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MARITIME EDUCATION AND DIGITAL TECHNOLOGIES – THE NEW WAYS OF POLLUTION PREVENTION OF SEA ENVIRONMENT

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Abstract. Ensuring ecological safety in maritime operations requires modernized education that integrates digital monitoring technologies with practical training. This study proposes an educational model designed to enhance cadets' competencies in pollution assessment, marine pollution control, environmental protection, and ecological risk management in maritime transport.

The model consists of three core components: Field-based environmental monitoring – Cadets conduct water, air, and sediment sampling to analyze pollution levels. Digital tools for surveillance and data analysis – Unmanned aerial vehicles (UAVs) capture high-resolution imagery of pollution hotspots, while Geographic Information Systems (GIS) map and simulate waste distribution in marine environments. Curriculum integration – Digital monitoring tools are embedded into training through interactive simulations, real-time pollution assessments, and decision-making exercises.

Long-term observations have identified significant pollution sites along the Adjara coastline, reinforcing the need for advanced monitoring strategies. The study presents a structured educational framework that integrates digital technologies into maritime training, equipping cadets with the skills to assess environmental risks, comply with international ecological standards, and apply technology-driven solutions for pollution prevention.

By combining hands-on research with digital monitoring, this approach fosters an interdisciplinary learning experience, where cadets actively participate in scientific studies, environmental planning, and decision-making. This model strengthens their professional knowledge and enhances their ability to address ecological safety challenges and sustainable navigation practices.

Keywords: Maritime Education; Pollution Prevention; Digital Monitoring; GIS; UAV-Based Environmental Assessment.

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1. INTRODUCTION

Ecological safety in maritime operations is a growing global concern, especially in the face of increasing marine pollution, which threatens biodiversity, food security, and coastal economies. Maritime education institutions are uniquely positioned to address these challenges by preparing future seafarers with the tools, knowledge, and environmental responsibility required for sustainable navigation.

Traditional approaches to maritime environmental education are no longer enough. The rise of digital technologies, such as Unmanned Aerial Vehicles (UAVs) and Geographic Information Systems (GIS), offers new opportunities for pollution detection, risk assessment, and mitigation. Integrating these tools into educational programs enhances both the scientific understanding and the operational readiness of cadets.

This paper explores the development and implementation of an educational model at Batumi State Maritime Academy that embeds digital monitoring technologies into the training process. Through direct engagement in environmental monitoring activities—including field sampling, aerial surveillance, and geospatial mapping—cadets acquire practical skills in pollution prevention and ecological risk management. This innovative approach aligns with international environmental standards and supports the broader decarbonization goals in the maritime sector.

2. RESEARH OBJECTIVES AND AIM

The primary aim of this study is to develop and implement an innovative educational model that integrates digital technologies into maritime training programs to enhance cadets' competencies in environmental protection, pollution monitoring, and ecological risk management.

This study is guided by the following objectives:

- To design a maritime education model that combines practical environmental monitoring with digital tools such as UAVs and GIS.
- To actively engage cadets in real-world pollution assessment through field sampling, drone surveillance, and geospatial mapping.
- To improve environmental awareness and strengthen the professional capacity of future maritime officers in line with international ecological standards.
- To contribute to the broader goal of decarbonization through climate-focused education and digital innovation in maritime curricula.

This framework addresses the growing need for sustainable practices in the maritime sector and equips cadets with the interdisciplinary knowledge and digital skills necessary to tackle contemporary marine pollution challenges. The primary aim of this study is to develop and implement an innovative educational model that integrates digital technologies into maritime training programs to enhance cadets' competencies in environmental protection, pollution monitoring, and ecological risk management.

3. METODOLOGY

3.1. Field-Based Environmental Monitoring

Cadets conducted sampling of surface water, air, and bottom sediments at selected coastal sites. These locations were chosen based on proximity to urban outfalls, industrial discharge zones, and river mouths [3, 6] (e.g., Chorokhi and Jochostskali rivers). Standardized scientific procedures were followed to ensure reliable environmental data collection. Cadets conducted sampling of surface water (Fig. 2), air, and bottom sediments at selected coastal sites. These locations were chosen based on proximity to urban outfalls, industrial discharge zones, and river mouths (e.g., Chorokhi and Kubistskali rivers) (Fig. 1). Standardized scientific procedures were followed to ensure reliable environmental data collection.

