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Spatial Analysis and Informatics

Attila Korompai (ed.)

John von Neumann University

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Spatial Analysis and Informatics

Edited by Attila Korompai

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Editorial preface

This volume is the first one to be published in the series of textbooks recommended for the Master Program of the Regional and Environmental Economics. It consists of five chapters.

The first one written by István Tózsa gives an overview of the wide range of the applications of spatial geographical data procession reflected in the GIS (Geographical Information systems) and the digital procession of satellite images.

The second chapter written by Júlia Schuchmann focuses on the spatial aspects of economic activities, especially the interaction between the geographical location and the economic and social development processes. It provides an insight into theoretical and mostly practical knowledge about the territorial (regional) analysis, and the most important territorial (regional) databases for secondary analyses.

The third chapter written by the Editor of this textbook gives practice-oriented insight into basic quantitative and qualitative methods applied in territorial/regional/urban analysis. It concentrates on the interpretation of statistical indicators and their calculation in Excel. Methodologically the spatial and temporal relations reflected in the indicators are emphasised.

The fourth chapter written by Júlia Gutpintér presents a practical approach and a training manual of Geographic Information Systems (GIS) and thematic mapping, covering key concepts, methods and some historical background. Furthermore, it covers spatial data types, spatial analysis, coordinate systems, map design principles, and the types of thematic maps.

Finally, the fifth chapter written by Ágnes Jenei introduces the latest technical innovations in spatial analyses, in the form of Virtual Reality applications.

Attila Korompai

I. GIS and Satellite Images – Smart Tools for Spatial and Urban Development

István Tózsa[1]

Contents

1. What is GIS?

When you ask people today, whether young or old, what GPS is, what Google Maps is, what YouTube is, what Facebook is, what WhatsApp Messenger is, or even what Gmail is; most of them will have the answer as a matter of course. However, when asked what GIS is, far fewer can give an adequate answer.

Yet, GIS is considered the most important field of the future in America, and the most profitable high-tech field, after biotechnology and Nano-metrics, the third most important and profitable field after micro-world research. As such, it is also one of the most important factors in the operation of the smart city, alongside the internet and often of course in combination with it.

[1] University professor, head of the Centre for Economic Geography and Urban Marketing, John von Neumann University, Kecskemét, Hungary

GIS literally stands for Geographical Information System, It stands for geoinformatics, i.e. the set of operations performed on a set of digitally displayed maps (Figure 1).

GIS can be used in many areas of scientific research and practice. In urbanism, in applications related to the operation of so-called smart cities, GIS can be used in the role of a simple digital map database or in the role of a truly intelligent information system that answers questions (Figure 2). In database applications, we can only query the map data entered the system, of course using various filters and groupings. In information system applications, the input data is processed according to an algorithm, using averaging, standard deviation, weighting, factor analysis, regression analysis, maximum and minimum distance calculation, etc., and thus, new information (processed data) is extracted from the output data that has not been entered into the digital map database. The GIS used in the management of municipalities as a database is therefore a data-oriented GIS, where map data on the population of a municipality, district, county or country can be queried, of course in different groupings, e.g. grouped by gender, ethnicity, age, education, income - depending on the level of detail of the data input. In the same way, map data on technical services facilities (technical infrastructure) can be queried: where are roads, railways, pipelines, utilities, what is their condition, what are their uses - again, the query options depend on the level of detail of the data entered. Finally, map-able, geo-locatable data on real estate assets can also be stored and queried in a GIS database-type application: where individual properties are located, grouped by technical condition, size, commodity, function, ownership, infrastructure provision.

