Geospatial Data Visualization of Marine Plastic in Davao Gulf Using Python-Data Driven OpenDrift Modeling

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Abstract

A growing global problem of marine plastic pollution has resulted from the widespread use of plastic and poor waste management practices, especially in coastal regions like the Davao Gulf in Region XI, Philippines. Thus, this study examined the movement and accumulation of plastic waste in the sea during both dry (November–May) and rainy (June–October) seasons, originating from 39 nearby rivers in the Davao Gulf. This study applies the Python-based OpenDrift framework, which uses the Lagrangian method to track each particle (i.e., plastic) as it moves through time and space. The simulation released 100 synthetic plastic particles per river per month and tracked their trajectories using environmental data, including ocean currents from HYCOM and wind data from NCEP. Results show that during the dry season, plastics tend to drift toward the southwest, reaching as far as Malaysia and Indonesia. In contrast, the rainy season simulations revealed more localized movement, with plastics largely circulating and stranding along the coastlines of Davao Gulf. These findings highlight the significance of seasonal factors in the transport and accumulation of marine debris. By identifying high-risk zones and understanding seasonal drift patterns; this research informs waste management interventions to protect one of the world's most biodiverse marine areas.

***Keywords**:* Davao Gulf, marine macro plastic, OpenDrift, Python-driven simulation, sustainable society

1. Introduction

Plastics are widely used for their beneficial characteristics, including flexibility, strength, lightweight, transparency, and durability. The plastic production has surged significantly (Acot Jr. *et al*., 2022). According to a study conducted by Barboza *et al*. (2019), global plastic production exceeded 320 million tons. Moreover, in 2024, this figure rose to 460 million metric tons (Tsakona, 2021). This is largely due to humans' heavy reliance on plastics (Andrady & Neal, 2009). Multiple studies have identified macro plastic pollution as one of the most widespread and alarming global challenges, with plastics accounting for approximately 80% of ocean waste (United Nations Environment Programme, 2022) and reaching concentrations of up to 580,000 pieces per square kilometer (Acot Jr. *et al*., 2022). With the continued increase in plastic production and its input into the oceans, projections warn of significant and large-scale ecological consequences, posing a serious threat to marine life, as all marine species are exposed to plastic debris throughout their habitats (Sheavly *et al*, 2007).

This is evident in several studies documenting that marine ecosystems in Southeast Asia are currently under significant strain due to increasing levels of marine microplastic pollution (Nguyen *et al*., 2023). The Philippines, an archipelagic nation in Southeast Asia located between the South China Sea and the Pacific Ocean is renowned for its stunning landscapes and rich marine biodiversity. With an extensive river system, including 18 major rivers, the country plays a crucial role as a watershed supporting diverse ecosystems. Nonetheless, a model developed by Meijer *et al*. (2021) indicates that the Philippines is among the world's top contributors to plastic pollution through riverine sources (Mai *et al*., 2023), ranking just behind China and Indonesia, with an annual contribution of approximately 0.28–0.75 million metric tons of plastic debris (Jambeck *et al*., 2015). This is particularly alarming, as the Philippines harbors a significant share of global marine biodiversity, making it a critical hotspot for species interactions with plastic pollution (Abreo, 2018).

In Davao Gulf, Mindanao, Philippines, a documented case of a green sea turtle (Chelonia mydas) ingesting plastic resulted in an intestinal blockage in the distal part of its stomach, ultimately leading to its death. Abreo *et al*. (2016) initially reported this incident on April 17, 2015, in Brgy. Lapu-Lapu, Agdao, Davao City. Given that marine turtle populations have been declining globally due to various threats, including overfishing for human consumption, accidental bycatch, vessel collisions, and marine pollution (Bagarinao, 2011; Carman *et al*., 2014; Poli *et al*., 2014), the mortality of this endangered marine species from plastic ingestion is an increasingly alarming issue for marine biodiversity.

Inadequate waste management infrastructure, improper disposal practices, and the widespread use of single-use plastics contribute to marine macroplastic pollution in the Philippines (Van *et al*., 2020; Fuentes *et al*., 2024). Hence, the underlying concerns on macro plastic pollution paved the way for calls for the authorities to optimize waste management strategies to prevent plastics from reaching marine environments (Jambeck *et al*., 2015). With this, understanding pollution dynamics is essential to identify how plastic waste moves and accumulates over time. Ocean currents, wind patterns, and river discharge rates fluctuate with the seasons, influencing the transport and deposition of plastic debris (Abreo *et al*., 2019). Mapping these variations provides insights into high-risk pollution zones and helps predict when and where these threats are most severe, enabling more effective conservation efforts. In support of this, the study aims to analyze historical and seasonal data on macro plastic drift in the Davao Gulf, originating from major riverbanks using Python-based OpenDrift modeling.

The visualization patterns and transport mechanisms of marine macro plastic drift provide a foundation for understanding debris movement, particularly in the context of the Davao Gulf. Several global studies have contributed significantly to this area of research. Schmidt *et al*. (2017) empirically analyzed global riverine plastic pollution, establishing a strong positive correlation between plastic loads and the amount of mismanaged plastic waste in river catchments. Their results showed a nonlinear relationship, with large, densely populated rivers contributing disproportionately to marine plastic pollution. The study estimated that the top 10 rivers account for 88–95% of the global riverine plastic load, with total inputs ranging from 0.41 to 4 million tons per year. Despite recognizing significant uncertainty due to limited data, Schmidt *et al*. (2017) proposed including additional predictors, such as hydrological conditions, to improve future estimates.

