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PRINCIPLES OF CARTOGRAPHIC DIFFERENTIATION AND EPIDEMIOLOGIC ZONING OF NTURAL PLAGUE FOCI APPLIED TO ASSESS AND MINIMIZE POPULATION HEALTH RISKS

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In some South American, African, and Asian countries epidemiologic complications in natural plague foci occur due to people consuming meat of rodents, namely rats, bandicoot rats, guinea pigs, etc. People catch bubonic plague when splicing rodents' carcasses.

Our research objects were rules for cartographic differentiation and epidemiologic zoning of natural plague foci that are applied in epidemiologic surveillance performed by plague control authorities in the country.

Our research goal was to unify differentiation rules as it will help to more rationally organize epidemiologic surveillance in natural foci of dangerous infections on a large territory (a region, some regions, the country as a whole).

We suggest to apply a conventional topographic mapping and to take a list of a map scaled 1:25 000 ("a sector") as a minimum formalized unit for spatial analysis. We recommend to perform epidemiologic zoning as per potential epidemiologic hazards that are characteristic for specific sectors. To determine these hazards, we should take into account prevalence and number of potential infection sources in this or that sector. We should also assess a character or a possible course of epizootic processes in populations of infection carriers and (or) carriers of infectious agents, frequency of epizooties detection, density of population who live in this or that area permanently or stay there temporarily, as well as data on morbidity registered there over the last 25 years.

Morbidity, epizootic activity, and precise localization of contagion points are significant arguments for ranking such zones as the most epidemiologically hazardous. A risk of catching plague by people has become higher in natural plague foci on the RF territory due to, for example, an increase in quantity of marmots and gophers that are caught and consumed by local population. In 2014–2016 there were some single cases of people catching bubonic plague in Gorno-Altaysk highland focus; it substantiated assigning of contagion areas into the most epidemiologically hazardous category. The same situation is observed in plague foci in Tyva Republic and Kalmykia Republic.

Detailed epidemiologic zoning of natural plague foci based on cartographic differentiation is applied to perform well-grounded planning and carrying out examinations and prevention activities in each focus in order to minimize population health risks.

Key words: *natural plague foci, cartography, epidemiologic surveillance, hazardous infections, prevention activities.*

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In some South American, African, and Asian countries epidemiologic complications in natural plague foci occur due to people consuming meat of rodents, namely rats, bandicoot rats, guinea pigs, etc. People catch bubonic plague when they splice rodents' carcasses [1–3]. In Russia and neighboring countries most plague cases occurred due to a transmissible mechanism when an infectious agent was caught via a bite of an infected flea [4]. Nowadays commercial spices of marmots have recovered their numbers and populations of little and long-tailed gophers have also grown; local population are now hunting these animals more actively as their meat is consumed as a delicacy, cavitory fats are used as a medication, and their skins are curried. In 2013-2016 people, including children, caught bubonic plague in marmot foci in Kyrgyzstan and Russia; contagion occurred due to contact between damaged skin and carcasses of plague-carrying animals when they were spliced [5–8]. In this relation, it is becoming more vital to get better insight into contemporary situation with this infection and other ones that are being registered again [9]. Epidemiologic surveillance in plague foci is now performed with new techniques, including geoinformation systems (GIS) and technologies that allow to systematize great volumes of retrospective and live data on the dynamics of spatial and biocenotic structure of foci [10–12].

Epidemiologic surveillance over plague helps to achieve a primary goal, namely epidemiologic well-being of population. Epizootologic monitoring in natural foci of this extremely dangerous infection is one of its basic instruments; in Russia this monitoring is performed by anti-plague establishments on the basis of their differentiation as per a formal-territorial principle [13, 14]. Minimal structural differentiation units are standardized and systematized via conventional mapping of state topographic maps that is common for the whole country territory. A list of a topographic map scaled 1:25,000 which is called "sector" is taken as a minimal unit. The necessity to apply such formalized units can be explained by the following: plague foci can be located in different administrative and economic units (regions, districts, etc.) that are large in their square, variable in their configuration, and are built as per economic, national, and other social and political criteria without taking natural zoning into account. For example, the whole Gorno-Altaysk highland natural plague focus is located within just one administrative district, Kosh-Agachskiy. Such administrative differentiation (or identification) of foci territories is undoubtedly necessary, but it is not sufficient for more profound and targeted assessment of epidemiologic state existing on a specific area. But if vast administrative territories are divided into relatively small standard parts, it leads to a drastic increase in possibilities for detecting and mapping of dangerous zones and it becomes especially vital when such zones don't have any apparent natural boundaries. The same absence of detailing is also characteristic for biogeographical zoning based on maps of natural zones, landscape or geobotanical provinces. Additional argument for introducing such small formalized differentiation units is a necessity to arrange data that are accumulated during epizootologic research; such arrangement is especially vital when geographic information technologies are applied [13, 14].

