Integrated Information System for Regional Flood Monitoring Using Internet of Things

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***Abstract*—In the work the methodology of creation of the integrated information system (IIS) for regional flood monitoring is proposed, which is based on a combination of technologies of Internet of Things (IoT) and geographic information systems (GIS). It has been shown that the effectiveness of flood forecasting and decision support for their caution, prevention and mitigation can be greatly improved through the use of the IIS, which provides input, processing, analysis and visualization of data from various sources of information. Important role in the structure of the IIS is the analysis of data, based on the combination of GIS and Multiple-criteria decision analysis (MCDA). It is shown that the inclusion of MCDA in GIS improves the intelligence of the system and improves the processing of spatial data. The proposed IIS prototype and the results of this study can be used for regional management of territories and water resources.**

***Keywords*—flood monitoring, integrated information system, Internet of Things, geographic information systems; multiple-criteria decision analysis**

I. Introduction

Recently, geographic information systems are increasingly used in the simulation of various natural processes and phenomena: floods, droughts, snowfalls, forest fires, etc. [1–3]. One of the most dangerous natural disasters is flood, the negative effects of which are observed on average 27% of the territory of Ukraine. Reliable monitoring and forecasting of floods are very important for supporting decision-making on cautioning, preventing and mitigating the effects of disasters by the relevant administrative authorities.

In this regard, it is very relevant to create a GIS-based integrated real-time information system for regional monitoring and flood forecasting. Such a system typically integrates a wireless sensor network for collecting meteorological and hydrological data in an interactive mode, that is, being built on the Internet of Things (IoT) [4].

Possibilities for creating information systems of this class are growing every year and are conditioned on the one hand by increasing the spatial and temporal capacity of the measuring equipment, the accuracy and detail of the recorded values, on the other hand by improving the sensors; Radio Frequency Identification Technology (RFID) designed for control elements identification by marking chips, not expensive CPUs suitable for mobile calculation by Internet means (large amount of censor-provide data analysis); Wireless Sensor Networks (WSNs) enabling the creation of distributed, self-organizing sensor networks and devices that communicate with the radio channel independently; energy-efficient data transfer technologies (such as Bluetooth Low Energy (BLE), Near Field Communication (NFC), telecommunication technology.

The development of IoT technologies has led to an increase in data volumes that are difficult to process using DBMS data management tools and traditional data processing applications. Therefore, it is important to predict the storage of big data in data warehouses or cloud-based technologies.

Analysis of recent publications shows that there are many works in which authors analyze the application of IoT in urban planning and building smart cities [5, 6], in home automation [7], for environmental monitoring [8], in water management [9, 10], etc. In addition, individual technologies that are widely used in resource management and the environment are components of the IoT (RS, GPS, GIS,). So, the work [11], presents an integrated approach to water resource management based on geoinformatics, Enterprise Information Systems (EIS), and cloud services. Over the past few decades, a large number of studies have been conducted to assess the risk of flooding based on the combination of GIS and MCDA [12]. In this paper, the creation of an integrated flood monitoring information system is based on IoT for collecting and inputting data and GIS and MCDA for data analysis and visualization. Such an approach allows to construct a hazard map and a vulnerability map with certain areas of different probabilities of their occurrence. Based on the appropriate maps, a decision can be made on flood risk management.

II. MATERIALS AND METHODS

A. *Common framework of regional flood monitoring system based on IoT*

Common framework of regional flood monitoring system based on IoT is shown in Fig. 1.

