

Research Article

Tracking and modeling macro plastic debris in north of Hormuz Strait, Persian Gulf

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Abstract

Plastics are the most important pollutants in oceans and seas and are regarded as serious threat to aquatic ecosystems. The effect of tide, wind and water depth on movement of plastic marine debris has been examined in north of Hormuz Strait in Hormozgan province coasts, Hormuz Island and east of Qeshm Island. Particle tracking is used by numerical modeling using MIKE software for time interval of January to March 2017. Field study and model output clarified that direction of the particle movement during a tidal period made an elliptical shape that the small diameter formed due to wind and the large diameter varied with tide motion. The highest movement of the particle was observed one hour after high water (low water) to one hour before low water (high water). Wind was the most effective parameter within one hour before and after low water (high water). At same the time interval, as the area deepened, more movement was observed. Tracking the samples showed that more than 60% reached Bandar Abbas coasts in less than 8 days after release. The other regions receiving the samples were coasts of Hormuz Island and East of Qeshm Island with estimates of 30% and 2%, respectively. The results can be used to forecast marine macro debris accumulation zones and time duration which assist the management system as a cleanup tool.

Keywords: Marine Debris, Tide, Numerical Simulation, Hormuz Strait, Persian Gulf

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Introduction

Marine debris move along with surface water circulation on the sea. Most of debris consists of plastics (Moore *et al.*, 2011). Long life time of plastics and increased usage of these products have increased their probability of accumulation along coasts, surface water, and seafloor (Ryan and Moloney, 1993). Plastic pollutants are classified according to their size, material, shape and composition so plastics over 5 mm in size fall into category of macro plastics (Driedger *et al.*, 2015). Macro plastics are a serious threat to aquatic life, including fish, turtles and birds due to being devoured or trapped (Sheavly and Register 2007; Boerger *et al.*, 2010; Codina-García *et al.*, 2013). Identification of ocean currents can help identify direction of movement of marine debris and its accumulation site to control pollution and mitigate its deleterious effects (Kubota *et al.*, 2005). The main factors affecting movement of marine debris over the sea surface include physical factors, such as wind, wave activity, tide or other factors like weight and density of debris (Thornton and Jackson 1998; Astudillo *et al.*, 2009; Laurent *et al.*, 2013).

Due to commercial ports in north of Hormuz Strait as Shahid Bahonar and Shahid Rajai in Bandar Abbas and passenger shipline between Bandar Abbas and Qeshm and Hormuz Islands this area is always affected by plastic pollution. Movement of marine debris is dependent on surface current and wind so field and numerical studies

regarding surface currents of Strait of Hormuz are needed in this study. Field surveys in north of Hormuz Strait were performed by Eulerian method and role of the effective factors within three points along Strait of Hormuz during month of January 2006 to May 2007 for 8 days were measured by Torabi and Hamzei. The results showed that tide was the major factor in movement of northern currents of Strait of Hormuz then surface currents was the next effective factor. Water motion from the center of Strait of Hormuz to northern coasts was increased due to the velocity of tidal currents (Hunter, 1982; Torabi and Hamzei, 2016).

Within a sea voyage between Bandar Abbas and the island of Qeshm, plastics, garbage bags, creels, and bottles of mineral water were visible on the surface of water (Fig. 1). In this research, the effects of local tide, wind and depth on macro plastic movement in north of Hormuz Strait of Bandar Abbas coast, Hormuz Island and east of Qeshm Island is studied. First, movement of water current was monitored by a drifter and interval of a released plastic sample was tracked by GPS. Then the particle motion was tracked and the effective atmospheric and marine factors on it was investigated by numerical simulation of MIKE's hydrodynamic module and calibrated with field results.

The purpose of this study was to determine the factors affecting movement of plastic floating debris in north of Hormuz Strait using particle

tracking and numerical simulation. Then based on the results, to identify

accumulated and exposure pollution areas.



Figure 1: Plastic debris and mineral water bottles dumped on east coast of Bandar Abbas (Author, April 10, 2017).

Materials and methods

Straits of Hormuz, the junction of the Persian Gulf and Oman Sea (Fig. 2-A,

B). Movement of plastic floating debris in north of Hormuz Strait was studied.

