The development and implementation of a multidimensional relational database of fire danger metrological data

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Abstract. The study designs and implements a multi-dimensional relational database of fire danger metrological information, as well as areas with vegetation. During conceptualization, OLAP algorithms are taken into account as applied to the selection of long-term meteodata and their mathematical processing presented by multidimensional hypercubes. When designing the SQL structure, a layered architecture of geographic information system (GIS) is used, including attribute and geographical characters. The data according to the technology is tested in the Jewish Autonomous Region. The database contains metrological information from five weather stations from 1960 to 2020 and five branches of local forest districts from 1997 to 2020. At present, data is being filled in for the Omsk Region, Primorsky Krai of the Russian Federation and the Osh Region of the Kyrgyz Republic.

1. Introduction
Vegetation fires are the main natural risks to the infrastructure in urban and rural areas. Understanding the processes of forecast risk and developing the best methods for the strategy of fire spreading control, especially their forecast according to various criteria, weather condition parameters, and the state of plant combustible materials [1], demands to use a large amount of statistical data for the land and remote monitoring/sensing [2]. Modeling plant combustible materials burning is considered in different areal extent [3], regional data include daily data on the distribution of meteorological elements around the hydro weather station [4], and global data affect weather forecast models based on the previous observation of a variety of parameters (vegetation state, climatic conditions, topography, a local landscape, the territory development) [5, 6]. The consideration of all of them describes the territory fire danger fully. The software development for the map data representation of the simulation result, initialization and online testing procedures is impossible without using multidimensional databases and data aggregation tools upon spatial-temporal requests [7]. A time slice of data available provides the construction of operational schemes for monitoring the territory and controlling key indicators [8, 9], managing interregional interaction and force distribution during the elimination of fire hazards.
The aim of the study is to design and implement a multidimensional relational database of fire danger metrological information.

2. Methods
Daily monitoring of fire danger on the territory of the Russian Federation is carried out in the ISDM-Rosleshoz system, and forest fire indicators modeled by the Nesterov method are used for calculations [10]. This method is fixed in all-Union State Standard 22.1.09-99 of 2000.

The research studies Forest Fire Danger Meter Weather Indices [11] and Canadian Fire Weather Index [12] to assess fire danger and drawing up scenarios of evolving situations and fire spread [13], while additionally including forest fuels moisture content, temperature and atmospheric moisture capacity, surface slope, wind speed. They determine the behavior of forest fireguard forces to prevent and extinct vegetation fire, in particular, the patrol schedule and the number of active landing teams, aircraft flights and transportation of firefighting equipment.

When designing a conceptual database model, a system analysis of weather indices is carried out, and flowcharts for processing On-Line Analytical Processing (OLAP) of multi-dimensional cubes (hypercube) are constructed [14]. A hypercube consists of a set of time values of space (cells), while the requirements for normalization of relational databases are not met, but a logical space of computed values (aggregates) is composed according to the specified fire hazard assessment methodology.

When developing the SQL structure of the meteodatabase, the Relation OLAP (ROLAP) organization scheme is taken. In the ROLAP scheme, the concept contains an intermediate layer of metadata, dimension tables, and facts that are interconnected.

The MapInfo software system is used to implement the database.

3. Results and discussion
To describe the aggregates, a hypercube is made up of three faces: the day/week/month/year of the fire season, weather stations/local forest areas, weather parameters and indices.

![Figure 1. Organization of hypercube dimension and fact tables.](image)

The Star Scheme concept diagram contains nine dimension tables and one fact table. The fact table is controlled by a multiple topic key [15]. The measurement table contains descriptive information, while the fact table contains meteodata for the fire season of each meteodata monitoring point.

The multidimensional relational database contains the following values: the duration of the fire season (during snowfall and snowmelt), the number of days with a high class of fire danger (class IV-V) in the season, thunderstorm activity (keraunic level) (the number of days with thunderstorms), population size (population density), values of the territory fire frequency (the number of fires per unit area of the territory) (figure 2).
Different types of values are recorded annually according to the data from various services: hydrometeorological, forest protection and municipal. Then, the values are aggregated in the table `Values`. The table `Dynamics` is used to accumulate data about the dynamic patterns of the intensity indices of fire hazard seasons in municipal districts, for example, to identify the current trend characteristics. The main database table is the `Dynamics` entity. This entity contains the following attributes: a primary thematic key; an external topic key of the Municipal District table; the angles of linear trends of indicators and an integrated index.

Figure 3 shows an example of the location of weather stations for the data collection on the territory of the Jewish Autonomous Region (figure 3).

The database is tested in the IT system modules for assessing fire seasons illustrated by the territory of branches of local forest districts of the Jewish Autonomous Region. The database consists of the settlements/planning quarters of five branches of the local forest districts, which correspond to the forestry management plans of the Forestry Department of the Jewish Autonomous Region.

At the moment, information on plots/units of local forest districts is being collected and filled in in the system modules:

- Module #1 is for calculating fire hazard indicators in the area where the weather station is located. Constructing a 30 km. radius buffer zone/field and Thiessen polygons, as well as determining whether vegetation areas are among these zones.
- Module #2 is for restoring fire danger indicators in the settlements of local forest districts that are far from the weather station. The use of the GIS overlay analysis tools is for finding out if vegetation areas are in the affected zone of the station.
• Module #3 is for checking the forest fire indicator recovery. The use of interpolation methods and global model data to determine the weather elements and further calculation of fire danger indicators with different advance time;
• Module #4 is for calculating the natural-anthropogenic impact of fire seasons. Determining the centre of vegetation areas and calculating the daily anthropogenic stress because of the settlements and a traffic network, depending on the distance of buffer zones and the period of flash fire;
• Module #5 is for building trends of the intensity indicators of fire seasons. It is used for identifying the trend component of the selected indicator, calculation of equation coefficients and a canting angle of the linear trend. To rank trends of the indicator, the standard topic design of the instrument GIS (square deviation) or the author’s map delineation/appearance is used. An array of the corners of the trends is made up. It is tested for the normality of distribution according to the Kolmogorov–Smirnov test. If the criterion is getting done, then grading of normalizing values is performed providing for mean-square deviation.

![Figure 3. Location of weather stations.](image)

At present, data is being filled in for the Omsk Region, Primorsky Krai of the Russian Federation and the Osh Region of the Kyrgyz Republic.

4. Conclusion
In conclusion, the suggested database of metrology information on weather elements in vegetation areas can be used to estimate fire danger, make short - and long-term forecasts, identify the territorial dynamics of fire danger in different periods, and develop optimal fire monitoring schemes.
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