Forecasting of oil spillage in the coastal waters of Nigeria

E. O. Obi[*1], I. O. Ewona[1] and D. A. Obi[2]

ABSTRACT

Semi-empirical equation of diffusion was used to model the dynamics and destruction of oil spillage in the coastal waters of the Republic of Nigeria. A Software called "slickmovement" was developed and used to study the behaviour of the oil spilled in the Nigerian coastal waters. The results shows that during the dry season the spillage will reach the Nigerian Coastline after 62hrs from the time of pollution and during the rainy season the spillage will not reach the Nigerian Coastline within the limit of the area of study. Generally, it is observed that within the same period an oil spillage in the coastal waters of the Republic of Nigeria will pollute a greater area in the raining season than in the dry season.

INTRODUCTION

The coastal waters of Nigeria has experienced oil spillage several times and is likely to experience more oil spillages in the years to come. The basic sources of oil pollution are accidents at the oil extracting platforms, accidents by tankers transporting crude or refined oil through sea and by old/rusted oil pipelines. Some of the oil pipelines are deliberately broken by militants in the Niger delta region in an attempt to sabotage the effort of the Government. The total number of incidents of oil spillage from 1976 to 2005 is 9092(Table 1) and.the consequence is that 3097806.50 barrels of oil was spilled into the environment (Nwilo et al.; 2000). The largest incidents of oil spillage were in 1978 at Shell Petroleum Development Company's Forcados terminal, where 580,000 barrels of oil was spilled into the water, and in 1980, at Texaco Funiwa-5 platform where 400,000 barrels of crude oil was spilled into the surrounding water (Harry, 1992).

Considering the rate at which oil is spilled into the coastal waters of Nigeria, it has become necessary to be able to forecast the behaviour of oil that is spilled, with the view of determining the trajectory of the spillage and the best method of cleaning the pollution. This can be achieved by the help of a mathematical model (Thompson, 1996), as carried out in the present study.

MATERIALS AND METHODS

Mathematical model

The mathematical model of oil pollution on the surface of the sea subject to natural and artificial destruction of the spillage can be described by a semi-empirical equation of diffusion:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}-K_x\frac{\partial^2 C}{\partial x^2}-K_y\frac{\partial^2 C}{\partial y^2}+f(C)=0, \qquad (1)$$

where C = concentration of oil in kg/m^2, t = time in seconds, u,v = component of the speed of the current (dependent on the season of the year) in m/s, x, y = Cartesian coordinate, K_x,K_y= coefficient of turbulent diffusion in m^2/s along axes of coordinates x and y respectively. The function f(C) describes the corresponding process of destruction. Depending on the character of the process of destruction of the oil, f(C) has the form:

$$\frac{\partial C_i}{\partial t}+u\frac{\partial C_i}{\partial x}+v\frac{\partial C_i}{\partial y}-K_x\frac{\partial^2 C_i}{\partial x^2}-K_y\frac{\partial^2 C_i}{\partial y^2}+\frac{K_E X_i P_i}{RT}M_i^{(m)}=0, \quad i=1 \qquad (2)$$

$$\frac{\partial C_i}{\partial t}+u\frac{\partial C_i}{\partial x}+v\frac{\partial C_i}{\partial y}-K_x\frac{\partial^2 C_i}{\partial x^2}-K_y\frac{\partial^2 C_i}{\partial y^2}=0,\ i=3 \qquad (3)$$

where $\frac{K_E X_i P_i}{RT}M_i^{(m)}$ describes reduction of the concentration of the oil only on account of evaporation, t = time in seconds, K_E = coefficient of mass transfer of the hydrocarbon in m/s, X_i = molecular portion of component with number i = $\frac{M_i}{\Sigma M_i}$, P_i = vapour pressure of the i*th* component, R = gas constant, 8,314 $Jmol^{-1}K^{-1}$, T = temperature of the surrounding environment in degrees kelvin. Similarly, the system of equations describing the transfer, destruction and dissolution of the hydrocarbon has the form:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}-K_{1x}\frac{\partial^2 C}{\partial x^2}-K_{1y}\frac{\partial^2 C}{\partial y^2}+ \backslash$$
$$K_D^{(W)}X_iS_iM_i^{(m)}=0,\ \ i=1,\ i=2, \qquad (4)$$

$$\frac{\partial C_i}{\partial t}+u\frac{\partial C_i}{\partial x}+v\frac{\partial C_i}{\partial y}-K_x\frac{\partial^2 C_i}{\partial x^2}-K_y\frac{\partial^2 C_i}{\partial y^2}=0,\ i=3. \qquad (5)$$

