UNIVERSIDADE TÉCNICA DO ATLÂNTICO
INSTITUTO DE ENGENHARIA E CIÊNCIAS DO MAR

WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE
AND ADAPTED LAND USE

Master Thesis

COASTAL VIEW: APPLICATION OF UAV IN MONITORING AND MAPPING COASTAL HABITATS OVER SÃO VICENTE, CABO VERDE

FERDINAND, Bebo

Master Research Program on Climate Change and Marine Sciences

São Vicente
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Master's thesis presented to obtain the Master's degree in Climate Change and Marine Sciences by the Institute of Engineering and Marine Sciences, Atlantic Technical University in the framework of the West African Science Service Centre on Climate Change and Adapted Land Use.

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São Vicente
2021

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Dedication

To my two biological parents and my adoptive father, I wish that today, when I am defending my Master's thesis, that you were alive to see the fruits of your sacrifices.

To the Essen family in Ghana, I express my gratitude to you for allowing me to dream big again. You have taught me perseverance, and you can now contemplate the fruit of your investment.

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May the grace of GOD help me in this task.

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Resumo

As zonas costeiras caracterizam-se por uma mudança constante devido à interacção dinâmica entre o oceano e a superfície terrestre. Ondas, mares e ventos aparecem como factores cruciais num processo contínuo de erosão e deposição de sedimentos. Além disso, as áreas costeiras são o lar de ecossistemas vegetais, incluindo florestas de mangais, leitos de ervas marinhas, e pântanos salgados, o que favorece muitos serviços para o ser humano. No entanto, estas zonas costeiras e os seus ecossistemas são ameaçados pela pressão humana e pelos efeitos das alterações climáticas. Estes factores conduzem à degradação destes ecossistemas costeiros e à perda de biodiversidade. Por conseguinte, é necessário implementar medidas eficazes e menos dispendiosas para sustentar e gerir os habitats costeiros. Com o aparecimento da tecnologia dos veículos aéreos não tripulados (UAV) durante a última década, os drones encontraram um papel bem sucedido em áreas de investigação como a agricultura de precisão, a silvicultura e a eco-ogia. A sua flexibilidade e facilidade de utilização permitem a realização de levantamentos rentáveis à escala da parcela e da mesoscala. A esta escala, os UAV podem produzir repetidamente im-ages de alta resolução semelhantes a outros produtos de teledetecção. Neste projecto, foi examinada a utilização de um UAV de grau de consumo para mapear habitats costeiros. O mapa de habitats resultante serviu de ferramenta de gestão de ecossistemas e de base para avaliar futuras mudanças na condição e distribuição dos habitats, complementando o mapeamento ecológico anterior e os levantamentos em Cabo Verde. Foi indicado que é viável utilizar um drone para produzir mapas das regiões costeiras submersas em São Vicente, em Cabo Verde, em condições meteorológicas e de iluminação adequadas. Durante um período de 1 ½ meses, foram criadas cinco orto-mosaicos de alta resolução a partir de imagens adquiridas por um DJI Phantom 4 Pro V2.0, equipado com uma câmara RGB. O mosaico ortofoto da baía de Baia é classificado em modelo de Máxima Probabilidade. Embora o conjunto de dados de formação seja baseado na interpretação manual de fotografias, o modelo não foi adequado para classificar os corais e algas de águas pouco profundas e as variáveis terrestres com uma precisão inferior a 70%. Este estudo fornece a base para futuras abordagens de mapeamento e monitorização baseadas em UAV em Cabo Verde.

Alavras-Chave: Ecossistema costeiro; monitorização do habitat; UAV-drone; viabilidade e necessidade; classificação; cartografia; Cabo Verde

Abstract

The coastal areas are characterized by constant change due to the dynamic interplay between the ocean and the land surface. Waves, seas, and winds appear as crucial factors in a continuous erosion and sediment deposition process. In addition, the coastal areas are home to vegetated ecosystems, including mangrove forests, seagrass beds, and salt marshes which provides many services to human. However, these coastal areas and their ecosystems are threatened by human pressure and the effects of climate change. These factors lead to the degradation of these coastal ecosystems and the loss of biodiversity. Therefore, there is a need to implement effective and less costly measures to sustain and manage the coastal habitats. With the emergence of uncrewed aerial vehicle (UAV) technology over the past decade, drones have found a successful role in research areas such as precision agriculture, forestry, and ecology. Their flexibility and ease of deployment allow cost-effective surveys to be carried out at a small scale and mesoscale. At this scale, UAVs can repeatedly produce high-resolution images similar to other remote sensing products. In this project, the use of a consumer-grade UAV was examined to map coastal habitats. The resulting habitat map served as an ecosystem management tool and a baseline for assessing future changes in habitat condition and distribution, complementing previous ecological mapping and surveys in Cabo Verde. It was indicated that it is feasible to use a drone to produce maps of the submerged coastal regions in São Vicente, in Cabo Verde, under suitable weather and lighting conditions. During 1 ½ month, five high-resolution orthomosaics were created from images acquired by a DJI Phantom 4 Pro V2.0, equipped with an RGB camera. The orthophoto mosaic of Baia bay was classified in Maximum Likelihood model. Though the training dataset was based on manual photo interpretation, the model classifies the shallow water coral and algae and the terrestrial variables with an accuracy of around 70%. This study provided the basis for future UAV-based mapping and monitoring approaches in Cabo Verde.

Keywords: Coastal Ecosystem; Habitat Monitoring; UAV-Drone; Feasibility and Need; Classification; Mapping; Cabo Verde

Abbreviations and acronyms

AAC	Agência de Aviação Civil (Cabo Verde)
C	Carbon
CO2	Dioxide of Carbon
DEM	Digital Elevation Model
DGEM	Direção Geral da Economia Marítima
DGTT:	Direção-Geral do Turismo e Transportes
DJI	Da-Jiang Innovations
DNA:	Direção Nacional do Ambiente
EBA	Ecosystem-Based Approach
EBM	Ecosystem-Based Management
EEZ	Exclusive Economic Zone
ENAPOR:	Portos De Cabo Verde
GIS	Geographical Information System
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
ICAO	International Civil Aviation Organisation
ICES	International Council for the Exploration of the Sea
IMAR:	Instituto do Mar
IMP	Instituto Marítimo Portuário
INGT	Instituto Nacional de Gestão do Território
ITCZ	Intertropical Convergence Zone
LIDAR	Light Detection and Ranging
MERDCV	Ministry of Environment, Rural Development, and Marine Resources
MPA	Marine Protected Area
MSP	Marine Spatial Planning
PM:	Policia Marítima
RGB	Red Green Blue
RPAS	Remotely Pilote Aircraft System
SDG	Suitable Development Goal
SDTIBM :	Sociedade de Desenvolvimento Turístico das Ilhas de Boa Vista e Maio
SFM	Structure from Motion
SST	Sea Surface Temperature

UAS	Unmanned Aerial System
UAV	Unmanned Arial Vehicle
UICN	International Union for Conservation of Nature
UK	United Kingdom
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
WWF	World Wildlife Fund
ZDTI	Zonas de Desenvolvimento Turístico Integral

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1. Introduction

The coastal area is a land-sea interface characterized by continuous change due to the dynamic ocean-land surface interactions. The major forces driving continuous erosive and depositional processes are waves, currents, tides, and winds Nelson (2013). Coastal habitats are used by many organisms whose lives depend on them (Henseler et al., 2019). Coastal habitats, such as meadows, kelp, and mussel beds, as well as open and sandy habitats, carry out essential ecosystem services, as many species rely on them during some or all of their life cycle stages (Rönnbäck et al., 2007; Henseler et al., 2019). Coastal habitats differ in their hydrodynamics, structural complexity, and substrate composition, which structures the associated species communities (Rönnbäck et al., 2019; Henseler et al., 2019). Fish often depend on multiple habitats during their life cycle and visit coastal habitats seasonally (Henseler et al., 2019).

However, climate change is now widely acknowledged as a global threat that challenges the success of marine and coastal conservation, management, and policy (Patrizzi & Dobrovolski, 2018). Ocean warming, ocean acidification, and sea-level rise are predicted to modify present ocean patterns dramatically, and other drivers of change are also expected (Santos et al., 2016).

According to (Rönnbäck et al., 2007), coastal areas are exposed to various threats due to high population densities, rapid economic development, and climate change effects. As a result, marine ecosystem functions will be reallocated. The ocean uses that depend on these services will be affected by spatial and temporal changes through either local decrease or increase or relocation. Some ocean uses, such as fishing or conservation, are likely to be more sensitive, i.e., More at increased risk and less resilient to the impacts of climate change (Frazão Santos et al., 2020). On the other side, new research has highlighted the unique role of coastal and marine ecosystems in carbon dioxide (CO_2) storage. The carbon (C) fixed in vegetated coastal ecosystems, namely mangrove forests, seagrass beds, and salt marshes, has been termed "blue carbon." The capacity of coastal habitats, per unit area, to fix carbon over the long term is much greater, partly due to their ability to capture suspended matter and associated organic carbon during tides and flooding. Despite the value of mangrove formations, seagrass beds, and salt marshes in sequestering carbon, as well as the other goods and functions they provide, these systems are disappearing at a dramatic rate, and urgent action is necessary to prevent further degradation and loss (Mcleod et al., 2011).

The sustainable use and preservation of the world's oceans and their resources are one of the 17 Global Goals that aim to " change our world " as part of the United Nations (UN) 2030

Agenda for Sustainable Development. The principal challenges in managing ecosystem services are that they are not independent of each other (Rodríguez et al., 2006), and the connection between them can be highly non-linear (Panayotov, 2018).

Although such a global agreement on the advancement of sustainability in the oceans is relatively recent, the protection of marine ecosystems has been at the international forefront for decades. Numerous actions, approaches, frameworks, and plans have been developed and implemented to this end. It includes the ecosystem approach, which finds its origin in the United Nations Convention on Biological Diversity, and ecosystem-based management (EBM). EBM is derived from the integrated management concept under Chapter 17 of Agenda 216 or international treaties such as the United Nations Convention on the Law of the Sea (UNCLOS). Simultaneously with the developments and integration of many concepts, such as the ecosystem approach and management, in the 1990s, a management process commonly referred to as Marine Spatial Planning (MSP) emerged and has spread widely over the past 15 years. It can be generally described as the analysis and allocation of the spatial and temporal distribution of human uses in the marine and the coastal zone to minimize conflicts and promote compatibility between these uses and between human benefits and the environment. MSP can balance several and often contradictory human demands and environmental protection spatially.

Therefore, MSP has grown globally, and marine spatial plans are currently being drawn up in around 70 countries, from high to low latitudes and in all ocean basins (except the Southern Ocean). Around half of all coastal countries, including over half of the world's Exclusive Economic Zones (EEZs), have maritime spatial planning initiatives in progress. However, most are in the first stages of development (Ehler, 2014). Climate-induced changes in ocean conditions and marine ecosystems' The structure and functioning of the world's oceans will lead to changes in the allocation and intensification of ocean-related human uses. Such a redistribution of benefits will lead to new potential conflicts between service and the environment and legal issues at the core of MSP processes (Frazão Santos et al., 2020). MSP must be able to integrate these issues and dynamics to support the realization of overall sustainability goals(Frazão Santos et al., 2020; "Guiding Ecological Principles for Marine Spatial Planning, 2010).

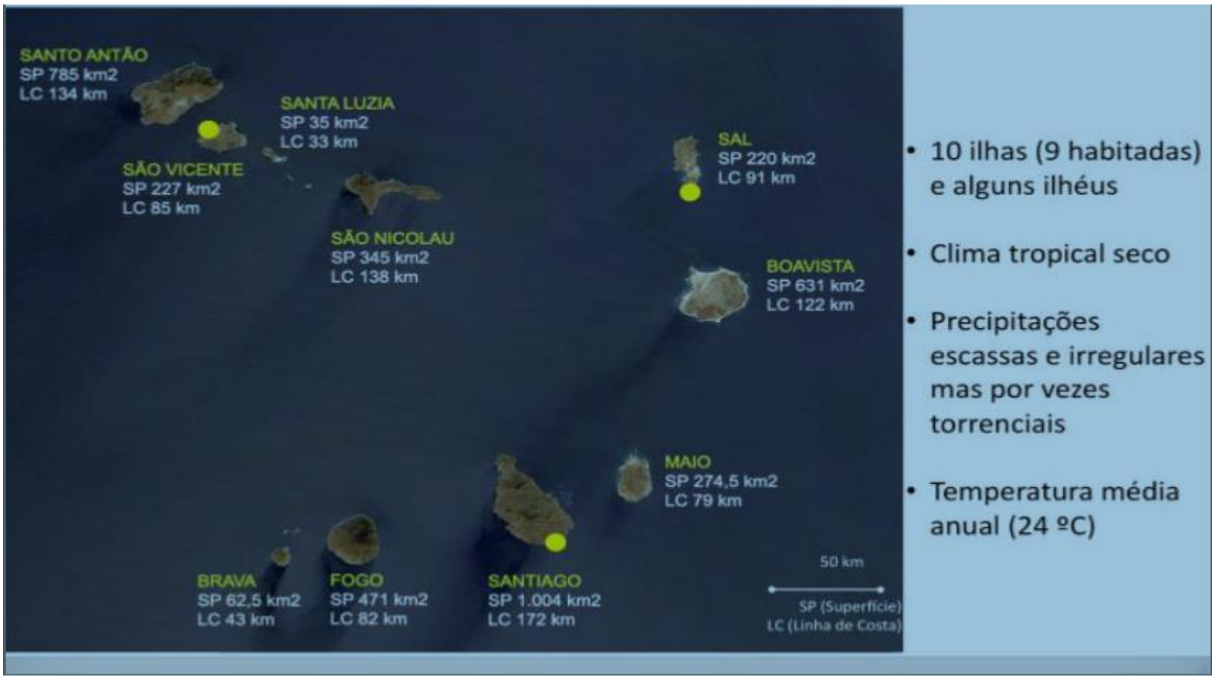
The health of global marine ecosystems, including the Cabo Verde marine ecosystem, is in severe decline. Multiple stressors, including overfishing, pollution, invasive species, coastal development, and climate change, compromise the ability of the ocean and coastal ecosystems to support and sustain the goods and services people want and need.

