Article

**Integrated use of a numerical model and remote sensing for oil spill monitoring in Balikpapan Bay, Indonesia**

**Supplementary materials**

**Table S1.** Model parameters.

|  |  |  |
| --- | --- | --- |
| Parameter | Sources | Link |
| Water depth | Bathymetry from CMap Norway | https://www.c-map.com/ |
| Coastline | Basemap from Indonesia Geospatial Portal | https://tanahair.indonesia.go.id/ |
| Temperature;salinity | World Ocean Atlas (WOA) & Conductivity, Temperature & Depth (CTD) in-situ Observation | https://www.ncei.noaa.gov/products/world-ocean-atlas/ |
| Rainfall;sea surface wind;evapotranspiration; wave radiation | ERA-Interim | https://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/ |
| Oil properties | PERTAMINA Laboratory |  |

**Table S2.** Primary data input.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Position of oil leakage** | **Parameter** | **Value** | **Unit** | **Remark** |
| Coordinate | Longitude | 116°47'22.17"E | Lat/Long WGS84 | Coordinates of pipe breakage (UTM50S: 476581.14, 9862304.51) |
|  | Latitude | 1°14'44.75"S |
| Pipeline Depth | From Sea Surface | 28 | meter | - |
| Pipe Dimension | Diameter | 20 | inch | - |
| Flow of Oil in Pipeline | Discharge | 1200 | m3/hr | - |
| **Time and date of oil leakage** | **Parameter** | **Value** | **Unit** | **Remark** |
| Time Event | Time | 1: 20 |  UTC +8 | - |
|  | Date | 31-Mar-2018 | AD (Anno Domini) |
| **Duration of oil leakage** | **Parameter** | **Value** | **Unit** | **Remark** |
|  | Time Begin | 23:30 |  UTC +8 | - |
|  | Date Begin | 30-Mar-2018 | AD (Anno Domini) |
|  | Ending Time | 11:10 |  UTC +8 | The time all pumps were turned off: April 1, 2018 - 11:10 WITA. Whereas starting from March 31, 2018, one pump was operational. Normal operation is with two pumps. |
|  | Ending Date | 01-Apr-2018 | AD (Anno Domini) |
|  | Estimated oil volume | 2402.97 | m3 |  |
| **Oil type of oil leakage** | **Parameter** | **Value** | **Unit** | **Remark** |
| General | Type | Crude Oil | Type of Oil | - |
| Physical | Specific Gravity | 0.8265 | (kg in 1 liter oil) | Specific Gravity @60/60F |
| Physical | Density at Standard Temperature | 826.5 | (kg/m3) | - |

**Table S2.** (*Continued*).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Rate of oil leakage** | **Parameter** | **Value** | **Unit** | **Remark** |
| Flow Rate | (Unit Volume per Time) or (Unit Mass per Time) | 1100 | m3/hr | - |
| **Oil characteristic of oil leakage** | **Parameter** | **Value** | **Unit** | **Remark** |
| Oil Fraction 1 | Mass of volatile oil fractions (weight below 160 g/mol, boling point well below 300 ℃) | 59.16 | vol% | Consisting of gas components (light end), light naphtha, heavy naphtha, kerosene, light gasoil, and part of heavy gasoil. |
| Oil Fraction 2 | Mass of heavy oil fractions (weight above 160 g/mol, boling point above 300 ℃) | 40.84 | vol% | Calculated, derived from the remaining fraction other than oil fraction 1 |
| Oil Fraction 3 | Wax mass in oil (conservative) | 8.01 | wt% | Total wax content di whole crude |
| Oil Fraction 4 | Asphaltene mass content in oil (conservative) | 0.31 | wt% | Total asphaltene di whole crude |
|  | Water fraction of oil | 0.4 | vol% | Data analysis of crude CDU IV for sediment and water parameters |
| **Oil clean up** | **Parameter** | **Value** | **Unit** | **Remark** |
| Booms or skimmers or dispersants or in-situ burning or beach clean up | Effectiveness of Oil Clean Up | 1.17 | (%) | - |

**Table S3.** Model assumption.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Name** | **Description** | **Unit** | **Value** |
| 1 | EvaporationType | Select between a simple, time depended (=1, default) or detailed (=0) evaporation formula | switch (0/1) | 1 |
| 2 | Sc | Detailed Evaporation: Schmidt number | dimensionless | 2.7 |
| 3 | MW | Detailed Evaporation: Average molecular weight of volatile fraction of oil | g/mol | 117 |
| 4 | Pvp | Detailed Evaporation: Vapor pressure of volatile fraction | atm. | 0.002 |
| 5 | Simple\_Evap\_type | Simple Evaporation: select logarithmic or quadratic oil type (logarithmic = 0, quadratic = 1) | switch (0/1) | 0 |
| 6 | evap180 | Simple evaporation formulation: distillation percentage (by weight) at 180 ℃ | dimensionless | 26 |
| 7 | evapA | Simple evaporation formulation, 1st oil specific constant | dimensionless | 2.67 |
| 8 | evapB | Simple evaporation formulation, 2nd oil specific constant for temperature dependency | dimensionless | 0.06 |
| 9 | hterm | Spreading: Terminal thickness | m | 0.0001 |
| 10 | kbiodv | Biodegradation volatile fraction: Decay rate | per day | 0.005 |
| 11 | kbiodh | Biodegradation heavy fraction: Decay rate | per day | 0 |
| 12 | MaxWater\_Fract | Emulsification: Maximum water fraction | dimensionless | 0.75 |
| 13 | Kao | Emulsification: Constant Kao equal 3.3 at 293 °K | dimensionless | 3.3 |
| 14 | Kaw | Emulsification: Constant Kaw equal 200 at 293 °K | dimensionless | 200 |
| 15 | kem | Emulsification: emulsion rate | s/m2 | 1.00E-06 |
| 16 | densL | Buoyancy: Density of original oil, volatile fraction (20 ℃) | kg/m3 | 755 |