Expanding on these findings, Nguyen *et al*. (2023) investigated the transport of microplastics from the Mekong River to Southeast Asia using the OpenDrift model, incorporating realistic ocean currents and wind conditions. Simulations lasting three to fifteen months showed that seasonal monsoon patterns significantly affect the drift of plastic waste. The study identified the coastlines of the Philippines and Indonesia as primary accumulation zones. Furthermore, the authors emphasized the critical roles of wind drift, river discharge, vertical mixing, and uncertainties in sinking rates in determining plastic distribution. Despite inherent variabilities, the study provides useful insights into the seasonal dynamics of marine plastic pollution and calls for targeted mitigation. Similarly, Lebreton *et al*. (2017) developed a global model to estimate riverine plastic waste discharges into the oceans, revealing that emissions peak between May and October. Their findings indicated that approximately 67% of this waste originates from just 20 rivers, predominantly located in Asia. This study provided essential baseline information for ocean plastic mass balance calculations and for informing future monitoring and mitigation plans.

The study by Jambeck *et al*. (2015) also provided a global assessment of plastic waste generated by 192 coastal countries, estimating that 275 million metric tons of plastic waste were produced in 2010, with 4.8 to 12.7 million metric tons entering the ocean. In their analysis, they highlighted the critical role of population size and waste management quality in determining a country's contribution to marine plastic pollution. They projected that, without significant improvements in waste management infrastructure, the total volume of plastic waste entering the ocean could increase tenfold by 2025. Christensen *et al*. (2023) applied the dynamical renormalization-resampling scheme (DRRS) to model macro plastic transport in the Baltic Sea. Their simulation revealed that positive buoyancy, coastal boundaries, and varying physical forces influence accumulation patterns and litter wave formation. Overall, these studies offer a comprehensive understanding of the factors driving marine macro plastic transport and accumulation. Their findings are particularly useful for guiding local and regional management actions intended to reduce plastic pollution in vulnerable marine ecosystems like the Davao Gulf.

2. Methodology

2.1 Study Area, Survey and Observations

Davao Gulf is a rich marine ecosystem surrounded by river systems that serve as conduits for plastic waste. It is home to a diverse marine ecosystem. It also plays an important role in the Davao region’s marine ecological and economic landscape. However, the growing problem of plastic pollution, driven by the rapid development of nearby cities in the region, increasingly threatens it. Numerous river systems surround the gulf, sustaining local communities and wildlife. It also acts as a pathway for plastic waste to enter the marine environment of the Gulf. This study takes a closer look at this issue by focusing on 39 specific riverbanks identified around Davao Gulf. This study selected these riverbanks based on their geographic distribution and their potential to transport plastic debris from inland areas to the sea. Understanding these key entry points is essential for developing targeted interventions and policies to reduce plastic pollution and protect the health of the Davao Gulf's ecosystem.

2.2 External Forcing and Model Setup

This study sourced ocean current and wind data from the HYbrid Coordinate Ocean Model (HYCOM) and the National Centers for Environmental Prediction (NCEP), respectively. HYCOM is a global ocean circulation model that uses a hybrid vertical coordinate system combining isopycnal, z-level, and sigma layers to better represent ocean dynamics across different depths and regions. It provides approximately 1/12° or 7–9 km spatial resolution of the ocean current data and with 3-hourly temporal updates, making it suitable for detailed marine simulations like plastic drift modeling. On the other hand, NCEP is a division of the National Oceanic and Atmospheric Administration (NOAA) that produces global atmospheric data. Wind forcing came from the NCEP Global Forecast System (GFS), which offers 10-meter wind fields at approximately 1° or 110 km spatial resolution and 6-hourly temporal intervals. Together, these datasets provide the ocean and wind conditions necessary for driving particle simulations in OpenDrift, including the assessment of plastic dispersion from the major rivers inside Davao Gulf, Davao Region, and Mindanao, Philippines, as shown in Figure 1. Table 1 shows the summary of the external forcing in this study.

Table 1. Summary external forcing in the OpenDrift simulation

Dataset	Parameters	Resolution (Spatial: Temporal)
HYCOM	Ocean current	~1/12°, or ~7–9 km: 3-hour
NCEP	Wind velocity	~1°, or ~110 km: 6-hour

