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Numerical Study of the Distribution of Floating Debris in the Coastal Zone of the Black Sea of Georgia

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ABSTRACT

Numerical modeling of the distribution of floating marine debris in the coastal waters of the Black Sea of Georgia using marine litter monitoring data is presented. The monitoring was carried out in Poti and Batumi nearshore water areas during September 2019 under the framework of EU project RedMarLitter. To simulate floating marine debris a 2D nonstationary advection-diffusion model is used, which is coupled with the regional model of the Black Sea dynamics of Institute of Geophysics of I. Javakhishvili Tbilisi State University (RM-IG), The RM-IG is a core of the regional forecasting system for the easternmost part of the Black Sea and is based on a full system of ocean hydrothermodynamics equations written in a Cartesian coordinate system. The modeling results showed the important role of advection and diffusion processes in the spatial-temporal distribution of floating solid waste.

Key words: *Circulation, marine litter, modeling system, advection-diffusion equation.*

1. Introduction

At the present stage of human development, environmental pollution with different anthropogenic impurities has become a global problem, the study of which is one of the main issues of modern environmental sciences. Among the environmental pollution problems, the pollution of the seas and oceans by solid waste (marine litter) has become one of the most important challenges for the world. Studies show that the world ocean is heavily polluted with debris – plastic bags, rubber, bottles, paper/cardboard, etc., which have a very negative impact on the marine ecosystem [1-4]. Some of them float on the sea surface, but most of marine litter sink and accumulate on the seabed. Marine litter enters the marine environment from both land- and sea-based sources. The source of this kind of waste is the garbage discharged from the ships, the household waste dumps along the banks of rivers, that are discharged into the rivers during floods, the waste accumulated on the sea coasts during the holiday season, etc. Most marine debris is plastics, which tends to break down into small particles and is often ingested through food and leads to various adverse health effects [2, 3]. Furthermore, plastics are a source of toxic chemicals, very dangerous for marine life. By estimation of some experts, 6.4 million tons of litter are entering the oceans each year [3].

Monitoring of solid waste in the seas and oceans is an important part of the marine environment monitoring in general and is a prerequisite for maintaining the ecological safety of marine systems and sustainable development of society. This problem is highlighted in the EU Marine Strategy Framework Directive (MSFD), where among 11 descriptors providing for good environmental status of the sea environment, descriptor 10 considers the survey of marine litter in marine environment (properties and quantities of marine litter).

Over the last two decades, a lot of works on marine litter monitoring have been conducted at sea beaches, at the sea surface and at the seabed in order to estimate and study litter spatial distribution, its composition and to identify the sources (e. g., [1-9]). In [1] beach litter was considered as a threat to beach tourism and studies have focused on the quantification and classification of marine litter on the beach of the City of Ensenada (Baja California, Mexico). During the monitoring, which was carried out on April-August 2000, the beach of Ensenada revealed a total of 16474 objects, including 2686 plastics (16,3%).

Spatial and temporal variability of the floating debris was studied in [2] based on data collected during oceanographic cruises in 1997 and 2000 in the north-western Mediterranean sea. A debris density in 1997 was 15-25 objects km^{-2}, while for the 2000 data, a lower density of the order 3 – 1.5 km^{-2} was found. This result indicates a significant time variability in the debris concentration in the Mediterranean basin. According to the authors, possible reasons for the observed variability are meteorological forcing, marine currents or debris input variability.

In [3] a rather detailed study of the distribution of marine debris in the waters of the European seas was carried out based on the analysis of data collected during 588 video and trawl surveys across 32 sites in European waters. In the Mediterranean Sea, which is an inland sea like the Black Sea, several hotspots were discovered. The hotspot with a maximum litter density 21-40 kg.ha^{-1} was observed near the Spain shore. One of the conclusions of this study is that the highest litter density occurs in submarine canyons, whilst the lowest density can be found on continental shelves and on ocean ridges. It turned out that the most prevalent litter item found on the seafloor.

In [4] benthic marine litter were investigated during the period January-March 2013 in five study areas from the Eastern Mediterranean and Black Seas (Constanta Bay). Plastics were predominant in all study areas ranging from 45.2% to 95%. In total 5398 marine litter items were collected from all the study areas. The highest density was found in the Saronikos Gulf (1211 ±594 items/km^2), in the Constanta bay 291±237 items/km^2 litter density was found.

