T.Imnadze, N. Begalishvili, T. Davitashvili, D. Demetrashvili
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Two Dimensional Numerical Model Of Emergency Spilling Oil Distribution In The Sea

1. Introduction

Oil and mineral oils have toxic influence upon the groups of sea organisms. Therefore it is necessary to define the zone of possible spreading of oil pollution upon the area of sea-water, at the bottom and on shore – otherwise Affected Zone (AZ) of shore oil discharge into the sea, which may occur as a result of railway accident in the seaside of Black Sea in the Region of Supsa-Kobuleti-Batumi or at the break of the oil-pipe line in the port of Batumi.

It is well known that the range of minimal biologically active oil concentration in the sea environment equals to 10^{-3} – 10^{-4} mg/l [9]. Maximum Permissible Concentration (MPC) of the dissolved oil in the sea-water equals to 0.01 – 0.05 mg/l [3,10]. Therefore here in the given work the AZ is defined as oil range upon the sea surface, limited for 3 times less than MPC. Here two circumstances are taken into account. First of all, the quantity of the oil spilled into the sea in the examined scenarios of emergency conditions amounts to approximately 100-200 t. Second, basically the oil in the sea-water is in un-dissolved state, usually not more that 5 % of oil is subject to dissolving [2,3,9,11]. AZ is estimated by mathematical modelling of shore discharge and space-time of oil evolution in the sea by accident 2 scenarios. As a basis of the model it is assumed the equation of advective transfer and turbulent diffusion taking into account the source of the shore discharge and physical processes of evaporation, solution, emulsification and sedimentation. Oil flow after the discharge into the sea depends on hydrodynamic field of current flows, where superficial wind-induced flows are imposed (drift, set-down and onset, wave activity or Stokes flow), as well as horizontal turbulent diffusion, conditioned by friction of wind pulsation upon the water surface. As a source of information it is used the information about current flows filed, wind speed and direction, water and surface and air temperature according to monthly sea hydrographic and climatic data. Numerical solutions of the equation of advective and turbulent transfer are determined based on the use of finit difference scheme with directed and upstream one-way differences.

It is necessary to mention that the result of mathematical modelling cannot give estimation of real scales of oil spreading in individual case of discharge, which will depend on concrete conditions of flows, temperature of water-air and wind in the post-accidental period. The results of the modelling show the probability of oil particles spreading upon the concrete area - space-time spreading of probability of the oil existence and its quantity in each cell of the area of sea-water with the size of 2x2 km^2 in the sector of Batumi-Poti-Sukhumi. The monitoring time of oil spreading amounts to 72 hours (3 days) after the accidental overflow.

2. Regularity of the oil pollution spreading and transformation in the marine environment.

The oil occurred on the water surface first of all begins to spread under the influence of gravity. For Tengiz oil the density comprises of 788 kg/m^3, and for the sea-water it equals to 1025 kg/m^3. As the water density is more than oil density, the oil as if raises above the sea surface and stipulates for the influence of force of gravity. Then the forces of surface tension start influencing. In the process of discharging the oil partially evaporates and dissolves in the water. Therefore, its density and viscosity increase. After a definite period of time form the moment of the oil discharge into water the flow stops. This effect takes place in the mode of surface tension.

According to different empiric data, the film thickness while the flow ceasing comprises of 0,025 mm [1-3]. For comparison we'll mention that after the "volley" (instantaneous source) overflow of 150 ton of oil in the sea - the mean thickness of surface film in the cell with the area of 2x2 km^2 may comprise of about 0,05m.

In the process of the flow and after its cessation, especially during the first hours of the oil stay in the water, the physical and chemical processes of oil transformation prevail, such as: evaporation, solution, emulsification, dispersion, aggregates creation, sedimentation and destruction, including chemical oxidation or photochemical oxidation under the influence of solar radiation, as well as biodegradation (microbial breach and assimilation by planktonic and bottom dwellers).

