www.ijarp.com ISSN 2456-9992 Page: 01-16

International Journal Advanced Research Publications

Research Article

Volume: 02
Issue: 09

A LOW-COST A-GPS/4G DRIFTER FOR LAGRANGIAN TRACKING OF FLOATING MACRO-DEBRIS: HARDWARE DESIGN AND A FIRST FIELD TRIAL IN FIVE ESTUARIES OF SOUTHEASTERN VIETNAM

C. H. Vo[1], N. T. Pham[1*], H. X. Pham[2]

[1]Thuyloi University, Ha Noi, Vietnam.

[2]Mien Dong Innovative Technology University, Bien Hoa, Dong Nai Province, Vietnam.

Article Received: 18 July 2026, Article Revised: 13 August 2026, Published on: 02 September 2026

****Corresponding Author: N. T. Pham**

Thuyloi University, Ha Noi, Vietnam.

Doi: https://doi-doi.org/101555/ijarp.9372

ABSTRACT

Floating macro-debris discharged from estuaries in southeastern Vietnam accumulates seasonally on beaches near Vung Tau, yet its transport from source to shore has so far been described only through numerical models, without in-situ Lagrangian observation. This paper reports the design of a drifter built around a low-cost assisted-GPS receiver and a SIM7600X 4G cellular modem, and the results of its first field trial: five units, one per site, released in November 2025 at five estuaries of the Ba Ria-Vung Tau and Ho Chi Minh City coast. Positions were transmitted over the national cellular network and converted to segment-mean speeds and headings with the Haversine formula. None of the five units was recovered, all lost to entanglement in fishing gear or to advection beyond cellular coverage. Segment-mean speeds fell between 0.3 and 4.0 km/h, lowest at the sheltered Cua Lap site and highest on the Mekong track; two tracks exceeded 100 km, and one track reversed direction repeatedly at tidal frequency. With one drifter per site and a single campaign, these trajectories are exploratory: they demonstrate that the instrument resolves debris pathways at a cost compatible with dense deployment, and identify candidate retention sites for a future replicated campaign.

KEYWORDS: Marine Macro-Debris; Lagrangian Drifter; Low-Cost Instrumentation; A-Gps Telemetry; Estuarine Transport; Vietnam.

INTRODUCTION

The rivers of Southeast Asia deliver a large share of the plastic that reaches the world ocean, and Vietnam, with dense riparian settlement along an extensive coastline, is among the countries where that delivery is concentrated (Nguyen et al., 2023; Strady et al., 2021). Within Vietnam, the Sai Gon river system has itself been identified as a particularly severe pollution pathway (Cleveland & Morrison, 2025). Along the coast of Ba Ria-Vung Tau Province in southeastern Vietnam, floating debris arrives on beaches in seasonal pulses tied to the monsoon, and the material is dominated by inland vegetative matter, chiefly water hyacinth, entangled with plastic film, bottles and abandoned fishing gear. Removal is currently organised as shoreline collection after grounding, which acts on debris only at the end of its transport path.

What is known about the standing stock of plastic in Vietnamese coastal waters comes chiefly from concentration and source-attribution surveys: baseline microplastic concentrations have been measured in the northern branches of the Mekong Delta (Kieu-Le et al., 2023), in the surface sediment of the Red River estuary (Le et al., 2023), and in peatland areas of Long An Province (Nguyen et al., 2022), and source-specific patterns of stranded debris have been surveyed in the Red River estuary of Xuan Thuy National Park (Giles et al., 2021), alongside a national baseline across marine and freshwater environments (Strady et al., 2021). Surveys of this kind quantify how much material is present at a place and a time. They do not measure where an individual item came from, how fast it moves, or where it goes, and none of them concerns macro-debris of the size that grounds on a beach.

Estimates of transport itself have been produced through numerical simulation combining hydrodynamic modelling with ground-truthing estimates of litter sources and sinks in estuarine gradients elsewhere (Krelling et al., 2017). For Vietnamese waters specifically, Eulerian and particle-tracking models have been applied to plastic transport from the Red River to the coast (Liao et al., 2024), to microplastic transport in the Bach Dang estuary (Le et al., 2022), and to river-to-sea plastic dynamics in Thanh Hoa using OpenDrift (Tran et al., 2025). Model results of this kind depend on the wind-drag parameterisation assigned to floating objects, on the horizontal resolution of the flow field near the river mouth, and on the treatment of temporary trapping. None of these Vietnamese applications has been evaluated against measured trajectories of the objects being modelled.

