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MONITORING OF WASTE ACCUMULATION ON THE BLACK SEA COAST OF ADJARA AND THE DECARBONIZATION PROCESS

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Abstract. The Black Sea faces significant environmental pressure due to coastal pollution, exacerbated by climate change and human activities. In Georgia, one of the primary pollution sources is the municipal landfill near the Chorokhi River, where waste decomposition leads to CO_2 and CH_4 emissions, increasing the region's carbon footprint. This study examines the use of drones for coastal monitoring, pollution mapping, and greenhouse gas analysis to enhance waste management strategies. To identify waste accumulation sites and assess emissions, drone-based aerial surveys were conducted, capturing high-resolution images and thermal data to detect pollution hotspots. Geospatial analysis was applied to map waste distribution, while air and water samples were collected to measure CO_2 and CH_4 concentrations. Additionally, pollution dispersion modeling was performed to analyze waste movement influenced by coastal hydrodynamics. Cadets and students participated in data collection and analysis, integrating environmental monitoring into their education. The study identified major waste accumulation zones and quantified greenhouse gas emissions, leading to recommendations for preventing waste from entering the sea. A database of polluted areas was created to support ongoing monitoring efforts. The findings confirm the effectiveness of drones in marine pollution surveillance and highlight the potential of automated monitoring systems in reducing the carbon footprint and enhancing environmental safety. Integrating students into this process promotes sustainable waste management practices and greenhouse gas reduction.

Keywords: Waste; Decarbonization; Monitoring; Drone.

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1. INTRODUCTION

The coastal region of Adjara on the Black Sea has seen increasing levels of pollution due to a combination of urban development, improper waste management, and climate-induced hydrological changes. One critical point of concern is the Chorokhi River, which acts as a conduit for solid waste from inland landfills directly into marine environments. This pollution not only degrades marine ecosystems but also contributes significantly to greenhouse gas emissions, undermining global decarbonization efforts.

Historically, environmental monitoring in the region relied on periodic manual sampling and tools like photometers to assess pollution levels. These methods, while valuable, lacked the spatial coverage and precision offered by newer technologies such as drones and GIS-based systems. The transition toward remote sensing and geospatial integration represents a significant evolution in the region's monitoring capabilities. In addition to technological limitations, longstanding anthropogenic pressures have compounded pollution risks. Population growth, increased maritime activity, urban expansion, and runoff from agriculture have collectively stressed coastal ecosystems, with the Chorokhi River frequently serving as a major transport route for waste into the Black Sea.

One critical point of concern is the Chorokhi River, which acts as a conduit for solid waste from inland landfills directly into marine environments. This pollution not only degrades marine ecosystems but also contributes significantly to greenhouse gas emissions, undermining global decarbonization efforts. This builds on previous studies presented at international conferences (e.g., IAMU 2022 and Prague 2021) [2, 4, 8], which highlighted the link between waste mismanagement, methane release, and eutrophication in semi-enclosed seas like the Black Sea. The IAMU paper emphasized the importance of regional collaboration and academic integration in environmental monitoring, which this study advances by incorporating both UAV technology and maritime cadet participation.

2. METODOLOGY

2.1. Drone Model, Parameters, Geospatial Software and Algorithms

DJI Terra Pro Overseas Permanent (1 Device), code: 97WOP328C2, is an official software from DJI, specially created for professional geospatial data collection and analysis using the drones. It provides the full pack of 2D/3D, Field / Urban / Large Area Mapping, Oblique Photography, KML analysis, etc.

DJI Terra Pro – How the algorithms work (process diagram):

A [Drone flight & image capture] --> B [Geotagging with INS/GNSS data]

B --> C [Pre-processing of images]

C --> D [Photogrammetric algorithms]

D --> E [Orthomosaic / 3D model / point clouds]

E --> F [Analysis & export to GIS formats]

Detailed steps:

1. **Drone flight & image capture**

   The drone collects images according to a predefined flight mission (e.g., Grid, Linear, etc.).

2. **Geotagging**

   GNSS and INS sensor data are used to accurately assign geographic coordinates to each photo.

3. **Pre-processing**

   Quality check of images; removal of blurred or poor-quality images.

4. **Photogrammetric algorithms**

   Structure from Motion (SfM): reconstructing 3D points by analyzing overlapping images.

   Multi-View Stereo (MVS): creating detailed 3D surfaces.

   Bundle Adjustment: optimizing camera positions and orientations to reduce error.

5. **Generating results**

   Orthomosaic: a geometrically corrected, map-accurate image.

   Point cloud: a dense set of XYZ coordinates representing the surface.

   Mesh and texture: a visual 3D model of the surface.

