no field visit in September 2022 due to technical challenges.

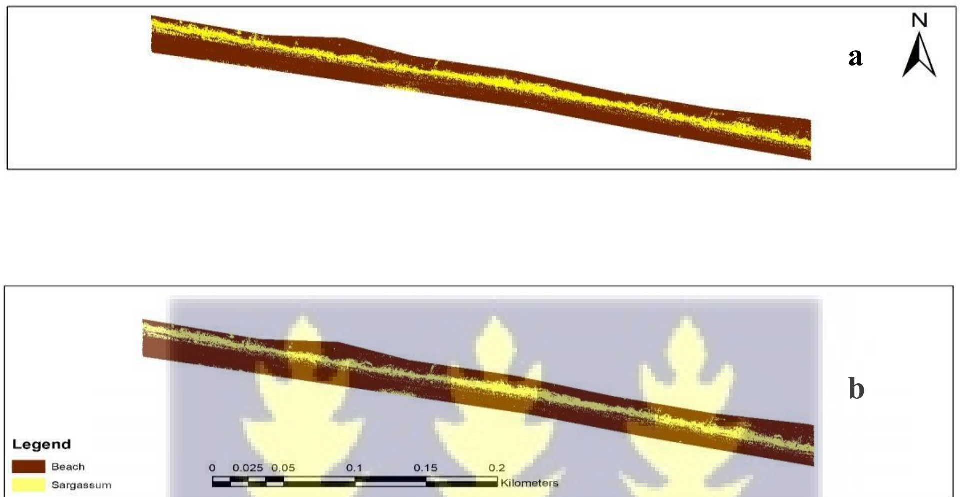

Figure 9: Sargassum beaching pattern observed in Sanzule in the year 2021 (September (a), October (b))

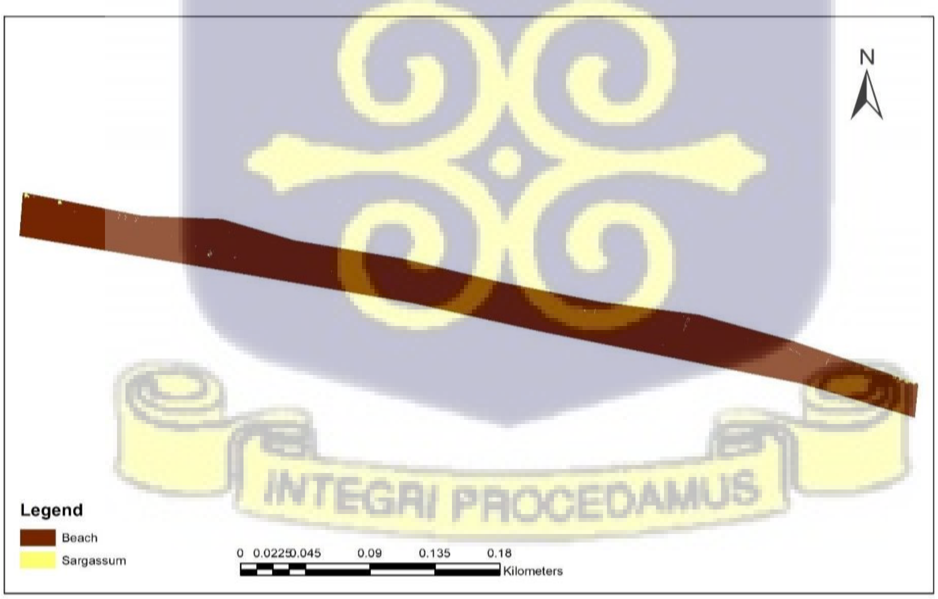

Figure 10: Pattern of Sargassum beaching observed in Sanzule in the year October 2022

As stated earlier, the observed trend shows a general decline in Sargassum beaching from 2021 to 2022 in all three communities (see Table 1). While Beyin and Esiama experienced high levels in 2021, 2022 recorded smaller accumulations. No Sargassum beaching was recorded in 2023, indicating an interannual variation in influx intensity likely linked to oceanographic and climatic factors.

Table 1: Estimated Area and Volume of Sargassum Beaching in the study

Town	Month	Area (m^2)	Volume (m^3)
Beyin	September 2021	16,845	7,386
	October 2021	15,861	6,982
	September 2022	14,772	5,732
	October 2022	13,662	4,893
Esiama	September 2021	29,865	24,732
	October 2021	29,321	24,242
	September 2022	27,692	22,154
	October 2022	15,272	12,218
Sanzule	September 2021	21,688	10,844
	October 2021	19,726	9,863
	September 2022	No data	No data
	October 2022	15,202	7,601

The observed trend of *Sargassum* beaching along the three study sites on the western coast of Ghana shows a consistent decline in both area and volume from 2021 to 2022 (Figure 11). However, no beaching was observed in September and October 2023 across the sites.

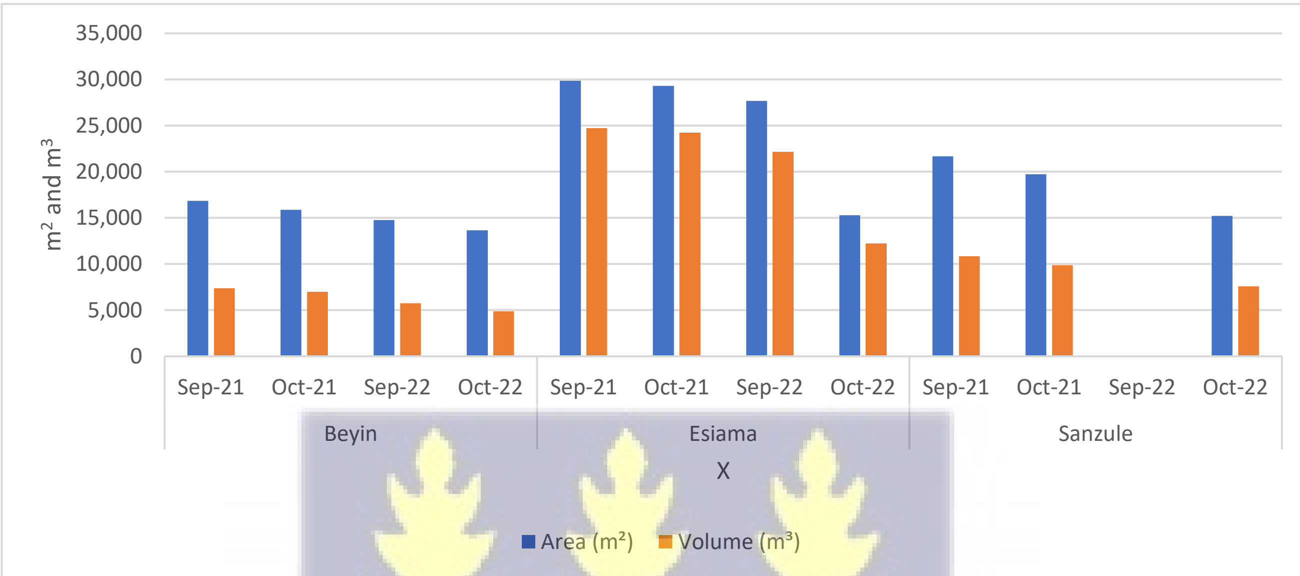

Figure 11: Area and Volume of Sargassum Beaching in the Three Study Towns

Table 2 provides summary statistics for the area and volume of *Sargassum* beaching. The mean and standard deviation give an idea of the average and spread of the data, respectively. The minimum and maximum values indicate the extreme values observed. The quartiles divide the data into four equal parts, providing insights into the distribution of the data.

