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OPTIMIZATION OF QUANTITATIVE INDICATORS OF COMPLEX SEISMO-HYDROGEOCHEMICAL MONITORING WITH THE PURPOSE OF FORECASTING STRONG EARTHQUAKES

Abstract. The quantitative indicators of seismic hydrogeochemical monitoring (SHCM) conducted on the geodynamic forecasting sites of Asia are considered. It is noted that continuous multi-parameter observation is implemented on the basis of simultaneous measurement from several to tens of parameters of groundwater. The most common complex includes about 10-15 parameters (F, CI, HCO_3, CO_3, SO_4, H_4Si0_4, Rn, He, H_2, CO_2, Ph, Eh, Q_{hole}, H_{level}, T_{water}.) monitoring over many decades it has been established that the informativeness of the obtained forecast data does not depend on the number of measured parameters, but is determined by the cumulative effect of sensitive components for a given water product observed. Therefore, the optimization of the list of observable parameters for the entire landfill as a whole should be differentiated taking into account the features of each water point. This allows you to dramatically reduce the number of parameters of observation and get rid of the "ballast" indicators.

Key words: seismic hydrogeochemistry, monitoring, earthquakes, forecast, hydrogeochemical anomalies, informative.

After Tashkent (1966), Dagestan (1970) and especially, the Haichen catastrophic earthquake (1975), predicted by Chinese seismology, intensive multidisciplinary seismic prognostic studies began all over the world. Along with seismological and geophysical methods, large-scale geochemical and hydrogeological observations were deployed in order to search for precursors and forecast strong earthquakes [1,3,4,5,8,9]. It is necessary to emphasize that earthquakes of various energies constantly occur on the Earth as a continuous chain of events; meanwhile, the forecast can be made only for those rare events that are of a destructive nature. The need to forecast such earthquakes for different areas is determined differently, based on the level of their seismic activity [2,3].

Ideology of geochemical and hydrogeological monitoring. The forecast paradigm was based on the well-known models of earthquake preparation and on this basic avalanche-unstable crack formation (AUC) and diffusion-dilatant development of the source (DD). It was assumed that in the focal zone of the earthquake there occurs a jump-increasing accumulation of elastic energy, which after a critical state passes to a mechanical discontinuity of the continuity of the medium with the generation of seismic waves, i.e. to an earthquake. It is assumed that in this process a wide class of precursors of various amplitudes should arise in deformation, geophysical, geochemical, and hydrogeological fields. The occurrence of hydrogeochemical anomalies was associated with the arrival of new fluids from the focal zone or the displacement of different chemical composition in the preparation zone of the earthquake [1,2,4-11]. The forecast paradigm consisted in solving the inverse problem: by the signs - the precursors and by the time of their development in the controlled area to establish the probable time and place of occurrence of the expected event, and by the intensity of anomalies - their probable energy. This scientific concept has determined the main way to achieve the goal - the creation of continuous mode multidisciplinary observations at special test sites on the principle: the wider the area and the larger the set of observation parameters, the more reliable the detection of precursors. With sufficiently strong financial support from the states, especially the USSR, China, Japan, Italy, Greece, etc., in the 1980s – 1990s, large-scale monitoring observations were conducted to predict earthquakes on so-called geodynamic or prognostic sites. For example, in the USSR such landfills unfolded in all seismic areas of the Caucasus, Central Asia, Kazakhstan, Baikal and the Kuril-Kamchatka region, where they began to observe more than a hundred wells and water points. The most powerful development of hydrogeochemical (HGC) and hydrogeodynamic (HGD) observations unfolded in the People's Republic of China on the basis of more than 1,000 wells and special wells with the extensive development of a network of "people's-observers-enthusiasts." At various landfills, the list of observed parameters with discreteness from continuous hourly to daily was different, but the overall large set of indicators, in general, in the world amounted to more than 40 items [1,13-15] (table 1-9). It should be noted that the largest developed program of field observations with a large set of measured parameters was organized in Kazakhstan [1,3,4,5,8,9] (tables 1 and 2). All observation grounds in the USSR were constructed according to special guidelines [12].

The main results of field observations and experimental studies.

