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Petroleum Inputs to the Persian Gulf

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ABSTRACT

This study presents results of mass balance calculation for petroleum discharges produced by littoral countries mainly into the Persian Gulf in their endangered or polluted points. Recent budget for total and local point source petroleum discharges to marine environment of the region calculated according to the outputs of a model based on reported trend in global petroleum discharges rates in the past three decades. Agreement between calculated petroleum discharges and reported values indicates the accuracy of applied assumptions. Based on above description, it has been estimated that petroleum discharges in the Persian Gulf is about 120186 t year^{-1} or 600930 barrels year^{-1}.

Key words: Petroleum inputs, Persian Gulf, mass balance

INTRODUCTION

Marine environmental quality preservation in the Persian Gulf (Fig. 1) is crucial for several socio-economic reasons. Pollution accompanies most kinds of human activities in marine environments. In contrast with land ecosystems, in the water environment, pollutants quickly spread over large distances from the sources of pollution (Hamza and Munawar, 2009). The Persian

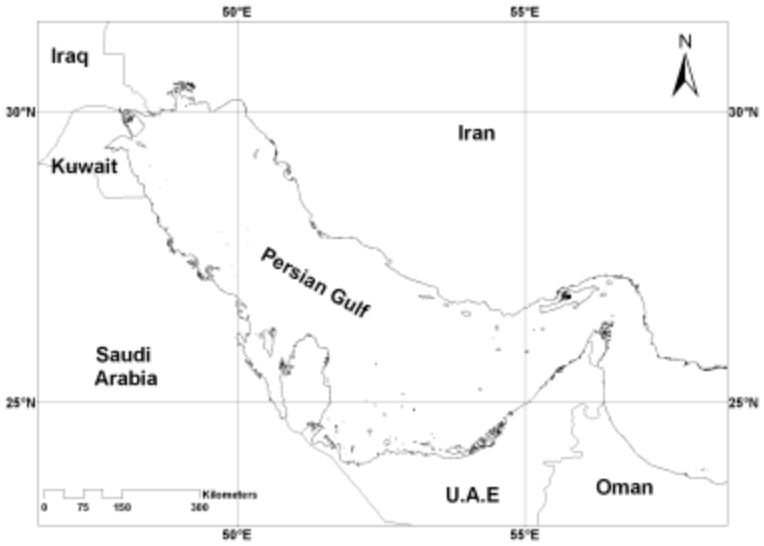

Fig. 1: Map of study area

Gulf region possesses some of the most endangered coastal areas in the world due to petroleum point and non point sources. Over half of the world oil supply is transported from the Persian Gulf and offshore oil exploitation in this region is considered the most extensive in the world (Golob and Bruss, 1984). In addition, as a result of the 1991 war, the marine environment in the Persian Gulf was subjected to an estimated 6 million barrels of crude oil, making it the largest oil spill ever recorded (Burger, 1997). In spite of the fact that the overall pollution in the Northern coasts of the Persian Gulf is in medium range for many petroleum-associated contaminants (Eghtesadi *et al*., 2002) but there are reports on sediment accumulation of higher molecular weight Polycyclic Aromatic Hydrocarbons (PAHs) in this area (Eghtesadi-Araghi, 2004). The PAHs can exert their effects on different marine habitats and their constituents like biological membranes (Eghtesadi-Araghi, 2005; Karami-Varnamkhasti *et al*., 2008) as the first barriers of contact with PAHs. Although, many of these biological responses can be used as estimators of marine ecosystem health (Eghtesadi-Araghi *et al*., 1999) but approximating studies on quality and quantity of contaminants and pollutants is necessary due to the fact that the hazards of pollution in the Persian Gulf have increased significantly in the last three decades as a result of the high levels of production and transportation of petroleum as well as growing industrialization and urban development around its shore (Heilman *et al*., 2008).

Available data shows that land-based and atmospheric sources account for about two-thirds of the total input of contaminants into the marine environment, constituting 44 and 33%, respectively. The main pollution press undoubtedly falls on the shelf zones and especially on the coastal areas (Windom, 1992). In order to analyze large-scale pollution and its global effects, it is common to distinguish entering pollutants to risky marine environments.