Like the world ocean, the Black Sea pollution with marine litter has become very relevant in the last two decades [5-9], which has a very negative impact on the marine ecosystem. Studies have shown that the bottom of the Black Sea coastal zones is often filled with municipal solid waste - bottles, banks, plastic materials, and more. The number of start-ups has been established for processing and recycling the plastic debris from environment, including the marine area (e. g. Tene Ltd.- https://www.facebook.com/TeneUSB/)

Following MFSD requirements, monitoring of marine litter has been conducted on 3 selected beach sections (Ureki, Kobuleti and Sarpi beaches) of Georgia within EC-UNDP funded project EMBLAS I/II in the period from 2015 to 2017 [6]. As a result of the monitoring work carried out, the authors conclude that the litter on the surveyed sections of beaches is generated from land-based sources. Monitoring results showed that Ureki beach is more loaded by litter, the volume of plastic in total amount of litter is 95-96 %.

At present, numerical (mathematical) modeling is widely used to study the features of the floating marine litter distribution in the world ocean. A rather large number of publications are devoted to this issue (e. g., [10-18]).

The use of mathematical modeling methods allows to estimate the scales of marine litter distribution and contribution of different factors (sea circulation, atmospheric wind, etc) to floating litter dispersion process, providing better understanding litter dispersion processes. Distribution of floating marine debris in marine environment largely depends on the sea circulation parameters, which are calculated from ocean circulation models. In [10] different numerical models of ocean circulation are described, the output of which can be applied to simulate drifting of marine debris. These models are: the Navy Layered Ocean Mode (NLOM), the Navy Coastal Ocean Model (NCOM), the Hybrid Coordinate Ocean Model (HYCOM), etc.

Most of publications on numerical modeling consider a particle-tracking method to describe the distribution of floating debris by virtual particles. In [11] a global ocean circulation model HYCOM were coupled to the Lagrangian particle-tracking model Pol3DD to simulate 30 years of transport and accumulation of floating debris in the world ocean. The model outputs showed the formation of 5 accumulation zones in the subtropical latitudes. In terms of numerical modeling, considerable interest is [12], where modeling the distribution and accumulation of floating debris entering the ocean in large quantities as a result of well-known Tohoku tsunami by the 11 March 2011 is presented. This disaster has generated a massive influx of debris washed from the coastline into the ocean. To simulate the transport of flouting debris a modeling system is applied consisting of a global ocean circulation model HYCOM and a Lagrangian particle-tracking model Pol3DD. The model Pol3DD grid covered a part of the North Pacific and comprised 1551 x 701 grid nodes with 7 km spacing. In [13] the drift of marine litter in the southern North Sea was simulated with the Lagrangian particle-tracking model PELETS-2D for a nine year period 2000-2008. The model was coupled to pre-calculated current and wind fields based on the 3D operational circulation model BSHcmod of the Federal Maritime and Hidrographic Agency of Germany (for more information reference to [10]) .

In [16] overview of models of floating marine debris focusing on marine micro-plastics (< 5 mm diameter) is presented and some ways to improve modeling of transport of marine debris in a future are discussed. The authors are of the opinion that presently used ocean circulation models, commonly having 10 km horizontal and 10 m vertical resolution, require 10 m details or even finer grid, which is associated with the exponentially growing computer power.

It should be mentioned the model, recently elaborated by researchers from Naval Academy (Burgas, Bulgaria) within the EU funded project "Innovative Techniques and Methods for Reducing Marine Litter in the Black Sea Coastal Areas – BSB552 RedMarLitter", which is based on consideration of the trajectory of individual floating objects (https://map.redmarlitter.eu/en/waste-flow-modelling).

The present paper provides numerical modeling of the distribution of floating marine debris in the coastal waters of the Black Sea of Georgia using data of litter monitoring conducted in Poti and Batumi nearshore water area during September, 2019 (within the EU/UNDP project "Improving Environmental Monitoring in the Black Sea-Selected Measures – EMBLAS Plus" and EU funded project "Innovative Techniques and Methods for Reducing Marine Litter in the Black Sea Coastal Areas - BSB552 RedMarLitter"). There is considered advection-diffusion approach based on numerical solution of 2D nonstationary advection-diffusion equation. Unlike the particle-tracking method, within this approach we do not track the movement of every solid object floating on the sea surface, but use the concept of the average density of marine litter (concentration), that is, mass per unit area of the sea surface.

