Artículo de investigación

Situational modelling of oil pollution risks monitored by distributed monitoring

Ситуационное моделирование рисков загрязнения нефтью, контролируемых распределенным мониторингом

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Abstract

The work is studying the distributed system of natural environment monitoring points. The purpose of the study is to solve two main problems of optimization: a) optimization of risks of emergency events; b) optimal cessation of environmental monitoring, which allows to reduce the costs of observation.
Monitoring of the environment contaminated with petroleum products is relevant. Traditionally used methods and monitoring itself are expensive and technological complex mechanisms, often requiring satellite data.
When studying environmental pollution, it is important to consider situational risks and stochastic irreversible changes in nature. For this purpose, it is necessary to apply the methods and methodology of the system approach, which are used in the article for analysis of complex data structures and entropy of the system. For the informativeness of less long monitoring, it's represented by four main subsystems (capture, operation, selection and decision-making) and evaluated using an information-entropy

Аннотация

В работе изучается распределенная система пунктов мониторинга природной среды. Цель исследования – решить две основные проблемы оптимизации: а) оптимизация рисков аварийных событий; б) оптимальное прекращение экологического мониторинга, что позволяет снизить затраты на наблюдение за средой.
Актуален мониторинг окружающей среды, загрязненной нефтепродуктами. Традиционно используемые методы, как и сам мониторинг – дорогостоящие и технологические сложные механизмы, зачастую требующие спутниковых данных.
При изучении загрязнения окружающей среды важно учитывать ситуационные риски и стохастические необратимые изменения в природе. Для этого необходимо применять методы и методику системного подхода, которые используются в статье для анализа сложных структур данных и энтропии системы. Для информативности менее длительного мониторинга он представлен

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approach. The work will solve the practical task of monitoring the contaminated environment.

Keywords: simulation, risks, pollution, petroleum products, monitoring.

четырьмя основными подсистемами (захват, эксплуатация, отбор и принятие решений) и оценивается с использованием информационно-энтропийного подхода. Работа позволит решить практическую задачу мониторинга загрязненной среды.

Ключевые слова: моделирование, риски, загрязнение, нефтепродукты, мониторинг.

Introduction

The content of petroleum products at different types of oil pollution is always different. Oil pollution - multivariate, different classes of hydrocarbons in oil products have different degree of resistance (0-100%) to biodegradation. There's no universal method of oil pollution control, which allows estimating absolute reduction of pollution during cleaning works. Therefore, the development of mathematical and computer models of ecosystem pollution, its prediction is a pressing task of ecology.

The systemic approach is the need to study emissions and monitor pollution with petroleum products, risks in the environment (Ivanov, 2019). The territorial emergency monitoring system is taken into account (Nicheporchuk, 2018).

It's important to explore the emergence of the system, its complexity and self-organization (Glukhova, 2018), as well as to use modern analytical approaches, tools of geographic information and monitoring systems (Kolesenkov, 2016). Especially given the high costs of monitoring pollution using satellite data, UAVs, precision laser sensors and spectral data analysis tools.

A system approach is needed, allowing to consider complexes of local (locally optimal) tasks and to form a system of observations and their optimal termination. This should be taken into account when deciding whether there are risk situations, such as those resulting in geological or biospheric changes.

The task is essentially as follows: it's necessary to optimize the risks of oil pollution, monitoring expensive measures, ensuring prompt, full adoption of a situational solution. In the environmental environment, it's necessary to have a distributed system of pollution monitoring points for relevance. The system should also be minimized by observation time, integrated by observation results.

The solution of this problem is always difficult, considering the technical and technological limitations of mass environmental sensors, its algorithmical and structural complexity.

Theoretical basis

Oil pollution is a consequence of uncertainty, unpredictability and systemic (not necessarily deterministic) accumulation of negative effects in the environment. Therefore, relevant environment monitoring is so necessary, with distributed observation points, the use of aerospace images (Fetisov, 2018).