Elsewhere, that evaluation has been carried out with Lagrangian drifters. Drifter observations at a tidal inlet showed that surface transport there departs from the modelled mean flow (Spydell et al., 2015), and shallow-water GNSS drifters have been used to quantify surface dispersion at metre scale (Suara et al., 2015). In estuaries specifically, drifter releases have measured residence time and trapping in the Salish Sea (Pawlowicz et al., 2019) and retention and dispersion of buoyant plastic debris in a well-mixed estuary (Chen et al., 2022). The bidirectional behaviour such releases reveal has been described for the Chao Phraya network as a "tidal trap" in which macro-debris is held within the estuary rather than passed through it, and tidal and floating-plant control of river plastic transport has been demonstrated more broadly (Mani et al., 2025; Lotcheris et al., 2024). Two studies bear most directly on the present work. Mani et al. (2023) released five satellite-tracked drifters of grapefruit size in the Chao Phraya estuary at Bangkok, Thailand, obtained positions at up to 4 m and 5 min resolution over as much as 48 days, and found that individual units covered between 9 and 696 km, became stuck as many as 23 times, and spent about 80% of their river lifetime in retention (Mani et al., 2023). Kang et al. (2025) released eleven drifter buoys at four river outlets on Jeju Island, South Korea, and reported mean drift rates of 965, 984 and 1,396 m/h over paths of 18.3, 137.8 and 74.0 km respectively, together with windage coefficients of 0.013 +/- 0.002 and 0.014 +/- 0.003 (Kang et al., 2025). The cost of the platform constrains how many units can be released at once: the Smart Drifter Cluster of Merlino et al. (2023), built to lower that cost using consumer Internet of Things components, reports a target unit production cost of about 200 euro at production volumes of several thousand (Merlino et al., 2023).

Three consequences follow for the Vietnamese case. No drifter-based observation of floating macro-debris in a Vietnamese estuary has been published, so the particle-tracking studies cited above (Liao et al., 2024; Le et al., 2022; Tran et al., 2025) remain unvalidated in the setting they describe. The drifter studies that do exist were carried out in a tide-dominated urban river (Mani et al., 2023), on a volcanic island with short steep streams (Kang et al., 2025), and in temperate well-mixed estuaries (Pawlowicz et al., 2019; Chen et al., 2022), none of which reproduces the combination of monsoon-driven discharge, semi-diurnal tidal forcing and dense artisanal fishing activity found on the southeastern Vietnamese coast. And the instruments used in those studies, whether commercial oceanographic drifters or the consumer-component cluster of Merlino et al. (2023), have not been demonstrated at a unit cost and survival profile suited to a Vietnamese provincial monitoring budget. This is an empirical and instrumental gap rather than a gap in method theory: the analytical technique of Lagrangian tracking is established, and what is missing is an instrument affordable in this setting and any field measurement made with one.

The object of the research is floating and semi-submerged macro-debris in the estuarine-coastal transition zone of southeastern Vietnam. The subject of the research is the surface kinematics of that debris as represented by tracked drifters, together with the instrumentation required to observe it. The aim is to design an A-GPS/4G drifter suited to dense provincial deployment and to establish its field performance in a first trial. The objectives are: (1) to specify and build a drifter whose electronics survive a saline, high-energy estuarine environment and whose telemetry operates over the national cellular network; (2) to release the instrument at five estuarine emission points representing distinct hydrodynamic settings and to record its trajectories; (3) to compute segment-mean speeds and headings from the recorded positions and to compare them with values published for drifter releases elsewhere; and (4) to report the operational failure modes observed, so that a subsequent replicated campaign can account for them.

The scope of what follows is set by the trial design. One drifter was released per site in a single campaign during the November 2025 monsoon transition, giving five trajectories in total. That design supports statements about instrument performance and about the qualitative behaviour of individual tracked objects. It does not support statistical inference about the debris population, comparison of means between sites, or attribution of observed motion to a particular forcing mechanism. Section 2 is written within that limit.

MATERIALS AND METHODS

1.1. Study area and trial configuration

The trial was carried out along the coast of southeastern Vietnam, between the Mekong Delta and the Ba Ria-Vung Tau headland (Figure 2). The region is subject to a mixed, mainly semi-diurnal tidal regime, to a monsoon cycle that reverses the prevailing wind between the northeastern and southwestern seasons, and to the freshwater discharge of two large systems: the Dong Nai-Sai Gon river system, which reaches the sea through the Soai Rap mouth, and the Mekong, whose distributaries discharge to the south. Ba Ria-Vung Tau Province was incorporated into Ho Chi Minh City in the 2025 administrative reorganisation of Vietnam; the provincial name is retained here because it was current at the time of the field campaign.

Five release points were selected to represent different settings within the transition zone (Table 1). Releases took place in November 2025, during the transition into the northeastern monsoon, with one drifter released at each site.

Table 1. Release points and trial configuration.

