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ISO 19113:2002 with Reference to Digital Terrain Models

1. Introduction

Digital Terrain Models (DTMs) are a very important GIS layer and are used extensively in scientific and practical applications, ranging from geoinformation to civil engineering. Multiple spatial analyses are being held with the usage of DTM – starting from simple queries, through map analysis derived from DTM: slope and aspect maps and finally finding application in complex modelling of environmental phenomenon. Recently more and more attention is paid to the GIS analysis credibility, which makes the quality issues and data sets accuracy more important then ever. Owing to fact that quality is an extensive concept, one criterion assessment cannot be applied to every possible situation. Domain of the problem as well as the goals of specific application need to be recognized and the acquired knowledge must be confronted with the information regarding possessed data. It is in connection with the reliability and fitness to use issue which states that every certain DTM is appropriate only for some set of applications, and the user must be aware of that. It is important for the user to have the sense of purpose. Whether a DTM is of sufficient quality for particular application depends on the data itself and on the purpose of its usage.

Among others DTMs serve as an input for decision making and risk handling, e.g. they are employed for flood hazard analyses. To make these decisions reliable quality must be described using adequate methods and measures and communicated to the user. If so, it is most frequently done by providing global quality measures which is represented by single value concerning a large area like map section, e.g. in Poland LPIS DTM where whole country was covered with this photogrammetric-based model (aerial orthophotomap in 1 : 13000 and 1 : 26000 scales) for Land Parcel Identification System (LPIS) purposes. Model error is usually

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derived from check survey which gives one, global value defining its accuracy. However, in mentioned above flood hazard analyses the spatial variation of DTM quality is of special interest while this issue concerns human lives and no mistakes are allowed. Finally the user that possess the DTM would like to know the quality of the product and it seems that single value of error is not a sufficient parameter.

The data can be gathered with various methods which have an influence on the DTM final accuracy. Currently direct terrain survey, cartographic and photogrammetric methods or ALS and InSAR technologies are applied to sample elevation data. According to the characteristics of each method elevation survey accuracy can vary from few centimeters (direct terrain survey, ALS) to few dozen meters (Space InSAR). Source data are obtained with error of the survey method. However it is not identical with the error of the generated DTM because of criteria used during the survey: point density and placement, measured features, DTM parameters.

For each survey method different algorithms for models generation exist as well as representation schemes in order to visualize them but what they have in common is that in most cases they refer to so called 2.5D DTMs. The elevation is a single-valued bivariate function $h(x, y): R^2 \mapsto R$. It means that for each planimetric position only one height may exist, i.e. overhangs and bridges are not modeled correctly because for one planimetric position usually (or at least) three heights exist. The problem appears also when modeling nearly vertical surfaces where large elevation differences come with small planimetric extent, e.g. cliffs. In this case 2.5D representation is possible, however the quality of surface description is poor, because of low point density in comparison to the actual, inclined surface area. 3D DTM is devoided of these limitations but is much more complex to handle and little work on 3D terrain modelling has been done so far.

The ISO 19113:2002 Standard establishes the principles for quantifying the quality of geographic data and specifies components for reporting quality information. It also provides an approach to organizing information about data quality. According to it, the issue of quality is a multifactor problem and includes such data quality elements like: completeness, logical consistency, positional accuracy, temporal accuracy, thematic accuracy. It also states data quality subelements and seven descriptors that determine the mechanism for completely recording information for each data quality subelement. Its principles are applicable to digital geographic data, however they can be extended to many other forms of geographic data such as maps, charts and textual documents. For data users it answers a crucial question whether or not specific geographic data is of sufficient quality for their particular application. Additionally it may be used for describing quality requirements.

In the following section related work on DTM quality assessment is presented. In Section 3 principles for describing the quality according to ISO 19113 are listed with reference to DTM. In Section 4 final conclusions are contained.

2. Related Work on DTM Quality Assessment

The ISO 19113:2002 with its multi criterion attitude to the quality of geographical data causes that "error button" concept [10] is rather utopian than possible because matters connected with DTM quality are known and studied for at least two decades and simple method for taking DTM error into consideration has been not yet worked out. The quality assessment algorithm is expected to be more complex. For this reason GIS software creators do not develop tools supporting accuracy analysis. The simplest parameter describing DTM accuracy is the root mean square error (RMSE), which is not always most appropriate, because error characteristics of DTM not always meet up to the accidental conditions and normal distribution (e.g. [8, 11]). In that case more specific values may be used: mean error, which is the measure of the systematic element and its standard deviation (e.g. [3, 8, 11]). Described parameters have global character whereas elevation error usually varies spatially (e.g. [2, 3, 7, 9, 11]). Interesting, non-geostatistic method of quality assessment taking into consideration spatial correlation of error suggested Kraus et al. [7]. The usage of this methodology is dependent on having both Grid DTM and source data set. The following factors influence the accuracy of the DTM points: the number and alignment of the neighbouring original points, the distance to the respective grid point, the terrain curvature in the neighbourhood of the grid point and the accuracy in height of the original points. This approach can be applied to both existing and new DTM and does not depend on its interpolation algorithm. The only condition is the possession of source data set from which the model has been derived. Author of this paper began his own implementation in Java programming language of this methodology which has been not yet tested. In ideological meaning similar attitude was presented by Wysocki [12] where empirical formula is shown and compared to equation proposed by Ackermann [1]. The former has given better results in DTM error calculation then the latter. In addition it provides spatially distributed error generation.