Maintaining the well-being of ocean ecosystems, as well as their ability to provide essential ecosystem services for human populations, will require an alternative strategy to replace the current patchwork of complex, uncoordinated, and often disjointed rules and regulations governing the use of coastal and ocean waters around the world (Foley et al., 2010).

Besides, the coastal margin habitats such as dunes and fine sand beaches, machair, salt marshes, pebbles and beaches, sea cliffs constitute a transition zone between terrestrial and marine habitats. They are doubly sensitive to climate change, changes in precipitation, temperature, storms, etc., and the loss of habitats due to coastal erosion and sea-level change. Sediment provision and transport are vital natural processes that these habitats require for a natural and dynamic state on which their unique biodiversity depends. Therefore, climate change may increase recreational uses but create significant coastal defence challenges, requiring coastal space planning and integrated management of sediment balances in all habitats (Jones et al., 2013). The higher financial costs and institutional limitations of climate change adaptation require joint planning with other development and environmental priorities, especially in small island developing states like Cabo Verde (Khan & Amelie, 2015). In response, ecosystem-based adaptation (EBA) is gaining recognition as a cost-effective and synergistic way to improve livelihoods through nature's services, build community livelihood resilience. Using the Cabo Verde archipelago in the eastern Atlantic Ocean as a case study.

1.1 Background and Context

The coastal zone of Cabo Verde is estimated at 1020 km of white and black sand beaches alternated with cliffs. An accentuated coastline essentially characterizes it. The easternmost islands have a shallow topography with sandy coasts. Cabo Verde Coastal areas are ecologically sensitive interfaces between sea and land and respond to land-use changes. This natural setting denotes the vulnerability shared by most small island states, with coastal areas that require special attention in the face of potential adverse impacts resulting from global climate change. Also, they are under increasing pressure from human activities. Indeed, any rise in sea level will dramatically affect coastal areas and the population, considering that approximately 80% of the inhabitants of Cabo Verde live in these areas and the potential loss of habitat, biodiversity, and fisheries. Therefore, the Organisations concerned about the impact of human activities climate change effects on coastal areas need new data sources to monitor changes such as coastal erosion, loss of natural habitats, urbanization, sewage, and marine pollution. Remote sensing technology can map and observe much of the dynamics of the open ocean and changes in the coastal zone.



- 10 ilhas (9 habitadas) e alguns ilhéus
- Clima tropical seco
- Precipitações escassas e irregulares mas por vezes torrenciais
- Temperatura média anual (24 ºC)

Figure 1. Coastal Context in Cabo Verde (source: Giordano, 2013).

1.2 Problem Statement

Resource exploitation, climate change, habitat modification, and pollution have led to dramatic changes in the composition of coastal marine ecosystems. This change inevitably leads to the physical destruction and unsustainable exploitation of marine and coastal natural resources. The result is a complete breakdown of the food chain (Hassan et al., 2013); preservation of these habitats is essential for coastal protection, nurturing, protecting marine life, and mitigating the effects of global climate change. It is in this context where remote sensing came into play to assess ongoing change and coastal mapping.

For mapping ecology, there are significant challenges, especially in situations where high spatial and temporal resolution is essential for environmental management. This gap can usually be filled by using proprietary remote sensing products, such as traditional aerial surveys or high-resolution satellite imagery. This method can be very costly, especially for ecological governance purposes, where high temporal resolution is desired. Due to the low entry-level, UAVs can fill this niche, especially for small-scale survey needs. In this case study on the island of São Vicente (Cabo Verde), the feasibility of UAV monitoring in coastal habitats was explored further to improve knowledge of conservation targets and facilitate the management method for repeated surveys.

1.3 Research Questions

1- What characterizes São Vicente's coastal habitat?
2- How to fill the knowledge gap in terms of information and data for feasible ecosystem monitoring?
3- How to access the feasibility of conducting a coastal monitoring study in São Vicente, considering drone limitation?

1.4 Relevance and Importance of the Research

This research is important because it allowed Cabo Verde in general, but the island of São Vicente mainly to acquire a new tool for managing and monitoring coastal habitats. The use of high-resolution UAV images is more suitable for small-scale mapping areas and also small targets. Therefore, coastal habitats and their dynamics can be easily mapped with a UAV, and it can be used to identify areas of erosion from mosaic orthophotos. Therefore, this work advanced the application of UAVs for mapping and monitoring coastal habitats in Cabo Verde and its strengths and limitations. It was a baseline work for other future projects in the region and for monitoring ecosystem change.

1.5 Objectives of the Work

In the pursuit to gain knowledge and provide information for better ecosystem monitoring and natural resource management in Cabo Verde, this study aims to develop a comprehensive and accessible map of the presence and extent of coastal marine habitats of specific areas. The resulting habitat map will be served as an ecosystem management tool and a baseline for assessing future changes in habitat condition and distribution, complementing previous ecological mapping and surveys in Cabo Verde. This broad aim was separated into four main objectives:

1) Assess the feasibility and necessity of mapping specific habitats in São Vicente: 4 study areas (Calahu, Baia das Gatas, Salamansa, Laginha) were pre-selected for this assessment. This objective considers the previous survey by drone and the evaluation of stress factors and natural and anthropogenic conflicts of the surveyed areas. The results are then plotted against the feasibility of the site, with a preference for the size as the most suitable location for establishing a baseline study area for a long-term monitoring framework.

2) Map the coastal use and coastal habitat: consisting of drone mapping of coastal habitats based on the selected area. The drone images were processed using a "structure from motion" (SfM) approach to obtain orthogonal photomosaics of the chosen location.
3) Validate of the obtained data: it consists of an evaluation of the data, including quality control, repeatability considerations, and refinement of the obtained ortho-mosaics and digital elevation models. Geographic Information System (GIS) for data classification and the generation of land use and habitat maps was used.
4) Conduct a baseline study: This activity was to map coastal habitats, highlight land use cover, and provide information supporting coastal ecosystem monitoring and management and marine spatial planning.

1.6 Structure of the Work

This project used a UAV equipped with a Red, Green, and Blue (RGB) camera to collect images in four different locations in the coastal area of São Vicente.

This study is divided into five main sections to reach the above objectives, which are, in turn, subdivided into sub-sections. The introduction included the background and general context of this research, the problem statement, the research questions, the relevance and importance of the study, the objective, and the work's structure. The literary review. The general context and the definition and importance of concepts such as coastal and marine ecosystems, coastal habitat monitoring, UAVs, and their importance in coastal habitat monitoring.

The materials and methods section first discussed the state of the geology, climate characteristics, vegetation, and biodiversity of the coastal and marine environment of Cabo Verde. Then in the research methodology explained the conditions of the drone survey, listed the equipment, gave details of the data acquisition and analyzed, and summarized the techniques used to map and classified the coastal habitats of Baia.

The following section included the map results for Laginha, Salamansa, Baia das Gatas and Calhau produced from Mosaic orthophotos. Next, the feasibility of drone against requirements, the mapping of the small bay of Baia, and finally, the comparison between the classification and the RGB image.

Two main points were discussed. This discussion centered around the feasibility Vs. and need of the survey areas and the mapping and classification of the coastal habitats of Baia. The final section was the conclusion, which provided an overview of the work, followed by some recommendations for future improvements that could be made to this research better. Finally, all bibliographies and references were cited.

2. Literature Review

2.1 The General Context of the Study

The entire ecosystem service is presently under threat by various pressures that can have significant impacts. Population growth, economic growth, and coastal development lead to increased physical alteration and degradation of habitats, increased pollution, and increased demand for renewable resource extraction. Combined with the pressures of climate change, these phenomena can alter the physical and chemical environment, modifying the diversity and coverage of coastal habitats, affecting the distribution and abundance of species in coastal ecosystems, and reducing the availability of essential ecosystem goods and services. Similarly, (Foley et al., 2010) have drawn the same caveat in their study.

2.2 Overview of the Coastal and Marine Ecosystems and their Importance

According to (Duarte et al., 2013), coastal areas represent the ocean and land interface. They are characterized by constant abrupt changes due to dynamic interactions between the sea and the land surface. Waves, currents, tides, and winds are the main drivers of erosion and sedimentation.

The report from (Gustavon 2010)characterized and classifies coastal habitats in a variety of ways. Still, the primary habitats in the Gulf of Maine are salt marshes, mudflats, seagrass beds, kelp beds, shellfish beds, rocky and gravel beaches, and sandy beaches. The coastline includes the intertidal zone and the foreshore zone at a depth of approximately 100 meters.

Coastal areas host many habitats such as salt marshes, seagrass beds, mangroves, coral reefs, cliffs, rocky shores, sand and gravel beaches, dunes, mudflats, salt marshes, and machair, which provide many benefits to coastal ecology and economy (Barbier et al., 2011). In addition, (Myers et al., 2019) stated that marginal nearshore habitats are globally significant in their role in storing and sequestering carbon. But their continued loss due to environmental degradation and human land-use decisions reduces their ability to provide this ecosystem service.

Furthermore, for (Pelage et al., 2019), coastal habitats are of great socio-economic and ecological Importance worldwide. They contribute raw materials and food and make essential contributions to shoreline protection, erosion control, water purification, carbon storage, tourism, recreation, and education (Barbier et al., 2011). They also contribute to fisheries conservation by providing a habitat for fish and increasing marine productivity. Therefore, they are vital for local culture and traditional knowledge (Walters et al., 2008). These forests' salt-tolerant species allow complex food webs to develop (Valiela et al., 2001). Because mangrove ecosystems provide essential ecological functions, any significant loss of mangrove forests will have important consequences for these food webs and species diversity and abundance.

In addition, coastal habitats, such as dunes, provide some essential benefits underpinned by the region's geomorphological coastal processes and ecosystems, including direct and indirect economic benefits to people. Coastal dune ecosystems are ecologically important, but their specific values and uses are poorly understood and undervalued (Richardson & Nicholls, 2021).

The coastal areas host a variety of habitats, such as salt marshes, seagrass beds, mangroves, shellfish reefs, coral reefs, cliffs, rocky shores, sandy and shingle beaches, dunes, mudflats, salt marshes, and machinery, which provide a range of benefits to coastal ecology and economy (Barbier EB et al., 2011). Furthermore, (Beaumont et al., 2014) marginal coastal habitats are of global importance for their ability to sequester and store carbon. Still, their continued loss due to environmental change and human land-use decisions reduces their ability to provide ecosystem services.

2.3 Overview on Coastal Habitats Monitoring

Monitoring should be regular and continuous and should occur after the program's start and throughout the program's life or intervention. The data collected focuses primarily on inputs and outputs and is generally used as an ongoing strategy to determine the effectiveness of implementation. The success of conservation efforts is highly dependent on the identification and protection of natural habitats that serve as reservoirs of biodiversity and play a critical role in ecosystem functioning and stability (Checon et al., 2018). Once habitats have been defined, they can be used to plan monitoring programs. The ecological and socio-economic importance of the coastline and the marine area Caboverdian’s requires safeguarding the environmental value of these essential areas, which significantly impact attracting tourists and the sustainability of economic, marine, fishing, and aquaculture resources.

According to an INGT report in 2019, the coastal zone in Cabo Verde is very vulnerable due to the following natural and anthropogenic conditions: uncontrolled extraction of aggregates in coastal areas, coastal areas, marine, and coastal pollution, unrestrained construction of tourist and other facilities on the waterfront, non-compliance with coastal zone legislation, water erosion, the occurrence of extreme weather conditions Tropical storms, frequent episodes of extreme temperature variations, torrential rains.

Thus, in Cabo Verde, several institutions are involved in the management and monitoring of the marine area, each with specific competence. INGT, DGEM, DNA, PM; ENAPOR; SDTIBM; DGTT, and Camaras Municipais can be mentioned among others.

2.4 Overview on Drones and their Importance

To manage coastal and marine ecosystems effectively, they need to be monitored using the most effective and affordable tools, such as drones. UAS, also known as Unmanned Aerial Systems, or UAVs, or more commonly drones. Another term is RPAS, or Remotely Piloted Aircraft Systems, adopted by the ICAO (International Civil Aviation Organization).

In addition, Ivoševi et al. (2015) defined UAVs as robotic aircraft, also known as unmanned aerial vehicles (UAVs), unmanned aerial systems (UASs), and remotely piloted aircraft (RPAs). They also highlighted the rapid development of these aircraft in the last decade, especially for military and civilian purposes. They further argued that although drones have military origins, it is becoming increasingly clear that they are also helpful in many other areas, such as coastal areas. Ivoševi et al.(2015) stated that drones are not yet fully developed and explored but will soon become an essential commercial surveillance tool (Getzin et al., 2012).