[*1]Corresponding author. Email: emaobi2005@yahoo.com

Manuscript received by the Editor May 14, 2009; revised manuscript accepted July 17, 2009.
[1]Department of Physics, Cross River University of Technology, Calabar, .Nigeria
[2]Department of Geology University of Calabar ,Calabar, Nigeria

Table.1. A record of the number of incidents of oil spillage in Nigeria within the period (1976 – 2005)(after Nwilo et al.,2000)

Year	Number of oil spillage	Volume of spilled oil in barrels
1976	128	26,157.00
1977	104	32,879.25
1978	154	489,294.75
1979	157	694,117.13
1980	241	600,511.02
1981	238	42,722.50
1982	257	42,841.00
1983	173	48,351.30
1994	151	40,209.00
1985	187	11,876.60
1986	155	12,905.00
1987	129	31,866.00
1988	208	9,172.00
1989	195	7,628.161
1990	160	14,940.816
1991	201	106,827.98
1992	367	51,131.91
1993	428	9,752.22
1994	515	30,282..67
1995	417	63,677.17
1996	430	46,353.12
1997	339	59,272.30
1998	390	98,345.00
1999	225	16,903.96
2000	637	84,071.91
2001	412	120,976.16
2002	446	241,617.55
2003	609	35,284.43
2004	543	17,104.00
2005	496	10,734.50
Total	9092	3,097,806.50

where t = time in seconds, K_D = coefficient of mass transfer of hydrocarbon in m/s, X_i molecular portion of components with number i = $\frac{M_i}{\Sigma M_i}$, S_i = solubility in water of the i*th* component in kg/m

The equation describing the bacterial decomposition of crude oil has the form:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}-K_x\frac{\partial^2 C}{\partial x^2}-K_y\frac{\partial^2 C}{\partial y^2}+\frac{1}{q}\frac{\mu_m C}{C+K_s}M=0 \quad (6)$$

where K = coefficient of proportionality between the quantity of bacteria and the absorbed substratum; μ_m = maximum growth rate of the microorganisms, K_s = coefficient of saturation; M = population of bacteria.

The boundary and initial conditions depend on the type of pollution (Corps, 2002). For a spontaneous spillage on the surface of the sea the initial and boundary conditions respectively has the form:

$$C\Big|_{t=0,\,(x,y)\in S_0}=C_0 \quad (7)$$

$$C\Big|_{t=0,\,(x,y)\notin S_0}=0 \quad (8)$$

where S_0 = area covered by the spillage and C_0 = concentration of oil in the area of study.

An algorithm was developed on the bases of explicit scheme. Equation (1) was solved numerically taking the boundary condition in Equations(8) and (9) into consideration. Software called "**slickmovemen**t" was subsequently developed by the lead author to simulate and study oil spillage in the coastal waters of Nigeria. (Obi, 2008).

Numerical experiment

The numerical experiment was carried out for an assumed spillage point located at latitude $5^0 33^/$N and longitude $4^0 06^/$E, about 70 km off the Nigerian coastline. The speed of the surface current at the Nigerian coastal waters is about 30 cm/s during the raining season, and may reach the sea bed at points less than 50m deep (Arnault, 1987). The sea current is transported in the dry season by Benguela current. Shannon (1985) assessed information on surface current from previous studies and concluded that the average speed of the sea current in the dry season is 17 cm/s. Wedepohl (2000) also found that the average speed of surface current in the dry season ranges from 11cm/s to 23cm/s. Oil spillage was therefore simulated for the dry season (December to March) and rainy season (April to November) periods.

RESULTS AND DISCUSSION

The program "slickmovement" allows us to simulate and visualize an oil spillage in the coastal waters of Nigeria. The results of the simulation and visualization during the dry and rainy seasons are as presented in Figs 1-6 and Tables 2 and 3.

