Polish Cartographical Review
Vol. 57, 2025, pp. 40–57
DOI: 10.2478/pcr-2025-0003
Received: 07.02.2025
Accepted: 26.05.2025

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Evaluation of persuasiveness of selected map designs for presenting dominance of phenomena on thematic maps

Abstract. Various editorial decisions made during the cartographic design process may lead to different interpretations of the same phenomena, potentially emphasizing one phenomenon at the expense of another. Such decisions occur at different stages of map development, including the selection of enumeration units, a form of data representation (map type), and map graphics, including color scales.

This article presents the results of a user study examining the impact of selected map design choices – specifically: a level of spatial unit aggregation, a type of color scale, and a form of data presentation (a qualitative area map, a choropleth map, a cartogram, graduated symbols with choropleth colors) – on the accuracy of perceiving the dominance of a phenomenon shown on thematic maps. The study employed thematic maps visualizing two socially relevant topics: ethnonational diversity and presidential election results, each displaying two categories. The survey, conducted using the CAWI (Computer-Assisted Web Interviewing) method, involved 151 participants. Respondents were asked to identify which of the two categories was dominant on a given map. Response accuracy (identification of the actual dominant phenomenon), the perceived difficulty of the tasks, and the perceived magnitude of dominance were measured. Participants were also asked to describe the spatial distribution of the dominant phenomenon and indicate a map design preferred by them.

Based on the collected responses, the analysis revealed statistically significant differences in metrics depending on the map designs tested. The tested map designs, therefore, vary in their degree of persuasiveness in portraying dominance. The article concludes by identifying the techniques that more or less effectively distort the information conveyed by thematic maps.

Keywords: information distortion, visual perception, thematic maps, user study, data visualization, persuasiveness

1. Introduction

A fundamental feature of any map is the simplification of the represented reality, achieved through processes such as generalization, classification, and symbolization. This simplification may lead to greater or lesser distortions of the information presented (Monmonier, 1991). In some cases, these distortions are intentional; in others, they are unavoidable consequences of the underlying assumptions of a particular map type. A key question arises: to what extent do these distortions influence the user's perception of the map? Which of the map designs are more persuasive and most strongly affect map perception and interpretation – potentially leading to erroneous conclusions among users? Due to the broad nature of this issue, the presented study focuses specifically on the visual presentation of the dominance of one among two presented categories of a phenomenon shown on a thematic map. The aim of the study is to compare the suggestiveness of selected map design choices in portraying dominance on maps. The study concentrates on three design choices made at different stages of map development: spatial enumeration units, the form of data presentation (map type), and a color scale. The tested solutions covered: level of spatial aggregation (three administrative levels – municipalities, counties, and districts), map types (qualitative area map, choropleth map, cartogram, and graduated symbols map), and color scale for a choropleth map (sequential and diverging). Two types of maps were tested: showing ethnonational diversity in the former Lwów Voivodeship, and depicting the results of the presidential election in Poland. An online survey involving 151 participants was conducted. Respondents answered questions based on the information acquired from maps developed for the study. The analysis of responses regarding the perceived dominance of phenomena in both map sets provides insight into how the tested cartographic solutions influence users' perception and interpretation of spatial information.

2. Map design solutions for presentation of phenomenon dominance

Design choices play a significant role in shaping how users perceive and interpret the data presented on maps. Some of these decisions may lead to distortions of the represented information by creating a visual impression that diverges from the underlying reality (Tyner, 1982). One such example is the level of aggregation of spatial enumeration units. For instance, Kuby et al. (2013) observed that the level of aggregation influences the spatial patterns perceived by users and is dependent on the spatial scale of the analytical units. Ratajski (1989) emphasized that selecting an appropriate level of data aggregation is essential for achieving a clear and accurate cartographic visualization that allows for the correct interpretation of the depicted phenomena. Monmonier (1991) similarly noted that altering the level or method of aggregation can lead to different conclusions, highlighting the importance of caution and transparency in the process of data generalization.

One example of intentional distortion in map communication – known as cartographic manipulation – through the grouping of spatial data is the Modifiable Areal Unit Problem (MAUP), formulated by Openshaw (1984). He argued that high levels of aggregation may obscure local variability and differences, while low levels of aggregation (i.e., smaller enumeration units) can emphasize extreme values that may be interpreted as dominant. The way of grouping spatial units results in differing intensity values of the phenomena presented (Figure 1).

Another approach in data aggregation manipulation is gerrymandering. This approach involves combining areas to strengthen the influence of one group at the expense of another (Pierzgalski, 2015). Gerrymandering has been most commonly used for political purposes, influencing the interpretation of spatial data

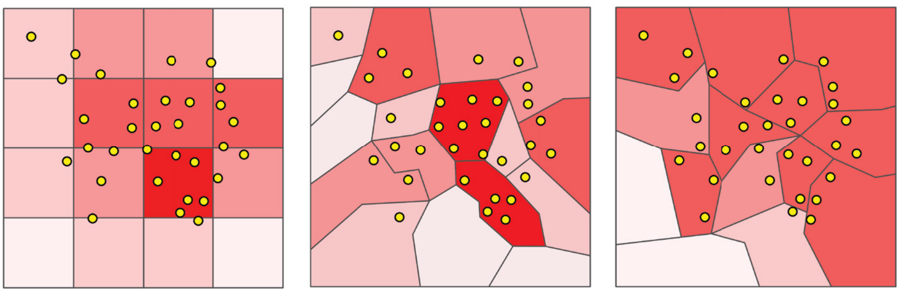

Figure 1. Different methods of spatial grouping of discrete data resulting in varying intensity values of the phenomenon (Modifiable Areal Unit Problem – MAUP). Source: author's own work

through the strategic design of boundaries. The most well-known techniques of gerrymandering are "packing" and "cracking" (Wu et al., 2020). Packing involves concentrating undesired units (e.g., people or votes) into one or several districts to reduce their influence in surrounding areas. This lowers the number of districts where they can achieve dominance, even if their numbers are locally significant. In contrast, cracking refers to spreading these undesired units across many districts in such a way that they are too dispersed to secure dominance in any of them, despite having strong overall values across the region. These techniques are of great importance in cartography, as the selection of enumeration unit boundaries can affect how a map is interpreted by its users.

Previous research (Karsznia et al., 2021) has shown that determining the optimal size of spatial units (in the context of choropleth maps) is a complex issue, dependent, among other factors, on the nature of the phenomenon being represented. In the analysis of eight sizes of hexagonal units, the authors found that both excessively small and excessively large units can hinder users' ability to recognize spatial patterns effectively. The choice of the aggregation level is particularly evident in a qualitative area map type. This map type typically emphasizes phenomena with a broader spatial extent, but not necessarily with higher intensity, as it is a qualitative technique (Robinson et al., 1995). Its advantage lies in the simplicity of interpretation and the ease of distinguishing areas; however, a characteristic limitation is the lack of information about the intensity of the phenomenon (Ratajski, 1989). Phenomenon intensity, in turn, is often visualized using a choropleth map, which employs a quantitative color scale – either sequential or diverging. Brewer (1996) recommends using a sequential color scale to represent data that show a unidirectional change (increase or decrease), with lightness progressing from high to low. A diverging color scale should be applied when data contain a meaningful midpoint (e.g., zero, average, or neutral value), from which values diverge in two directions. Harrower and Brewer (2003) state that sequential scales are easier to interpret, whereas diverging scales are essential for data where both positive and negative values are relevant. The appropriate selection of a color scale is one of the key components of effective cartographic data visualization, as it directly affects users' perception and interpretation of maps. For example, research by Borkin et al. (2011) shows that spectral color scales are most often preferred by participants due to aesthetic appeal and familiarity; however, the study also pointed out their limitations – such as the lack of an intuitive association between color and value, which hinders fast and accurate reading of the data.

