Influence of Raster Data Quality on Spatial Modelling and Analyses

Jitka Komarkova, Pavel Sedlak, Martin Jedlicka, Lucie Horakova, Petr Sramek, Jana Hejlova

Abstract—A good decision making is partially based on a good quality of data and/or information provided by information systems. Without input data at an appropriate level of quality, information systems cannot provide quality information. Therefore, many standards and data quality models have been developed. Later on, spatially oriented decision-making have become more important, so attention was focused on spatial data too. Quality evaluation of spatial data requires special standards because of the special properties of spatial data. The contribution is mainly focused on raster data models. At first, a brief description of spatial data quality evaluation is provided. Then, a set of quality characteristics and parameters for raster data within the framework of existing ISO standards is proposed. Finally, the proposed set is used to evaluate two example data sets and several practical examples connected to the raster data quality and its influence on spatial modelling are described.

Keywords—Raster data model, Raster, Quality parameters, Data quality model, Spatial modelling

I. INTRODUCTION

Decision making processes, namely quality and speed of decisions, are highly influenced by quality of data and quality of an information system. Information system is usually used as a tool to process input data and transform them into required information. Geographic information systems (GIS) are used in such a way to support spatial decision-making [1].

Importance of information quality on user satisfaction and intention to use information system again is highly recognized [1], [2]. For example according to DeLone and McLean Updated Information Systems Success Model (see Fig. 1), user satisfaction and use of information system depends on the following issues [2]:

- Information quality, e.g. its accuracy, timeliness, completeness, relevance, and consistency
- System quality, e.g. ease-of-use, functionality, reliability, flexibility, portability, and integration
- Service Quality, i.e. the overall support delivered by the service provider.

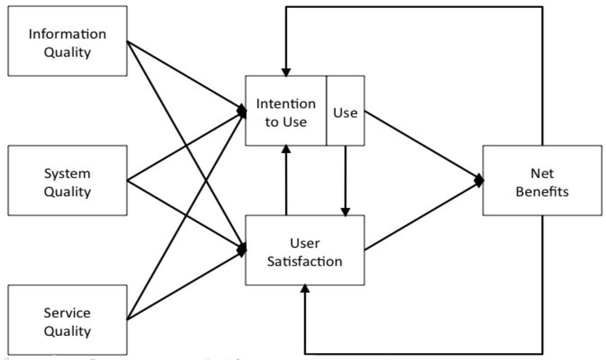

Fig. 1 - DeLone and McLean Updated Information Systems Success Model [2]

Providing quality information of course requires a good quality input data. Thus, data quality has been widely recognized as an important issue connected to information systems quality. It is one of the reasons why many standards of data quality and several directives, laws exist, e.g.:

- ISO 8000 – Data Quality, parts 100, 102, 110, 120, 130, 140
- ISO/IEC 25012:2008 – Software engineering -- Software product Quality Requirements and Evaluation (SQuaRE) -- Data quality model
- Directive 2003/98/EC of the European Parliament and of the Council of 17 November 2003 on the re-use of public sector information
- Data Quality Act (USA, Public Law 106-554).

It is quite difficult to define the term quality. According to the ISO 9000 quality is [3]: „the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs." SDMX (Statistical Data and Metadata Exchange; the BIS, ECB, EUROSTAT, IMF, OECD, UN, and the World Bank common initiative) defines quality as [4]: "the degree to which a set of inherent characteristics fulfils requirements." In general, data quality is defined as a multifaceted concept with several different dimensions [5] or as a set of particular characteristics [6], [7]. All

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authors, including [2], mention context of use of data and information as an important factor which significantly influences requirements on data quality. All potential users of data and information and their needs should be taken into account during analytical phase of system development life cycle and planning projects.

The following example of data quality model consisting of several categories and dimensions is described in [7]:

- Intrinsic quality: accuracy, objectivity, believability, reputation
- Accessibility: accessibility, access security
- Contextual quality: relevancy, value-added, timeliness, completeness, amount of information
- Representational quality: interpretability, ease of understanding, concise representation, consistent representation, ease of manipulation.

The SDMX defines its own set of data quality dimensions [4]:

- Accessibility
- Accuracy
- Clarity / interpretability
- Coherence
- Comparability
- Credibility
- Integrity
- Methodological soundness
- Punctuality
- Relevance
- Timeliness.