Site	Location	Setting	Drifters released
Ben Loi - Binh Chau	Ba Ria-Vung Tau, Vietnam	Small coastal river mouth, open shelf exposure	1
Loc An	Ba Ria-Vung Tau, Vietnam	Barred lagoon outlet	1
Cua Lap	Ba Ria-Vung Tau, Vietnam	Sheltered embayment adjacent to the Vung Tau headland	1
Soai Rap	Ho Chi Minh City, Vietnam	Main mouth of the Dong Nai-Sai Gon system, tide-dominated	1
Long Thuan	Mekong Delta, Vietnam	Mekong distributary, discharge-dominated	1

1.2. Drifter design

Two drifter configurations were prepared: a fully floating configuration, carrying minimal ballast and riding with most of its housing above the waterline to approximate light vegetative debris such as water hyacinth, and a semi-submerged configuration, ballasted to more than 90% submergence to approximate denser organic matter and high-density plastic items carried by subsurface flow. Both configurations were represented across the five deployments; the manuscript does not report which configuration was released at which site, and this is noted as a limitation in Section 2.6.

The electronics comprise a microcontroller unit with onboard memory, an assisted-GPS (A-GPS) receiver, a SIM7600X 4G cellular modem and a lithium battery, mounted on a single board (designation W07B_800K_G133_T2, Figure 1B). The assembly is sealed in a custom PVC-114 housing rated to IP67. Manufacturer- and model-level detail for the microcontroller, GNSS receiver and battery, together with the fix and transmission intervals and the unit production cost, are not disclosed in the project records available for this account; full disclosure of this specification is identified in Section 2.6 as a requirement for any future submission on this instrument.

The response of a surface float to wind is conventionally expressed through a windage coefficient, the ratio of the wind-induced component of drifter velocity to the wind speed at reference height. No in-situ calibration of that coefficient was performed in this trial, and no wind correction was applied to the recorded positions; reported speeds are therefore the speeds of the instrument, which include an unquantified wind-slip component relative to the water. For comparison, drifter buoys of similar exposure at Jeju Island yielded windage coefficients of 0.013 +/- 0.002 and 0.014 +/- 0.003 (Kang et al., 2025); if that order of magnitude applies here, a 10 m/s monsoon wind would contribute roughly 0.13 m/s, or about 0.5 km/h, to the observed speed.

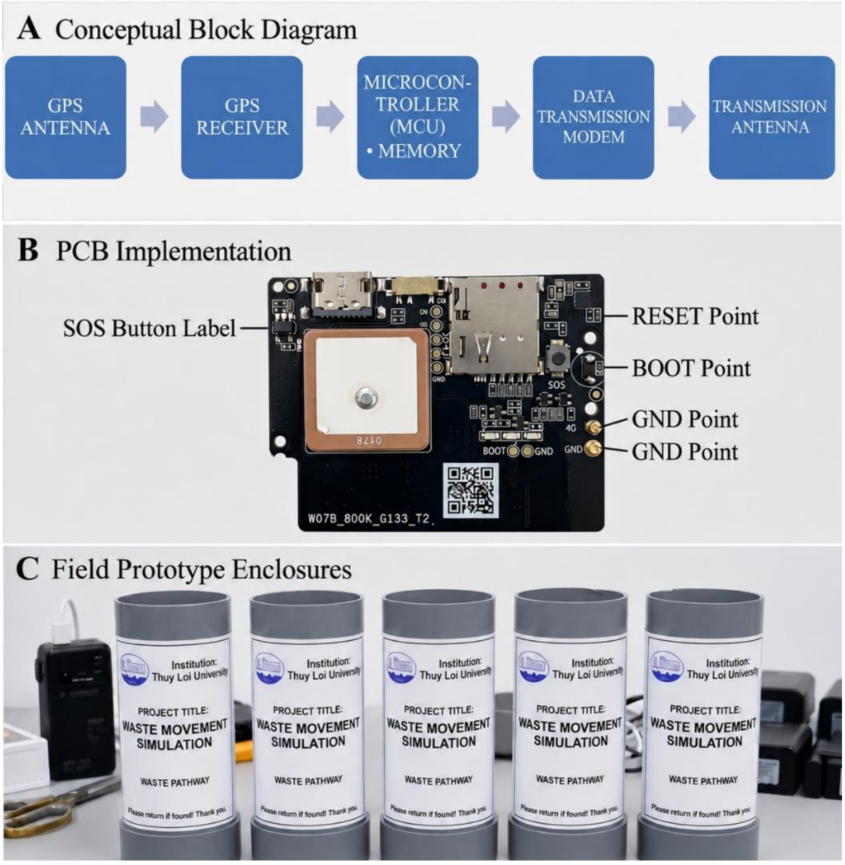

Figure 1. System architecture and physical prototype of the A-GPS/4G drifter. A: conceptual block diagram. B: assembled board, designation W07B_800K_G133_T2. C: sealed PVC-114 enclosures before deployment.