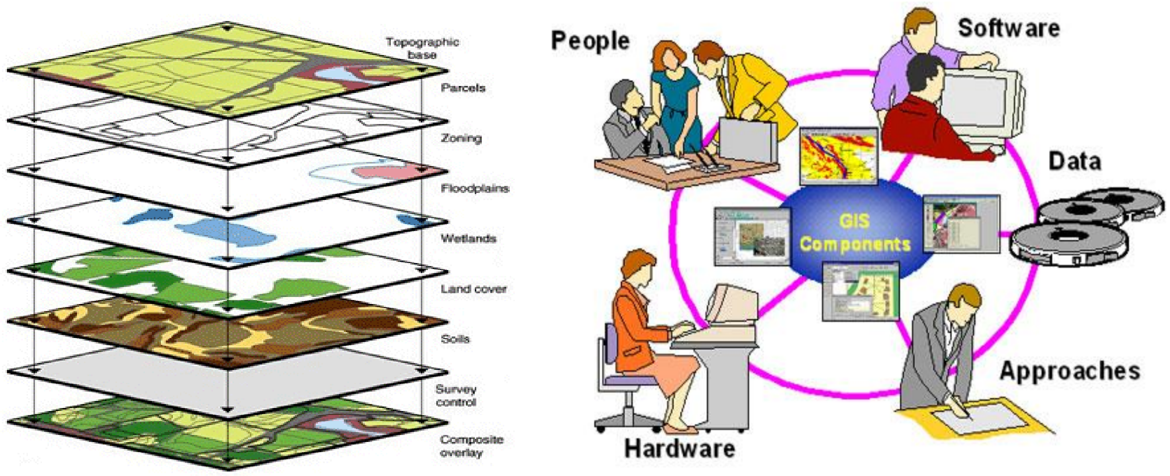

Figure 1. The essence of GIS (Geographic Information Systems) is that several overlapping digital maps cover a geographic space with a variety of different information for a single point (see left). GIS applications involve planners, data, software, hardware and users (right).

An "intelligent" GIS application, i.e. one that can provide answers to the questions posed in the form of new, processed data, i.e. information, can be either tool-oriented or decision-oriented (2). Tool-oriented GIS is so specialised and adapted to the requirements of the application that it can be used for a specific purpose. Examples are GPS, navigation at sea, or positioning, route planning and guidance on roads. This is the case of 'classical' GIS applications, which combine land use, infrastructure, property and population in urban planning, in particular in town and country planning, and which also incorporate remotely sensed imagery (from drones, aircraft, satellites). Finally, the 'smartest' GIS application is the decision-oriented role, where you can ask the system questions such as: where is the best or least suitable area to carry out an activity? To what extent is an area suitable or unsuitable for a particular use, economic or business purpose? This is the "real" GIS application, as it provides answers to questions (location-based information) that were not originally included in the input data - in other words, the GIS creates new data, i.e. information.