In a comparative analysis of quantitative map types – choropleth map, graduated symbols map, and isolines – conducted by Słomska-Przech and Gołębiowska (2021), the choropleth map proved to be the most effective form for supporting participants' performance. The use of this map type resulted in the highest answer accuracy, the shortest task completion times, and the lowest levels of perceived difficulty. However, the authors emphasized that the preference for a choropleth map may be influenced by its frequent use in school-based geography education. A choropleth map method can be combined with the graduated symbols map, using a selected color scale to fill the symbols. Such graduated symbols with choropleth colors may be more effective for experienced map users, as it not only presents relative quantitative data within units but also conveys the absolute values of the phenomenon through the size of the symbols.

A qualitative area map can also be combined with other methods, e.g., a cartogram. In a cartogram, the size and shape of spatial units (e.g., countries, voivodeships) are distorted proportionally to the values of a given phenomenon (Dorling, 1996). Cartograms are becoming increasingly popular, and the current development of cartographic anamorphoses is closely tied to the growing use of GIS software (Faliszewska, 2012). A cartogram can be particularly informative when combined with a choropleth map, but due to the transformation of area shapes and sizes, this map type should be used only for large and well-known reference units – such as countries and provinces (Dębowska & Korycka-Skorupa, 2010). It is important to remember that a correct interpretation of cartographic anamorphoses depends both on the skills of a mapmaker creating the map and a user's ability to read and understand its content (Dent, 1975).

At many stages of the cartographic design work, multiple decisions are made that may influence how the magnitude and dominance of a phenomenon are estimated within the mapped area. It is valuable to examine the extent to which these decisions affect the user's final interpretation of the map.

3. User study

3.1. Motivations

The aim of the study was to determine the impact of selected map designs on the interpretation of the dominance of one of two categories of a phenomenon. Two types of maps were tested: one illustrating ethnonational diversity in the former Lwów Voivodeship, and the other presenting the results of the presidential election in Poland. The choice of these two topics was motivated by their representation of different subjects of significant social importance (Lewis-Beck & Rice, 1992). The selection of data types was guided by both the magnitude of dominance and the spatial extent over which the dominant category prevailed. On the maps of the Lwów Voivodeship, the dominance was substantial (25.6 percentage points), and the phenomenon primarily prevailed in urban areas. In contrast, in the case of electoral data, the difference between the categories was minor (2.06 pp), and the dominant phenomenon was concentrated mainly in rural areas.

The independent variables in the study were:

(1) map types: *qualitative area map* and *simple choropleth map* (for ethnonational data), and *qualitative area map*, *cartogram*, and *graduated symbols map* (for electoral data);

(2) a color scale: *sequential* and *diverging* scales (applied to the choropleth map for ethnonational data);

(3) a level of data aggregation: *districts*, *counties*, and *municipalities* (analyzed for ethnonational data), and *voivodeships*, *counties*, and *municipalities* (for electoral data).

The dependent variables were response accuracy and user preference. The purpose of the study was thus to examine how selected map designs influence the perception of dominance between two data categories.

3.2. Preparation of maps used in the study

3.2.1. Maps of ethnonational diversity

Historical nationality data of the former Lwów Voivodeship were selected for tasks aimed at examining the impact of the level of aggregation on the assessment of dominance and the spatial distribution of categories. According to the 1931 census (published in 1938), the Lwów Voivodeship was home to 3.13 million inhabitants. The largest ethnic group were Poles (1.80M, 57.6%), while Ukrainians and Ruthenians constituted 34.1% of the population (1.07M). The remaining 8.3% consisted mainly of people of Jewish origin. For the purpose of the study, only Poles and Ukrainians were considered. In this case, they accounted for 62.8% and 37.2% of the voivodeship's population, respectively. The Polish population dominated the northwestern part of the region and urban areas, while the Ukrainian and Ruthenian population prevailed in the south and east, particularly in rural areas.

To illustrate the impact of aggregation on the perception of the presented phenomena, three maps were designed showing the dominant population group at different levels of administrative division (Figure 2): (a) at the municipality level, (b) at the county level, and (c) at the district level. The districts (Figure 2c) are areal units created by the author based on the concept of gerrymandering. These units were independently defined and recalculated by grouping counties in a way that fulfilled gerrymandering assumptions – aiming to maximize the area that could be marked as having a Polish population majority. The data were visualized using a qualitative area map presenting two categories: Poles (in red) and Ukrainians (in green). To ensure the most accurate representation possible, ethnic composition maps were used as base materials and supplemented with additional data sources: for urban and rural areas, data from the second General Census (Szturm de Sztrem, 1937, 1938) were applied. Supplementary data were taken from the first General Census (Główny Urząd Statystyczny Rzeczypospolitej Polskiej, 1924) and other sources (Kałuski, 2023).

In the *municipalities* map (Figure 2a), which depicts the dominant ethnonational group using a qualitative area map based on the

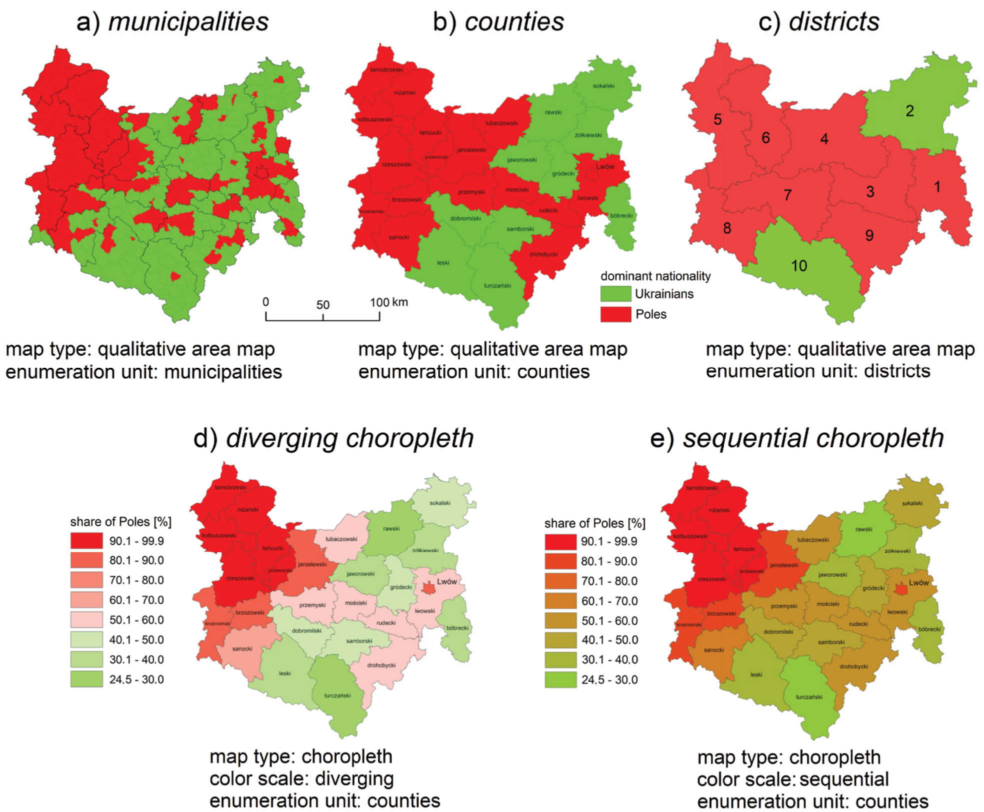

Figure 2. Ethnonational maps tested in the study: a) *municipalities*, b) *counties*, c) *districts*, d) *diverging choropleth*, e) *sequential choropleth*