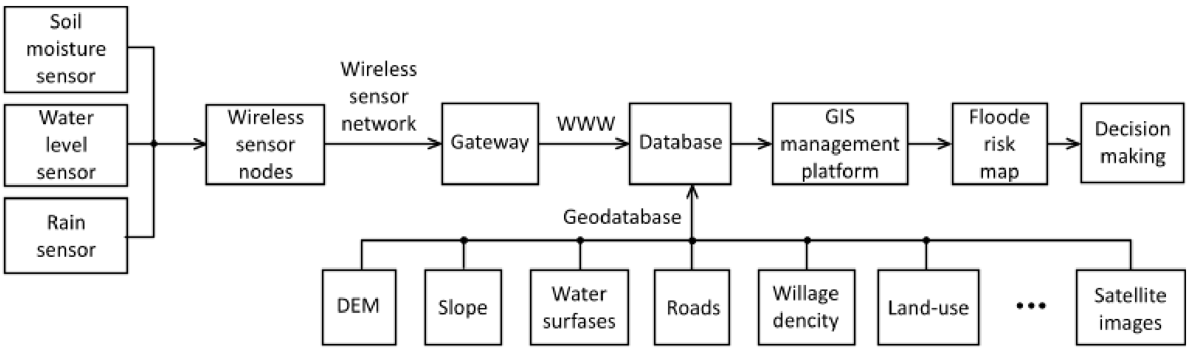


Fig.1. Common framework of regional flood monitoring system based on IoT

For real-time environmental data collection a wireless sensor network, which consists of separate sensors with autonomous power supplies, is used. Sensory node is the node of the core network, which is responsible for data collection. Each sensor automatically searches for the data receiver at the appropriate network address. Each sensor network has a communication server to connect the sensor network to an external network (Fig. 2).

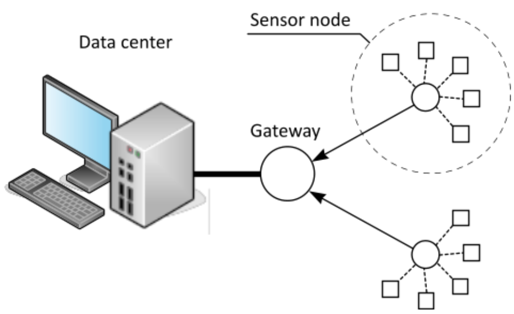


Fig. 2. Wireless sensor network structure

Through the gateway, information can be transferred to the monitoring center via the Internet (Ethernet, Wi-Fi, 3G/GPRS). For real-time data collection, remote sensing means [13] (namely satellites, balloons, airplanes and radar), mobile devices (that is GPS, 2G, 3G, 4G and LTE), IEEE 802.X (namely WiFi, Bluetooth and ZigBee), RFID and other sensors.

B. *GIS multi-criteria methodology for hazard zones' mapping*

The monitoring data enters the geospatial repository and can be used in spatial modeling and GIS analysis using special GIS platform libraries (ArcGIS, QGIS, MapInfo).

Flood risk map can be obtained by using the GIS-MCDA spatial model [14], which includes the following methods: boolean overlays, weighted linear combination (WLC), analytic hierarchy process (AHP), ordered weighted average (OWA), etc.

The methodology based on the GIS-MCDA spatial model consists of the following steps:

1) Determination of the main purpose and hierarchical structure of the model.

2) Determination of the criteria influencing the flood.

3) Data collection and construction of spatial database criteria.

4) Model GIS-MCDA

a) Fuzzy standardization of criteria.

b) Creating pair-wise comparison matrix and the calculation of the normalized weight of the criteria (AHP).

c) Aggregation results (WLC).

d) Checking the results.

5) Model GIS-visualization of final decision and recommendations.

C. *Selection of criteria*

Flood risk map is usually based on integrated hazard and vulnerability maps, so the criteria may differ for certain maps.

The hazard map is a zoning for the degree of flood hazard. The choice of criteria for constructing this map is usually based on expert assessments and field studies of a specific area. Usually, the following criteria are used to assess the flood exposure: elevation, slope, distance from water surfaces, rainfall, soil moisture (or groundwater level), soil type. The set of criteria may be partially changed for different territories.

Vulnerability is exposure to hazards. Each hazard type identifies different groups of risk-sensitive elements, therefore it is customary to build separate maps of vulnerabilities of the population, agriculture, transport infrastructure objects, etc. Therefore, for the construction of appropriate maps it is necessary to have maps of village density, roads, population density, land use, etc.

Each criteria that is taken into account when constructing a flood hazard map is presented in the form of a raster layer with a raster cell of the same size and is stored in the spatial geodatabase. The layers of the spatial distribution of rainfall and soil moisture can be obtained by interpolating reference points that contain values derived from the wireless sensor network. Other layers can be obtained using the spatial modeling tools of a particular GIS package based on data from different sources of information, such as satellite images.