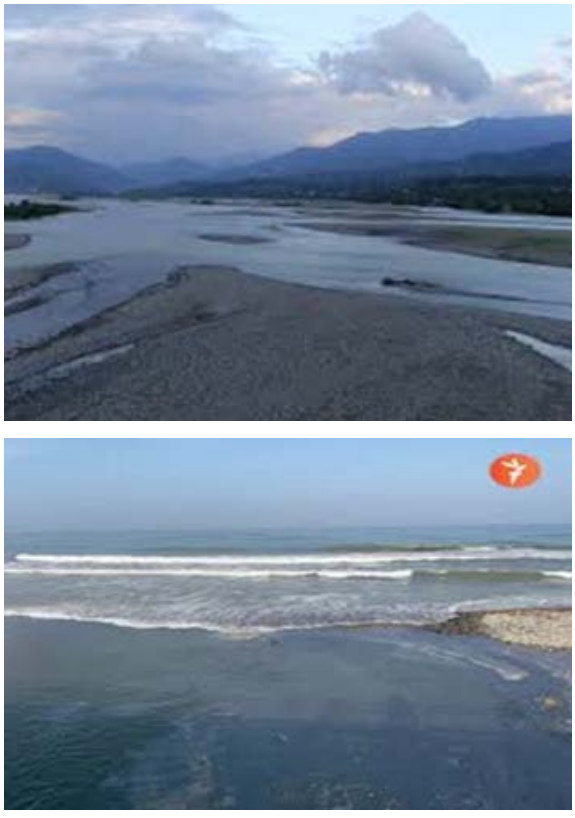

Figure 1. Chorokhi and Kubistskali rivers

Figure 2. Sampling of surface water and bottom sediments

3.2. UAV Surveillance and Data Collection

Unmanned Aerial Vehicles (UAVs), specifically the DJI Matrices 30 FREE BASIC COMBO drone [1], were used for aerial monitoring of coastal zones. The drone, equipped with high-resolution cameras and cloud-based storage, enabled real-time visual documentation of pollution hotspots and supported rapid data (Fig. 4). retrieval and environmental assessment. Unmanned Aerial Vehicles (UAVs), specifically the DJI matrices 30 FREE BASIC COMBO drone, were used for aerial monitoring of coastal zones. The drone, equipped with high-resolution cameras and cloud-based storage, enabled real-time visual documentation of pollution hotspots [6]. and supported rapid data (Fig. 3). retrieval and environmental assessment.

3.3. GIS Mapping and Simulation

Geographic Information Systems (GIS) tools were employed to map polluted areas and simulate the distribution of marine litter. Environmental variables such as wind direction, current flow, and river input were factored into the spatial analysis. Cadets used these maps to study pollution dispersion patterns and propose mitigation strategies. Geographic Information Systems (GIS) tools were employed to map polluted areas [5, 6] and simulate the distribution of marine litter. Environmental variables

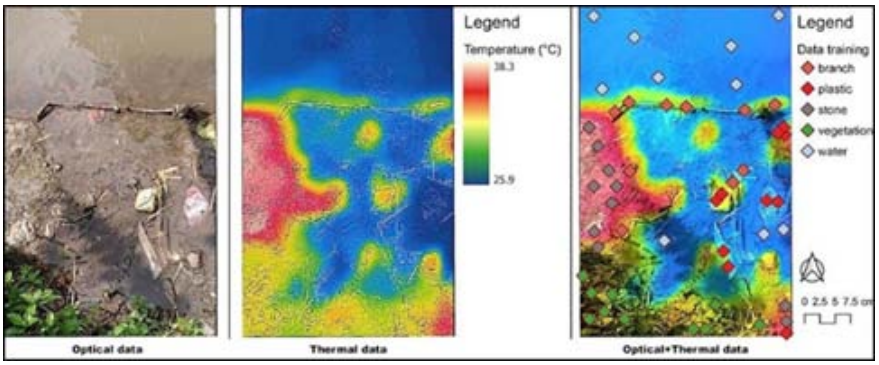

Figure 3. Optical and thermal image of waste (example).

Figure 4. Data collection, environmental assessment.