aggregation of municipalities and cities, a visually large portion of the territory is dominated by Ukrainians over Poles: the category with Ukrainian dominance covers 55.7% of the map area, while in reality, Ukrainians constituted only 37.2% of the population. This discrepancy is related to population density: Poles predominated in most urban areas, but cities cover a small area on the map compared to rural regions, where the Ukrainian population was significantly more prevalent. In this case, aggregation to smaller spatial units resulted in the Ukrainian category occupying a much larger share of the map's area than on the *counties* map. Aggregation to counties (Figure 2b), in turn, resulted in the Polish-dominated areas covering approximately 56.3% of the map – closely reflecting their actual population share of 62.8%.

In the development of the *districts* map (Figure 2c), gerrymandering techniques were applied by aggregating counties into larger units (labelled as districts) to make the dominance of the Polish population maximized in terms of the area of the map. Counties sharing long borders were grouped into zones with comparable population sizes, usually composed of three counties. Through this approach, by separating counties dominated by the Ukrainian population, a Polish majority was achieved in most districts – even when the differences were minimal, with two districts showing less than a 0.5 pp advantage. As a result, Polish dominance is shown in units covering a total of 73.6% of the voivodeship's area.

To analyze the impact of a color scale, two choropleth maps were tested: one using a quantitative multi-hued diverging color scale (*diverging* *choropleth*, Figure 2d), and the other using a sequential color scale (*sequential choropleth*, Figure 2e). Both maps illustrate the proportion of the Polish population relative to the Ukrainian population.

3.2.2. Maps of the presidential election

The maps used in the study were based on data from the second round of the 2020 presidential election in Poland, provided by the National Electoral Commission (in Polish: Państwowa Komisja Wyborcza, n.d.). Based on the election results – 51.03% of the vote for Andrzej Duda and 48.97% for Rafał Trzaskowski – qualitative area maps were developed (Figure 3), using different spatial enumeration units: voivodeships, counties, and municipalities. The colors on the maps correspond to the political affiliations of the candidates: orange for Trzaskowski, blue for Duda, and pink for municipalities with a tie.

The election results showed regional differences: Andrzej Duda won primarily in rural areas and in the southeastern regions, while Rafał Trzaskowski prevailed in urban areas and in the northwestern part of the country. On maps using smaller spatial units (e.g., *municipalities*), areas won by Duda covered larger areas of the map (Figure 3a). In contrast, on the *voivodeship* map (Figure 3c), Trzaskowski was marked as the winner in most voivodeships; however, Duda's advantage in certain regions – such as the Podkarpackie Voivodeship – was significantly greater.

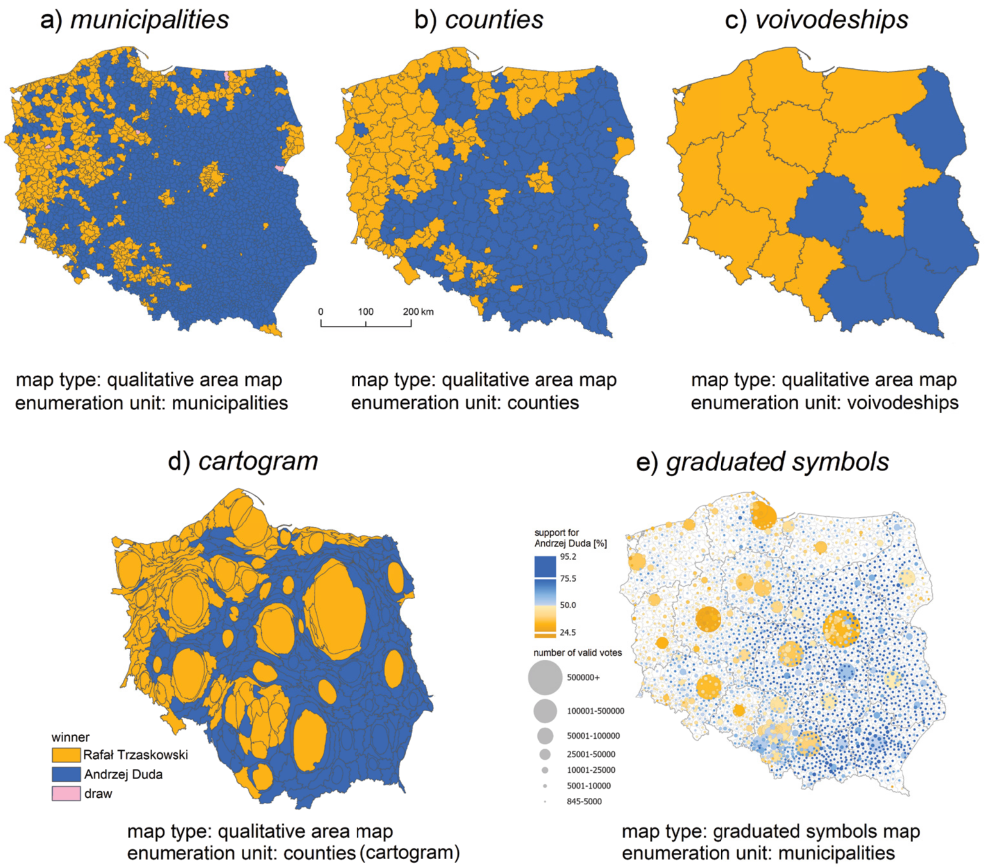

Figure 3. Presidential election maps prepared for the study: a) *municipalities*, b) *counties*, c) *voivodeships*, d) *cartogram*, e) *graduated symbols*

The study also employed a *cartogram* (Figure 3d) based on counties, where the size of each county corresponds to the number of valid votes cast. This type of visualization enlarges major urban areas and reflects the vote distribution more proportionally than the standard *counties* map. In this cartogram, the area representing Duda's victory accounts for 50.6% of the total map surface, while Trzaskowski's accounts for 49.4% – closely mirroring the actual election results (51.03% vs. 48.97%).

The last visualization method selected for the study was the *graduated symbols* map enhanced with continuous choropleth map colors (Figure 3e), in which the size of the symbols reflects the number of valid votes cast, while the fill color indicates the magnitude of the candidate's lead. A diverging color scale was applied: intense blue represents a lead for Duda, and intense orange indicates a lead for Trzaskowski, with a central reference point at 50% marked with white. In all municipalities, where Andrzej Duda received more than 75.5% of the vote, the same maximum color intensity was used, as his lowest recorded support level was 24.5%. This approach ensured a symmetrical color distance from the 50% threshold for both candidates.