The correlation coefficient of 0.924 shows a strong positive correlation between the area and volume of Sargassum beaching. This suggests that larger areas of *Sargassum* are generally associated with larger volumes.

Table 2: Descriptive Statistics and Correlation Analysis of Sargassum Beaching Area and Volume

Statistic	**Area (m²)**	**Volume (m³)**
Mean	17,153.33	11,387.25
Standard deviation	9,293.64	8,068.67
Minimum	0	0
Maximum	29,865.00	24,732.00
25th percentile (Q1)	13,248.00	6,669.50
50th percentile (median)	16,353.00	8,732.00
75th percentile (Q3)	23,189.00	14,702.00
Correlation coefficient (area, volume)	0.924	

4.1.1 Accuracy Assessment Outcomes for Classified *Sargassum*

The accuracy assessment for classifying *Sargassum* was reported to be 74%. It was noted that this relatively low percentage could be attributed to the limited presence of *Sargassum* on the beach during the time of validation. The scarcity of *Sargassum* likely reduced the sample size of *Sargassum* on the beach and the likelihood of them being well-segmented, which may have affected the overall accuracy of the results. However, this does not undermine the results of the study.

4.2 Socio-demographic Characteristics of Respondents Administered Questionnaire

The demographic profile of the participants in this study indicated a population with a diverse range of age groups, towns, gender, educational backgrounds, occupations, household sizes, and lengths of stay in their respective communities (Table 3).

Geographically, the participants are distributed across three key towns: Beyin (30.5%), Esiama (33%), and Sanzule (36.5%), reflecting a balanced representation across these areas. Gender-wise, the sample is predominantly male, with 65.7% of the participants identifying as male, while 32.5% are female. This gender distribution highlights a significant male majority in the sample.

The age demographics of the participants reveal that half (50%) are within the 18-30 age range, making this the largest group. Those aged 31-45 constitute 32% of the participants, while 12% are between 46-60 years old. The smallest group, those over 60, accounts for 6% of the total sample.

Educational level attainment among the participants is predominantly low, with nearly half (46%) having no formal education. A significant portion, 35%, has completed only primary school, and 15% have reached the secondary school level. A small minority, 4%, have attained tertiary education, and none of the participants hold a postgraduate degree.

Study participants are predominantly engaged in fishing-related activities, with 50% identifying as fishermen and 31% as fishmongers. Other occupations are less common: 5% are self-employed, 6% are students, and 3% are unemployed. A negligible proportion, 2%, are teachers, while none are engaged in office work or artisanal trades. Additionally, 3% of the participants are involved in other unspecified occupations.

The household sizes in the study vary, with the majority, 54%, living in households consisting of 3-4 members. Households with 5-6 members make up 23% of the sample, while 15% of participants reside in smaller households with 1-2 members. A minority, 5%, live in larger households with more than six members.

In terms of the period of stay in their communities, 30% of participants have lived in their communities for more than 20 years, indicating a strong sense of community attachment and stability. Another 26% have resided in their communities for 6-10 years, and 19% have been there for 11-15 years. Participants who have lived in the community for 16-20 years make up 18% of the sample, while those with the shortest tenure, 1-5 years, account for 7%.

Table 3: Population characteristics of participants in the study

Description	Variable	Percentage
Towns	Beyin	30.5
	Esiama	36.5
	Sanzule	33
Gender	Male	67.5
	Female	32.5
Age	18-30	50
	31-45	32
	46-60	12
	Over 60	6
Educational Level [Completed]	None	46
	Primary School	35
	Secondary School	15
	Tertiary Education	4
	Postgraduate	0

Occupation	Fisherman	50
	Teacher Self-	2
	employed	5
	Fishmonger	31
	Student	6
	Office Work	0
	Unemployed	3
	Artisan	0
	Other	3
Length of stay in the community	1-5 years	7
	6-10 years	26
	11-15 years	19
	16-20 years	18
	More than 20 years	30

4.2.1 Socio-demographic data on focus group discussion participants

Seven participants were interviewed across Beyin, Esiama, and Sanzule (representing a critical segment of the local coastal population). These participants play various roles within the fishing industry, as chief fishermen, with extensive experience within their communities (Table 4). Twenty per cent (20%) were categorized as fishermen, reflecting the traditional, hands-on engagement with the fishing trade. Additionally, 5% of the participants worked as boat repairers, a crucial support role that ensures the maintenance and functionality of the fishing fleet. The remaining participants held roles outside of direct fishing activities but within the broader coastal economy: 10% were fishmongers, involved in the critical post-harvest handling and sale of fish, and 15% were hotel managers.

Educational attainment among these participants was notably low. A significant majority, 75%, had no formal education, and the remaining 25% had achieved some level of educational attainment, though specific levels were not detailed. This disparity in educational backgrounds reflects broader trends within the region, where traditional skills and occupations often take precedence over formal education.

Table 4: Data on the position and education levels of key office holders in the study towns

Town	Gender	Occupation	Education level completed
Beyin	Male	Chief Fisherman	Primary School
	Male	Assist. Chief Fisherman	No Education
	Female	Fishmonger	No Education
	Male	Fisherman	Secondary School
	Female	Hotel manager	Secondary School
	Male	Boat Repairer	Primary School
	Male	Fisherman	No Education
Esiama	Female	Fishmonger	No Education
	Female	Fishmonger	No Education
	Male	Fisherman	No Education
	Male	Chief Fisherman	Primary Education
	Male	Fisherman	No Education
	Female	Hotel manager	Tertiary Education
	Female	Hotel manager	Secondary Education

Sanzule	Male	Chief Fisherman	No Education
	Male	Assist. Chief Fisherman	No Education
	Male	Fisherman	No Education
	Male	Fisherman	No Education
	Male	Boat Repairer	No Education
	Male	Hotel Manager	Secondary Education
	Female	Fishmonger	Primary Education