The above listed quality parameters cannot be used to evaluate quality of spatial data because they do not take into account the specific nature and properties of the data. There is a set of characteristics for raster data quality evaluation proposed in this contribution which respects the ISO standards framework. A suitable set of parameters is supplemented with their values applicable on raster data suitable for selected type of spatial analysis. In the paper the terms "data" and "information" will be used similarly because it is not necessary to distinguish between them.

II SPATIALLY-ORIENTED DECISION-MAKING

Natural phenomena happen somewhere. Many activities of mankind take place somewhere too. It means many phenomena and activities can be located in a space. Thus, for some decision-making processes special data are required. Importance of support of spatial decision-making process has been recognized for a long time [1], [8], [9] and today it is obvious to use spatial decision support systems (SDSS) to support decision-making. Geographic information systems can be used to manage knowledge [10], to implement resettlement strategy in mining area [11], GIS-based SDSS for reclamation on lands contaminated from coal mine waste [12], transportation network design [13], land use allocation [14], planning urban infrastructure [15] or evaluation of land consolidation projects [16].

Importance of both raster and vector spatial data quality was identified during a case study run for the Municipal police (MP) [17]. Methods of multi-criteria decision-making were used, namely the Analytic Hierarchy Process (AHP) was used to let policemen set an importance of particular parts of the information system used by the chosen MP institution. Results are shown in the Fig. 2.

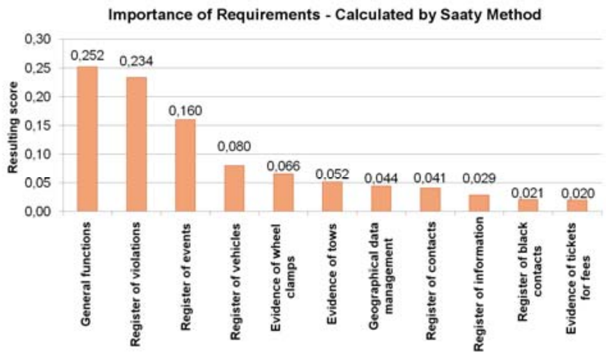

Fig. 2 – Resulting scores of importance of the requirement groups [17]

Spatial data management (most precisely geographical data in this case) is in the middle of the evaluated functions. It means that utilization geographical data belongs for the municipal policemen to the very important functions of the information system. Additional information is provided in the Table 1.

Table 1 – Requirements of Users (Municipal Policemen) on IS Functions and Their Priorities **[17]**

Group of Requests	No. of Requests	Priority
General functions	16	high
Register of events	16	high
Register of violations	12	high
Geographical data management	**15**	**middle**
Register of contacts	5	middle
Register of vehicles	5	middle
Evidence of tows	4	middle
Evidence of wheel clamps	4	middle
Register of information	2	low
Register of black contacts	2	low
Evidence of tickets for fees	1	low

III. PROBLEMS CONNECTED TO SPATIAL DATA QUALITY EVALUATION

As it was stated before, information systems should support decision-making process by providing good information. Good information can be provided only in the case that data of a good quality are available. Data quality should be evaluated with respect to users' expectations, both implicit and explicit, and according to the context of use of data and resulting information.

Because spatial data are used to support many important decision-making processes, their quality must be at an appropriate level. This fact resulted in several spatial data quality directives and standards:

- Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) and connected regulations
- ISO 19100 Series – Geographic Information Quality Standards; adopted by The European Committee for Standardization (CEN)
- ISO 14825:2004 – Intelligent transport systems -- Geographic Data Files (GDF).

Data quality concept according to ISO 19113 is shown in the Fig. 2.