All maps were developed using ArcGIS Pro software (ESRI). Data analysis was conducted using the PS IMAGO PRO package and IBM SPSS Statistics.

3.3. Task types

The study consisted of 36 questions. For both the ethnonational and electoral maps, participants were asked four questions for each of the five tested maps:

1. Based on the presented map, which nationality had the majority in the entire Lwów Voivodeship / who won the election?
2. How difficult was the above question to answer?
3. Was the dominance of one nationality / the election winner significant?
4. In which part of the Lwów Voivodeship / Poland was the dominance of Ukrainians / Rafał Trzaskowski the strongest? (multiple answers possible)

In addition, the following preference-related questions were asked:

1. In your opinion, which map best reflects the actual distribution of ethnonational groups? (Poles – 57.65%, Ukrainians – 34.12%) / the actual election results? (Duda – 51.03%, Trzaskowski – 48.97%)
2. In your opinion, which map least accurately reflects the actual distribution of ethnonational groups? (Poles – 57.65%, Ukrainians – 34.12%) / the actual election results? (Duda – 51.03%, Trzaskowski – 48.97%)

3.4. Participants

The study was conducted in the form of an online survey with 151 participants. A significant portion of the sample – 119 individuals (78.8%) – were students of geography and spatial management at the Faculty of Geography and Regional Studies, University of Warsaw (WGSR UW). Additionally, 32 participants (21.2%) were not students of geography. The gender distribution was balanced, with a slight majority of male respondents (49.7%) over female respondents (47%). The remaining 3.3% of participants did not disclose their gender. The vast majority of respondents (89%) were aged between 15 and 24. Given that most participants were students of WGSR UW, it can be assumed that their skills and knowledge in map interpretation were higher than those of the general population. However, their relatively young age may have contributed to a lower awareness of historical and political issues.

4. Results

4.1. The effect of data aggregation level in the qualitative area map and a color scale in the choropleth map

The correct answer (Poles) to the first question regarding the dominant nationality was given by between 11% of participants (based on the *municipality* map, Figure 2a) and 99% (based on the *districts* map, Figure 2c). An analysis of response accuracy using Cochran's Q test for related samples ($\chi^2 = 335.75$, df = 4, N = 151, $p < 0.001$) revealed statistically significant differences between the maps. A Bonferroni *post hoc* analysis indicated statistically significant differences in eight out of ten compared map pairs (Figure 4).

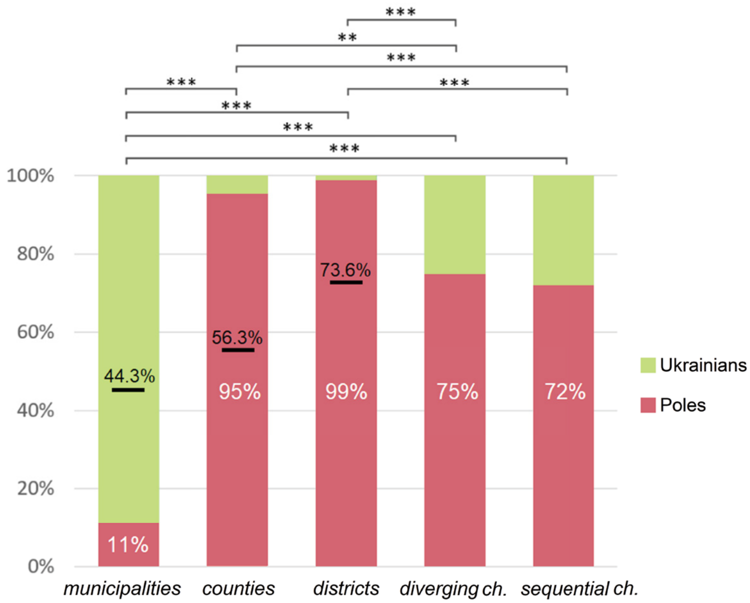

Figure 4. Indicated dominant nationalities in the entire voivodeship based on the tested maps. The black line marks the share of the map area occupied by regions classified as having a Polish majority. Statistical significance: ***$p < 0.001$; **$0.01 > p > 0.001$

When answering based on the *municipalities* map, only 11% of respondents provided the correct answer. For the *counties* map, accuracy reached 95% (with Polish-majority areas covering 56.3% of the map's surface), and for the *districts* map, it was 99% (73.6% of the surface). Among the tested maps, those in which the dominant category occupied 56.3% or more of the map area yielded response accuracy levels above 90% (Figure 4).

A comparison of maps using the same reference unit level (counties), but different map types, revealed that qualitative area maps resulted with higher response accuracy than choropleth maps. Bonferroni *post hoc* analysis yielded statistically significant differences between the county-based map pairs: between the *counties* and the *diverging choropleth* ($p = 0.003$), as well as between the *counties* and the *sequential choropleth* ($p = 0.000$). At the same time, the Bonferroni *post hoc* test did not yield a statistically significant difference between the *sequential choropleth* and *diverging choropleth* maps ($p = 1.000$).

Respondents rated the difficulty of identifying the dominant nationality in the Lwów Voivodeship using a five-point Likert scale (1 – very easy, 5 – very difficult). The perceived difficulty of the task varied depending on the type of map: the *districts* map was rated as the easiest ($M = 1.69$, $SD = 0.72$), while the *diverging choropleth* and *sequential choropleth* maps were rated as the most difficult ($M = 2.90$, $SD = 0.95$ and 0.94, respectively, Figure 5).

The Friedman test for related samples ($\chi^2 = 185.124$, $df = 4$, $N = 151$, $p < 0.001$) yielded statistically significant differences in perceived tasks' difficulty across the analyzed maps. Bonferroni *post hoc* analysis indicated that statistically significant differences occurred only between the *districts* map and all other types of maps ($p = 0.000$). Despite considerably lower response accuracy of participants using the *municipalities* map than participants using the *counties* map, the difficulty ratings were similar for the two maps. When comparing the results for maps using counties as the spatial enumeration unit (i.e., the *counties*, *sequential choropleth*, and *diverging choropleth*), it was observed that the level of perceived difficulty did not differ significantly, despite the statistically significant differences in response accuracy.

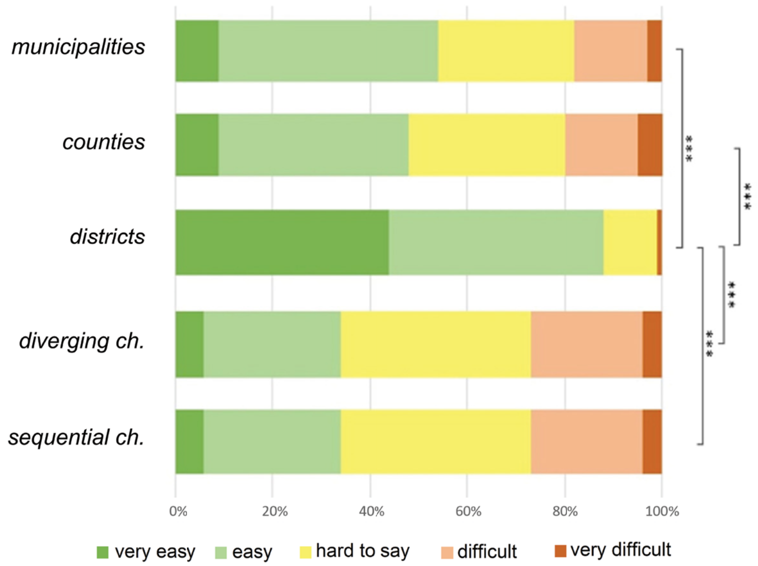

Figure 5. Perceived difficulty of the question on identifying the dominant nationality in the entire voivodeship. Statistical significance: ***p < 0.001