6. **Analysis & export**

   Use results in CAD/GIS software for mapping, volume calculations, inspections, and more.

2.2. Selection of Hydrodynamic Parameters by Drone and Model Validation

Research Goal:

To identify and verify hydrodynamic parameters that have the greatest impact on the accuracy and reproducibility of pollution dispersion models, based on data collected by drones.

Research Tasks:

Use drone (for example, DJI Terra Pro) collected geospatial and photographic data to assess hydrodynamic parameters;

Figure 1. Coastal area cleanup and water sampling

Analyze the influence of various parameters (flow velocity, wave height, wind direction, small stream structures, etc.) on the pollution dispersion results;

Validate the models with real monitoring data or historical data;

Define reproducibility indicators and propose ways to improve them.

Methodology:

Integrate hydrodynamic modeling software (such as MIKE 21, Delft3D) with data obtained by drones;

Test different scenarios in the parameterization process (changes in wave energy, flow direction, etc.);

Compare model predictions with actually recorded data (based on geotagged photos, video material, sensor data, etc.).

Expected Results:

Increased accuracy of hydrodynamic modeling results;

Improved reproducibility of pollution spread forecasts;

Recommendations for the validation and use of models in drone-equipped monitoring systems.

2.3. Air and Water Sampling

CO_2 and CH_4 levels were measured using portable sensors and water samplers at selected sites. These sites were chosen based on visual pollution indicators and drone-detected hotspots. Measurements were repeated over time to observe emission trends.

2.4. Observation Method

Cadets from Batumi State Maritime Academy participated in all fieldwork stages [3, 5, 6]. Their involvement included drone piloting, sample collection, data analysis, and the preparation of field reports, turning monitoring into an educational and capacity-building activity (Fig. 1).

Figure 2. Coastal zone of Adjara

2.5. Drone-Based Monitoring

Unmanned Aerial Vehicles (UAVs) equipped with RGB and thermal sensors were deployed along the coastline to perform regular surveillance [1]. The drones captured high-resolution imagery, identifying visible waste accumulation areas and potential sources such as river outlets and stormwater discharges (Fig. 2).

2.6 Geospatial Analysis

GIS software was used to map waste distribution zones, overlaying drone imagery with hydrodynamic models of current and wind patterns. This helped trace the likely movement paths of floating debris and sediment-borne waste

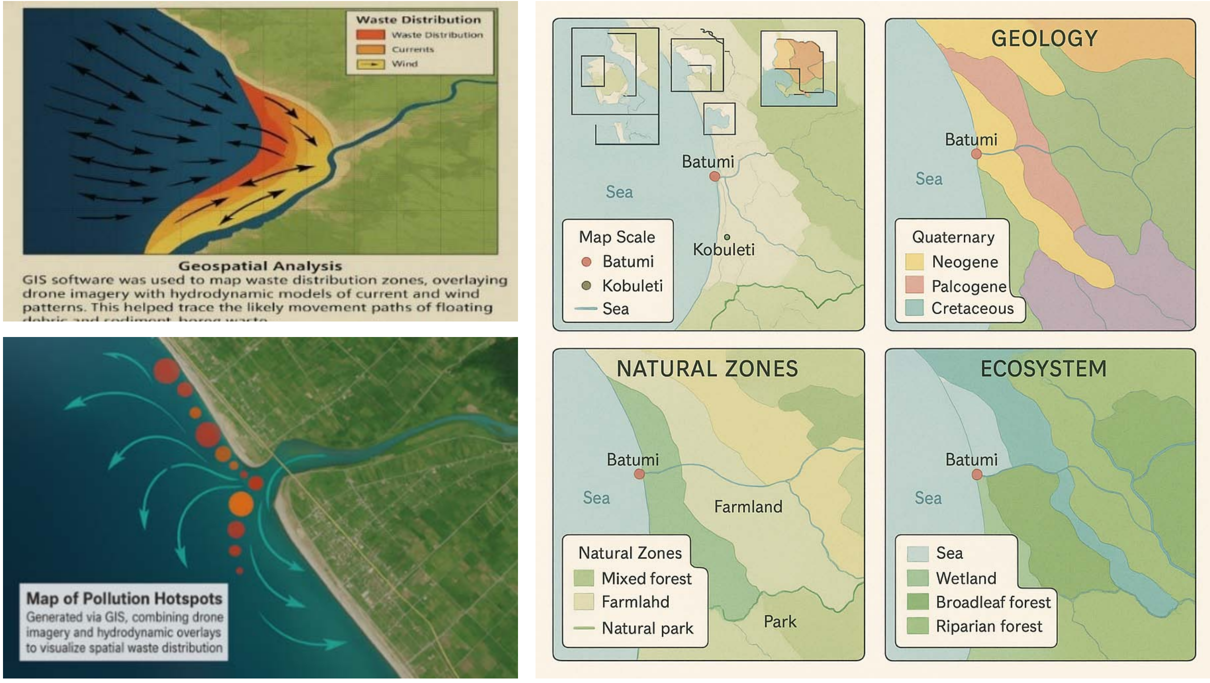

Figure 3. Geospatial Analysis, infographics

3. RESULTS AND DISCUSSION

The project revealed several critical insights:

Hotspots Identified: High waste accumulation was observed at the mouth of the Chorokhi River, the southern beach areas of Batumi, and near outflow canals.

GHG Emissions: Significant emissions of CO_2 and CH_4 were measured near landfill-adjacent water bodies, supporting the hypothesis that unmanaged waste decomposition contributes to greenhouse gas buildup.

Waste Drift Modeling: Simulated drift patterns showed seasonal variation in waste dispersion, affected by wind speed, wave action, and river discharge.

Educational Impact: Students showed increased awareness and technical capacity in marine environmental monitoring.

3.1. Identified Major Waste Accumulation Zones in Adjara

Through drone-based aerial surveys, ground inspections, and student-led field monitoring, the following waste accumulation hotspots were identified [4, 7]:

Mouth of the Chorokhi River: Large volumes of municipal and plastic waste were seen entering the sea due to landfill proximity. This zone showed severe pollution during flood events (Fig. 4). Southern Beaches of Batumi (Makhinjauri to Kvariati): These tourist zones suffer from peak-season littering and poorly managed waste disposal (Fig. 5).

Figure 4. Mouth of the Chorokhi River

Figure 5. Southern Beaches of Batumi

Stormwater Drainage Outlets near Batumi Boulevard: Waste from urban runoff, including plastics and food debris, accumulates heavily here (Fig. 6). Semi-enclosed Bays and Inlets like Gonio and Sarpi: These areas trap floating debris due to low water exchange, leading to chronic waste buildup (Fig. 7).

Figure 6. Stormwater Drainage Outlets near Batumi

Figure 7. Semi-enclosed Bays and Inlets like Gonio and Sarpi

3.2. Quantified Greenhouse Gas Emissions

GHG emissions were monitored using portable gas sensors at selected coastal zones [9]. Results are summarized below:

Table 1. GHG emissions

Monitoring Site	CO_2 (ppm)	CH_4 (ppm)	Observation
Chorokhi River Mouth	460–520	2,0 – 3,5	Highest emissions from landfill runoff zones
Batumi Southern Beaches	430–450	1,5 –2,0	Waste decay from seasonal tourism activities
Gonio-Sarpi Coastal Zone	420–440	1,0 – 1,8	Trapped organic waste in semi-enclosed waters
Urban Drainage Outlets	435–470	2,2 – 3,1	Anaerobic decomposition near waterlogged outlets

These measurements support the conclusion that unmanaged waste contributes directly to GHG build-up in Adjara's marine and coastal zones.

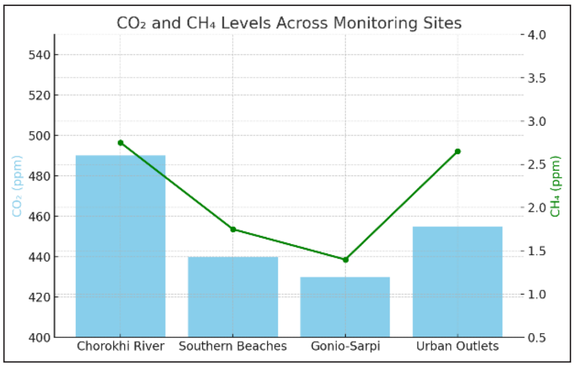

Figure 8. Chart: CO_2 and CH_4 Levels Across Monitoring Sites

4. THE DECARBONIZATION PROCESS IN THE SEA MARITIME CONTEXT

The process of decarbonization—reducing carbon emissions from maritime and coastal activities – is essential for mitigating climate change impacts and improving environmental health in coastal zones [8]. In the Black Sea region, port operations, shipping emissions, and inland waste incineration all contribute to the carbon footprint. The research conducted along the Adjara coastline identified several linkages between waste accumulation and carbon emissions:

- Burning of coastal waste (especially plastics and organic debris) significantly contributes to localized air pollution and CO_2 release.
- Diesel-powered port operations and ship maneuvers near Batumi contribute to greenhouse gas emissions.
- Lack of electrification and renewable energy use in coastal infrastructure prolongs fossil fuel dependency.