Fig. 1. Initial position of assumed spillage (in brown colour) during the dry season

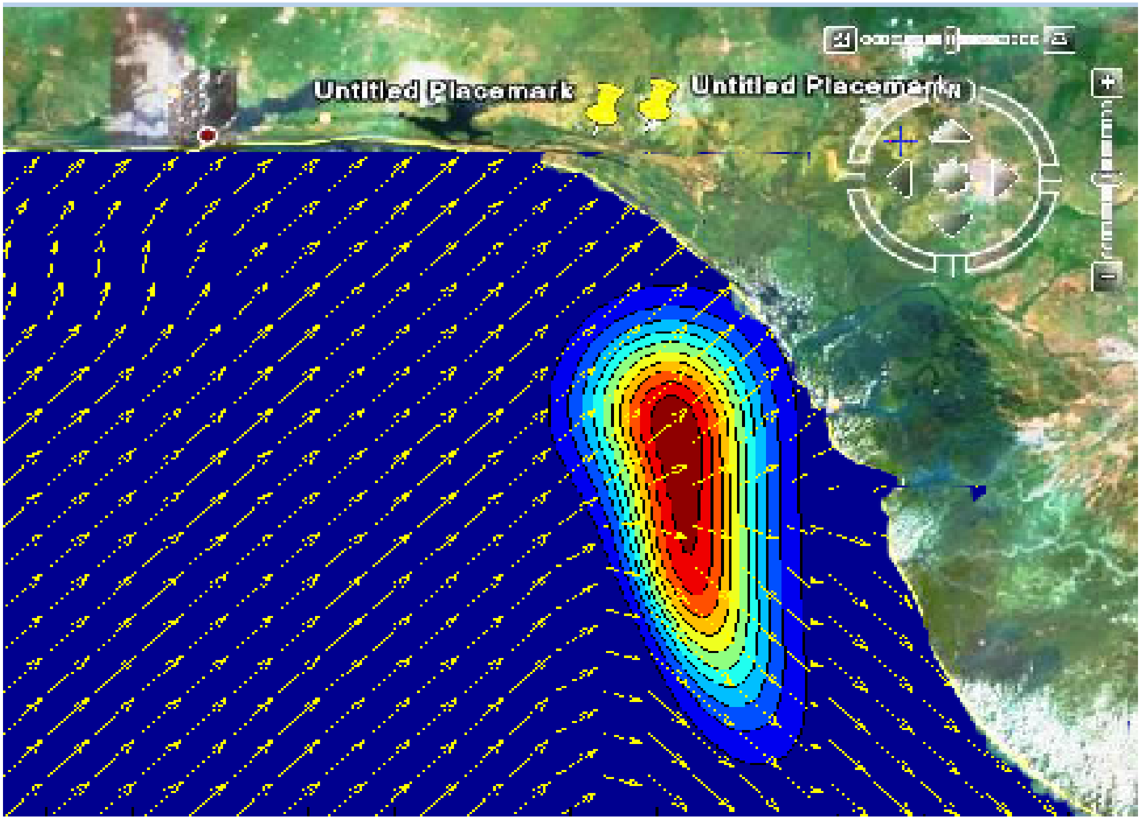

Fig. 2. Displacement of assumed spillage 62 hours after pollution during the dry season.