2. Description of the modeling system

The distribution process of floating solid debris entering the sea by rivers or otherwise discharged into the marine environment is a complex problem and largely depends on the sea currents, turbulent diffusion, atmospheric wind speed and direction, surface waves. To simulate and study this process, we considered a coupled modeling system consisting of two subsystems. The first subsystem represents a hydrodynamic block based on a high-resolution regional model of sea dynamics developed at M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University (RM-IG). The second one is a numerical model of marine litter transport based on the solution of a 2D non-stationary advection-diffusion equation.

Fig.1.Modeling and forecasting area in the easternmost part of the Black Sea marked with a rectangle. The numbers show amount of grid points of numerical model on the horizons.

The RM-IG is a core of the marine regional forecasting system for the easternmost part of the Black Sea [19-23], which covers the Georgian sector of the Black Sea and the adjacent water area with sizes about 215 x 340 km (Fig. 1). The study area is limited from the west by liquid boundary coinciding with the meridian 39,08^{0}E passing near the city of Tuapse (Russia). The regional forecasting system is one of the components of the Black Sea basin-scale Nowcasting/Forecasting System [24, 25, 26].

2.1 Regional model of sea dynamics

The RM-IG is based on a full system of ocean hydrothermodynamics equations in hydrostatic and incompressible fluid approximations [19] and is a high-resolution version of the basin-scale model [27], adapted to the easternmost part of the Black Sea. The model equation system is written in z coordinates for deviations of temperature, salinity and pressure from their standard vertical profiles. Atmospheric forcing is taken into account by upper boundary conditions by given of wind stress components, heat flux, evaporation and atmospheric precipitation on the sea surface, which is considered as a rigid surface. This model with 1 km spatial resolution is nested in the basin-scale model of the Black Sea dynamics of the Marine Hydrophysical Institute (MHI, Sevastopol) with 5 km spatial resolution [26] using one-way nesting method, which provides forcing of open sea processes on the regional processes via the liquid boundary. All required input data for initial and boundary conditions are available from MHI via ftp site, providing integration of equations of RM-IG for 4 days.

To solve the model equation system with corresponding initial and boundary conditions, a two-cycle splitting method with respect of physical processes, coordinate planes, and lines is applied [28, 29]. The splitting method enables solution of nonstationary 3D equation system of ocean hydrothermodynamics to reduce to solving of relatively simple 1D and 2D problems.

The sea surface current field calculated from the RM-IG with use of real input data is used in the 2D numerical advection-diffusion model of marine litter distribution.

2.2 Advection-diffusion model of marine litter transport

If we consider the transport of small floating debris, the size and shape of which can be neglected, then this process can be described by a 2D nonstationary advection-diffusion equation, similar to the transfer of an oil slick (the x axis is directed to the east, y - to the north)

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial \mathrm{v}C}{\partial y}=\frac{\partial}{\partial x}\mu_c\frac{\partial C}{\partial x}+\frac{\partial}{\partial y}\mu_c\frac{\partial C}{\partial y}+f\,(x,y,t). \qquad (1)$$

Here C is the concentration (density) of solid waste (kg / m^2), μ_c is the turbulent diffusion coefficient, the function *f*, generally, describes a temporal-spatial distribution of source power, which can be represented by δ-function in a particular case of a point source

$$f=Q\,\delta\,(x-x_0)(y-y_0), \quad .$$

where Q is the amount of solid waste getting into the whole area per unit time, x_0 and y_0 are the source coordinates.

The velocity components u, v along x and y axes consist of two terms

$$u = u_s + \alpha u_w, \quad \mathrm{v} = v_s + \alpha v_w,$$

where u_s and v_s are the components of the sea current velocity along the x and y axes calculated from the regional model of sea dynamics; u_w and v_w are velocity components of atmospheric wind along the x and y axes, respectively.α is the wind drift coefficient which, defines contribution of the atmospheric wind to drift of solid waste on the sea surface.

The diffusion coefficient was calculated on each time level by the formula, offered in [30]

$$\mu_\varphi=\gamma\,\Delta x\,\Delta y\sqrt{2\left(\frac{\partial u_s}{\partial x}\right)^2+\left(\frac{\partial u_s}{\partial y}+\frac{\partial v_s}{\partial x}\right)^2+2\left(\frac{\partial v_s}{\partial y}\right)^2},$$

where Δx and Δy are grid steps along x and y axes, respectively; γ is some constant depending on the average size of floating objects. To clarify this dependence further research is required.

The equation (1) is solved using the following boundary and initial conditions. If the lateral boundary (solid or liquid) is far from the source, zero litter density is assumed, but if the boundary Γ is close to the source location, in general, we can write

$$\partial C/\partial n=\beta C \quad \text{on } \Gamma,$$

where β is the factor describing release of solid material ashore, *n* is a normal to the solid boundary.

$$C = C_0 \qquad \text{at } \ t = 0,$$

where C_0 is the initial density distribution of marine litter.

