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Inspecting map compilation in earth sciences for better communication

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Abstract

The use of thematic cartography in earth sciences is a frequent task for researchers when publishing. When creating a map, researchers intend to communicate important spatial information that enhances, supplements or replaces textual content. Not only visual but substantial requirements exist for those who create maps. Cartographic visualisation has several well-established rules that must be taken into account during compilation, but not all researchers apply them correctly. The present study aims to identify the factors determining the quality of geoscientific maps and what needs to be improved during a map compilation process. To get to know the tendencies, we have investigated maps in designated journals – one Hungarian and one international per earth science branch: geography, cartography, geology, geophysics, and meteorology. A system of criteria was set up for evaluating the maps objectively; basic rules of cartography, quality of visual representation, and copyright rules were investigated. The results show that better map quality is connected to journals with strict editorial rules and higher impact factors. This assessment method is suitable for analysing any kind of spatial visual representation, and individual map-composing authors can use it for evaluating their maps before submission and publication.

Keywords: thematic mapping, cartography, data visualisation, earth sciences

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The role of cartography in earth sciences

Visual processes using cartographic methods have an essential role when publishing different kinds of spatial data. Maps are important supplementary materials of scientific results, according to DiBiase, D. (1990). They can be used when analysing data, giving conclusions, or presenting outcomes. Cartographic visualisation is considered as an integral part of scientific research that can open the gates of science towards a larger audience as well (Philbrick, A.K. 1953; DiBiase, D. 1990; Robinson, A.H. *et al.* 1995).

In geoscientific research, a map has different meanings for the mapmaker and the map reader. The mapmaker works with the map, he/she uses spatial data to analyse, explore and evaluate the observed phenomena, and finally to present the results to the peers. A map reader from the scientific community sees only the representation (the final map) without going through the process of the spatial analysis. However, a researcher must aim for the reproducibility of the research when publishing the results, so the map should represent as much as possible from the process as well. The process and different purposes of map (or spatial data) use were visualised as a cube model by MacEachren, A.M. (1994), where the role of maps changes according to the task, the frequency of inter-

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actions and the type of the users *(Figure 1)*. In this model, the cognitive process of geoscientific research, which uses maps/spatial data, is represented as the body diagonal.

The third dimension (user types) of the cartographic cube is essential in presenting scientific results – the audience can interpret the researcher's message only this way (MacEachren, A.M. and Ganter, J.H. 1990; MacEachren, A.M. 1994). Furthermore, when a map is published as a representation of the results of research, it can also serve as a basis for other scientific works – both in analogue and digital forms (Kraak, M-J. 2002; Kraak, M-J. and Ormeling, F. 2010). This emphasises the importance of proper maps in publications: if the map figure is inappropriate, it can be misinterpreted or not understood. The cycle of maps being interpretations and then base materials, then interpretations again, sometimes lead to scientific discoveries if the map was properly created in the first place; this was the case when Albert, G. *et al.* (2015) predicted the Pálvölgy Cave's volumetric size to be the largest in Hungary, based only on archive maps and polygonal survey data.

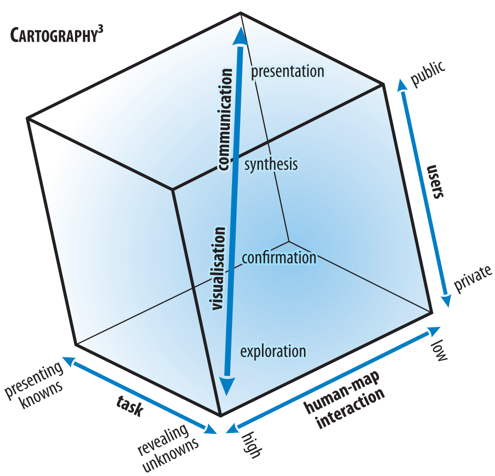

Fig. 1. The cartographic cube (MacEachren, A.M. 1994). Geoscientific thematic cartography is built on the steps presented in it.

DiBiase, D. *et al.* (1992, 1994) analyse the geovisualisation methods of earth sciences on the theoretical basis of the cartographic cube model, but data visualisation methods and interpretation have undergone many changes since that time. Due to today's data collection and recording methods, more and more spatial data are collected in geodatabases, which are too time-consuming to evaluate with traditional 2D methods, so instead of maps, the cognitive process often takes place in a virtual space (Albert, G. 2018). Even so, the final representation is still dominantly 2D (printed maps, figures, still images, etc.), and its purpose is to provide well interpretable scientific information for the reader.

Map figures must fit in the body of the publication and must enrich its content – or should be understandable alone without additional text (it is very useful when we just scan through articles for raising our interest). Map editing is usually an extra task for the authors and might be hard for non-cartographers to consider advanced visual and thematic cartographic rules, but certain features do not need cartographers' expertise and may improve the map significantly. With the correct use of them, map figures can be interpreted easier – gathering a broader audience.