3. Evaporation – one of the first processes of oil transformation in the marine environment which is actively developes at the initial stage of its spreading. Evaporation depends on physical and chemical properties of the oil, marine environment and air temperature, wind speed, wave activity and etc. The oil which spreads upon the sea-water will evaporate with the speed depending on the level of the boiling limiting point and pressure of prime steam of hydrocarbon components, thickness and flow sizes, its spreading speed, hydrographic and meteorological conditions. Evaporation decreases the mass (volume) of crude oil, its inflammability and toxicity, however increases the density of precipitations. The total quantity of evaporated oil comprises of 10-20 % to 60-70 % form the total mass of discharge. For the high-gravity oil such as Tengiz one, the losses may amount not less than 30-40 %. Most intensively the loss of discharge mass takes place within the first hours of the flow and the process of evaporation is noticeable on the first day [4,5,8,9].

In compliance with the data [8] for the overflow of 150 t., when the loss of its evaporation comprises of 50 t (30 %), the mentioned quantity of the oil disappears in the discharge, with the area of 2x2 km^2, within the period of the next 4 hours in the terms of January temperature and wind speed 1/ms. At the wind speed of 5m/s the time of evaporation decreases to 1,5 hours and while the wind of 10 m/s it equals to 45 min. In the terms of July temperature the time of full evaporation of 50 t. of oil in the area of 4 km^2 comprises of about 1 hour, 20 and 10 min in compliance with the mentioned wind speeds.

4. Dissolving. Oil hydrocarbons are dissolved in the water very weakly. But exactly the dissolved fraction of oil hydrocarbons is more toxically one. The oil is dissolved in the sea-water due to immixture as a result of wave activity which is concerned with the wind blowing. Especially the oil is dissolved in the sea-water due to the processes of destruction – physical and chemical oxidation and biodegradation. Hydrocarbons dissolubility in the water distinctly decreases with the increase of their molecular weight and sea-water salinity and increases with the temperature increase. Due to different sources not more that 50 % of oil discharged in the water is dissolved [2,3,9,11]. The part of paraffin and naphthene left in the line of dissolving as a result of immixture transfer into dispersed state and transformation into "resinous globules".

5. Emulsification, dispersion and sedimentation. After the loss of volatile and water-soluble components the tendency to spreading of irreducible oil - decreases. Emulsion creation promotes to viscosity increase. Emulsification depends on physical and chemical properties of the oil and Hydrometeorologycal factors: wind, choppiness, turbulence, water temperature, as well as the presence of dredges and solid particles in the sea top layer. Emulsification takes place on the first day in the line of the oil spil# The oil which is emulsified effected by the waves and turbulent flows penetrates into water thickness, settles at the bottom and accumulates in the base sediments [2]. For instance, in [9] it is given estimation according to which approximately 5 t (5 %) form 100 ton penetrates into 5-meter underlying layer of water on the first day.

6. **Destruction.** Oil hydrocarbons which occurred in the marine environment after the evaporation, solution, dispersion and emulsification undergo physical and chemical and biochemical oxidation - destruction. Experimental investigations showed that after the water saturation with the oil it begins its intensive decomposition under the general influence of physical and chemical and microbiological factors, which lasts within 10-15 days. Then the destruction speed noticeably decreases. While the transformation of organic contaminants the processes of chemical oxidation of oil hydrocarbons take place, which are free radical reactions of oxidation.

Important role plays the process of physical oxidation or photooxidation, where along with the ultraviolet sun radiation the ozone and oxygen have evident influence also. It is well-known that ozone is able to oxidize oil hydrocarbons 5-6 times more actively than ultraviolet radiation does.