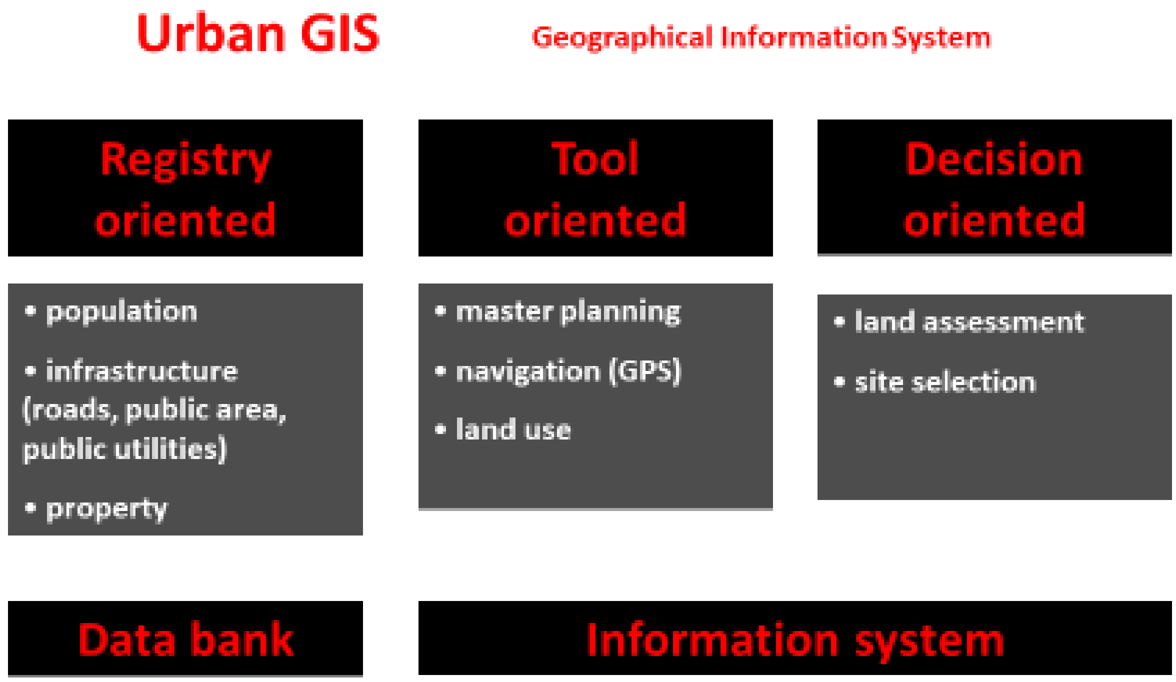

Figure 2. Simple types and applications of municipal GIS

In all countries, the basis for GIS mapping, specialised in database and data management, is a national digital base map - so that maps and data can be compatible with each other and their use in public administration can be uniform. Such GIS are most used in public administration, in monitoring, in the provision of public data and in the operation of municipal public services; by utility and utility service providers, by territorial bodies of central government (these are the deconcentrated bodies) and, of course, by local governments, the decentralised bodies of territorial administration. The keywords for the application are the operating systems (e.g. DOS, Windows, Unix), the database management systems (e.g. Oracle, dBase) and the specific programs (Arc/Info, ArcView, MapInfo, Erdas, MicroStation, etc.)

2. Tool-oriented GIS

The two major basic areas of municipal planning are settlement development and settlement planning (Figure 4). The two basic textual parts of settlement development are the settlement development concept and the settlement development programme. To simplify, the best way to define these two areas is that the settlement development concept answers the questions of what needs to be developed in a settlement (kindergarten, hospital, overhead crossing, access road, metro, etc.) and why (demographic and economic forecasts, interviews with residents, questionnaire surveys, scientific evidence of the need for development). Finally, the third question, without which the urban development concept can only be a wish list without realistic foundations, is: 'what' can be used to finance the development? The urban development programme is also a textual document that answers the question of "when" and in what timeframe development can be achieved.