3. Principles for Describing the Quality According to ISO 19113

The International Standard 19113 can be used, when:
- identifying and reporting quality information,
- evaluating the quality of dataset,
- developing product specifications and user requirements,
- specifying application schemas.

A quality description can be applied to data sharing common characteristics so that its quality can be evaluated.

It shall be described using two components:

- data quality elements – together with data quality subelements and the descriptors of data quality subelements, describe how well a dataset meets the criteria set forth in its product specification and provide quantitative quality information,
- data quality overview elements – provide general, non-quantitative information.

3.1. Data Quality Elements and Their Subelements

The following data quality elements, where applicable shall be used to describe how well a dataset meets the criteria set forth in its product specification:

- **Completeness –** presence and absence of features, their attributes and relationship:
  - Commission – excess data present in the dataset.
  - Omission – data absent from a dataset.

  Both data quality subelements are applicable in relation to the DTM, because the data set may be extended to cover both larger and smaller area than is required. We then talk respectively about data commission and data omission in the data set. In addition, it would be necessary to reflect on the accuracy of the source data that were used to build the model, since it is inextricably linked to its quality. We can talk about the commission and omission also at the data acquisition stage. The former is the case with too many measurement points or structural lines for little varied terrain, while about the latter we can speak in too far-reaching generalization of the terrain or wrongly made survey neglecting essential details of the terrain.
- **Logical consistency –** degree of adherence to logical rules of data structure:
  - Conceptual consistency – adherence to rules of conceptual schema. An important issue is to define the conceptual schema. A question of what constitutes DTM must be answered: whether they are just raw data, only the same model or maybe both at once? Not without significance is the fact that the algorithm for generating the model should be a DTM component, as creating a model from the same source data but using different algorithms will give us the different models. Another important question is what model we are dealing with. Are they Digital Terrain Models, Digital Surface Models, DTM 3D or draped models in which apart height different data source is used to provide better land presentation e.g. orthophotomap. In these cases about conceptual consistency the presence of all elements would decide, however, would not it be the pre-

viously discussed data quality element (completeness)? It therefore follows that this data quality subelement is not sufficiently specified and can cause inaccuracies in the interpretation.

- Domain consistency – adherence of values to the value domains. This data quality subelement seems to be not applicable, as in the case of DTM there is only one attribute – height, which does not apply to a specified range of values. Domain consistency may also be related to the type of data. In DTM dataset stored as text files it may occur due to human error when other than a numerical value, such as text, may appear. Then if you try to load the model an error will be generated. In the case of DTM consisting of integer numbers the occurrence of a floating point number can be considered as being outside the domain.
- Format consistency – degree to which data is stored in accordance with the physical structure of the dataset. Format consistency can be viewed in two ways: responding to the question whether the DTM is consistent in terms of size and location of the GRID starting point with the specification or may be related to compliance with imposed format type of the model (text, ArcView, Idrisi, etc.). Errors arising from the lack of internal integrity of a file, which is identical with the errors in the physical record on disk and file structure inconsistency, are omitted, because in this case, the model can not be read, and hence can not carry out quality assessment.
- Topological consistency – correctness of the explicitly encoded topological characteristics of a dataset. As in the case of completeness this data quality subelement usage also depends on the type of DTM. For the GRID models it does not apply. TIN models are defined by the relationship between nodes, edges, and the relationship between adjacent triangles – points connection correctness by the sides of the triangles as a result of triangulation and the closure of the triangles are being checked. For the hybrid models topological consistency is the topology of the connections between GRID points with structural lines which are usually stored as a separate file. GRID data points should be relevant to lines course. Two types of data: grid and irregular lines after merge must form a coherent whole.

– **Positional accuracy** – accuracy of the position of features:
  - Absolute or external accuracy – closeness of reported coordinate values to values accepted as being true. To determine the absolute accuracy of the DTM man must first define what data is considered as true or being true and thus may serve as reference data: are they as survey points, in the profile lines or maybe another DTM with at least ten times better accuracy. An important issue is the definition of a measurement method that ensures sufficient accuracy against tested model.