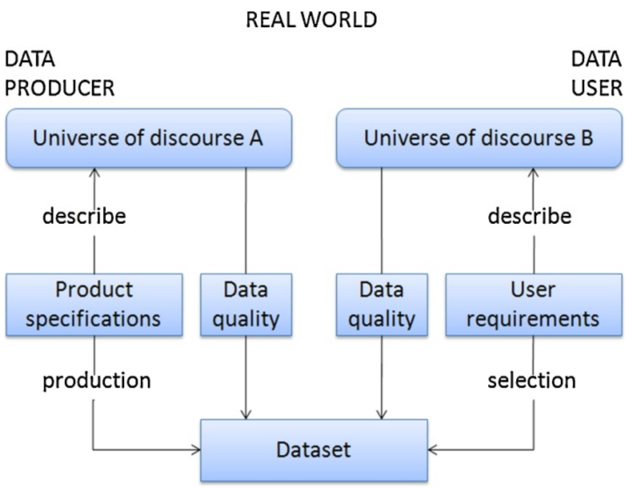

Fig. 2 - ISO 19113:2002 standard, data-quality concept [18]

General data quality models cannot be simply used to evaluate quality of spatial data because of their special nature. Spatial data model the reality and describe it usually from three basic points of view:

- Geometric (i.e. location, size, shape, topology)
- Thematic (i.e. attributes, non-spatial properties of features/phenomena, ...)
- Temporal (changes of features and their properties in time).

The first two points of view must be present in data to understand them as spatial data. Besides, two basic data models are used in GIS – vector and raster data model. Data quality model and its characteristics must fully cover all the above mentioned issues.

In the quite remote past, it was realized that electronic spatial data quality suitable for computer-based GIS and SDSS should be evaluated in another way than analogue spatial data quality (i.e. maps) [19].

Besides existence of ISO standards, European project EuroRoadS [20] proposed the quality model shown in the Fig. 3. The model was focused on vector data representing European road network.

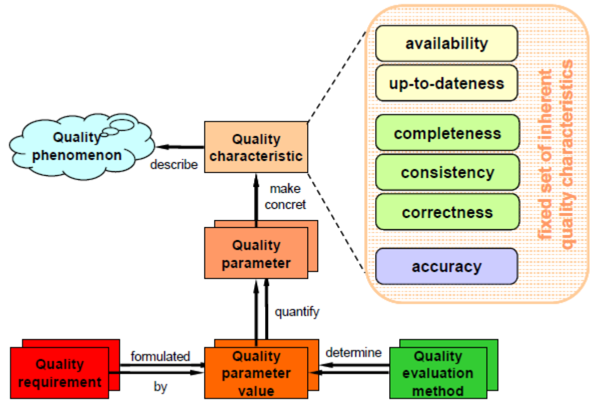

Fig. 3 - EuroRoadS quality model [20]

The main reason for the new proposal was to create a quality model with just one quality characteristic for each quality phenomena and to clearly cover all three parts of feature description (i.e. geometric, thematic and temporal) [20]. The final result is shown in the Fig. 4.

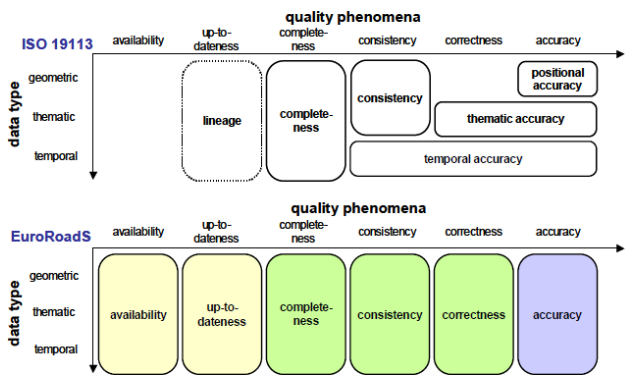

Fig. 4 - Quality elements of ISO 19113 and quality characteristics in EuroRoadS quality model [20]

The above described approach of the EuroRoadS project is very inspiring because of the clearness of the proposed quality model. There is one significant property of the model and its parameters – it is focused on vector data and data about the road transportation only. It does not deeply deal with raster data which belong to the important types of spatial data suitable for many spatial analyses.

Aim of this paper is to fill this gap and propose a suitable set of quality characteristics and parameters for raster data within the framework of existing ISO standards.

IV. QUALITY CHARACTERISTICS AND PARAMETERS FOR RASTER DATA

The following proposal of data quality parameters is focused on spatial data in raster format. All parameters will be divided only into two main groups: quantitative parameters which are measurable, and qualitative parameters. Raster data do not primarily distinguish particular features and they store geometric properties only implicitly. Topological relationships are not explicitly stored in data; they cannot be used for analyses. These facts will be taken into consideration.