4.3 Assessing the Impacts of *Sargassum* Beaching on the Livelihoods in Coastal Communities.

4.3.1 Environmental Impacts of *Sargassum* Beaching

Participants were interviewed to explore their perceptions of the environmental impacts associated with Sargassum beaching. *Sargassum* beaching is known to come with environmental impacts, particularly in terms of odor, pollution, and the disruption of activities. As *Sargassum* accumulates and decomposes on shorelines, it emits a strong, unpleasant odor due to the release of hydrogen sulfide gas. This foul smell not only affects the quality of life for residents and visitors but also contributes to air pollution, making coastal areas less appealing and potentially harmful. One focus group participant shared, *"The weeds smell so badly that we can hardly breathe, especially those of us on the shoreline,"* while another added, *"The weeds have a bad odor, and when the waves hit, it's very bad."* These comments highlight the pervasive and detrimental effect of the odor on daily life in affected areas. One participant lamented, *"Children cannot do any of these (play football, swim) because of the weeds*, while another expressed their frustration, stating, *"It's very* *disgusting and smells very bad."* These reflections emphasize the profound impact of *Sargassum* on the daily activities and overall well-being of coastal communities.

The bar graph (Figure 12) shows the percentage of responses on the effects of *Sargassum* influx on the environment. The influx of *Sargassum* has raised significant concerns among respondents regarding its potential negative impacts on coastal ecosystems and local communities. A significant portion of respondents (85.1%) expressed worry about the negative impact on the local fishing industry. Additionally, 6.7% expressed concern about the potential disruption of biodiversity and ecosystem functionality, while 3.6% acknowledged the direct impact on marine life. Furthermore, 1.5% identified altered water quality as a potential concern. Surprisingly, a small percentage of respondents (0.5%) admitted to having no idea about the impacts of Sargassum influx on the environment.

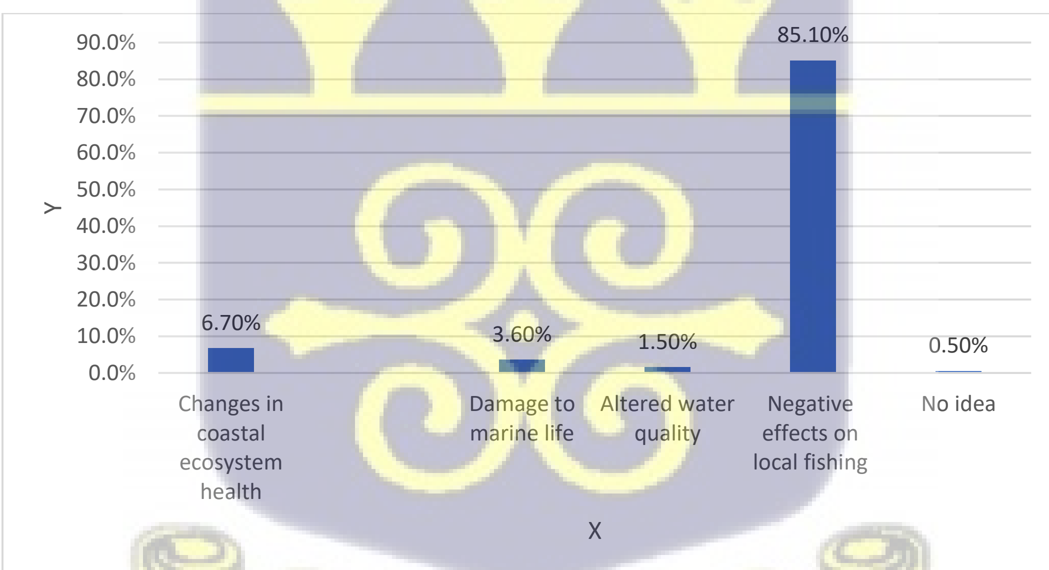

Figure 12: Distribution of responses on the effects of Sargassum influx on the environment of Respondents

4.3.2 Economic Impacts of *Sargassum* Beaching

The beaching of *Sargassum* has significant economic impacts on coastal communities, particularly affecting their livelihoods. The accumulation of *Sargassum* along shorelines disrupts local economies, leading to a loss of fishing income as fishermen struggle with entangled nets and reduced fish stocks in affected areas. One focus group participant highlighted this struggle as captured below:

> *"My father for instance has a boat, he can buy petrol to go fishing and return with Sargassum instead of fish."*

This situation underscores the immediate financial strain on families dependent on fishing, as their once-reliable source of income becomes increasingly unpredictable. The inability to catch fish not only impacts individual fishermen but also affects their families and the wider community, leading to increased economic vulnerability. As Sargassum continues to accumulate, it not only threatens the sustainability of local fisheries but also exacerbates poverty levels, forcing families to seek alternative income sources that may not provide adequate support. The decline in fishing activity further contributes to reduced market revenue, as the availability of fresh seafood diminishes, impacting local markets and businesses reliant on the sale of these goods. The economic downturn caused by *Sargassum* beaching often leads to job loss, particularly in sectors directly linked to fishing and tourism. As businesses experience financial strain, they may be forced to reduce their workforce or shut down entirely. This cascading effect creates financial strain not only on individuals but on the broader community, as reduced income affects spending power and local economic circulation.

Furthermore, many affected communities face inadequate support from government or external agencies, leaving them to bear the brunt of these economic challenges with limited resources. One participant expressed frustration with the lack of official response:

"We have not heard of any announcements concerning plans to manage the weeds."

The absence of sufficient financial aid, infrastructure support, or effective management strategies exacerbates the economic vulnerability of these communities, deepening the impact of *Sargassum* beaching on their livelihoods.

The survey data revealed a diverse range of perspectives on the potential impact of the sargassum influx on tourism in affected areas, with a clear majority of 49.23% of respondents asserting that they believe the phenomenon contributed to a decline in tourism (Figure 13). Conversely, 23.59% of respondents expressed a contrasting viewpoint, firmly stating that they do not believe the sargassum influx has played a role in the observed decline in tourism. In the midst of these polarized opinions, a significant portion of the surveyed individuals, comprising 27.18%, remains uncertain about the connection between sargassum and the decline in tourism.