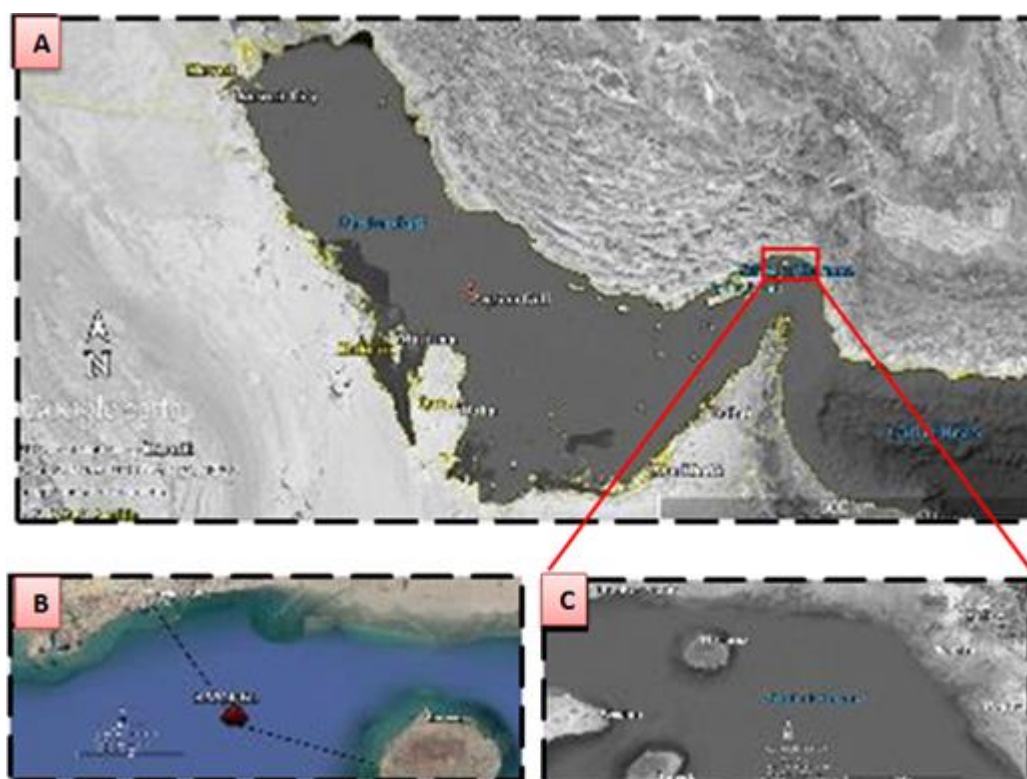


Figure 2: A: Location of the study area in the Persian Gulf, Hormuz Strait and Oman Sea. B: Analyzed area in March 2017 field data, C: particle release location and distance from Bandar Abbas and Hormuz Island.

Particle tracking

A sample, similar to marine debris, equipped with a GPS was released to perform particle tracking phase (Fig. 3). Sample weight was 740g and the draft was 50mm. To investigate effects of currents on the specimen movement, a

drifter with a height profile of 900 mm and a fin length of 500 mm was simultaneously released alongside the sample. GPS data was set up to send its position to satellite every minute in order to track the particle with great accuracy.

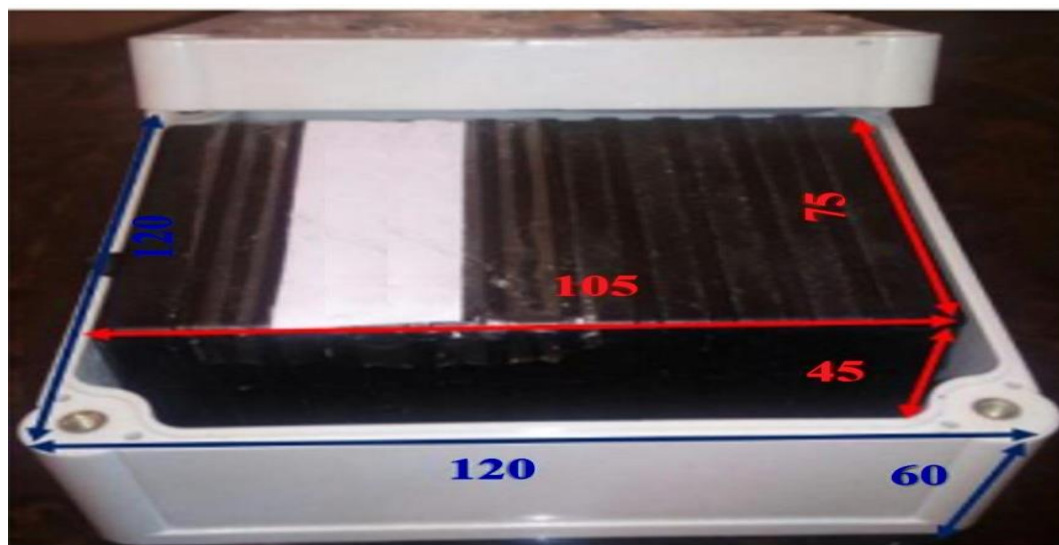


Figure 3: Released sample consisting of a seal box and a GPS (105x45x75/ mm).

Three samples path were tracked from Shahid Haqqani as the release point. The passenger dock up was about 1500m in May 2016. It is observed that current template and small dock domain brought the samples to the dock armor in less than a tidal period and their movement was stopped. The study area was extended to examine the sample behavior in at least one more tidal period. In the second sampling, which took place on March 1-4, 2017, the sampling site dimension was 10 km northwest of Hormuz Island and 11 km south of Bandar Abbas coast. A sample and a drifter were simultaneously

released (Fig. 2-C). Final analysis of the results is based on the second sampling.

Current simulation and particle tracking

To investigate and track movement of marine debris, first surface movements and current were simulated in the hydrodynamic model and then the marine debris was added and movements were tracked. For this purpose, several models were used, including HYCOM model for hydrodynamic simulation and POL3D for particle tracking (Lebreton *et al.*, 2012; Potemra 2012; Laurent *et al.*, 2013). In this study MIKE's software

developed by DHI was used to perform both simulations. MIKE's numerical software was able to track a floating object on surface of the water by Lagrangian method. Its simulation system is based on numerical solution of two-dimensional equations in shallow water and includes continuity, momentum, temperature, salinity and density equations. This software included a set of modules with two-dimensional and three-dimensional solving capability with irregular networking which was responsive to simulate this area. The simulation of oil pollution in Assaluyeh region was performed by this software (Faghihifard and Badri, 2016).

other effective parameters were investigated by tracking a marine debris particle in this region. To prevent effects of open borders, the entire Persian Gulf and Strait of Hormuz were selected as a computational domain with an open boundary with mesh. The zone was divided into three areas, the largest mesh size for simulating the target area (area 3) was set at $4.7 \times 10^{-5} \text{ deg}^2$ (12203 nodes and 23487 elements). Calibration was based on particle tracking and size of the mesh became smaller, hence number of the areas increased to 4 with $8 \times 10^{-6} \text{ deg}^2$ (18492 nodes and 35959 elements, Fig. 4).