The proposed set of characteristics and parameters for raster data quality evaluation follows. It respects existing standards but it takes into account more aspects and it focuses namely on parameters suitable for raster data. Thus, some characteristics, parameters and their description follows from [4], [5], ISO standards and EuroRoadS project [20], some of them were proposed by the authors previously ([21], [22]) and some of them are newly proposed by the authors.

Quantitative characteristics and parameters:

1. Accuracy:

- Geometric accuracy – dealing with absolute and relative position accuracy. It expresses the difference between the data and true locations, it should include both vertical and horizontal accuracy when required
- Thematic accuracy – measures the difference of attribute values from the true values; e.g. it expresses the accuracy of raster classification
- Temporal accuracy – focused on an accuracy of time measurement, i.e. validity in a time and time consistency are measured

2. Level of detail

- Spatial resolution – describes size of the cells in relation to the reality (i.e. how large area is covered by the cell); it consequently influences size of the smallest objects that can be resolved in the imagery and raster data. This characteristic is not applicable to vector data models
- Scale

3. Completeness:

- Completeness – omission of features, their attributes or relationships is measured
- Completeness – redundancy and excesses in data (data contain not necessary features and attributes)
- Spectral resolution – number of spectral bands available; valid for remote sensing data only

4. Correctness:

It expresses the extent of conformity of data with the reality; a low level of correctness can be for example caused by low accuracy or not up-to-dateness of data; with a focus on all three points of view. Parameters:

- Geometric correctness
- Thematic correctness
- Temporal correctness – temporal resolution in the case of remote sensing data

5. Consistency:

Levels of observing logical (conceptual) schemas and models of reality are considered. Topological consistency is not applicable for digital raster data due to their nature, so it is omitted. Parameters:

- Geometric consistency
- Thematic consistency

6. Up-to-dateness – describes how quickly data follows changes of the real world in time. In some cases data can be several years old, in another cases they must be quire new. Parameters:

- Frequency of updates
- Date of the last updates

7. Availability – valid mostly for online data or shared data which are stored on the server side:

- Failure rate – frequency with which data are not accessible (measured in percents or in seconds, minutes or hours per given period)

Qualitative characteristics and parameters:

1. Source:

Source of data – data can come from trustworthy sources (e.g. national statistical office, public administration authority) or from not well-known source, e.g. from a Web site without clear responsibility for data

2. Accessibility:

- Data format – the best data format is the format which is regularly used by users; data transformation and conversion can introduce some errors into data and it could be time-demanding and/or costly
- License – describes author rights and conditions under which data are available
- Costs – high costs can limit some users

3. Aim:

Purpose of data creation – intention to their future use, is important because it influenced content, accuracy, level of detail, accessibility and many other quality parameters of the dataset.

4. Utilization:

Real utilization of data – references to projects where data were used

5. Coordinate system:

In many countries, more coordinate systems are used. Coordinate systems is characterised by its distortion. It is good to use just one coordinate system to prevent problems caused by different systems and their different distortions.

V. UTILIZATION OF THE PROPOSED QUALITY PARAMETERS

In this chapter, there is provided an example of utilization of the proposed set of quality parameters. Then, several selected parameters are deeper discussed.

A) Digital Elevation Model

Digital elevation model (DEM) will be used in this example to evaluate aspect, slope and calculate hillshade to evaluate amount of sunlight.

Task description: it is required to find suitable places for new vineyards in the given region. South-west or south-facing slope, at 250 – 300 m above sea level is expected. The slope itself should be about 10 - 25° to assure enough sunlight on one side and a possibility of cultivation on the other side [22]. The task will be solved just to show differences in obtained results when data of a good and poor level quality are used. Values of quality parameters proposed for the solved task as shown in the Table 2.