7. Mathematical Model and Initial Data Mathematical model describing oil pollution transfer in the Black Sea is based on non-stationary equation of oil concentrations $\varphi(x,y,t)$ advective transference and turbulence diffusion taking into consideration sources and flow

$$\frac{\partial\varphi}{\partial t}+u\frac{\partial\varphi}{\partial x}+v\frac{\partial\varphi}{\partial y}=\mu\left(\frac{\partial^2\varphi}{\partial x^2}+\frac{\partial^2\varphi}{\partial y^2}\right)-\sigma\varphi+f(x,y,t), \quad (1)$$

equation (1) is solved in the closed area D with a lateral curve line Γ by the following initial and boundary conditions:

$$\varphi(x,y,0)=\varphi_0(x,y), \qquad at \quad t=0, \quad (2)$$

$$\varphi(x,y,t)=\varphi_1(x,y,t), \quad (3)$$

at the liquid sectors of Γ,

$$\frac{\partial\varphi}{\partial n}=0, \quad (4)$$

at the solid sectors of Γ,

where *n* is external normal for Γ; φ is volumetric concentration of admixture; μ is horizontal coefficient of turbulence; σ is the coefficient that determines the velocity of substance concentrations changes during the process of substance decomposition and transformation; $f(x,y,t)$ is known function which represents algebraic, sum of functions q_m circumscribing sources and flow in (1)

$$f=\sum_{m=1}^{m_1}q_m, \quad (5)$$

U(x,y) and V(x,y), are component of velocity $\overline{U}$ in the directory ox and oy, respectively. The vector of velocity $\overline{U}$ is equal of sum four components.

$$\overline{U}=\sum_{i=1}^{u}u_i$$

Where $\bar{u}_1$ represents background hydrodynamic flow on the surface of sea. Its may be given by experimental data, for instance, by monthly hydrodynamic data, or using the results of the sea dynamic calculations;. $\bar{u}_2$ - is determined by drifting flow, stimulated by wind; $\bar{u}_3$ is gradient flow (arising) conditioned by drift at coastal zone with size 1-2 km. As drift is conditioned by wind so gradient flow will be defined by module of wind velocity and mutually arrangement of wind velocity direction and Sea shore line; $\bar{u}_4$ is surface rough of sea stipulated by wind (Stock's current).

Constant currents on surface of the Bleak Sea represents an exclusive circle circulation of sea water, directed (contrary apposite) against to clock's hand parallel to shove line. At the south of coastal zone of the Bleak Sea the currents are directed to the East, further at the Batumi's Port they turn North-East directions and from Poti to Novorosisk the water steam is directed to the North-West. Much more clear the constant stream is observed at the distance 5-20 km from the sea shore line. Here the water currents are rather (enough) steady (stable), average velocity at the Batumi-Poti-Cukhumi region equal 0.5 m/c in January and 0.25 m/c in July. In the West-direction of the Sea shore line of Batumi-Poti and at the distances more than 50 km there are observed (contrary, opposite) against circulatory water streams, directed to clock's hand, with diameter of 40 km. It is well observed as for Winter as well for Summer periods.

We have considerated hydrodynamic field of the Black Sea currents which are observed in January and July. The vector characteristics of the currents were used for calculations of components $\bar{u}_i$ Calculations of the components $\bar{u}_2$, $\bar{u}_3$, $\bar{u}_4$ were performed by the known expressions, well imitated experimental and theoretical investigations.

Calculations of these components lead to the following conclusions:

- The module of velocity of drift $\overline{u_2}$ compose about 2 % of the wind velocity module and directed at angle 45^0 right to the wind direction;
- The magnitude of velocity of gradient current $\overline{U_3}$ compose from 2,5% to 3% of the velocity module and as it was mentioned above, its direction is defined by the angle between sea shove line and wind direction.
- The module of velocity of winds rough (or Stocks stream) $\overline{U_4}$ is equal about 1% of the wind velocity altitudes and it is mainly directed in the direction of wind velocity.

8. Numerical Scheme

Equation (1) is integrated by finite-deference explicit numerical scheme.