Numerical simulation of particle tracking

In this simulation first current pattern of the region was determined and then

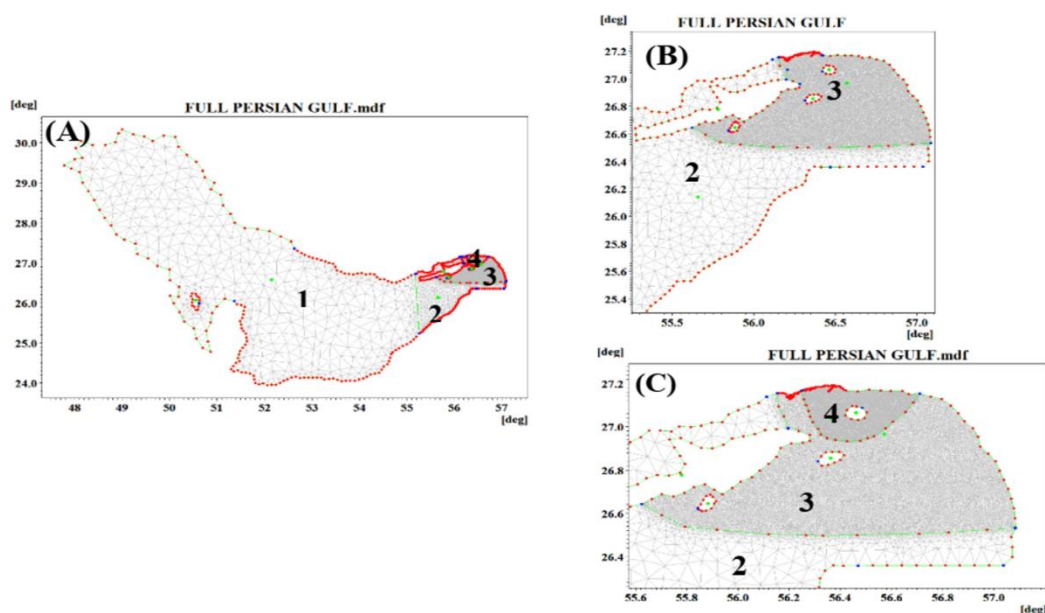


Figure 4: A: Numerical simulation mesh; B: Mesh No.1 for hydrodynamic analysis, 12203 nodes and 23487 elements; C: Mesh No. 2 for particle tracking, 18492 nodes and 35959 elements.

Water level data were extracted from TMD software with 8 main tidal parameters (M_2 , S_2 , N_2 , K_2 , K_1 , O_1 , P_2 and Q_2) over a 10 minute interval that was used for open boundary conditions. Selection of optimum distances between the points of this boundary

indicated that distance of 0.057° was an appropriate size (Fig. 5).

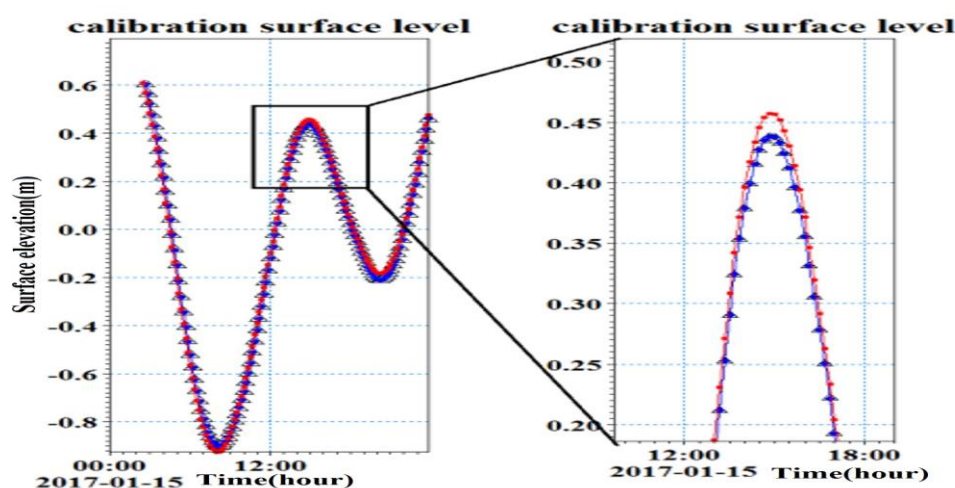


Figure 5: Optimization of optimal distance for tide at the open boundary.