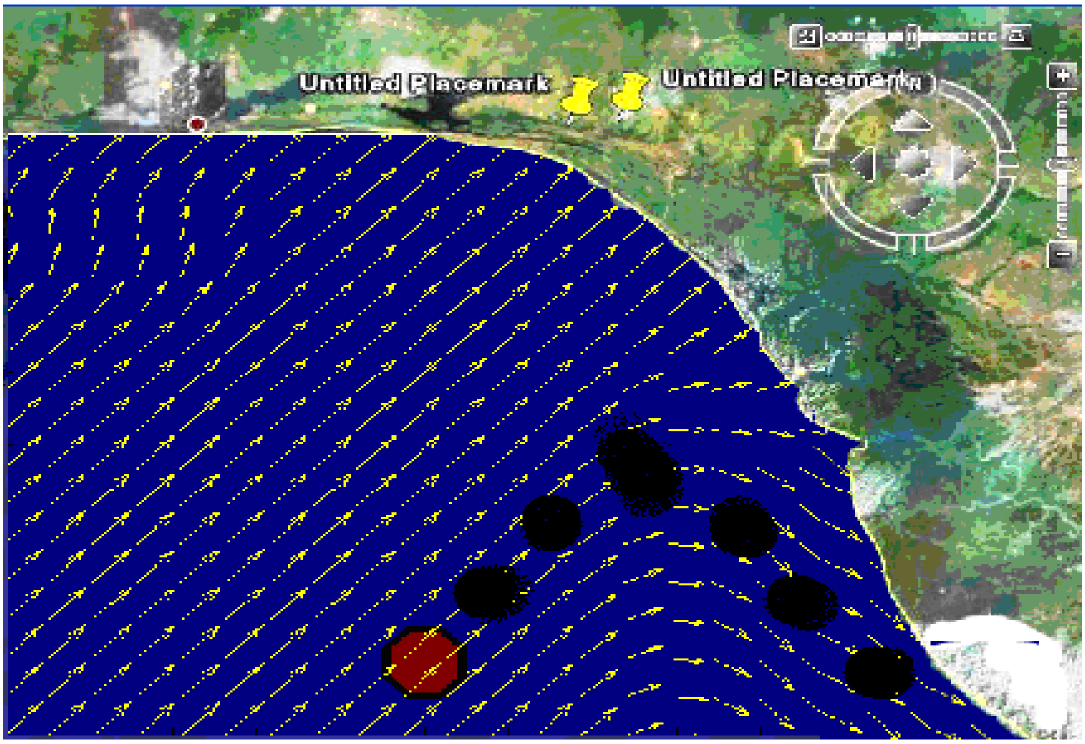

Fig. 3. Trajectory of assumed oil spillage during the dry season

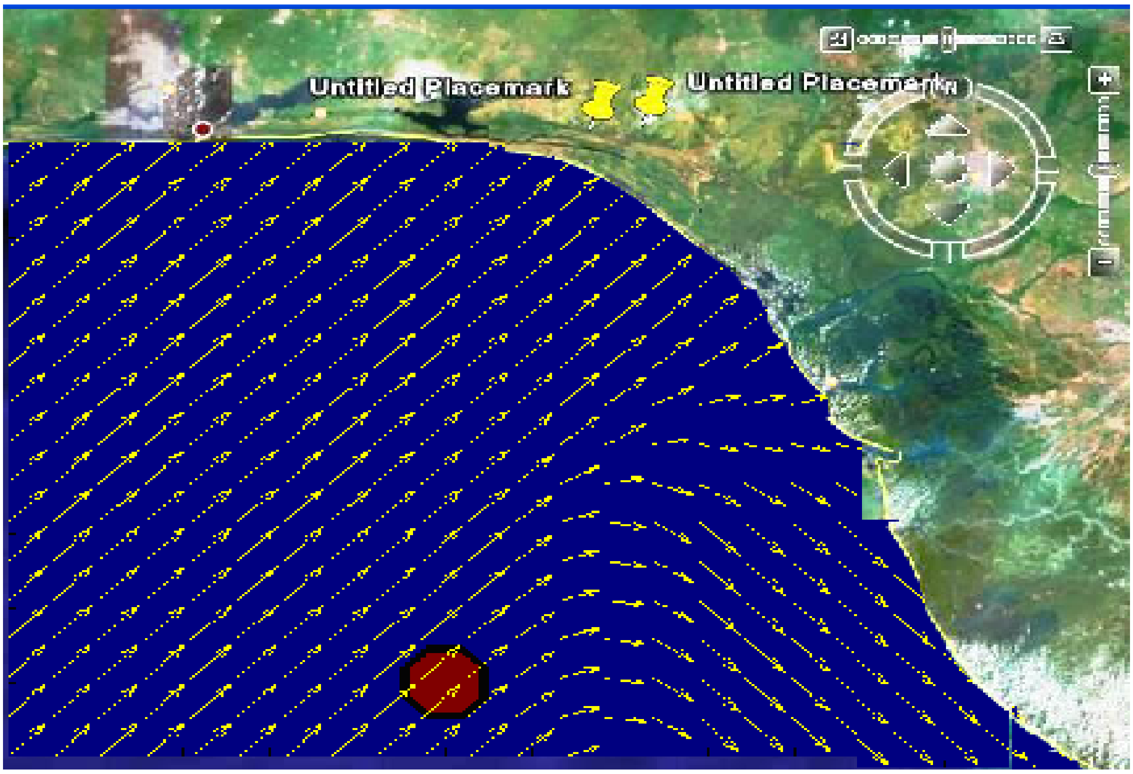

Fig. 4. Initial position of assumed spillage (brown colour) during the rainy season