Table 2 – Values for Quality Parameters (Source: Authors, Based on [22])

Quality Parameter	**Value**
Geometric accuracy – horizontal	min. 2 m
Geometric accuracy – vertical	min. 5 m
Thematic accuracy – accuracy of raster classification	min. 95 %
Thematic accuracy of quantitative attributes	deviation max. 5 %
Temporal accuracy – the date of the last update for DEM	max. 10 years ago (2001)
Temporal accuracy – the date of the last update for land cover/ortophoto	max. 1 year ago (2010)
Completeness	min. 99 %
Spectral resolution	3 bands (RGB)
Consistency	min. 99 %
Geometric correctness	deviation max. 5% (= 0,01 m)
Spatial resolution	2 m
Frequency of updates	not applicable (one purpose analysis)
Failure rate	not applicable (one purpose analysis)

In this case only evaluation by stating the values was used. The next possibility is to use multi-criteria evaluation methods, e.g. AHP, etc.

Data sets used for the example task solution:

- ArcCR500 – aim: data for students, a data set in scale 1 : 500 000, source: ARCDATA PRAHA, s.r.o., year 2002, data format: SHP, contours: 50 m, license: free for study purposes
- ZABAGED – aim: a digital equivalent of the Base map of the Czech Republic 1 : 10 000 (an official state map), source: Czech Office for Surveying, Mapping and Cadastre, example data set, year 2007, data format: SHP, contours: 5 m, license: free example for the selected region.

The whole area of interest is shown in Fig. 5 and Fig. 6. The pictures show DEM and contours based on each of the data sets, i.e. input data were at first visualized. A corresponding hillshade was used as a background layer to improve visualization. The difference between the data sets can be seen easily. It is caused namely by different scales (spatial resolution). ZABAGED (see Fig. 5) is much more detailed dataset, its horizontal accuracy is 1 – 10 m, and its vertical accuracy is 3 m at maximum. Spatial resolution of DEM was 2 m. ArcCR500 (see Fig. 6) has accuracy 100 – 250 m and it provided DEM with spatial resolution 5 m [22]. Because of the study purpose, older example data sets were used which were available for free. Both data sets were complete, only topographical data were required. Coordinate system was the same in both cases – one of the official Czech coordinate systems: S-JTSK.

ArcGIS for Desktop 10, Advanced license level (former ArcInfo) was used as a software tool to solve the example task.

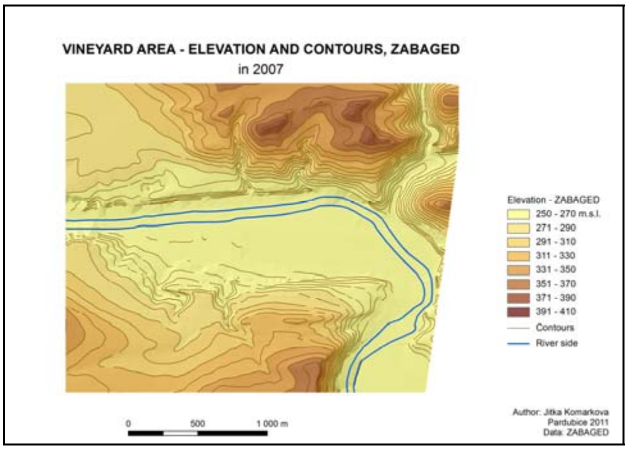

Fig. 5 - Area of interest, input data: ZABAGED (authors)

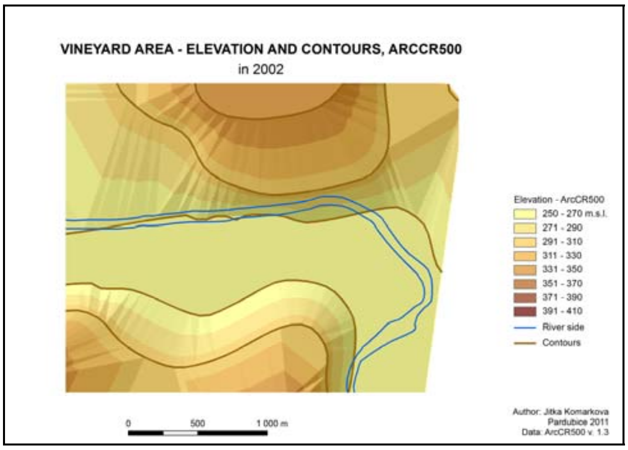

Fig. 6 - Area of interest, input data: ArcCR500 (authors)

The first step in this example task was to calculate slope, aspect and solar radiation. Areas which matched all the given conditions were selected by means of map algebra. Obtained results were verified by comparison with ortophotomap during the last optional step. These steps are not described in the paper because of their length and low importance. Both data sets were treated by the same way, using the same tools and keeping their original spatial resolution during the whole analysis.