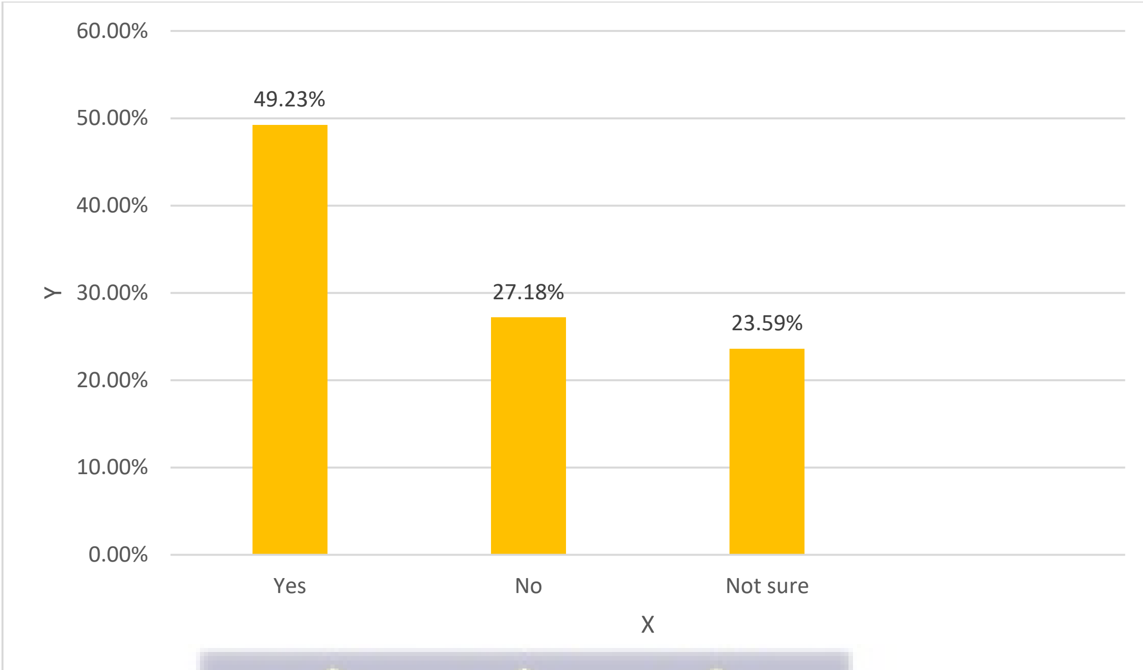

Figure 13: Respondents' perception of the effect of Sargassum beaching on tourism in the study communities

The bar chart (Figure 14) shows the percentage of responses on the impacts of *Sargassum* influx on their Local Economy and Livelihood. The survey data illuminates the profound impact of the *Sargassum* influx on the local economy and livelihoods of respondents, unveiling a range of challenges that have manifested in various sectors. The majority of respondents, represented by 80.51% underscore a significant concern: a considerable decrease in income for fishermen. Additionally, 6.67% of respondents highlighted the issue of limited access to coastal resources. The survey also revealed that 5.13% of respondents reported a reduced income for businesses catering to tourists.

Furthermore, 3.08% of respondents identified a loss of jobs in tourism-related industries. The financial burden associated with the *Sargassum* influx is further emphasized by 2.56% of respondents, who noted an increased cost of cleaning and removal.

A smaller number of respondents, accounting for 0.51%, highlighted the dual impact of *Sargassum* on both fishermen and food vendors, resulting in income loss. In the midst of these challenges, it is noteworthy that 1.54% of respondents expressed uncertainty, indicating a lack of clarity or awareness regarding the specific economic ramifications of the *Sargassum* influx.

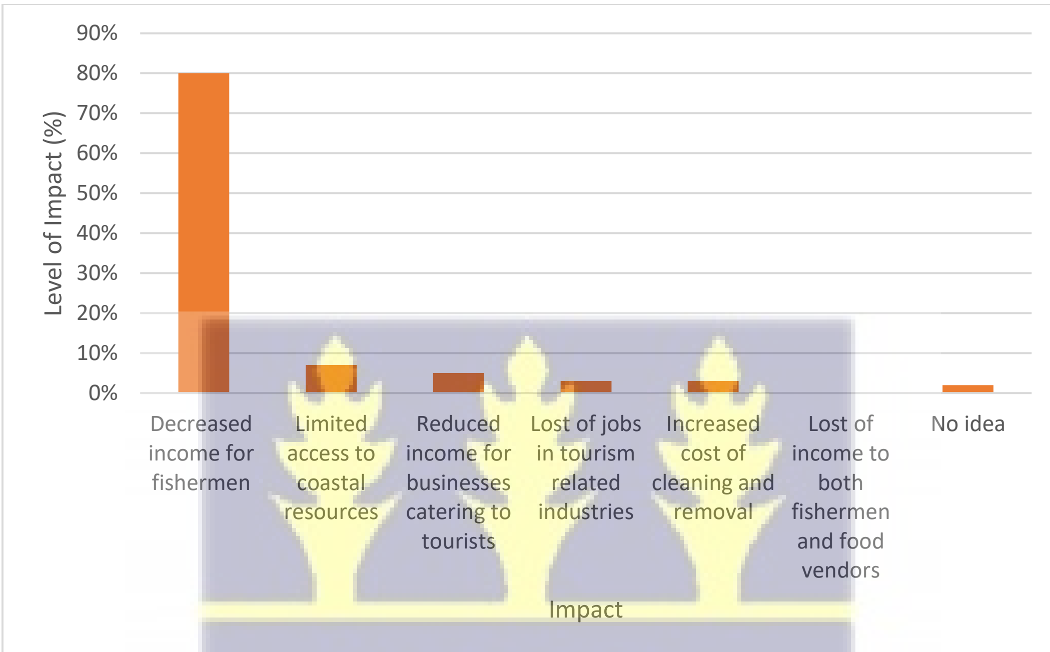

Figure 14: Respondents' perception of the effect of Sargassum beaching on the local economy and livelihood in the study communities

4.4.3 Health Impacts

The beaching of *Sargassum* poses significant health risks to coastal communities, particularly through respiratory issues and skin problems, according to the U.S. Environmental Protection Agency (EPA, 2024). One focus group participant vividly described the impact: *"The bad smell from the weeds makes me want to vomit,"* while another shared, *"I get a runny nose frequently, which I was not experiencing before."* These comments highlight the immediate and distressing effects of Sargassum on respiratory health.

In addition to respiratory issues, direct contact with decomposing *Sargassum* can result in skin problems (EPA, 2024). A participant mentioned, *"My younger sibling has developed skin rashes which he was not experiencing previously,"* illustrating the potential for new health issues arising from contact with *Sargassum*. Another participant emphasized the discomfort caused by the seaweed: *"The weeds are very itchy in nature. When one comes into contact with it, it is very itchy."* These personal accounts underscore the broader health challenges faced by communities dealing with the persistent presence of Sargassum on their shores.

The pie chart (Figure 15) shows the percentage of responses on the impacts of *Sargassum* influx on their Health. The influx of *Sargassum* has been linked to a range of health issues among respondents. The most commonly reported symptom was skin itchiness, affecting 17.71% of individuals, followed by respiratory infections in 7.29% of respondents. Eye itchiness was noted by 3.13% of the population, while fever was reported by 2.08%, and malaria by 1.04%. Additionally, 3.13% of respondents experienced fluid-related symptoms. Despite these concerns, a significant majority of 65.63% did not report any discernible health effects.

