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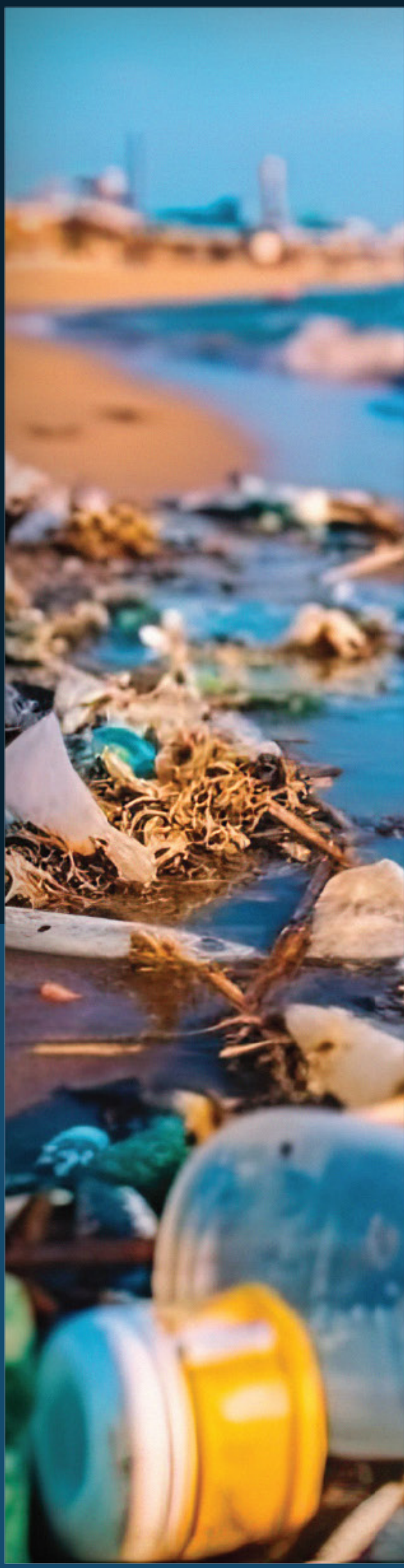

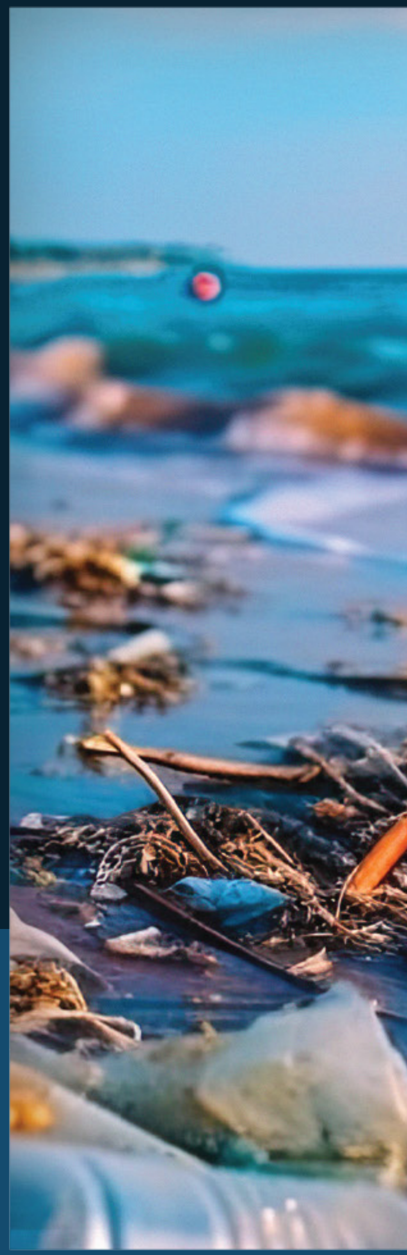

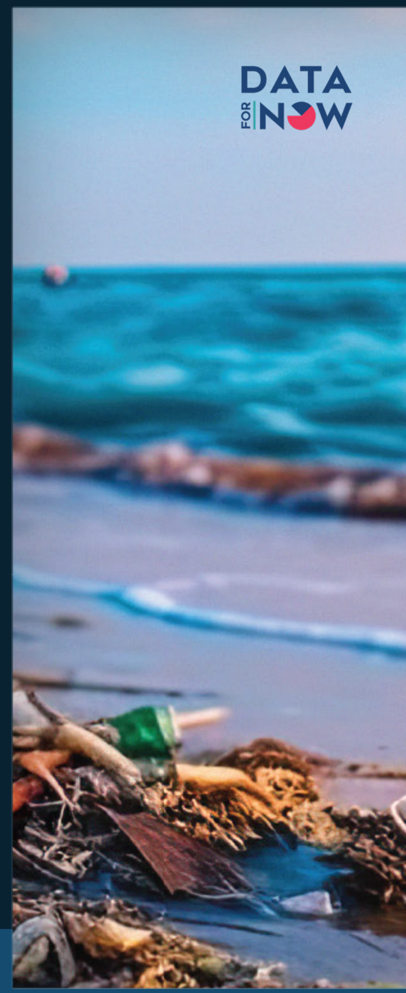

Feasibility study on marine litter detection and reporting in Ghana

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TABLE OF
CONTENTS

EXECUTIVE SUMMARY

Ghana produces an estimated 1.1 million tons of plastics annually. The buildup of plastic waste can increase chemical pollutants from microplastic particles that contaminate water sources and the soil, posing threats to both human health and the ecosystem. Accurate and timely data on the movement and density of plastic pollution flowing into marine areas is critical to local, national, and worldwide efforts to eradicate plastic pollution. New technologies and non–traditional data sources provide a window of opportunity to guide decision-making processes and combat plastic pollution effectively.

Drones capture images that can help detect plastic debris. During the GeoBlue Planet Symposium in 2022, a drone was deployed over a beach near Black Star Square in Accra. In a few minutes, the drone captured 40 images spanning a distance of 200 meters. The images were processed to generate a map highlighting the concentration of marine litter within the specified area. Leveraging this approach at a national level in Ghana can streamline the decision-making process by providing detailed information on litter accumulation zones or the type and size of debris, leading to accelerated responses and enabling more precise strategies for the management and mitigation of plastic pollution.

This report presents the outcomes derived from a feasibility study that thoroughly explores four scenarios for coastal mapping and marine litter detection: 1) mapping the entire coastline; 2) mapping three cities (Accra, Cape Coast, and Sekondi-Takoradi) and Ada once; 3) mapping Accra seasonally; and 4) mapping Accra once. This study, conducted by experts from the International Institute for Applied Systems Analysis (IIASA) and the University of the Aegean, involved the Ghana Statistical Service and Environmental Protection Agency (EPA Ghana) to create comprehensive maps of marine litter accumulation areas. The report also analyzes the technical, financial, and ecological dimensions of employing drone imagery, artificial intelligence (AI), and citizen science methodologies to collect data along Ghana's coastline.

The first phase of the work in Ghana, completed in 2021, aimed to demonstrate the potential offered by citizen science data for addressing marine plastic litter monitoring gaps by leveraging the framework of the Sustainable Development Goals (SDGs). As a result, citizen science data were integrated into the official statistics of Ghana and published in Ghana's 2022 Voluntary National Review. Drawing from this experience, this report underscores the essential role of skill development and the establishment of a robust knowledge base as foundational cornerstones for the successful implementation and progression of the feasibility study.

This innovative approach demands a multidisciplinary team comprised of individuals with varied skill sets encompassing advanced data analysis, artificial intelligence (AI), and environmental science, as well as citizen science and community engagement. Accounting for various factors, the scenario targeting densely populated locations better supports planning efforts and action in high-risk accumulation areas and thus considered to be the most optimized option.

Given the urgency of addressing data gaps on marine plastic litter, timely data, effective stakeholder engagement, cross-sector collaboration, and citizen engagement are critical to advancing this feasibility study. The innovative and integrated approach outlined in this report can also support the fulfillment of SDG 14.1.1b (measurement of plastic debris density) as well as informing policy formulation and action plans. The ability to harness the aforementioned innovative data sources, involve members of the public and communities in the process, and communicate findings in accessible formats, empowers people and communities, policymakers, and various stakeholders with the insights necessary for guiding sustainable practices.

