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Original article

A Software Tool for Operative Data Preparation for Assessing the Structure of Longshore Sediment Flows in the Coastal Zone of the Sea

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Abstract

The paper describes the geoinformation software developed for automated formation of an array of input parameters necessary to assess the direction and relative intensity of alongshore sediment flows using the wind energy method. This method establishes a direct relationship between the energy of wind action on the water surface and the intensity of sediment movement. The method can be applied to calculations for shallow and relatively straight coastal sections with sand and gravel deposits. As input parameters, the software uses information about both the wind direction and speed, as well as the length of the wave acceleration along the sectors of different directions and the average depth along the acceleration rays. These parameters are individual for each segment of the approximation of the study coast section. The possibility of using wind data as the only parameter characterizing the driving force provides an advantage when using the method to conduct preliminary and reconnaissance assessments of the structure and main parameters of sediment movement in the areas that are poorly studied or not covered with disturbance data. The basics of the method were developed in the absence of computer technology. Therefore, the considerable complexity of preparing regional data limited the possibility to detail the coastline when approximating it by a piecewise linear function. The same limitation was imposed on the number of sectors in the wind direction when calculating the energy interpreted as a sediment movement force. The development and availability of modern geoinformation technologies in terms of creating new digital models of the bottom relief or using existing ones predetermined that the authors develop a modified version of the calculation scheme of the wind energy method and a specialized software tool to automate the preparation stage of a set of regional input parameters. The software allows to significantly accelerate preparation of digital data arrays to clarify the structure of sediment flows for extended sections of the coastal zone of Western Crimea.

Keywords: longshore sediment flows, wind energy method, wind-wave regime, GIS, lithodynamics processes, coastal zone, automation of calculations

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Программный инструмент оперативной подготовки данных для оценки структуры вдольбереговых потоков наносов в прибрежной зоне моря

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Аннотация

Описываются результаты разработки геоинформационного программного инструмента, предназначенного для автоматизированного формирования массива входных параметров, необходимых для оценки направления и относительной интенсивности вдольбереговых потоков наносов с использованием ветроэнергетического метода. Указанный метод устанавливает непосредственную связь между энергией ветрового воздействия на водную поверхность и интенсивностью перемещения наносов. Его применение корректно в случае выполнения расчетов для отмелых и относительно прямолинейных участков береговой зоны с песчано-гравийными наносами, при этом в качестве входных параметров используется информация о направлении и скорости ветра, а также длина разгона волнения по секторам различного направления и средняя глубина по лучам разгона. Указанные параметры являются индивидуальными для каждого отрезка аппроксимации исследуемого участка побережья. Возможность использования данных о ветре как о единственном параметре, характеризующем вынуждающую силу, предоставляет преимущество при использовании метода для проведения предварительных и рекогносцировочных оценок структуры и основных параметров движения наносов в малоизученных и не обеспеченных данными о волнении районах. Основы метода разрабатывались в условиях отсутствия вычислительной техники, поэтому значительная трудоемкость подготовки региональных данных накладывала ограничения на возможности детализации береговой линии при ее аппроксимации кусочно-линейной функцией. То же ограничение накладывалось и на количество секторов по направлению ветра при подсчете энергии, интерпретируемой в качестве наносодвижущей силы. Развитие и доступность современных геоинформационных технологий в части создания новых либо использования уже существующих цифровых моделей рельефа дна послужили предпосылкой к разработке авторами модифицированного варианта расчетной схемы ветроэнергетического метода и специализированного программного инструмента для автоматизации этапа подготовки набора региональных входных параметров. Практическое его применение позволило значительно ускорить процесс подготовки цифровых массивов данных для уточнения структуры потоков наносов для протяженных участков береговой зоны Западного Крыма.

Ключевые слова: вдольбереговые потоки наносов, ветроэнергетический метод, ветро-волновой режим, ГИС, литодинамические процессы, береговая зона моря, прибрежная зона, автоматизация расчетов

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Introduction

The study of lithodynamic processes in the coastal zone of the sea is one of the most important and relevant areas in the development of scientific research in the coastal zone of the seas, which is reflected in a variety of both classical [1), 2)] [1, 2] and modern [3)] [3–5] publications. This is stipulated by the urgent need to use the results of such research when studying the state of sea coasts and forecasting trends in their development, manifested both in natural conditions and under various scenarios of anthropogenic impact. Such results are especially important when implementing projects of large-scale technogenic transformation of the coastal zone, aimed at preserving coastal areas in use and infrastructure facilities located on them. The projects for the development of new promising regions of the Russian Federation, which primarily include hard-to-reach areas on the Arctic and Far East coast, can serve as one more example.