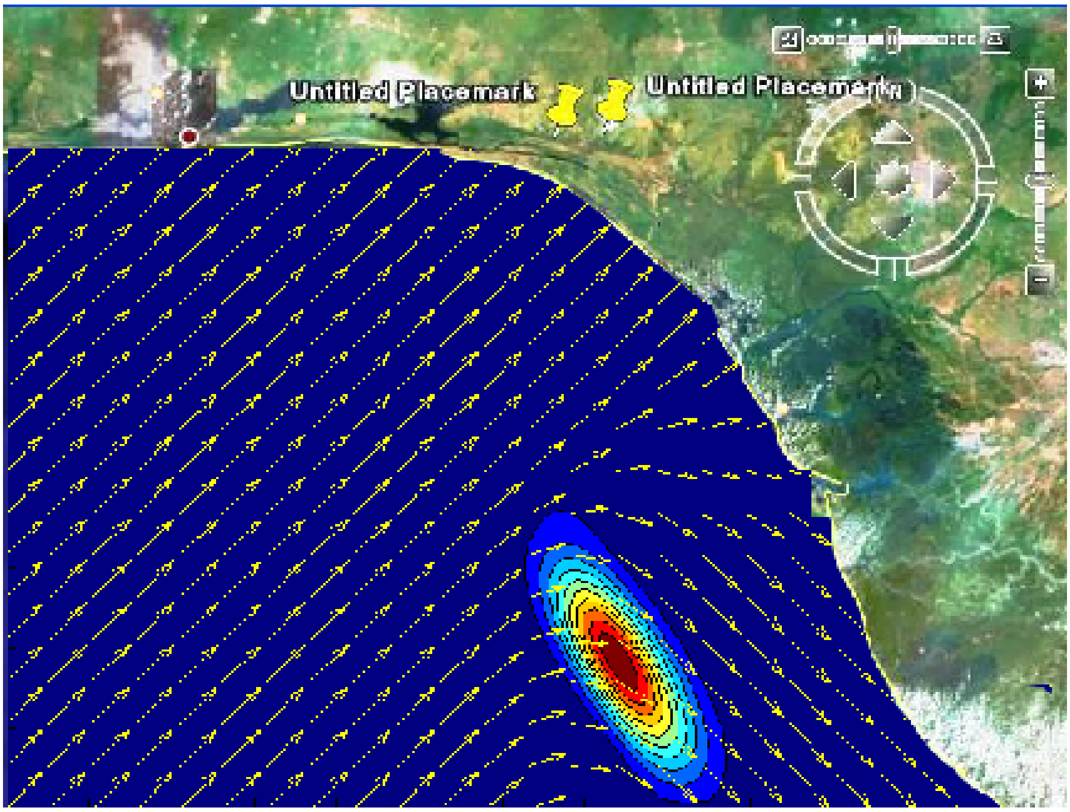

Fig. 5. Displacement of assumed spillage 28.6 hours after pollution during the rainy season.