Evaluating maps is not an easy task because there are many elements and aspects that can make a cartographic product a good spatial representation. However, there are some objective factors, such as map accessories (e.g. scale, legend, coordinates, name, and orientation), which help the reader, and their lack may cause misinterpretation. The quality of the topographic base, thematic coverage (raster/vector type), and printing (in the case of printed materials) are also objective factors, along with the presence of references for source materials. Altogether, these objective factors determine the reproducibility of the represented scientific results and give a clue to the reader how the research process took place in the first place. The preludes of this study examining the objective characteristics of geoscientific maps reach back to the 20th Carpathian-Balkan Geological Congress in 2014 (Tirana, Albania), where the greatly varying quality of the presented studies' map figures triggered the idea of a systematic analysis of the problem. The core of the map evaluation system presented here was worked out during this conference by Gáspár Albert, and he also gathered some samples there. The main idea then was to determine the factors that make a map less interpretable.

This study examines the maps of different geoscience branches focusing on the map accessories and the quality rooting from cartographic standards. The classification of geoscientific maps declared by the ICA Commission on Thematic Cartography in the 1970s (led by Emil Meynen) distinguish seven categories (Klinghammer, I. and Papp-Váry, Á. 1983): 1) morphometric, 2) geophysical, 3) geological, 4) pedological, 5) geomorphological, 6) hydrological and 7) meteorological (climate) maps. Elements of this system refer to an individual science branch in geosciences.

To evaluate how the different disciplines manage maps, we have chosen journals and conference posters from the field of cartography, geography, geophysics, geology, and meteorology. The working idea was that we would find differences among the disciplines in the use of the objective factors determining the reproducibility of certain research. The spatial variability of map use was also supposed – there might be remarkable differences between each countries' map representations. This was observed in the prelude study as well: authors from countries where scientific publication has a longer tradition produced clearer maps. We especially focused on the differences between Hungarian and international scientific literature. Our main aim was to conclude the connections between thematic map use, scientific journals, scientometry, science fields, and geographical diversity.

Map sources: designated journals

To analyse the differences between the map use of geoscientific disciplines we have designated one Hungarian and one international English language journal dealing with geography, geology, meteorology, cartography, and geophysics. The reason for choosing Hungarian and English language international papers was to find the characteristics of thematic map use in Hungary too and make comparisons with the 'worldwide' data.

Only a few Hungarian earth science journals are in high quartiles or have high H indices, but we have selected the best one in each field based on scientometry (Hodge, D.R. and Lacasse, J.R. 2011). The international papers were chosen from high quartiles (Q1 or Q2). The source for scientometric data was the database of SCImago Journal & Country Rank (SCImago 2020).

The data gathering process from journals was the same for all five disciplines. We looked for the last available issue and started from there backward until reaching approximately 300 maps per field (~200 maps from international and ~100 maps from Hungarian articles). Besides these, we also took nearly 100 photographs of maps from posters at international conferences. They were also included in the evaluation.

We have tried to maintain a balance between each field in the number of representations to examine. Taking into consideration maps from journal articles and posters, we have evaluated a total of 1,509 maps. Data about the journals involved in this study can be found in *Table 1*.

The methodology of the evaluation

During the evaluation, each journal issue was searched for maps. The Cartographic Journal, Geodézia és Kartográfia and Földrajzi Közlemények were available in the library of the Institute of Cartography and Geoinformatics. The other papers were online: a print screen was taken from each examined map figure. Unique ID numbers were assigned to each representation to make further identification easier. The evaluation model is built up of six main groups, each of them defined by directives concerning the criteria (*Table 2).* The nationality of the first author was noted

Table 1. Scientometric data about the journals examined in this study based on the information from the database of SCImago Journal & Country Rank at the time of the study

Discipline	Journal	Country	H index*	Quartile**	Total cities in 2018
Cartography	*The Cartographic Journal* (from issue 2014-1 to 2018-3)	United Kingdom	25	Q2	132
	Geodézia és Kartográfia / Geodesy and Cartography (from issue 2014-1 to 2019-4)	Hungary	7	Q4	2
Geography	*Geoheritage* (from issue 2019-1 to 2019-3)	Germany	21	Q2	264
	*Földrajzi Közlemények**** / *Geographical Review* (from issue 2017-1 to 2019-2)	Hungary	–	–	–
Geophysics	*Earth & Planetary Science Letters* (from issue 2019-1 to 2019-4)	Netherlands	215	Q1	8,720
	Magyar Geofizika / Hungarian Geophysics (from issue 2010-1 to 2014-2)	Hungary	7	Q4	1
Geology	*Geology* (from issue 2019-6 to 2019-12)	United States	189	Q1	4,256
	Földtani Közlöny / Bulletin of the Hungarian Geological Society (from issue 2017-1 to 2019-4)	Hungary	9	Q3	21
Meteorology	*Quarterly Journal of the Royal Meteorological Society* (from issue 2019-7 to 2019-9)	United States	125	Q1	2,843
	Időjárás / Weather (from issue 2018-4 to 2019-4)	Hungary	13	Q3	59

*An entity has an H index value of y if the entity has y publications that have all been cited at least y times (Hodge, D.R. and Lacasse J.R. 2011). ** The set of journals have been ranked according to their SCImago Journal Ranking and divided into four equal groups, four quartiles. Q1 comprises the quarter of the journals with the highest values, Q2 the second highest values, Q3 the third highest values and Q4 the lowest values (SCImago 2020). *** Földrajzi Közlemények is not indexed currently in SCImago.

separately to provide data for visual criteria analysis by countries.