2.5 Importance of Drones in Coastal Habitat Monitoring

Puri et al. (2017) mentioned the first practical role of drones. According to them, drones, commonly called UAVs, are mainly associated with the military, industrial, and other specialized missions. However, with the development of sensors and information technology in the last two decades, the scope of UAVs has expanded to other areas such as agriculture, transportation, and research.

The use of lightweight unmanned aerial vehicles (UAVs) such as drones is revolutionizing many areas of the geosciences (Anderson & Gaston, 2013; Castellanos-galindo et al., 2019; Christie et al., 2016; Duffy, 2018). They can be easily applied to the following conservation and management needs (Castellanos-galindo et al., 2019; Koh & Wich, 2012). Drones flying at low altitudes and using sensors to observe the terrain and collect high-resolution data are economically and practically competitive(Woellner & Wagner, 2019). Coastal ecosystems are often considered rapidly changing environments, and the spatial and temporal resolution and flexibility of drones provide information on a wide range of ecological processes.

Several studies have used drone technology for environmental monitoring in coastal areas and have obtained reliable results. Thayer et al. (2003) discussed that the concept of monitoring for coastal restoration could provide tools for planning management strategies and help improve future restoration practices and projects. They stated that monitoring can determine whether project objectives are being met and whether interim corrections are needed. Monitoring provides information on whether the selected project objectives are reasonable for future projects and how to perform routine maintenance in the restored area.

According to Yang et al. (2020), unmanned aerial vehicle (UAV) or drone technology, with its high spatial resolution, temporal flexibility, and the ability to repeat photogrammetry, enables significant advances in other remote sensing approaches for coastal mapping, habitat monitoring, and environmental management. In their previous work (Yang et al., 2019) assumed that much research has looked at the advantages/disadvantages of different types of remote sensing approaches.

The traditional satellite remote sensing can capture historical data dating back to the 1960s with various revision cycles. Still, the relatively coarse spatial resolution limits the use of satellite imagery in coastal monitoring and management.

In Ghana, where drones are beginning to be widely used in many areas. Addo et al . (2018) applied different remote sensing approaches, including aerial photography, satellite imagery, light, and aerial distance sensing (LIDAR) technology, and video technique in their research on "Drone as a tool for coastal flood monitoring in the Volta Delta, Ghana." They then compared these remote sensing tools, highlighting the limitations and advantages of each. They then concluded by mentioning the challenge of operating a drone in the coastal environment of the Cabo Verde islands due to the strong winds from the Canary Islands (Gonçalves & Henriques, 2015). However, they put more emphasis on the importance of drones in monitoring and managing coastal habitats. The research has concluded that UAVs have high accuracy in coastal monitoring. They finally compared the drone-produced images with high-quality time-averaged photos with the satellite and video system images. They also said that drone has advantages over the satellite and video system as it allows for more excellent spatial coverage, favourable viewpoint and portability, and rapid deployment.

In this regard, (Gomes et al., 2018; Kerr & Ostrovsky, 2003; Nagendra, 2001; Wang et al., 2010) argue that remote sensing, including aerial or satellite imagery and acoustic data, can be used to create large datasets with a high spatial and temporal resolution, reducing physical or biological disturbance. Nevertheless, there is still a significant gap between pixel resolution and the spatial scale of ecological features and processes of interest for remote sensing (Philipson & Lindell, 2003; Zharikov et al., 2005).

Thus, the main factors to consider when planning an aerial data collection campaign are the size of the survey area, spatial resolution requirements, spectral resolution (wavelength range), frequency of image collection, and cost. A significant challenge for ecological research in tidal areas is the spatial scale of the data collected and the logistical problems associated with studying tiny organisms at very high densities. In addition, sampling is limited to appropriate frequency intervals. In theory, therefore, tidal surveys should involve rapid assessment and cover large areas with the most excellent taxonomic precision.

The application of UAVs to study marine animals is becoming increasingly common as they allow the observation of movements (Raoult et al., 2020). Unmanned aircraft vehicles (UAVs) have the potential to become an effective tool in the fight against climate change that provides inexpensive but sufficiently accurate map products to support environmental management (Castellanos-galindo et al., 2019).

With the rapidly increasing number of studies on the ecology and habitat use of various marine taxa applying drones, there are concerns that it may be misused. It can invalidate research results due to inappropriate equipment or faulty flight protocols that could affect the behaviour of the observed animals. One of the strengths of drones is their ability to provide visual information, such as behaviour, photogrammetry (measuring objects from photographs), and SfM (building 3D models from multiple images). Photogrammetry and SfM can create maps from orthophoto mosaic and digital surface models from point cloud data. At the same time, morphometrics can estimate wildlife's health, weight, and demographic characteristics without recording them (Raoult et al., 2020).

During the review of the existing literature, it was noticed that less research had been done on coastal habitat monitoring in Cabo Verde in general and São Vicente, in particular, using unoccupied aerial vehicles or drone technology. Nevertheless, there are numerous researches related to this work that has been done in different domains, mainly in developed countries.

3. Materials and Methods

3.1 Case Study: Cabo Verde

Cabo Verde is located between parallels 17º 12' and 14º 48' North latitude and meridians and 22º 44' and 25° 22' west longitude. It is composed of ten islands, nine of which are inhabited, and several uninhabited islets, divided into two groups by their location relative to the prevailing winds: the Barlavento (windward) group to the North, including from West to East the islands of Santo Antao, São Vicente, Santa Luzia (uninhabited), São Nicolau, Sal, Boavista and the Sotavento (leeward) group to the South, formed from East to West by Maio, Santiago, Fogo, and Brava. The majority of the population resides in urban centres (303,776 inhabitants), representing approximately 62% of the total, while the remainder lives in rural areas (187,799 inhabitants), and accounting for 38% of the total. The most urbanized cities, Sao Vicente, Praia, and Sal, achieved around 92.6%, 96.6%, and 92.9%, respectively. Despite the higher population density in Praia and Mindelo's cities, the fastest growth occurs in Praia (MERDCV, 2010). Although the extent of the continental shelf is limited, Cabo Verde's EEZ covers about 789 400 km², a large part of which is not used for national fisheries (Benchimol et al., 2009). The primary current of the Canary Islands is directed towards the Cabo Verde islands, forming an unprotected rocky coast.

Figure 2. Cabo Verde Archipelago (source: Magellan geographix, 1997).

3.1.2 Geology

The Cabo Verde islands are located 567 km off the west coast of Africa and take their name from the Cape Verde peninsula in Senegal and 2000 km east of the Mid-Atlantic Ridge (Pim et al., 2008).

Carracedo & Troll (2021) affirmed, like the Canary Islands, Cabo Verde sits on the ancient oceanic crust (120-140 Ma), despite its proximity to the African continent. Generally accepted that the Cabo Verde Islands represent long-lived volcanism within the marine plate associated with the Cabo Verde Plateau, which is thought to be fed by a hotspot (Courtney & White, 1986; Madeira et al., 2010; Ramalho et al., 2010). Due to their proximity to the slow-moving rotation pole of the African plate, these islands are effectively stationary concerning the moving lithosphere. This situation explains why the Cabo Verde Islands appear more rigid than the Canary Islands, for example. The erupted lava is mostly black alkaline basalt, and silica saturates are pretty rare.

The islands are geometrically arranged in a horseshoe shape, open to the west (Ramalho, 2011), which includes two directions: North (upwind) and South (downwind), where there seems to be an age gradient of the oldest exposed rocks. The age gradient is also reflected in the topography of the southern island chain (Knudsen et al., 2009; Madeira et al., 2010). Sal island is the oldest island in the archipelago, deeply eroded and essentially flat in the northwestern part of the chain. The island structure gradually rises at the southwestern end of the chain, on the islands of Santiago and Fogo. Like Fuerteventura, the islands of Mayo and Santiago exhibit sedimentary and volcanic rocks of the Jurassic age(Stillman et al., 1982) and submarine lavas representing the transition from Miocene to Miocene subaerial volcanism (Carracedo & Troll, 2021).

Volcanism in the Cabo Verde region probably began in the early Miocene. It continued during the Holocene, but historical volcanic eruptions in Cabo Verde (the archipelago was discovered in 1460) have been limited to one island, Fogo (Carracedo et al., 2015; Carracedo & Troll, 2021).

3.1.3 Climate Characterization

The archipelago of Cabo Verde belongs to the Sahel climatic zone and is characterized by an abridged rainy season, sometimes very short. The effects of drought are well known but have been particularly severe over the past ten years (Martins, 1988). It is located in a region where the variability of the Azores subtropical acts as a regulatory factor of rainfall anomalies by controlling the seasonal oscillation characteristics of the trade winds with maritime and continental features during the dry months (November to June). In the rainy season (July to October), the ITCZ's oscillatory movement is characterized by southeast winds and disturbances from the east. The islands are affected by air masses from extra-tropical latitudes (Silva et al., 2011). The spatial-temporal distribution of rainfall is affected by regional phenomena and remote influences as dominant forms of variability (Silva et al., 2011).

As summer ends, Cabo Verde begins its rainy season, which in September accounts for almost half of the islands' average annual rainfall. In autumn, visitors to Cabo Verde enjoy a more tropical climate. However, September and October are the two warmest months on the islands, with temperatures between 26 and 28°C and the average daytime temperature reaching 29 to 30°C during this period. The rainy season in Cabo Verde is a distant memory in late autumn, with 10 mm of rain falling again in December and 3 mm in January. Winter is the coldest season in Cabo Verde, but tourists encounter temperatures between 21°C and 26°C, which are still very warm. As in summer, the days in Cabo Verde are much shorter in winter than in spring or autumn, and the visitors can expect approximately 6 hours of sunshine per day in winter (UK Met Office, 2021).

Cabo Verde has a tropical climate with two seasons: a dry season from December to July and a warm and humid season from August to November. The higher islands, where active volcanoes, rain significantly more than the lower, flatter islands due to the shadow effect (WWF). Temperatures range from 20 to 35 °C, with an average of 25 to 29 °C. The volcanic soil is relatively fertile, but on most islands, it is too dry for farming. The islands suffer from prolonged droughts and severe water shortages from time to time.

3.1.4 Vegetation

White's (1983) classification of African Vegetation, which covers all of Africa, does not include Cabo Verde. Before human settlement, the arid lowland islands were probably covered with savanna and steppe vegetation, while the flatter inland areas were perhaps covered with semi-arid vegetation. Dry heath was also found in the higher elevations. The higher elevation and slightly wetter islands have a climate suitable for dry monsoon forests (Bullock et al., 1996), which may have existed in the past. However, much of the vegetation has been converted to agricultural land, and forest patches are currently limited to mountaintops, steep slopes, and other areas that cannot be cultivated.

3.1.5 Biodiversity and Ecosystems Features

The islands Cabo Verde are so remote and peculiar that they deserve their ecoregion. The islands are host to many endemic plants and vertebrate species, especially birds and reptiles. Cabo Verde has numerous marine protected areas, nature parks, nature reserves, marine reserves, integral nature reserves, integral natural monuments, protected landscapes, including Monte Verde on the island of São Vicente.

Four species of land birds are endemic to these islands (Fischer & Deloison, 1996; Stattersfield et al., 1998), and there are many endemic subspecies of birds. The essential species generally live on the ground or in the shrubbery. Two endemic bird species, the Cape Verdean sparrow (Passer iagoensis) and the Cabo Verdean tern (Apus alexandri) are widespread on these islands, occurring on at least nine of the ten main islands. Two other species are found on only one island each, the endangered lark (Alauda razae, CR) on Lasso Island and the Cabo Verdean warbler (Acrocephalus brevipennis, NL) on Santiago Island.

These islands are also crucial for rare breeding seabirds. In particular, they host breeding populations of the Fea (or Cabo Verdean) petrel (Pterodroma feae), which is virtually indigenous to this ecoregion as a breeding population (BirdLife International 2000). Other significant breeding populations of seabirds include the magnificent frigatebird (Fregata magnificens) and the tropical red-tailed kingfisher (Phaethon rubricauda).

Cabo Verde is home to 15 species of lizards, 12 of which are endemic. These include the giant skink (Macroscincus coctei) of Raso Island and the giant gecko (Tarentola gigas), which occurs on Raso Island and Branco Island. Other endemics include five Mabuya skinks, three Hemidactylus lizards, and three Tarentola geckos (Stuart et al., 1990).

About 92 plant species (14%) are endemic to these islands, although little is known about their current distribution status (WWF and IUCN 1994). At least one of the native plant species on these islands is threatened with extinction, namely the understory of the marble tree (Sideroxylon mermulana). The endangered Canary dragon tree (Dracaena draco) also grows here. The only endemic mammals are 5 small bats.

In the 500 years since the first human settlement on the islands, the natural habitat has been severely degraded. This loss has been caused by converting natural habitats to agricultural land, unsustainable farming practices resulting in soil erosion, the introduction of alien species, the presence of large numbers and densities of goats and other introduced animals, and drought. The remaining natural habitats are limited to cliffs and ravines on mountainous islands and fragments on flatter islands, and none of these areas are protected.

Breeding seabirds have declined significantly and are restricted to small islands due to the combined effects of habitat loss. Human exploitation of natural resources is also essential: seabird eggs and chicks are a traditional food source for islanders. Recently, some important bird habitats, tiny islands off the coast of the main islands, have been declared protected areas.

Human activities and introduced species severely threaten the remaining habitats and their remarkable flora and fauna. Threats include overgrazing of livestock, overfishing, inappropriate land use that often leads to widespread soil erosion, and logging that has led to deforestation and desertification.