As part of the proposed environmental monitoring model, the following decarbonization strategies are recommended:

- Adoption of shore power (cold ironing) for vessels docked at Batumi Port to reduce emissions.
- Promotion of electric waste collection and sorting vehicles along the coast.
- Use of remote sensing and drone surveillance to monitor illegal waste burning and measure local emission concentrations.
- Integration of climate and carbon literacy into cadet training modules.

This integrated approach supports both waste reduction and emissions minimization, aligning maritime education with global sustainability goals such as IMO's GHG Strategy and the EU's Green Deal.

5. EDUCATIONAL AND ENVIRONMENTAL INTEGRATION

A major success of the study was the integration of scientific monitoring with maritime education. Cadets not only gained technical experience but also developed a deeper understanding of environmental stewardship. Their participation has been documented and included in BSMA's environmental curriculum.

The role of students in environmental monitoring has been emphasized in all previous publications. In this study, cadets collected samples, mapped waste, and produced analysis reports. A total of 18 cadets participated across three distinct field sessions held in spring and summer 2024. Each group was trained in drone piloting, GPS coordination, water and air sample collection, and GIS software use.

Among the practical results, cadets produced 6 geo-referenced waste maps and contributed to the development of the emission database now used in coursework at BSMA. Student-led documentation of polluted zones was instrumental in updating waste accumulation records used by local municipal services. These results reflect the earlier BSMA case study on "Citizen Science for Coastal Monitoring" (Poland, 2021), where student work led to enhanced public awareness and actionable environmental data.

One cadet participant noted, "This fieldwork gave me real insight into the environmental impact of shipping and coastal development—we weren't just studying pollution, we were measuring it." In this study, cadets collected samples, mapped waste, and produced analysis reports. This reflects the earlier BSMA case study on "Citizen Science for Coastal Monitoring" (Poland, 2021) [5], where student work led to enhanced public awareness and actionable environmental data.

6. CONCLUSIONS AND RECOMMENDATIONS

Drone-based monitoring and geospatial analysis offer reliable, cost-effective methods for tracking marine pollution and understanding its environmental impact. The integration of academic training with real-world application creates a sustainable model for ongoing monitoring and response.

- Implement routine UAV monitoring along the Black Sea coast;
- Strengthen waste management near riverbanks;
- Use GIS-based pollution maps in decision-making.

Expand student involvement in environmental monitoring initiatives.

Drone-based monitoring and geospatial analysis offer reliable, cost-effective methods for tracking marine pollution and understanding its environmental impact. This updated methodology integrates modern tools with academic training, offering a model for sustainable monitoring. Drawing on findings from the IAMU and previous BSMA-led projects:

- UAV monitoring should be standardized across coastal Black Sea zones.
- Pollution dispersion maps should guide municipal waste policy.
- Student-led monitoring is scalable and effective.
- Urgent cleanup efforts are needed at major river mouths, especially the Chorokhi River, to prevent waste from reaching marine ecosystems.

Thermal imaging combined with visual detection is recommended for high-accuracy waste classification, particularly in flood-prone or landfill-adjacent areas. and understanding its environmental impact. This updated methodology integrates modern tools with academic training, offering a model for sustainable monitoring. Drawing on findings from the IAMU and previous BSMA-led projects:

- UAV monitoring should be standardized across coastal Black Sea zones.
- Educational programs must integrate real data and sampling.
- Pollution dispersion maps should guide municipal waste policy.
- Student-led monitoring is scalable and effective.

Drone-based monitoring and geospatial analysis offer reliable, cost-effective methods for tracking marine pollution and understanding its environmental impact. The integration of academic training with real-world application creates a sustainable model for ongoing monitoring and response.

6.1. Policy and Governance

It is recommended that local governments adopt a regulatory framework requiring periodic drone-based waste audits for high-risk coastal zones.

An inter-agency working group should be formed in Adjara to consolidate data from academic institutions, local authorities, and environmental NGOs.

6.2. Community Engagement

Introduce community-based cleanup programs aligned with drone monitoring data, focusing on zones of recurrent accumulation. Educational outreach campaigns should be launched in schools and ports to build a culture of zero waste along the Black Sea coast.

6.3. Funding and Scalability

National and EU environmental funding mechanisms should be leveraged to expand the drone-GIS monitoring infrastructure. This model can be scaled to other Black Sea coastal regions such as Poti or Kobuleti to ensure uniform data coverage and action.

6.4. Data Innovation

Explore blockchain or cloud-based platforms for storing and sharing waste data across agencies and institutions. A mobile app could be developed to allow real-time reporting and visualization of coastal waste hotspots by citizens and cadets alike.

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