Map visualisation

There are three criteria in the 'Visualisation' group: excellent, medium, and poor. Although these categories seem to be subjective ones, the evaluation focuses on characteristics, which can be identified objectively. Good readability (due to properly sized and placed symbols and texts), unique and theme-fitting symbol set, the balance between the base map and the thematic content, and between the printing quality and the resolution of the map are the basis of the assessment within this group.

Layout types

The 'Type' group is evaluated by determining the purpose of the examined map in the article. It can place the study in question into a larger geographical content ('overview'), can show results in either small or large scale ('main') or can be a detailed map about the conclusions of the article ('detail'). However, there can be mixtures of these types that are

Table 2. Criteria of the map evaluation system

A) Visualisation
- *Excellent:* The map is designed for its purpose. The symbols are unique or appropriately selected for the topic. The base map and the thematic content are in harmony. The printing quality matches the resolution of the map.
- *Medium:* The content is readable, but the symbols are not designed for the purpose of the map (e.g. usage of default colours, line types). Base map and thematic coverages are compiled differently. The printing quality matches the resolution of the map.
- *Poor:* The content is hardly readable due to inappropriate symbols (in vector-based maps), rough resolution (in raster-type maps) or the bad quality of printing.

B) Type
- *Overview:* The map is for showing the location of the study area. It is a small-scale map, which can be solitary, or in pairs with the main map.
- *Main:* The map shows the results of the research subject. It can be solitary or in pairs with a main- or a detail map.
- *Detail:* The map shows the results of the research subject in a large scale. It is always in pairs with the main map.
- *: in the case of mixed types, use the * sign for the inferred and '1' for the dominant type.

C) Accessorial (coordinates, orientation, scale, legend, name/title)
- When doing the survey, put a checkmark in the proper column if the accessorial type exists on the map (consider the captions of figures as names/titles in some cases).

D) Topographic content (put a checkmark in the proper column if the accessorial type exists on the map)
- *Hypsography:* contours, shaded relief, graded hypsometry, etc.
- *Hydrography:* watercourses, lakes, rivers, channels, springs, wells, marshes.
- *Road network:* roads, trails, streets, etc. (manmade structures).
- *Boundaries:* delineator signs of administrational territories.
- *Settlements:* signs of human build structures/administrational units (i.e. cities, villages, farms).
- *Names:* geographical names (of natural and manmade objects).

E) Thematic content (in this criterion, all existing map types from the evaluated set should be written). In our case:
- Geological, geophysical, geographical, geomorphological, meteorological, cartographical, ethnographical or general, if there is no thematic content.

F) Base map type
- *Copy unreferenced:* scanned raster from an existing map without citation.
- *Copy referenced:* scanned raster from an existing map with citation.
- *Edited:* edited topography/thematic base map content with references to the source of data.
- *Vector:* the base map seems to be edited, but the data source is not indicated.
- *No data:* the base map exists, but there is no information about it.
- *No base map.*

G) The nationality of the article's first author

marked with the help of an asterisk (inferred type) and a '1' (dominant type). In the latter case, the maps counted as their dominant type.

Map accessorial

The presence of certain elements makes a compiled figure a map. The role of map accessorial is to give information about the geographic position and extent of the presented territory, the meaning of the thematic symbols, and others. Some of them are necessary, and some of them are optional. The necessary ones are the coordinates, orientation (usually the direction of North is marked – but sometimes the letters before the coordinates substitute this), and name (this can be substituted by the figure caption). Optional accessories are the legend (it can be omitted, for instance, on overview maps), the graphic or numeric scale (coordinates may serve as scale bar), and the colophon (not present if such information is mentioned elsewhere, e.g. in the article/book that contains the map). Each accessorial, except for the colophon, was checked during the evaluation; either it was on the map layout or in the caption.

Topographic content

Some topographic content is essential in all thematic maps: by looking over the plotted physical characteristics of the examined area the reader can imagine the displayed topic in a geographical context. The topographic content comprises features such as hypsography, hydrography, road network, boundaries, settlements, and geographic names. However, there exist geoscientific maps that do not require the presence of some of these features – either because of thematic data density (e.g. hypsography is often omitted from geological maps), irrelevance (e.g. detailed hypsography is irrelevant on some geophysical maps), or small scale (e.g. meteorological maps). The topographic content is part of the background map unless one or more of its features are clear subjects of the article's topic (e.g. in case of research on relief, hydrology, traffic, etc.). We recorded the presence of the topographic features on the examined maps, which made it possible to get the different thematic map types under a unique evaluation.

Type and source of data content

The next evaluation criterion is the determination of the genre of the thematic content (e.g. the map is geological, meteorological, ethnographical, general, or any other). This category usually came automatically due to the journal where the map figure was published. The categories refer to the type of base data that was processed in the compilation of the thematic content.