The Monte Verde Natural Park is the only protected area on the island of São Vicente, and São Vicente also has many protected species such as turtles and marine mammals. Furthermore, most of the island's beaches are classified under Caboverdian's law as areas of integral tourist development (ZDTI). In addition, São Vicente is part of a large project to develop renewable energy zones, which covers an area of 422 ha, 124 ha of which is for the implementation of two renewable energy projects at Salamansa (Bonnin et al., 2016).

3.1.6 Marine and Coastal Environment

Therefore, understanding how these organisms are distributed geographically and temporally in these habitats is essential for several reasons, including conservation. It has been concluded that a necessary step in understanding the spatial and temporal dynamics of organism distribution is to characterize the marine environment at the appropriate spatial scale (Nagelkerken, 2009; Grober-Dunsmore et al., 2009). High-resolution imagery collected by drones can serve such a purpose.

Climate change is a primary cause of stress for marine ecosystems along coastal rivers in West Africa. Living marine resources are expected to respond to anthropogenic-induced climate stressors in many complex ways. This response is often exacerbated by non-climate stressors such as marine pollution and habitat degradation. Many aspects of this response are uncertain, and most impacts are neither spatially nor temporally homogeneous across the global ocean (Mizuta et al., 2014; Opova et al., 2016). The initial responses of marine ecosystems to stressors have been observed: elevated sea surface temperatures (SST) have led to widespread coral bleaching (e.g., Ateweberhan et al., 2011), changes in main currents, and the intensification of severe weather events such as ocean heatwaves have led to changes in the distribution of marine species (Coleman et al., 2013; Cetina-Heredia et al., 2015).

3.2 Methodology

The methodology applied, has three main sub-headings; materials, data acquisition, and data analysis.

3.2.1 UAV Condition Survey

The condition survey was undertaken along different coasts of the Island of São Vicente, in the North region of Cabo Verde, which is geographically located in the east-central Atlantic Ocean. Most of the coast is composed of rocky shores and sandy beaches. The coastline is exposed to the open ocean and is historically vulnerable to high hydrodynamic conditions and human activities pressure. These are exposed at low tide variation, as tides of 0.8 m in amplitude characterize the sites. The surveys were executed at low tide, under clear sky conditions, and with calm winds (less than 30 km/h). The survey needed these conditions to avoid distortions on the images of leaves and surface water movements (Castellanos-galindo et al., 2019).

During this research, real-time data was collected from UAV images. Four survey areas were targeted in the framework of this project. These four case study areas were selected in São Vicente Island (Figure 3). The criteria applied to select these areas were done according to their accessibility of the areas, the stakeholders' needs, scientific needs, and the number of regulations but also according to the turbidity of the water, winds then visibility. Baia das Gatas is located in the North-East of São Vicente's Island, at 8 km of Mindelo; Calhau village is at 17 km, in the East; Salamansa beach in the North has situated at 9 km from the central city. The last survey area was Laginha beach which is at Mindelo in the main town and capital of the island.

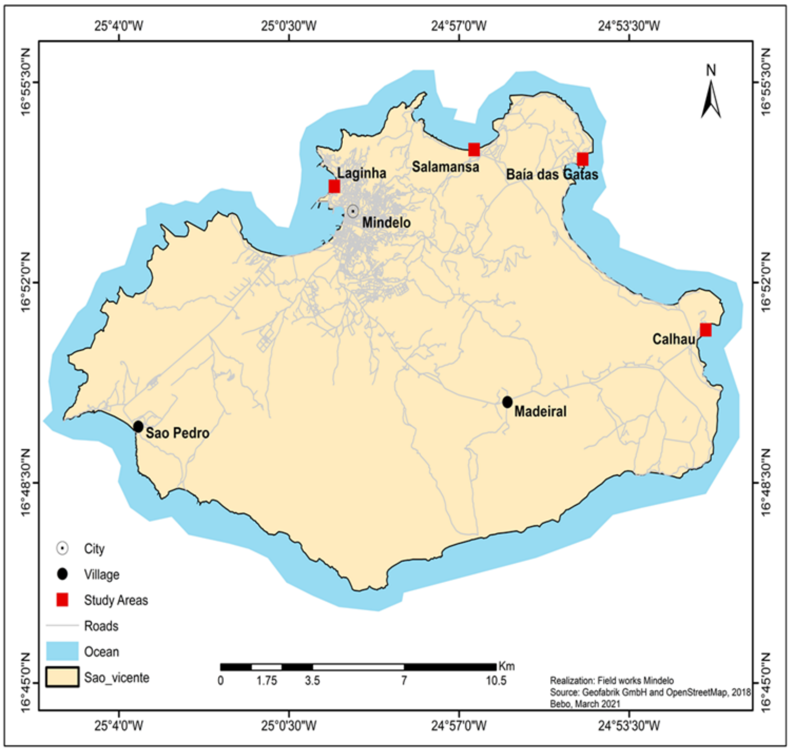


Figure 3: Study areas in São Vicente.

3.2.2 UAV Survey Equipment

The condition survey was performed using a Professional drone, DJI Phantom Pro 4 V 2, weighing approximately 1375 g, battery and propellers included. A total of 3 batteries were available during the data collection. The Unmanned Aerial Vehicle (UAV), equipped with an RGB camera, allowed the improvement satellite imagery for coastal zone management because of its very high spatial resolution and the ability to collect images in real-time (Yang et al., 2019). The Phantom 4 Pro V2.0 had an integrated photo camera, FC6310S, with a sensor of 1/2.3″ inch (1.10 cm) RGB CMOS camera sensor with (effective pixel:12.4 M), the focal length of 8.8 mm, a pixel size of 2.41 × 2.41 μm and a resolution of 5472 × 3648 pixels (Table 1). The camera was equipped with a polarised filter during the flight at Baia. All photos were geolocated during the flight by the DJI integrated GPS/GLONASS location system with a horizontal and vertical precision of up to ±1.5 m and ±0.5 m, respectively. The ground resolution was 1.71cm/pix.

Table 1. Camera caracteristics.

Camera Model	**Resolution**	**Focal Length**	**Pixel Size**	**Precalibrated**
FC6310S (8.8mm)	5472 x 3648	8.8 mm	2.41 x 2.41 µm	No

3.2.3 Data Acquisition

The survey flights were taken place in different sections to effectively cover the larger area without running out of battery power. The flights were undertaken between July and August, which is summer in Cabo Verde, from 6 am to 8 am, to minimize interference with public members, high winds, the sun glint over the ocean, and flight activity. The flights were executed in automated mode and each flight were programmed using the web app Pix4Dcapture for our training. For data acquisition, the survey missions were planned with the Map Pilot application, then the data was stored on a 32 Gigabit memory card integrated in the drone. Later, all the images were transferred in an external drive of 2 terra bits. It took fourteen days to cover the four study areas and 3 weeks for the selected area (Table 1). As for the orientation of the camera, it was placed vertically during all the flights.

According to Cabo Verde's national aviation authority, the Cabo Verde Civil Aviation Agency (AAC) flying a drone is legal in Cabo Verde. Still, it is recommended to be aware of and compliant with the drone regulations. So, for holding a drone training certificate, we were conscious of all the rules in the country. It was not allowed to fly above 100 meters, and since May 2021, I held regular authorization to fly a drone as an operator.

Figure 4: Drone set-up for field survey (top left), remote control to pilot the drone (lower left), drone at take off (upper right and lower right).

A total of four study areas for seven scheduled tasks, such as two at Laginha, two at Salamansa, two at Calhau, and one at Baia das Gatas (Table 2). Due to battery limitations, each mission was planned for 3 to 6 batteries with 80% overlap with 60 m height. The flight speed was limited to 2.0 m/s with 22 minutes per battery (Table 2). The second stage of data collection covered the two bays and the land area of Baia Das Gatas village. It took one month, including repeat flights, to complete this second phase.

Table 2. Drone mission plans for the study areas.

Study Zone	Laginha	Salamansa	Baia das Gatas	Calhau	Baia Areas of interest
Flying Altitude(M)	60	60	60	60	80
Coverage Area(Km²)	0.353	0.465	0.219	0.411	1.94
Batteries	10	9	7	9	40
Number Of Images	1,809	1,729	887	1,711	9,839
Overlap(%)	80	80	80	80	80
Path Speed(M/S)	2	2	2	2	2
Camera Stations	1,362	1,686	853	1,637	5,232
Flight Distance(Km)	18.85	33.63	18.48	25.74	103
Ground Resolution(Cm/P)	1.71	1.55	1.75	1.68	2.25
Flying Duration(Min)	220	198	160	198	792
Projections	3,035,342	5,923,566	2,926,799	4,709,742	17,036,367
Reprojection Error(Pix)	1.87	1.11	1.52	1.32	1.25
Starting Date	1/7/2021	7/7/2021	5/7/2021	13/7/021	27/8/2021
Ending Data	3/7/2021	12/7/2021	7/7/2021	15/7/2021	15/9/2021

3.2.4 Data Preprocessing

The study included the application of both qualitative and quantitative analysis techniques. For the qualitative analysis, interpretations, comparisons, and arguments was employed, then descriptive and deductive statistical methods for the last.

The resulting images were analysed and processed using Agisoft Metashape software (a photogrammetry suite adapted for image processing). Agisoft is based on the Structure from Motion (SfM) method (Runeson & Lind, 1981) and multi-view stereo reconstruction methods (Scharstein & Briggs, 2001; Seitz et al., 2006). The orthophoto mosaic and the Digital Elevation Model (DEM) were generated from each study area. The data pre-processing was done in Agisoft Metashape software, and a manual map and classification were performed in the open-source software QGIS and the commercial ESRI ArcGIS software, respectively. The steps below detail a complete description of the SfM method used in Agisoft Metashape.

Structure from Motion Algorithm

The SfM algorithm was used to calculate the three-dimensional profile of the survey site from a sequence of overlapping aerial images and known UAV movements (Figure 5). The procedure is comprised of four steps as described by (King et al., 2017).

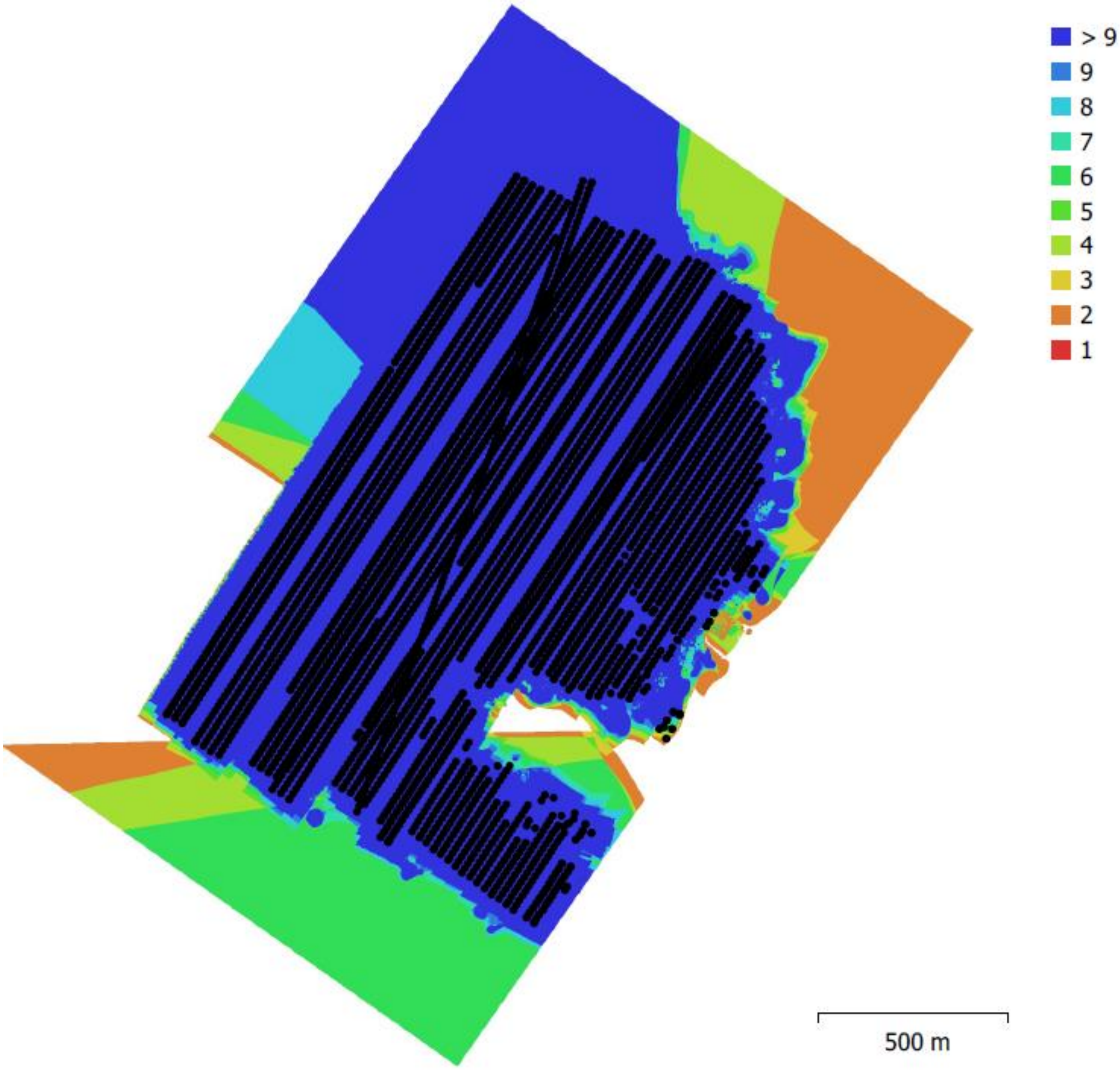


Figure 5: Automatic report of camera locations and images overlap at Baia generated by Agisoft Metashape. The black surface is the area covered by the drone. Each black point represents a camera shot. Blue areas indicate the highest overlap densities, and red areas correspond to low overlap densities. 80% flight overlap.