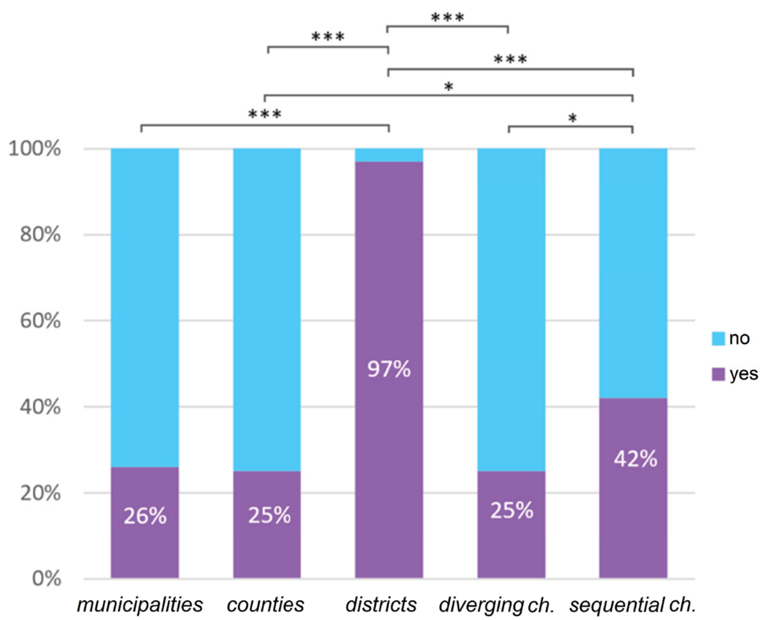

Figure 6. Response to question if the difference was considerable. Statistical significance: ***p < 0.001; *0.05 > p > 0.01

The third question participants answered, "Was the dominance of one nationality considerable?" (the actual data difference was 25.6 pp), revealed substantial variation in responses: the correct answers ranged from 25% for the *counties* to 97% for the *districts*. Cochran's Q test ($\chi^2 = 238.33$, df = 4, N = 151, $p < 0.001$) indicated statistically significant differences. Bonferroni *post hoc* analysis yielded statistically significant differences in answers based on seven out of ten map pairs. Statistically significant differences were found between answers given based on the *districts* and all other map types, as well as between the *sequential choropleth* map and the *counties* ($p = 0.038$), and between the *sequential choropleth* map and the *diverging choropleth* map ($p = 0.026$, Figure 6).

The *districts* map (Figure 2c) most clearly conveyed the dominance – 97% of respondents indicated that Poles had a significant advantage. In contrast, only 26% of participants described the advantage as large based on the *municipalities* map (Figure 2a), even though 89% of respondents incorrectly identified Ukrainians as the dominant group – demonstrating the map's high persuasiveness potential in distorting data perception. Meanwhile, on the *counties* map (Figure 2b), 95% of respondents correctly indicated Poles as the majority, but only 25% believed the advantage was substantial. The answers given based on *diverging choropleth* and *sequential choropleth* maps yielded similar levels of correctness in identifying the dominant group (75% and 72%, respectively). However, perceptions of the magnitude of the advantage varied significantly: 25% of respondents described it as large when viewing the *diverging choropleth* map, compared to 42% when reading the *sequential choropleth* map.

The results indicate that although both tested choropleth maps enabled correct identification of the dominant nationality, the estimation of the magnitude of the advantage was more effective when using the *sequential choropleth* map. This finding may be unexpected, as sequential color schemes typically have a narrower range of brightness, which often makes intuitive comparisons and the assessment of intensity more difficult. Therefore, this issue requires further research, involving end-users and a broader selection of color palettes as well as thematic data.

When identifying areas of the Lwów Voivodeship with the greatest Ukrainian dominance (question with possible multiple answers from nine subregions), the most frequently selected areas across all maps were the northeastern and southern parts. Based on each tested map,

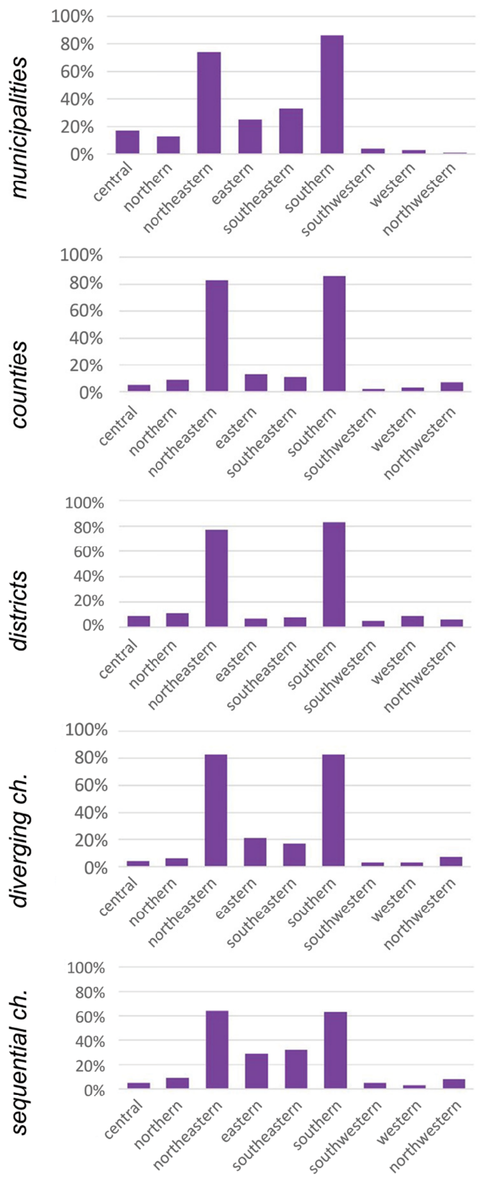

Figure 7. Responses to the question: "In which part of the Lwów Voivodeship was the greatest dominance of Ukrainians observed? (multiple answers allowed)"

at least 63% of participants selected these areas, while on the *municipalities* and *counties* maps, the southern part was indicated by as many as 86% of respondents (Figure 7).

The northeastern and southern parts of the Lwów Voivodeship were frequently identified regardless of the level of aggregation of the reference units. Based on each map, at least 74% of respondents indicated these areas. Among the maps using the same spatial enumeration units of counties (*counties*, *diverging choropleth*, and *sequential choropleth*), response frequencies differed significantly. When reading the *sequential choropleth* map, fewer respondents indicated the northeastern (64%) and southern (63%) areas than those assessing the *diverging choropleth* map (83% indicated both areas) or the qualitative area map *counties* (83% for the northeast and 86% for the south). These differences suggest that using a sequential color scale may make it more difficult to clearly distinguish areas with extreme values, even though the brightness changes continuously from minimum to maximum. In the sequential scale, the extreme values are not visually emphasized as distinct endpoints, unlike in the diverging color scale, where both poles of the data range are highlighted symmetrically and distinctly. As noted by Brewer (1996), extreme values are better visually emphasized when using a diverging color scale.