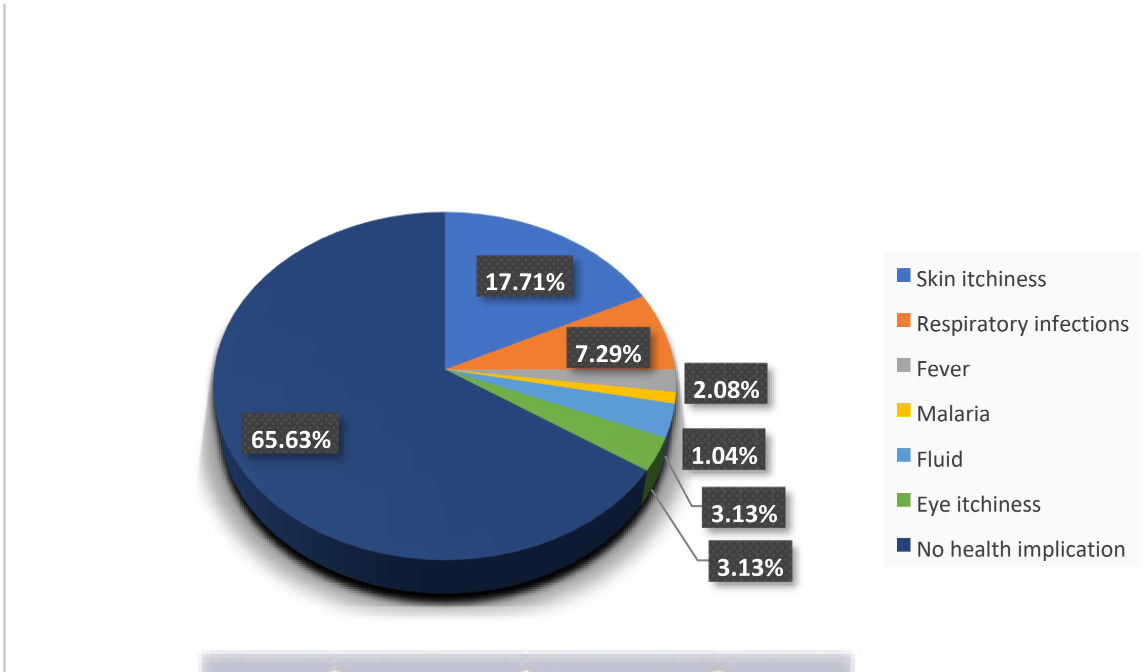

Figure 15: Respondents' perception of the effect of Sargassum beaching on health in the study communities

4.4 Evaluating Community Management Strategies for the Impacts of *Sargassum* Invasion on Socio-Economic Livelihood.

A participant mentioned, *"A group of people were assigned to clean up the beach,"* highlighting the organized efforts within communities to address the problem. Another added, *"They give allowances for cleaning,"* indicating that there is some level of support and compensation for those involved in these labor-intensive efforts.

From the survey, 63% of respondents expressed their adoption of the sweeping and burning strategy to address the *Sargassum* issue. On the other hand, 37% of respondents favor the burying strategy, which entails collecting the Sargassum and depositing it in designated pits or trenches.

In gauging the community's awareness of the uses of *Sargassum*, the study revealed distinct trends. The responses indicate a varying degree of familiarity with the potential applications of this seaweed, with 16% of respondents affirming their awareness and 84% reporting a lack of knowledge in this regard.

The influx of *Sargassum* has had a significant negative impact on coastal communities, affecting their environment, economy, and health**.** The study revealed that *Sargassum* beaching has caused environmental problems such as odor pollution and disrupted daily activities. Economically, it has negatively impacted the fishing industry, tourism, and local livelihoods. Additionally, *Sargassum* has posed significant health risks to coastal residents, leading to respiratory issues and skin problems. These findings highlight the urgent need for effective management strategies to mitigate the detrimental effects of Sargassum on coastal communities.

CHAPTER FIVE

DISCUSSION

This study explored the role of geographical information systems and remote sensing tools in examining the beaching trend of Sargassum and its impacts on livelihoods. Findings revealed that the area and volume of Sargassum reduced over the three-year period, with no recorded strands in 2023, and that the influx had a negative impact on the livelihoods of several coastal communities. This section discusses these findings in relation to the objectives of the study and previous research.

5.1 Trend of Beaching of Sargassum in the Western Region of Ghana

The observed trend of *Sargassum* beaching along the western coast of Ghana indicates a noticeable decline in both area and volume of the seaweed across all three study sites, Beyin, Esiama, and Sanzule, from 2021 to 2022. At Beyin, a 19% reduction in area and a 34% decrease in volume were observed, indicating a significant drop in the overall mass of *Sargassum* arriving on the beach. Similarly, Esiama experienced nearly a 50% drop a much larger decline with the area reducing from 29,865 m² in September 2021 to 15,272 m² in October 2022. The volume also halved, falling from 24,732 m³ to 12,218 m³. The steep decline at this site might reflect localized environmental factors that influenced the amount of *Sargassum* landing.

In Sanzule, a comparable pattern emerged, where the beaching area decreased from 21,688 m² in September 2021 to 15,202 m² in October 2022. The volume similarly decreased, from 10,844 m³ to 7,601 m³, representing a 30% reduction in area and about 30% in volume.

This reduction suggests a lessening intensity of *Sargassum* influx within the region during this period, potentially linked to shifts in oceanographic conditions, nutrient availability, or changes in wind and current patterns that drive Sargassum movement.

These findings align with those of Hu et al. (2016) and Wang et al. (2019), who noted that interannual variability in *Sargassum* abundance is strongly influenced by sea surface temperature changes, nutrient enrichment, and wind-driven circulation in the tropical Atlantic. The observed decline between 2021 and 2022 corresponds with reduced upwelling intensity and weaker current transport along Ghana's western coastline, conditions similar to those described by Fidai et al. (2020) and Marsh et al. (2021).

The complete absence of *Sargassum* beaching across all sites in 2023 is particularly noteworthy, suggesting a major shift in the dynamics of *Sargassum* influx. This absence may be attributed to various factors, such as changes in wind and current regimes, nutrient depletion in the waters, or a redistribution of *Sargassum* rafts. This finding has significant implications for coastal communities, as it could lead to temporary relief from the economic and environmental burdens associated with Sargassum beaching.