For each water point, first of all, long-term background values of the parameters were obtained and their anomalous fluctuations were recorded on the eve of many strong earthquakes. They were noted at various distances from the epicenters (tens and hundreds of kilometers). Such anomalies consisted of intermittent alternating temporal changes of various parameters having various forms, which can be reduced to the following four morphogenetic groups: coves, semi-bottoms, “jumps-pulsations” and spontaneous bursts. In amplitude of changes, they usually exceed the background values of the parameters by 20-50% to 100%, and sometimes they have significant one-time variations. The most important features of these anomalies are: 1) the instability of their development over time and in the area (flicker); 2) their rapid return to the initial background value after earthquake relaxation; 3) “long-range”, manifested in tens and hundreds of km from the earthquake source, it turned out that many anomalies are not associated with specific earthquakes and were caused by the impact on the relevant parameters of external atmospheric and cosmophysical factors and man-made interference [1]. Anomalies caused by the nature of periodic rhythmic phenomena. These factors created a lot of noise and false alarms, comparable in magnitude and time with the anomalies that occur during the preparation of earthquakes.

Very often, HGC and HGD anomalies occurred in the non-focal zone of earthquakes at significant distances, reflecting the stress-strain state (SSS) in the surface part of the earth's crust, where water observation points are located. The observed anomalies were a consequence of the development of deformation processes. Thus, we can conclude that the fluid anomalies of the expected earthquake are the result of an imbalance in the local equilibrium hydrogeochemical water-rock-gas systems with the generation of dissipative temporal anomalies as a response of these systems to external forces in full compliance with Le Chatelier's law [1]. From this it becomes obvious that strong earthquakes are being prepared on a fairly large area as a result of the restructuring of the geoblocks' SSS and their repacking [1,2,4,6,9-11]. Detailed studies of the time course, parameters of geochemical, hydrogeochemical and hydrogeodynamic fields on the eve of earthquakes showed that anomalies are not only statistically significant changes in the course of parameters of different nature and changes in the frequency-spectral characteristics of the series itself in those time intervals that reflect the non-linear development of the instability process itself with the formation of a violation in the correlation of regular components of time series such as, for example, with R_{atm}, T_{water}, TF (tidal forces). It is established that the high-frequency component of the geochemical, hydrogeochemical and hydrogeodynamic fields carries the greatest information in terms of recognizing geodynamic instability.

At the beginning of seismic hydrogeochemical studies (70-90s of the 20th century) in large research laboratories of GEOKHI, IGEM and IPD of the Academy of Sciences of the USSR; SIMS and VSEGINGEO MG of the USSR, as well as the Institute of Seismology, Academy of Sciences of Uzb. SSR, IS AN Kaz. SSR, Institute of Physics, Academy of Sciences Kirg. USSR and others, where mass spectrometers and other devices were installed, and it was revealed that on the eve of the realization of strong earthquakes, significant precursor changes in the isotopic ratios of many elements take place: hydrogen, oxygen, carbon, uranium, helium, argon (^{3}He / ^{4}He, ^{13}C / ^{12}C, ^{36}Ar / ^{40}Ar, ^{234}U / ^{238}). However, due to the high complexity and laboriousness of these analyzes, their high costs and the impossibility of performing analyzes in a continuous mode, such parameters have not been developed in the number of indicative monitoring indicators of earthquakes.

Table 1 – The list of measured parameters of the complex hydrogeochemical monitoring
and the equipment used at the Almaty prognostic site for the purpose of predicting strong earthquakes (Kazakhstan)