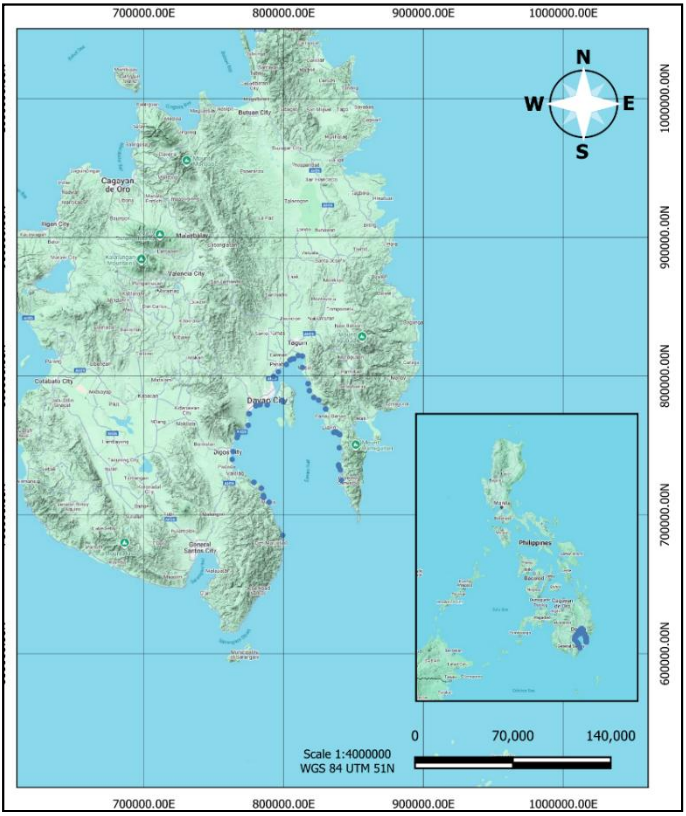

Figure 1. Study area: Davao Gulf riverbanks

Although HYCOM and NCEP provide reliable large-scale ocean and atmospheric conditions, their native spatial resolutions remain coarser than many local circulation features within Davao Gulf. As a result, fine-scale dynamics such as small eddies, river plume structures, coastal boundary currents, and nearshore wind effects may not be fully resolved. This smoothing of local variability may introduce some uncertainty in near-coast transport pathways. Nevertheless, these global datasets remain suitable for regional and seasonal-scale drift simulations, which are the primary focus of this study. Future work may incorporate higher-resolution nested coastal models to improve representation of localized hydrodynamics inside the gulf, similar to the unstructured grid-based river–coastal circulation modeling approaches demonstrated by Jeong *et al.* (2023).

This study applied the OpenDrift model version 1.9.2 for particle drifting simulations, configured within Davao Gulf, Mindanao, Philippines (Figure 1).

The PlastDrift model component simulated the drifting pattern of plastics across the 39 rivers inside Davao Gulf (Table 1, the list of rivers). The study ran two timeframe simulations: the dry season, from November 2023 until May 2024, and the rainy season, from June 2024 until October 2024. OpenDrift ran with a time step of 3 hours, releasing 100 marine macro plastic particles per month per river across both simulations. The study applied cosine weighting for river runoff, as none of the rivers inside Davao Gulf has recorded river discharge data. The coastline action is set to stranding, ensuring that plastics stranded on the coastline remain stationary throughout the simulation. The final outputs, with a 6-hour time step, include a weighted map, an animation of the plastic drifting pattern, and a comparison of stranded versus floating particles at the end of the simulation period.

This study represents commonly found buoyant debris in Davao Gulf using synthetic micro plastic particles, with the following physical properties applied during model simulation setup. First, a constant windage value of 2% of the 10-m wind speed accounts for wind-induced drift, a setting widely used in regional marine litter modeling that reflects the typical response of lightweight floating micro plastics to surface winds. Second, the model treats all particles as fully buoyant with randomized release depths within 0–1 m, allowing vertical motion of micro plastic particles due to turbulence while still representing plastic debris floating at the surface. Lastly, the default OpenDrift random-walk scheme drives vertical turbulent displacement, ensuring that simulated particles behave realistically as floating micro plastic debris under the combined influence of ocean currents and surface winds.

2.3 The OpenDrift Framework

OpenDrift is an open-source framework developed by the Norwegian Meteorological Institute (MET) for modeling ocean trajectories. It employs an offline Lagrangian particle tracking method, and various studies have tested it on drifting objects and oil spills in the North Sea (Ricker *et al.*, 2020). Researchers have also applied it to assess potential oil spill risks in Cuba (Hole *et al.*, 2021) and to track micro plastic movement in the French Mediterranean Sea. In this approach, the Lagrangian equation (Equation 1) governs the movement of each particle, as shown below.

$$\frac{dx}{dy} = u(x,t) + w_{wind} + w_{turbulence} + w_{buoyancy} \qquad (1)$$

where x is the position of the particle; $u(x,t)$ is the ocean current velocity at position x and time t from HYCOM; w_{wind} is the wind-induced drift based on NCEP wind fields; $w_{turbulence}$ is the vertical and horizontal displacement caused by turbulence; $w_{buoyancy}$ is the terminal velocity due to the particle's buoyant behavior.

HYCOM ocean currents and wind drift from NCEP reanalysis data primarily drove the horizontal transport of plastic particles in this study. Researchers typically estimate wind drift as a percentage of wind speed, commonly between 1% and 6%, depending on the object's shape and buoyancy. For floating macro plastics, a drift factor of 2–3% is standard, and studies using OpenDrift have shown that 2% yields reliable results when compared to observed trajectories.

For vertical motion, the model included the effects of: vertical current velocity (included where available from HYCOM) (1); turbulent mixing, parameterized using eddy diffusivity based on wind speed and implemented via a random-walk method (2); and buoyancy, expressed through terminal velocity, which depends on the particle's size, shape, and density (3).

In this case, the model assigned buoyant particles a terminal velocity of 0.01 m/s to simulate upward drift, and sinking particles velocities of 2 and 5 meters per day, reflecting different settling rates due to negative buoyancy.

2.4 Model Reliability and Sensitivity Assessment

The absence of long-term in situ measurements or surface drifter observations in the Davao Gulf prevented direct field-based validation of the simulation forcing fields (i.e., currents and wind data). While HYCOM and NCEP provide physically consistent hydrodynamic and atmospheric information, the lack of field-based validation prevents independent verification of their reliability and accuracy at the fine spatial scale of the gulf.