CHAPTER 1

INTRODUCTION

Marine litter is a growing threat to the environment, health, and the economy, where plastics account for 85% of all marine litter (Haward, 2018; UNEP, 2021a; Nelms et al., 2022). It is estimated that from 19 to 23 million metric tons of plastics produced in 2016 have ended up in the aquatic environment (Borrelle et al., 2020). However, the real extent of the problem is unknown because of the extent of the oceans and the widespread distribution of plastics reaching the most remote locations around the world (Cózar et al., 2014).

About 80% of marine litter is considered to come from land-based sources (GESAMP, 2019), which is mostly due to inadequate collection and disposal (Kaza et al., 2018). For example, in Ghana, which is the focus of this report, only 5% of the estimated 1.1 million tons of plastic waste generated annually is collected and recycled (GPAP, 2021). This situation is of grave environmental concern as the coastal zones represent an important natural and economic resource for the country (Van Dyck et al., 2016). Fortunately, positive actions to help mitigate this problem are now underway. In 2019, Ghana became the first nation in Africa to join the Global Plastic Action Partnership (Government of Ghana, 2020; GPAP, 2021), and Ghana's Integrated Marine and Coastal Management Policy is currently under development (Olen, 2022).

Acknowledging the urgent need for global action, the United Nations Environment Assembly (UNEA) adopted a resolution in 2022 to end plastic pollution and to forge a legally binding agreement by 2024 (UNEP, 2022). Additionally, the Kunming-Montreal Global Biodiversity Framework and the UN Sustainable Development Goals (SDGs) address plastic pollution within their monitoring frameworks (UN, 2015, 2022). In particular, SDG target 14.1 is about preventing and significantly reducing marine pollution of all kinds, which is partially monitored through indicator 14.1.1b on plastic debris density, and recommends beach litter as an important indicator which countries should actively monitor and report upon (UNEP, 2021b). The global methodology for this SDG indicator also highlights that citizen science—defined as public participation in scientific research and knowledge production—can help to address data and monitoring gaps on marine plastic litter (UN, 2021b). The value of citizen science in marine litter research, however, goes beyond addressing data and monitoring gaps. It also includes removing litter through cleanup events and raising awareness of the importance of this issue (Martin, 2013; Hidalgo-Ruz & Thiel, 2015; Campbell et al., 2019). Despite this potential, there is still a lack of formal monitoring of 14.1.1b that incorporates citizen science as an official source of data.

The first phase of the Citizen Science for the SDGs project in Ghana, which was completed in 2021, aimed to demonstrate the potential offered by citizen science data for addressing marine plastic litter monitoring gaps by leveraging the SDG framework (Fraisl et al., 2023; Olen, 2022; UNDP, 2023). Building on a scientific study showing that 33% of SDG indicators can benefit from citizen science data (Fraisl et al., 2020), the project resulted in citizen science beach litter data being integrated into the official statistics of Ghana, published in Ghana's 2022 Voluntary National Review, and reported to the UN SDG Global Database as country-validated data (UN, 2021a; UN Ghana, 2022). Through the project, Ghana has become the first country to report on SDG indicator 14.1.1b using citizen science data. The results will also be used to inform Ghana's Integrated Coastal and Marine Policy. Finally, the project linked local and community level citizen science data collection efforts with the global SDG monitoring processes, which can set an example for citizen science initiatives working on this and other topics, from biodiversity monitoring to disease tracking.

In this second phase of the Citizen Science for the SDGs project, which ran between January and June 2023, the UN Sustainable Development Solutions Network Thematic Research Network on Data and Statistics (SDSN TReNDS) and the International Institute for Applied Systems Analysis (IIASA) have worked together with the Ghana Statistical Service (GSS), the Environmental Protection Agency (EPA Ghana), and the University of the Aegean to understand the feasibility of using drones, citizen science, and AI to collect data along Ghana's coastline, identifying marine litter hotspots—areas with significant accumulation of plastics. This integrated approach will help to better understand where the litter is concentrated and can complement the official methodology and data outlined in the SDG 14.1.1b methodology. It can also help to organize more targeted beach cleanup and data collection activities for subsequent SDG monitoring and reporting, as well as to have positive and far-reaching environmental and societal impacts.

This report presents the results of this feasibility study, including an analysis of the target area, and covers the technical, financial, and environmental aspects of such an approach. Case study results, findings, and recommendations are also outlined, including the potential scientific, environmental, policy and capacity building impact of a follow-up project.

CHAPTER 2
FEASIBILITY ANALYSIS

2.1. AREA ANALYSIS AND SCENARIOS FOR MARINE LITTER DETECTION

The coastline of Ghana stretches for approximately 560 kilometers (350 miles) along the Gulf of Guinea (Figure 1), which is part of the Atlantic Ocean, running from the border of Côte d'Ivoire on the west to the border with Togo on the east (Dei, 2010). It is known for its varied morphology, which is a result of several factors, including geology, ocean currents, and human activities. Along the eastern part of the coast, there are long sandy beaches that are ideal for swimming and water sports, and are popular tourist destinations. Some favorite beaches include Labadi Beach, Bojo Beach, Kokrobite Beach, Cocoloco Beach, Busua Beach and Ada Foah Beach. The central and western parts of the coastline, on the other hand, are characterized by rocky cliffs and rugged terrain with some beaches as well, such as Butre Beach and Cape Three Points Beach. These areas are less developed than the eastern beaches, and they are often inaccessible. However, they are important for biodiversity conservation, as they provide habitats for several plant and animal species. Some of the most notable areas of the rocky coastline include Takoradi, Sekondi and Shama, as well as the Cape Three Points Forest Reserve. In addition to sandy beaches and rocky cliffs, the Ghanaian coastline is also home to several lagoons, estuaries, and mangrove swamps. These areas are also important for supporting a diverse range of marine and coastal ecosystems, as well as providing habitats for migratory birds and other wildlife. Keta Lagoon, the Muni Lagoon, and the Songor Lagoon are examples of some of the most notable lagoons along the coast. In addition, Ghana has several marine and coastal protected areas, including the Ada Songor Ramsar Site, the Keta Lagoon Complex Ramsar Site, and the Ankasa Conservation Area.

Figure 1: Map of Ghana showing the coastline. Source: https://www.worldatlas.com/maps/ghana

In terms of human impact, the coastline of Ghana is home to several fishing communities and ports, as well as several cities and towns. The most populated coastal cities in Ghana are:

- **Accra:** the capital city of Ghana located on the coast of the Greater Accra region with a population of its coastal towns summing up to 658,272. Accra is a major economic and cultural center and home to several universities, museums, and other institutions.
- **Ada:** an area located in the eastern coast of Ghana with a population of 25,133 and home to the estuary of the Volta Lake and the Gulf of Guinea. Many beach resorts have been built in the area in recent years.
- **Cape Coast:** a coastal city located in the central region of Ghana with around 22,530 people. Cape Coast is known for its historical sites, including the Cape Coast Castle.
- **Sekondi-Takoradi:** twin cities located next to each other in the western region of Ghana with a combined population of around 94,697 people. Sekondi-Takoradi is an important industrial center and a major port. Takoradi is home to several oil and gas companies.

Given the size of the coastline, we propose four scenarios for mapping and hotspot identification as outlined in Table 1, along with the pros and cons of each scenario.

Table 1: Scenarios for coastal mapping to identify hotspots of marine litter (with pros and cons)

Scenario	PROS	CONS
Scenario 1 Full monitoring of the whole coastline (560 km), mapped once	• Provides a comprehensive understanding of the marine litter situation along the entire coastline of Ghana • Helps identify areas that are more prone to marine litter accumulation • Enables better planning for management and cleanup efforts along the entire coastline	• Can be costly and time-consuming to map the entire coastline • Requires a large number of resources, including drones, infrastructure, and personnel.
Scenario 2 Mapping the coastline around the three major coastal cities (Accra, Cape Coast, Sekondi-Takoradi, 50 km extent each), and Ada in the eastern coast of the country (50 km extent) once (covering 200 km in total)	• Provides a good understanding of the marine litter situation in areas with the highest population density • Provides a more representative assessment of the whole country • Enables better planning for management and cleanup efforts in the areas with the highest risk of marine litter accumulation • Requires fewer resources than scenario 1	• May not provide a comprehensive understanding of the marine litter situation along the entire coastline • Other areas of the coastline may be neglected, leading to unmanaged accumulation of marine litter
Scenario 3 Mapping the coastline of the capital Accra (25 km extent) four times per year (covering 100 km in total)	• Provides a regular understanding of the marine litter situation in an area with the highest population density • Enables better planning for management and cleanup efforts in the areas with the highest risk of marine litter accumulation • Requires fewer resources than scenario 1 and 2	• May not provide a comprehensive understanding of the marine litter situation along the entire coastline • Other areas of the coastline may be neglected, leading to unmanaged accumulation of marine litter
Scenario 4 Mapping the coastline around the capital Accra (50 km extent) once	• Provides a basic understanding of the marine litter situation in areas with the highest population density • Enables planning for management and cleanup efforts in the areas with the highest risk of marine litter accumulation • Requires fewer resources than scenario 1, 2, and 3	• May not provide a comprehensive understanding of the marine litter situation along the entire coastline • Other areas of the coastline may be neglected, leading to unmanaged accumulation of marine litter

Other scenarios are possible depending upon the objectives of a specific monitoring program.