In such cases, the main direction of engineering surveys is to identify and clarify the qualitative and quantitative characteristics of the coastal topography transformation in the work area at various spatial and temporal scales under the influence of natural and anthropogenic factors. At the same time, at the initial stages of planning and feasibility studies of projects, it is often necessary to obtain information about the main cause-and-effect relationships between the wind-wave regime and the longshore movement of sediments within the boundaries of a separate coastal section in a short time.

In the absence of the required amount of field observation data, it is now possible to use methods based on simplified empirical and semi-empirical relationships so that to obtain the required preliminary information with a minimum set of input parameters promptly and to solve such problems [3), 4)]. Most of such methods were developed before the implementation of computer technology. However, they are still relevant today. Thus, the research is conducted, primarily aimed at calibrating coefficients while maintaining the basic calculation formulas [6].

[1)] Zenkovich, V.P., 1962. [*Fundamentals of Theory of Marine Coasts Development*]. Moscow: Nauka, 710 p. (in Russian).

[2)] Longinov, V.V., 1963. [*Dynamics of the Coastal Area of Tideless Seas*]. Moscow: Izd-vo Akademii Nauk, 379 p. (in Russian).

[3)] CERC, 1984. *Shore Protection Manual*. Vicksburg: Coastal Engineering Research Center. Vol. II. 652 p.

[4)] Production and Research Institute for Engineering Survey for Construction, 1975. [*Manual on Methods for Investigations and Calculations of Sediment Transport and Coastal Dynamics in Engineering Surveys*]. Moscow: Gidrometeoizdat, 239 p.

The development and availability of digital technologies, especially in terms of creating new digital models of the bottom relief or using existing ones, predetermined that the authors develop a modified version of the calculation scheme of the known wind energy method (WEM). Subsequently, it resulted in a specialized software tool to automate the preparation stage of a set of regional input parameters.

The paper is aimed at the development of software algorithms and a simple tool for spatial calculations of coefficients determined by the influence of external conditions on the characteristics of sediment flows.

Materials and methods of research

Hydrometeorological methods should be highlighted among the calculation methods for the operational assessment of the direction and intensity of sediment flows, which determine the main trends in the topography transformation of the coastal zone relief [9]. Based on the results of a large number of studies and field observations, they are successfully used in order to solve practical issues related to the implementation of coast protection, construction of hydraulic structures, maintenance of port water areas and approach channels. As a rule, such geomorphological characteristics of the study area as bottom topography, coastline detail and particle size distribution of offshore sediments, influence the choice of a specific calculation scheme.

In shallow and relatively straight coastal sections with sand and gravel deposits, the WEM, which was proposed in the 1930s [5), 6)] and was subsequently developed and improved [7), 8)], is recommended for usage [7–9]. This method establishes a direct connection between the energy of wind action on the water surface and the intensity of sediment movement. The calculation scheme is based on the summation of energy transferred to the aquatic environment under winds of different directions relative to the coastline orientation. In this case, the entire range of wind directions is divided into separate sectors, for each of which the general expression for the transmitted energy is written in the following form:

$$e = p \cdot W^n \cdot D^m, \quad (1)$$

where p – wind frequency within a sector (in relative units or percentage); W – average wind speed; D – length of wind acceleration over the water surface;

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5) Munch-Petersen, I., 1933. [Sediments Transport Along Shores of Tideless Seas. Conference Report]. In: LGGI, 1933. P*roceedings of the 4th Hydrological Conference of Baltic Countries.* Leningrad: LGGI, 17 p. (in Russian).

6) Glushkov, V.G., 1934. [Role of Wind Influence, Migration Vector, Sediment Transport Vector and Drag Vector]. In: LGGI, 1934. *Za Ratsionalizatsiyu Gidrologii*. Leningrad: LGGI, pp. 13–27 (in Russian).