The trend analysis of *Sargassum* beaching from 2021 to 2023 across the study sites revealed a significant decline in *Sargassum* influx, culminating in its complete absence in 2023. This finding suggests changes in oceanographic conditions that have likely influenced *Sargassum distribution*. The absence of beaching in 2023 could signal a temporary shift in the influx, aligning with previous studies that noted fluctuating *Sargassum* dynamics based on environmental factors (Hu et al., 2016; Suida et al., 2016). This trend adds new insight into *Sargassum* beaching in Ghana, particularly regarding the factors leading to its abrupt reduction.

This finding corroborates local reports from fishermen in Axim and Beyin, who observed that "some years are worse than others." The evidence thus supports the notion of interannual variability in *Sargassum* arrival, making Ghana's coastal experience consistent with the broader Atlantic *Sargassum* cycle described by Johns et al. (2020).

5.2 Impacts of Sargassum Beaching on Livelihood

An analysis of the survey data reveals the multi-dimensional challenges coastal communities face due to *Sargassum* influx—spanning environmental degradation, socio-economic difficulties, and health implications. These findings echo earlier studies that have documented the severity of Sargassum impacts across the Caribbean and West Africa (Hu et al., 2016; Suida et al., 2016).

Similar to observations by Suida et al. (2016) and van Tussenbroek et al. (2018), the data highlight that coastal eutrophication caused by the decomposition of *Sargassum* can degrade nearshore ecosystems, affecting seagrass and coral communities. As such, the environmental impacts discussed in the literature are strongly reflected in the survey responses of affected community members.

One significant environmental impact of *Sargassum* beaching identified in the survey is the release of hydrogen sulfide gas during the decomposition process, causing a foul odor that hampers daily life and tourism in affected areas. This finding aligns with those of Chavez et al. (2020), who noted that *Sargassum* beaching emits toxic gases like hydrogen sulfide and ammonia, which irritate the respiratory system and contribute to the deterioration of living conditions along the coast. Survey respondents expressed discomfort with the foul odor, similar to observations made by UNEP (2018), which documented how unpleasant smells from *Sargassum* drive tourists away, further compounding the economic strain on tourism-dependent communities.

Additionally, the disruption of daily activities, such as beach games and swimming, due to large piles of decomposing *Sargassum* was a common concern among survey participants. As described by Chavez et al. (2020) and UNEP (2018), *Sargassum* mats not only impact recreational activities but also contribute to the decline of tourism by making the coastal environment unattractive. In particular, a 35% drop in tourism in Mexico due to *Sargassum* has been reported (UNEP, 2018), and the survey respondents' concerns about tourism decline in this study mirror this trend. The effect on tourism is also reflected in the frustration expressed by respondents, as they reported the difficulty of sustaining tourism-related activities, echoing findings by CAST (2015).

Beyond the environmental impacts, the survey revealed that the livelihoods of local fishermen are severely affected by *Sargassum* beaching. Fishermen reported significant declines in income due to the frequent entanglement of fishing nets in the Sargassum, a problem also observed by Sowah et al. (2022) in Ghana, who highlighted that financial losses in the fishing industry are linked to the damage caused by *Sargassum* on nets and outboard motors. Similar to the findings of Nunoo et al. (2014), which underscore the reliance of coastal communities on fishing as a primary source of income, the fishermen in this study also experienced a reduction in catch size, leading to economic hardship.

5.2.1 Environmental Impacts

The environmental impacts of *Sargassum* beaching identified in the literature relate favorably with the survey results. The accumulation and subsequent decomposition of *Sargassum* lead to beach erosion, fouling, and the death of seagrass and mangrove seedlings, as highlighted by Suida et al. (2016) and van Tussenbroek et al. (2018). These environmental effects are compounded by the disruption of the local benthic community and the alteration of food webs, as noted by Robledo et al. (2021).

Survey respondents mentioned the negative impacts on water quality and ecosystem health, which mirror the findings of Suida et al. (2016), who discussed how *Sargassum* decomposition leads to nutrient overloading and coastal eutrophication. The survey responses also revealed growing concern about biodiversity loss, particularly in relation to marine life entanglement and habitat destruction, which aligns with the findings of Maurer et al. (2015).

For instance, the destruction of nesting sites for sea turtles due to large *Sargassum* mats, as described in Maurer et al.'s study, was also reflected in some participants' concerns about marine wildlife. This indicates that Sargassum beaching not only affects human activities but also poses a serious threat to marine ecosystems, a concern echoed in the broader literature.

Furthermore, the alteration of water quality due to the release of organic matter from decomposing *Sargassum* has been identified as a critical issue by some survey respondents. While this concern was mentioned by only a small percentage of participants, the issue is well-documented in the literature. Studies such as those by Chavez et al. (2020) and Robledo et al. (2021) have shown that *Sargassum* can lead to harmful algal blooms and other water quality issues, which, over time, could have severe consequences for both marine life and human populations reliant on coastal waters for fishing and recreation.

These environmental issues are consistent with observations in Ghana by Fidai et al. (2020), who reported that decaying *Sargassum* along Axim and Beyin coasts led to temporary loss of fish landing sites and nearshore habitat degradation. Hence, the ecological consequences of *Sargassum* are evident both globally and locally.

5.2.2 Economic Impacts

The economic repercussions of *Sargassum* beaching were emphasized by a majority of survey respondents, particularly in relation to the fishing and tourism industries. The loss of income for fishermen due to the entanglement of nets and the reduced availability of fish is consistent with findings from studies in the Caribbean and West Africa (Sowah et al., 2022; UNEP, 2018). Fishermen's livelihoods are highly sensitive to disruptions in their activities, and *Sargassum* influxes have made it increasingly difficult for them to maintain their operations.

This is particularly concerning given the dependence of coastal communities on artisanal fisheries, as noted by the FAO (2022), which found that 80% of Ghana's fisheries workforce is employed in the artisanal sector.

The implications are far-reaching: lower catches mean less household income and reduced capacity to invest in fishing gear or maintain boats. This downward cycle of productivity and poverty mirrors similar findings by Oxenford and Franks (2015), who reported comparable trends among small-scale fishers in Barbados.

Tourism, another critical sector for coastal economies, has also been severely impacted by the influx of *Sargassum*. Survey participants highlighted how the unattractive appearance of *Sargassum*-covered beaches and the strong odor of decaying seaweed have led to a noticeable decline in tourist arrivals. This aligns with Chavez et al. (2020), who reported a significant reduction in tourism across the Caribbean due to *Sargassum* beaching. Vacation cancellations, room closures, and a general drop in tourist activity were also reported in CAST (2015), emphasizing the direct link between Sargassum influx and economic downturns in tourism-dependent regions.

Moreover, the increased costs associated with the removal of *Sargassum* from beaches were identified by some respondents as a financial burden on local governments and communities. This observation supports UNEP (2018) findings that significant resources are required to maintain beach cleanliness, further straining the budgets of coastal municipalities. These increased maintenance costs, coupled with reduced revenue from fishing and tourism, create a challenging economic landscape for affected communities.