A finite-difference method –the two-cycle splitting method by x and y coordinates is used to solve the equation (1) with appropriate initial and boundary conditions. With this purpose, we divide the entire integration time interval (0, T) by the 2τ step intervals, where $\tau = t_j - t_{j-1}$. Within every 2τ time step interval ($t_{j-1} \le t \le t_{j+1}$) we make the two-cycle splitting by coordinates of the equation (1), resulting in the solution of the problem in the following three steps:

1. at time interval $t_{j-1} \le t \le t_j$ the advection-diffusion equation along the axis x is solving

$$\frac{\partial C_1}{\partial t} + \frac{\partial u C_1}{\partial x} = \frac{\partial}{\partial x} \mu_c \frac{\partial C_1}{\partial x}$$

with initial condition

$$C_1^{j-1} = C_3^{j+1}$$

2. at time interval $t_{j-1} \le t \le t_{j+1}$the advection-diffusion equation along the axis y is solving

$$\frac{\partial C_2}{\partial t} + \frac{\partial \mathrm{v} C_2}{\partial y} = \frac{\partial}{\partial y} \mu_c \frac{\partial C_2}{\partial y} + f(x,y,t)$$

with initial condition

$$C_2^{j-1} = C_1^{j} ,$$

3. at time interval $t_j \le t \le t_{j+1}$ the advection-diffusion equation along the axis x is solving again

$$\frac{\partial C_3}{\partial t} + \frac{\partial u C_3}{\partial x} = \frac{\partial}{\partial x} \mu_c \frac{\partial C_3}{\partial x}$$

with initial condition

$$C_3^{j} = C_2^{j+1} .$$

At each stage, the Krank-Nicholson scheme is applied for time approximation, and the derivatives by x and y are approximated with central finite differences. The obtained algebraic equations are solved using the factorization method. In general, numerical method of the problem solving approximates the task with second-order accuracy with respect to spatial and temporal variables.

The software of the developed coupled modeling system is a integrated software package elaborated in the algorithm language “Fortran”.This unified package contains a solid waste distribution software package as a separate module. If the solid waste enters the sea from rivers, ships, etc., then computer realization of this module requires to input source coordinates, the amount of solid material entering the sea and the duration of entering. If the initial distribution of litter density is given and we are interested in further evolution of the density field, to input above data is not needed.

Thus, the present model describes the distribution process of floating solid waste at the sea surface, which is caused by the advection, turbulent diffusion, wind speed and direction, source action.

3. Model outputs and discussion

3.1 Input parameters

For the purpose of computational realization of the numerical models involved in the modeling system the modeling area is covered by a spatial grid whose parameters are: in the RM-IG 30 calculated levels on a vertical with non-uniform vertical steps with a minimum step of 2 m at the sea surface and a maximum step of 100 m at the seabottom. The number of grid points on each horizon is 215x347 with the spatial horizontal resolution 1 km; The time step is 0.5 h. $\gamma = 0.5$, $\alpha = 0$.

With the purpose of validating the RM-IG, the computed sea surface temperature and surface flow fields were compared with satellite observational data showing the ability of the model to really reflect the hydrophysical processes occurring in the easternmost coastal zone of the Black Sea [19, 22, 23].

3.2 Main features of the regional circulation

Marine circulation is one of the main factors that largely determines the drift of solid floating debris on the sea surface. Studies based on the RM-IG with use of real input data show that the easternmost water area of the Black Sea is characterized by very high dynamic activity, where mesoscale and submesoscale vortex formations are continuously generated and evolve throughout the year [31, 32]. Such vortex formations obviously play an important role in the distribution of various impurities in the sea, including solid waste. One of the general features is that the structure of the sea surface circulation is characterized by significant seasonal and interannual variability and differs significantly in the warm and cold seasons. During the warm season, the main element of the regional circulation is often the anticyclonic eddy, which is known as the Batumi eddy. For the last decade, the Batumi eddy has been the most stable and intense formation in the summer and early autumn of 2010, covering an area of about 200 km in diameter [19, 20]. The process of spreading solid waste into the sea coming from land-sources depends significantly on the nature of the nearshore sub mesoscale circulation structure. The results of our modeling show that in a narrow strip 15-20 km wide along the coastline of Georgia, the formation of very small coastal unstable eddy structures with a lifetime of about 2-3 days is often observed. Here the current has a pronounced non-stationary character and in a short period of time the directions of the current change sharply.