Source: by C.H. Vo, N.T. Pham.

1.3. Data acquisition and kinematic computation

Each unit operated a repeating cycle of wake, GNSS acquisition, position fix, cellular transmission and deep sleep. Each transmitted packet contained a timestamp, longitude (λ) and latitude (φ), written to a cloud data platform for real-time spatial rendering.

Displacement between consecutive fixes was computed with the Haversine formula, which returns great-circle distance on a spherical Earth:

$$d = 2R \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos(\varphi_1)\cdot\cos(\varphi_2)\cdot\sin^2\left(\frac{\Delta\lambda}{2}\right)}\right) \quad (1)$$

where d is the displacement (m), R is the mean radius of the Earth (6,371,000 m), φ_1 and φ_2 are the latitudes of the two fixes (rad), λ_1 and λ_2 are their longitudes (rad), and $\Delta\varphi = \varphi_2 - \varphi_1$, $\Delta\lambda = \lambda_2 - \lambda_1$ (rad). The segment-mean speed over the interval between two fixes follows as

$$v = d / \Delta t \qquad (2)$$

where Δt is the elapsed time between fixes (s). The heading of the segment was computed as

$$\theta = \operatorname{atan2}\left(\sin(\Delta\lambda)\cos(\varphi_2), \cos(\varphi_1)\sin(\varphi_2) - \sin(\varphi_1)\cos(\varphi_2)\cos(\Delta\lambda)\right) \qquad (3)$$

with θ converted to a bearing in the interval (0°, 360°) measured clockwise from true north. Equations (1)-(3) yield one speed and one heading per segment. The quantity reported per site in Section 2.2 is the interval spanned by these segment-mean speeds along the single trajectory recorded at that site, not a mean over replicate drifters; no standard deviation, confidence interval or between-site significance test is reported, because with $n = 1$ drifter per site no such statistic can be defined.

1.4. Limitations imposed by the trial design

Three features of the design constrain every result that follows and are stated here rather than after the fact.

The sample is one drifter per site and five in total. Any between-site difference reported below is a difference between two individual objects, each released once, and cannot be separated from the variability that would be observed among replicate drifters released together at the same site.

The campaign covers a single monsoon transition in November 2025. Tidal range, river discharge and wind direction all vary seasonally in this region, and the trajectories recorded are specific to the conditions of that month.

Trajectories terminate for reasons related to the environment being measured. Units were lost to entanglement in fishing gear and to advection beyond cellular coverage, so the record is right-censored, and censoring is not random with respect to the process of interest: a drifter that becomes entangled stops reporting precisely because it has encountered the retention mechanism the study seeks to observe. The terminal fate of the simulated debris is therefore unknown, and no statement below should be read as an observation of where debris finally accumulates.

RESULTS AND DISCUSSION

2.1. Operational performance

All five units acquired a position fix and established cellular telemetry after release. Transmission continued without interruption while a unit remained within the coverage of the national cellular network, and ceased at the coverage boundary offshore. None of the five units was physically recovered; the two identified loss mechanisms were entanglement in artisanal fishing gear within the nearshore zone and advection beyond cellular coverage into offshore waters. A recovery rate of zero out of five is the principal operational result of the trial and is treated in Section 2.6 as a design requirement for future nearshore drifter work in fished waters, rather than as an incidental failure.

2.2. Trajectory observations and segment-mean speeds

Figure 2 shows the recorded track at each site. The tracks fall into three descriptive categories, applied after inspection of five trajectories; no threshold in speed, displacement or residence time was defined to separate them, and they are not proposed as a formal classification scheme.

Sustained alongshore transport was recorded at Ben Loi-Binh Chau and at Long Thuan on the Mekong distributary, where the released units moved away from the release point in a single dominant direction and covered more than 100 km before telemetry ended. Reversing motion at the river mouth was recorded at Soai Rap, where the track showed a repeated zig-zag, with successive segments directed alternately seaward and landward. Confined motion was recorded at Cua Lap, where the unit described a looping path close to its release point, and at Loc An, where the unit moved offshore approximately normal to the shoreline immediately after clearing the outlet.

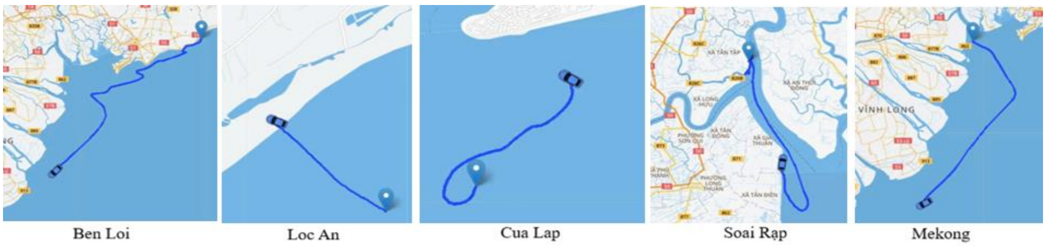

Figure 2. Recorded drifter tracks at the five release sites (screen captures from the field telemetry platform; see Section 2.6 for a note on cartographic presentation).