2.2. TECHNICAL ANALYSIS
2.2.1 TECHNICAL REQUIREMENTS AND FEASIBILITY

A comprehensive solution for detecting, mapping, monitoring, and tracking marine litter along the Ghanaian coastline should integrate various technologies, such as drones, AI, and geo-visualization techniques, as well as citizen science. These requirements are outlined below.

DRONES

Large-scale monitoring relies on drones equipped with high-resolution optical cameras to collect data on marine litter. The drones must be able to fly over coastal areas and capture high-quality images, which can then be used to identify the litter. Additionally, the drones should have a long flight time, be able to cover large areas to maximize their efficiency, and work in different (as well as adverse) weather conditions operated by a team of skilled drone pilots. Finally, the drone systems must be accompanied by multiple batteries, which is crucial for extended flight durations, operational flexibility, and mitigating risks associated with power failures. This also allows for longer flight times, quick battery swaps, and uninterrupted data collection. Figure 2 below is an example of a drone image in Accra showing litter on the beach.

Figure 2. Example of drone image in Accra, Ghana containing marine litter items. Source: Coastal Marine Litter Observatory (CMLO), developed by the University of the Aegean and operated by SciDrones

DATA MANAGEMENT INFRASTRUCTURE

A central data management infrastructure is required, where the data collected by the drones will be uploaded, stored, processed, and analyzed. This infrastructure must possess the capability to handle large data volumes, provide secure data storage and backup, enable real-time data processing and analysis, ensure data security and privacy, and offer scalability and flexibility for future developments. In addition, a fast and reliable internet connection is crucial for efficient data transmission from the field to the data management infrastructure.

HUMAN RESOURCES

A team of trained personnel is required to operate the drones, collect the aerial images, and upload them into the platform for analysis. The team must be able to work effectively with local communities and stakeholders to promote the adoption and use of the system. Additionally, experts in geo-visualization are needed to create reports, and manage the system effectively. The latter team must have the necessary expertise in drone operation, data management, data analysis, and software development.

PLATFORM FOR ANALYSIS AND RESULTS

To process and analyze the data, a range of pre-processing algorithms, geo-visualization techniques, and machine learning and computer vision algorithms are required. These algorithms should be capable of identifying and quantifying different types of marine litter, such as plastic bags, bottles, and fishing nets, and be able to differentiate between litter and natural features such as seaweed and rocks. They also need to be capable of identifying litter items specific to the local context such as water sachets that are used to store and sell drinking water in Ghana, which may not be very common in other parts of the world. The web-based platform **Coastal Marine Litter Observatory (CMLO)**, a pioneer tool developed by the University of the Aegean and operated by the spin-off company SciDrones to detect and map the marine litter in coastal zones, which has a dedicated AI algorithm to analyze and classify the data collected by the drones, can be used (Papakonstantinou et al., 2021). The AI algorithm is capable of detecting seven categories of marine debris: plastics, rubber, metal, glass, paper, cloth/textile, and wood. The platform can also generate reports and provide insights into the types and quantity of litter detected, which can be used to inform decision-making. The platform incorporates all the pre-processing steps, and the machine learning algorithms can automatically detect and classify marine litter from the drone imagery and produce results: a) the detectable marine litter (points or squares containing litter), b) the litter accumulation maps, and c) the confidence level of the detection.

ACCURACY ASSESSMENT CAMPAIGNS

Accuracy assessment campaigns aim to evaluate and validate the accuracy and performance of the litter detection and classification based on the local context. These campaigns involve conducting field surveys and collecting ground-truth data to compare with the results obtained from the automated detection and classification algorithm. By comparing the algorithm's output with manually collected data, the accuracy, precision, and reliability of the detection will be assessed, allowing for continuous improvement and refinement of the system's performance. The insights expected from accuracy assessment campaigns will help ensure that the system provides reliable and trustworthy data for effective monitoring and management of marine litter pollution.

PUBLIC AWARENESS

The monitoring and mapping will rely on the participation and cooperation of local communities and stakeholders. Therefore, the system requires a campaign to educate the public on the importance of marine litter management. The public awareness campaign should be targeted at various audiences, including local communities, businesses, and policymakers.

CITIZEN SCIENCE

The project can leverage citizen science approaches in three different ways:

- → Flying the drones to collect aerial images and to upload them to the system for further processing
- → Collecting ground-truth data to compare the results from the AI algorithm with the data gathered from the field, to test the accuracy, precision, and reliability of the algorithm
- → Producing a reference dataset through the annotation of drone images to train the algorithm.

The first involvement deals with data collection and may be possible depending on the drone use and ownership by citizens in Ghana. The other two ways in which citizen science can be involved are valuable for further improving the accuracy of the results. All three approaches can also help empower the individuals and local communities participating in the project and support them to be part of the solution, while at the same time reducing data collection costs and facilitating public education and awareness on the importance of the marine plastics issue.

For the first approach it is necessary to have a local team responsible for flying the drones. This local team plays a crucial role in data acquisition and ensures the timely and accurate collection of aerial imagery. Overall, having a dedicated local team for drone operations and data collection is critical for the success of the project. Allocating resources to involve skilled operators, provide necessary equipment, and manage logistical requirements will contribute to the efficient and reliable collection of aerial images, enabling the project to achieve its goals in monitoring and managing marine litter pollution effectively.

For the second approach the existing volunteer groups and networks in Ghana, who participated in the first phase of the project, such as the **Smart Nature Freak Youth Volunteers Foundation**, can be leveraged. These groups organize cleanup activities involving the local communities using data collection tools designed by **Ocean Conservancy's (OC) International Coastal Cleanup (ICC)**. The ICC tools for data collection include the **Clean Swell** mobile app (Ocean Conservancy, 2023) and a data sheet (Ocean Conservancy, 2017). These data are then reported to **OC's Trash Information and Data for Education and Solutions** (TIDES) database (Ocean Conservancy, 2022) and are made openly available.

The third approach would require the use of a different tool that enables rapid classification of drone imagery. The **Picture Pile** tool, which allows visual interpretation of images such as those from satellites and drones, can be employed in this approach. More specifically, the use of Picture Pile in the project would provide large amounts of reference data that are needed for the training of the AI algorithm to improve its accuracy.

Table 2 provides the technical specifications for the four different scenarios, including the number of drones needed; the number of days needed to collect the data; how much imagery will be collected; and the number of accuracy assessment campaigns required. Table 3 provides an overview of the feasibility of the four scenarios based on the technology, equipment, and resources required.

Table 2: Technical specifications for the four scenarios

Scenario	COASTLINE TO BE MONITORED (KM)	NO. OF DRONES TO BE USED	ESTIMATED FIELD DATA COLLECTION DAYS	ESTIMATED NO. OF AERIAL IMAGES	ESTIMATED RAW DATA VOLUME (GB) *	NO. OF ACCURACY ASSESSMENT CAMPAIGNS
Scenario 1 Mapping the whole coastline	560	5	56	55,100	280	4
Scenario 2 Mapping three cities and Ada once	200	4	20	20,000	100	4
Scenario 3 Mapping Accra seasonally	100	2	10	10,000	50	4
Scenario 4 Mapping Accra once	50	1	5	5,000	25	1

** Based on the assumption of 5 MB size for each aerial image*

2.2.2 ENGAGEMENT WITH CITIZEN SCIENCE NETWORKS AND STAKEHOLDERS IN GHANA

During the first phase of the project, where existing citizen science data collected by citizen scientist networks and civil society organizations (CSOs) were validated and reused for official reporting in Ghana of the SDG indicator 14.1.1b, partnerships with local CSOs and networks were already established. Additionally, collaborations with relevant ministries and government departments were also built through several workshops organized by the GSS and EPA at a country level. These included the Ministries of Planning, Environment Science Technology and Innovations, Fisheries and Aquaculture Development, Sanitation and Water Resources, and the National Development Planning Commission, among others. The United Nations Development Program (UNDP) Ghana and the University of Legon were also involved in these workshops to share experiences and perspectives. The objective in the second phase is to leverage and broaden these connections, while also bringing in global actors such as the United Nations Development Programme (UNEP), who was also a partner in the first phase of the project.