Figure 5. The mouths of the rivers

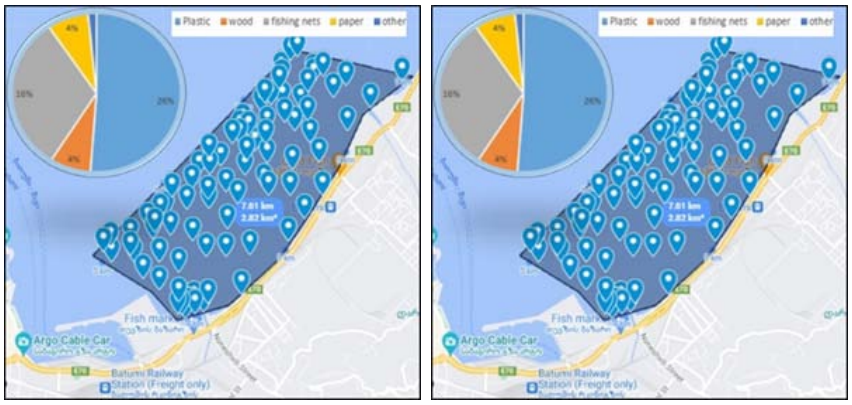

Figure 6. The accumulation and movement of plastic waste

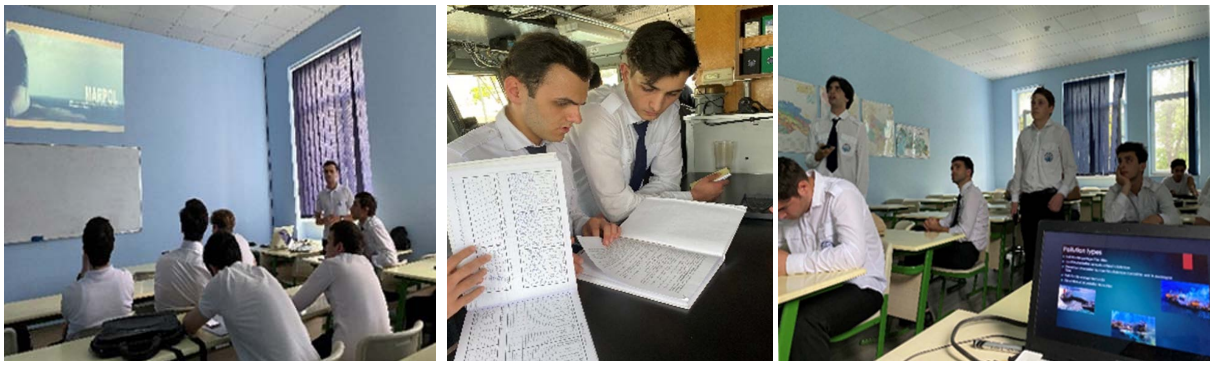

Figure 7. Data interpretation, scenario-based simulations, and group discussions.

such as wind direction, current flow, and river input were factored into the spatial analysis [5, 6]. Cadets used these maps to study pollution dispersion patterns and propose mitigation strategies. As a result, revealed that the mouths of the rivers (Fig. 5) in the Adjara coast were the most polluted areas, based on the observational analysis of the results, we created a "waste map" on which the locations of different types of pollutant [7, 8] were marked.

3.4. Curriculum Integration

Findings from fieldwork and drone monitoring were embedded into interactive training modules. Students engaged in data interpretation, scenario-based simulations, and group discussions (Fig. 7). This interdisciplinary learning approach [10] fostered critical thinking, decision-making, and applied knowledge in environmental protection. Findings from fieldwork and drone monitoring were embedded into interactive training modules.

4. RESULTS

4.1. Identification of Key Pollution Hotspots

Long-term observations and drone-assisted monitoring revealed several high-risk areas for pollution

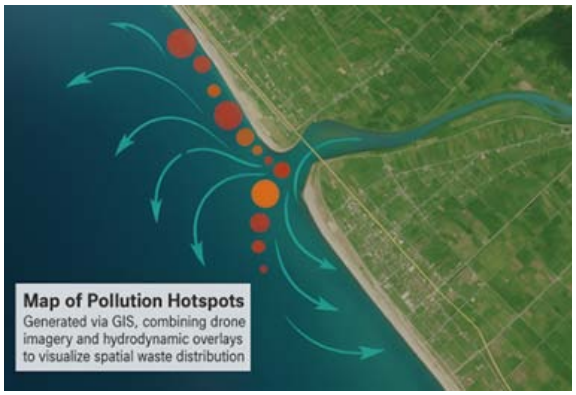

Figure 8. Map of pollution hotspots

accumulation along the Adjara coastline. Notable hotspots include:

- Bartskhana district – near a residential-industrial zone with significant plastic debris.
- Gonio beach area – affected by tourist and recreational waste.
- Batumi fish market outfall – a site of organic and packaging waste discharge.