Source: by C.H. Vo, N.T. Pham.

Table 2 reports, for each site, the interval spanned by the segment-mean speeds computed from Equations (1)-(2) along the single trajectory recorded there.

Table 2. Segment-mean speeds along individual drifter trajectories. Each row describes one drifter; the speed column gives the interval between the slowest and the fastest segment along that trajectory, not a mean with dispersion.

Site	Drifters (n)	Segment-mean speed, min-max (km/h)	Observed behaviour
Ben Loi - Binh Chau	1	2.0 - 4.0	Sustained alongshore transport
Long Thuan (Mekong)	1	3.0 - 4.0	Sustained alongshore transport
Soai Rap	1	1.0 - 2.0	Reversing motion
Loc An	1	0.5 - 1.0	Confined motion, offshore departure
Cua Lap	1	0.3 - 0.8	Confined motion

Headings computed from Equation (3) and pooled across all five trajectories are shown in Figure 3. The distribution is concentrated in the southwestern sector, with a secondary concentration in the southern sector; the eastern half of the compass is essentially unoccupied. The count basis and bin width underlying Figure 3 are not reported in the source project records, which limits how precisely the distribution can be read; this is noted in Section 2.6.

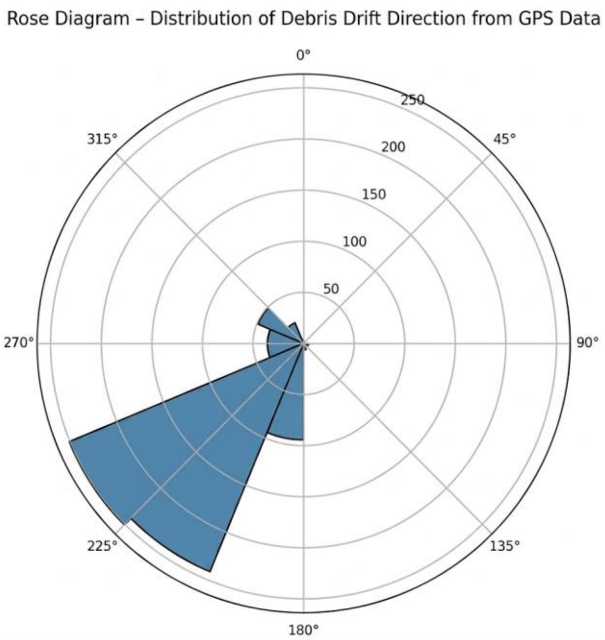

Figure 3. Distribution of segment headings pooled across the five trajectories.

Source: by C.H. Vo, N.T. Pham.

2.3. Comparison with published drifter observations

Table 3 places the present trial alongside the two drifter studies most directly comparable to it.

Table 3. The present trial compared with published drifter releases tracking floating debris in estuarine and river-mouth settings.

Study	Site, country	Units (n)	Telemetry	Path length per unit	Reported speed
Mani et al. (2023)	Chao Phraya estuary, Bangkok, Thailand	5	Satellite, up to 4 m / 5 min	9 - 696 km	Not reported as speed; 80% of river lifetime spent in retention, up to 23 retention events per unit
Kang et al. (2025)	Four river outlets, Jeju Island, South Korea	11	GPS buoy	18.3 - 137.8 km	965, 984 and 1,396 m/h (0.97 - 1.40 km/h)
Present trial	Five estuaries, southeastern Vietnam	5 (1 per site)	A-GPS / 4G cellular	Two of five tracks exceeded 100 km	0.3 - 4.0 km/h, segment means

The speeds observed here span a wider interval than those reported at Jeju Island. The upper values recorded on the Mekong distributary track, 3.0 to 4.0 km/h, are two to four times the 0.97 to 1.40 km/h mean drift rates of the Jeju buoys (Kang et al., 2025), consistent with the difference in freshwater forcing: the Jeju outlets drain short, steep island catchments, whereas the Mekong distributary carries the discharge of a continental river. The lower values recorded at Cua Lap, 0.3 to 0.8 km/h, lie below the whole Jeju interval. Direct comparison with Mani et al. is limited because that study reports retention statistics rather than speeds (Mani et al., 2023); the correspondence is qualitative, in that a large fraction of trajectory time spent nearly stationary was observed there and is consistent with the confined motion recorded at Cua Lap here.