Arial Triangulation

The high-quality aerial images are aligned by detecting common points shared by at least 3 images. A sparse point cloud was then generated based on the estimated camera positions based on GPS coordinates optimization.

Optimization

Non-linear deformations within the model were automatically removed from the sparse point cloud; obvious outliers were also removed manually. High precision ground control points visible within the images are used to scale and georeferenced the point cloud.

Dense Cloud Surface Reconstruction

The pair-wise depth maps for each image were computed before being combined into a final dense point cloud used to construct a mesh in preparation for the Orthophoto Generation. Metashape allowed creating a dense point cloud based on the calculated exterior and interior image orientation parameters. Depth maps were calculated for the overlapping image pairs considering their relative exterior and interior orientation parameters estimated with bundle adjustment.

Orthophoto Mosaic Generation

The Orthophoto mosaic were generated by calculating the texture atlas for the model. The final meshed digital terrain model and Orthophoto mosaics were then exported.

Agisoft Metashape generated an orthogonalized photo mosaic and a digital elevation model (DEM) from nadir images collected in flight. The output models were georeferenced to the WGS84 datum in Agisoft Metashape Professional. The results of the photogrammetric dataset were to estimate different environmental variables at a site(Castellanos-Galindo et al., 2019) through supervised classification and digital maps.

3.2.5 Coastal Habitats Mapping and Classification

The four study areas were mapped but the classification was applied on Baia das Gatas map, and it covers a total area of 0.219 km². The manual method was first proceeded through photo interpretation, and new shapefile layers were originated according to the characteristics of the environment. The manual classification aimed to include all possible details of Baia.

As there was no other field data available at the early stage, this method has been chosen based on the shallow water and surface pictures collected with a camera to provide training and a validated dataset for the supervised Maximum Likelihood classification model. The manual map was generated in QGIS version 3.6, while the supervised pixel-based classification was made with ArcGIS 10.8.

The classification method applied, was the pixel-based approach. In pixel-based classification, each pixel in the image is analyzed according to the RGB bands. It is the traditional approach for classification since the pixel is the most fundamental (spatial) entity of the UAV image, and therefore it is natural and often easy to implement. Different algorithms are available in pixel-based classification, but the maximum likelihood method was applied in this study. Nine classes (Rocky shore, Coral, Algae, Water, Groyne, Beach, Barren-Land, Road and terrace, and Building) were defined according to the characteristics of the pixel values. Supervised classification was the technique used in this method. In supervised classification, the analyst guides the classification procedure by providing representative samples for each predefined class. The minimum number of points in the supervised classification was 6000, while the maximum was 150,000 points.

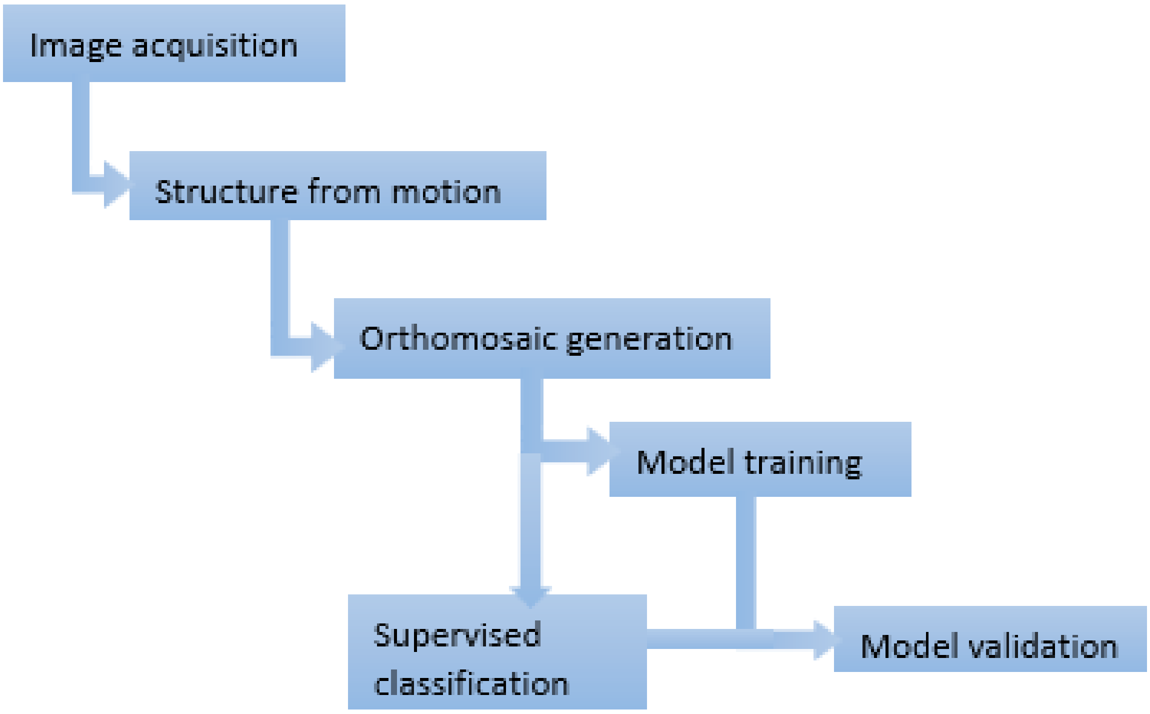


Figure 6: Processing workflow of the orthophoto mosaic image.

4. Results

4.1. UAV Mapping of São Vicente's Coastal Areas

The study areas showed different environmental, economic, and social aspects. Nevertheless, the sites have significantly different coastal characteristics, but all ware affected by natural factors and human activities.

4.1.1 Laginha

Laginha is located in the bay of Porto Grande. The orthophoto of Laginha has two particularities (Figure 7). One side is a white sandy beach and on the other side is an area framed by two groins. The other side extended to the shipyard, is home to many businesses, such as a desalination plant and a ship repair garage. Also, it is a bustling beach; hence the UAV should flow very early in the morning and avoid the crowd's presence. Due to the lack of a suitable RTK system, the whole flight was made without the ground control point. Waves and winds caused many distortions at the beginning of July. In addition, the water at Laginha showed low turbidity, which made easy to observe the bottom without much difficulty down to three meters on a single image **(**Figure 7b) and (Figure 7c). On the other side of the sandy beach, there is a community of coral which many species.

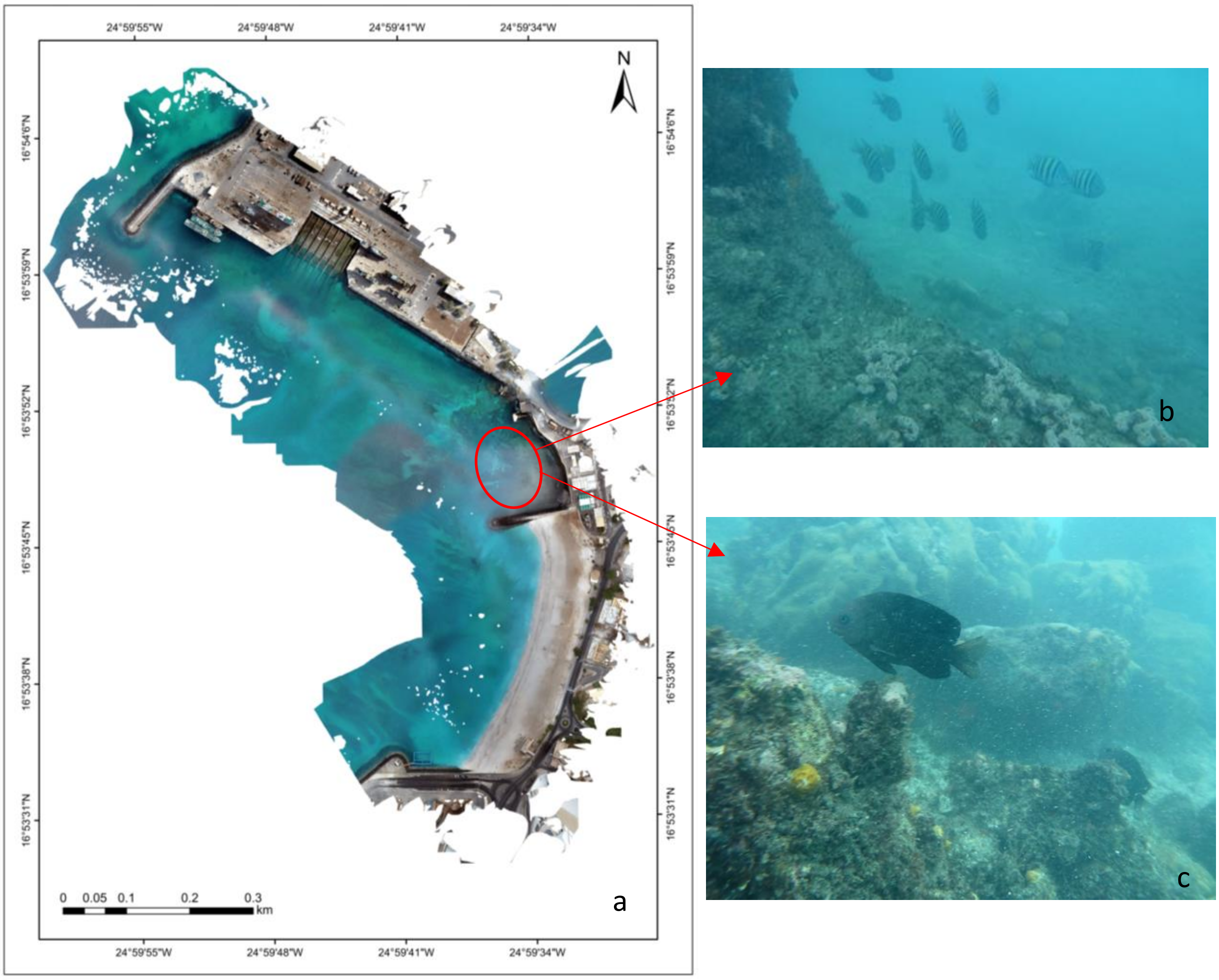


Figure 7: Laginha beach at Mindelo: a) orthophoto from drone images, b) a school of fish, and c) Coral

4.1.2 Salamansa

The figure below showed the mosaic orthophoto of Salamansa. It is on the northern coast of the island of São Vicente. On this map, some houses are observed in the village of Salamansa (Figure 9). This map presented huge deformations, and the water surface was almost invisible. It is undoubtedly caused by solid winds regularly blowing over the water creating strong motion. Salamansa is characterized by a coastal dune (8 and 9). There is a dune landscape in its western part and shrub vegetation on the eastern side.

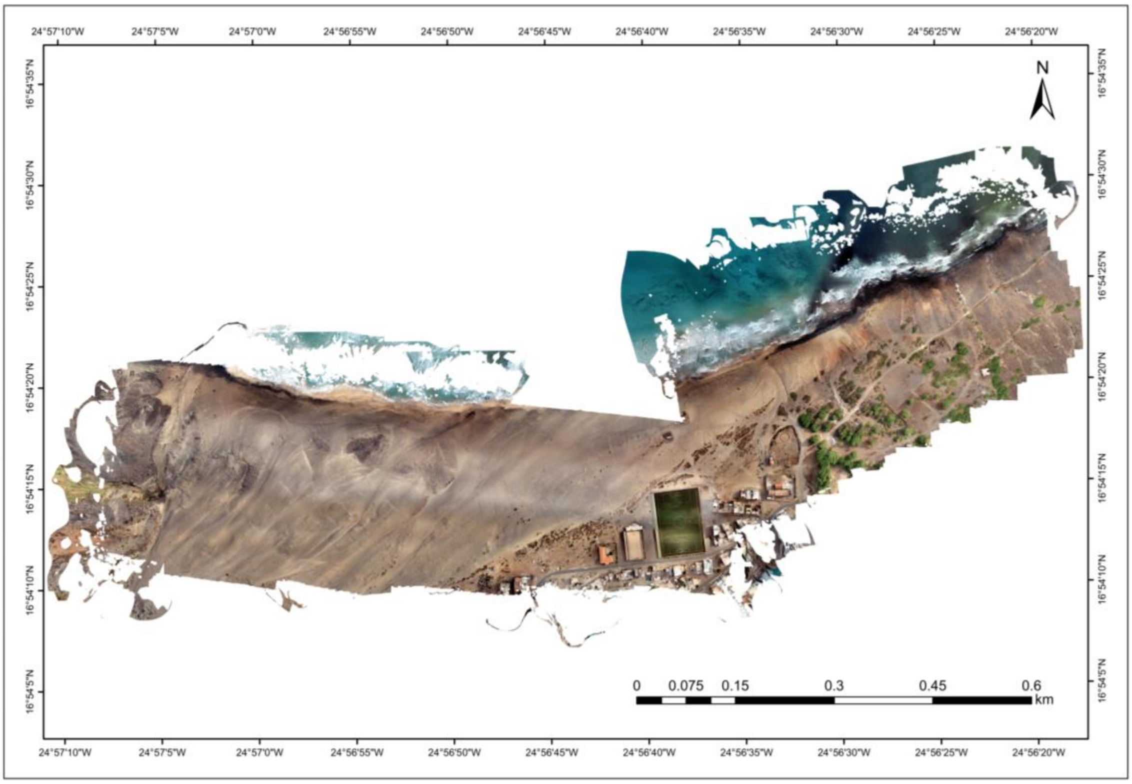


Figure 8. Orthophoto mosaic of Salamansa coast with strong waves caused images distortion.