The mass balance loom is a useful tool for approximating and verifying the rates of entrance of petroleum constituents in marine ecosystems. Petroleum hydrocarbons (PHCs) are among the group of organic contaminants which are of extremely complex grouping in chemicals from varied sources. Important processes such as equilibrium partitioning of diverse individual components between particulate and dissolved phases in seawater, biological metabolism and photo-oxidation modify hydrocarbons discharged to the sea which make it difficult to quantify and interpret the analytical data.

Model development: Total petroleum input estimation: To develop the proper model for assessing petroleum pollution sources, pollutions' point sources were divided to land based (their sources located in or near the sea shore) and sea based pollution. To estimate land based pollution, we focused on per capita discharges from urban and rural populations and used the estimates of Eganhouse and Kaplan (1981) of 1014 g/year/person for urban populations and 398 g/year/person from rural populations as river discharges. For sea based pollution the rate of oil spillage or leakage from different sources (e.g., petroleum exploration and exploitation) of bunkers, pipelines or ballast water of tanker ships etc should be accounted. Limited number of scientific literature had been published previously in related fields for this study. Therefore, estimations were applied about flux of contaminants in some points or generalize our assumptions to other points or locations in order to collect helpful data for our model of study and estimate releasing rate of petroleum in Persian Gulf. For better estimation of total pollution discharges, we assumed that chronic pollution is more important than accidents (Burns and Saliot, 1986) and then focused on global oil hydrocarbon discharges in to the marine environments (Table 1) (Patin, 1999) and its ratio to total crude oil production over the years 1973 to 1990 (Table 2). The relationship between annual oil production

Table 1: Estimates of global inputs of oil pollution into the marine environment (thousands tons/year of oil hydrocarbons)

Sources	1973	1979	1981	1990
Land-based sources				
Urban runoff and discharges	2,500	2,100	1,080 (500-1,250)	1,175 (50%)
Coastal refineries	200	60	100 (60-600)	-
Other coastal effluents		150	50 (50-200)	-
Oil transportation and shipping				
Operational discharges from tankers	1,080	600	700 (400-1,500)	564 (24%)
Tanker accidents	300	300	400 (300-400)	-
Losses from non-tanker shipping	750	200	320 (200-600)	-
Offshore production discharges	80	60	50 (40-60)	47 (2%)
Atmospheric fallout	600	600	300 (50-500)	306 (13%)
Natural seeps	600	600	200 (20-2,000)	259 (11%)
Total discharges	6,110	4,670	3,200	2,351

Table 2: World and selected OPEC producers' crude oil production, 1960-2006 (Million barrels per day)

Years	Persian Gulf countries	Iran	Iraq	Kuwait	Saudi Arabia	United Arab Emirates	World
1973	20.67	5.86	2.02	3.02	7.60	1.53	55.68
1974	21.28	6.02	1.97	2.55	8.48	1.68	55.72
1975	18.93	5.35	2.26	2.08	7.08	1.66	52.83
1976	21.51	5.88	2.42	2.15	8.58	1.94	57.34
1977	21.73	5.66	2.35	1.97	9.25	2.00	59.71
1978	20.61	5.24	2.56	2.13	8.30	1.83	60.16
1979	21.07	3.17	3.48	2.50	9.35	1.83	62.67
1980	17.96	1.66	2.51	1.66	9.90	1.71	59.56
1981	15.25	1.38	1.00	1.13	9.82	1.47	56.05
1982	12.16	2.21	1.01	0.82	6.48	1.25	53.45
1983	11.08	2.44	1.01	1.06	5.09	1.15	53.26
1984	10.78	2.17	1.21	1.16	4.66	1.15	54.50
1985	9.63	2.25	1.43	1.02	3.39	1.19	53.97
1986	11.70	2.04	1.69	1.42	4.87	1.33	56.20
1987	12.10	2.30	2.08	1.59	4.27	1.54	56.63
1988	13.46	2.24	2.69	1.49	5.09	1.57	58.69
1989	14.84	2.81	2.90	1.78	5.06	1.86	59.79
1990	15.28	3.09	2.04	1.18	6.41	2.12	60.49
1991	14.74	3.31	0.31	0.19	8.12	2.39	60.19
1992	15.97	3.43	0.43	1.06	8.33	2.27	60.12
1993	16.71	3.54	0.51	1.85	8.20	2.16	60.17
1994	16.96	3.62	0.55	2.03	8.12	2.19	61.04
1995	17.21	3.64	0.56	2.06	8.23	2.23	62.33
1996	17.37	3.69	0.58	2.06	8.22	2.28	63.70
1997	18.10	3.66	1.16	2.01	8.36	2.32	65.59
1998	19.34	3.63	2.15	2.09	8.39	2.35	66.92
1999	18.67	3.56	2.51	1.90	7.83	2.17	65.85
2000	19.89	3.70	2.57	2.08	8.40	2.37	68.37
2001	19.10	3.72	2.39	2.00	8.03	2.21	67.98
2002	17.79	3.44	2.02	1.89	7.63	2.08	66.97
2003	19.06	3.74	1.31	2.14	8.78	2.35	69.23
2004	20.79	4.00	2.01	2.38	9.10	2.48	72.22
2005	21.50	4.14	1.88	2.53	9.55	2.54	73.65
2006	21.23	4.03	2.00	2.54	9.15	2.64	73.47