Path length is the quantity on which the datasets agree most closely: two of the five units here exceeded 100 km, against 18.3 to 137.8 km at Jeju (Kang et al., 2025) and 9 to 696 km at Bangkok (Mani et al., 2023). Transport distances of order 10^2 km therefore appear to be a general property of floating debris released at river mouths in tidal tropical and subtropical settings, rather than a feature specific to the Vietnamese coast.

The instrument reported here reaches these path lengths using a cellular rather than a satellite link, which is also the source of the coverage limitation described in Section 2.1. A cellular link avoids the recurring satellite-subscription cost that a link such as Iridium or Argos carries, which is the cost category the low-cost consumer-component platform of Merlino et al. was designed to reduce, with a reported target of about 200 euro per unit at production volumes of several thousand (Merlino et al., 2023). A corresponding production-cost figure for the present instrument is not available in the project records used for this account and is identified in Section 2.6 as an outstanding item for future reporting.

2.4. Interpretation of the observed trajectory behaviours

The reversing motion recorded at Soai Rap is consistent with tidal control of surface transport at the river mouth, in that the alternation of seaward and landward segments occurred on a timescale compatible with the semi-diurnal tide. That interpretation is not established by the present data: no concurrent tidal elevation or wind record was collected at the release point, and the alternation is equally compatible with lateral wind stress reversing with the land-sea breeze, with steering of the surface flow by channel bathymetry, and with interaction of the housing with the density interface in a partially stratified mouth. Distinguishing these requires the drifter record to be paired with a tide gauge and a wind record at the site.

The confined motion at Cua Lap is similarly open to more than one reading. Low segment-mean speed and a looping path are consistent with retention in a recirculation cell, but a drifter that has grounded intermittently on a shoal, that has been caught and released by a fishing line, or that has been carried and dropped by a small boat would produce a comparable trace; speed alone does not discriminate between retention by the flow and retention by an obstacle.

The two high-speed alongshore tracks were recorded during the monsoon transition and both moved in the direction of the seasonal alongshore current. Whether river discharge, wind or the shelf current dominated cannot be resolved: the trial provides no simultaneous measurement of any of the three, and with one drifter per site there is no statistical basis on which to associate speed with a forcing variable.

2.5. Implications for monitoring and management

Two findings are usable now. The instrument resolves the pathway of a floating object from a Vietnamese river mouth to its offshore or alongshore destination using components not previously reported in combination for this purpose in the region, which supports releasing many units at once at a cost below that of commercial satellite-linked platforms. And the trajectories show that debris leaving these mouths is not confined to the province of origin:

path lengths exceeding 100 km place material from Ba Ria-Vung Tau and from the Mekong distributaries well outside the jurisdiction that generated it, which makes shoreline collection organised at district level structurally incomplete as a response.

What the trial does not yet support is the siting of interception infrastructure. The three locations where confined or reversing motion was recorded - Cua Lap, Soai Rap and Loc An - are candidates for retention, identified by one drifter each in one month. Placing a boom or a skimmer is a capital decision with a service life of years, and it requires the seasonal persistence of the candidate location to be established first; the appropriate next step is a replicated campaign, not construction.

The instrument design and the failure modes documented in Section 2.1 apply wherever cellular coverage extends over the nearshore zone and artisanal fishing is dense, which describes much of the coast of Vietnam, Thailand, Cambodia, Indonesia and the Philippines. The order of magnitude of the path lengths agrees with observations from Thailand and South Korea (Mani et al., 2023; Kang et al., 2025) and is therefore unlikely to be local. The specific candidate retention locations, by contrast, are properties of the bathymetry and forcing at each site and do not transfer.

2.6. Limitations and requirements for the next campaign

Beyond the design constraints stated in Section 1.4, four further limitations qualify the results and set out what a replicated campaign needs to address.

Wind slip is unquantified, as noted in Section 1.2; the confined-motion result at Cua Lap is the one most exposed to this uncertainty, since a wind contribution of a few tenths of a km/h is a small fraction of the 4.0 km/h upper speed recorded here but a substantial fraction of the 0.3 km/h lower one.

The correspondence between drifter and debris is assumed rather than verified: the two configurations were designed to bracket the buoyancy of vegetative and dense plastic debris, but no paired release of instrumented and natural debris was carried out, and the housing differs from a water hyacinth mat in area, drag and flexibility.

Reproducibility is limited by the level of disclosure available for this account. The microcontroller, GNSS receiver and battery are named by component class but not by manufacturer or model, fix and transmission intervals are not stated, and no unit production cost is reported. A full bill of materials and cost breakdown, together with the count and bin width underlying Figure 3 and a cartographically complete version of Figure 2 – drawn to a common projection and scale, with a graticule, scale bar, north arrow, and release and last-fix markers - is identified here as required components of any future submission on this instrument, rather than left unstated.