Obtained results, i.e. places suitable for vineyard and meeting the given conditions are summarized in the Table 3 and shown in the Fig. 7.

Table 3 – Comparison of the Results of Analyses [22]

Data set	ZABAGED	ArcCR500
No. of places	1 788	82
Total area	283 744 m^2	232 044 m^2
The smallest place	2,6 m^2	16 m^2
The largest place	28 625 m^2	102 803 m^2
Average size of place	158,7 m^2	2 830 m^2

It can be clearly seen from the Fig. 7 that data at lower level of quality (ArcCR500) provided quite incorrect results.

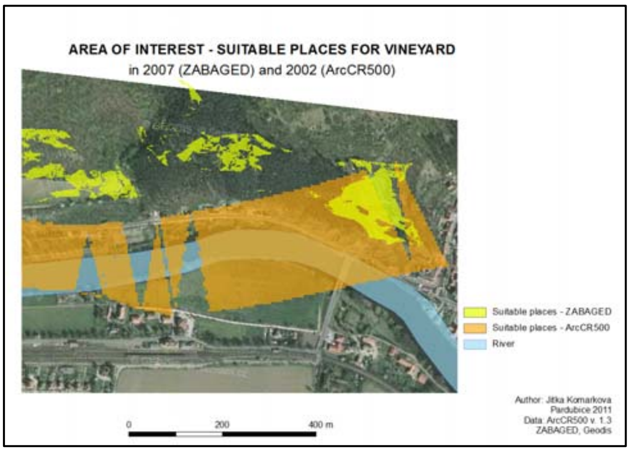

Fig. 7 – Differences in results (authors, based on [22])

B) Discussion of the Selected Raster Data Quality Parameters

As it was stated before, **spatial resolution** belongs to the very important quality characteristic of raster data models. It says how large area is covered by the raster cells (regular grid is assumed), more precisely how long distance on the ground is represented by the cell side [23]. It determines how large objects will be modelled by raster dataset. The following important rule was proposed by Waldo Tobler, as stated by Rajinder [24]: "divide the denominator of the map scale by 1,000 to get the detectable size in meters. The resolution is one half of this amount."

Spatial resolution of raster data is determined at the moment of data recording. Later, it can be decreased but it cannot be increased – it is difficult to resample raster data to obtain finer (higher) spatial resolution. On the other side, higher resolution produces significantly larger amount of data [19].

The following examples come from the study [25] which was aimed at utilization of raster data for modelling and planning barrier-free environment in the city Dvůr Králové nad Labem.

ArcGIS for Desktop 10, Advanced license level (former ArcInfo) was used as a software tool to solve the task. Ortophotomaps of the city with spatial resolution 20 cm and several vector data layers (e.g. buildings, pavements, etc.) were used as input data.

One of the first tasks was to transform all vector data into raster data for further analyses. In the very beginning, it was necessary to determine proper spatial resolution of new raster data layers to ensure correct analyses and visualisation of data and obtained results. In the Fig. 8, there is shown difference between resolution 2 m and 5.2 m. On the top, the pavements are drawn by raster data with resolution 2 m. In this case the pavements more precisely follow the network shown in the ortophotomap, see Fig. 8.