Engagement with the government actors can aid in data collection, statistical analysis, official reporting, and public awareness activities, whereas the CSO and the academia partnerships can support citizen science efforts such as field surveys and image classification tasks, as well as the public engagement and awareness raising activities. Such an engagement can also support skills development and transfer of knowledge among the local partners of the project, such as in flying drones following the specific flight protocol to collect the data, and detecting and classifying marine litter on aerial imagery, which will help to create a large database with the types of litter that exist in the local context. Additionally, as part of the project, the local team will be able to learn, understand, and re-use marine litter categories, where their sub-classes will help with the mapping procedure to create marine litter maps using open geographic information systems (GIS) software. The local partners can also be trained to develop a dedicated AI algorithm devoted to local requirements. This knowledge transfer requires geo-visualization, remote sensing, and image processing experience. This means the addition of an educational "training package" that must be implemented simultaneously with the litter mapping and reporting.

Table 3: The feasibility of the scenarios based on technology, equipment, and resource requirements

Scenario	TECHNOLOGY	EQUIPMENT	RESOURCES
Scenario 1 Mapping the whole coastline	The project would require advanced drone technology capable of flying long distances, collecting high-resolution imagery, and processing large volumes of data. Other technology requirements may include software for data analysis and visualization.	The project would require a large number of drones, cameras, and other equipment to cover the entire coastline of Ghana. The equipment would need to be durable, reliable, and easy to transport.	The project would require a significant number of trained personnel to operate the drones and upload the data. Resources would also be required for the transportation of personnel, equipment, communication, and logistics.
Scenario 2 Mapping three cities and Ada once	The technology required would be similar to Scenario 1, but on a smaller scale. The drones and cameras would need to be capable of collecting high-resolution imagery of the coastline near the four main coastal cities.	The equipment required would also be smaller in scale than Scenario 1, but still sufficient to cover the coastal areas near the three main cities and Ada.	Fewer resources would be required than Scenario 1 but would still require trained personnel to operate the drones and process the data. Resources would also be required for the transportation of equipment, communication, and logistics.
Scenario 3 Mapping Accra seasonally	The technology required for this scenario would be similar to that required for Scenario 2, but the drones and cameras would only need to collect data seasonally. This would reduce the need for advanced drone technology and data processing software.	The equipment required for this scenario would be smaller in scale than Scenario 2, but still sufficient to cover the coastal areas near Accra.	Fewer resources than Scenarios 1 and 2 but would still require trained personnel to operate the drones and process the data. Resources would also be required for the transportation of equipment, communication, and logistics.
Scenario 4 Mapping Accra once	The technology required for this scenario would be similar to that required for Scenario 3, but the drones and cameras would only need to collect data once. This would reduce the need for advanced drone technology and data processing software.	The equipment required for this scenario would be the smallest in scale among all scenarios, covering only the coastal areas near Accra.	This scenario would require the least resources among all scenarios but would still require trained personnel to operate the drones and process the data. Resources would also be required for the transportation of equipment, communication, and logistics.

2.3. FINANCIAL ANALYSIS

The financial analysis of the study encompasses a thorough examination of all the financial aspects related to the research project. It entails assessing the budgetary requirements and analyzing the costs and expenses.

COST OF THE DRONES

The cost of the drones is a significant factor to consider in the feasibility of this approach. Drones vary in price depending on their features, capabilities, and intended use. Factors that influence the cost include the type of drone (fixed-wing, multi-rotor), payload capacity, flight range, camera quality, and additional features such as obstacle avoidance and GPS navigation. The cost of drones can range from a few hundred euros for entry-level consumer models to several thousand euros for professional-grade drones with advanced functionalities. A careful evaluation of the current requirements should result in drones that strike a balance between cost, and the necessary features to ensure optimal performance and data collection capabilities that are fit for purpose. Additionally, ongoing expenses such as maintenance, repairs, batteries, and accessories should be considered when estimating the total cost of owning and operating the drones. For the scenarios outlined here, consumer drones can be used (e.g., DJI Mavic 3 Enterprise). In any case, the drones that will be used for the project will be part of the equipment needed and will remain with the local partners, which is important for the sustainability of the project, along with the skills that will be developed and the knowledge transfer that will take place in order to fly the drones.

DATA COLLECTION

The cost of data collection in the field is a significant aspect of the feasibility. These costs include personnel costs for the field team, which may consist of researchers, technicians, and field assistants. Additionally, there are expenses related to travel and accommodation, such as fuel, rental vehicles, hotel accommodation, meals, and other incidentals. The local community will also be involved in data collection and uploading, which can potentially reduce costs associated with hiring external personnel. Instead of incurring expenses for wages or salaries, more resources could be allocated to providing training and capacity-building programs for the locals involved. All the data that will be collected as part of the project will be co-owned by the local partners, which is important for the local ownership of the project.

DATA MANAGEMENT

Data management costs encompass the expenses associated with handling, storing, processing, and analyzing the data collected in an efficient and secure manner. This includes investing in a robust server system, storage devices, and network infrastructure that is capable of handling the data load. Additionally, data management requires data quality control and data validation, cleaning, and standardization procedures to ensure data accuracy and consistency. Lastly, support and maintenance of the data management system should be considered. This includes allocating resources for system upgrades, troubleshooting, and technical support to ensure the smooth operation of the data management infrastructure. The server that will host the drone images will be placed in Ghana and handled by the local partners.

MARINE LITTER DETECTION AND CLASSIFICATION

The cost of marine litter detection and classification is an essential aspect to consider in the financial analysis. It includes the expenses associated with the implementation and fine-tuning of the AI algorithm that will be used for detecting and classifying marine litter, as well as generating results such as point maps, litter accumulation data, and detection confidence metrics. The fine tuning of the AI algorithm based on the local context is particularly important, as the types of litter found in Ghana may differ from other types of litter that are used to train the AI algorithm. For example, water sachets are quite common in Ghana, while in many parts of the world plastic bottles are used to store water. Implementation costs encompass the integration of the AI algorithm into the data management system and into the **CMLO web-based platform**. This involves coding, testing, and configuring the algorithm to ensure seamless operation within the existing infrastructure. An ongoing process of fine tuning the results for Ghana is crucial to ensure the algorithm’s performance and accuracy over time. This includes monitoring the algorithm’s performance, retraining it with new data periodically, and making necessary adjustments to improve its detection and classification capabilities. Furthermore, the cost includes the production of specific outputs for each monitored area such as point litter maps, litter accumulation data, and detection confidence metrics.

DATA ANALYSIS AND REPORTING

The cost associated with data analysis and reporting includes various activities and resources. First, the data analysis process involves processing and analyzing the data collected to extract meaningful information and identify patterns or trends related to marine litter. This may include applying statistical techniques to uncover valuable insights. Additionally, the data analysis phase may involve data cleaning and quality assurance to ensure the accuracy and reliability of the results. This includes addressing any data inconsistencies, outliers, or missing values that could impact the analysis outcomes. Once the data analysis is complete, the next step is to create reports summarizing the findings and presenting them in a clear and understandable manner. The cost includes personnel with skills and expertise in reporting, data visualization, chart generation, and creating narratives. The reporting phase also involves interpreting the results and providing recommendations or actionable insights based on the findings. This requires expertise in the field of marine litter and an understanding of the objectives of the monitoring and the stakeholder needs. All the products of the analysis will remain with the local partners and will help to identify the most polluted areas and target litter collection.