Main indicators	№	Options	Method of Definition		
			Manual measurements	Automatic measurements	
Dynamic performance	1	H_{level}	Visual (by line), by level gauge	Ultrasound method	All automatic sensors instituted on AWP Readings are automatically taken each hour
	2	Q	Volumetric (using a measuring tank and a stopwatch)	volumetric	
	3	P_{hole}	Manometer	Manometer	
Physical and chemical indicators	4	Ph	Potentiometric method (ionomers)	Potentiometric method	
	5	Eh			
	6	P	Water conductivity	Portable tester	
	7	T_{water}	visual	Thermometer	
	8	Rn	Emanational	Emanational device, method ("Radon")	
	9	Gf	Volumetric method		
The main ion-salt composition of thermal waters	10	Ca^{2+}	Volumetric visual method (titrimetric)		
	11	Mg^{2+}			
	12	C1			
	13	H_4Si0_4	Colorimetric method ("KFK-2", "KFK-3")		
	14	$S0_4^{2-}$			
	15	F			
	16	K^+	Flame Photometric Method ("PFP -7")		
	17	Na^+			
	18	$HC0_3$-	Volumetric titromereous method ("BAT" -block aut. Titration)		
	19	$C0_3^2$-			
	20	OH"			
Gas composition	21	He_{cn}	Chromatographic Spontaneous gas method (chromatograph “COLOR - 800”)		
	22	He_p			
	23	H_2			
	24	CH_4			
	25	CO_2			
	26	O_2			
	27	N_2			
Geophysical indicator of external fields	28	(ЕНП)	Natural neutron flux (NNF). (detector of slow neutrons "PKC-01H-COJIO")		
Related Parameters	29	$P_{атм}$ ^{1}атм	Automatic recording of air temperature and atmospheric pressure ("Barometers and thermometers")		
	30	$T_{воз}$			

Table 2 – The abbreviated list of hydrogeochemical parameters adopted
for seismic forecast observations in the MG system of the Kazakh SSR in 1985-1988 (Kazakhstan)

Defined parameters	Rn, F, CI, Li, Sz, He, H_2, CH_4	Quantity
		8

Table 3 – Bishkek polygon (Kyrgyzstan)

Dynamic and physical parameters	Gases	Chemical composition of groundwater	Quantity
Ph, Eh. $Q_{СКВ}$. H_{vn}. $T_{воаы}$	$C0_2$, Gf	F, C1, HCO_3^-, $S0_4^{2-}$, Ca, Mg^{2+}	13

Table 4 – Tashkent polygon (Uzbekistan)

Dynamic and physical parameters	Gases	Chemical composition of groundwater	Quantity
Ph, Eh, $Q_{СКВ}$, $H_{УР}$,$T_{воды}$	$C0_2$, H_2,CH, Rn, He, A1	Br, B, F, $HC0_3$, $S0_4$, Cl, Si	20

Table 5 – Dushanbe polygon (Tajikistan)

Dynamic and physical parameters	Gases	Chemical composition of groundwater	Quantity
Ph, $Q_{скв}$, $H_{ур}$, $T_{воды}$	H_2S, He, Rn, $C0_2$	$HC0_3\backslash C0_3^{-2}$,Cr	11

Table 6 – Urumqi polygon (XUAR of China)

Dynamic and physical parameters	Gases	Chemical composition	Quantity
Ph, Eh, $Q_{СКВ}$, $H_{УР}$,$T_{воды}$	Rn, $C0_2$, He, H_2S	C1, $HC0_3^-$, F^-, SO_4^{-2}, Mg^{2+}	15

Table 7 – Dagestan seismic polygon (Caucasus)

Dynamic and physical parameters	Gases	Chemical composition of groundwater	Quantity
$Q_{СКВ}$, Ph, M	Rn, $C0_2CH_4$, H_2,T°C, H_2S	$HC0_3$, CI^-, $S0_4^{2-}$Ca, Na, Mg	15

Table 8 – Kurile-Kamchatka polygon (Russia)

Dynamic parameters	Gases	Chemical composition of groundwater	Quantity
$Q_{СКВ}$, $H_{УР}$	C_3H_6, C_2H_4	HCO_3^- ,CГ, $S0_4^{2+}$, Na^- , Ca^{2+}	9

Table 9 – Japan Geochemical Monitoring Program

Dynamic parameters	Gases	Isotopes	Chemical composition of groundwater	Quantity
Gases and $H_{ур}$,$T_{воды}$	Rn, $C0_2$, He	$^3He/^4He$	CI, $S0_4$, K, Na, Ca, Mg, Si, B, Mo, Sr	16

Optimization of the required list of measured parameters of hydrogeochemical monitoring.