Let us introduce the following grids

$$x_i = i \times \Delta_x \quad (i = 0,1,..., I), \quad _i = t \times \Delta_x \quad (i = 0,1,..., I).$$

where Δ_x, Δ_y are steps in the directions $oxand\, oy$ respectively. Then finite-difference approximation of the (1) may be written in the form.

$$\begin{aligned} \varphi_{i,j}^{n+1} = \varphi_{i,j}^{n} - \frac{\Delta t \cdot u_{i,j}}{\Delta x}\left[(1-\varepsilon_u)(\varphi_{i+1,j}^{n} - \varphi_{i,j}^{n}) + \varepsilon_u(\varphi_{i,j}^{n} - \varphi_{i-1,j}^{n})\right] - \\ - \frac{\Delta t \cdot u_{i,j}}{\Delta y}\left[(1-\varepsilon_v)(\varphi_{i+1,j}^{n} - \varphi_{i,j}^{n}) + \varepsilon_v(\varphi_{i,j}^{n} - \varphi_{i-1,j}^{n})\right] - \sigma\varphi_{i,j}^{n}\Delta t + \\ + \frac{\Delta t}{\Delta x}\left[\mu_{i+1/2,j}\frac{\varphi_{i+1,j}^{n} - \varphi_{i,j}^{n}}{\Delta x} - \mu_{i-1/2,j}\frac{\varphi_{i,j}^{n} - \varphi_{i-1,j}^{n}}{\Delta x}\right] + \\ + \frac{\Delta t}{\Delta y}\left[\mu_{i,j+/2}\frac{\varphi_{i+1,j}^{n} - \varphi_{i,j}^{n}}{\Delta y} - \mu_{i,j-1/2}\frac{\varphi_{i,j}^{n} - \varphi_{i-1,j}^{n}}{\Delta y}\right] + f_{i,j}^{n}\Delta t \end{aligned} \qquad (6)$$

where $\varepsilon_u = 1$ if $u_{ij} > 0$, $\varepsilon_u = 0$ if $u_{ij} < 0$, $\varepsilon_v = 1$ if $v_{ij} > 0$, $\varepsilon_v = 0$ if $v_{ij} < 0$

here Δ t is temporary step, $\bar{U}_{i,j}, V_{i,j}, \varphi_{i,j}$ significances of velocity of currents on the grid functions with index i,j. Conditions (2) and (3) are approximated by the following form:

$$\varphi_{i,j} = \varphi_{0,i,j}$$

$$\varphi_{0,j} = \varphi_{I,j} \;\; \varphi_{I,j} = \varphi_{I-1,j} \;\; j=1,\dots,J-1 \qquad (7)$$

$$\varphi_{i,0} = \varphi_{i,J} \quad \varphi_{i,J} = \varphi_{i,J-1} \quad i=1,\dots,I-1$$

Numerical scheme (6-7) is first order accuracy in time and second order accuracy in space. The scheme is conditional stable and therefore it must satisfy the Kurant-Levi condition

$$\Delta t \le \frac{\Delta z^2}{4\mu + (|u| + |v|)\Delta_x}$$

9. Results of Numerical Calculations

The analysis of the results of hydrodynamic modeling of drift, turbulent diffusion and transformation of oil pollution in the marine environment indicates to the variety and complexity of those processes as a result of vital difference of their spatialtemporal scales, participation of great number of physical and chemical and biochemical factors which are variable in the time, existence of mutual feedback, which stipulates for the creation of nonlinear effect of interaction. Many of the problems concerned with the processes of oil transfer and evolution in the sea and their interaction require additional theoretical and experimental investigations. Comparing the data of the observation with numerical evaluation of the speeds of evaporation, solution, emulsification and destruction it is possible to formulate the basic provisions which are taken into account while working out of a model of the oil pollution:

- In case of Tengiz oil outflow in the quantity of 150 t. it ought to be expected not less than 30 % loss (50 t) for evaporation within the period of not more than 4 hours at the most adverse Hydrometeorologycal conditions for that processes in January. In July the evaporation takes 1 hour time and even less.
- The processes of solution, emulsification and destruction considerably influence upon the evolution of oil patch, especially on the first day after the discharge. The destruction results in the flow in the model with the speed equal to approximately 1 % of the oil starting weight within the first day. As a result of resultant action of all the mentioned processes the daily speed of sedimentation of oil aggregates within the period of the whole drift, which brings to natural pollution, may be accepted as equal to 5 % of the accumulated mass in the cells.
- Within the first day of the drift and diffusion of the oil pollution it is most probably to be met as an oil film and separate sink and during the next two days the probability to reveal the accumulated masses in the cells as emulsified and dispersed parts of oil - increases.