5.2.3 Health Implications

Health impacts resulting from *Sargassum* beaching are significant yet varied among coastal communities. The survey indicated that about 18% of respondents experienced skin itchiness, a direct result of contact with decomposing seaweed, which aligns with Chavez et al. (2020) and Robledo et al. (2021) findings on physical discomfort caused by *Sargassum* accumulation.

Additionally, respiratory infections reported by 7% of respondents correspond to the literature's emphasis on the inhalation of toxic gases released during *Sargassum* decomposition, which can exacerbate respiratory conditions (Chavez et al., 2020; Robledo et al., 2021).

Eye irritation, reported by 3% of respondents, further illustrates the direct health hazards posed by *Sargassum*, although less prevalent than other symptoms. The occurrence of more severe health issues like fever and malaria, albeit reported by smaller percentages (2% and 1% respectively), may be indirectly linked to environmental changes caused by *Sargassum*, such as stagnant water providing breeding grounds for mosquitoes, as suggested by Chavez et al. (2020).

Interestingly, about 66% of respondents did not report any health effects, which might indicate variability in exposure levels or individual health conditions. This discrepancy highlights the need for targeted public health interventions to address the specific health risks associated with *Sargassum* beaching, as emphasized by Suida et al. (2016).

These health findings emphasize the importance of including *Sargassum*-related issues in Ghana's coastal public health programs. Collaboration between the Ghana Health Service and the Environmental Protection Agency could help monitor hydrogen sulfide emissions and advise coastal residents on exposure prevention.

5.3 Community Management Strategies for the Impacts of Sargassum Invasion

The survey revealed diverse management strategies adopted by coastal communities to mitigate *Sargassum* impacts, predominantly favoring sweeping and burning (63%) over burying (37%). This preference reflects the immediate need for visible cleanliness and health safety, as sweeping quickly removes *Sargassum* from beaches, aligning with the urgent response strategies suggested by Chavez et al. (2020) and UNEP (2018).

However, sweeping and burning have significant environmental drawbacks, including air pollution and soil degradation from ash, concerns raised in the literature by Chavez et al. (2020) and Robledo et al. (2021). These environmental implications necessitate a careful evaluation of this strategy to balance immediate relief with long-term sustainability.

Conversely, the burying strategy, preferred by 37% of respondents, offers a more environmentally friendly approach by allowing natural decomposition and nutrient recycling. This method aligns with sustainable management practices discussed by Chavez et al. (2020), which advocate for eco-friendly solutions to *Sargassum* disposal. However, the practicality of burying depends on adequate resources and infrastructure, a challenge noted in both the survey and literature.

The diverse coping strategies underscore the need for comprehensive management plans that incorporate both immediate and sustainable responses. Caribbean Alliance for Sustainable Tourism (CAST, 2015) and UNEP (2018) recommend integrated approaches that combine effective removal methods with initiatives to recycle *Sargassum* into valuable products, such as biofuels or fertilizers, as explored by Chavez et al. (2020) and exemplified by Algas Organics (Speede et al., 2024).

For Ghana, these findings imply that coastal municipalities could partner with research institutions to develop low-cost composting and biogas pilot projects using *Sargassum*. Such collaboration would align with the Ministry of Environment's circular economy agenda and create employment opportunities for youth in coastal towns.

5.3.1 Community Awareness of the Uses of Sargassum

A significant knowledge gap exists regarding the potential uses of *Sargassum*, with only 16% of survey respondents aware of its applications. This low level of awareness highlights a critical area for intervention, as discussed by Chavez et al. (2020) and UNEP (2018), who emphasize the importance of community education in transforming *Sargassum* from a nuisance into a resource.

The lack of awareness can be attributed to several factors, including limited access to information, socio-economic constraints, and insufficient educational outreach, as identified in the survey and supported by Chavez et al. (2020). Addressing this gap requires targeted strategies, such as community workshops, demonstration projects, and integration of *Sargassum* utilization into local education curricula, aligning with the recommendations of Chavez et al. (2020) and UNEP (2018).

Increasing community awareness can unlock economic opportunities by promoting the recycling and reuse of Sargassum for various applications, as demonstrated by Algas Organics (Speede et al., 2024). By educating residents on the benefits and methods of utilizing *Sargassum*, communities can diversify their livelihoods and reduce the environmental burden of *Sargassum* beaching, as advocated by Chavez et al. (2020) and supported by the survey findings.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The mapping of *Sargassum* beaching in the chosen localities between 2021 and 2023 revealed a significant decrease in both area and volume, with 2023 recording no visible beaching. This pattern suggests that Sargassum influx dynamics may have shifted due to changes in oceanographic or environmental conditions such as sea surface temperature, current direction, and nutrient levels. These findings confirm the usefulness of GIS and remote sensing as effective tools for monitoring and visualizing *Sargassum* movement and spatial extent in Ghana's coastal zone.

The *Sargassum* beaching had a major effect on the livelihoods of coastal residents, disrupting fishing and reducing tourism-related income. The burden on residents was further worsened by health problems—mainly skin and respiratory disorders—resulting from prolonged exposure to decomposing *Sargassum*. These outcomes highlight the interconnection between environmental degradation and socio-economic wellbeing in coastal ecosystems.

The community management measures identified in the study offered only temporary relief and mostly relied on manual removal techniques such as sweeping and burning. Although these approaches provide short-term cleanliness, they pose long-term environmental risks, including air pollution and soil contamination. Sustainable methods such as composting, burial, and reuse of *Sargassum* remain underutilized despite their potential to reduce ecological impacts and create alternative livelihood opportunities.

Overall, the study demonstrates that while Ghanaian coastal communities have shown resilience and adaptability, institutional and technical support are essential to transform *Sargassum* from an environmental nuisance into an economic resource.

6.2 Recommendations

Based on the findings, the study recommends the development and implementation of monitoring programmes by Universities and research organizations to support accurate *Sargassum* mapping, detection, and prediction using satellite imagery, drones, and GIS models. This will support early warning systems to alert coastal populations of potential influxes. Partnerships with institutions such as the Ghana Meteorological Agency and the Fisheries Commission could improve predictive accuracy.

Furthermore, the Ministries of Fisheries, Agriculture, and Health, together with non-governmental organizations should support coastal communities with training, resources, and alternative livelihood programs. Initiatives could include *Sargassum*-based composting, aquaculture, and eco-tourism ventures. Health interventions should also focus on mitigating respiratory and skin ailments linked to exposure.