Thus, the hierarchical structure of the flood risk assessment model will look like in Fig. 3.

D. Standardization of criteria

All sets of data should be standardized in units that can be compared. Frequently, fuzzy logic is used to standardize the criteria. Since the source data may have discrete or continuous values, discrete and continuous fuzzy standardization methods are used. The membership function is selected by experts in accordance with the physical characteristics of the investigated area. To assess the similarity of attributes, a continuous scale is used in the range from 0 to 1, where 0 is the least risky, and 1 is the most risky value of the attribute for the possibility of flooding. Fig. 4 shows an example of fuzzy standardization of the slope criterion using the linear membership function.

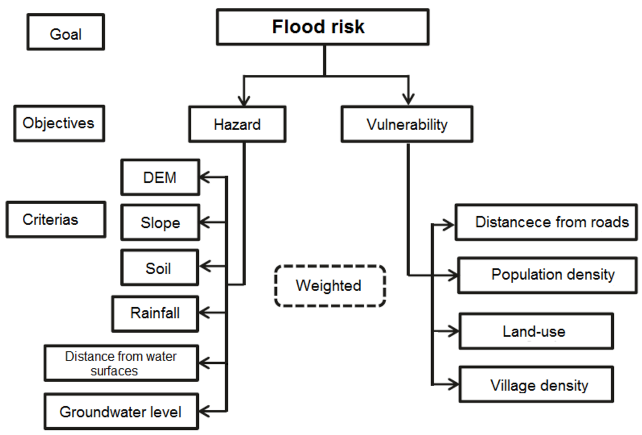


Fig. 3. Hierarchy of flood risk assessment

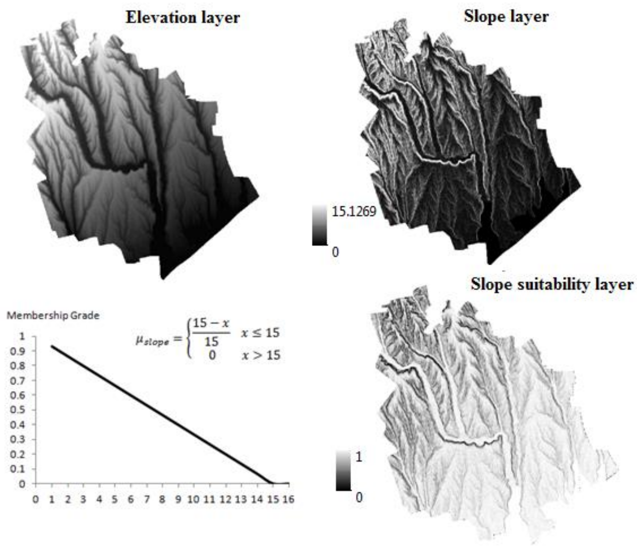


Fig 4. Fuzzy standardization Slope layer

E. Criteria weighing (AHP)

For calculation of the normalized weight of the criteria multicriterial technique AHP (Analytic hierarchy process) [14] is often used, which is based on a pair-wise comparison of elements at a given hierarchical level with respect to the elements at a higher level. Using the pair-wise comparison method (PCM), you can compare the criteria with each other and calculate their relative importance for the top-level element (goal). The result is a pair-wise comparison matrix based on the formula (1).

$$A = \left[r_{ij} \right] = \begin{bmatrix} 1 & r_{12} & \dots & r_{1j} \\ 1/r_{12} & 1 & \dots & r_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ 1/r_{1j} & 1/r_{2j} & \dots & 1 \end{bmatrix} \tag{1}$$

where r_{ij} are numbers that represent the relative importance of the *i*-th element in comparison with the *j*-th in relation to the goal.

If, according to some criteria, it is possible to obtain objective quantitative estimates of elements, then the relation of these estimates is taken as a priority. When evaluating criteria on the basis of subjective judgments of experts, the 9-point scale of relative importance Saaty [15] is used.

At the next stage, there are eigenvalues and eigenvector of the matrix and a vector of local priorities is formed.