ACCURACY ASSESSMENT

Accuracy assessment campaigns involve conducting systematic assessments to measure the accuracy of the algorithm's results and validate its effectiveness in identifying and classifying marine litter. The cost of accuracy assessment campaigns includes various elements that involve the planning and organization of the assessment process: defining the evaluation criteria, designing the assessment methodology, and identifying suitable evaluation sites or reference datasets for comparison. Additionally, fieldwork costs are a significant component of accuracy assessment campaigns, including the cost of mobilizing personnel and equipment to collect ground-truth data on marine litter at specific locations. The expenses may cover travel costs, field data collection tools, and any necessary permits or permissions for accessing the evaluation sites. Data analysis and processing are crucial for comparing the algorithm's results with the ground-truth data. This involves extracting relevant metrics, such as detection accuracy, false positives, and false negatives, and performing statistical analyses to assess the algorithm's performance. The cost includes personnel with expertise in data analysis, software tools for data processing, and computing resources for carrying out the analyses. There are four accuracy assessment campaigns scheduled for Scenarios 2–4 and one for Scenario 1. However, because capacity building is an important component of the project, local partners will gain the necessary skills and expertise that will support the sustainability of the project and will prove helpful in other projects implemented by the local partners.

CITIZEN SCIENCE

Although citizen science approaches can help reduce the costs of official and/or environmental monitoring activities, they also come with a price, as they require an interdisciplinary team working on citizen engagement, motivation, app development and/or deployment, and data management activities. As (i) there are three different options presented regarding the use of citizen science approaches in the project (see 2.2.1) and (ii) four different scenarios highlighted with regards to the implementation of the project, and finally (iii) because the cost will also depend on the specifics that will be determined under each one of these three approaches and/or scenarios, it is difficult to estimate specific costs at this point. Local project partners will build capacity and develop skills within the community, teaching citizen science approaches and how to work with this type of data. This is very helpful for the project in the long run, as well as other initiatives that they are, or will be involved in, due to the increased use of citizen science in Ghana and beyond for official monitoring and reporting activities.

The full costing of each scenario will be made available upon request depending on the scenario and the citizen science approach chosen, but is subject to change. However, the capacity built as part of the project will help to reduce the costs of official monitoring of marine litter in the long run, mobilize public action on the issue, and achieve policy action, as well as being useful for addressing other sustainable development issues in the longer term.

2.4. LEGAL ANALYSIS

2.4.1 SECURITY

All drone operators shall adhere to the relevant state rules and procedures for the operation of unmanned aircraft. Regarding public security and protection of privacy and personal data, drone operators shall follow all relevant state regulations. To locate litter and produce litter-related metadata through the use of various AI algorithms, user-uploaded data (“images” and “datasets”) will be processed. These data may not always adhere to state regulations on public security and protection of privacy and personal data. As such, it is the responsibility of the drone operator to ensure that the relevant rules are adhered to. Non-registered users will be able to view generic dataset metadata only (e.g., the coverage of the dataset, a timestamp, etc.), whereas registered users will be able to retrieve additional data specifically related to their uploads, i.e., image footprints, raw images, and inference results. Any data that do not adhere to state regulations on public security and protection of privacy and personal data will be removed and will not be available to any user. Face recognition will not be performed and any methods to identify individuals will not be used.

2.4.2 ETHICS

The use of drones can raise ethical concerns in various areas, such as privacy, safety, and security. To address these concerns, several ethical principles and guidelines should be followed to promote responsible and ethical drone usage. Firstly, all drone operators shall adhere to the relevant state rules and procedures for the operation of unmanned aircraft in respect of privacy. Drones can capture images and videos of individuals and their property, which can violate their privacy rights. Drone operators should, therefore, respect people’s privacy and not fly drones over private property without permission. Additionally, people have a reasonable expectation of privacy while enjoying their time at the beach, and the use of drones to capture images or videos of them without their consent can be a violation of their privacy rights. Drone operators should, therefore, respect people’s privacy and not fly too close to individuals or capture images of them without their permission. Secondly, drones can pose a risk to people and property if not operated safely. Drone operators should, therefore, follow safety guidelines and regulations to ensure the safe operation of their drones. Thirdly, drone operators should also consider the potential impact of their drone usage on the environment and wildlife. Drones can disturb wildlife and cause damage to sensitive habitats if not used responsibly. Drone operators should receive training on all aspects related to flying drones, including technical, environmental, security, and ethics-related issues.

2.5. ENVIRONMENTAL ANALYSIS

While the project's primary objective is to monitor and reduce plastic pollution, it is essential to consider the potential environmental impacts of using drones for marine litter detection. One significant impact could be noise pollution, as drones produce a lot of noise when flying (Mulero-Pázmány et al., 2017). Noise pollution can affect marine life, particularly aquatic animals (Christiansen et al., 2016) such as fish and marine mammals that rely on sound for communication, navigation, and feeding. Therefore, it is essential to mitigate noise pollution impacts by scheduling drone flights during low tides when marine life is less active, or reducing the frequency and duration of the flights.

Another environmental impact of the project is the potential disturbance to bird populations, particularly seabirds (Hayes et al., 2021). Seabirds are known to nest in coastal areas and can be disturbed by drone flights. Such disturbances can disrupt their breeding, feeding, and nesting patterns, leading to population decline. To mitigate the impact of drone flights on bird populations, it is crucial to establish a no-fly zone around bird nesting areas or schedule drone flights during non-breeding periods.
The use of drones in the project can also lead to visual disturbance (Duporge et al., 2021). Drones can be intrusive and distract from the natural beauty of the coastal environment, negatively impacting recreational activities such as bird watching and beach activities. To mitigate the impact of visual disturbances, it is necessary to communicate with the public and stakeholders about the project's benefits, including its role in reducing plastic pollution in coastal areas.

Furthermore, there is a risk of drones crashing or malfunctioning, potentially causing harm to wildlife or damaging the environment. Drones also require the use of batteries, commonly of type lithium-ion, which can cause soil and water pollution if not disposed of properly. Relevant state regulations for drone operation should be adhered to and strict safety protocols should be implemented, including avoiding sensitive habitats and operating at safe distances from wildlife. Regular monitoring and maintenance of drone equipment will prevent malfunctions or failures. Additionally, it is essential to develop a battery disposal plan that complies with local regulations and best practices, such as recycling or proper disposal in designated facilities.

These potential environmental impacts will be compiled as part of a comprehensive environmental management plan, which will also identify measures to mitigate them. The plan will include measures such as noise reduction, bird nesting zone management (Santangeli et al., 2020), visual impact mitigation, and battery disposal plans, among others. Another measure to mitigate the potential environmental impacts of any drone monitoring program is to engage with stakeholders and the public throughout the mapping process. Engaging with stakeholders can provide valuable insights into any potential environmental impacts and identify areas of concern. This can also help build support for monitoring efforts and ensure that stakeholders are fully aware of any measures being taken to mitigate negative effects.

2.6. RISK ANALYSIS

The project has several potential risks and uncertainties related to drone use and aspects of citizen science that need to be considered. One major risk inherent in drone data is unreliable quality. It is important to follow the drone data acquisition protocol to avoid low-resolution images or corrupted data. Not doing so could undermine the effectiveness of the project and the accuracy of the data collected. Additionally, there is a risk that the drone flights may cause disruptions to other coastal activities, such as tourism, which could lead to conflicts or safety issues. Also, there are potential legal or regulatory risks, as drone operations are subject to a complex web of laws and regulations that can vary by location. There will also be the need to apply to the relevant authorities in the country for permission to fly drones as part of the project. Finally, there is risk of breaches in data privacy and security, as the system will be processing user-uploaded data and storing sensitive information.

To mitigate these risks, several measures can be implemented. First, a rigorous maintenance and quality control program can be put in place for the drones, including checks for compliance with the drone data acquisition protocol to minimize the risk of technical malfunctions and the acquisition of unnecessary or unusable images. Second, a ground-based team would work closely with local authorities and other stakeholders to ensure that drone flights do not cause any conflicts or safety issues. Third, legal experts can be consulted to help navigate the complex regulatory landscape and ensure compliance with relevant laws and regulations. Finally, robust data privacy and security protocols will be implemented to protect any user data. In any case, the objectives of the project and the roles of each of the partners, especially local partners, will be clearly articulated to obtain the necessary approvals and to ensure the smooth running of the project. These steps together will minimize any risks associated with the use of drones.

Risks associated with the citizen science components of the project should be considered for both ground truthing, which requires field visits to collect data, and for image classification tasks carried out via a web and/or mobile application. For ground truthing, the safety of participants should be addressed, and they should be informed of any potential risks associated with data collection, such as losing a mobile phone or visiting unsafe locations, as well as how to avoid these risks. In any case, already existing citizen science networks in Ghana will be leveraged for this form of data collection. This will help address such risks, as these networks have experience managing these types of data collection activities through volunteers, and they are highly familiar with the local context. Additionally, there may be risks associated with engaging youth who are minors. The citizen science networks in Ghana have experience working with minors and will take additional measures to prevent any potential associated risk, e.g., requiring that they are accompanied and supervised by an adult.