Research techniques. We predominantly applied cartographic techniques in our work. Anti-plague establishments, just as any other anti-epidemic ones, apply two categories of maps in their functioning. A basic type is a general vector interactive map that comprises large territories and is used for mapping, generalization and demonstration of departmental data, their assessment and comprehensive analysis. Maps scaled 1:1,000,000 are accessible for free and they can be used as a basis for creation of subject skeleton maps with medical contents that are then applied in reports and reviews. But it is necessary to have topographic maps scaled 1:100,000 or 1:200,000 for overall planning and organization of inspections and prevention activities. Epizootologic monitoring that is performed directly in a natural focus as well as scientific research requires multi-list topographic maps scaled 1:25,000 (both vector and raster ones) that can be downloaded into mobile devices or a notebook.

Nowadays, a wide range of users have free access to open digital topographic maps with various scales, up to 1:25,000. There are electronic maps, both vector ones and their standardized raster copies (tiles) that can be printed on a large-format printer and it allows more convenient work with them in field conditions.

We should also pay some attention to a system of coding that is applied to formal-territorial units, or sectors, and was developed for registration of natural plague foci on the RF territory [13, 14, 15, 16]. According to it, each sector is assigned a digital code (cipher) which is formed from nomenclature of a relevant list of a topographic map scaled 1:25,000 and two-digit number of a natural plague focus. As each sector has its unique code, it provides additional opportunities for spatial identification of epidemiologic materials. Besides, as it was revealed by shaping of natural plague foci, in many cases sharp geodetic contours of sectors (lists of topographic maps) provide the only opportunity to determine an outer boundary of a focus if there are no linear elements in a landscape that can serve as such boundary in this particular area. But here we require reliable data on occurrence or absence of any enzootic signs as regards this particular infection on various sides from this formal boundary.

At present there is a most significant requirement to provide obligatory geo-coding of any information obtained via monitoring with global positioning systems GLONASS/GPS; that is, it is obligatory to state a longitude and latitude of any point where field data were collected, infection carriers numbers and numbers of infectious agent carriers were accounted, or any other work was performed on natural foci territory. When exact geographic coordinates are stated, it makes research data suitable for application in geographic information systems and provides an opportunity for their fast visualization and spatial analysis [14]. Besides, coordinates of any point at which data were collected automatically show which sector this point is located in as lists of topographic maps are framed with specific parallels and meridians.

Differentiation rules for enzootic territories are clearly regulated and it provides a significant advantage as this differentiation is greatly suitable for application for natural foci registration based on GIS principles. Rules for geographic differentiation of natural plague foci that are described in this paper can be applied by sanitary-epidemiologic institutions for mapping, systematization, and registration of natural foci of other dangerous and extremely dangerous infections. This proposition was our basic research goal.

Natural plague foci on the RF territory and in neighboring countries have a two-digit number (from 01 to 46) which comes from foci numbering accepted in the USSR; it is given in the right part of a cipher in round brackets [14, 15, 16]. To register natural foci of other infections, we can require greater number of digits that provides identification of foci as per an infection and their specific denomination that can have regional, landscape, or any other origin.

A cartographic model of the whole RF territory can be found on state topographic maps made in Gauss-Krueger cross-cylindrical projection; these maps have standard mapping based on an international million-scaled map. The biggest scale of maps that are in open access is equal to 1:25,000. Dimensions and locations (coordinates) of sectors are strictly regulated by normative and regulatory documents issued by the country cartographic and geodetic service and are not subject to any changes by other authorities.

It provides unification and standardization of differentiation units that are applied in anti-epidemic activities and prevents from any mistakes in determining exact points where field data were collected during epizootologic examinations. In order to synchronize differentiation units with cartographic analogues and to make documentation keeping more convenient, the order in which sectors are given their codes is to coincide with the rules fixed by the state cartographic, topographic and geodetic service for drawing up nomenclatures of topographic maps with variable scales. These rules are described in detail in manuals and reference literature on geodesy, topography, and cartography and cover both letter designations of lists and their digital analogues (nomenclature codes[1]).