To control the consistency of expert assessments, two related characteristics are introduced - the Consistency Index (C.I.) and the Consistency Ratio (C.R.):

$$C.I. = \frac{\lambda_{max} - n}{n - 1}, \tag{2}$$

where n is the number of criteria and λ_{max} is the biggest eigenvalue.

$$C.R. = \frac{C.I.}{R.I.}, \tag{3}$$

where R.I. is the Random Inconsistency index that is dependent on the sample size. A reasonable level of consistency in the pair-wise comparisons is assumed if C.R. < 0.10, while C.R. ≥ 0.10 indicates inconsistent judgments.

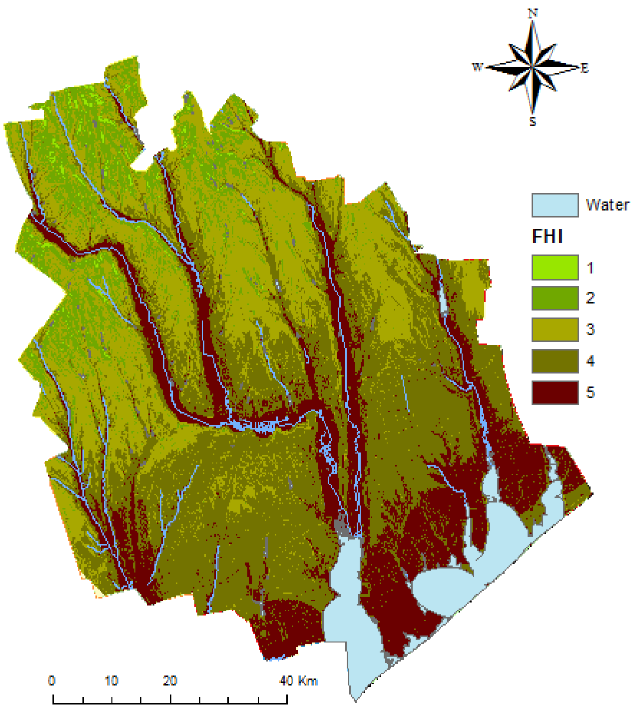
According to formula (1), an index of flood hazard index and a vulnerability index can be calculated. A flood risk map is the result of a combination of these two components (5).

$$S_{risk} = S_{hazard} \cdot S_{vulnerability} \tag{5}$$

III. Result and Discussion

The methodology proposed in this study was used to construct a flood hazard map for the southern areas of Odessa region, namely for the region including Tarutinskyi, Artsyzkyi, Tatarbunarskyi and Saratskyi districts.

The hazard map was presented in the same range of fuzzy values as the criteria from 0 to 1, and then reclassed to five classes of the Flood Hazard Index (FHI) from very low (FHI = 1) to very high (FHI = 5) . The raster cells with higher values characterize the territory more risky in terms of flooding. The final flood hazard map is presented in Fig. 5.



F. Aggregation of the composite map

To obtain a composite map in the GIS they most often use the technique of Weighted Linear Combination (WLC) [14], which is based on the weighted average calculation (4).

$$S = \sum w_i x_i \tag{4}$$

where S is hazard index, w_i is normalized weight of the criteria i, and x_i is fuzzy flood hazard value according to criterion i.

Thus, the weight of the criteria derived from the AHP is multiplied by the fuzzy cell of each criterion, and as a result, the resulting composite flood hazard map is generated.

Fig 5. Flood Hazard Map

The analysis of the results of cartographic modeling has shown that the area with the greatest danger of flooding is 27% (1757 km2) of the investigated territory. On the other hand, 9.8% (640 km2) do not have a real danger of flooding (FHI = 1, FHI = 2). The most dangerous central and southern parts of the region, which are located on the plains along the riverbeds.

The simulation results are in good agreement with the maps of flooding of the territory based on historical flood data, which took place in September 2013. These cards have been provided by Odessa Regional Water Resources Management Agency.

IV. Conclusion

The work proposes a methodology for creating an integrated regional flood monitoring information system based on a combination of Internet of Things and geographic information systems. IoT technologies are used to collect and enter of data, GIS and MCDA are used for analysis and data visualization. This approach allows to construct maps of hazard and vulnerability of flood, on the basis of which a flood risk map can be obtained. The proposed IIS prototype and the results of this study can be used for regional management of territories and water resources of different regions with similar geographical characteristics. It should be noted that the model can be improved through the use of modern WEB-technologies.

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