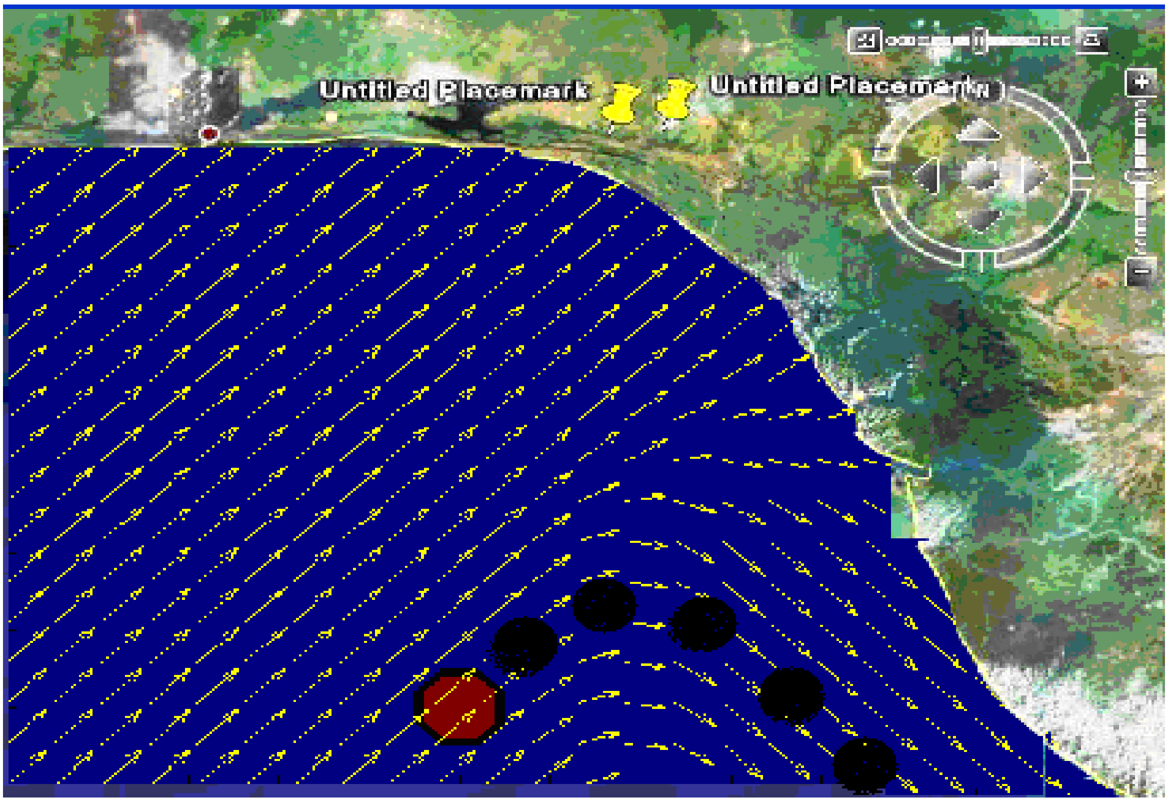

Fig. 6. Trajectory of assumed oil spillage during rainy season

Table. 2. Data obtained from the numerical experiment for the dry season.

Time (hours)	Radius of the spillage (km)	Area covered by the pollution (km^2)	displacement of the centre of the spillage (km)	Displacement of the edge of the spillage (km)	Concentration of oil in the center of the spillage Kg/m^2	Concentration of oil at the edge of the spillage Kg/m^2
0,0	5,0	78,5	0,0	7,1	1,000	1,0000
2,2	6,0	113,0	1,4	9,9	0,890	0,0920
4,3	6,5	132,7	2,8	12,0	0,790	0,0850
6,4	7,0	153,9	3,5	14,1	0,680	0,0810
8,4	7,5	176,6	4,9	17,0	0,580	0,0620
10,6	8,0	201,0	7,8	18,4	0,480	0,0570
12,8	8,3	213,7	9,9	21,2	0,410	0,0360
14,8	8,5	226,9	11,3	24,8	0,340	0,0330
16,7	8,8	240,4	12,7	25,5	0,280	0,0300
18,8	9,0	254,3	14,1	26,9	0,240	0,0230
20,9	9,3	268,7	15,6	29,0	0,200	0,0200
23,2	9,5	283,4	17,0	31,1	0,160	0,0160
25,9	10,0	314,0	19,1	33,9	0,130	0,0120
29,9	10,5	346,2	22,6	36,8	0,090	0,0100
33,3	11,0	379,9	24,0	41,0	0,080	0,0060
37,0	11,5	415,3	28,3	43,8	0,060	0,0057
40,9	11,8	433,5	31,1	46,7	0,043	0,0053
45,4	12,0	452,2	33,9	50,9	0,031	0,0030
49,3	12,2	467,4	36,8	52,3	0,024	0,0021
52,8	12,3	475,1	39,6	56,6	0,019	0,0019
57,4	12,4	482,8	43,8	60,5	0,014	0,0015
61,5	12,7	502,5	46,7	65,1	0,010	0,0010