The data archived from National Oceanographic Center of Iran (inio.ac.ir) were used for the sea floor modeling. Wind velocity and direction data were provided by ECMWF Institute with 6 hours interval and 0.125 mesh distance which input them into the software. In this study three numerical simulations were performed. In the first simulation, simultaneous effects of wind and tide were applied, the software was calibrated, sea bed, and wind resistance coefficients were modified based on the particle tracking results (Fig. 6). Second tidal effect was individually investigated by simulation while removing wind data. In the third

simulation effects of tide was removed and wind effect on the particle was investigated. Summary of the numerical simulations and MIKE software settings are shown in Table 1.

Results

The results were analyzed in two parts, movement of the real sample and drifter at sea for a three-day interval then MIKE's calibrated as numerical software. Based on the field results and numerical simulations, trajectory of the released sample (particle) was analyzed regarding the influence of tide, wind, and bed topography changes.

Particle tracking at sea

In order to study and record the movement behavior of sample debris, effects of wind and current in the area were studied simultaneously. Sample and drifter were released on first of March 2017 at 12:37 pm at latitude

27°08'58"N and longitude 56°32'55"E (Fig. 2-C) and tracked for three full days. Characteristic changes in water surface elevation and wind in the time interval of 1 to 3 March 2017 are shown in Fig. 7 A and B, respectively.

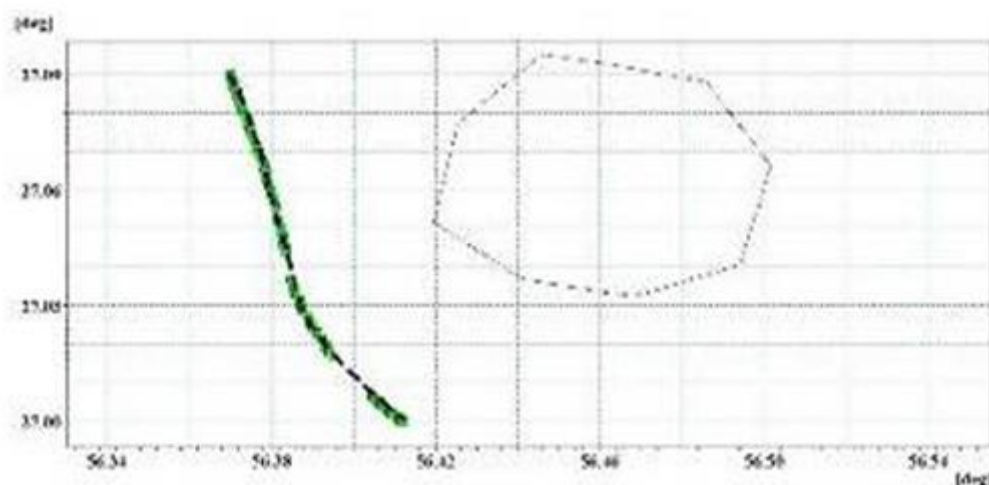


Figure 6: Interference of particle tracking and numerical simulation from 22:00 pm March 1, 2017 to 03:30 am March 2, 2017 (Green points real tracking, black line Mike result).

Table 1: Boundary condition and setting of MIKE software.

	Boundry condition	Mike setting
Simulation No 1	Wind- Tide	Horizontal eddy viscosity: Smagorinsky constant: 0.28.
Simulation No 2	Tide	Bed Resistance: Manning number 32 m ^{1/3} /s
		Density: Barotropic
Simulation No 3	Wind	For Simulation 1 and 3: Wind Friction = 0.00125

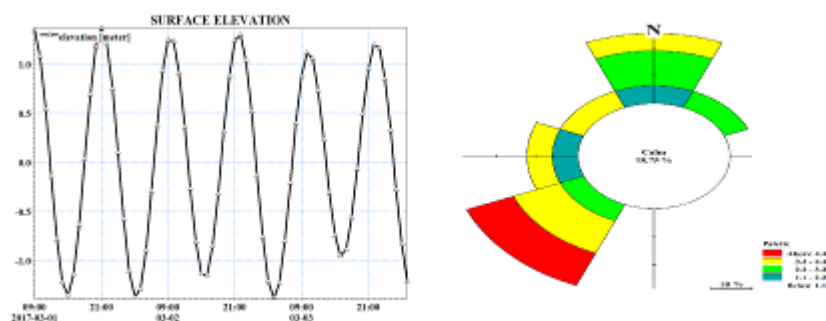


Figure 7: Changes at point 27°08'58"N 56°32'55"E 1 to 5 March 2017, (A): water surface elevation, B) Wind rose.

The observations clarified that the drifter movement at each tidal period was in elliptic form. In tracking at a tidal interval (March 2, 2017), the large diameter of ellipsoid was about 6000m and the small diameter was 1450 meters (Fig. 8). Within one hour after low water to one hour before high water, the current velocity was high and the sample passed through the large diameter (Fig. 8, red arrow). One hour before and after the high water, current velocity tends to zero and the particle moved to the direction of small elliptic diameter (Fig. 8, blue arrow). Within one hour after the high water state to one hour before the low water, the absolute value of current velocity again

increased and the particle passed along the large elliptic diameter for its return path (Fig. 8, Green arrow). This periodic movement repeated again for the period of low water to high water.