Government agencies such Environmental Protection Agency (EPA), NGOs, and local authorities should collaborate to develop and enforce policies addressing the economic, environmental, and health impacts of *Sargassum* beaching. The framework should emphasize sustainable waste management, research funding, and community participation. They can promote the conversion of *Sargassum* into valuable products such as organic fertilizers, biofuels, animal feed, and compost. This will create economic opportunities while reducing environmental pollution, aligning with Ghana's circular economy agenda.

Finally, it is crucial to raise public awareness on *Sargassum* management. To ensure long-term environmental benefits, local authorities, NGOs, and schools should encourage community involvement through education campaigns, workshops, and coastal cleanup programs that promote sustainable practices and reduce negative perceptions of *Sargassum*.

6.3 Directions for Future Studies

Future research should focus on exploring the underlying environmental and oceanographic drivers behind the observed reduction in Sargassum influx, including possible links to changes in sea temperature, current circulation, and nutrient availability.

To assess health impacts, long-term epidemiological studies have to be initiated to evaluate the health effects of *Sargassum* exposure on coastal populations, particularly respiratory and dermatological conditions, to inform coastal health policy and preparedness.

Studies should Assess the effectiveness and scalability of sustainable *Sargassum* management options such as composting, biofuel production, and material reuse to optimize their implementation in Ghana's coastal communities and minimize ecological risks.

Policy-Oriented Studies: Examine the role of national and local policy frameworks in facilitating or constraining *Sargassum* management efforts, and propose evidence-based strategies for improved governance and community participation.

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APPENDICES

APPENDIX A: QUESTIONNAIRE

This questionnaire is designed for coastal residents in Beyin, Esiama and Sanzule to assess the impacts of beaching of *Sargassum* on their livelihood. The questionnaire is divided into two sections. Section A is made up the demographics of residents and questions to assess the impacts of Sargassum Beaching on their livelihoods consisting of their economic income, social life, health and their environment. The second part which is the Section B establishes the management practices for the beaching of *Sargassum*.

Section 1: Demographic Information

1. Gender:
   a. Male
   b. Female

2. Age:
   a. Under 18
   b. 18-30
   c. 31-45
   d. 46-60
   e. Over 60

3. Education Level:

a. None

b. Primary School

c. Secondary School

d. Tertiary Education

e. Postgraduate

4. Occupation:

a. Fisherman

b. Teacher

c. Self-employed

d. Fishmonger

e. Student

f. Office Work

g. Unemployed

h. Artisan

i. Other (Please specify: ______)

5. Household size:

a. 1-2 members

b. 3-4 members

c. 5-6 members

d. More than 6 members

6. Residential location:

7. Length of stay in community?

   a. 1-5 years
   b. 6-10 years
   c. 11-15 years
   d. 16-20 years
   e. More than 20 years

Section 2: Awareness and Experience of Sargassum Influx

7. How would you describe your understanding of "Sargassum influx"?

   a. Excellent
   b. Very Good
   c. Good
   d. Poor

9. Have you personally witnessed or experienced sargassum influx in your community?

   a. Yes
   b. No

10. If no, we terminate the questionnaire here. Thank you for your time.

11. If yes, how frequently does sargassum influx occur in your community?

a. Daily
b. Weekly
c. Monthly
d. Quarterly
e. Annually

Section 3: Effects of Sargassum Influx on the Environment

11. Please rate the following environmental impacts of Sargassum influx in your community on a scale of 1 to 5, where 1 represents "No Impact" and 5 represents "Significant Impact."

	1(No Impact)	**2**	**3**	**4**	**5 (significant Impact)**
Changes in coastal ecosystem health					
Damage to marine life (fish, turtles, etc.)					
Altered water quality					

Negative effects on local fishing activities					
Beach erosion					
Impact on tourism and recreation					

Section 4: Socioeconomic Effects

13. How has the sargassum influx affected the local economy and livelihoods? (Select all that apply.)

a. Decreased income for fishermen

b. Loss of jobs in tourism-related industries

c. Reduced income for businesses catering to tourists (Hospitality Industry?)

d. Limited access to coastal resources

e. Increased cost of cleaning and removal

f. Other (Please specify:

……………………………………………………………………………………

Section 5: Health and Well-being

14. Have you experienced any health-related issues due to the sargassum influx? a. Yes

b. No

15. If yes, which of the below health issues have you experienced? (Please select all that apply.) a. Skin diseases
    b. Respiratory problems
    c. Irritation of the eyes
    d. Any other health issue

Section 6: Community Response and Government Support

16. Have there been any government initiatives or support to manage the sargassum influx in your community?
    a. Yes
    b. No
    c. Not sure

17. If yes, please select the nature of the government support. (Please select all that apply.) a. Financial support
    b. Beach clean-up
    c. Training on utilization
    d. Do nothing
    e. Other (Please

specify……………………………………………………………………
……

Section 7: Coping Strategies and Adaptation

18. Have you or your community adopted coping strategies for the sargassum influx? a. Yes

    b. No

19. If yes, please select some coping strategies from the list below. (Please select all that apply.) a. Beach clean-up

    b. Burning

    c. Burying

    d. Do nothing

APPENDIX B

INTERVIEW GUIDE

Interview Protocol for Environmental Science Officer

Interview Date………………………………………. Time ……………………………..

My name is Paul Adu. I am a student from the Institute for Environment and Sanitation Studies, University of Ghana. As part of my MPhil Programme, I am conducting a study on 'Assessing the

Impact of beaching of Sargassum on Livelihoods in the Western Region of Ghana.' As an

Environmental Science Student your input will help give me a better understanding of the impacts Sargassum beaching have on your livelihoods and measures in place to manage this 'menace'. The interview is anonymous, and all information gathered will be treated with confidentiality

Biodata

1. Position of interviewee………………………………………………………………

2. Gender: a. Male b. Female

1. What do you believe is the primary cause of the weeds (Sargassum) appearing on the shore?

2. How long have you been experiencing the presence of the weeds on your shore?

3. Are there specific months or seasons when the weeds are more likely to appear?

4. How have the weeds affected the fishing activities in your community?

5. What economic challenges have arisen for your community due to the presence of the weeds?

6. Have you or anyone in your community experienced health issues that you believe are related to the presence of the weeds?

7. How does the presence of the weeds affect the environment in your community?

8. How has the presence of the weeds affected daily activities and recreation in your community?

9. Between the youth and the elderly, who do you think suffers more from the consequences of the weeds?

10. Between men and women, who do you believe is more affected by the presence of the weeds?

11. How have the weeds impacted those whose jobs are directly or indirectly related to fishing?

12. Have there been any measures or interventions from the government or other institutions to help manage the weeds?

13. Has your community taken any steps to deal with the weeds, such as clean-up efforts or other management practices?

14. Do you see any potential for the weeds to be used beneficially in the future, or do you believe they will continue to be a problem? **Interviewer: Paul Adu**

Course: Environmental Science

Institution: University of Ghana Legon