Hydroelectric station confluence (Chorokhi & Jochostskali Rivers) – a major zone for riverine waste convergence. Long-term observations and drone-assisted monitoring revealed several high-risk areas for pollution accumulation along the Adjara coastline. Notable hotspots (Fig. 8) include: Fish restaurants, cafes seasonally with an increase in tourist flow.

4.2. Cadet Engagement and Competency Development

Cadets actively participated in all stages of environmental assessment and monitoring. As a result, they demonstrated improved competencies in:

- Operating UAVs for coastal surveillance
- Conducting scientific sampling of water, air, and sediments
- Using GIS tools for environmental mapping
- Interpreting ecological data to inform decision-making.

Participating in group analysis and scenario-based simulations Cadets actively participated in all stages of environmental assessment and monitoring. As a result, they demonstrated improved competencies in:

- Working on a master's thesis leads to more effective results.

4.3. Geospatial Analysis of Waste Accumulation

By integrating drone imagery with GIS-based spatial mapping, students identified both floating and submerged debris along the coastline. This geospatial approach produced the following key insights:

- Seasonal variations in plastic waste accumulation
- Trajectory mapping of debris influenced by marine currents
- Application of thermal imaging to detect pollution invisible to the naked eye.

These analyses directly supported data-driven environmental planning and increased student proficiency in digital marine monitoring technologies.

5. DISCUSSION

The integration of UAV surveillance and GIS mapping into maritime education has demonstrated significant benefits for both environmental protection and professional competency development among cadets. By engaging in real-world monitoring, students moved beyond theoretical instruction and developed practical skills essential for addressing modern ecological challenges.

UAVs enabled safe, rapid, and wide-scale observation of pollution hotspots, minimizing the need for direct exposure in contaminated areas. GIS applications allowed cadets to visualize environmental risks spatially and simulate waste movement influenced by natural forces such as wind, currents, and river inflows. These tools collectively enhanced cadets' capacity to understand complex environmental systems and propose data-driven solutions.

A key feature of this model is its direct integration into the academic curriculum at Batumi State Maritime Academy. Digital environmental monitoring technologies are embedded in courses such as:

- Marine Pollution Control
- Environmental Management on Ships
- Geospatial Technologies in Maritime Operations.

The curricula on shipboard environmental management and energy efficiency will be enhanced through the integration of data and findings from practical exercises and monitoring activities.

Modules include:

- Drone operation labs for monitoring coastal zones
- GIS mapping exercises based on real collected data
- Scenario simulations based on actual pollution cases from the Adjara coastline

- Field sampling as part of semester-long ecological monitoring projects
- Educational modules at both bachelor's and master's levels will incorporate and reflect the outcomes of the practical work undertaken.

This practical orientation ensures cadets gain firsthand experience with environmental data collection and analysis. Instructors use real UAV imagery and GIS layers in their lectures and assignments. Assessments include map interpretation, pollution source analysis, and designing pollution prevention strategies based on observed cases.

This approach supports current global tendencies in maritime education — emphasizing interdisciplinary learning, digital skill development, and alignment with IMO environmental goals (e.g., GHG Strategy, MARPOL Annex V, and SDG 14).

Challenges during implementation included:

- Technical constraints (e.g., drone range, weather conditions)
- Limited funding for digital infrastructure and software licenses
- Faculty training needs in geospatial analysis and UAV integration

Nonetheless, the positive student response and skill gains reinforce that maritime education must evolve to include such hands-on, tech-based learning pathways – making digital technologies not only tools for monitoring but also vehicles for education and transformation. The integration of UAV surveillance and GIS mapping into maritime education has demonstrated significant benefits for both environmental protection and professional competency development among cadets.

6. CONCLUSIONS

The integration of digital technologies into maritime education represents a vital step toward ensuring ecological safety in marine operations. By combining UAV-based surveillance, GIS mapping, and field-based environmental monitoring, the proposed educational model equips cadets with the competencies necessary to assess, manage, and mitigate marine pollution.

This approach not only enhances technical skills but also cultivates environmental awareness and civic responsibility. The direct involvement of students in pollution detection and data interpretation creates a dynamic learning environment that aligns with international sustainability goals and the evolving requirements of the maritime industry.

The experience gained through the Adjara coastline case study illustrates that maritime education can serve as a proactive force in marine protection. With further investment in equipment, digital infrastructure, and faculty development, this model can be expanded and adapted by maritime academies worldwide. It offers a scalable, practice-oriented blueprint for preparing the next generation of seafarers to address environmental challenges through innovation and interdisciplinary learning.

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