[1]Persian Gulf countries are: Bahrain, Iran, Iraq, Qatar, Saudi Arabia and United Arab Emirates. Source: www.eia.doe.gov

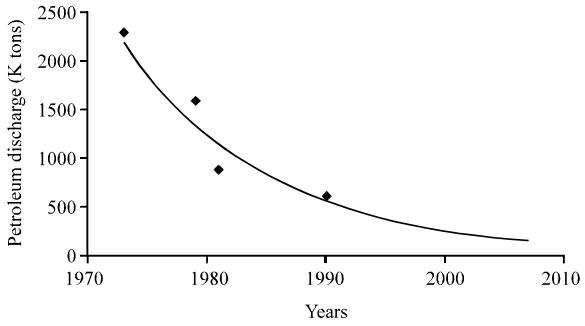

Fig. 2: Total petroleum discharges/year of the Persian Gulf counties

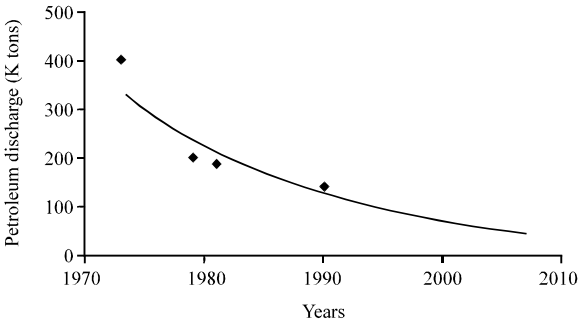

Fig. 3: Petroleum discharges/year of the Persian Gulf littoral countries from shipping operation

and oil discharge was estimated. This global relation can be adopted for regional areas. The situation reflected in Table 1 may differ at regional level, however one can expect similar situation in the region of intensive off shore oil and gas Developments, for example, Red sea, Persian Gulf, Caspian Sea or Gulf of Mexico. So, we calculated oil production ratio to discharges values for drawing a plot that allow the relation of petroleum discharges per year for Gulf littoral countries (Fig. 2). Equation of this exponential curve is $y = 2E+72e^{-0.0805x}$ and the correlation is high and significant ($R^2 = 0.9012$, $p = 0.0426$, $F = 11.53342$). By extrapolating this curve for 2006 year in the equation, it was estimated that 148 thousand tons of petroleum hydrocarbons discharged in to the Persian Gulf area. While crude oil production in Gulf region is 21.23 M barrels/day (Table 2) or 1061.5 M ton $year^{-1}$. Calculated oil discharge will be 0.014% of oil production in the region. This factor is utilizable for local oil fields and terminals, or in coastal refineries of all littoral countries in the region. Traditional shipping and oil transportation routes are more exposed to the impacts of oil-polluted discharges from tankers and other vessels than other areas. For example, observation in the Caribbean basin (Corbin *et al.*, 1993) showed that where annually up to 1 million tons of oil enter the marine environment, showed that 50% of this amount came from tankers and other ships (Patin, 1999). Sea based pollution mainly arises from oil tankers shipping and transportations which we could barely find updated information about these kinds of operations in the region. So, assumptions were made here e.g., global oil discharges from shipping within 1973-1990 are shown in Table 1. These values were used for drawing a curve to obtain the corresponding equation from which, 2006 oil discharges from shipping could be calculated from (Fig. 3). Then the ratio between oil this value and oil discharges from production (estimated total oil discharge for the Gulf region)