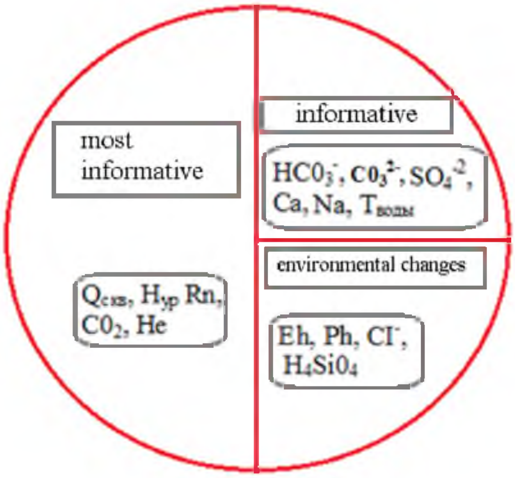
A large list of parameters on landfills has always created a lot of technical problems, as well as difficulty in the operational processing of many time series. Conducting full chemical analyses of groundwater online is difficult. Meanwhile, the experience of long-range field observations [9] makes it possible to move from initially multicomponent observations to rationally reduced, which allows significant savings in financial resources, facilitates chemical analyzes, makes fuller use of automated observation systems. The procedure of optimization of the list of measured parameters implies, first of all, to comply with the condition: "not to lose information". It is necessary to observe such parameters that meet the following requirements:

1) the highest frequency of abnormal changes before earthquakes;

2) simple and real-time measurability of parameters in automatic mode with a data sampling frequency of at least 1 hour;

3) availability of a reliable instrumental base of measured parameters;

4) sensitive parameter response to deformation processes in locally equilibrium hydrogeochemical systems.



Fundamental classification of informativity of seismic and hydrogeochemical field indicators

It has been established that there is no single stable for all precursor parameter or set of hydrogeochemical parameters for all regions and polygons and even observation points, which indicates the absence of universal precursors of earthquakes. Analysis of data for all forecasting polygons of the world shows that anomalous variations of certain parameters are not permanent indicators of earthquake preparation. Indicator in some cases, the components in other cases were not. Some earthquakes were generally not preceded by any anomalies, but occurred suddenly. However, in general, a certain range of parameters is established, which manifests itself most often when monitoring earthquakes. These include: the level of groundwater (flow rate of self-discharging wells (H_{level}, Q), as well as T_{water}, Rn, CO_2, He, Hg, and in the composition of groundwater CI, SO_4^{2-}, $HCO_3^-Na^+$, Ca^{2+} and thermodynamic indicators states of water - Eh (redox potential), as well as the cumulative parameter - E, Pn ionic strength (Is), groundwater (solution). The degree of relative and informativeness is presented in the figure.

Comparative data analysis of the entire list of parameters over a long observation period allows you to go from studying the seismic prognostic information content of a wide range of components to a rationally reduced list of parameters (table 10), up to 13 items (no chemistry to 7). Together, by calculating the integral indices, they give, possibly, maximum information about the real seismic situation at the landfill. In case of lack of opportunities for express chemical analyzes of water, it is possible to conduct monitoring on the basis of the necessary abbreviated list of 5 items, which can be carried out completely on an automated basis (table 11).

Table 10 – List of parameters of the complex seismic and hydrogeochemical monitoring of groundwater for predicting strong earthquakes, recommended by the results of long-term observations at the forecasting sites of Kazakhstan, Kyrgyzstan, Uzbekistan and XUAR of China

Main indicators	List of indicative parameters	Quantity
Physical parameters	Ph, T_{water}	2
Dynamic parameters	Q_{hole}, H_{level}	2
Gas components	Rn_{water},Rn_{soil} , $C0_2$, He,H_2	4
Chemical composition	[Na^+ , Ca^{2+}], C1, $HC0^-$, SO_4^{-2}	5
	Total	13

Table 11 – Necessary abbreviated list of parameters of seismic and hydrogeochemical monitoring for prediction of seismic hazard in local areas of automated observation

1	Groundwater dynamics	Q_{hole} or H_{level}	Quantity
2	Variations of radon in the surface atmosphere	Rn_{soil}	1
3	Through gas flows	CO_2, H_2	2

Such methods allow you to continuously calculate very important and sensitive integral indicators of groundwater, such as the ionic strength of the solution (Is) and the time course of anion-cation ratios (P_{acr}= A/K), as well as determine the radon emanation (Rn) in water and in the surface atmosphere (soil) and their ratios. Such optimization of the list of integrated HGC monitoring fundamentally improves the quality of measurements, helps to simplify monitoring technology, significantly save material resources and speed up data processing, and also allows concentrating on the operational collection of a limited range of data and improving the short-term forecast method of strong earthquakes.