7) Knaps, R.Ya., 1962. [Hydrometeorological Method for Characterising the Movement Regime of Sand Sediments]. In: Mintransstroy, 1962. [*Technical Guidelines for the Design of Offshore Shore Protection Structures on Sandy Shores. VSN 80-62*]. Moscow: Orgtransstroy (in Russian).

8) Shishov, N.D., 1956. [Method for Calculating Capacity and Flow of Sand Sediments in Seas and Large Lakes]. In: SoyuzmorNIIproekt, 1956. *Trudy SoyuzmorNIIproekta*. Moscow: Morskoy Transport, iss. 3, pp. 45–56 (in Russian).

n and m – exponents that can vary in different conditions. In the standard version, it is recommended to use sectors within the boundaries of geographic points (through 45°) or half-points (through 22.5°) and to enter the point sector completeness coefficient to calculate e values. The acceleration length is determined by the limit value calculated according to the relation $D_{lim} = 0.8W^2$.

It is possible to apply several variants of calculation formulas built on the basis of expression (1), the most common of which are those given in [7, 9]. In this case, exponent n is set as equal to two or three by different authors, and exponent m is usually equal to 1/3. The energy dimension e is given by all authors in conventional units.

Without going into the details of the method, which are discussed in a number of works, such as [10, 11], it is possible to organise the information described above as follows.

The currently used WEM is quite simple, and the main obstacle to its operational use is the large volume of pre-prepared data characterized by the homogeneous tabular format. Based on the general approach, the coastline of the study area is approximated by a set of straight segments, from the middle of which a number of rays are drawn towards the sea in directions from the normal to the shore up to 120° in both directions every 5 or 10° until intersecting with the opposite shore or, in some cases, with the border of the map. The adopted step is designed to use data from direct measurements of wind speed, based on the fact that the directional error is 5–10° for most modern instruments. After this, if data on the bathymetry of the adjacent sea region is available, the vertical depth profile along each of the rays is determined. Thus, the spatial resolution of the bathymetry data affects the accuracy of subsequent calculations. Therefore, the total number of tables with data for calculation is $m \cdot n$, where m – number of rays equal to 25 when their interval is 10° and 49 when their interval is 5°; n – number of approximated coastline segments.

This marks off the direct work with the tool. According to the above sources, further steps involve geometric summation of longshore components calculated for all active sectors. Based on the summation results, vectors that characterize the direction and relative intensity of longshore sediment flows at each segment within the boundaries of the coastal section under study, are constructed. Similar results have been repeatedly published in the public domain and are not considered in this paper.

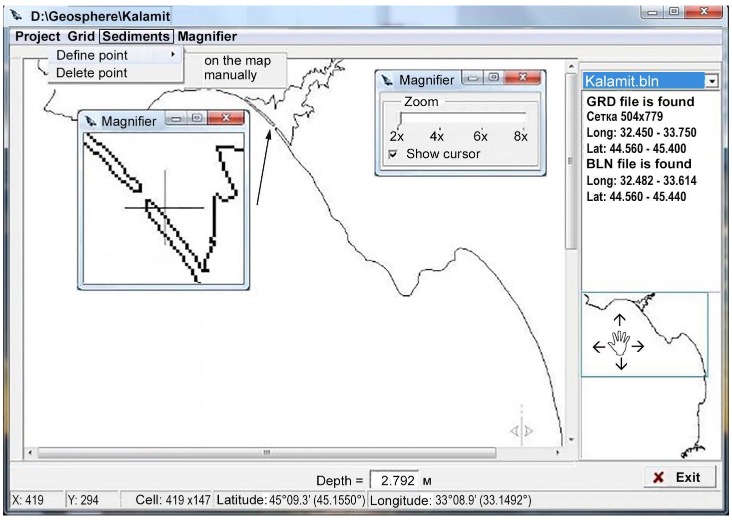
Main results

In order to automate the entire complex of time-consuming work on preparing input data for the WEM, the authors created a specialized software tool based on the use of GIS technologies. The main task of the tool is to calculate the lengths of the wind acceleration rays above the sea surface and the average depths along the bottom profile for each segment of the coastline approximation.