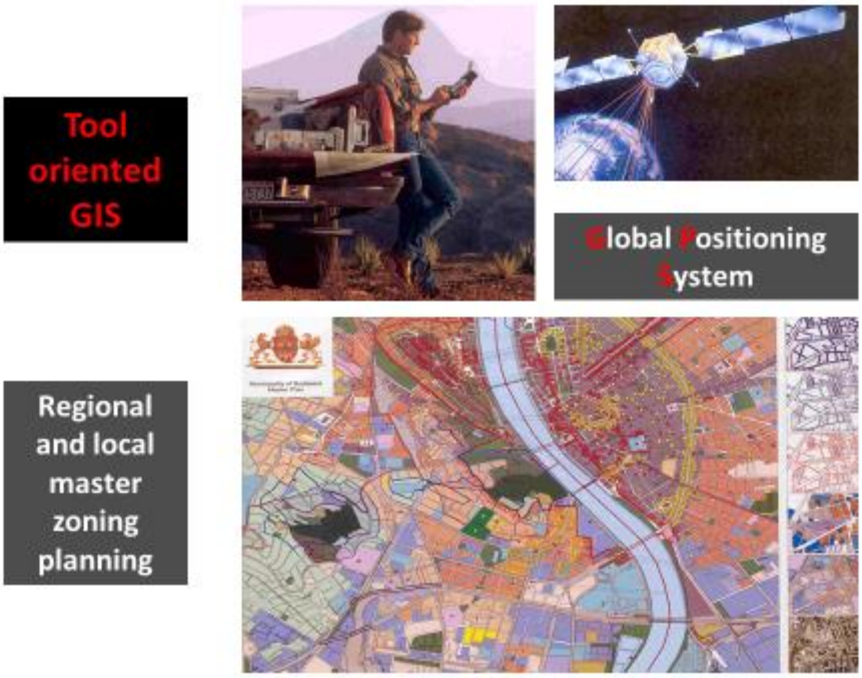

Figure 3. Areas of tool-oriented municipal GIS in municipal planning and remote sensing

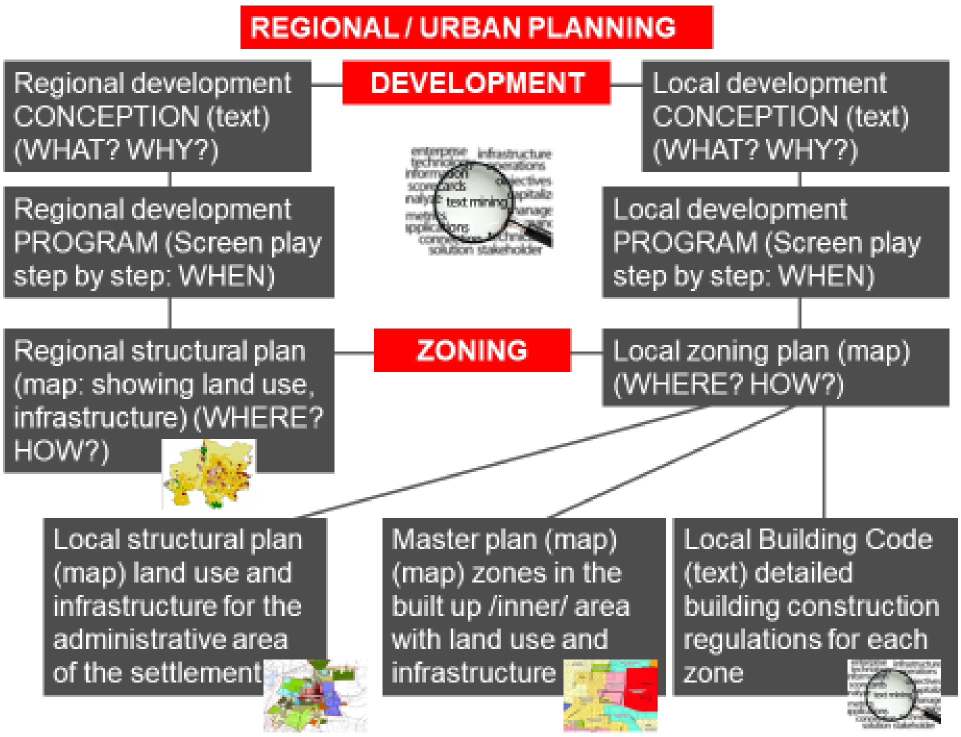

Figure 4. The emergence of GIS in smart city municipal planning

Urban planning is made up of four disciplines, three of which all involve tool-oriented GIS applications: the smarter the city, the more. Between the zoning maps, the urban structure plan can have two stages: once it covers the whole administrative area of the municipality, with the land use and land use of the outlying areas (the areas not intended for development) and the linear technical infrastructure (roads, railways, pipelines, sewers) located there. In this context, the structural part of the zoning plan answers the questions of exactly 'where' and 'how' development should take place. The more detailed version of the settlement structure plan depicts the whole built-up area (the inner area), with the function of each built-up area within it being indicated, what are the building zones - at property level. In addition to these, the linear technical infrastructure located here is also included. The enlargement of this map is the regulatory plan depicting each municipal part or district. This shows the details of each building zone. At the property level, the land parcel details of the property with land registrations, the exact details of the technical infrastructure associated with the property, with the location of the connection points for the pipelines, the exact location of the property.