**Table S3.** (*Continued*).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Name** | **Description** | **Unit** | **Value** |
| 17 | densH | Buoyancy: Density of original oil, heavy fraction (20 ℃) | kg/m3 | 831 |
| 18 | Cwsatv | Water solubility: volatile fraction | dimensionless | 2.00E-05 |
| 19 | Cwsath | Water solubility: heavy fraction | dimensionless | 2.00E-07 |
| 20 | ktempv | Volumetric temperature expansion coefficient volatile oil fraction | 1/℃ | 0.0007 |
| 21 | ktemph | Volumetric temperature expansion coefficient heavy oil fraction | 1/℃ | 0.0007 |
| 22 | kphotv | Photooxidation volatile fraction: Decay rate at 100 watt/m2 | per day | 0 |
| 23 | kphoth | Photooxidation heavy fraction: Decay rate at 100 watt/m2 | per day | 0 |
| 24 | eta | Photooxidation: Light extinction coefficient | 1/m | 1 |
| 25 | kdisl | Dissolution: Rate, light fraction | per day | 0.4 |
| 26 | kdish | Dissolution: Rate, heavy fraction | per day | 0.4 |
| 27 | wspdi | Vertical dispersion: Wind speed for initiation of wave breaking | m/s | 5 |
| 28 | E | Vertical dispersion: wave energy dissipation rate per unit volume | J/m3/s | 1000 |
| 29 | minSurfDist | Max distance below surface to belong to surface amount | m | 0.05 |
| 30 | minBotDist | Distance above bed to belong to bottom amount | m | 0.05 |
| 31 | Mooney\_K | Mooney constant in the viscosity-equation | dimensionless | 0.7 |
| 32 | ViscosityT0 | Dynamic oil viscosity at reference temperature | cP | 6 |
| 33 | Viscosity\_temp | Reference temperature for dynamic oil viscosity | ℃ | 15 |
| 34 | Viscosity\_coef | Coefficient for exponential temperature dependency of viscosity | dimensionless | −0.111 |
| 35 | AreaGrowth | Oil Area growth rate constant | per second | 150 |
| 36 | RemoveMass\_Threshold | Particles with a total oil mass below this threshold will be removed | kg | 0.001 |
| 37 | Layer\_start | Depth where extra output layer starts | m | 0 |
| 38 | Layer\_end | Depth where extra output layer ends | m | 10 |
| 39 | Enable\_Dispersion | Vertical dispersion: on-off switch (0 = off, 1 = on) | switch (0/1) | 1 |
| 40 | Enable\_EVAP | Evaporation: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 41 | Enable\_BIOD | Biodegradation: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 42 | Enable\_PHOT | Photo-oxidation: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 43 | Enable\_Diss\_s | Surface dissolution: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 44 | Enable\_Diss\_wc | Water column dissolution: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 45 | Enable\_Wateruptake | Water uptake: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 46 | Enable\_Waterrelease | Water release: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 47 | Enable\_Diameterchange | Droplet diameter change: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 48 | Enable\_Areachange | Area change: on-off switch (1 = on, 0 = off) | switch (0/1) | 1 |
| 49 | Gas Constant | Gas Constant | Built-in |  |
| 50 | Time Step | Time Step | Atm m2/mol K | 8.21E-05 |
| 51 | Dynamic Viscosity | Dynamic viscosity of water at 20 ℃ | cP | 1.002 |

**Table S4.** Secondary model forcing.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Description** | **Type** | **Value** | **Unit** |
| 1 | Horizontal drift speed | Built-in |  |  |
| 2 | Horizontal drift direction | Built-in |  |  |
| 3 | Vertical drift speed | Constant | 0 | m/s |
| 4 | Wind speed | Built-in |  |  |
| 5 | Water Temperature | Constant | 30.19564 | °C |
| 6 | Density of water | Constant | 1016.997 | kg/m3 |
| 7 | Solar radiation | TS file | Varying | watt/m2 |
| 8 | Wave height | Constant | 0.289455 | m |
| 9 | Wave period | Constant | 5.5 | s |
| 10 | Area map with probability of a particle getting absorbed when beached | Constant | 0 | probability |
| 11 | Area map with probability of a particle to not move | Constant | 0 | probability |
| 12 | Area map of activity for dispersant | Constant | 1.17 | dimensionless |

**Table S5.** In-situ measurement of water level.

|  |  |  |  |
| --- | --- | --- | --- |
| **Station** | **WL in Spring tide [m]** | **WL in Neap tide [m]** | **The tidal range [m]** |
| **Maximum** | **Minimum** | **Maximum** | **Minimum** | **Full moon tide** | **Neap tide** |
| TD1 | 1.59 | −1.55 | 0.41 | −0.40 | 3.02 | 0.81 |
| TD2 | 1.54  | −1.48 | 0.43 | −0.51 | 3.02 | 0.94 |

**Table S6.** The simulated concentration of stranded oil on C1–C4 transect.

|  |  |
| --- | --- |
| **Transect** | **Oil concentration stranded [mg/kg]** |
| **Minimum** | **Maximum** | **Average** |
| C1 | 3133 | 17,475 | 6890 |
| C2 | 1001 | 31,555 | 4663 |
| C3 | 3885 | 78,056 | 33,372 |
| C4 | 6060 | 29,634 | 17,838 |



**Figure S1.** The computational domain utilized for the numerical simulations.