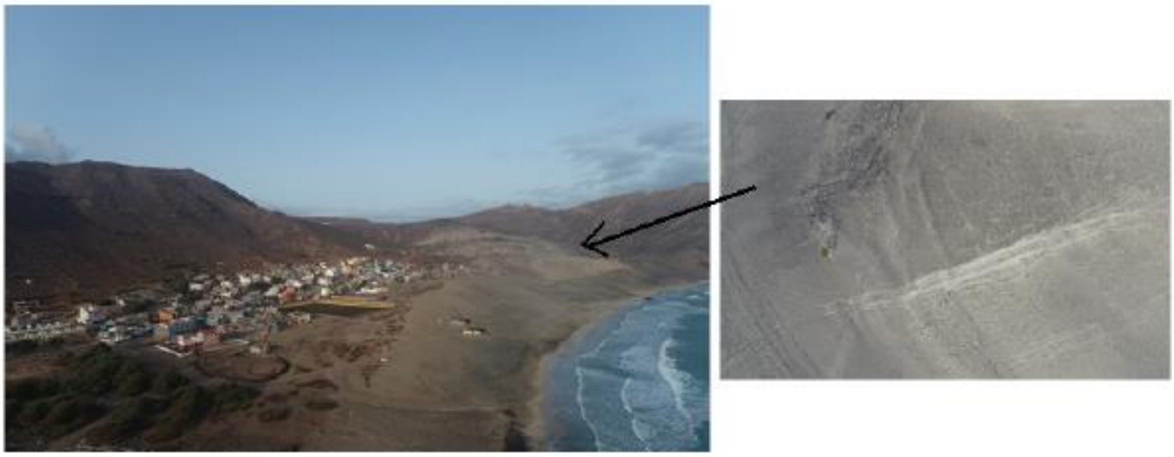


Figure 9: coastal dune at Salamansa. The village of Salamansa behind the dune.

4.1.3 Baia

Survey data collection at Baia were the easiest, and the field survey of this area was covered within two flight days. The clarity of the image was perfect inside the bay (Figure 10), but the impact of the waves on the map naturally delimits the bay. This figure presented more explicit images inside the bay but distorted images outside the bay. Black rocks shore is a barrier against which the waves crash (Figure 10). The red arrow showed the rocky shore.

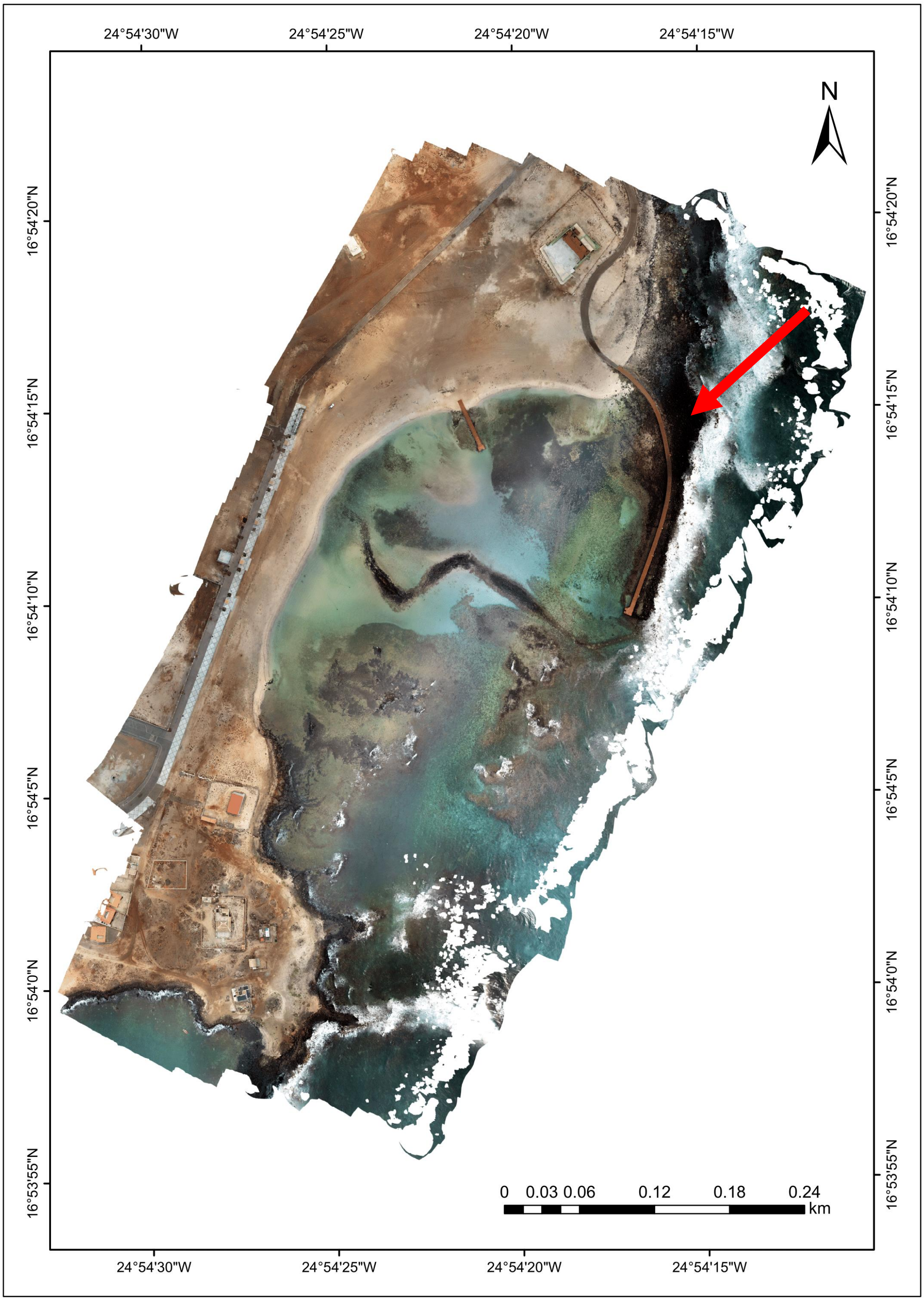


Figure 10: Orthophoto of Baia das Gatas. Red arrows showing rocky shore in black.

4.1.4 Calhau

Compared to the other study areas, Calhau presented an unprecedented singularity. The village is in direct contact with the ocean (Figure 11), with most of the inhabitants concentrated on the shoreline, bounded by the rocks. Although the waves were somewhat firmed, they did not degrade the quality of the image too much and the visibility was good.

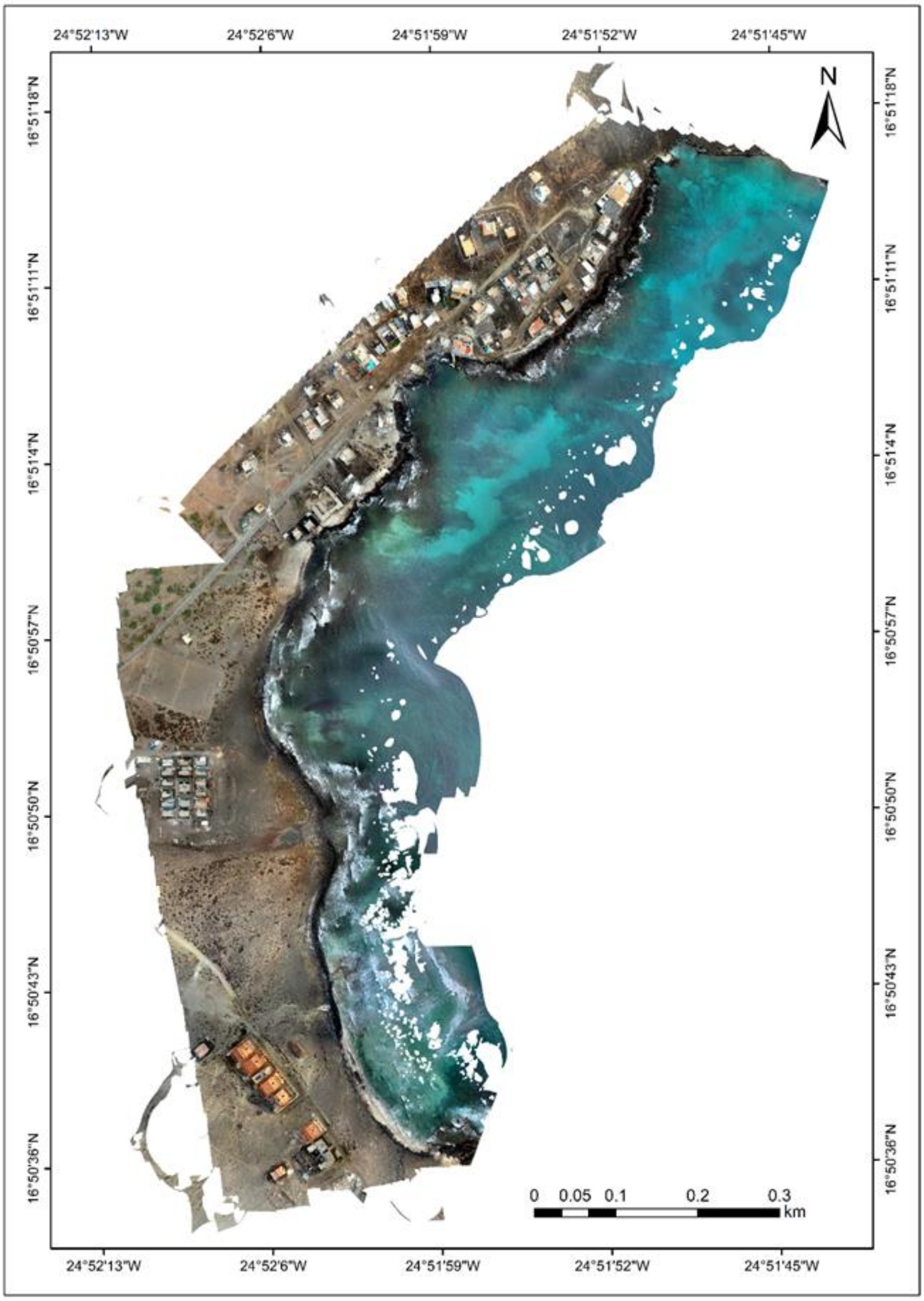


Figure 11: Orthophoto of Calhau's Coast.

4.2 UAV Feasibility Vs. Need

Our feasibility and need plot (Figure 12) showed the feasibility rate on the x-axis and the need rate on the y-axis. Each of the four study areas was represented by a colored dot. Thus, the blue point represented Laginha, the orange one is Salamansa, the grey point was Baia, and the yellow one showed the coastal area of Calhau. The figure indicated that all four survey areas have very high requirements 90 and above. However, the feasibility was at a variable level. Calhau had the lowest drone mapping feasibility rate, but Baia had the highest feasibility of about 100 and a need level of 100. The UAV collected around ten thousand images over a total area of 1.94 km² (Figure 16).

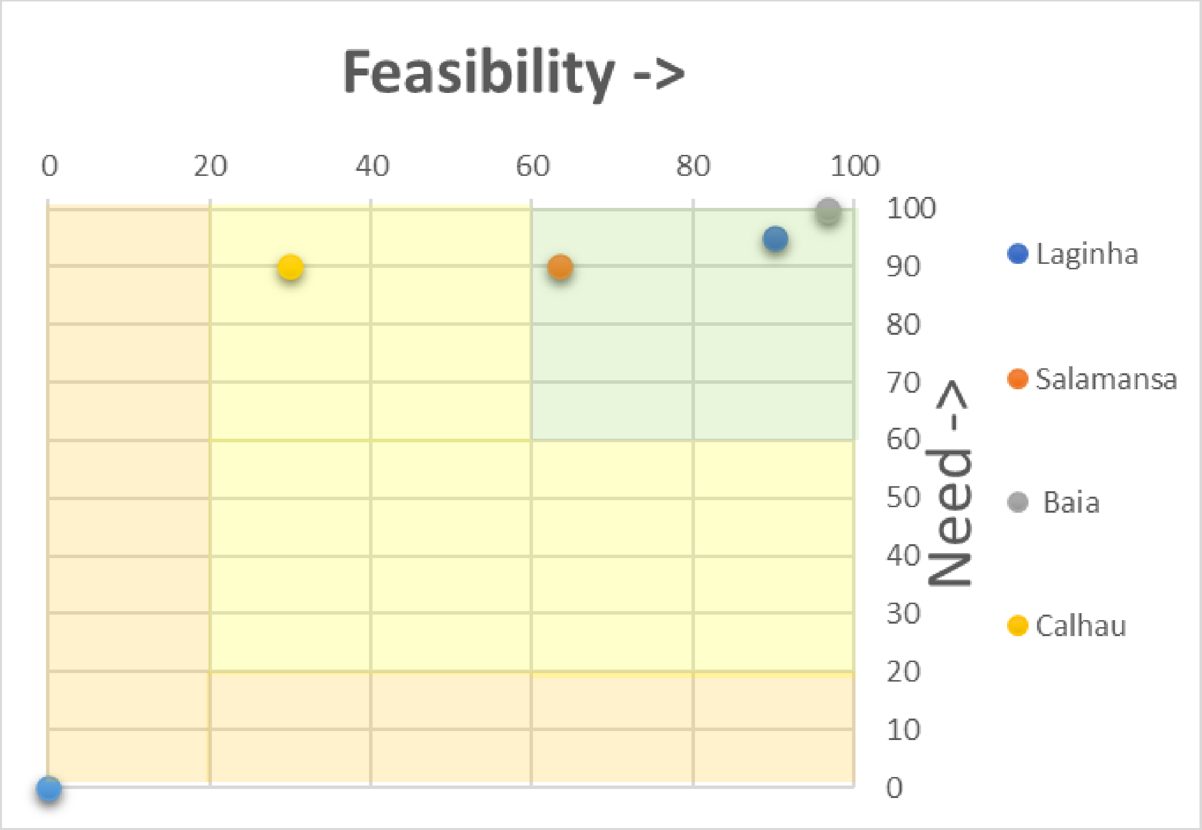


Figure 12: UAV Mapping in Cape Verde, Feasibility vs. Need.