3.3 Modeling of floating marine litter

Modeling of the distribution of floating marine litter in the Georgian coastal waters was carried out with taken into consideration the results of the monitoring conducted by the Georgian research team in Poti and Batumi nearshore waters within the EU project "**RedMarLitter**" during September 2019. The monitoring was carried out from the boat – at the coast of Poti on the area 42.12^0– 42.20^0N, 41.65^0– 41.62^0E during 10:09-11:53 (local time) on September 4 and at the coast of Batumi on the area 41.66-41.67N, 41.65-41.68E during 11:21-13.59 (local time) on September 5.

Modeling of solid waste propagation was carried out under the conditions of the real sea circulation mode for the period from 4 to 12 September 2019 calculated on the basis of the RM-IG using the corresponding real input data. Monitoring results were used to determine the initial field of litter density.

During observations 75 floating objects were found on the Poti transect along a length of 50 m and 29 solid objects were observed on the Batumi transect along a length of 30 m. The average size of solid objects ranged from 5 to 20 cm.

Assuming that the average mass of an object was 100-150 g, we could approximately estimate the initial densities of the litter (in kg per unit square) near Poti and Batumi coasts. At the initial moment $t = 0$, litter density was zero throughout the modeling area, except for one grid point near the Poti and Batumi coast, which approximately corresponded to the geographical coordinates of the monitoring. Based on the above data, in the first numerical experiment, we obtained the initial concentration of solid waste equal to 0.0033 kg/m^2 in the point with grid coordinates $212\Delta x$, $124\Delta y$ ($\Delta x = \Delta y = 1$ km) near the Poti shore. In the second one, the initial density was 0.0024 kg/m^2 in the point with grid coordinates $208\Delta x$, $88\Delta y$ near the Batumi shore. These points approximately corresponded to the geographical coordinates of the monitoring. In the first numerical experiment, the start of integration of the advection-diffusion equation was 08:00 GMT, September 4, 2019, which approximately corresponds to the monitoring time period in Poti coastal waters, but in the second one, the start of integration was 10:00 GMT, September 5, 2019 corresponding to the monitoring time period in Batumi coastal waters.