A potential risk related to the classification of drone imagery on a computer or smartphone is that local communities and individuals may have limited or no access to such technologies. This risk is more relevant to this kind of citizen science activity than the one described above, as data sheets are available in the event that participants lack a smartphone or internet for data collection in the field. However, if engaging with the local communities proves to be challenging, there is already an established community using Picture Pile (a rapid image classification tool developed by IIASA) that can support this specific activity.

Lack of participant engagement is a risk that applies to the majority of citizen science activities, including the two approaches outlined above. Understanding participant motivations while designing a citizen science project or campaign and keeping the tasks simple and appealing, such as by using gamification aspects and facilitating participant feedback throughout the project, can help to mitigate this risk (Fraisl, Hager, et al., 2022). Additionally, with the support of citizen scientist networks and CSOs in Ghana, the project team aims to reach out to as many and as diverse target audiences as possible, which will aid in addressing this risk.

Assuring data quality is another risk that is frequently encountered in citizen science projects. However, this is not a major concern for any of the citizen science activities presented here. This is because, as part of the first phase of the project, the GSS and EPA have already validated the data that they collected for official reporting of the marine plastic litter indicator 14.1.1b. For the image classification activity in Picture Pile, several data quality assurance and control measures are integrated into the tool to ensure the accuracy of the results. This includes training volunteers, providing feedback based on a set of expert classifications, and the multiple classification of each image by different participants, among others.

CHAPTER 3

DEMONSTRATION THROUGH TWO CASE STUDIES

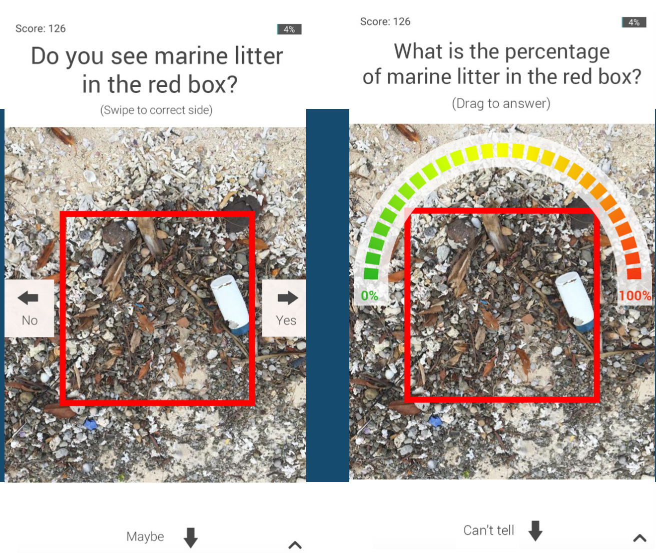
3.1 USE OF PICTURE PILE FOR CLASSIFYING DRONE IMAGERY

Picture Pile facilitates the visual interpretation of drone imagery, enabling volunteers to identify and mark marine litter within the images. The annotated images produced using the Picture Pile app can serve as a reference dataset for training AI algorithms (Fraisl, See, et al., 2022).

In a previous citizen science campaign, volunteers were asked to classify images taken by drones that were used to survey the Stomio coastline in western Crete. Examples of screenshots from the Picture Pile tool used in this campaign are shown in Figure 3. Figure 3a shows an example where volunteers classify images to establish the presence of plastic marine litter, swiping the image to the right if they see marine litter, to the left if no litter is present, and to the bottom if they are uncertain. Figure 3b shows an alternative version of Picture Pile for collecting continuous data, where volunteers dragged the image towards the percentage that reflected the amount of marine plastic shown in the red box.

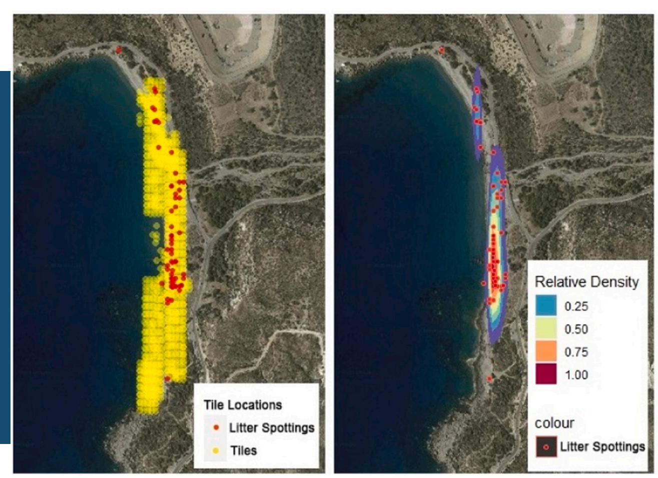
The drone was divided into a series of tiles, which are shown in Figure 4a as a set of yellow squares. Of the 1,215 images classified, most of the volunteers identified the presence of marine litter in just over 100 images, which are depicted by red dots in Figure 4b. A geospatial model was then used to create a marine plastic density map, also shown in Figure 4b (Fraisl, See, et al., 2022). Through this campaign, we demonstrated how Picture Pile can play a crucial role in enhancing the detection and reporting of marine litter, helping to create accurate plastic density maps to support informed decision-making and management efforts.

The ultimate aim of the Picture Pile data collection would be to provide citizen science inputs to a machine learning model for identifying marine litter from drone and satellite-based remote sensing, see e.g., Papakonstantinou et al. (2021). Note that the drone imagery can also be used by volunteers to count plastic items found in each image (of known size), which could provide supplementary data to beach cleanups and in situ citizen science projects, or could supplement and validate other methodologies used during beach cleanup campaigns, such as paper and pencil checklists.



(a) (b)

Figure 3: Screenshots from the marine litter campaign showing (a) a three category "yes," "no," or "maybe" data collection and (b) a continuous percentage data collection interface. Source: Fraisl et al. (2022).

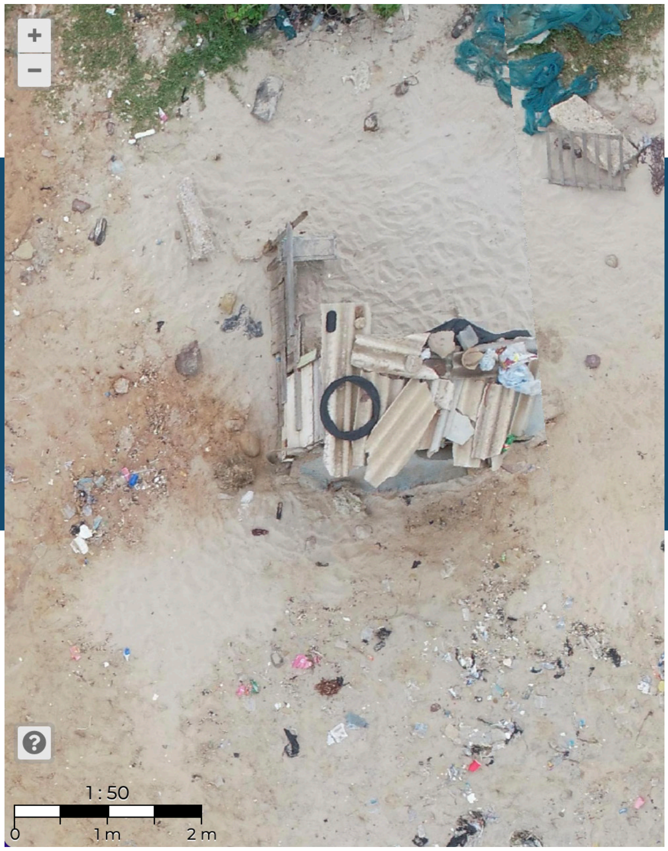


(a) (b)