Table. 3. Data obtained from the numerical experiments for the rainy season

Time (hours)	Radius of the spillage (km)	Area covered by the pollution (km^2)	displacement of the centre of the spillage (km)	Displacement of the edge of the spillage (km)	Concentration of oil in the center of the spillage Kg/m^2	Concentration of oil at the edge of the spillage Kg/m^2
0,0	5,00	78,5	0,0	7,1	1,00	1,000
2,2	6,50	132,7	2,1	10,7	0,86	0,060
4,2	7,00	153,9	4,2	14,1	0,72	0,058
6,3	7,50	176,6	5,7	17,0	0,58	0,470
8,4	8,00	201,0	8,5	19,8	0,46	0,038
10,5	8,25	213,7	10,6	21,1	0,36	0,029
12,6	8,50	226,9	12,6	25,5	0,28	0,023
14,7	8,75	240,4	14,1	26,9	0,23	0,021
16,7	9,00	254,3	15,6	29,0	0,18	0,017
18,8	9,50	283,4	18,4	32,5	0,13	0,011
20,9	10,00	314,0	21,2	35,4	0,12	0,010
24,3	10,25	330,0	24,0	36,8	0,08	0,009
28,6	11,00	380,0	28,3	45,2	0,05	0,004

The results show that during the dry season, the pollution at the given coordinates will reach the Nigerian coast 62 hours after the spillage. From the same position, during the rainy season, the pollution will not reach the coast of Nigeria within the area of study. These differences can be seen from the trajectory of the spillage as shown in Figs. 3 and 6. It was observed that the oil pollution moves in the same direction with the direction of movement of the surface current (sea current and direction of the wind). Analyzing the data further, it was observed that the area affected by the spillage change from the initial value of 78.5 km^2 to 502.5 km^2 in 62 hours during the dry season, while similar changes in the raining season, were 78.5 km^2 to 380 km^2 in about 29 hours. It should be noted that the concentration of the oil slick on the surface of the water is the key parameter that is used to determine the best method applicable for containing and cleaning of the oil pollution, taking other environmental factors into consideration. This parameter can only be known by using a suitable mathematical model for the area under study.

ACKNOWLEDGEMENT

The authors appreciate the efforts of Professor T. Shapasnikova of Kuban State University of Technology, Krasnodar, Russia for his assistance in the software development and Professor M. Uternov of Kuban State University for his contribution during interpretation. This paper is the outcome of the PhD research carried out by the lead author of this article in Kuban State University of Technology, Russia.

REFERENCES

Arnault S., (1987).Tropical Atlantic geostrophic currents and ship drifts. *Journal of Physical Oceanography*, 18: 212 -222.

Corps J.M (2002). Oil Spill Modelling for Tanker Accidents in Iskenderun Bay, Turkey // *Marine oil spill modelling report*. Appendix B. AEAT/ENV/R/0939 Issue 2, 2002.

Harry B., (1992). Summaries of significant U.S. and international spills. *Hazardous materials response and assessment division. Washington*.

Nwilo P.C., Peters K.O. and Badejo O.T. (2000). Sustainable Management of Oil Spill Incidents along the Nigerian Coastal Areas. *Electronic Conference on Sustainable Development Information Systems.*

Nwilo P.C. & O.T. Badejo, (2005). Oil spill problems and Management in the Niger Delta. *International Oil Spill Conference,* Miami, Florida, USA.

Obi, E. O. (2008). Modeling of oil spillage in the coastal waters of Nigeria. Unpublished PhD Thesis. Kubom State University of Technology, Krasnodar, Russia

Shannon, L.V., (1985). The Benguela Ecosystem, In: Evolution of the Benguela, physical Features and processes. *Oceanography and Marine Biology*, 23: 105-182.

Thompson A.(1996). Modeling of oil spills of the water resources engineering division. State- of the- art review of modeling transport and fate of oil spills. *Journal of Hydraulic Engineering*, 24: 45-48.

Wedepohl P.M., Lurjeharms, J.R.E. and Meeuwis, J.M. (2000). Surface drift in the southeast Atlantic Ocean. *South African Journal of Marine Science*, 22: 71-79.