2.4.1 Field Validation Efforts (Buoy Development)

To address the limitation stated above, the authors developed a custom macroplastic-tracking buoy equipped with GPS, designed to transmit geolocation data every 5 minutes to record real drift trajectories at sea. This buoy approximates the drift behavior of floating macro plastic and serves to validate model-derived surface drift patterns in future studies. However, an ongoing patent application covering the buoy design and communication system currently prevents the authors from including the associated drift data in this manuscript. Once the intellectual property process concludes, the authors will use the buoy-based observations to empirically validate the hydrodynamic forcing fields and improve uncertainty assessment in subsequent research, with findings to follow in this journal as a continuation of this study.

2.4.2 Windage Parameter Sensitivity Analysis

Prior Lagrangian modeling studies have extensively assessed the influence of wind drag (windage) on the transport of floating debris and plastic. For instance, numerical modeling of floating debris in the world's oceans (Lebreton *et al.*, 2012) used a windage coefficient of ~2% and showed that including wind forcing increased the stranding probability of floating debris compared with no-wind scenarios, demonstrating that small but nonzero windage is a realistic and relevant setup. Similarly, the Lagrangian-based Floating Macroalgal Growth and Drift Model (FMGDM v1.0) (Zhou *et al.*, 2021) applied windage values between 2.7% and 3.5% for surface-floating drifters. Sensitivity experiments in Zhou *et al.* (2021) over this range produced similar drift and movement patterns over short time scales, supporting the robustness of the results under realistic windage variability. Furthermore, theoretical and experimental work on wind drag dynamics confirms that most surface-floating objects drift at approximately 2–3% of the free-stream wind velocity across a broad range of object shapes, sizes, and buoyancies (Wagner *et al.*, 2022).

Thus, adopting a fixed windage coefficient (2%) in this study is consistent with established modeling practice. The modest uncertainty associated with a ±10% perturbation of this coefficient falls within the variability range already explored in the literature, and earlier studies have shown that such variation does not substantially alter large-scale transport and accumulation patterns (Wagner *et al.*, 2022). Recent Lagrangian modeling studies further confirm that realistic windage parameterization significantly influences coastal accumulation and cross-shelf transport of floating marine debris under varying seasonal forcing conditions (Jeong *et al.*, 2024). Accordingly, this paper considers the model configuration well justified without additional sensitivity runs.

2.5 Model Flowchart

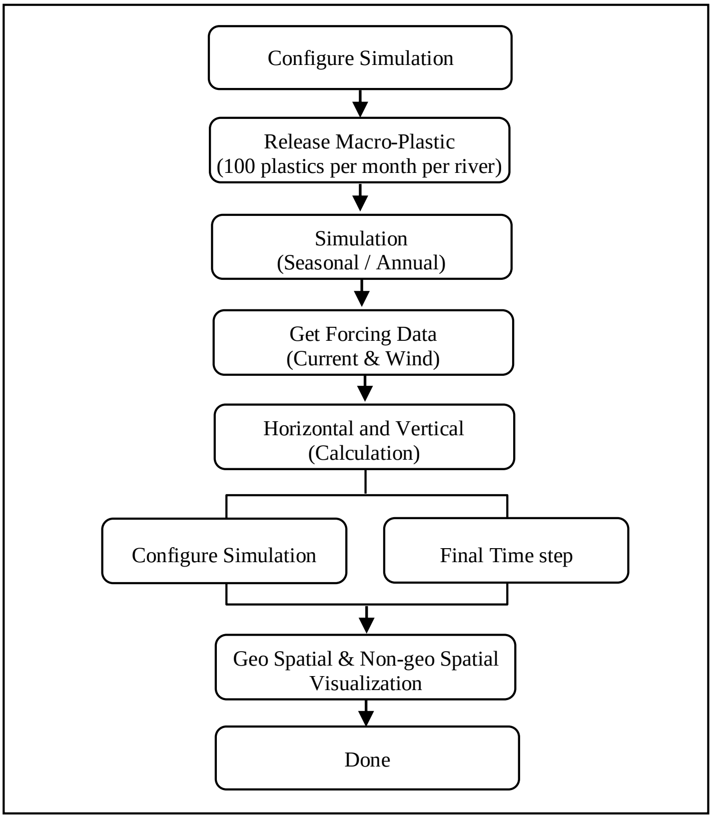

Figure 2. Plastic drifting simulation flowchart

The flowchart in Figure 2 illustrates the systematic process for simulating and validating the movement of macro plastics from river sources using an oceanographic and atmospheric drift model. The process begins with configuring the simulation parameters, including settings for coastline interaction, vertical mixing, and the simulation period. The simulation releases macro plastics at a rate of 100 particles per month per river. The model runs over a defined period (dry and rainy season). The dry season simulation covers from November 2023 until May 2024, while the rainy season simulation starts from June 2024 until October 2024. The simulation incorporates environmental forcing data such as ocean currents and wind fields. These data drive the horizontal and vertical movement calculations of macro plastic particles. Particles that strand on land deactivate; otherwise, they continue to drift until the final time step. At the end of the simulation, the results are visualized both geospatially and statistically.