Such methods make it possible to calculate important and sensitive integral indicators of groundwater, such as the ionic strength of the solution (Is) and the anion-cation ratio (P_{acr} = A / K), as well as determine the radon emanation (Rn) both in water and in the surface atmosphere (soil). Such optimization of the list of integrated HGC monitoring fundamentally improves and facilitates the monitoring technology, allowing you to significantly save material resources and speed up data processing, which leads to an improvement in the short-term forecast method of strong earthquakes. At the final stage, on the basis of such monitoring data, a seismohydro-information analytical system should be created for earthquake prediction [13].

Conclusion. A large list of measured parameters does not increase the information content of the landfill; moreover, it distracts for the prompt processing of a huge array of related and secondary data. In this regard, it is necessary to optimize the list of observed parameters for each water point and determine their degree of information in the general list. The key to success in this option lies in the efficiency and continuity of a limited range of parameters for a short-term forecast. In all cases, it is necessary to measure the indicators of external factors (R_{atm}, T_{air}, etc.) that affect the course of indicative parameters.

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КОМПЛЕКСТІК СЕЙСМОГИДРОГЕОХИМИЯЛЫҚ МОНИТОРИНГТІҢ САНДЫҚ КӨРСЕТКІШТЕРІН КҮШТІ ЖЕР СІЛКІНІСТЕРІН БОЛЖАУ МАҚСАТЫНДА ОҢТАЙЛАНДЫРУ

Аннотация. Азияның геодинамикалық болжау учаскелерінде жүргізілген сейсмикалық гидрогеохимиялық мониторингтің (СГГХМ) сандық көрсеткіштері қарастырылған. Көптеген параметрлерді үздіксіз бақылап отыру жер асты суларының бірнеше ондаған параметрлеріне бір мезгілде өлшеу негізінде жүзеге асырылатынын атап өту керек. Ең көп тараған кешен 10-15 параметрді (F, CI, HCO_3, CO_3, SO_4, H_4Si0_4, Rn, He, H_2, CO_2, Ph, Eh, Q_{scv}, $H_{ур}$, $T_{воды}$) қамтиды. Көптеген ондаған жылдар бойы бақыланған ақпарат алынған ақпараттардың ақпараттылығы өлшенген параметрлер санына тәуелді емес, бірақ байқалатын су өнімдеріне сезімтал компоненттердің кумулятивтік әсерімен анықталғаны анықталды. Сондықтан тұтастай полигондар үшін бақыланатын параметрлер тізбесін оңтайландыру әрбір су нүктесінің ерекшеліктерін ескере отырып саралануы керек. Бұл байқау параметрлерінің санын айтарлықтай азайтуга және «балласт» индикаторларынан құтылуга мүмкіндік береді.

Бастапқыда геохимиялық (ГМ) және гидрогеологиялық мониторингтің (ГГМ) жер сілкінісіне дайындықтың танымал модельдеріне – көшкін-тұрақсыз жарықтардың пайда болуына (ЛНТ) немесе диффузиялық-дилатанттық фокустық дамуга (ДД) негізделген болатын. Зерттеушілер жер сілкінісі ошақты аймағында серпімді энергияның жинақталуының күрт артуын болжады, ол критикалық деңгейге жеткеннен кейін, сейсмикалық толқындардың пайда болуымен ортаның механикалық ажыратылуына көшеді жер сілкінісіне дейін. Бұл процесте әртүрлі салаларда – деформация, магниттік, геофизикалық, геохимиялық, гидрогеодинамикалық, геотермалдық және т.б. алдын-ала ауытқулардың кең тобы пайда болады деген сенім болды. Бұл жағдайда ГГХ және ГХ прекурсорларының пайда болуы фокустық аймақтардан сұйықтықтардың жаңа бөліктерінің келуімен немесе әртүрлі химиялық құрамдар мен газ эмменттерінің суларының араласуымен және күшті жер сілкіністерін дайындау аймағында жер қыртысының қызуымен тікелей байланысты болды. Шын мәнінде, болжамды парадигма кері есепті шешу үшін болды: болжамды жер сілкінісінің болжамды уақыты мен орнын және олардың бақыланатын аймақтағы даму уақытын және аномалиялардың қарқындылыгымен оның ықтималдыгын анықтау.