Study participants were also asked to evaluate which map, in their opinion, best and worst reflects the actual distribution of ethnonational groups. They were provided with information about the real share of nationalities (Figure 8).

The *districts* map was most frequently indicated as the worst, even though the proportion of the map marked as dominated by Poles (73.6%) was relatively close to reality (62.8%). Among the maps prepared using the chorochromatic method, the *counties* map was rated as the most accurate representation of reality, and notably, no respondent selected it as the worst. In contrast, the *municipalities* map was considered the worst by only 25% of participants, despite only 11% of respondents answered correctly on the question of the majority group based on this map. The *sequential choropleth* map was more frequently selected both as the best (by 30% – the highest overall rating) and as the worst (by 19%) compared to the *diverging choropleth* map. Responses were converted to a point system: 1% of responses indicating the map was the best = +1 point, 1% of responses indicating the map was the worst = –1 point. This allowed the maps to be ranked from worst to best based on perceived effectiveness in presenting the ethnic majority data:

- *districts* –36 points
- *municipalities* –12 points
- *diverging choropleth* +9 points
- *sequential choropleth* +11 points
- *counties* +28 points

The evaluation of maps with varying levels of data aggregation can be interpreted as an indirect indicator of the subjective effectiveness of cartographic generalization. When using the

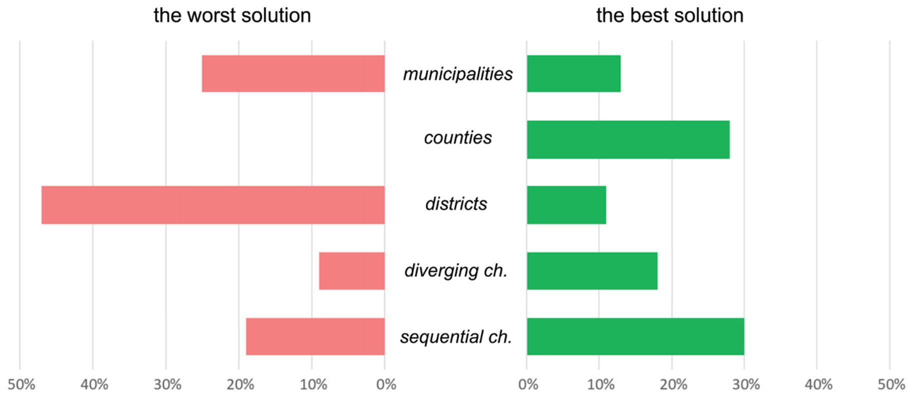

Figure 8. Editorial solutions rated by respondents as the worst and best for presenting data on ethnic majority in the Lwów Voivodeship

same map type, the accuracy of interpretation and correctness of responses depend, among other factors, on how well the level of generalization corresponds to the actual spatial distribution of the phenomenon. The results indicate that the level of aggregation, the color scale, and the form of presentation all significantly influence users' subjective assessment of the map.

4.2. The effect of a map type

The analysis was conducted with regard to answers given based on maps presenting the results of the presidential election. The correct answer to the question "Based on the presented map, who won the election?" was Andrzej Duda (51.03% of the vote). The accuracy of responses varied depending on the map: from 70% for the *cartogram* to 100% for the *municipalities*. Cochran's Q test ($\chi^2 = 52.07$, df = 2, N = 151, $p < 0.001$) yielded statistically significant differences between the maps. Bonferroni *post-hoc* analysis confirmed statistically significant differences for all map pairs ($p = 0.000$ between *municipalities* and the other types, and $p = 0.002$ for the *cartogram* vs. the *graduated symbols* map, Figure 9).

On the *municipalities* map, where 73.7% of the area was marked as the region of Andrzej Duda's victory, all respondents gave the correct answer. On the *graduated symbols* map, the accuracy was 84%, while on the *cartogram* it was 70%.

Respondents rated the difficulty of the question "Who won the election?" on a five-point Likert scale (1 – very easy, 5 – very difficult). The mean responses varied depending on the accompanying map: when paired with the *municipalities* map, the question was rated as the easiest (M = 1.58, SD = 0.65), whereas with the *cartogram* (M = 2.95, SD = 0.98) and the *graduated symbols* map (M = 2.91, SD = 1.01), it was rated as more difficult (Figure 10).

The Friedman test ($\chi^2 = 161.650$, df = 2, N = 151, $p < 0.001$) revealed statistically significant differences in responses depending on the map presented alongside the question. Statistically significant differences occurred when the question was accompanied by the *municipalities* map ($p = 0.000$), which was rated as significantly easier compared to the same question accompanied by the other tested maps.

The percentage of responses indicating that the advantage was large ("Was the advantage substantial?") varied depending on the map (the actual difference was 2.06 percentage

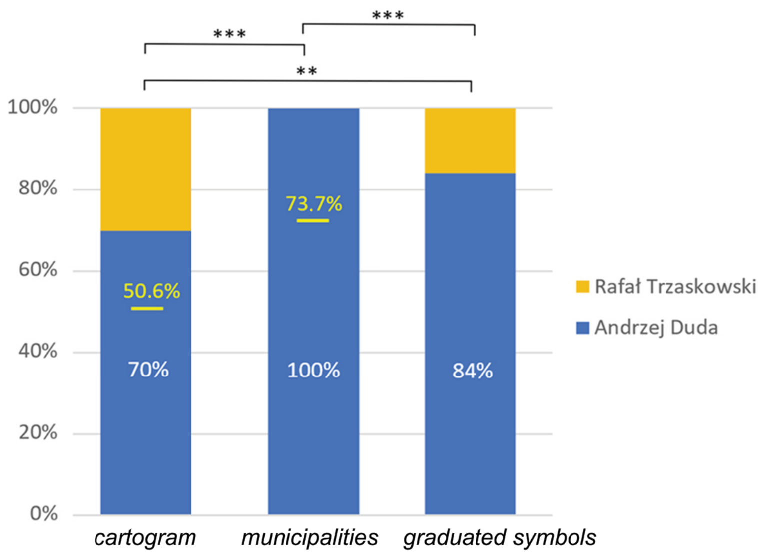

Figure 9. The election winner identified based on the tested maps. The yellow line indicates the proportion of the map area marked as dominated by Andrzej Duda. Statistical significance: ***p < 0.001; **0.01 > p > 0.001

points): from 91% for the *municipalities* map to 16% for both the *cartogram* and the *graduated symbols* map. The Cochran's Q test ($\chi^2 = 197.97$, df = 2, N = 151, $p < 0.001$) yielded statistically significant differences between answers given based on the *cartogram* and *municipalities* map ($p = 0.000$), as well as between answers given based on the *graduated symbols* map and *municipalities* map ($p = 0.000$, Figure 11).