3. Results and Discussion

3.1 Macroplastic Survey

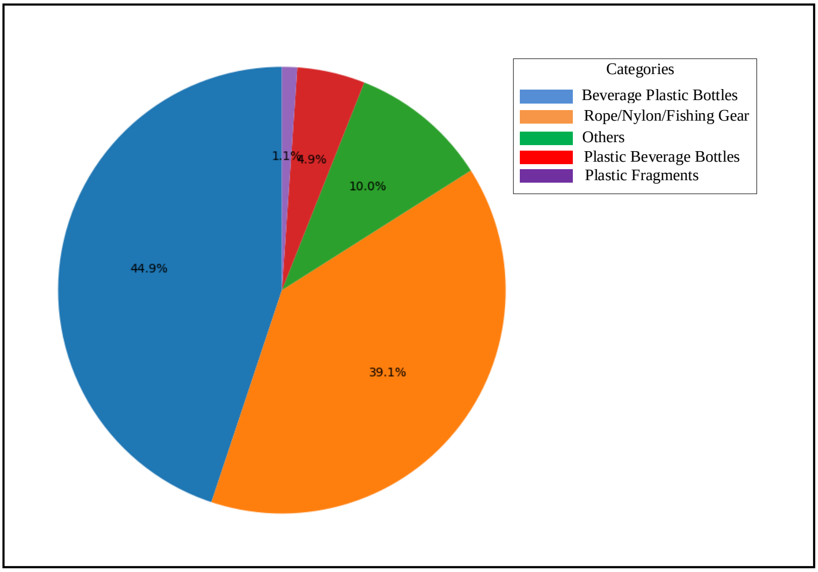

Figure 3. Percentage distribution of the total collected macroplastics in San Isidro, Davao Oriental

The researchers under the Macro and Micro Plastic Project (M2P2) of Davao Oriental State University conducted a macro plastic survey along the coast of Cuabo Village, Brgy. Batobato, San Isidro, Davao Oriental last April 2023. The researchers plotted four (4) transects with five (5) plots per transect. Table 2 and Figure 3 below show the results of the macro plastic survey by category. Three hundred fifty (350) macro plastics were recorded: approximately forty-five percent (45%) were plastic cellophane or wrappers, followed by fishing gears, others not specified, plastic beverage bottles, and lastly, plastic fragments, with percentages of thirty-nine percent (39%), ten percent (10%), five percent (5%), and one percent (1%), respectively. On average, there are about 87.5 plastics collected per month. These collected macro plastics were rounded off to 100 (assumption) as the basis for the input of the OpenDrift simulation per river.

Table 2. The macroplastics data collected at the municipality of San Isidro

Name of Macroplastic	Unit (pc)
Beverage plastic bottles	17
Plastic cellophane/wrapper	157
Plastic fragments	4
Rope/Nylon/Fishing Gear	137
Others	35

3.2 Dry Season Macro-Plastic Pattern from the Davao Gulf Riverbanks

To assess the macroplastic drifting pattern in a seasonal setup, the simulation released 100 particles per month per river in both dry and rainy seasons (DRY: 39 rivers × 7 months × 100 = 27,300 particles). Particles that stranded on the coastline deactivated immediately. Figure 4 shows the macroplastic drift pattern during the dry season with wind and wave external forcing. Figure 5 illustrates that after 7 months of dry season simulation, approximately 99.33% or 27,118 particles stranded, while the remaining 0.67% or 182 particles remained active. Most particles stranded at the west-southwest of Mindanao Island and in Palawan, while others came to rest in Sabah and East Kalimantan, Malaysia. Some also reached Sulawesi Island, Indonesia, and the islands of Java, Banda, and the Timor Sea. The remaining active particles scattered across the Timor and Banda Seas, but concentrated mostly in the Java Sea in Indonesia and the Sulu Sea in the Philippines.

To assess the dry season drifting pattern and the role of wind drift in the distribution of marine macro plastics, the particles were released gradually every month with wind external force turned on (Figure 4) and off (Figure 5). The general pattern in the dry season is that the plastics drift to the south and the southwest of Mindanao, with a large number of particles ending up in East Malaysia, Indonesia, and the southwest of Mindanao, Philippines. Enabling wind drift caused most marine macroplastic particles to drift and strand in Malaysia and Indonesia (Figures 4 and 5 for the spatial comparison).

Table 3 shows the stranded plastic particles per country. There were 27,118 (98.33%) and 26,842 (98.32%) stranded in the Philippines, mostly in Mindanao, during the dry season in wind-wave and wave simulations, respectively. Meanwhile, the wind-wave simulation stranded only 36 and 225 particles in Malaysia and Indonesia, respectively. The wave-only simulation stranded 1, 255, and 27 particles in East Timor, Indonesia, and Malaysia, respectively.

Table 3. Summary of the stranded plastic per country in the dry season simulation

Simulation	Philippines	Malaysia	Indonesia	East Timor	Total
Wind-Wave	26,857	36	225	0	27,300
Wave	26,846	27	255	1	27,125

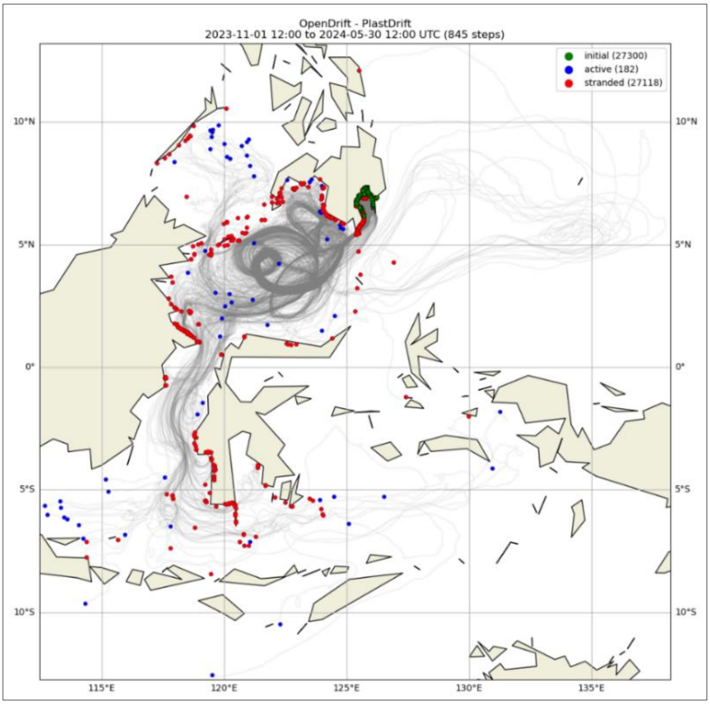

Figure 4. Macro-plastics drift pattern with wind and wave external forcing during dry season