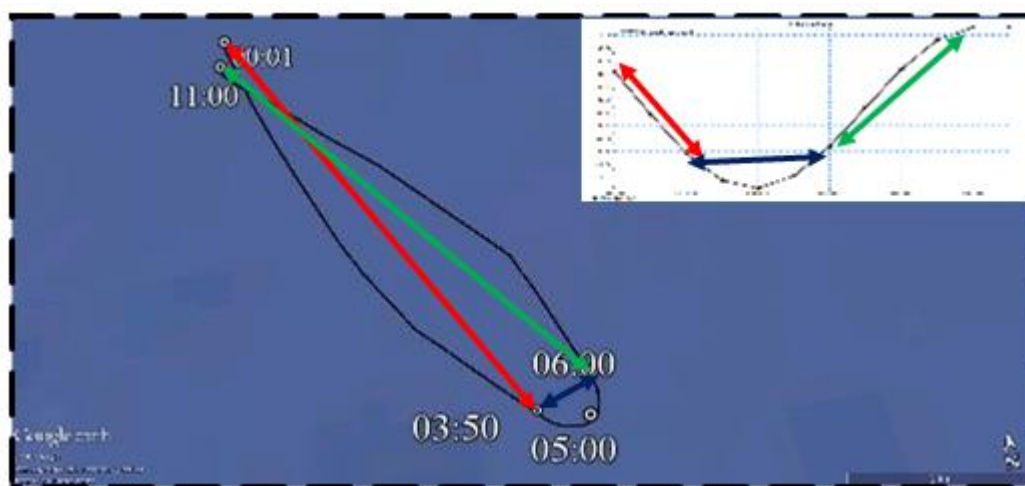


Figure 8: Tracking motion by the marine derbies on March 3, 2017 from 12:00 pm to 11:00 pm, large and small diameter of ellipse of 6000 and 1450 m, respectively.

Due to low wind speed, the sample that was afloat freely on surface of the water on March 1st 2017 moved in a drifter direction. The sample had the most displacement in direction of small elliptical diameter in the period of one hour before and one hour after the low

tide, in other words, wind speed and direction affected surface flow and wind surface. As well the particle moved with an angle to the wind direction one hour before and after low tide. Therefore, it can be said that even when there is wind, if we assume the

distance between a high tide and a low tide is 6 hours, from the moment of high water in low tide to one hour after it and also from one hour before to the moment of low water in high tide wind speed and direction determined the direction of movement of debris. Within the remaining 4 hours between these two tidal flow was the main factor on motion direction and its displacement was up to 10 times more than that in the time interval of 2 hours. It was also observed that in the period of 2 hours before and after low tide (high water), the sample moves non-parallel to wind direction. When wind speed was high, the sample moved more than the drifter motion and when wind speed was low the sample motion was less than the drifter.

Movement analysis of marine debris, numerical simulations

Tidal effects on marine debris

Tidal current made a reciprocal flow. This was investigated for a marine debris particle in a semi diurnal tide. The marine debris particle was sequentially released and tracked at the point 27°11'70"N 56°35'50"E for 12 hours and movement changes were extracted at one hour intervals. The particle movement pattern within this time interval indicated that direction and magnitude of tide motion changed to a 360° rotation of the particle. During the tide period movement dimension was larger and reversed with the low or high water (Fig. 9).

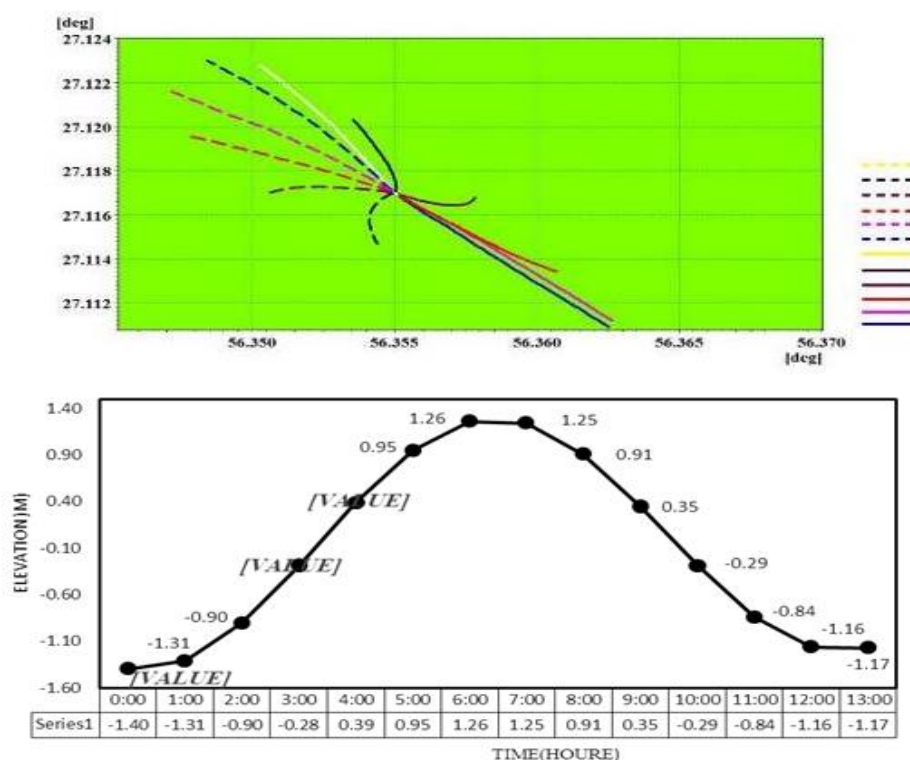


Figure 9: Movement and trends at the 27°11'70"N 56°35'50"E point at a depth of 9.5 m at one-hour intervals for a half day (March 2, 2017), A: Movement of a particle, B: Trend of the corresponding changes elevation.