- Relative or internal accuracy – closeness of the relative positions of features in a dataset to their respective relative positions accepted as or being true. Relative or internal accuracy for the DTM can be understood in three different ways. First, as the discrepancy between the source data used for the construction of the model and the model itself. Secondly, as the discrepancy between the location of the object in the examined model and the same object in the reference model – but would not it be absolute or external accuracy then? Finally, maybe this data quality subelement in case of DTM does not apply and its used only for quality assessment of vector data stored at different layers of the same database. Descriptions and examples contained in the ISO 19113 and ISO 19114 Standards explain too little to the user in order to clearly define the subelement. The basic question to be answered by reading these two standards is what is meant by the term relative coordinate values. Does it mean coordinates in a local coordinate system? It is not clearly specified.
- Gridded data position accuracy – closeness of gridded data position values to values accepted as or being true. At first glance, the subelement is a subset of an absolute or external accuracy that covers only the GRID models. In this case it seems to be superfluous, because the accuracy of position can be described with absolute or external accuracy already mentioned, which is more comprehensive because it covers all types of DTM, not only GRID models. After a while of thinking, this data quality subelement can be considered as the accuracy of data points surveyed in a grid layout in relation to the specified theoretical grid. In this case, this element would not apply to GRID DTM models because they are usually interpolated from scattered data, so the theoretical and practical grids are identical to each other. A similar situation occurs in the case of DTM derived from aerial photographs by matching method. Determining the accuracy of the grid data position would have been relevant at the time by direct surveying in grid layout, but in practice height data is no longer obtained this way. The conclusion may be that this data quality subelement is irrelevant in relation to DTM.

– **Temporal accuracy –** accuracy of the temporal attributes:
  - Accuracy of a time measurement – reporting of error in time measurement. It measures the difference between time reported in the data set and that in the universe of discourse. It is not applicable to DTM.
  - Temporal consistency – correctness of ordered events or sequences. This data quality subelement gives information about a distinguished historical events sequence contained in the data set. The data are temporal consistent if they were made in the same time. If they have not been collected at one time on their consistency decides their order, which should

be consistent with the chronological order of data acquisition. In DTM case this data quality subelement is important when we model the changes in surface features such as calculating volume of excavated material in open pits. In other cases, usually the newly built model simply replaces the previous model, which ceases to be valid.

- Temporal validity – validity of data with respect to time. It answers the question what fraction of data in the data set is compatible with the date of actual acquisition, in which the collection of information took place. Degree of importance of the survey time accuracy depends on the measured object and the purpose for which the data will be used. In the case of measuring objects such as roads, precision to determine the time has no bigger influence – changes do not occur rapidly except natural disasters such as floods or tornadoes. The situation is quite different in the case of DSM where temporal validity is of great importance because of the changing vegetation. The problem of the vegetation is particularly important for models created using LIDAR. In these models, especially the ones used for forest density and tree quality assessment, determining the time of data collection is very important. To obtain meaningful results, all models must be obtained within a very narrow time window. Here arises the problem of model validity – it depends on the pace of growth. Situation is similar for areas of strong anthropogenic activities.

– **Thematic accuracy**:
  - Classification correctness – comparison of the classes assigned to features or their attributes to a universe of discourse. It answers the question how many items in the dataset is classified correctly and how many of them are misclassified. Since DTM is not being classified this data quality subelement is not applicable.
  - Non-quantitative attribute correctness – correctness of non-quantitative attributes means whether the names of the items in the dataset are correct and spelled in the right way against those in the universe of discourse. Since DTM stores only height data which are numbers this data quality subelement is also not applicable.
  - Quantitative attribute accuracy – accuracy of quantitative attributes. In DTM 2.5 D height is the only quantitative attribute which quality has already been described in the absolute or external accuracy data quality subelement and therefore quantitative attribute accuracy does not apply to DTM.

The International Standard allows creating additional data quality elements or subelements to describe a component of the quantitative quality but every aspect of data quality assessment regarding DTM is covered by described elements so it is unnecessary add more.

3.1.1. Descriptors of Data Quality Subelement

Recording quality information shall be done with the use of seven descriptors of a data quality subelement listed bellow:

1) Data quality scope – extent or characteristic(s) of the data for which quality information is reported.
   In one dataset quality may vary, so multiple ranges of data quality can be defined so that it could provide more accurate quantitative information about quality. The scope can be described by specifying:
   a) the level – a dataset series to which a dataset belongs; the dataset itself; smaller grouping of data located physically within the dataset sharing common characteristics;
   b) the types of items (lists of feature types, features attributes and feature relationships) or specific items (lists of feature instances, attribute values and instances of feature relationships);
   c) the geographic extent;
   d) the temporal extent – the time frame of reference and accuracy of the time frame.