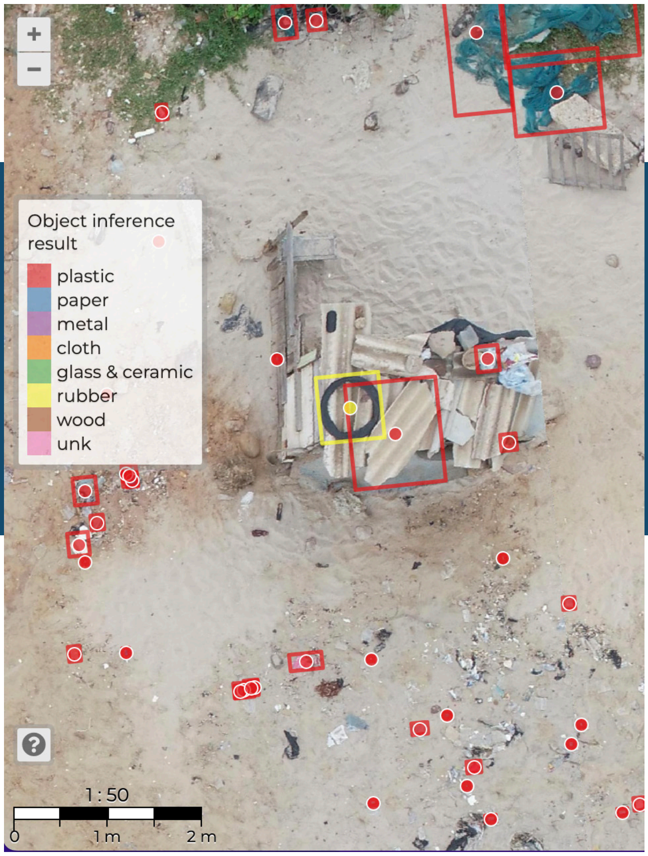
Figure 4: (a) Map of the location of the tiles provided to Picture Pile, including the ones where marine litter was identified, which was used to produce (b) a litter density map. Source: Fraisl et al. (2022)

3.2 DRONE MAPPING AND HOTSPOT GENERATION

To test the feasibility of using drone data for Ghana's coastline to produce litter density maps, a demonstration case was conducted at a beach near Black Star Square, located in the center of the capital city Accra. This demonstration took place during the GeoBlue Planet Symposium on October 25, 2022 (GEO, 2022). The drone used for the monitoring was a Phantom 4 Pro, operated by Ignatius Williams from the University of Ghana. During a flight lasting approximately 10 minutes, a total of 40 images were captured, covering an area of approximately 200 meters. An example of an image is shown in Figure 5a. These images were subsequently uploaded to the **Coastal Marine Litter Observatory (CMLO) system** (Papakonstantinou et al., 2021; Topouzelis, Moutinho, et al., 2022; Topouzelis, Papakonstantinou, et al., 2021, 2022a, 2022b). The system successfully detected plastic litter from the images, shown for a single drone image in Figure 5b, and a mosaic of images in Figure 6, which then generated a map showing the concentration of marine litter (Figure 7). These maps were then utilized for presentation and discussion purposes during the conference (GEO, 2022).



(a)



(b)

Figure 5. (a) Example of a drone image from a beach next to Black Star Square, Accra, Ghana, 25/10/2022 and (b) processed using an AI algorithm for point detection of plastics.

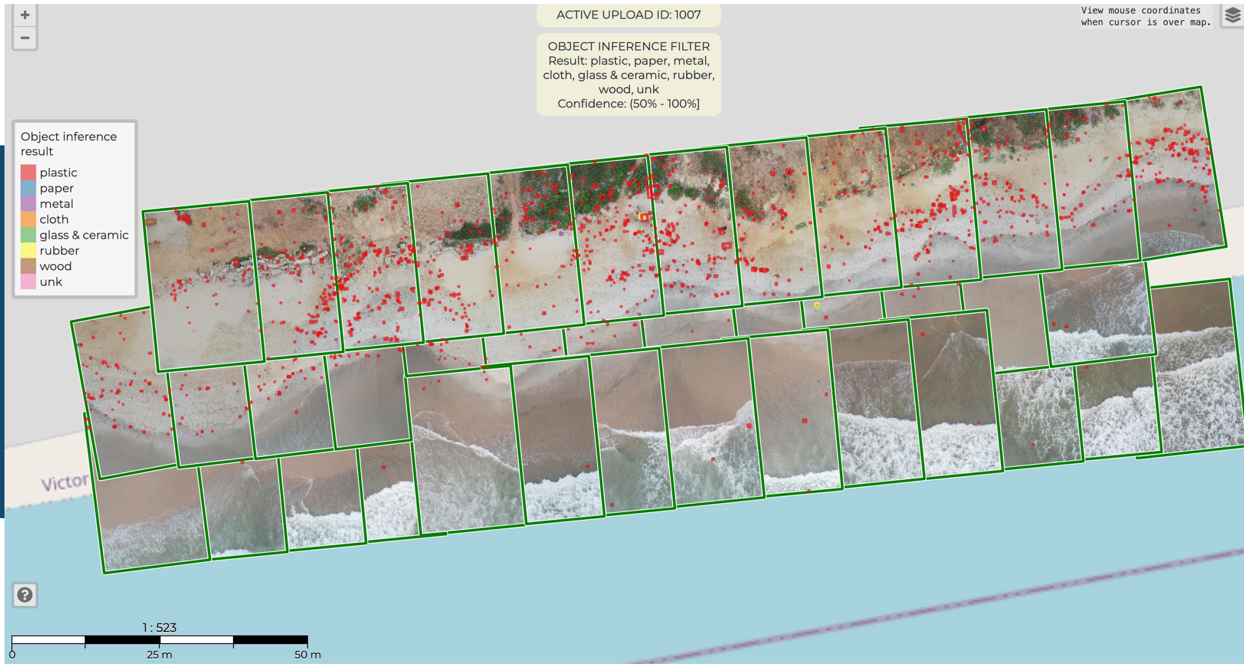


Figure 6: Example of the point detection of litter from several drone images (25/10/2022).

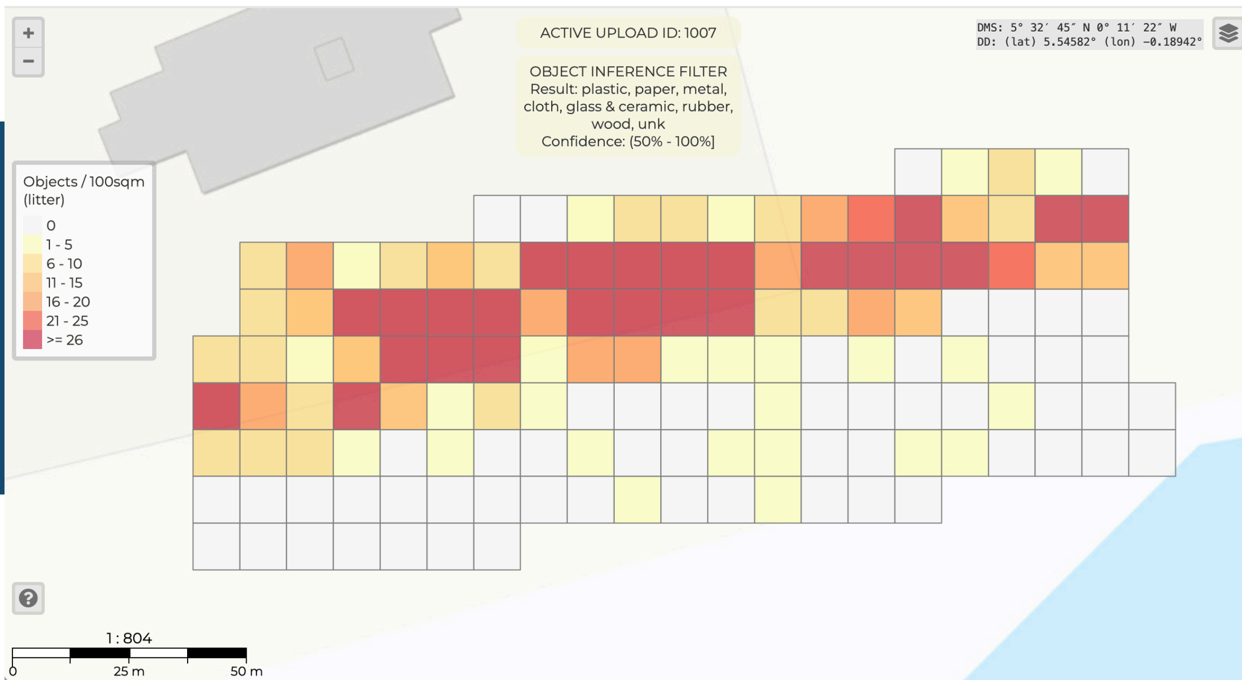


Figure 7: Example of a litter concentration map of a beach next to Black Star Square, Accra, Ghana (25/10/2022).