Table 3: Petroleum released from land and sea based sources in different locations and selected countries in the Persian Gulf

Country	Oil export share (%) in the Persian Gulf [1]	Oil production (million barrels/day)[2]	Total oil dscharges (t year^{-1})[3]	Land based oil discharges[4]	Sea-based oil discharges based on GPA (t year^{-1})	Sea-based oil discharges[5] (t year^{-1})	Total oil discharges (ton year^{-1}) land-based+ sea based oil discharge on GPA	Total oil discharges (t year^{-1}) land-based+ sea based oil discharge
Bahrain	0.1	0.05	350	608	193	116	801	724
Saudi Arabia	47.0	9.15	65730	2378	90436	21048	92814	23426
United Arab Emirates	14.0	2.64	17290	1544	26911	5740	28455	7284
Kuwait	12.0	2.54	17528	784	23100	5729	23884	6513
Qatar	6.0	1.10	7700	537	11550	2556	12087	3093
Iran	13.0	4.03	28337	3410	25063	9408	28473	12818
Sum	92.1	19.51	136935	9261	177253	44597	186514	53858

[1,2]from: http://www.eia.doe.gov/emeu/cabs/Persiangulf/oil.html, [3]Calculated based on its attribution to annual oil production (global ratio), [4]Based on Eganhouse and Kaplan estimates for per capita discharge (Eganhouse and Kaplan, 1981), [5]Oil discharges from sea based activities were proportional to 33.2 percent of oil discharges resulted from annual oil production

in 2006 were found. Resulted equation was $y = 5E+51e^{-0.0574x}$ ($R^2 = 0.8517$, $p = 0.0501$, $F = 10.1079$). Resulted calculated ratio is 33.2% that were used for calculating the polluted areas which their sea port activity were unknown but their oil production were given. As an example, pollution resulted from sea port activity (predominantly oil pollution) in Qatar were reported about 11,550 t year^{-1}. Therefore, Qatar is responsible for 6% of oil export among the Gulf countries. Hence in estimation, based on the value reported for its sea-based pollution and oil export rates of the other Gulf countries, proportional sea-based oil pollution of those countries has been calculated and shown in Table 3.

Rough estimations of petroleum pollution input into marine environment from the main point sources in the gulf region (Fig. 1) from plots, equations and related calculated ratios are mentioned in Table 3 with respect to Table 1 and 2, as an applicable model for total oil pollution. Sea-based sources of pollution for individual countries were estimated as mentioned in methodology considered 33.2% of total oil discharges of the country. Results of Land based pollution in Iranian coasts were obtained by applying the Eganhouse and Kaplan's (1981) rates to population in the area (2,675,572 in urban and 1,751,858 in rural areas) which led to 3410 t year^{-1} oil discharge (2713 t year^{-1} from urban and 697 t year^{-1} from rural areas). For other countries and points the similar estimation was applied (Table 3).

Petroleum release in the littoral countries of the Persian Gulf: Results of estimation of sea-based oil discharges based on global oil production to oil transportation ratio (33.2%), for UAE, Kuwait and Saudi Arabia were shown in Table 3. In case of Bahrain, value for sea-based pollution was extremely low due to very low oil export (0.1%) compared with its crude oil production. For Iran and Qatar the figures were obtained from sea port activity in important oil terminals and GPA report of ROPME (Vaughan, 2006), respectively. Therefore their sea based pollution is higher than other countries. In summary with above estimations and assumptions, petroleum hydrocarbons pollution in selected Persian Gulf littoral countries will be in the following ranges : Saudi Arabia 21,000-90,000, UAE 5,700-26,000, Iran 9,000- 28,000, Kuwait 5,700-23,000, Qatar 2,500-11,500, Bahrain 116-350 t year^{-1} petroleum hydrocarbon. According to results of Table 3, highest rates of the land-based oil discharges in the studied area, are found in Saudi Arabia (65,730 t year^{-1}) and Iran (28337 t year^{-1}) which their annual crude oil production in 2006 were the highest among the