In this case, depth arrays of varying granularity and coastline detail covering the study area are used as initial data. Taking into account the characteristics of the source data, the information structures presented by *Golden Software*, an American company, in the form of contour files (BLN) and regular spatial grid arrays (GRD) were chosen as the main formats. In fact, the GRD is a digital elevation model (DEM) of the bottom surface. A description of the structure of these arrays is on the open Internet and free to download from it [9]. Herewith, all operations with the described tool consist of loading pre-prepared regional arrays and indicating the geographic coordinates of the middle of the coastline approximation segment.

In the version of the tool developed for the Windows operating system, the interface is traditionally made in a windowed version for visualizing the cartographic basis of the data with the placement of management tools in the form of a menu and information board (Fig. 1).

Two stages are necessary to work with the tool. At the first stage, the contour of the coastline is loaded with the automatic loading of the DEM of the same name. The loading process is accompanied by a zoomable coastline visualization, while the depth map is initially hidden so as not to clutter the ray display later. The lower information line displays the characteristics of the grid cell corresponding to the current cursor position on the map, which makes it possible to control such values as latitude, longitude and depth. Additionally, the corresponding menu displays the full version of the depth array in the form of an independent table with the ability to edit it interactively.

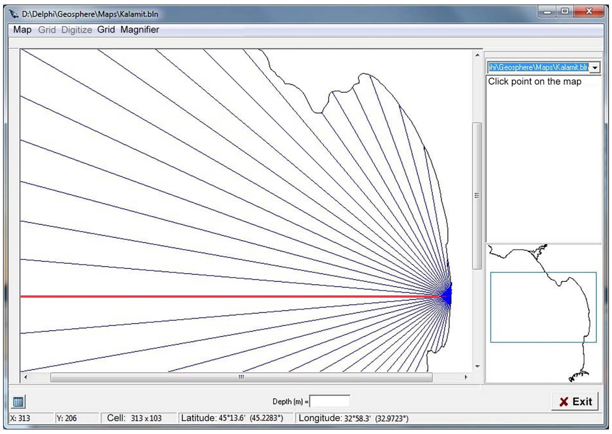


F i g. 1. The user interface of the software tool

[9] Available at: www.goldensoftware.com [Accessed: 30 November 2023].

At the second stage, a design point, which is located near the coastline and represents the middle of the modeled section of the coast, is assumed to be indicated. This information can be entered either digitally in a pop-up window when called by the menu, or indicating its position directly on the map. In this case, for more accurate positioning, it is possible to use the tool to enlarge the area of the map in which the cursor is located (inset in Fig. 1). The implementation of this feature makes it possible to correct the position of a given point promptly in cases where it falls on the coastline or an adjacent strip of land.

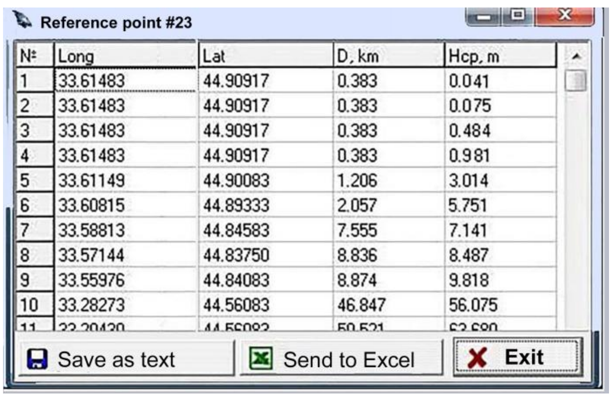
Further operation of the tool is based on an algorithm presented on the example of a coastline approximation segments corresponding to the maximum eastern point of the Gulf of Kalamita, the Crimean Peninsula. The results obtained after calculations are subsequently saved for each point automatically based on its coordinates and DEM resolution.



F i g. 2. Visualization of the construction of acceleration beams for one of the shoreline approximation segments in the Gulf of Kalamita

After confirming the correct input data, the program constructs a series of rays automatically, starting from the central one, specified by the value of the normal angle and highlighted in red during the visualization process (Fig. 2).