This approach plays a crucial role in identifying and providing information on litter accumulation zones, contributing to our understanding of marine litter pollution, and supporting targeted actions for its management. In Figure 7, the accumulation zone is clearly shown. By delineating these zones, this approach empowers stakeholders to make informed decisions and take effective measures in addressing the challenges posed by marine litter accumulation.

CHAPTER 4

FINDINGS AND RECOMMENDATIONS

Based on the scenarios presented in Table 1, Scenario 2, which suggests mapping the coastline around the three coastal cities (Accra, Cape Coast, Sekondi-Takoradi) and Ada once, each for about a 50 km extent, for a total of 200 km is our recommended option. This approach will provide a good understanding of the extent of the marine litter problem in areas with high population density in the country, while at the same time enabling better planning for management and cleanup efforts in the areas with high risk of marine litter accumulation. It also requires fewer resources in comparison to some of the other scenarios presented in Table 1, such as Scenario 1. Furthermore, including the eastern coast of the country, Ada, in the analysis will help improve the representativeness of the results according to the feedback from the project partners representing the GSS and EPA.

If the resources are insufficient to implement Scenario 2, Scenario 3 can also be a recommended option as a proof of context to demonstrate the potential of using innovative approaches including drone data, citizen science, and AI to address the data gaps related to marine plastic litter in Ghana. Although this scenario covers only Accra, which is less representative of the country than Scenario 2, it would provide a more complete overview, as seasonal variations in the plastic load can be detected for the coasts around Accra using this approach.

As for the potential of citizen science approaches, which can be leveraged in the project, we recommend using the Picture Pile application to produce a reference data set for the annotation of drone images to train the AI algorithm, which will improve the accuracy, precision, and reliability of the algorithm. The other two citizen science approaches presented in 2.2.1, namely flying the drones to collect aerial images and to upload them to the system for further processing and collecting ground-truth data to compare the results from the AI algorithm with the data gathered from the field to test the accuracy, precision, and reliability of the algorithm, would require more resources, and may bring additional risks, if not carefully implemented. These potential risks are related to the disruptions that the drone flights may cause to coastal activities such as tourism, or about potential conflicts and safety problems including the legal or regulatory issues and data privacy and security breaches as presented in section 2.4. However, there is value in applying all the aforementioned citizen science approaches if the time and resources allow.

This recommended way forward will connect the innovative approaches that are planned as part of this project with the previously implemented Citizen Science for the SDGs project highlighted in the introduction section, and further complement it. This is because producing litter density maps will allow for a more targeted approach for beach cleanups and data collection for 14.1.1b monitoring and a better evidence-based approach for policy making.

4.1 IMPACT

More specifically, the project is expected to have an impact in addressing the marine plastic litter data and policy gaps and needs in Ghana, which has been identified as a priority at a national level (Government of Ghana, 2020; GPAP, 2021). The approach implemented in Ghana can serve as a model for other countries that might want to develop a similar monitoring system for addressing their relevant data gaps. The methodological process applied in the project can also be used as guidance for integrating citizen science data into other SDG indicators.

Another important impact of the project is the knowledge transfer and skills development among the local partners. Skills development and the establishment of a robust knowledge base are fundamental for the project. Hence, the sustainability and the success of this innovative initiative depends on the existence of a local multi-disciplinary team equipped with a diverse set of skills, ranging from advanced data analytics and AI to environmental science and community engagement. More specifically, at the core of the skills development efforts of the project is the proficiency in operating and managing drones equipped with high-resolution cameras. Drone pilots will be well-trained to execute flights according to the standardized protocol, ensuring consistent and reliable data collection. Additionally, expertise in GIS is crucial for accurately processing, georeferencing, and analyzing the aerial imagery collected. Improving this skill set among local project team members will also be part of the project, which will allow for the creation of accurate litter density maps and hotspot identification in the longer term. To sum up, the project will support capacity building among the local project partners in analyzing aerial imagery; machine learning; operating drones; and handling and analyzing unstructured data, image annotation, and predictive modelling, among others, which may benefit the local team beyond this particular project.

In terms of the benefits of the infrastructure set up for the project for the local partners, all the data that will be collected will be owned by these partners, and the server that will host the drone images will be situated in Ghana. As for the marine litter concentration maps and the spatiotemporal analysis, all the products will remain with the local project partners and will help to identify the most polluted areas to target litter collection. These products will also guide the cleanup and citizen science efforts and support the official monitoring and reporting work at a national and international level, such as the SDGs, and monitor the status of the beach against plastic pollution temporarily. This approach and infrastructure set-up will have a long-lasting capacity building impact among local partners. Additionally, effective stakeholder engagement and collaboration require individuals with expertise in community outreach, communication, and policy advocacy, which will also be part of the skills developed among local partners. Such skills will help bridge the gap between scientific findings and actionable solutions, fostering partnerships with local communities, governments, non-governmental organizations (NGOs), and industry stakeholders. The ability of the local project team to convey findings in accessible formats, which is intended to be developed as part of the project, will empower decision-makers with the information needed to drive policy changes and sustainable practices.

The project can also have an impact on science, mainly through innovation and demonstrating the value of innovative and participatory approaches in scientific activities. Additionally, we would expect broader use of data collected by citizens in scientific research, as well as in policy making, with citizen science acknowledged as a valid and valuable approach that can produce high quality data complementary to the monitoring of sustainable development and official monitoring. The project is expected to contribute to scientific advances in utilizing citizen science for data-driven policy making. The results can help demonstrate that citizen science data can be integrated and mainstreamed into international policy frameworks such as the SDGs to complement official monitoring and broaden the use and reuse of citizen science data and tools, showing the effective use of open science and the transparency of data. The project can support advances in transferable quality frameworks and mechanisms, as well as data standards, and ultimately lead to an increased uptake of citizen science data and improved policies. The project is also expected to expose scientists and policy makers at all levels to innovation and new technologies for tracking progress towards sustainable development, which can then provide new opportunities for data collection and further citizen engagement.

Another expected impact is related to reduced costs associated with official monitoring. The official statistics community and governments continue to have doubts about the value of data offered by citizens. Some of this may be caused by an inability to handle heterogeneous data streams, and more evidence of the increased socioeconomic worth of data from different sources is required to address this issue. This project can contribute to greater stakeholder trust in citizen science data by putting in place effective data quality assurance and control procedures to align with official monitoring. The project as a case study can inspire a more inclusive approach to monitoring the marine plastic litter problem, as well as trust in citizen science data and new data sources and innovative techniques in general. This can, therefore, result in a greater appreciation of the usefulness of citizen science data for environmental monitoring and beyond, and more generically, for the monitoring of sustainable development, which would lower the cost of official monitoring for government agencies.

Finally, the project can have an impact on integrating innovative models that enable sustainability to achieve better informed decision-making processes, societal engagement, and innovation. It can help improve the availability and quality of data for environmental and SDG monitoring more broadly, which can support efforts related to sustainable development, as well as improving decision-making processes, emphasizing inclusive data ecosystems and citizen participation in decision-making.

CHAPTER 5

CONCLUSIONS

In this report, we presented the results of a feasibility study that aims to use drones, citizen science, and AI to collect data along Ghana's coastline for producing marine litter density maps. This innovative and integrated approach can help to improve understanding of where the marine litter is concentrated, and complement the official methodology and data outlined in the SDG metadata for 14.1.1b. It can also help to organize more targeted beach cleanup and data collection activities for SDG monitoring and reporting, as well as having positive environmental, societal, and capacity-building impacts.

Our results show that, considering the resources required and available, as well as other government priorities and timelines, the recommended option is to map once the coastline around the three major coastal cities in Ghana (Accra, Cape Coast, Sekondi-Takoradi, each with a 50 km extent); and in addition to these cities, to map the eastern coast of the country, Ada, also once, to improve representativeness; for a total of 200 km. Additionally, using the Picture Pile application, which allows for rapid image classification by volunteers to produce a reference data set to train the AI algorithm, is the most useful and beneficial way of integrating the citizen science component into the project, given the resources and time that can be made available for the project. The marine plastics density maps will then be used to target specific clean-up operations and gather data on marine plastics on the ground through existing citizen science networks operating in Ghana.

In the next phase of the project, the project partners will leverage this report for fundraising, and the Ghanaian government partners will use it for launching a nationwide stakeholder engagement activity in Ghana to agree on the next steps. As the project team, we welcome any suggestions and recommendations on the content of this report, as well as any comments related to the design and implementation of the next phase of the project.

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