Figure 5. The representation of tool-oriented GIS in smart city spatial planning (top left: outer area structural plan; top right: inner area structural plan; bottom left: municipal regulation master plan; bottom right: regulation master plan combined with aerial photo).

Both the structural and the regulatory plan may be based on remotely sensed imagery, either from aerial or satellite data sources. This makes the orientation on the zoning maps easier; the information content of the maps is greater and they are more aesthetically pleasing. The GIS map of the regulatory master plan should be linked to the Local Development Code, which is the textual part of the urban planning. These regulations contain the detailed building regulations for each building zone. What percentage of the property can be built on, how many storeys can be built on, what type of building can be built on (whether there is a front garden, whether the property is detached, what the side distance on the building plot must be, whether the building must be a comb or a closed row, what style and colour of roof structure must be used, whether there can be a garage, outbuilding, etc.).

Tool-oriented municipal GIS applications include land use maps generated from satellite imagery. It is not a Google satellite image, but the result of satellite image processing based on the GIS principle, where information (land use categories) that was not present in the input data is displayed in the output data - as information. The imaging process of resource exploration satellites is itself a (tool-oriented) GIS. The first such satellite imagery, obsolete in the US military and handed over for civilian, scientific research purposes, was the ERTS and LANDSAT satellite families, and based on these, the first GIS-based satellite processing in Hungary took place in 1981, when the Institute of Geographical Research of the Hungarian Academy of Sciences (immodestly: the author of these lines) produced an urban land use map based solely on satellite data (Figure 6).

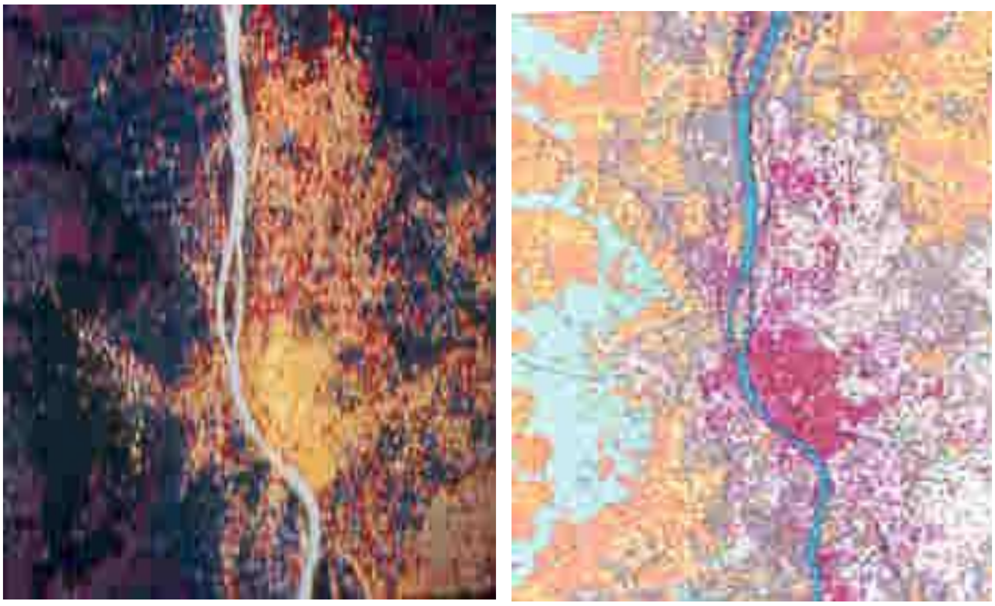

Figure 6. Land use map of Budapest - tool-oriented image as a result of GIS processing

The "eye" of a resource research satellite is a pivoting mirror that collects the reflected and emitted radiation from ground bands up to 100 km - not only in the visible range of reflectance. The near-infrared radiation range, no longer visible to the naked eye, where the chlorophyll is responsible for the colour green, has its maximum radiation. The colour of the human-inhabited areas of the Earth (i.e. not the desert and high mountain areas) is more or less green, when viewed from space. So, NASA engineers, using the analogy of the large black eyes of UFOs 😊 that can see in the dark, have sensitised the satellite's colour resolving prism to near-infrared radiation, which detects infrared radiation from the surface in addition to the green, orange and red that can be seen with the naked eye - and thus detects the smallest details of the green reflection (Figure 7).