Responses based on the *municipalities* map significantly diverged from reality – 91% of respondents subjectively assessed the winner's advantage as large, while the actual difference was only 2.06 pp. Such a substantial discrep-

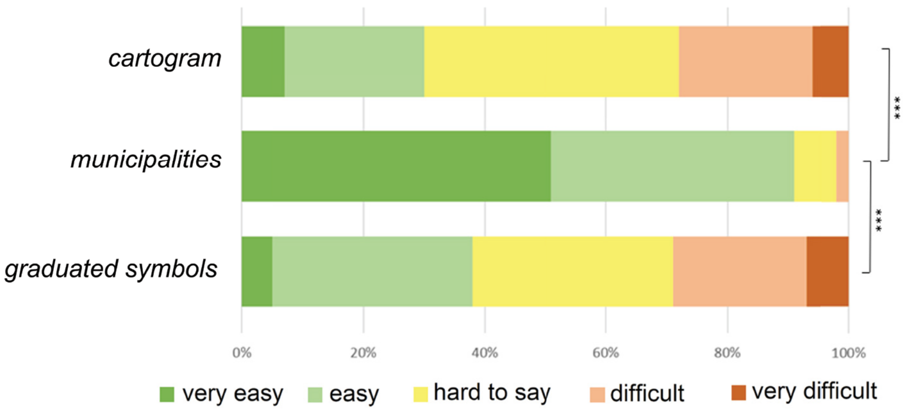

Figure 10. Difficulty rating of the question about identifying the election winner. Statistical significance: ***p < 0.001.

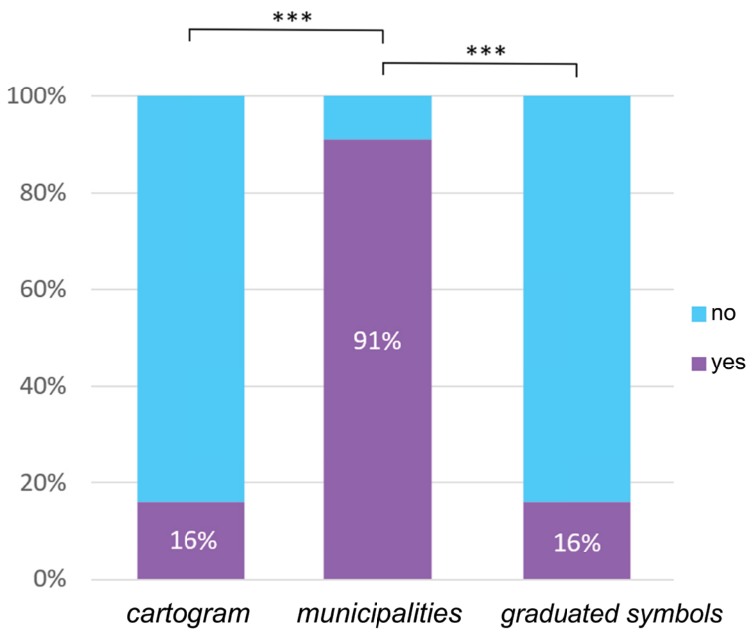

Figure 11. Response to question if the difference was considerable. Statistical significance: ***p < 0.001

ancy in responses may suggest that for phenomena with closely matched values, the use of quantitative methods – such as cartograms or graduated symbols – may present the data more accurately.

The most frequently indicated areas of Poland with a majority of votes for Rafał Trzaskowski across all maps were the western and northwestern parts of the country (63 – 77%, Figure 12). On the *graduated symbols* map, an additional 56% of respondents pointed to the northern part, which may be attributed to the visual enlargement of cities such as Gdańsk, Gdynia, and Olsztyn – places where Trzaskowski had a clear advantage. Indications also increased for the southwestern and central parts (to 24% and 23%, respectively). On the *cartogram*, the dominance of the central part was more apparent (43%). This may have resulted from the more explicit depiction of Warsaw compared to the *graduated symbols* map, where surrounding smaller towns with lower support for Trzaskowski may have influenced perception. The results suggest that the map type affects the perception of the spatial distribution of election results.

Respondents also evaluated which map best and worst reflected the actual results of the presidential election (Figure 13). Participants were informed about the real election results.

The worst-rated map was the *municipalities* (qualitative area map), selected by 48% of respondents. It showed a substantial advantage for Andrzej Duda (73.7% of the map's area), while his actual share of the vote was 51.03%. The *voivodeships* map was rated negatively by 27% of participants, likely because Trzaskowski won in 10 out of 16 voivodeships despite losing nationwide. However, 16% of respondents considered the *voivodeships* map to be the best. The *cartogram* was rated the best overall, chosen by 36% of participants. This map accurately reflected the election outcome – the category of winning by Duda covered 50.6% of the map's surface. This positive evaluation may also be due to respondents' good familiarity with Poland's shape and the clear use of only two categories. The *graduated symbols* map was selected as best by 27% of respondents, although 15% identified it as the worst.

The responses were converted into a scoring system: each 1% of answers indicating that a map was the best for presenting the data counted as +1 point, while each 1% indicating it was the worst counted as –1 point. This allowed for ranking the maps from worst to best evaluated:

- *municipalities* –45 points
- *voivodeships* –11 points
- *graduated sympols* +12 points
- *counties* +18 points
- *cartogram* +26 points

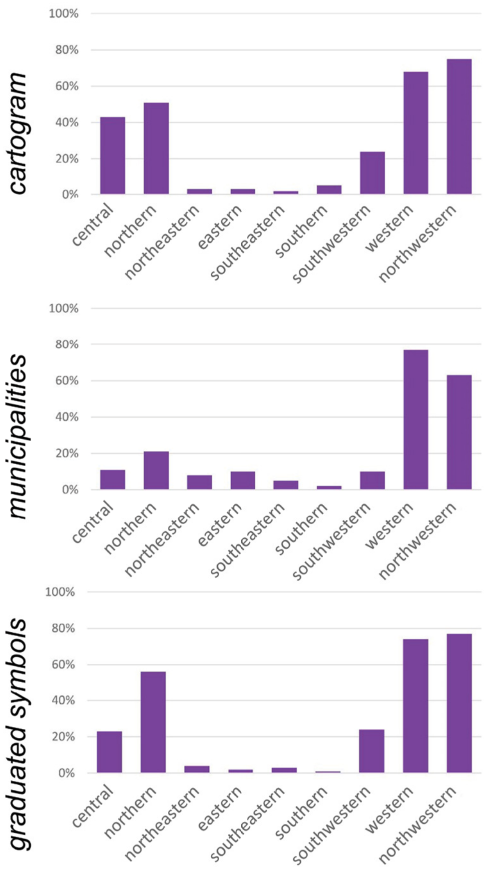

Figure 12. Responses to the question: "In which part of Poland was Rafał Trzaskowski's lead the greatest? (multiple answers allowed)"

5. Discussion

The study on data presentation revealed differences in the perception of spatial phenomena depending on the cartographic design solu-