4.3 Coastal Habitat Mapping

Figure 13 described the characteristics of the submerged habitats in Baia Bay. Coral and invasive algae could easily be identified on this map. It was observed that coral cohabits in symbiosis with algae. Thus, it is shallow water (not more than one meter in the period of high tide), the RGB camera was able to take clear images. Figure 10 mentioned in section (4.1.3) had made it possible to reproduce and obtain a base map for the classification data validation.

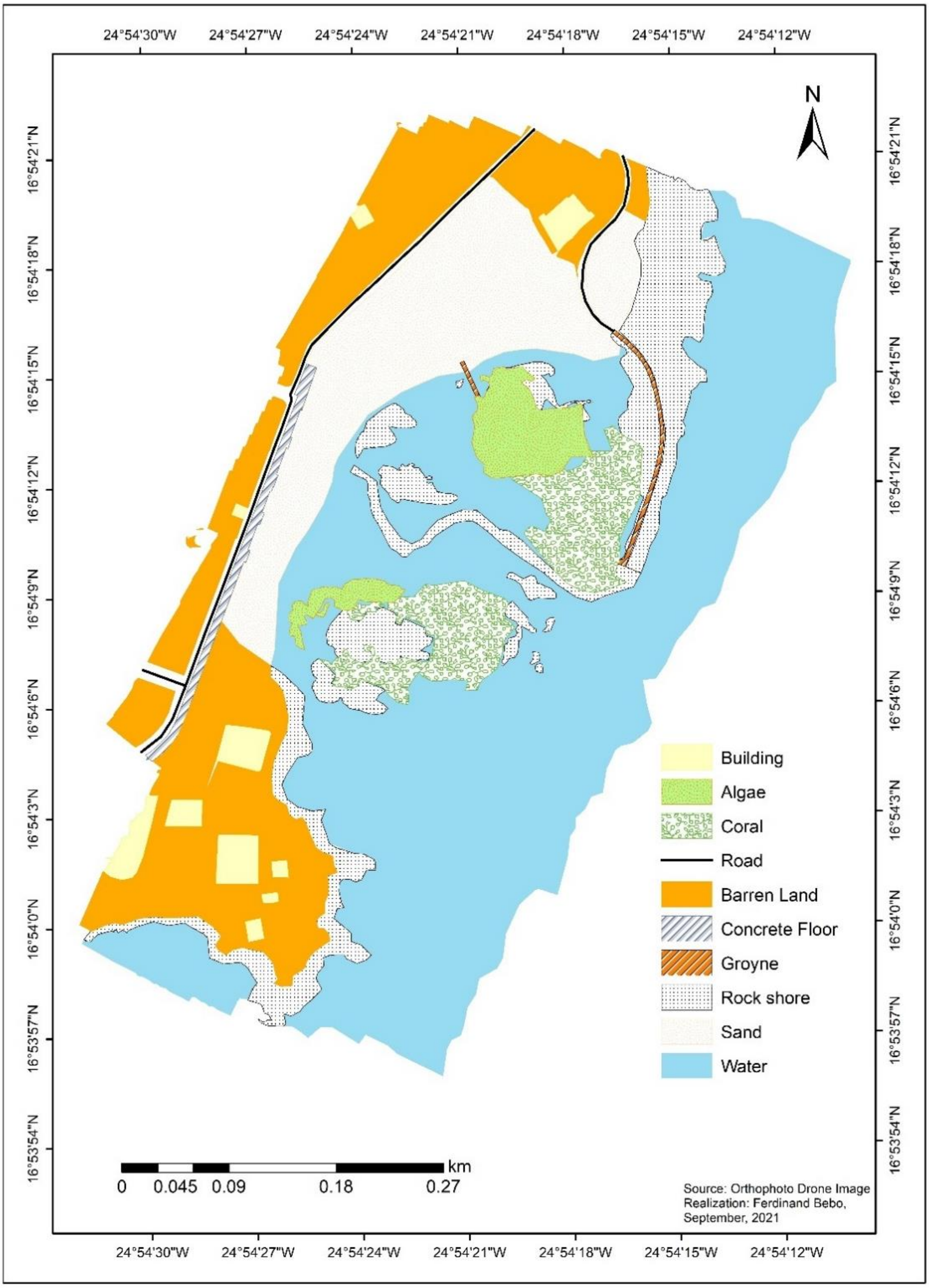


Figure 13: Baia bay map made from the mosaic image.

4.4 Comparison Between Supervised Classification and RGB Map

The supervised classification of the Baia marine and terrestrial area was carried into effect (Figure 14b), and it was compared with the RGB band image (Figure 14a). The result indicated that the classification did not achieve an excellent accuracy. Indeed, the model demonstrated that algae classification into green colours gave a good result regarding their proper distribution in the bay. The classification provided a high concentration of algae outside the bay (Figure 14b), but on the RGB image, verified in the field, these invasive algae in dark green and were less extensive. They are mainly clustered in the rocky areas of the bay.

As far as the spatial distribution of the corals in yellow is concerned, they were scattered evenly over the entire surface (Figure 14a). They are clustered more in the centre, inside the bay. Corals were also found in the North on the land part of the classified map. On the other hand, the corals were mainly identified on the dark-coloured bedrock in shallow water, with the RGB image supporting the ground-truthed data. The corals in pale yellow, live in symbiosis with green algae (Figure 15b). The conclusion that was drawn is that, the model did not give a good accuracy on the distribution of corals. As for the rocky shore, it was seen that the classification provided its real disposition on our RGB band.

The most significant confusion in the model is in the road-terrace variable, orange colour. The comparison between the RGB image with the classified image should not that the road-terrace variable had a good classification score on the land part. Still, it caused total confusion in the marine area. The method based on the pixel approach could not differentiate the road-terrace pixels from the wave effects and the water. Apart from the misclassification of road-terrace characteristics in the land area, bare ground, buildings, and beaches have better clarity same as it is observed on the drone's RGB image.

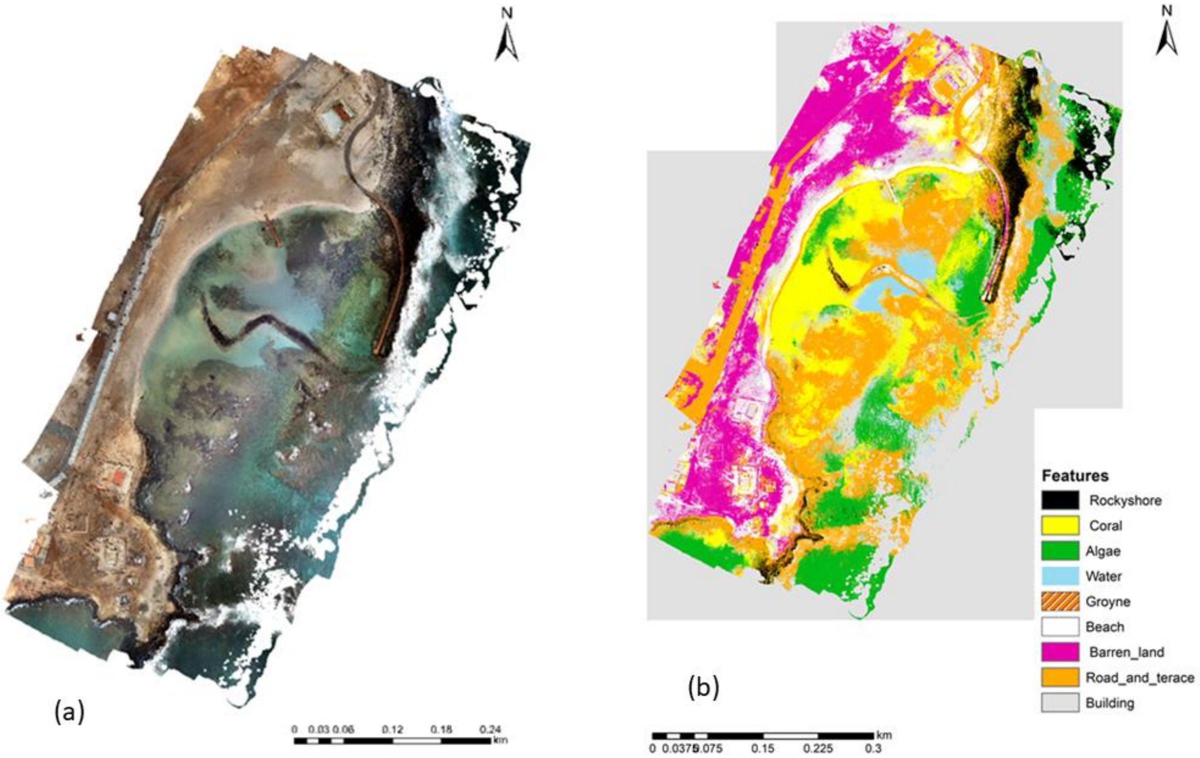


Figure 14: Images (a) and (b) showing RGB band and Maximum Likelihood Classification of Baia, respectively.

Figure 15: a) The Coral Siderastrea radians, and b) algae Caulerpa sertularioides with Cyanobacteria bloom.

5. Discussion

5.1 Feasibility Vs. Need of the Survey Areas

Coastal areas are often classified by their physical characteristics and grouped by their position to land and sea. These coastal environments are highly dynamic and productive and are socially crucial for environmental, economic, and social (Duffy, 2018). As observed in (section 4.1), these areas are overflowing with infrastructures such as the port, the desalination plant on the island of São Vicente, a ship repair unit.

Laginha beach is a part of the Porto Grande Bay with white sand, and it has a typical profile with a swash zone. Numerous infrastructures built or under construction surrounded Laginha, such as the Porto Grande, the groynes and seawalls shown in (Figure 8), boat repair, and water desalination factory, and not to mention that this beach is the most popular beach on the island. Many ecologists are interested in protecting the coral community found at Laginha(Ministros & Governo, 2019). All these elements mentioned above showed the changing nature of coastal areas.

The coastal area of Salamansa is essentially a sizeable fine dune with white and black colouring (Figure *8* and 9) on the western side and red soil in the eastern part. One of the particularities of this area is the strong waves that serve as a place for surfing and tourism **(**Figure 9**)**. In addition, this figure showed a coastal dune, forming a natural barrier to between the sea and the village, but this beach also serves as a hatching ground for the sea turtles that live there. Salamansa is declared an integrated tourism development zone and renewable energies development zone like the other coastal areas. Soon, Salamansa will home a golf course, hotel facilities, and approximately 200 hectares of renewable energy. Furthermore, the quality of the images was not so good due to the intense wind blowing and the strong waves, which affected the camera position.

The bay of Baia das Gatas shelter one of the most popular beaches on the island of São Vicente with its annual music festival, which attracts over 15,000 spectators over three days. The topography is relatively flat. However, numerous rocky outcrops act as sea walls to protect the coast from the waves. The bay hosts a coral reef community associated with algae in shallow water. The waves are stronger outside the bay, which created many distortions in the images.

Indeed, after surveys with Instituto do Mar and Instituto Marítimo Portuário officials, then documents from the Republic of Cabo Verde, it was possible to quantify the needs of the stakeholders and the scientific needs. In addition, this approach allowed us to assess the feasibility of conducting a drone monitoring study, taking into account water turbidity and wave action, and local regulations, as indicated in figures.

The plot (Figure 13) generated at the end of this short survey, showed that the four coastal areas of Laginha, Salamansa, Baia das Gatas, and Calhau need further scientific study. Furthermore, the involvement of all stakeholders such as public actors, private sectors, and researchers would allow more efficient and sustainable management of these areas. However, the feasibility of the study was not very consistent across all four study sites. The high waves in Salamansa and Calhau made it challenging to use UAVs as they can affect the quality of the images. Also, the visibility of the water column was not clear enough after the drone camera shots. From the above, the area of interest Baia das Gatas because of its ecological and economic importance. Still, Baia was chosen because it had the highest score for need and feasibility.

5.2 Coastal Habitats Mapping and Classification

The output of the work indicated that the application of UAV for coastal and marine habitat mapping in Cabo Verde in general and in particular in São Vicente is feasible. However, the meteorological conditions and the complexity of the areas in Cabo Verde must be taken into account. As no previous studies have been done on drone-based mapping and monitoring of coastal habitat on the island of São Vicente, similar studies were carried as referencing in other countries.