Modern pollution monitoring tools and techniques allow taking into account multicriteria interaction of risk situations in the environment, for example, situations leading to oil spills, waterlogging, flooding (landslides), etc. It's important to take into account all the main aspects of oil pollution (Dvadnenko, 2017) and modern methods, for example, cleaning of soil from fuel in severe natural and climatic conditions (Shtripling, 2016).

In ecology, pollution monitoring is an opportunity to compare situations close in characteristics, monitor change dynamics, effectively manage and make decisions. It's relevant to carry out monitoring studies when assessing the quality of solutions.

Monitoring procedures are carried out promptly, with objective diagnostics of quality and control. Their optimal combination makes it possible to improve the quality of diagnostics of the state of the environment. Monitoring results are used to account for and adjust environmental strategies, improve management, and inform.

The system analysis also includes an analysis of the distribution of observation points, corresponding time and space series, situational modelling and classification (taxonomy) of risks that are the main causes of oil pollution.

Methodology

Let M - "power" of a monitoring system, N - the quantity of the processed factors (elements) of pollution from space which's accidental distributed, with distribution functions $\xi_i(t)$. If $M < N$, an algorithm based only on "suspicious" (in terms of pollution) values of factors in the data stream is needed. At the same time, the flow can be "noisy" for example, both "white noise" and "pink noise" can be present in the system.

Let a be the signal-to-noise ratio and X be the threshold of the monitored "suspicious" elements in the monitoring system at $\xi > X$. Then $\xi_i(t)$ we will determine function by density of probabilities of $f_a(x)$.

If $a = a_0$, the noise and signal fixation probabilities are, respectively,

$$P_N = \int_X^\infty f_{a_0}(x)dx \, , \qquad (1)$$

$$P_c = \int_X^\infty f_{a_1}(x)dx \, . \qquad (2)$$

The monitoring system can be conditionally presented by the subsystems:

1) Regular analysis, viewing and generation of suspicious elements, events, situations;
2) Statistical, DataMining-based, BigData (Big Data in Computational Social Sciences & Humanities, 2018), the search for patterns ("traces", "profiles") in the environmental environment;
3) Search and classification, taxonomy of suspicious accumulation of risk elements;
4) Decision-making on the basis of independent modules, units, including termination of monitoring.

Due to dynamic changes in the environment, it's necessary to quickly (faster than the changes themselves) maintain procedures 1 to 4 and process data.

Let the situation formally described by the structure be considered $X =< s_1, s_2, \dots, s_n, S, Y >$, $0 \le s \le 1$, *i=1,2, …,n,* $s_i \in Y$, where s_i – response of the monitoring point number i (it can be expert opinion, heuristic), X - data on the risk situation in the monitoring system, Y – many different types of meters (monitoring tools base).

The function (operator) of evaluating the current state of the environment is defined as:

$$E(Y) = max\,\{\, e_i\} \qquad (3),$$

where e_i is the risk assessment functionality in the X_i, $X_i \subseteq$ X group.

Functional e_i have properties: $e_i \in [0;1]$ and unambiguous dependence of e_i and X_i. We will build an iterative procedure to optimize pollution risks.

Results

The proposed risk assessment procedure is defined in the following steps:

1) divide the range of monitoring measurements into gaps $[t_i; t_{i+1}], i = 0,1, \dots, n-1$;

2) define range

$$\Delta\, t_{k+1} = \min\,(t_{max}, t_k - k\big(E(X_{k+1}) - E(X_k)\big) \qquad (4),$$

where Δt_{max} is the limit expected horizon, Δt_k is an interval between consecutive monitoring measurements, k - coefficient risk influence;

3) iterations to optimize risks according to the scheme $X^{\Delta k} \rightarrow E(X)$, with the actual delay ("lag") in the arrival of monitoring data.

Having reduced Δt_k it's possible to improve control of pollution and to optimize risks. At the same time, the likely increase in data volume, computational and monitoring costs can be leveled by paralleling the process of finding e_i.

The system's efficiency measures dictate monitoring tasks and the environment, such as tracking the "traces", "profiles" of the process under study, as well as the problem of stopping observations.