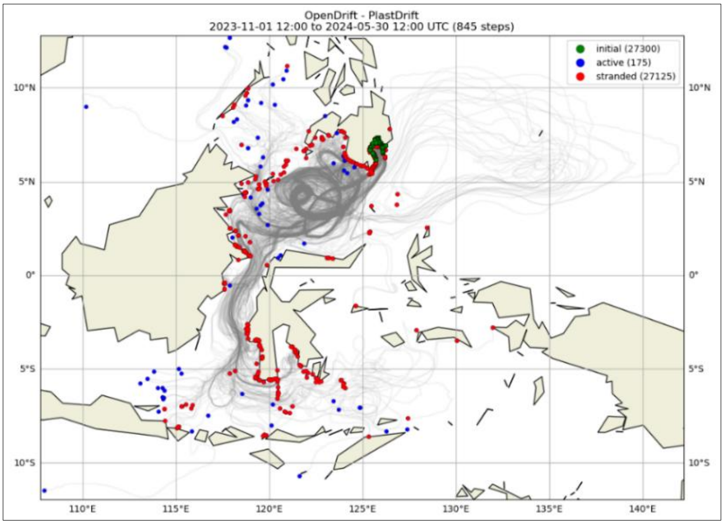

Figure 5. Macro-plastics drift pattern with wave only external forcing

3.3 Rainy Season Macro-Plastic Pattern from the Davao Gulf Riverbanks.

The rainy season simulation ran from June 2024 to October 2024, releasing 19,500 particles from the riverbanks (RAINY: 39 rivers × 5 months × 100 = 19,500 particles). Particles that stranded on the coastline deactivated immediately. Figure 6 shows the macro plastic drift pattern during the rainy season with wind and wave external forcing, while Figure 7 illustrates the drift pattern under the wave-only simulation.

Figure 6 demonstrates that after 5 months of the rainy season simulation, approximately 76.86% or 14, 987 particles stranded, while the remaining 23.14% or 4,513 particles remained active. Most particles circled around Davao Gulf, with stranded particles distributing almost evenly along the coastline of Davao Region Gulf. Meanwhile, Figure 7 depicts that around 93.11% or 18,156 particles stranded, and 6.9% or 1,344 particles remained active at the end of the simulation. The wave-only simulation shows that waves pushed almost all particles inside the gulf area.

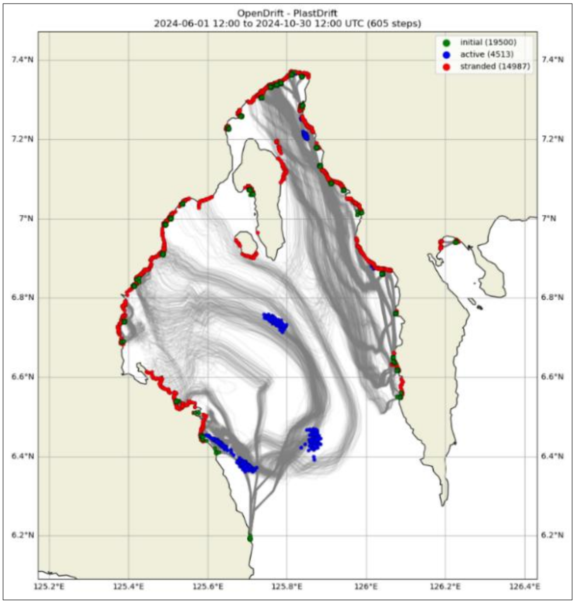

Figure 6. Macro-plastics drift pattern with wind and wave external forcing during the rainy season

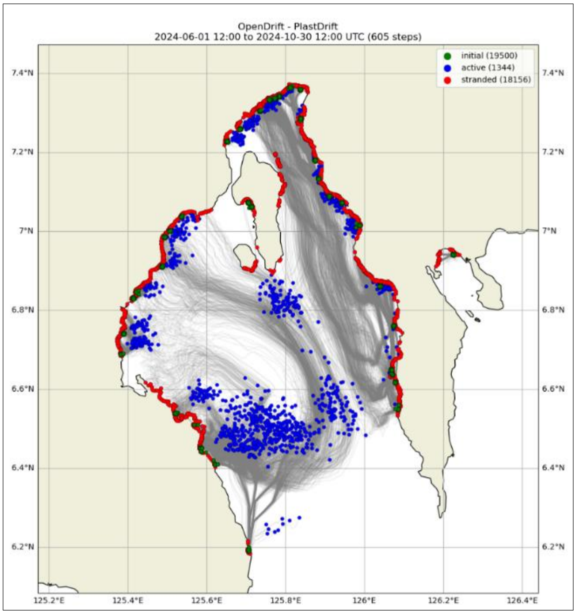

Figure 7. Macro-plastics drift pattern with wave external forcing during the rainy season

To understand better the macro plastic drifting pattern during the rainy season, the simulation released 100 particles per riverbank per month under both wind-enabled and wind-disabled configurations. The general rainy season pattern shows plastics drifting inside Davao Gulf. In the wave-only simulation (i.e., wind drift off), most marine plastics stranded directly on the coastline. Meanwhile, enabling wind drift caused particles to circle within Davao Gulf Sea before stranding (Figures 6 and 7 for the spatial comparison).