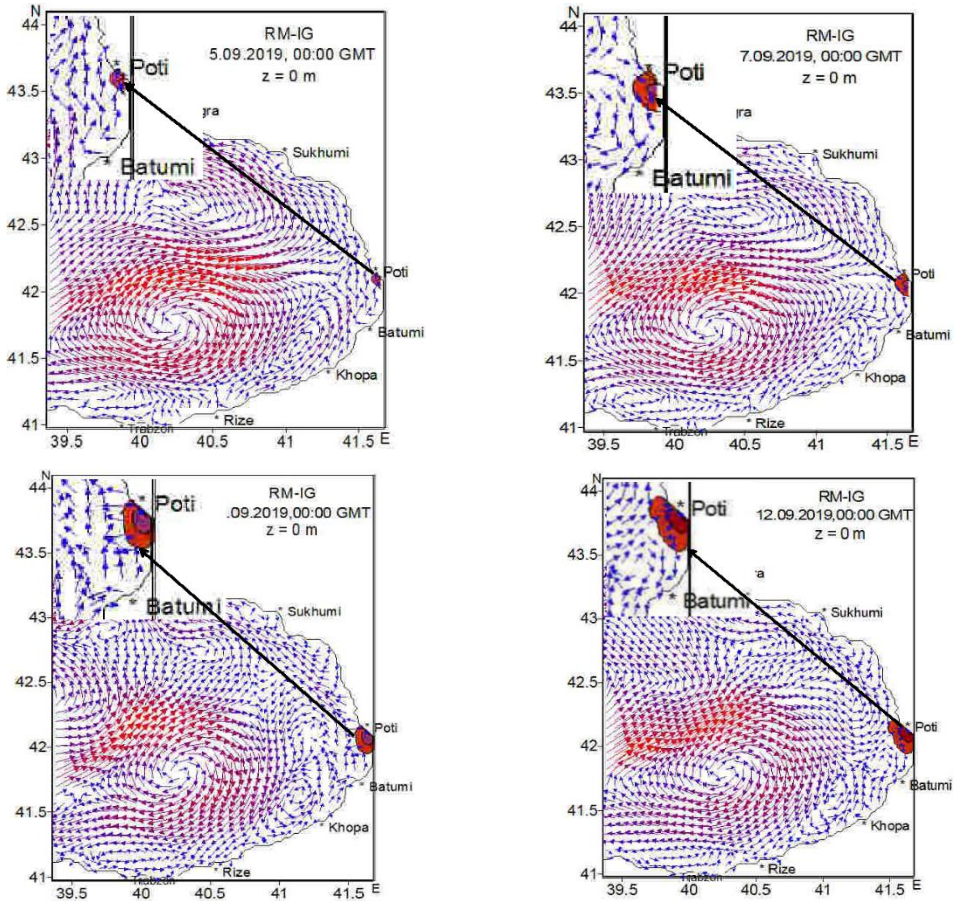

Fig.2. Modelled surface circulation field and solid waste distribution area for the time moments shown in the Figure in September 2019. The initial density of the waste was at the grid point near the Poti coast on September 4, 2019, 08:00 GMT.

In Fig. 2 the sea surface circulation field and the area of solid waste distribution at different times of September 2019 are demonstrated, when the initial concentration of waste was given near the coast of Poti.

Similar pictures are shown in Fig.3, when the initial litter density was given near the Batumi coast. For better visualization, the coastal circulation and distribution of solid waste in the Poti-Batumi waters are shown in an enlarged form in the upper left corner of the Figs 2 and 3.

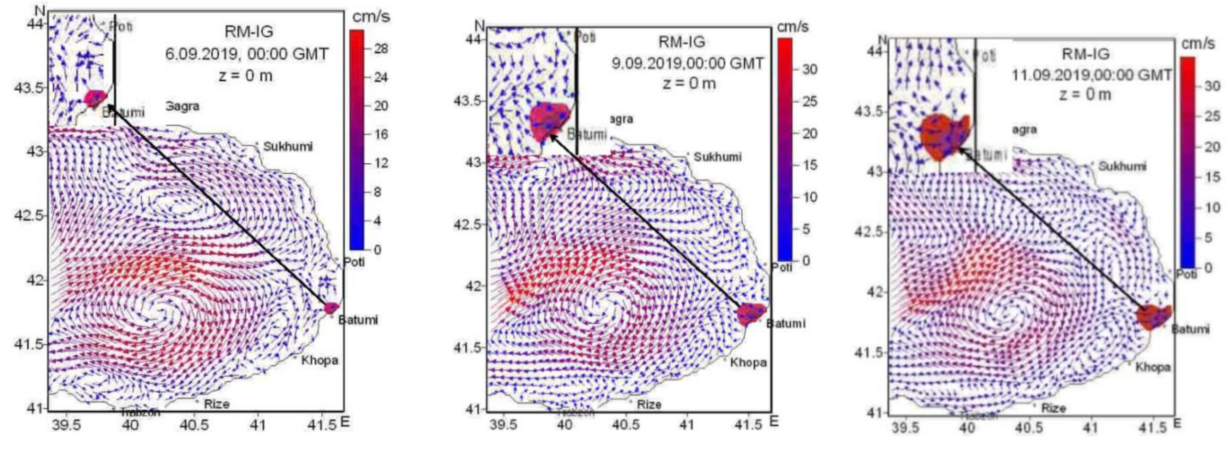

Fig.3. The same as in Fig.2, but the initial density of the waste was given close to Batumi beach on September 5, 2019, 10:00 GMT.

It is clear from Figs. 2 and 3, that the coastal microcirculation at Poti and Batumi nearshore for the considered period is characterized by significant non-stationarity, where the dominated current direction does not observed and flow directions change dramatically over a short period of time. For example, in Fig.2, it is clearly shown that within two days from 5th to 7th September the current's direction changed from north to south. Calculations showed low speeds equal to 2-4 cm/s near Poti-Batumi coastline. Such character of the flow field has a direct impact on the floating solid waste distribution. The modeling results show that during the 7-8 days since initial time moment, solid objects can spread from the shore at a distance not more than of 8-10 km from the shore under the conditions of the mentioned microcirculation regime. Under the influence of advection and diffusion processes, the distance between floating objects increases over time and their distribution area takes up significantly more space. In our case, the diameter of the area occupied by solid waste is about 10-12 km.

If we take into consideration that the alternation of different circulation modes is often observed in the Georgian sector of the Black Sea, it is of important scientific and practical interest to evaluate the influence of the sea surface circulation on the process of floating solid waste distribution. For this purpose, computational experiments were conducted under different circulation modes in conditions of the same initial marine litter density field.