According to these rules, Latin letters that denominate latitudinal rows on "million-scaled" maps ("10-km-scale") are replaced with ordinal numbers of rows starting from the equatorial (first) row A and step-by-step moving to the North Pole. Rows K, L, and M, where natural plague foci are located in the RF, are numbered 11, 12, and 13. A list of a million-scaled map is divided into 144 lists with 100-thousand ("kilometer") scale (from 001 to 144); each such list contains 16 lists of 25-thousand ("250-meters") scale.

An overview of numeration given to lists of maps with above-mentioned scales (and, accordingly, sectors) is given on Figure 1 that shows one of sectors in Prikaspiyskiy sand plague focus. This sector has the following code: 123807224(43) where an underlined part corresponds to nomenclature of a list belonging to the International topographic map scaled 1:1,000,000. The sector corresponds to a list of a 25-thousand scaled map with its number L-38-72-Б-г in the focus No. 43 (letters а, б, в, г are replaced with numbers 1, 2, 3, 4 regardless of their register). Lists of the next map with larger scale are numbered from left to right and top-down starting from the upper left (north-western) corner. Nomenclature of a list that was printed in a print office is given beyond the frame, either on the top to the right or in the middle (variant with numbers is given in blue color - 12-38-072-2-4, variant with letters is black – L-38-72-Б-г). When there are fragments of different foci located in the same sector and there are distinct landscape boundaries between them,

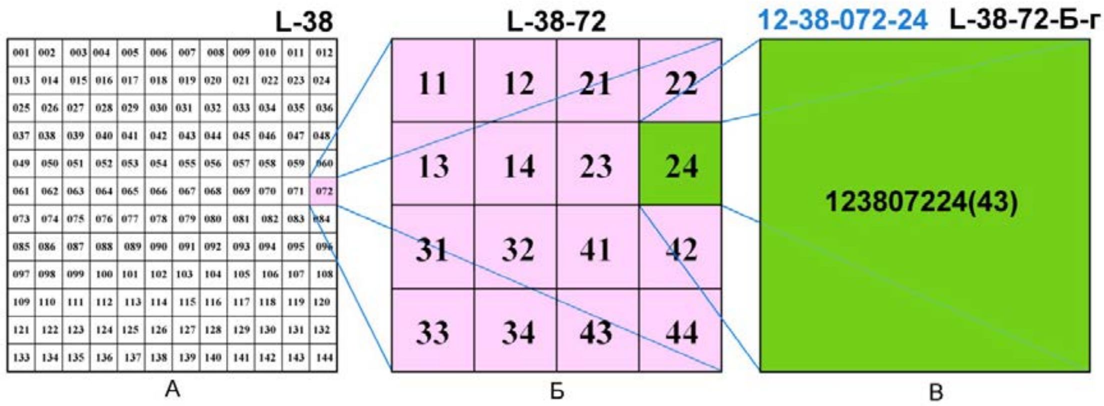

Figure 1. Order of numeration and placement: A shows lists of maps scaled 1:100,000 within one list of a map scaled 1:1,000,000; Б shows lists of maps scaled 1:25,000 (sectors) within one list of a map scaled 1:100,000; В is nomenclature of a list belonging to a map scaled 1:25,000 and a code of a relevant sector

[1] The Guide on cartographic work and printing of maps. Part 1. Drawing up and preparing topographic maps scaled 1:25,000, 1:50,000, 1:100,000 for printing. GKINP-05-050-77. – M., 1978. – 78 p.

each such fragment (relevant area on a map of a sector) is given its code that contains the original number of a focus in brackets. According to this rule, a code of a sector with a focus number on the border of an enzootic territory is given only to its focus part (area), if a boundary of a focus is drawn as per a landscape element (for example, a bank of a river or a sea) and not as per a frame of this sector.

Lists of topographic maps (just as sectors corresponding to them) are limited by frames that are represented by specific parallels and meridians. Consequently, geographic coordinates of any point on the Earth surface automatically show which list (sector) this point is located in (in our case it is somewhere within the eastern part of the northern hemisphere). In case any code of any sector is lost, it can be easily recovered as per coordinates of a point where filed materials were collected bearing in mind that meridians limiting a sector "width" are located 7' 30" away from each other starting from the Greenwich ("zero") meridian, and parallels limiting a sector "height" are located 5' 00" away from each other starting from the Equator.