4. Conclusion and Recommendation

This study demonstrates the efficacy of using Python-driven OpenDrift modeling to visualize and analyze the seasonal behavior of marine macro plastic dispersion in the Davao Gulf. OpenDrift, a Python-based data-modeling tool, has allowed us to trace the journey of marine plastic waste, offering a geospatial representation and scientific narrative of how it travels vast distances, from the rivers of the Davao Gulf to the shores of neighboring nations. The simulation output clearly shows that plastic movement patterns are not random and follow seasonal patterns, driven by wind and ocean currents. During the dry season, plastics travel farther, often leaving Philippine waters. Meanwhile, in the rainy season, particles tend to circulate within the Davao Gulf, affecting its coastlines and potentially endangering marine life and livelihoods. Davao region policymakers, local government units (LGUs), environmental groups, and communities must recognize the importance of strengthening waste management systems and enforcing sustainable practices, especially in the rainy season, when marine plastics roam or circle the Davao Gulf. Identifying areas at risk during this season can help align plans for clean-up activities and other mitigations, such as trash interception systems near river mouths and intensified monitoring for high micro plastic waste accumulation. Furthermore, the results can help LGUs allocate clean-up budgets more efficiently, enhance municipal solid waste programs, and strengthen enforcement of regulations against improper waste disposal and illegal dumping. Most importantly, there is a need for public awareness. People must understand that the waste humans discard in the ocean does not simply vanish; it drifts, accumulates, and affects ecosystems. In conclusion, this research not only contributes valuable insights into the transport dynamics of macro plastic pollution in the Davao Gulf but also emphasizes the urgent need for a coordinated, science-based approach to address marine litter. The results serve as a basis for informed decision-making by policymakers, environmental agencies, and coastal communities, aiming to mitigate the long-term ecological and socioeconomic impacts of plastic pollution in marine environments.

However, there is still room for improvement in the simulation of fine-scale coastal processes within Davao Gulf, such as localized eddies, river discharge dynamics, and nearshore circulation patterns, given the coarse spatial resolution of the global HYCOM and NCEP datasets.

While these global datasets remain appropriate for regional- and seasonal-scale transport analysis, future research should incorporate higher-resolution nested coastal models or downscaled hydrodynamic fields to more accurately capture localized circulation features that may influence nearshore plastic drift pathways. Furthermore, future research should quantify high-risk coastal deposition zones by computing stranding density metrics. This spatially explicit analysis will support targeted interventions such as identifying priority cleanup areas, positioning riverine trash interception systems, and informing LGUs about which coastal segments require enhanced monitoring during critical months. Incorporating this high-resolution risk assessment framework in subsequent studies will strengthen the application of drift modeling results to coastal management planning.

5. Acknowledgement

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6. References

Abreo, N. A. (2018). Marine plastics in the Philippines: A call for research. *Philippine Science Letters, 11*(1), 20–21. https://scienggj.org/2018-20/

Abreo, N.A., Macusi, E.D., Blatchley, D.D., & Cuenca, G.C. (2016). Ingestion of marine plastic debris by green turtle (*Chelonia mydas*) in Davao Gulf, Mindanao, Philippines. *Philippine Journal of Science, 145*(1), 17–23.

https://philjournalsci.dost.gov.ph/ingestion-of-marine-plastic-debris-by-green-turtle-chelonia-mydas-in-davao-gulf-mindanao-philippines/

Abreo, N.A.S., Thompson, K.F., Arabejo, G.F.P., & Superio, M.D.A. (2019). Social media as a novel source of data on the impact of marine litter on megafauna: The Philippines as a case study. *Marine Pollution Bulletin, 140*, 51–59. https://doi.org/10.1016/j.marpolbul.2019.01.030

Acot Jr., F.T., Sajorne, R.E., Omar, N.-A.K., Suson, P.D., Rallos, L.E.E., & Bacosa, H.P. (2022). Unraveling macroplastic pollution in rural and urban beaches in Sarangani Bay Protected Seascape, Mindanao, Philippines. *Journal of Marine Science and Engineering, 10*(10), 1532. https://doi.org/10.3390/jmse10101532

Andrady, A.L., & Neal, M.A. (2009). Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1526), 1977–1984. https://doi.org/10.1098/rstb.2008.0304

Bagarinao, T.U. (2011). The sea turtles captured by coastal fisheries in the northeastern Sulu Sea, Philippines: Documentation, care, and release. *Herpetological Conservation and Biology, 6*(3), 353–363. https://www.herpconbio.org/contents_vol6_issue3.html

Barboza, L.G., Cózar, A., Gimenez, B.C., Barros, T.L., Kershaw, P.J., & Guilhermino, L. (2019). Macroplastics Pollution in the Marine Environment. In C. Sheppard World Seas: An Environmental Evaluation Volume III: Ecological Issues and Environmental Impacts https://doi.org/10.1016/B978-0-12-805052-1.00019-X