The last group examines the source of the base map and the copyright situation of the base map content. Referenced or unreferenced copies and edited or self-made base maps are also common. Though the base map usually contains topography, in some cases published thematic maps were used as base maps for the representations (e.g. tectonic lines placed on a published geological map). Most journals recommend submitting vector images and high-resolution raster maps that can be modified by the editor without significant loss in printing quality (note that printing quality was an evaluation criterion in the first group). However, it is very common to combine the two types in the course of editing the figure map, with the result being a raster-type figure. Ideally, the thematic content is edited by the author(s) on a properly cited good quality base map.

The structure of the database

The evaluation process was carried out with MS Excel software. Two individual tables were opened for each geoscience field and two for the posters. One contains information about each article (name of the journal, title, authors, date of issue), while the other table contains the evaluation records. The tables are connected by the unique ID of every article. As most of the evaluation criteria deal with the presence or lack of certain map features, we used a '1' mark to indicate if a certain feature is on the image and left the database cell empty if not. The statistics were separated into a new spreadsheet and organised for the desired purpose: to make comparisons between branches of science and based on the nationalities of the first authors.

Evaluation of map compilation habits in earth science disciplines

After summing up the scores in the worksheets, each criterion group was evaluated with basic statistics and visualised using bar charts. For the evaluation, we also used the built-in functions of Excel.

The quality of map visualisation was sorted into one of the following three categories (*Table* 2, A): excellent, medium, and poor. The general percentages concerning each field are the following: 62 percent of the cartographic, 80 percent of the geographical, 69 percent of the geophysical, 86 percent of the geological and 77 percent of the meteorological maps are excellent, 14–35 percent have medium quality while the proportion of poor maps is around or under 3 percent in all five cases (*Figure 2*). Larger differences between the disciplines exist in the medium and excellent categories.

The order of science branches according to the largest quantity of visually excellent maps may seem surprising. The largest number of 'excellent' maps (258) comes from the geological thematic category. It is followed by geographical (250), meteorological (230), and geophysical (210) maps. The least number of 'excellent' maps (181) occur in the cartographic dataset. The data are visualised in *Figure* 2.

The map visualisation in the various disciplines shows remarkable differences if we summarise the scores for the Hungarian and the international English language journals (*Figure 3*). In most cases (geography, geophysics, geology, and meteorology) international papers have a higher proportion of "excellent" maps (the largest contrast is between the quality of geophysical representations). The percentage of "poor" quality maps is low in both cases regarding every discipline. Surprisingly, the trend is reversed when examining maps of cartographic journals: more maps in the Hungarian papers are evaluated "excellent" than that of international issues.

The used map types – overview, main, and detail – also varies by disciplines (*Figure 4*). Geography, geophysics, and geology use mainly overview maps (66%, 63% and 82%, respectively) to present different characteristics of the sample area, while cartography and meteorology use this type less frequently (25% and 41%). The tendency is reversed in the case of main maps: maps in cartographic journals and meteorological maps use this type more often (68% and 59%) and the other disciplines rarely (17–37%). The presence of large-scale detail maps is not significant – the results are usually presented in main maps or inferred detail maps.

The results concerning map accessorial is also diverse (*Figure 5*). Nearly all maps have a name/title (97–100%), which partly comes from the evaluating method: figure captions were recognised as titles. The presence of legend is more diverse (52–83%), but the cartography discipline differs significantly from the other science branches.

The cases of the other three elements are also diverse. The use of "scale" on maps is equally high (73%) for the geography and geology disciplines and low for the geophys-

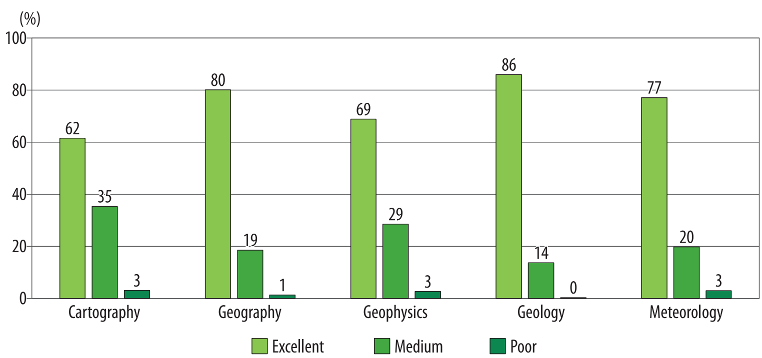

Fig. 2. Results of map visualisation criteria category. Most maps fall into the 'excellent' category, but the range of the difference is significant (24%) between the disciplines.