Мұндай тұжырымдама мақсатқа жетудің негізгі жолын анықтады – жер сілкінісіне дайындықты бақылау үшін арнайы полигондар құру: аймақ негұрлым кең болса және бақылау жиынтыгы негұрлым көп болса, жер сілкінісіне дайындық белгілерін дәлірек анықтайды.

Түйін сөздер: сейсмикалық гидрогеохимия, мониторинг, жер сілкінісі, болжау, гидрогеохимиялық ауытқулар, ақпараттылық.

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ОПТИМИЗАЦИЯ КОЛИЧЕСТВЕННЫХ ПОКАЗАТЕЛЕЙ КОМПЛЕКСНОГО СЕЙСМОГИДРОГЕОХИМИЧЕСКОГО МОНИТОРИНГА С ЦЕЛЬЮ ПРОГНОЗА СИЛЬНЫХ ЗЕМЛЕТРЯСЕНИЙ

Аннотация. Рассмотрены количественные показатели сейсмогидрогеохимического мониторинга (СГГХМ), проводимые на геодинамических прогностических полигонах Азии. Отмечается, что непрерывное многопараметрическое наблюдение реализуется на основе одновременного измерения от нескольких до десятков параметров подземных вод. Наиболее распространенный комплекс включает в себя около 10-15 параметров (F, CI, HCO_3, CO_3, SO_4, H_4SiO_4, Rn, He, H_2, CO_2, Ph, Eh, $Q_{скв}$, $H_{ур}$,$T_{воды}$.) В результате анализа эффективности количественных показателей ГГХ мониторинга за многие десятилетия установлено, что информативность полученных прогнозных данных не зависит от количества измеренных параметров, и определяется совокупным эффектом чувствительных компонентов для данного водопункта наблюдения. Поэтому оптимизация перечня наблюдаемых параметров для всего полигона в целом, должна быть дифференцирована с учетом особенности каждого водопункта. Это позволяет резко сократить количество параметров наблюдения и избавляться от «балластных» показателей.

Изначально идеология геохимического (ГХ) и гидрогеологического мониторинга (ГГМ) была основана на известных моделях подготовки землетрясений – лавинно-неустойчивого трещинообразования (ЛНТ) или диффузионно-дилатантного развития очага (ДД). Исследователи предполагали, что в очаговой области землетрясений происходит скачкообразное нарастающее накопление упругой энергии, которая после достижения критического уровня переходит к механическому разрыву среды с генерацией сейсмических волн, т.е. к землетрясению. Была уверенность в том, что в этом процессе возникает широкий класс предваряющих аномалий в различных полях – деформационном, магнитном, геофизическом, геохимическом, гидрогеодинамическом, геотермическом и т.д. при этом возникновение ГГХ и ГГ предвестников напрямую связывалось с поступлением новых порций флюидов из очаговых зон или смешением вод различного химического состава и газовых эманаций и прогревом земной коры в области подготовки сильных землетрясений. Собственно парадигма прогноза заключалась в решении обратной задачи: по предвестникам и временам их развития на контролируемой площади установить вероятное время и место реализации ожидаемого землетрясения, а по интенсивности проявления аномалий – его вероятную силу.

Такая концепция определила основной путь к достижению цели – создать специальные полигоны для отслеживания подготовки землетрясений по принципу: чем шире площади и больше набор наблюдения, тем надежнее обнаружение признаков подготовки землетрясений.

Ключевые слова: сейсмогидрогеохимия, мониторинг, землетрясения, прогноз, гидрогеохимические аномалии, информативность.

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