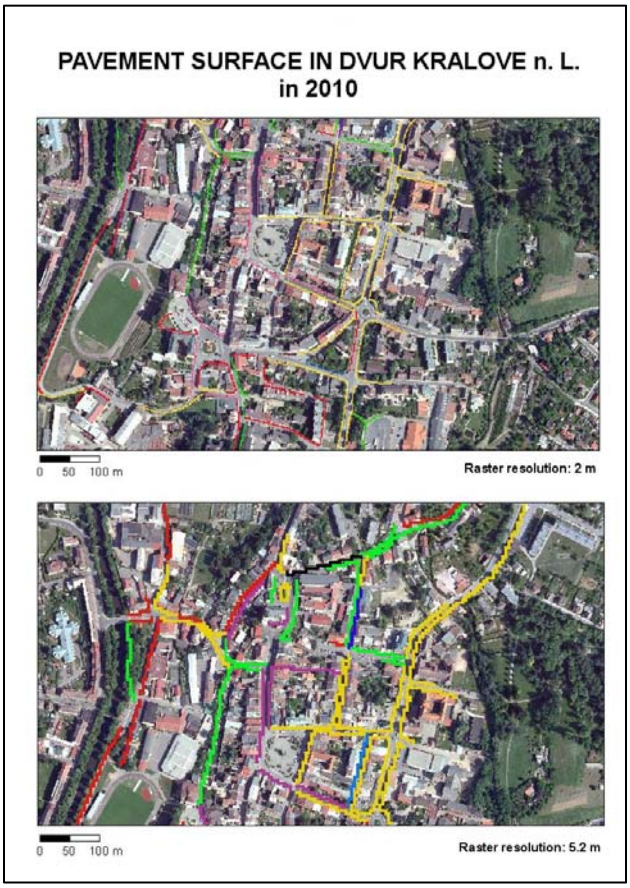

Fig. 8 – Pavement network in the city – represented by raster data layers with different spatial resolution; different colours represent different surface of pavement [25]

Filtering of spatial data is a set of techniques connected to spatial resolution. Filtering in general allows many different and opposite things, e.g. smoothing features, noise reduction (often accompanied with decreasing spatial resolution), directional enhancement and boundaries/edges sharpening. Spatial filtering by means of high-pass filters is a technique focused on enhancement of raster data which preservers high frequencies, e.g. by means of Laplacian filter. Detection of boundaries and their sharpening belong to aims of this kind of filtering. Low-pass filters are used to smooth the boundaries [23]. In the case of our study [25], both high and low-pass filters were used; the values were set experimentally. No smoothing was used before filtering the data. The following pictures (Fig. 9 – Fig. 12) show the differences between the four high-pass filters available in ArcGIS for Desktop 10. The aim of utilization of all these filters was to sharpen pavements and highlight the city centre. The following filters were used: Laplacian filter, Line detection horizontal filter, Sharpening filter and Sobel filter.

Laplacian filter – in the middle of 3x3 matrix there was set the value 4, in the corners the value 0 was set, the value -1 was set in the rest of the cells. The final result is shown in the Fig. 9.

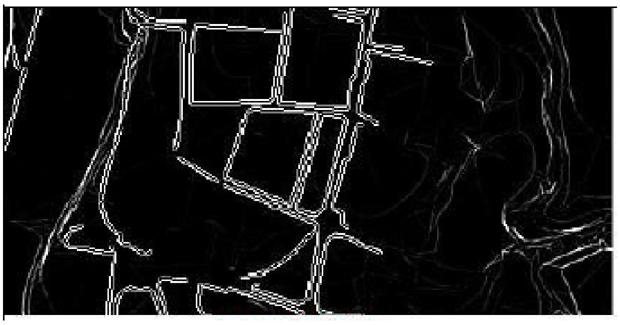

Fig. 9 – The Laplacian filter [25]

Line detection horizontal filter – the 3x3 matrix was used; in the first and third row the value -1 was set; the value 2 was set in the second row. Fig. 10 represents the obtained result.

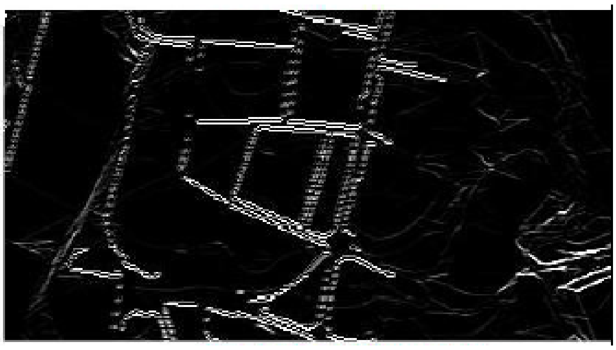

Fig. 10 – The Line detection horizontal filter [25]

The sharpening filter – in the middle of 3x3 matrix the value 2 was set; the corner cells kept the value 0 (the same like in the case of the Laplacian filter); the rest of the cells was set to the value 0.25. The final result is in the Fig. 11.