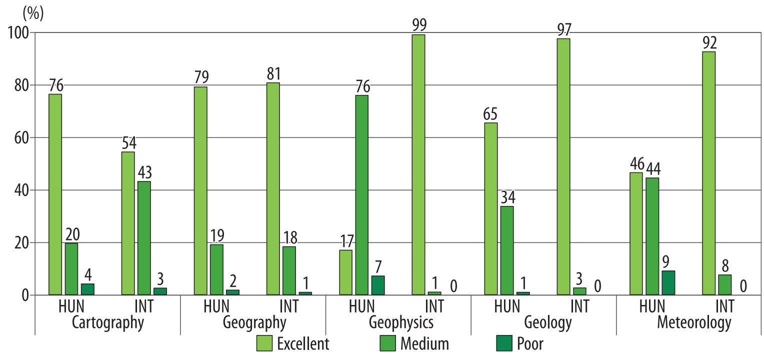

Fig. 3. Map visualisation criteria results per disciplines in case of Hungarian and international journals

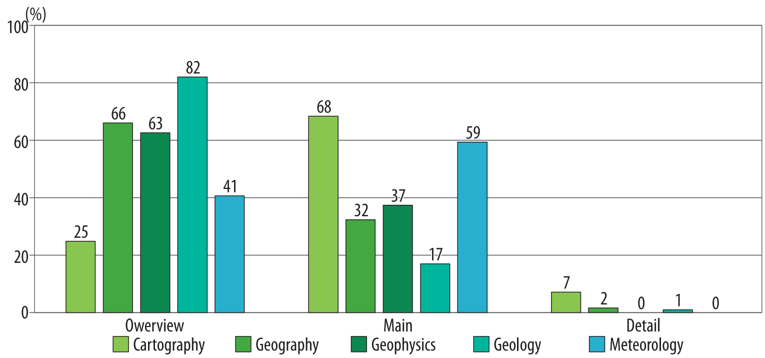

Fig. 4. Map types mainly used in geoscientific maps. Geography, geophysics, and geology mainly use overview maps, while main maps are rather common in cartographical and meteorological articles.

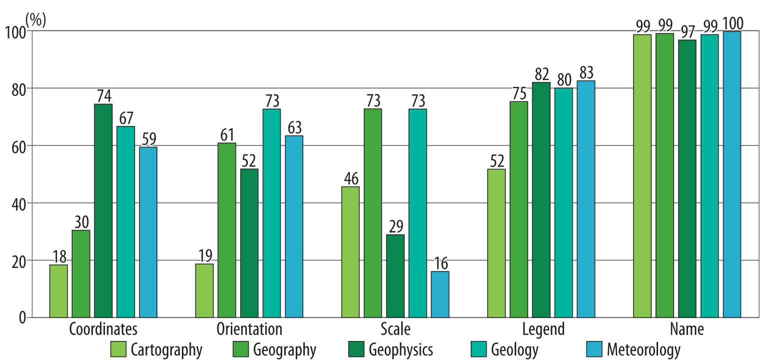

Fig. 5. Results of the accessorial category. The evaluation based on the presence of map elements have a more diverse outcome: coordinates, orientation and scale are often omitted from geoscientific thematic maps.

ics and meteorology (29% and 16%, respectively). Cartography is in between the two groups with 46 percent.

In the case of "orientation", the pattern is similar to the situation of "legend": the maps in cartographic journals do not usually show it (19%), while all the other disciplines do (52–73%). The use of coordinates on map figures can be divided into two discipline groups: those who rather display this information (geophysics, geology, and meteorology with 74%, 67% and 59%), and those who rather do not (cartography and geography with 18% and 30%).

The presence of topographic elements is evaluated by map feature categories. Hypsography is the least used on meteorological maps (7%) but is almost equally present on maps of the other disciplines with 23–33 percent. Nearly the same tendency (but with 11% on meteorological, 34% on geophysical and 52–57% on the other maps) is true for hydrography. Road network is the least common topographic element in geoscientific thematic maps: only 1–5 percent of geophysical, geological, and meteorological maps use this map data type. It is underrepresented even on geographical maps (21%) and on maps in cartographic journals (34%). Boundaries as the shapes of countries are mainly drawn in the maps to help the reader to place the shown area in a geographical context. Their proportion is relatively low in geological maps (27%), medium (48–52%) among cartographical, geographical, and geophysical maps, and high (77%) in the case of meteorological maps. Settlements are rarely shown on meteorological (6%) and geophysical (14%) maps, but three out of four geological maps also lack this map data type. The remaining disciplines show settlements between 43 and 52 percent (cartography and geography). Geographical names are the most common topographic elements in geoscientific thematic maps: 87 percent of geological, 73 percent of geographical, 59 percent of cartographical and geophysical representations contain such elements, and only the meteorological maps do not usually show them (13%). These data are visualised in *Figure 6*.

The base map type evaluation is the most diverse group: the deviation between the discipline percentage values is the highest in this evaluation category. Most maps are well-referenced (e.g. cartography – 46%) or without base (e.g. cartography – 49% and meteorology – 57%). Unreferenced scanned maps are not frequently used (0–15%), but it is relatively common not to provide any information about the base map, as, for example, in the examined geographical (41%), geological (41%) and meteorological (21%) articles. Well-referenced unmodified scanned raster maps as base maps are most common in cartography (46%), while the other disciplines tend not to use such base maps (5–18%).