Approximately one hour before and after low or high water, velocity was the smallest as it tends to zero and velocity was maximum when water level approaches to zero (Fig. 10).

Particle movement over a complete tidal period shaped an ellipsoid. The particle had the lowest movement and changed direction at high or low water. In other words, small diameter of the ellipse was formed during this period due to direction of wind. Spring tide

and neap tide occurred in March, on the 30th day at 9am and 21st at 3pm. The particle displacement was evaluated within 8 hours time interval (4 hours before and 4 hours after low water) at the $27^{\circ}11'68''\text{N}$ $56^{\circ}35'15''\text{E}$ point. The results showed that the particle transferred more than 7200m in spring tide and 3400m in the neap tide. Therefore spring tide increased the motion length but neap tide motion was less (Fig. 11).

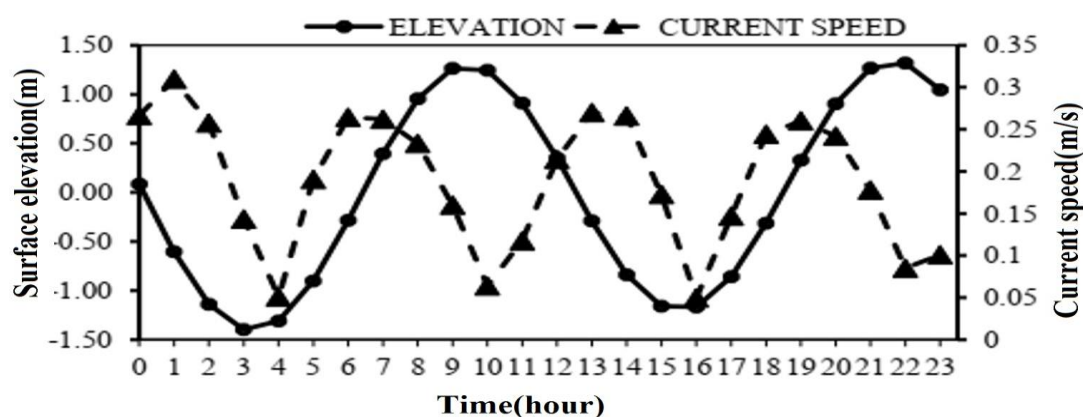


Figure 10: Velocity speed depended to water level variation, at the point $27^{\circ}11'70''\text{N}$ $56^{\circ}35'50''\text{E}$ during one day (March 2, 2017).

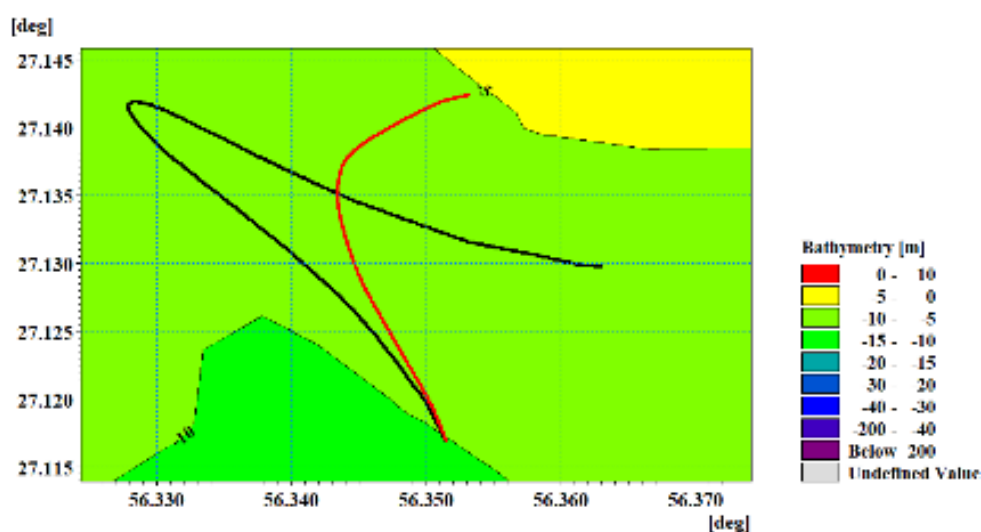


Figure 11: Comparison of displacement in spring and neap tide in March: black route is displacement in Spring Tide and red route is displacement in Neap Tide.

Effects of depth on movement of marine debris

Depth changes affect the surface current because of bed roughness and thus may change the magnitude and direction of marine debris motion. Four points with depths between 3 to 30m were selected according to Table 2 in order to test this

hypothesis and their movement was evaluated over a 3 hours period with constant wind for all particles. The results showed that water depth increase caused farther dispersion distance, also it caused movement velocity increase (Fig. 12).

Table 2: Comparison of current velocity and displacement between points with depths of 3 and 30m.