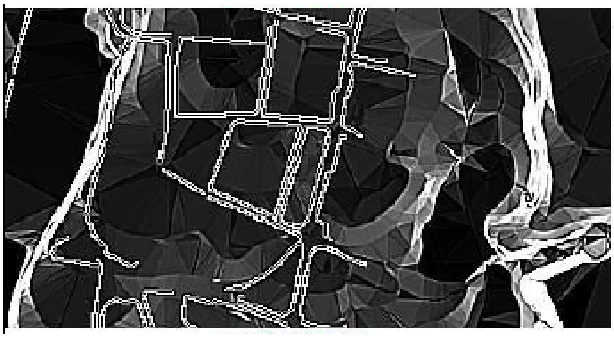

Fig. 11 – The Sharpening filter [25]

Sobel filter (horizontal) – another horizontal filter, where the middle of the matrix had the value 0; the first line carried the values -1, -2, -3 and the third line carried the values 1, 2, 3. The obtained result can be seen in the Fig. 12.

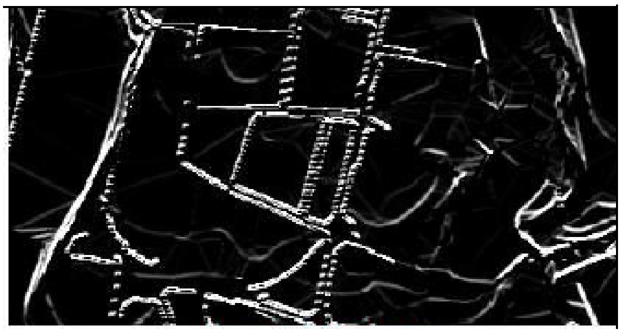

Fig. 12 – The Sobel filter [25]

Spectral resolution is the next important raster data quality parameter. It says which parts of electromagnetic spectrum (which wavelengths) were measured. Data can be captured as single-band (in one part of electromagnetic spectrum) or multi-band (in more parts of electromagnetic spectrum) ones [23]. Multi-band imagery allows users to create **colour composite images**, i.e. to change the bands in RGB (red, green and blue) channels. The appropriate band combination allows identification or highlighting of different features and/or properties of features which are not directly (or not so easily) visible in the visible part of electromagnetic spectrum. Fig. 13 shows result of the further described band combination. The original band combination was: red = band 1, green = band 2, blue = band 3. The new band combination, shown in the Fig. 13, is: red = band 3, green = band 2, blue = band 2 (so called false colour composite). The used band combination highlights vegetation, as it can be seen in the Fig. 13.

Fig. 13 – Pavement network in the city – represented by raster data layers with different spatial resolution; different colours represent different surface of pavement [25]

V. CONCLUSION

The most of mankind activities or phenomena in general are located, i.e. they happen somewhere. The location is a very important factor which can significantly influence a process of decision-making. Location, shapes and other spatial matter are in computer-based information systems modelled by spatial data. Mostly raster and vector data models are used in GIS.

High quality data is one of the preconditions for the decision-making process. Data quality is described by several standards and quality models, including ISO standards. The problem is that spatial data describing location and other spatial matter has very special properties which are not covered by general standards. Several attempts to propose quality models for spatial data were made, e.g. like EuroRoadS project [20]. According to the EuroRoadS project, ISO standards for spatial data quality bring a major problem - they do not propose just one quality characteristics for one quality phenomena and they are focused directly on technical parameters of data. EuroRoadS project tried to eliminate this problem, so it proposed clear set of characteristics but it was mostly focused on vector data, it omitted raster data [20].

This contribution bridges the above described gap. A set of quality characteristics and parameters for raster spatial data it proposed, with respect to existing ISO standards. Namely, spectral resolution, spatial resolution, temporal resolution, source, price, license, data format and purpose of data creation were proposed as quality characteristics.

Utilization of the proposed quality characteristics is demonstrated in the end of the contribution. An example case study is shortly described, and then two datasets are introduced and evaluated according to the proposed values of the quality parameters. In the end, some quality parameters are discussed deeper to show their influence on the spatial modelling and possible following analyses. For example, utilization of high-pass filters in ArcGIS for Desktop 10 is described in more detailed level and obtained results are shown to demonstrate their influence on the quality of spatial modelling.

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