Fig.4 shows the results of modeling the surface circulation and distribution of marine litter after 24, 48 and 72 hours, when the initial density of marine litter at Poti coastline was the same as in the first numerical experiment (Fig.2), but in this case the sea circulation was stationary and characterized by strong current along the Georgian coastline directed to the north-west with a maximum speed of 60 cm/s. The flow field corresponding to December 9, 2014 was calculated from the RM-IG using real input data. Comparison of Figs.2 and 4 shows that despite the same initial conditions, the process of spreading solid waste in these two cases is completely different. In Fig. 4 it is clearly seen that under the influence of the sea current and diffusion the solid waste moves to the north-west and the area covered by the waste takes an elongated shape along the sea current direction.

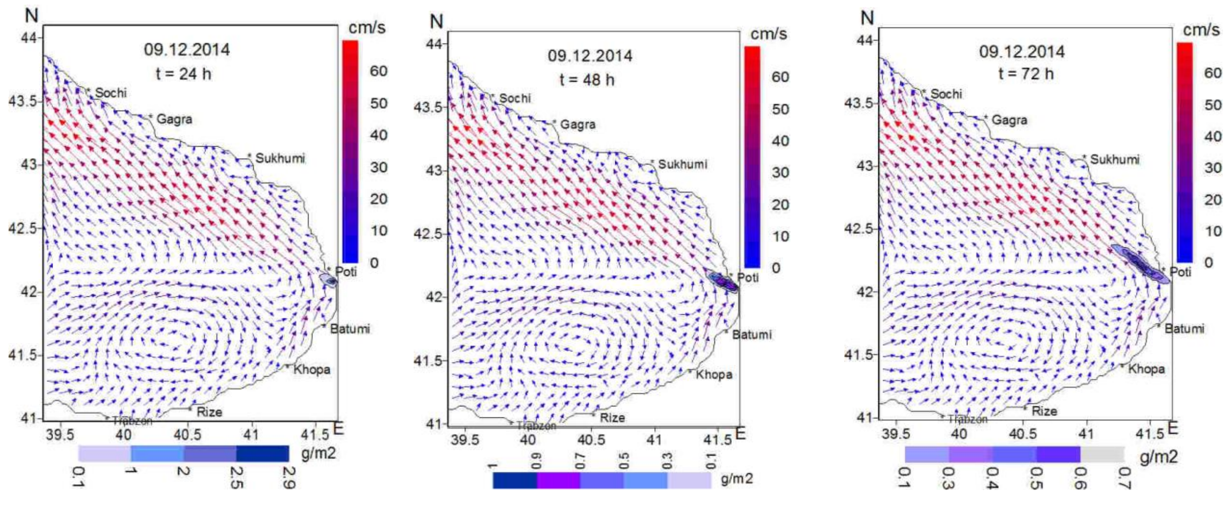

Fig. 4. Simulated surface current for 9 December 2014 and solid waste drift in the Georgian coastal zone in the indicated moments of time after the initial moment. Initial waste density was in the point near Poti shoreline.

Computational experiments have shown that the structure of the microcirculation in the area occupied with solid waste after entering the sea environment, may significantly determine the process of waste distribution.To illustrate this fact, In the next numerical experiment the circulation mode was the same as in the previous numerical experiment (corresponding to December 9, 2014), but initial location of marine waste was different – it located near the Batumi shoreline as in the second numerical experiment (Fig.3).

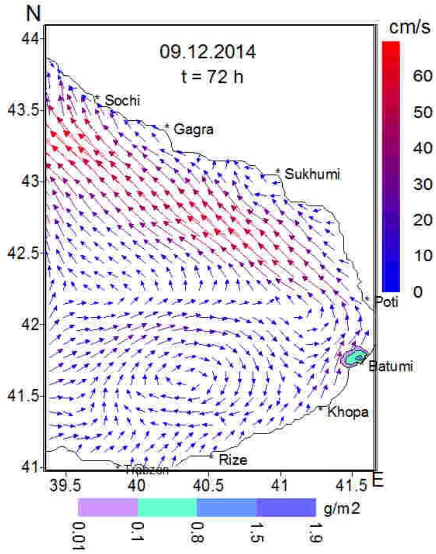

Fig. 5. Same as in Fig.4, but at the initial moment waste density was given in the point near Batumi shoreline.

in Fig.5 the marine litter distribution is shown at t = 72 h after the initial state. Comparison of Figs. 4 and 5 shows a large difference in the litter distribution. Unlike the previous case (Fig.4), where the area occupied by solid waste took an elongated shape along the flow direction having pronounced north-west direction, in this case, the shape of the area occupied by solid waste was approximately oval and does not move significantly from the shorline for three days.