   With regard to the DTM, which store only height information, scope may be described as the geographical extent. This may be one sheet (section) in the fixed scale of used coordinate system. In special cases of application e.g. the process of assessing the volume of excavated material in open pits, in addition to the geographical extent will be the temporal extent, which specifies the moment of data collection used to create a DTM.
2) Data quality measure – e.g. the percentage of the values of an attribute that are correct.
   For each data quality scope at least one data quality measure shall be provided. Greater their number should be used in cases where a single data quality measure may be insufficient for fully evaluating the quality for all possible uses of the data set. Every data quality measure shall briefly describe and name, where a name exists, the type of test being applied to the data specified by a data quality scope and shall include bounding or limiting parameters. Among its components we have:
   a) data quality measure description – a text describing the type of quality measure result e.g. pass-fail, number of commissions, RMSE;
   b) data quality measure identification code – it represents a unique ID number in an enumerated domain for each quality assessment of a data quality subelement;
   c) data quality evaluation procedure (described bellow);
   d) data quality result (described bellow).

3) Data quality evaluation procedure – operation(s) used in applying and reporting quality evaluation methods and their results. Among its components we distinguish:
   a) data quality evaluation method type – enumerated domain including three possible values: internal, external and indirect; the former two are direct methods;
   b) data quality evaluation method description – a text describing what does the method of verification of quality consist in; it should accurately describe what elements and to what extent are to be compared.
4) Data quality result – value or set of values resulting from applying a data quality measure or the outcome of evaluating the obtained value or set of values against a specified conformance quality level. Among its components we distinguish:
   a) data quality value type (described bellow);
   b) data quality value – it depends on data quality value type;
   c) data quality value unit (described bellow).
5) Data quality value type – value type for reporting a data quality result (obligatory). Its in an enumerated domain of following possible values: Boolean variable, number, ratio, percentage, sample, table, binary image, matrix, citation, free text, others.
6) Data quality value unit – value unit for reporting a data quality result (provided only when applicable) e.g. count, percentage, metre, hours etc.
7) Data quality date – date or range of dates on which a data quality measure is applied.

3.2. Data Quality Overview Elements

Purpose, usage and lineage are data quality overview elements where applicable are used to describe the non-quantitative quality of a dataset. Purpose shall describe the rationale for creating a dataset and contain information about its intended use. Usage shall describe the application(s) for which a dataset has been used both by the data producer and data user. It is not necessarily the same application described in data quality overview element purpose. Lineage shall describe the history of a dataset and, in as much as is known, recount the life cycle of a dataset form collection and acquisition through compilation and derivation to its current form. It may contain two unique components: source information and process step. The former shall describe the parentage of a dataset and the latter the record of events or transformations in its life.

The International Standard encourage to use additional data quality overview elements to describe an area of non quantitative quality.

4. Conclusions

The increase of DTM uncertainty affects the increase of spatial analysis uncertainty derived from the model so it is important to deliver full quality information about it. User must be aware where data came from, what was the purpose of its collection and acquisition and finally provide quantitative quality information in accordance to applicable data quality elements and their subelements provided by the ISO 19113 Standard. Quality information can be reported as:

- metadata – according to ISO 19115; this is the way data quality should be provided including with the data itself;
- quality evaluation report – according to ISO 19114:2003, Annex I; it provides more detail about the quality results and the procedures used to compute them than is recorded in metadata.

In table 1 data quality elements along with the subelements have been summarized in order to show which elements are relevant for DTM data quality reporting. Usage of every element was described extensively above in this paper.

Table 1. Summary of relevant quantitative quality information for DTM data quality reporting

Data quality element	Data quality subelement	Is relevant?
completeness	commission	yes
	omission	yes
logical consistency	conceptual consistency	?
	domain consistency	no
	format consistency	yes
	topological consistency	yes
positional accuracy	absolute or external accuracy	yes
	relative or internal accuracy	no?
	gridded data position accuracy	no
temporal accuracy	accuracy of a time measurement	no
	temporal consistency	no
	temporal validity	yes/no
thematic accuracy	classification correctness	no
	non-quantitative attribute correctness	no
	quantitative attribute correctness	no

Some of the data quality subelements are not quite clearly defined and might raise some doubt in the data user e.g. conceptual consistency which is the subelement of logical consistency for instance or internal accuracy from positional accuracy group. Having read the ISO 19113, ISO 19114 and ISO19115 man still does not exactly know what the data quality subelement stands for.

Another thing that is conspicuous is the reason for creation gridded data position accuracy subelement. It seems to be a subset of a absolute or external accuracy so it can be treated like a redundant element.

Ambiguity mentioned above may have a negative impact on the understanding of the quality description standard of geographic data by different users, and thus did not meet the standards of the basic ISO standard tenets of verification of compliance criteria set out in the specification.

The solution could be to enrich the standards of:

– more examples for each data quality subelement, especially for those which may cast doubt;
– details of quality assessment for the sample data sets included in the ISO 19113 Standard.

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