Consider the solution to this problem. Let $i_0 -$ the initial state from K of the monitoring studies with the transition probability matrix P, and $f(i), c(i) -$ the charge for returning to the i_0 state after t time and the cost for moving to the next $i_0 + 1$ state. Then, in order to find the states in which to return to the i_0 in order to minimize the average cost over a single period of time, it's necessary to solve the problem of linear programming (Breiman, 1968):

$$\min_{x_{i,q}} \left(-\sum_{i=1}^{k} \alpha_i x_i + \beta q \right), \qquad (5)$$

$$x_{i0} \leq q + \sum_{j=1}^{k} P_{i_0 j} x_j, \qquad (6)$$

$$x_i \leq \sum_{j=1}^{k} P_{ij} x_j, \qquad (7)$$

$$i = 1, 2, \dots, k, \qquad i \neq i_0,$$

$$tq + \sum_{i=1}^{k} x_i = 1, \qquad (8)$$

$$x_i \geq 0, \qquad q \geq 0$$

$$q = f(i_0), \; \alpha_i = -c(i) - \sum_{j=1}^{k} P_{ij} f(j) + f(i). \qquad (9)$$

The optimal recovery set then contains all states with $x_i = 0$.

Discussion

The effectiveness (significance) of the monitoring system is determined by the probability of information loss, for example, by the Shannon-Weaver type index (Crawford, 2018):

$$H = -\sum_{i=1}^{n} \frac{p_i}{S} log_2 \left(\frac{p_i}{S} \right), \qquad (10)$$

where p_i - contamination of i niche of medium with capacity *S*.

Pearson's statistics can be suggested:

$$\chi^2 = \sum_{i=1}^{n} \frac{(f_i - p_i n)^2}{p_i n}, \qquad (11)$$

where n is the sampling power, p_i is the predicted probability of the *i*-th state, f_i is the observed frequency of this state (based on monitoring data).

The Weibull distribution can also be used:

$$V(t) = 1 - exp \left(-\frac{\lambda t^{\alpha+1}}{\alpha + 1} \right), \qquad (12)$$

where λ is the scale, α is the asymmetry of the data flow.

If the cleaning dynamics of the medium is given by the function *F(t),* the mathematical expectation of the cleaning time will be:

$$T = \int_0^\infty F(t) dt. \qquad (13)$$

The problem of ecological purity of oil production and refining infrastructure, industry enterprises is topical. Insufficient attention threatens the costs of eliminating damage and pollution.

Exploration and development of oil reserves is connected with uncertainties, fuzzy, accidents, risks, excessive management confidence. Geographic information uncertainty, availability of alternatives for exploration, extraction, stock quality, deviations from exploration parameters and monitoring data complicate the monitoring system.

As well as the complexity of the deposit structure - large depths, distance of raw materials and processing centers, the need to apply innovative geological exploration technologies, etc. Due to uncertainty, "noises" of processes, structures in a complex environmental environment, both pollution risks and risks of distortion of monitoring data are possible.

Conclusions

Good planning, conduct and evaluation of monitoring studies should be based on forecasting the state of the environment through flexible procedures and models. Complex models can rarely be implemented in adaptive monitoring, identifying the time of its relevant completion. The risk assessment model and procedure considered is suitable for a large oil-producing country such as Russia.

A comprehensive solution to the problem of informative environmental monitoring for the distributed system, proposed in the work, is based on a system-situational approach. The use of a distributed system of monitoring points (centers) will allow optimizing monitoring research on time, costs, informative observation periods.

Efficiency, effectiveness of monitoring implies comparability of expenditures with the final result, its value. To solve the problems of situational modeling, the relevant tools are multidimensional scaling, classification, visualization, cognitive maps (Kohonen's maps), expert systems, etc.

The models used, algorithms of their identification are practically applicable, feasible. They are based on situational simulation scenarios, for example, according to the above steps of the iteration procedure. They reduce costs, increase the flexibility and reliability of the researcher's tools.

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