Carman, V.G., Acha, E.M., Maxwell, S.M., Albareda, D., Campagna, C., & Mianzan, H. (2014). Young green turtles, *Chelonia mydas*, exposed to plastic in a frontal area of the SW Atlantic. *Marine Pollution Bulletin, 78*(1–2), 56–62. https://doi.org/10.1016/j.marpolbul.2013.11.012

Christensen, A., Murawski, J., She, J., & St John, M. (2023). Simulating transport and distribution of marine macro-plastic in the Baltic Sea. *PLoS ONE, 18*(1), e0280644. https://doi.org/10.1371/journal.pone.0280644

Hole, L. R., de Aguiar, V., Dagestad, K. F., Kourafalou, V. H., Androulidakis, Y., Kang, H., ... & Calzada, A. (2021). Long term simulations of potential oil spills around Cuba. ``*Marine Pollution Bulletin*, 167, 112285. https://doi.org/10.1016/j.marpolbul.2021.112285.

Fuentes, H., Flores, J. P., Bacaltos, D. G., Fuentes, A., Roman, L., Schuyler, Q., & Hardesty, B. D. (2024). A comprehensive assessment of plastic pollution inland, on riverbanks, along the coastline and at the sea surface in Southern Mindanao, Philippines. *Marine Pollution Bulletin*, 209, 117134. https://doi.org/10.1016/j.marpolbul.2024.117134

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., & Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science, 347*(6223), 768–771. https://doi.org/10.1126/science.1260352

Jeong, J.S., & Lee, H.S. (2023). Unstructured grid-based river–coastal ocean circulation modeling towards a digital twin of the Seto Inland Sea. *Applied Sciences, 13*(14), 8143. https://doi.org/10.3390/app13148143

Jeong, J.S, Lee, H.S, & Mori, N. (2024). Abnormal surges and the effects of the Seto Inland Sea circulation in Hiroshima Bay, Japan. Frontiers in Marine Science, 11:1359288. https://doi.org/10.3389/fmars.2024.1359288

Lebreton, L.C.M., Van der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications, 8*(1), 15611. https://doi.org/10.1038/ncomms15611

Lebreton, L.M., Greer, S.D., & Borrero, J.C. (2012). Numerical modelling of floating debris in the world's oceans. *Marine Pollution Bulletin, 64*(3), 653–661. https://doi.org/10.1016/j.marpolbul.2011.10.027

Mai, L., Sun, X., & Zeng, E. Y. (2023). Country-specific riverine contributions to marine plastic pollution. *Science of the Total Environment*, 874, 162552. https://doi.org/10.1016/j.scitotenv.2023.162552

Meijer, L.J.J., Van Emmerik, T., Van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances, 7*(18), eaaz5803. https://doi.org/10.1126/sciadv.aaz5803

Nguyen, D.M., Hole, L.R., Breivik, Ø., Nguyen, T.B., & Pham, N.K. (2023). Marine plastic drift from the Mekong River to Southeast Asia. *Journal of Marine Science and Engineering, 11*(5), 925. https://doi.org/10.3390/jmse11050925

Poli, C., Lopez, L.C.S., Mesquita, D.O., Saska, C., & Mascarenhas, R. (2014). Patterns and inferred processes associated with sea turtle strandings in Paraíba State, Northeast Brazil. *Brazilian Journal of Biology, 74*, 283–289. https://doi.org/10.1590/1519-6984.13112

Ricker, M., Stanev, E.V., Badewien, T.H., Freund, H., Meyerjurgens, J., Wolff, J.-O., & Zielinski, O. (2020). Drifter observations and Lagrangian tracking of the 2018 easterly wind event in the North Sea. *Journal of Operational Oceanography, 13*(sup1), s155–s160. https://doi.org/10.1080/1755876X.2020.1785097

Schmidt, C., Krauth, T., & Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environmental Science & Technology, 51*(21), 12246–12253. https://doi.org/10.1021/acs.est.7b02368

Sheavly, S.B., & Register, K.M. (2007). Marine debris & plastics: Environmental concerns, sources, impacts and solutions. *Journal of Polymers and the Environment, 15*, 301–305. https://doi.org/10.1007/s10924-007-0074-3

Tsakona, M. (2021). Drowning in plastics: Marine litter and plastic waste vital graphics. United Nations Environment Programme. Retrieved from https://www.unep.org/resources/report/drowning-plastics-marine-litter-and-plastic-waste-vital-graphics

United Nations Environment Programme. (2022). From pollution to solution: A global assessment of marine litter and plastic pollution. Retrieved from https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution

Van Emmerik, T., Van Klaveren, J., Meijer, L. J., Krooshof, J. W., Palmos, D. A. A., & Tanchuling, M. A. (2020). Manila river mouths act as temporary sinks for macroplastic pollution. *Frontiers in Marine Science*, 7*,* 545812. https://doi.org/10.3389/fmars.2020.545812

Wagner, T.J., Eisenman, I., Ceroli, A.M., & Constantinou, N.C. (2022). How winds and ocean currents influence the drift of floating objects. *Journal of Physical Oceanography, 52*(5), 907–916. https://doi.org/10.1175/JPO-D-21-0145.1

Zhou, F., Ge, J., Liu, D., Ding, P., Chen, C., & Wei, X. (2021). The Lagrangian-based floating macroalgal growth and drift model (FMGDM v1.0): Application to the Yellow Sea green tide. *Geoscientific Model Development, 14*(10), 6049–6070. https://doi.org/10.5194/gmd-14-6049-2021.