Although weather predictions can help to choose the appropriate times for drone-based surveys, it is essential to always check the weather conditions at the site on arrival, in particular the wind, and be conscious that these can change (Duffy, 2018). The process for obtaining orthophoto images described in the methodology worked well with Agisoft Metashape. The images quality from the drone-based equipped with an RGB camera was good. On the other hand, some distortions were noticed in the pictures of Salamansa and Calhau. In Baia, the shadow affected the quality of the mosaic images, which made the application of machine learning challenging for the classification. Therefore, considering the weather conditions in São Vicente, the best time to use a drone for scientific purposes is between June and September. The wind is relatively low between June and September, and the atmosphere is less distorted by fog.

The application of machine learning to classify coastal habitats was a delicate and challenging exercise. Thus, the supervised pixel-based classification was applied at the coastal area of Baia da Gatas.

The similarity between the pixel values was almost the same. In this manner, the barren land and roofs had nearly the exact pixel values at the land surface. The same similarity was found between road-terrace pixel values and the action of the waves at the water surface. The coral, mainly Siderastrea radians, had approximately the same pixel values as the water (Figure 14).

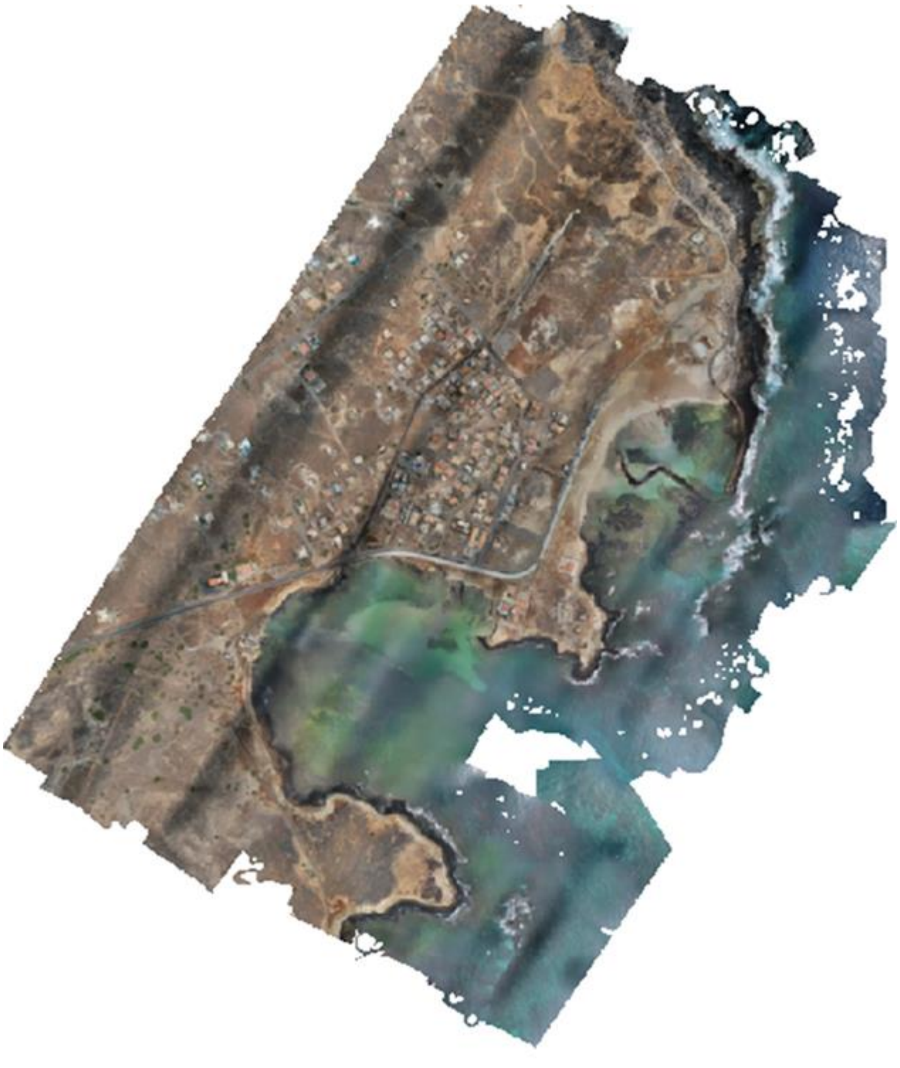


Figure 16: The orthomosaic of the village of Baia is affected by shading, making its classification difficult with the metho pixel approach.

Pixel-based remote sensing supervised classifiers using spectral information are applied on medium and low-resolution images and are often unsuitable for classifying very high spatial resolution data. The more satisfactory the spatial resolution, the greater the variance of the spectral values obtained within the land cover classes increases, making spectral partitioning between them more difficult, decreasing the classification's overall accuracy (Ventura et al., 2018). This statement corroborated sufficiently with the observation when the supervised classification by pixel approach of the study area of Baia went on. The RGB images and the pixel-based method hardly gave an excellent accuracy but the 70% accuracy was a good result.

However, according to (Yang et al., 2019), the other more appropriate method in complex areas is object-based classification. It generates image objects, which are deduced by dividing the entire image into small things depending on the image segments' shape, size, and spectral content.

Object-based classification generates classes at the object level, with suitable training samples and parameters, it can define objects at a local scale (Etter, 2019). This characteristic can be particularly useful in urban catchment studies such as the coastal zone in the survey areas at São Vicente, where multiple objects have complex spatial dispersion patterns. Compared to the traditional pixel-based classification models, which employs standardized pixels, object-oriented classification is more suitable for hydrological modeling and vegetation detection. Therefore, object-oriented imagery classification has been extensively used for automatic and semi-automatic image analysis (Yang et al., 2019).

The form and the size of objects in the images are significant components in object-oriented classification. There are some small bits of developed regions in the water body due to abnormal pixel values. On the other hand, the object-based classification method can model objects by considering their spectrum, shape, and relative location, which leads to more accurate results and a more precise delineation of the form of the objects. Moreover, most algorithms perform poorly in complex environments like Baia, because it is easy to have in the same class, a more comprehensive range of spectral characteristics than those generally found in a natural environment. The analysis of drone images is time-consuming because a single step can take hours or even days. But this time can be reduced with more powerful analysis tools. Hence the need for a powerful computer.

Indeed, the site chose for the drone survey at Baia is socio-economic but also ecological important for the island. Many projects of tourism development and renewable energy stations are in gestation in Baia das Gatas. These projects will undoubtedly lead to essential changes in the use of the land but also impact the coastal habitats of Baia. In addition, the corals, mainly

Siderastrea radians, live in symbiosis with algae (algae Caulerpa sertularioides with Cyanobacteria bloom) in shallow water (Ministros & Governo, 2019), suffering the effects of sea warming. Also, the beach of Baia is one of the most visited beaches of Sao Vicente, the coral and the algae, with them all the marine species, are regularly trampled by swimmers. Thus, the human presence causes enough stress to these coastal habitats.

6. Conclusions

At the end of this project, it noticed that the coastal and marine ecosystems of Cabo Verde are vulnerable. They are already affected by human aggressions such as overfishing, port and tourist infrastructures construction, and the dumping of sewage and solid waste in the ocean. In addition, there are the effects of global warming. Ocean warming drives coral bleaching and invasive algae that quickly adapt to this kind of environment. Thus, the results of this research allowed to evaluate the feasibility of using the drone in the mapping of coastal habitats of São Vicente. Indeed, the mapping of the coastal environment is feasible with the drone equipped with an RGB camera. The drone can be used effectively to implement of Planos de Ordenamento da Orla Costeira (POOC) projects in Cabo Verde. However, it is necessary to consider the meteorological and human parameters specific to each flight area. On the other hand, it is important to have a powerful computer and appropriate analysis tool to map and analyse drone mosaic orthophotos to quantify and qualify the status of these coastal habitats.

Thus, the protection and preservation of coastal and marine habitats become an emergency whose monitoring must involve all stakeholders in Cabo Verde: scientists, public and private decision-makers, and local communities. UAV approach is a rapid, efficient, and cost-effective method for obtaining small and large-scale estimates of habitat distribution.

This project will be studied in more detail in the future. Indeed, in Baia, the next step will be to apply the most appropriate classification method for this image to have high accuracy. Also, to collect accurate ground data, further analyse corals' spatial distribution and their health status. Additionally, the application of UAV will be extended to other types of coastal habitats in Cabo Verde, such as seagrass and wetlands.

The current stressors generated by human pressure are a real challenge for the conservation and sustainable use of marine and coastal habitats and a threat to national food security. Thus, marine biodiversity can objectively be a source of economic benefits for the sustainable development of the Cabo Verde Islands. Based on proper planning, marine and coastal biodiversity represents significant potential and can contribute and provide goods and services to the people. Given the existence of high marine and coastal biodiversity in Cabo Verde, in a relatively good state of conservation, and tourism as a critical sector for the country's development, this research proposes drone mapping to contribute to marine spatial planning. Marine spatial planning (MSP), through coastal monitoring using new technologies, can balance multiple and often conflicting human demands and protect the environment in a spatially and temporally explicit manner.

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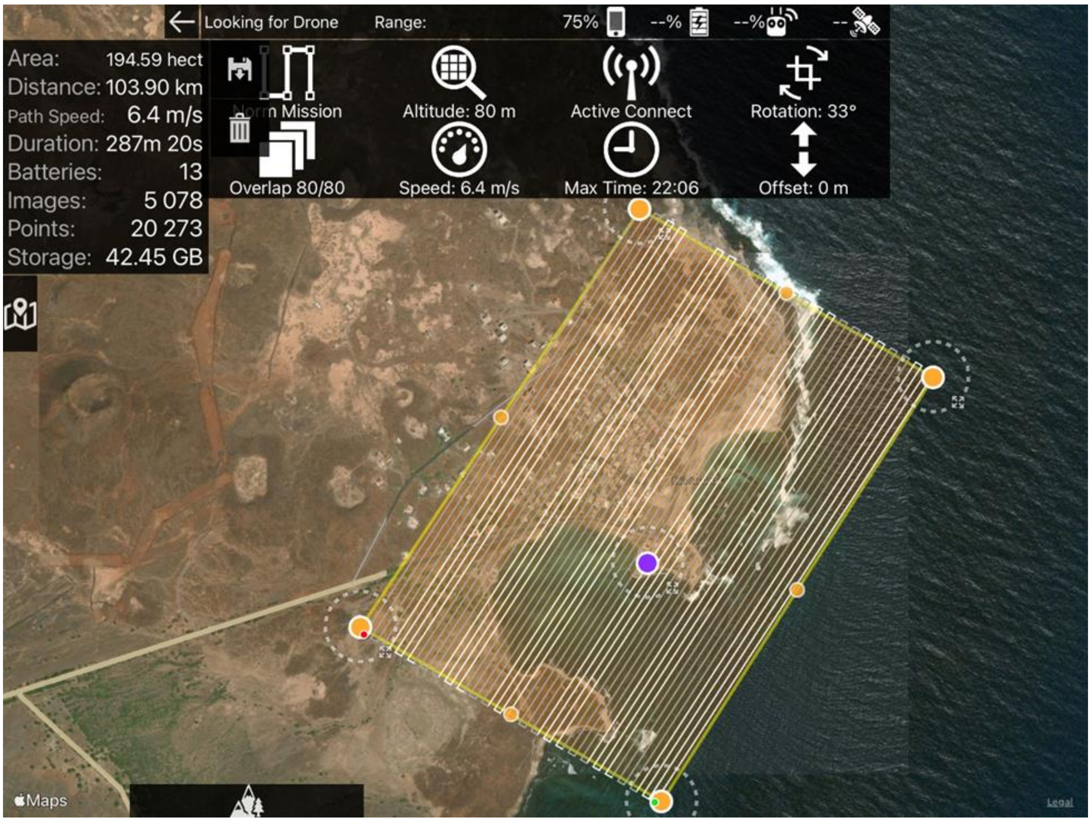
Appendix

Table 3. UAV Mapping CV: Feasibility vs. Needs

UAV Mapping CV					
Feasibility vs. Needs					
		Area 1: Laginha	Area 2: Salamansa	Area 3: Baia	Area 4: Calhau
Feasibility (Total)		**90**	**63.3333333**	**96.6666667**	**30**
Turbidity of Waterbody *(High Turbidity: 0 Low: 100*)		100	90	100	20
Wave Action *(High Waves: 0 No Waves: 100)*		100	0	100	0
Local Regulations *(Many Regulations: 0 No regulations: 100)*		70	100	90	70
Need (Total)		**95**	**90**	**100**	**90**
Scientific Need *(Score from 0-100%)*		90	80	100	80
Stakeholder Need *(Score from 0-100%)*		100	100	100	100
	Feasibility	Need			
	90	95			
	63.3333333	90			
	96.6666667	100			
	30	90			



Area: 194.59 hect
Distance: 103.90 km
Path Speed: 6.4 m/s
Duration: 287m 20s
Batteries: 13
Images: 5 078
Points: 20 273
Storage: 42.45 GB

Norm Mission
Altitude: 80 m
Active Connect
Rotation: 33°
Overlap 80/80
Speed: 6.4 m/s
Max Time: 22:06
Offset: 0 m

Figure 17. Details of mission plan at Baia

Figure 18: 3D structure from motion image of Baia.

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