Therefore, data on location of points where epizootologic research took place on this or that territory allow to group the obtained results as per significantly small standard formal-territorial units, or sectors (with their approximate square being 10 × 10 km). This additional grouping still allows any materials to be combined as per administrative districts and any other units that an examined territory is divided into. Differentiation as per sectors also allows to analyze spatial organization of natural infection foci in greater details since administrative districts are substantially greater in their sizes than sectors, and their configurations and sizes vary significantly thus making districts-based analysis extremely rough. Visualization of sector frames on a vector map that is shown on a PC screen is provided by a grade grid with relevant fractionality.

Cartographic technique based on up-to-date developments in geoinformatics is widely applied worldwide to study spread of diseases [17, 18]. Epidemiologic zoning of enzootic territories as per potential epidemic danger of this or that area is of great practical interest. When a territory is divided into standard formalized parts (sectors), it is convenient for zoning and provides better visualization of it. By now, Rospotrebnadzor offices have accumulated great volumes of information on epizootic and epidemic signs of various natural foci infections that allow to differentiate vast enzootic territories as per an epidemiologic criterion [19, 20]. It is important to make a correct choice on parameters that are applied to assess how dangerous this or that area is in terms of possible contagion of population. The basic parameters here are occurrence, distribution peculiarities, and quantity (number and density) of contagion sources. Contagion sources can be represented by warm-blooded carriers and (or) arthropods carriers (if there are any as per this or that infection enzooticity). Any registration of an infectious agent within animals population on this or that territory is also important regardless of how frequently this agent is registered. Any detected cases of contagion among population with their exact geographic localization also matter a lot. However, even if there are no disease cases on this or that territory, it is important to take into account density of population that can contact contagion sources if there are any and it is especially vital if any epizootic process was registered there in past or is registered now.

Contemporary improved epidemiologic zoning is based on epizootologic and epidemiologic status as well as on population density on a territory of specific sectors. Retrospective characteristics of epizootic signs within each sector has 2 positions: plague epizooties were detected at least once (over the last 50 years) or they have never been detected at all. The third position is epidemiological and it is related to cases of contagion among population over the last 25 years. Density of population living within a sector is also described as per 2 positions: less than 1 person per 1 km^2 and more than 1. Both characteristics are combined in a table where this or that combination of positions determines a level of potential epidemic danger in conventional scores with the following characteristics assigned to them: 1 means low level; 2, average; 3, high; 4, extremely high (Table).

Table

A level of potential epidemic danger (in scores) on a territory of a sector depending on plague occurrence and population density

Plague occurrence in a sector	Population density (people per 1 km^2)	
	Less than 1	More than 1
No occurrence	1	2
There have been plague epizooties (over the last 50 years or more)	2	3
People have caught plague (over the last 25 years)	4	4

Events that have happened over last years in Gorno-Altayskiy highland natural plague focus [21] determine the necessity to apply high-level gradation that is established only for three sectors in Altay mountains. However, profound specific and non-specific prevention activities that have been performed in the focus provide some sort of assurance that a number of such sectors will not grow in future. Nevertheless, population morbidity is registered annually or almost annually in natural foci of other dangerous infections; therefore, application of the fourth gradation there will be quite justified. On the whole, experience in epidemiologic zoning of natural plague foci can be applied for zoning of other infections foci that incorporates two or three gradations of potential epidemic danger.

In order to make epizootologic monitoring rational and efficient, it is necessary to accomplish epizootologic differentiation of an enzootic territory that is also made within specific sectors. Occurrence, intensity and duration of epizootic processes within populations of infection carriers and infection agent carriers are basic criteria applied to assess epizootologic status of a sector territory. Frequency of registered epizooties assessed over a long period of time is a simple but quite objective parameter; this frequency can be given within a specific sector or it can be based on increased detailing. Information on potential sources of contagion or infected animals is applied via extrapolation and interpolation of data obtained from a limited number of places and with variable techniques. Accounting and inspection work that is performed periodically in regulated volumes is a basic source of information. Extrapolation is basically performed as per landscape criteria when large-scaled topographic maps and images taken from space are applied; or it is done with round technique [13]. Interpolation involves averaging of data taken from neighboring cells in case there are no data on this or that sector.