Based on those provisions, the nonlinear effects taking place at the initial stages of spreading may not be taken into account, but evaporation, solution, emulsification, destruction and sedimentation should be taken into account with the help of the schemes of parameterization with the application of approximate expression for the speeds of the mentioned processes.

Such an approach greatly facilitates the solution of the task of oil outflow circumstances modelling. It may be carried out based on the equation of advective transfer and turbulent diffusion with the parameterization of physical and chemical and biochemical processes at the given hydrodynamic field of current flows.

For the oil distribution modelling there are examined three accidents: The first - oil spill from the pipeline with the length of 2 km at the approach to the oil bay of Batumi Port. It may be supposed the existence of small risk of such an accident in the area where the pipeline passes along the bank of river Bartskhana close to its mouth, as well as at the most susceptibilities – after the bend from the bank to oil jetty. In this area the pipeline is built close to the sea for a distance of 2-3 m. from the water line. The breach, for instance; may occur as a result of catastrophic hydrometeorological phenomenon (hurricane, storm, strong choppiness), offshore motion of sediments, earthquake, though there may occur technical causes too. After the breach it is supposed a full oil escape of the quantity of one of its sections. Taking into account the pressure in the pipeline, the oil discharge into the sea will amount to 150 t. within the period of not more than 1-2 hours. This may occur directly from the bank or at mouth of river Bartskhana while the oil transfer by river flow.

In the second case the accident may occur upon the 10 km. area of the railway in the region of Kobuleti-Makhinjauri seaside, when the oil train moves practically along the seashore.

Similar Accidents were observed in recent times. Taking into account the character of railway accidents we suppose that the contents of 2-3 turned over cisterns fully flow out on the shore and the most part of the oil (approximately 2/3) flows into the sea. Therefore the discharge will amount to 150 tons within the period of one or several hours.

Both examined cases may be joined into one – the first scenario. It is conditionally named oil outflow close to town Batumi. Accident areas in these cases are located in comparative proximity from each other.

The third case reveals the second variant of the scenario of accidental situation: railway accident at the bridges crossing, for instance on river Supsa, when the oil reaches the mouth of the river, transferred by water flow. Oil discharge into the sea may be admitted in the quantity not more than 150 ton within the period of 1-2 hours. The second scenario was named oil overflow in the region of river Supsa mouth. In the presented two scenarios there were selected the worst variants with the most quantity of poured oi# As by the spatial scale the accident does not cover the area more, than the examined minimal cell with the area of 2x2 km^2, the full time of tracing the evolution of oil patch amounts to 72 hours with the step of 10-30 min, than the source in the model is taken as punctual, momentary or prolonged acting depending on the scenario variant.

In general terms allocation of oil spot after three days stipulated by damaged spillage of oil in the Bleak Sea nearer of Batumi in January has distributed in the following form: On the surface of the sea there was about 42 ton (28%) of oil, Sedimentations (deposits) of oil on the bottom of Sea was about 8t (5%), about 50t (34%) was taken out on the coastal area. The Maximum value of volume concentrations on the surface layer was observed after 12 hours on the area 44 square km. with value 0.57 mg/l or 11 Muximum Permissible Concentrations. It is film of oi# with the thickness of 0.7 mkm. After 36 hours was observed crush of oil film and value of the concentrations in the some areas have decreased below of Muximum Permissible Concentrations. Maximum value of above bottom concentrations was marked after 12 hours on the area 12 km^2-with the value of concentrations. 66mr/m^2. Further the value of concentrations and area of deposition of oil particles stabilized and the concentrations wave 55 mr/m^2 on the area 20 km^2. Maximum value of oil caring out on the coast was performed after 12 hours nearer of Batumi's area and it is equal 20 t/km and further caring out of oil in the north direction was observed about 80 km from Batumi and about 40 km in the south direction of Batumi. The concentrations of oil caring out on the coastal are in the North and South directions were 110 and 80 kg/km., respectively. Thus whole extent (length) of the polluted shore is more than 120 km.(see Fig.1)