A replicated campaign should release several units per site, in both buoyancy configurations, in at least two contrasting seasons, each accompanied by a concurrent record of water level, current and wind, so that the interpretations left open in Section 2.4 can be tested rather than asserted. Units intended to cross the coverage boundary should carry a low-earth-orbit satellite module in addition to the cellular module, and units intended for the nearshore zone should be fitted with a snag-shedding profile and a recovery incentive, since the zero recovery rate observed here is a design failure a subsequent campaign can address.

CONCLUSION

1. An A-GPS/4G drifter for tracking floating macro-debris was designed and built around a SIM7600X cellular modem and a PVC-114 housing rated to IP67 (Figure 1); manufacturer-level component specification and unit production cost are not disclosed in the present account and are identified as an outstanding item for future reporting.

2. In the first field trial of the instrument, five units released one per site in November 2025 at five estuaries of southeastern Vietnam transmitted position continuously over the national cellular network until each left coverage. Physical recovery was zero out of five units, the losses caused by entanglement in artisanal fishing gear and by advection beyond the coverage boundary; this recovery rate is reported as a quantitative design requirement for nearshore drifter work in fished waters.

3. Segment-mean speeds computed along individual trajectories spanned 0.3 to 4.0 km/h, with 3.0 to 4.0 km/h on the Mekong distributary track and 0.3 to 0.8 km/h on the Cua Lap track; two of the five units travelled more than 100 km before telemetry ended. These are properties of five individual trajectories and are not site means.

4. Comparison with published releases shows the path lengths recorded here to be of the same order as those measured at Bangkok, Thailand (9-696 km) and at Jeju Island, South Korea (18.3-137.8 km), while the observed speed interval extends up to four times wider at its upper end than the 0.97-1.40 km/h reported at Jeju. Transport distances of order 10^2 km from river mouths therefore appear general to tidal tropical and subtropical settings rather than specific to Vietnam.

5. Three trajectories displayed motion that was confined or reversing rather than directed seaward, at Cua Lap, Soai Rap and Loc An. These locations are candidates for debris retention requiring confirmation. With one drifter per site, one season and no concurrent

hydrodynamic record, the trial does not establish the mechanism of that retention, and alternative explanations including grounding, wind reversal and bathymetric steering remain open.

6. The instrument design and the documented failure modes transfer to any nearshore setting with cellular coverage and dense artisanal fishing, and the order of magnitude of the transport distances is consistent with observations from two other Asian coasts. The specific candidate retention locations are properties of local bathymetry and forcing and do not transfer.

7. The results support a replicated multi-season campaign with concurrent hydrodynamic measurement and full hardware disclosure, as set out in Section 2.6. They do not yet support the siting of permanent interception infrastructure, which requires the seasonal persistence of the candidate locations to be established first.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTIONS

Vo C.H. - hardware design, field deployment, data curation; Pham N.T. - conceptualisation, methodology, formal analysis, manuscript preparation, project administration, funding acquisition; Pham H.X. - field deployment, review and editing.

DATA AVAILABILITY

The raw position time series recorded during the field campaign were not retained beyond the campaign itself and are not available as supplementary material.

ACKNOWLEDGEMENTS

The study was funded by the Department of Science and Technology of Ba Ria-Vung Tau Province, Vietnam (since 2025, the Department of Science and Technology of Ho Chi Minh City, Vietnam), under the research project "Assessment and pilot implementation of a floating debris collection system installed along the coastal area of Vung Tau City" (2024-2026).

Data Availability Statement

The raw position time series recorded during the field campaign were not retained beyond the campaign itself and are not available as supplementary material.