NO	Point	Depth (m)	Current Speed (m/s)			Movement (m)
			Start	After 195 min (half of period)	End	
1	27°11'50"N 56°45'50"E	3.12	0.1552	0.2	0.110	1933
2	27°08'10"N 56°39'20"E	10	0.096	0.168	0.082	2564
3	27°05'70"N 56°37'50"E	16.42	0.064	0.291	0.031	4294
4	26°99'50"N 56°39'90"E	28	0.117	0.260	0.057	5247

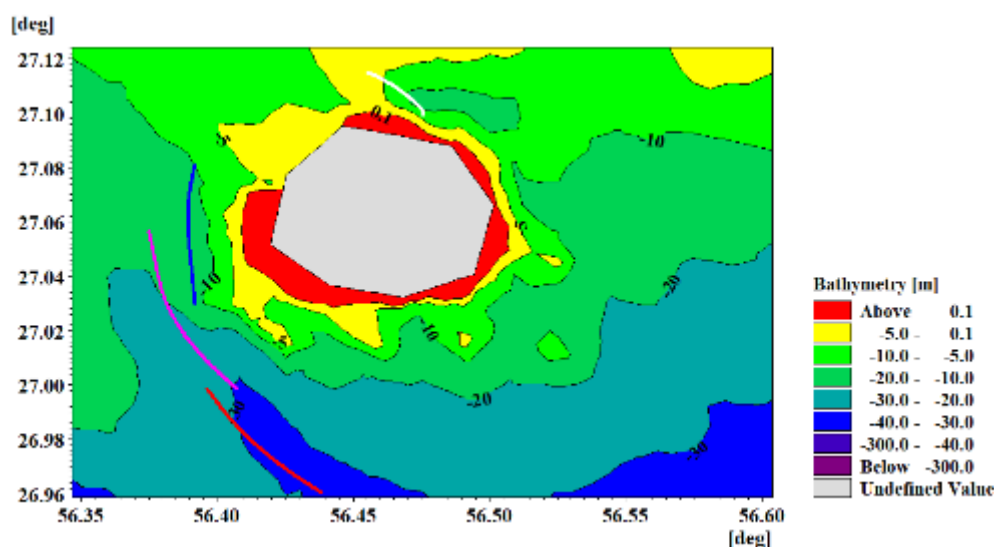


Figure 12: Comparison of movement within a 3 hours' time interval for release at depth: White: 3.12m, Blue: 10m, Pink: 16.42m and Red: 28m.

Effects of wind on marine debris

Regarding the obtained results wind was the most impacted factor on particle movement at the time of high or low water. Comparison between the three hydrodynamic parameters in

modeling and observation as wind, tide and wind-tide modes, tidal effects were about 10 times greater than wind. However, wind can change direction of the route toward small diameter of ellipse and divert the particle to right or

left, which was directly related to wind velocity. This effect occurred within an hour before and after high or low (tide) water. In this interval, when approximately 2h passed from the low water mode and similarly for high water (one third of the time for high or low water), the hypothetical elliptic diameter changed in deep region and spiral in the shallow region (Fig. 13).

Wind velocity effect on current in the hydrodynamic module was investigated. In this case, simulation was performed with only variable wind regardless of tide. Maximum wind velocity variations of 0.05m/s was estimated at the 27°05'N 56°30' E point on March 1 and March 3, respectively.

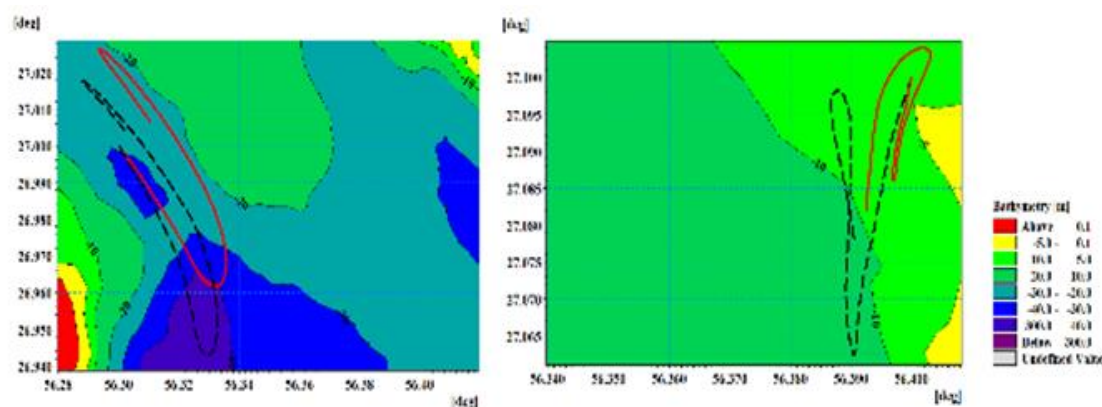


Figure 13: Comparison of wind effect on debris movement, (A) in deep water, (B) shallow water; red color represents movement direction with tidal boundary condition and black dashed line with wind-tidal boundary condition on March 2 from 12am for 12 hours.

Marine debris tracking movement

Selection and release of particles at different times and depths were calibrated according to 8 mentioned points with various depths and different tide periods (Fig. 14). Four points were selected to test depth effects (3m to 30m) and four points on high traffic route between Qeshm and Bandar Abbas. The time was chosen for the release in high and low water, with

maximum and minimum values and zero alignment, maximum and zero velocity of current were considered in time periods of January, February and March. The results showed that 67.8% of debris released for the first time were moved and reached Bandar Abbas coast, 30% to Hormuz Island coast and less than 2% to Qeshm Island coast (Table 3).