We have investigated a case when 200t of oil was spilled in the mouths of the rivers Rioni and Khobistskali. There were performed several numerical experiments imitated three kinds of oil products (disel, boiler and fresh oil) migration in the Georgian sector of the Bleak Sea in summer and winter periods. We have assumed that spilled oil in a moment has homogeneous distributed on the area 2X2 k m^2 (in a one cell of grid) with a conditional concentration 50 gr/m^3(Mg/L) at the sea surface with the thickness (width) of 0.059 mm.

Also there were performed four experiments, when occurs oil catastrophic spillage nearer Kulevi and Supsa terminals owing to oil tanker damages for Summer and winter periods. As in that case a mass of spilled oil was 10^4 t, so a thickness of oil film is 2.9 and with volume concentration 2.5 kg/m^3. As in winter period oil products penetration is characterized by high intensity and the oil surface concentrations are decreased faster than in summer. That is why on the sea surface, there is less oil mass but at the same time oil mass is increased at the sea shore and therefore there is the shore intensive pollution. The maximum pollution as observed at the rivers mouth, at the source area. A length of polluted coast area in winter is more than in summer, due to small wind velocity values in summer, and weak turbulence diffusion. In winter with high background streams, which stipulates intensity of turbulence diffusion and part of oil products, are included in the circulation currents at the west of Poti and that is why it is observed oil products transfer in the south direction.

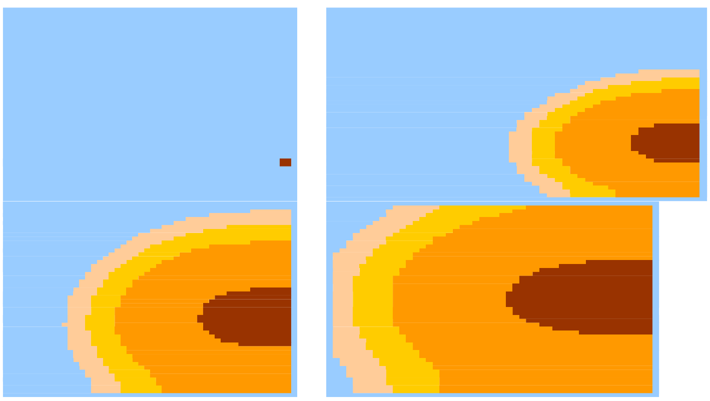

Fig.1 shows the results of numerical calculations of the Black Sea pollution at 24, 48 and 72 hours after accidential oil spillage nearer of Batumi in January.

200 t oil spillage in the sea: Oils surface concentration becomes less than MPC for 2 days in winter, but for summer for 3 days. The balance of oil's distribution in winter is the following: Oil at the surface – 46-50 t, Sedimentation on the bottom 9-13, carring out (remove) on the sea shore 42 t, evaporation – about 100. The maximum concentrations are the following: surface 0.008 mg/l on 5000 km^2 area, botton0.07 g/m^2 on 20-25 km^2 area, at sea shore – 11-12 t\km in Summer: Catastrophic spillage in open sea (15 km far away, remote from oil terminal in the west direction. The pollution mainly is penetrated in the North-west direction for 4-5 day in winter and in the course of 5-6 days in summer)

Conclusions

The results of numerical calculations have shown that after 3-4 days from dangerous and catastrophic disastrous oil spilling in the Georgian sector of the Black Sea practical surface, bottom and coastal pollution formation is completed.