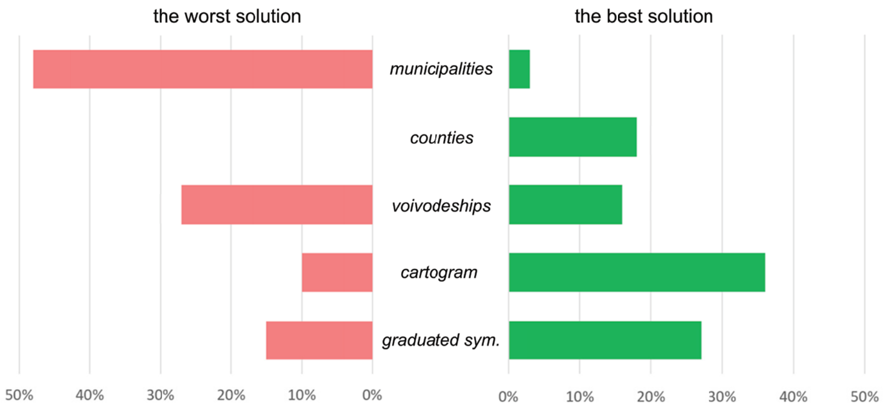

Figure 13. Design solutions evaluated by respondents as the worst and best for presenting data on the winning candidate's advantage in the presidential election

tions applied to the maps. As in many previous studies, objective indicators (i.e., response accuracy) did not always align with participants' subjective evaluations. Hegarty et al. (2009) demonstrated that users' subjective preferences – such as a tendency to favor animations or visual realism – often conflict with established cartographic principles, which emphasize the need to simplify information to enhance clarity and usability. A similar pattern was observed in the current study. Although the *districts* ethnonational map enabled the highest percentage of participants (99%) to correctly identify Poles as the dominant group, and was perceived as the easiest to interpret (with 97% recognizing the Polish majority), it was also the most frequently identified (by 47% of participants) as the least accurate in reflecting the actual distribution of the phenomenon. This discrepancy may be explained by the level of spatial units aggregation. Larger spatial units might have contributed to improved visual clarity and interpretive unambiguity, thereby increasing the likelihood of respondents giving consistent answers. However, this comes at the cost of oversimplifying the data and masking spatial variability.

The results of the study confirmed that, in qualitative area map, aggregating data into smaller territorial units tends to favor phenomena dominant in areas with larger surface coverage and lower population density (i.e., sparsely urbanized areas), regardless of whether the phenomenon is actually in the majority or minority at the regional level (e.g., Figure 2a – *municipalities* and 3a – *municipalities*). The analysis further showed that phenomena occupying at least 56% of the map's surface area were correctly identified as dominant by approximately 90% of respondents. Within the 56–74% range of the map's coverage, the percentage of correct identifications increased gradually, eventually reaching 99%. Testing the election maps revealed notable differences in interpretation depending on the map type. The findings suggest that phenomena concentrated in non-urbanized areas were clearly identified by 84% of participants even when presented using *graduated symbols* map. The *cartogram* provided the most balanced visual representation of the actual distribution.

The widespread knowledge that Andrzej Duda is the current President of Poland (as of 2024) may have influenced the study results. Participants, guided by a tendency to rely on familiar and up-to-date information (Tversky & Kahneman, 1973), may have been more inclined to indicate Duda as the winner. This *availability heuristic* could have led to a disproportionately high rate of answers consistent with real-world outcomes, thereby distorting the results. To eliminate this effect in future studies, it is advised to use fictional data, such as hypothetical election results between Candidate A and Candidate B.

The *municipalities* election map (qualitative area map, Figure 3a) was rated by participants as the least effective in representing the presented phenomenon (–45 points), due to its tendency to visually exaggerate the dominance of a phenomenon – a feature also noted in the *districts* map (Figure 2c). The results suggest that participants evaluated maps that strongly emphasized dominance as less accurate representations of the data, even when the actual dominance was substantial. It may be inferred that respondents – aware of the interpretative nature of maps – adopted a critical stance toward visualizations that too directly implied a specific conclusion. Moreover, it should be noted that the lack of task order randomization in the study may have influenced the results (Tourangeau et al., 2000), as responses to later questions might have been shaped by previous ones. This limitation highlights the need for randomization in future studies, ideally through a between-subjects design.

6. Conclusions

Map makers should strive for maximum clarity and transparency to enable users to analyze spatial data and ensure the reliability of the presented content. However, it is not possible to unequivocally identify a single best form of presentation or level of spatial data aggregation, as each approach has both advantages and limitations.

According to Monmonier (1991), changes in the level of data aggregation or the map type may lead to different interpretations of the same results. When the cartographer's goal is to highlight a phenomenon dominant in rural areas, the use of a qualitative area map based on the smallest possible spatial units constitutes an optimal solution, as it allows the phenomenon to be emphasized regardless of its numerical characteristics (e.g., minority dominance: 34.1% vs. majority: 51.03%). Conversely, if the intention is to emphasize a phenomenon dominant in urban areas, increasing the size of spatial units may be a suitable alternative. Enlarging spatial units can visually 'spread' a phenomenon that is concentrated within a small area. However, the effectiveness of this operation depends on the degree of unit enlargement. Gerrymandering, which involves manipulating the boundaries of spatial units, can effectively increase the visibility of a specific phenomenon by selectively grouping or dividing territorial units. In the study, this technique made it easier to identify the dominant nationality in the Lwów Voivodeship, thereby increasing the percentage of responses indicating Polish dominance – substantially facilitating correct identification of the prevailing group.

When the goal is to illustrate the magnitude of a phenomenon's dominance, the most effective approach turned out to be an intermediate level of spatial aggregation – at the county level – as well as the use of quantitative methods such as cartograms and graduated symbols map. These map types allow for a representation of results that more accurately reflect reality, conveying the scale of dominance in a more proportionate manner. According to participant responses, quantitative methods – such as the choropleth map with a sequential color scale, the cartogram, and the graduated symbols map – were more often perceived as showing a spatially balanced distribution of the phenomenon compared to the qualitative area method. This reduced the perceptual bias introduced by spatially dominant regions. However, the application of more complex methods – such as cartograms or graduated symbols – resulted in lower rates of correct identification of the dominant phenomenon compared to qualitative area maps. This outcome may be attributed to the higher level of abstraction required by these methods, demanding more advanced interpretation of both quantitative and spatial data from the viewer. In contrast, the qualitative area method – based on qualitative color differences – appears to be more intuitive and accessible, even for inexperienced map users.

When comparing results for maps using counties (e.g., *counties*, *diverging choropleth*, *sequential choropleth*) as the spatial unit of reference, it was observed that the level of perceived task difficulty did not differ significantly, despite statistically significant differences in the accuracy of responses. The use of a sequential or diverging color scale did not influence the identification of the dominant phenomenon or the perceived difficulty of the task; however, the sequential color scale more effectively conveyed the magnitude of the dominance. Respondents demonstrated a preference for maps that allowed for estimating the approximate strength of dominance (e.g., cartograms or graduated symbol maps), in contrast to the qualitative area maps, which can only display the phenomenon qualitatively. This preference suggests a trade-off between clarity in identifying the dominant phenomenon and the ability to assess its relative magnitude.

The tested map designs – such as a map type, a level of data aggregation, or a color scale – have a significant impact on the interpretation of a phenomenon's dominance, depending on the nature of the data. The selection of a particular map type can markedly alter the perceived extent of dominance, providing evidence that map design may be subjectively manipulated to achieve desired outcomes, for example, for political purposes. This underscores the importance of cartographic education, particularly at the school level, which should aim to develop competencies in comparative map analysis and critical evaluation of diverse spatial data visualization techniques. Such skills are increasingly essential given the growing role of data visualizations in media and public discourse. One way to enhance the effectiveness of cartographic communication is to present a set of maps using different levels of aggregation or map types. For instance, a primary map might apply the qualitative area map with small territorial units, while an accompanying map could depict the same data using larger spatial units or an alternative method, such as graduated symbols map. This type of composition facilitates a more comprehensive spatial analysis, enabling users to compare different visualization approaches and gain a deeper understanding of the data.

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