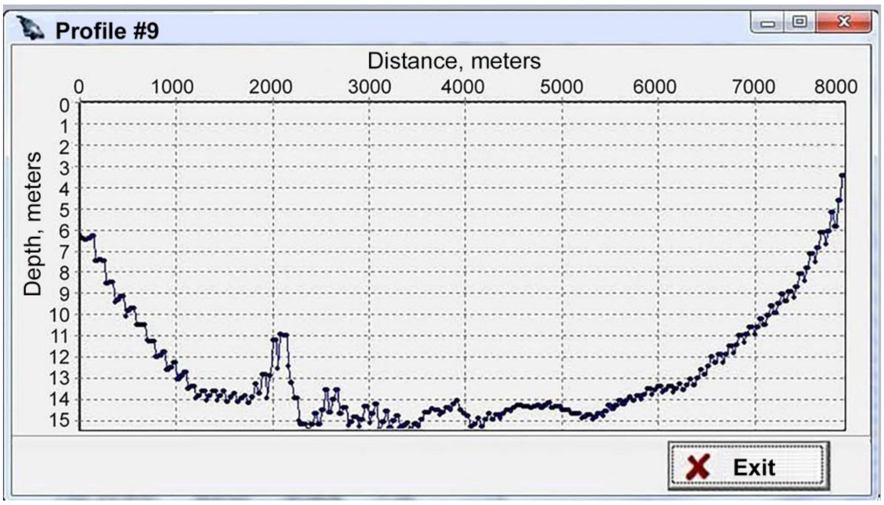
Together with the construction of rays along the drawn transversal lines, depth profiles corresponding to the loaded DEM grid are determined, from which, in turn, average values are calculated and displayed in the resulting table simultaneously with the coordinates of the end points of the acceleration rays (Fig. 3).


Reference point #23

№	Long	Lat	D, km	Hcp, m
1	33.61483	44.90917	0.383	0.041
2	33.61483	44.90917	0.383	0.075
3	33.61483	44.90917	0.383	0.484
4	33.61483	44.90917	0.383	0.981
5	33.61149	44.90083	1.206	3.014
6	33.60815	44.89333	2.057	5.751
7	33.58813	44.84583	7.555	7.141
8	33.57144	44.83750	8.836	8.487
9	33.55976	44.84083	8.874	9.818
10	33.28273	44.56083	46.847	56.075
11	[illegible]	[illegible]	[illegible]	[illegible]

Save as text | Send to Excel | Exit

F i g. 3. The resulting table of the bottom profile along one of the acceleration beams in the Gulf of Kalamita



F i g. 4. Example of a graphical representation of the bottom profile along one of the acceleration beams in the Gulf of Kalamita

In addition, the ability to graphically represent the bottom profile in the metric system has been implemented for the purpose of visual control of the bottom profile for each segment (Fig. 4).

This makes it possible to evaluate the blocking effect of critical bottom rises on the transfer of wave energy directly into the sediment movement zone under rugged relief. To calculate distances in this representation, the Haversine method [12] is used, which showed good results in the authors' previous papers.

Conclusions

A software tool for preparing data for a modified WEM calculation algorithm was used to study the structure and parameters of longshore migrations and integral sediment movement in extended sections of the coastal zone of Western Crimea. The results obtained made it possible to clarify the scheme of sediment flows and highlight the features of alongshore redistribution of sediments in different seasons of the year at the present stage of development of the lithodynamic system of this region.

With the use of the WEM, the developed software geoinformation tool makes it possible to prepare a set of data for calculating the direction and relative intensity of longshore sediment flows promptly in an automated mode. In addition, eliminating time-consuming work with cartographic material makes it possible to approximate the coastline in more detail by increasing the number of segments and improve the accuracy of processing data on wind speed in directions significantly as a result of reducing the width of a single sector.

A modified WEM-based version of the calculation scheme makes it possible to obtain estimates of the structure and relative intensity of longshore sediment transport in a wide range of time intervals. In this case, such intervals should be covered by the overall study period determined by the length of the data used concerning wind direction and speed. This makes it possible to study the contribution to sediment dynamics of individual periods of intense wind impact, including at the level of individual storm events, in more detail.

Thus, the implemented procedure for automated preparation of input data for the WEM can be used in calculating wind wave parameters based on the regime characteristics of the wind, when it is necessary to apply such initial values as wave acceleration lengths along open points and changes in depths along acceleration rays.

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Vyacheslav V. Dolotov – the algorithm and software tool development, preparation of the article text and illustrations

Vladimir F. Udovik – problem statement, data processing and analysis, preparation of the article text

All the authors have read and approved the final manuscript.