It is necessary to note that there are considerable distinctions between spilled oil concentrations distribution in summer and winter. In all cases pollution follows the main background currents and spreads in the north-west direction. But there are observed much more intensive (fast) distribution in winter due to more active turbulence. That is why it is observed oil products involving in cyclone type circle circulation current which stipulate oil products spreading to the south at the Turkish Sea shore (coastal line).

The heavy results of oil pollution have been discovered when oil had spilled nearer of oil terminal in Kulevi for accidental and especially for catastrophic ocean occurrence events.

, bottom and coastal areas, an appreciable were increased by oi#

Considerable lass pollution of surface and coastal areas was observed due to catastrophic spillage in the open sea, because after 4-5 days the area of pollution was going out from Georgian sector to Russian's coastal are in the direction of Sea of Azov.

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ავარიული დაღვრის შედეგად ზღაში ნავთობის გავრცელების ორგანზომილებიანი ამოცანის რიცხვითი მოდელირება./თ. იმნაძე, ნ. ბეგალიშვილი, თ. დავითაშვილი, დ. დემეტრაშვილი/ ჰმი-ს შრომათა კრებული -2011.-ტ.116.-გვ.100-105-ინგლ. რეზ. ქართ. ინგლ. რუს.

მოცემულ ნაშრომში განხილულია შავ ზღვაში ავარიულად დაღვრილი ნავთობის გავრცელების მათემატიკური მოდელი. ზღვაში ავარიული ჩაღვრების მოდელირებისათვის გამოყენებულია სამი სცენარი: პირველი – წრფივი დაღვრა, რომლის ვრცელდება 2,5კმ მანძილზე ბათუმის პორტის მახლობლად; მეორე – 10კმ-იან ქობულეთი-მახინჯაურის სარკინიგზო მონაკვეთზე, სადაც სატვირთო შემადგენლობა მოძრაობს ფაქტიურად სანაპირო ზოლის გასწვრივ; მესამე სცენარი იმეორებს მეორე სცენარს მდ. სუფსის მახლობლად, სადაც ნავთობი აღწევს მდინარის ნაპირს.

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T**wo Dimensional Numerical Model Of Emergency Spilling Oil Distribution In The Sea. /**T.Imnadze, N. Begalishvili, T. Davitashvili, D. Demetrashvili/ Transactions of the Georgian Institute of Hydrometeorology.-2011.-v.116. p.100-105-Eng; Summ.Georg; Eng; Russ.

In the present paper mathemaical modelling of oil outflow and speading in the Bleak Sea water is presented. The mathematical model taking into consideration oil transformation (evaporation, emulsification, dispersion and sedimentation). Oil distribution on the Bleak Sea water surface for the three scenarios: The first - oil spill from the pipeline with the length of 2,5 km at the approach to the oil bay of Batumi Port.In the second case the accident may occur upon the 10 km. area of the railway in the region of Kobuleti-Makhinjauri seaside, when the freight train moves practically along the seashore. The third case reveals the second variant of the scenario of accidental situation: railway accident at the bridges crossing, for instance on river Supsa, when the oil reaches the mouth of the river, transferred by water flow.

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Математическое моделирование двухмерной задачи аварийных разливов и распространения нефти в море./Т.М. Имнадзе, Н.А. Бегалишвили, Т.П. Давиташвили, Д.И. Деметрашвили/ Сб.Трудов Института Гидрометеорологии АН Грузии. – 2011. – т.116. – с.100-105- Анг.; рез. Груз., Анг.,Русск.

В существующей работе представлена математическая модель аварийных разливов и распространения нефти в море. Для моделирования нефтяного слива рассмотрены три случая аварии. Первый – это разлив трубопровода, длина которого 2,5км, при подходе к нефтяной бухте Батумского порта. Во втором случае авария может иметь место на 10 км участке железной дороги в районе прибрежной полосы Кобулети-Махинджаури, когда грузовой состав движется фактически вдоль берега. Третий случай представляет второй вариант сценария аварийной ситуации: железнодорожная катастрофа на переходах мостов, например, на р. Супса, когда нефть достигает устья реки, переносимая водным потоком.