REFERENCES

1. Chen, Z., Bowen, M., Li, G., Coco, G., & Hall, B. (2022). Retention and dispersion of buoyant plastic debris in a well-mixed estuary from drifter observations. *Marine Pollution Bulletin, 180*, Article 113793. https://doi.org/10.1016/j.marpolbul.2022.113793
2. Cleveland, P., & Morrison, A. (2025). Song Sai Gon: Extreme plastic pollution pathways in riparian waterways. *Sensors, 25*(3), Article 937. https://doi.org/10.3390/s25030937
3. Giles, R. K., et al. (2021). Source-specific patterns of marine debris and associated ecological impacts in the Red River estuary of Xuan Thuy National Park, Vietnam. *Frontiers in Environmental Science, 9*, Article 679530. https://doi.org/10.3389/fenvs.2021.679530
4. Kang, M., et al. (2025). Identifying coastal waste sources using drifter buoy-based floating debris pathway analysis at river outlets on Jeju Island, South Korea. *Korean Journal of Remote Sensing, 41*(5), 841–855. https://doi.org/10.7780/kjrs.2025.41.5.16
5. Kieu-Le, T.-C., et al. (2023). Baseline concentration of microplastics in surface water and sediment of the northern branches of the Mekong River Delta, Vietnam. *Marine Pollution Bulletin, 187*, Article 114605. https://doi.org/10.1016/j.marpolbul.2023.114605
6. Krelling, A. P., Souza, M. M., Williams, A. T., & Turra, A. (2017). Transboundary movement of marine litter in an estuarine gradient: Evaluating sources and sinks using hydrodynamic modelling and ground truthing estimates. *Marine Pollution Bulletin, 119*(1), 48–63. https://doi.org/10.1016/j.marpolbul.2017.03.034
7. Le, D. C., Duong, T. N., Duong, T. L., Nguyen, Q. T., Nguyen, V. T., Dao, D. C., & Du, V. T. (2022). Hydrodynamic modelling of microplastics transport in Bach Dang estuary. *Vietnam Journal of Marine Science and Technology, 22*(4), 447–456. https://doi.org/10.15625/1859-3097/16490
8. Le, N. D., et al. (2023). Microplastics in the surface sediment of the main Red River estuary. *Vietnam Journal of Earth Sciences, 45*(1), 19–32. https://doi.org/10.15625/2615-9783/17486
9. Liao, Z., Zou, Q., Vinh, V. D., Pan, Z., & Kaiser, M. J. (2024). Seasonal change in fate and transport of plastics from Red River to the coast of Vietnam. *Marine Pollution Bulletin, 208*, Article 116923. https://doi.org/10.1016/j.marpolbul.2024.116923
10. Lotcheris, R. A., Schreyers, L. J., Bui, T. K. L., Thi, K. V. L., Nguyen, H.-Q., Vermeulen, B., & van Emmerik, T. H. M. (2024). Plastic does not simply flow into the sea: River transport dynamics affected by tides and floating plants. *Environmental Pollution, 345*, Article 123524. https://doi.org/10.1016/j.envpol.2024.123524
11. Mani, T., et al. (2023). Gaining new insights into macroplastic transport 'hotlines' and fine-scale retention-remobilisation using small floating high-resolution satellite drifters in the

Chao Phraya River estuary of Bangkok. *Environmental Pollution, 320*, Article 121124. https://doi.org/10.1016/j.envpol.2023.121124

12. Mani, T., Ebner, R., & Lebreton, L. (2025). The tidal trap: Seasonal transport of floating macrodebris in the bi-directional Chao Phraya River network on the Gulf of Thailand. *Marine Pollution Bulletin, 212*, Article 117605. https://doi.org/10.1016/j.marpolbul.2025.117605
13. Merlino, S., Calabro, V., Giannelli, C., Marini, L., Pagliai, L., Sacco, L., & Bianucci, M. (2023). The smart drifter cluster: Monitoring sea currents and marine litter transport using consumer IoT technologies. *Sensors, 23*(12), Article 5467. https://doi.org/10.3390/s23125467
14. Nguyen, D. M., et al. (2023). Marine plastic drift from the Mekong River to Southeast Asia. *Journal of Marine Science and Engineering, 11*(5), Article 925. https://doi.org/10.3390/jmse11050925
15. Nguyen, M. K., et al. (2022). Occurrence and distribution of microplastics in peatland areas: A case study in Long An province of the Mekong Delta, Vietnam. *Science of the Total Environment, 844*, Article 157066. https://doi.org/10.1016/j.scitotenv.2022.157066
16. Pawlowicz, R., Hannah, C., & Rosenberger, A. (2019). Lagrangian observations of estuarine residence times, dispersion, and trapping in the Salish Sea. *Estuarine, Coastal and Shelf Science, 225*, Article 106246. https://doi.org/10.1016/j.ecss.2019.106246
17. Spydell, M. S., Feddersen, F., Olabarrieta, M., & Chen, J. (2015). Observed and modeled drifters at a tidal inlet. *Journal of Geophysical Research: Oceans, 120*(7), 4825–4844. https://doi.org/10.1002/2014JC010541
18. Strady, E., et al. (2021). Baseline assessment of microplastic concentrations in marine and freshwater environments of a developing Southeast Asian country, Viet Nam. *Marine Pollution Bulletin, 162*, Article 111870. https://doi.org/10.1016/j.marpolbul.2020.111870
19. Suara, K., et al. (2015). High-resolution GNSS-tracked drifter for studying surface dispersion in shallow water. *Journal of Atmospheric and Oceanic Technology, 32*(3), 579–590. https://doi.org/10.1175/JTECH-D-14-00127.1
20. Tran, T. M. A., Do, T. P. T., Duong, A. Q., & Nghiem, V. T. (2025). Modeling river-to-sea plastic waste dynamics using OpenDrift: A case study in Thanh Hoa, Vietnam. *Asian Journal of Water, Environment and Pollution, 22*(4), 75–88. https://doi.org/10.36922/ajwep025170129