4. Conclusions

For the purpose of mathematical modeling of floating solid debris in the Georgian Black Sea coast, a coupled modeling system has been considered, consisting of the RM-IG and floating marine litter distribution model. The RM-IG is a high-resolution z-level model based on a full system of ocean hydrothermodynamics and is nested in the basin-scale model of Black Sea dynamics of MHI (Sevastopol). Our approach to the simulation floating marine litter is based on a solution of a 2D nonstationary advection-diffusion equation, which is coupled with the RM-IG. The advection-diffusion model uses nonstationary sea flow field calculated from the RM-IG on each time level.

The mathematical modeling system makes it possible to simulate the spread of solid waste in the marine environment under various real modes of surface circulation with 1 km spatial resolution. If the solid waste enters the sea environment from ships, rivers and other land-based sources, then computer realization requires to input source coordinates, the amount of solid material entering the sea (in kilograms) and the duration of entering. If the initial litter density (kilogram per unit square) is given and we are interested in further evolution of the litter density field, to input above data is not needed.

Computational experiments were conducted to simulate and study the peculiarities of the spatial-temporal distribution of solid waste in the Georgian coastal waters with taken into consideration the data of the monitoring conducted in Poti and Batumi coastal waters in September 2019 within the EU project "**RedMarLitter**".

The numerical experiments have shown that water circulation mode and the initial position of solid waste entering the sea environment largely predetermine the main peculiarities of the marine litter propagation process.

Calculations have shown a significant role of advection and diffusion processes in the process of spatial-temporal propagation of solid waste floating on the sea surface. The general pattern is that the area covered with solid waste at the initial time, undergoes transformation over time - the area expands, that is the distance between different objects gradually increases and occupies more area, which is mainly due to the turbulent nature of the flow. At the same time, the marine litter is drifted under the influence of advection processes. The specific features of this process are expressed differently under different circulation modes.

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საქართველოს შავი ზღვის სანაპირო ზონაში მცურავი მყარი ნარჩენების გავრცელების რიცხვითი გამოკვლევა

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რეზიუმე

წარმოდგენილია საქართველოს შავი ზღვის სანაპირო წყლებში მცურავი საზღვაო ნარჩენების განაწილების რიცხვითი მოდელირება ზღვის ნარჩენების მონიტორინგის მონაცემების გამოყენებით. მონიტორინგი განხორციელდა ფოთისა და ბათუმის სანაპირო წყლებში 2019 წლის სექტემბერში ევროკავშირის პროექტის RedMarLitter-ის ფარგლებში. მცურავი საზღვაო ნარჩენების მოდელირებისათვის გამოყენებულია 2D არასტაციონარული ადვექციურ-დიფუზიური მოდელი, რომელიც შეწყვილებულია ი.ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტის გეოფიზიკის ინსტიტუტის შავი ზღვის დინამიკის რეგიონალურ მოდელთან (RM-IG). RM-IG არის შავი ზღვის განაპირა აღმოსავლეთი ნაწილის რეგიონული პროგნოზული სისტემის ბირთვი და ეფუძნება ოკეანის ჰიდროთერმოდინამიკის განტოლებათა სრულ სისტემას, რომელიც დაწერილია დეკარტის კოორდინატთა სისტემაში. მოდელირების შედეგებმა აჩვენა ადექციური და დიფუზიური პროცესების მნიშვნელოვანი როლი მცურავი მყარი ნარჩენების სივრცით-დროით განაწილებაში.

Численное исследование распространения плавающих твердых отходов в прибрежной зоне Черного моря Грузии

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Резюме

Представлено численное моделирование распространения плавучего морского мусора в прибрежных водах Черного моря Грузии с использованием данных мониторинга морского мусора. Мониторинг проводился в прибрежных акваториях Поти и Батуми в течение сентября 2019 года в рамках проекта ЕС RedMarLitter. Для моделирования плавающих твердых отходов используется двумерная нестационарная адвективно-диффузионная модель, связанная с региональной моделью динамики Черного моря Института геофизики Тбилисского государственного университета им. И. Джавахишвили (RM-IG). RM-IG является ядром региональной прогностической системы для самой восточной части Черного моря и базируется на полной системе уравнений гидротермодинамики океана, записанных в декартовой системе координат. Результаты моделирования показали важную роль процессов адвекции и диффузии в пространственно-временном распределении плавающих твердых отходов.