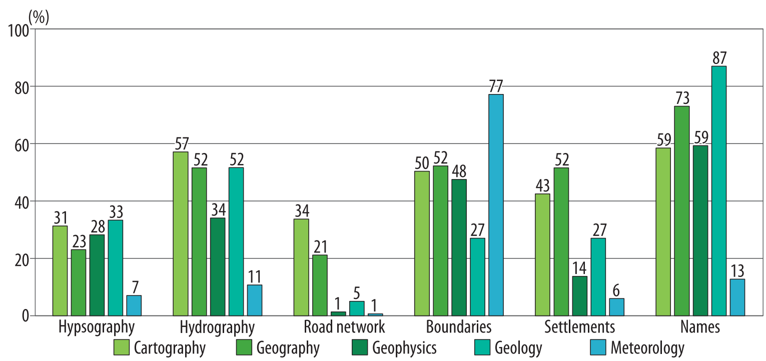

Fig. 6. The presence of topographic elements in geoscientific thematic maps. This is a rather unbalanced evaluation category. Road network is usually omitted from maps, while geographical names are common.

The use of edited (modified) base maps with references is frequent in the geophysical and geological papers (45% and 46%), less common in the geographical and meteorological papers (24% and 14%) and rare in cartographic papers (5%). Edited (modified/digitised) maps lacking the data source are not representative in the dataset except for the 1 percent in geophysics. The base map information is summed in *Figure 7*.

Analysis of the visual criteria by countries

The examined maps can be divided into two groups: maps from the Hungarian and the international papers. Approximately one-third of the maps per geoscience field came from a Hungarian journal (these are maps mainly with Hungarian first authors), while the remaining two-thirds came from international journals with mainly foreign first authors. Based on the affiliation of the first authors, the total number of countries was 48, where the number of recorded maps was 31.65 per country by average. We have analysed the visual criteria group to compare Hungarian means with international trends. Countries with more than 20 records can be seen in *Figure 8*.

Thirteen countries were selected for further analysis; these are mainly from Europe (8 countries), the United States, China, Australia and Brazil. In *Figure 9*, the 13 countries with more than 20 evaluated maps are compared to each other; also, these countries are the ones that set up the "International (developed)" category in *Figure 9*. The maps with first authors from Spain, Norway and the UK have the best proportion of visually "excellent" maps (greater than 90%), while the USA, Germany, France, Poland, and Brazil have just a bit more "medium-" and/or "poor-visualised" maps (less than 20% altogether). The situation of Chinese, Swiss, Australian and Italian maps is different: 69–77 percent of the evaluated maps are "excellent", 21–31 percent are "medium", and usually there is a little group (0–3%) of "poor-quality" maps.

Comparing the maps in the papers with Hungarian and foreign first authors *(Figure 9)*, the differences in the visual evaluation are remarkable: 85 percent of the maps in the international set are "excellent", while the rate of the same category in the Hungarian set is only 58 percent. The proportion of "medium-quality" maps is 14 percent internationally and 39 percent regarding Hungarian first-author articles. The number of "poor-quality" maps is nearly the same (3–1%) in both sets.

Upon the evaluation of the remaining countries from the international dataset, a

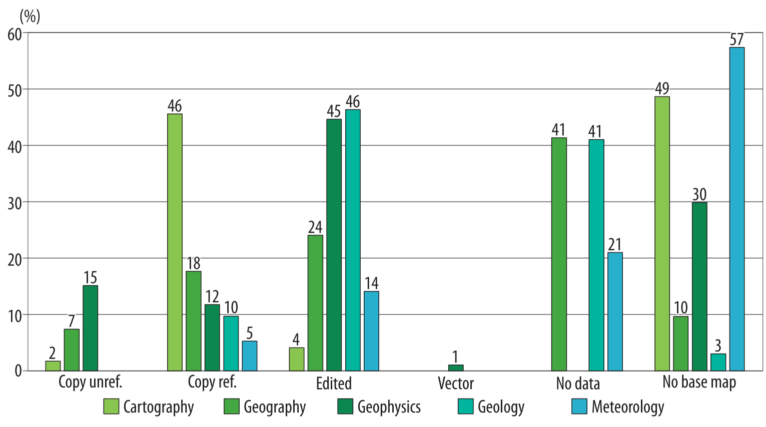

Fig. 7. Base map data of the examined maps by disciplines

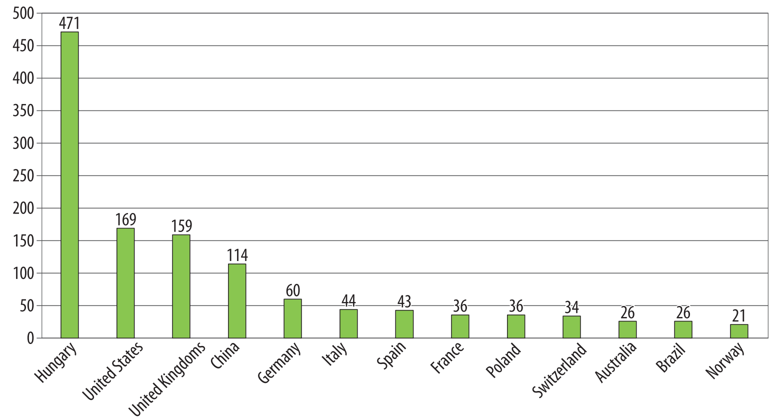

Fig. 8. The most common countries with the first authorship having more than 20 records in the examined maps database. The total no. of countries was 48 where the number of records was 31.65 on average.