Persian Gulf littoral countries (Table 1). The points or areas selected for this part (land-based source of pollution) were those mainly subjected to enormous and chronic crude oil production or refineries affairs in the Persian Gulf littoral countries. Therefore, the countries or areas with higher oil production, suffer from higher pollution. This can be seen in important oil producer countries in the area and in oil bearing points of Iranian coasts as well. Similarly, petroleum discharges in the most important oil terminals with known oil production were calculated. In the case of sea-based pollution, by comparing the oil export rates of every country with sea based oil discharges results (which have been obtained from description mentioned earlier), our estimate is close to expected values because countries with higher oil export have higher sea-based oil discharges. For example among the Gulf countries, Saudi Arabia with the highest oil export value (47%) has the highest oil pollution with sea-based source and other countries like UAE, Iran, Kuwait are the next. Bahrain with the lowest oil exports has the lowest sea-based oil pollution. The ratio of its oil production to Saudi Arabia is 8.3, but their oil export ratio is 7.8; therefore higher sea-based pollution in this country is expectable. Therefore the total petroleum release into the Persian Gulf region is estimated to be 120186 (between 53858 to 186514) t year^{-1} or 600930 barrels/year. The amount of land based oil discharges for Qatar and Bahrain is in agreement with the report by Awad *et al.* (1990) in which total land based petroleum release to the gulf of Oman is estimated to be about 305 ton year^{-1}. According to our estimations for land based petroleum discharges, Qatar and Bahrain liberate 537 and 608 ton year^{-1}, respectively (Table 3).

Comparisons of mass balance of hydrocarbons: Six out of 20 worldwide cases of oil spills greater than 10 million barrels of oil has been occurred in the Persian Gulf (Hinrichsen, 1996). We have not included these discharges into our estimations as we have not detected a reasonable way for approximation or prediction of these events in the region; although there is some reports that states is case of these predictions the amount of released petroleum reaches to 1 to 2 million barrels/year for the region (Hinrichsen, 1996).

For effective monitoring and simulation of oil pollution in marine environment of the Persian Gulf, accurate data and information around sources of pollutions, volume of oil entering into marine environment, highly polluted areas in significant time scales are needed. Overall decreasing trend of petroleum input into the Persian Gulf is obvious as a consequence of oil exploitation in the Persian Gulf. The estimated amount of total petroleum release into the Persian Gulf region 120186 ton year^{-1} is comparable to other data reported for Baltic Sea and Mediterranean Sea in which an annual input of hydrocarbons of various origin is estimated to be at 165,000 ton year^{-1} for 90's decade (Nemirovskaya and Zaretskas, 2000) or 883,000 ton year^{-1} in 80's decade (Burns and Saliot, 1986), respectively. According to the estimated model ($y = 2E+72e^{-0.0805x}$) for the Persian Gulf, petroleum release of those decades would be 808,000 and 358,000 t for 80's and 90's decade, respectively. These amounts of petroleum release for the Persian Gulf is in agreement with their corresponding releases in other areas of the world. Therefore, it seems that the amount of petroleum discharge into the Persian Gulf has been decreasing significantly which is confirmed by some reports (Al-Omran and Rao, 1999; Eghtesadi *et al.*, 2002; Madany *et al.*, 1994; Metwally *et al.*, 1997) on medium size pollution of this region with oil associated contaminants (e.g., PAHs). Hence although we believe that national or regional consecutive monitoring and investigation of oil related operations in the Persian Gulf, as well as evaluation and management of data collected, should be done in a periodical manner, but studies also should be done on alien species as an emerging issue in this region due to the high volume of incoming ballast water associated with

biological invasions which a few reports on jellyfish (Daryanabard and Dawson, 2008) or bacteria (Rao, 2005) already.

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