Figure 2 gives an example of epidemiologic zoning on skeleton maps of Prikaspiyskiy sand plague focus (A) and Gorno-Altaiskiy highland plague focus (B) that have attracted a lot of attention due to significant epizootologic and epidemiologic signs [21]. A result of foci zoning was obtained via analyzing history of epizootic signs during the whole examination period, present distribution of population across the territory and single cases of the diseases among population in the Altay republic in 2014–2016 [21].

These single cases of bubonic plague among population gave grounds for ranking contagion areas (three sectors) among territories with the highest epidemic danger. It is important to mention that local population poached gray marmots and consumed meat of these animals that were the basic carriers

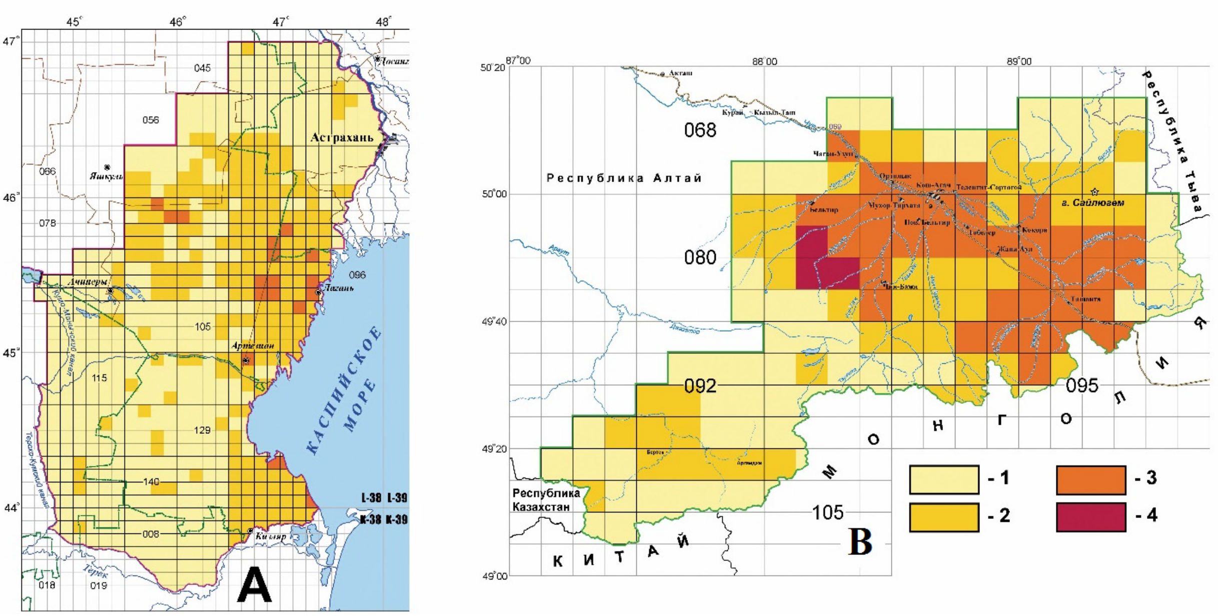

Figure 2. Differentiation of sectors located in Prikaspiyskiy sand plague focus (A) and Gorno-Altaiskiy highland plague focus (B) as per a level of potential epidemic danger: 1 means low level; 2, average; 3, high; 4, extremely high

of the plague agent. People spliced animals' carcasses at home and it resulted in contagion.

Results and discussion. It is necessary to highlight that speed, validity, and correctness of epizootologic assessment directly depend on how well an anti-plague service is equipped with contemporary means and devices for information gathering and analysis. When field groups are equipped with specialized vehicles, such as diagnostic autolaboratories and mobile housing, it increases their mobility and makes field research more comfortable and qualitative. Computers equipped with Internet connection, satellite navigators, large-scaled topographic maps, and high-resolution images taken from space help to bind areas with persistent occurrence of infectious diseases to landscape structures of various types or anthropogenic elements. Video-inspection and photo-fixation of a territory performed with air drones or even from helicopters is another promising observation technique.

Conclusion. Therefore, cartographic systematization and differentiation of natural infections foci of various etiology on the whole country territory can substantially enrich our knowledge on their location, sizes, and epidemiologic danger. Targeted work with maps secures correct spatial perception of vast enzootic territories and allows to objectively assess actual spread of contagion sources that are dangerous for population. Unification of differentiation principles for natural plague foci that is being implemented at present makes it possible to recommend these principles as a standard for zoning of natural foci of other dangerous infectious diseases; zoning itself is necessary for substantiated planning and accomplishing observation and prevention activities in each focus.

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