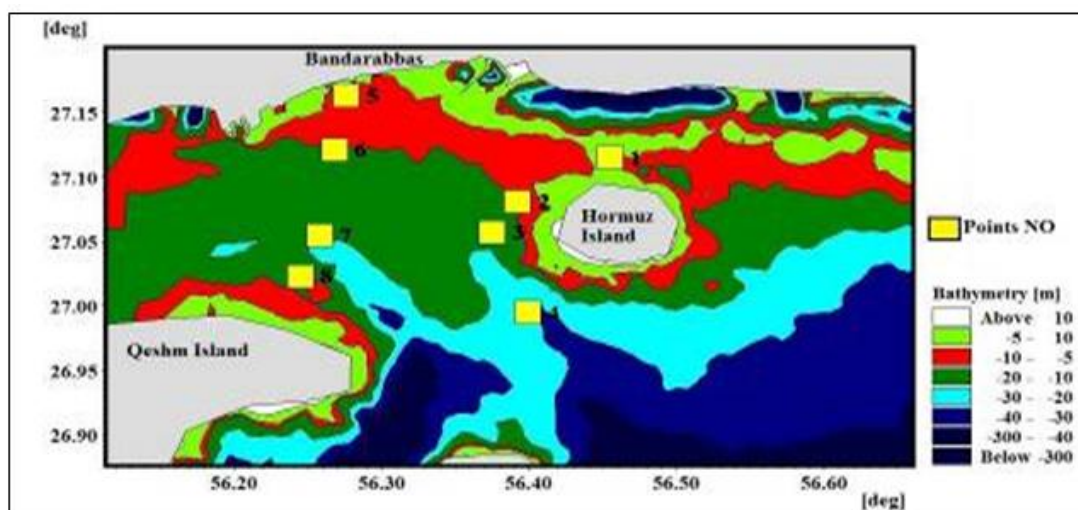


Figure 14: Release points for tracking debris movement.

Table 3: Characteristics of released particles in the model.

Point No	Long (deg) Lat (deg)	DEPTH (m)	Number of particles reached beach		
			Bandar Abbas	Hormuz Island	Qeshm Island
Point 1	27°11'50"N 56°45'50"E	3.2	6	1	0
Point 2	27°08'10"N 56°39'20"E	10	5	2	0
Point 3	27°05'70"N 56°37'50"E	16.5	2	5	0
Point 4	26°99'50"N 56°39'90"E	28	3	4	0
Point 5	27°16'30"N 56°27'60"E	5	6	1	0
Point 6	27°12'10"N 56°26'80"E	11.3	7	0	0
Point 7	27°05'50"N 56°25'80"E	18	5	2	0
Point 8	27°02'30"N 56°24'50"E	9.7	4	2	1
Accumulation assessment (%)	-----		67.86	30.36	1.79

The study of oil spill floating was conducted near sample release place of the present study, their results on the water surface indicated that direction of currents are in a way that oil spill was transferred to Badar Abbas coast (Farzinger *et al.*, 2011), it is the same as the obtained results showing macro plastic accumulation in this area.

Discussion

The purpose of this study was to determine the factors affecting movement of floating macro plastic debris and predict their accumulation in Hormuz Strait area in Hormozgan province. The results of particle tracking and numerical simulation clarified that the main hydrodynamic

factor on floating movement debris in Hormuz Strait was tidal current and current was impacted on the trajectory direction. The main discussed tidal parameters showed that M_2 parameter originating from the half-day lunar was the most important tidal parameter. The tide periodicity formed a roundabout and elliptical path. The small diameter of this ellipsoid was due to wind-driven flow rate. Tidal current velocity reached its lowest value in high or low water, and at this moment wind-induced velocity in northern hemisphere diverts particles to right side of wind direction. In the interval of more than two hours, the debris moved to the right by wind perpendicular to wind direction, after tidal current recede the sample is moved. The results showed that tidal currents were more effective than wind which was observed in field and modeling output.

But due to shallowness of the area, roughness of the bed had a significant impact on the sea surface. In the simulation results with increasing depth, the debris speed movement increased and vice versa. On the other hand, in deep areas direction of motion made an elliptical and in shallow and coastal areas this path formed a spiral. After identifying the factors that affected debris movement, the scenarios were simulated base on the tidal period with the depth of the area along the passenger buoys route. Intercepted samples identified that more than 60% of the debris are arrived in Bandar Abbas coast in less than ten days which

accumulated more on east coast of Bandar Abbas ($56^{\circ}35'E$ to $56^{\circ}43'E$). This is not only an environmental warning for the inhabitants of the area but also is a serious threat to the birds and aquatic ecosystems of the area and should be considered in coastal monitoring programs. The results of this study illustrated that the best time to cleanup plastic pollution is within spring or neap tide (full tidal time) in calm weather. At this time, debris is almost unobstructed at sea level and can be collected.

Failure to collect macro plastic debris may cause infiltration to the seafloor and convert to smaller particles entering the aquatic ecosystem cycles and causing irreparable environmental risks.

This study shows that when the water level is in mean sea level, the tidal current speed is in maximum value, and can cause movement of fishnets and even cause them to disappear, which is one of the most important environmental hazardous factors in fisheries, so local fishermen should be aware of this matter.

Acknowledgements

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¹. Danish Hydraulic Institute

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