group was distinguished that includes the developing countries of Africa, Asia, South America, some of the countries from the Balkan Peninsula, and the former communist countries of Central Europe. This group is referred to as the "developing areas" in this study and shows similar percentages in the visual evaluation as the Hungarian dataset. There are 773 maps (~50% of all) in the examined database from "developing areas", where the average visual score was considerably poorer (63% excellent, 34% medium, 3% poor), despite the maps having appeared in international journals.

Discussion

Each thematic map has different purposes, and the results confirm this. The criteria "Visualisation", "Type" and "Base map type" (see *Table 2*) can be assessed by universal means, but all other criteria depend not only on the author but also on the data that he or she wishes to transmit. This means that the attributes "Accessorial", "Topographic content", "Thematic content" and "Nationality" provide first and foremost an insight into the current state of map use in the earth sciences in the form of statistical data.

The relationship between the quality of journals and maps can be determined. Journals with higher H indices and higher quartiles have stricter editorial rules: images and maps of medium and poor quality are thoroughly filtered by the editorial board. These papers often require vector images that can be easily modified or resized during the editorial process. The difference in the visualisation scores can also be explained by this: disciplines with prestigious and long-standing journals having high scientometric scores produce more "excellent" maps.

Map quality is also connected with usability and legibility, not only with formal cartographic rules. The most important purpose of representations is to provide meaningful scientific information. Consequently, there are some factors that can be examined from the user's point of view. Feedback from map readers can contribute to map development by identifying and indicating features that make understanding difficult. As a result, further visualisation methods and editing aspects may emerge as new perspectives. Albert, G. *et al.* (2017), and Szigeti, Cs. *et al.* (2018) address, for instance, the interpretability of maps and the issues and editing solutions regarding map symbology. Such an examination can also be carried out on geoscientific maps.

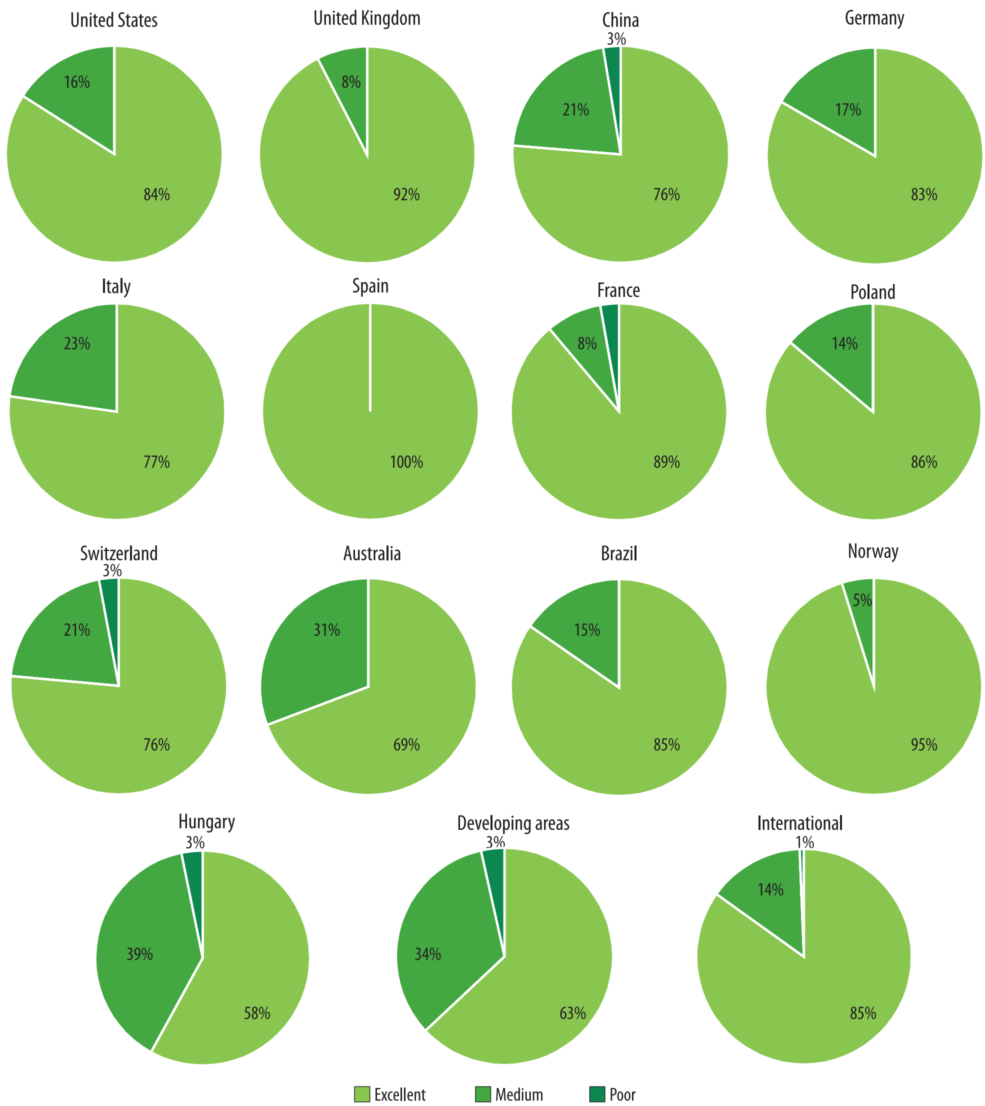

Fig. 9. Visual evaluation of maps from countries having more than 20 maps

Although map editing has become a routine task in the geoscientific community with the emergence of various GIS tools, knowledge of cartographic rules does not come with the software, and it is a difficult task to design visually satisfying and informative maps that conform to these rules. The presence of map accessorial (*Figure 5*: coordinates, orientation, scale, legend and name) was expected to be a good indicator for the author's experience in map making, but as their use was the least frequent in the cartography discipline, it is more likely to depend on the standards set by the journal or its editors. However, only the journal: "Geology" has guidelines regarding coordinates, scale, and orientation among the examined journals. This means that in most cases, the maps were probably enhanced by a thorough editorial process in which the inappropriate maps were filtered out and revised.

The topographic content (*Figure 6*) of a geoscientific map is mainly the part of the base map – and has a role in locating our thematic map in a geographic context. The hypsography, hydrography, road network, boundaries, settlements and geographic names are there to help the reader, and the various disciplines require some of these to be omitted. The base map (usually from a different source) that contains topographic information must be referenced. Higher editorial standards demand self-edited vector maps because these can be resized and edited easily during the editorial process. Raster base map layers are not suitable for modification because of the large quality degradation. Unclear copyright issues are not usual in high-ranking journals, but we can face some unclear issues, as this study also shows.

The main map types are closely related to the geoscientific branches (*Figure 4*). Some fields have a fundamental need for cartographic representation of their data (they mainly work with spatial information – such as cartography, geography, and meteorology). They use main maps to present results on a larger scale. But there might be topics that are not closely linked to spatial factors: e.g. geochemistry or atmospheric physics. These disciplines rarely use main or detail maps, just overview maps in some cases to depict the sample area.

We have examined the visual characteristics of the maps by countries of the first authors. The other criteria groups were not analysed in this way because a larger number of evaluated maps per discipline would be needed to examine country- and science branch-dependent factors at the same time. Correlations can be drawn between good visual quality and countries with a long history of modern scientific publishing. Thus, the UK and the USA have much better visual scores than China or Hungary, for instance. Many articles and maps come from developing countries, where the tradition of scientific publication is weak *(Figure 8)*.

Although we tried to reach an objective result, the proposed methodology may have some shortcomings or flaws. Its thematic map groups are based on the official ICA categorisation (Klinghammer, I. and Papp-Váry, Á. 1983), covering a very broad range of disciplines. This may result in distortions, as the use of maps in some scientific fields is not restricted to a narrow set of map features but uses a great variety of them (e.g., road networks are not necessary in a population density map but are useful when presenting transportation data – but both are geographical). The personal opinion of the evaluators can cause a potential bias: the aesthetic parameters and features influence the evaluation in a subjective way. This is controlled and, to a certain extent, kept in check by the numerical form of evaluation.

As 3D graphics are traditionally considered as map-like representations rather than maps, this methodological framework is not completely suitable for evaluating them due to the formal cartographic rules. A modified version of the model can be developed later to examine these representations.

Conclusions

In this study, we presented an evaluation system (see *Table 2*) that is available to assess any thematic map published in scientific journals. By using this objective method, visual qualities, map types, map accessorial, topographic elements, thematic content, base map types and unique geographical characteristics can be determined. We have conducted a case study involving 1,509 maps, ~300 per each field of geoscience (cartography, geography, geophysics, geology, and meteorology), from one Hungarian and one international English language journal per discipline. The selected maps were analysed according to the criteria groups of the presented model. The following conclusions can be drawn from the thematic maps for earth sciences:

We conclude that in the cases when the quality of maps is poor or medium, and essential map elements are omitted, the reason was partly due to the less strict editorial rules (e.g. Hungarian geoscientific journals) and the lack of modern scientific publishing tradition.

The analysis of the visual criteria, the type and the base map can be evaluated universally for all disciplines and serves as an important basis for comparison.

A new style of map use can be determined by thoroughly evaluating the scientific maps of the past years. This is specific to each discipline and can be characterised by the statistical analysis of map accessorial and topographic elements.

The presented method is suitable for the assessment of any kind of scientific thematic map, not only for the earth science disciplines discussed. Since certain directives on the preparation of figures and captions for maps are very rarely found on publishers' websites, the criteria presented here can also be used as a checklist for the preliminary evaluation of maps prior to publishing, as well as for journal editors and reviewers when working with submitted manuscripts.

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