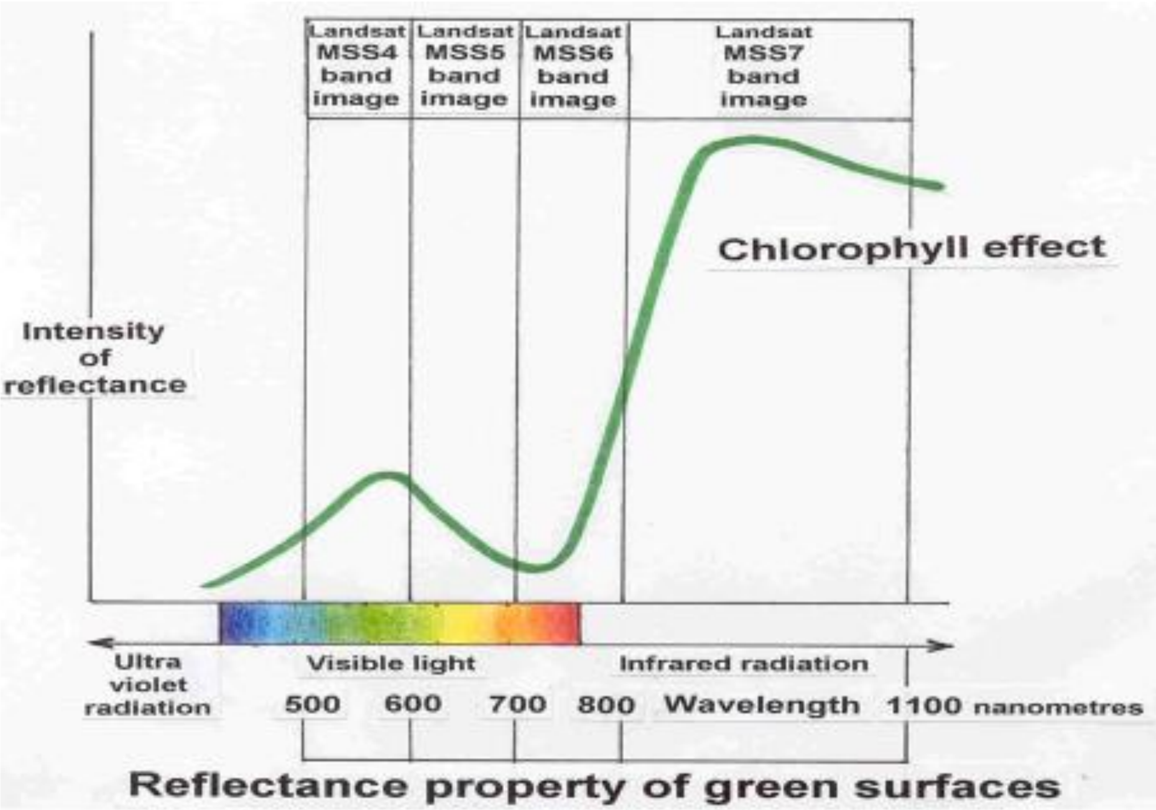

Figure 7. Chlorophyll-containing vegetation is green because it has a maximum radiation reflectance in the green colour range visible to the eye. However, the true maximum of green occurs in the infrared range. This is measured by resource research satellites.

Thus, characteristic changes in chlorophyll reflectance due to the effect of Soviet missile bases buried under the Siberian Far Eastern Taiga on the seemingly monotonous, monochromatic pine forest above them on the coniferous leaves became detectable. If the location of a single rocket base was identified, the location of all the other bases in the pine forest above it could be determined by the differences in the green colour, which were not visible to the eye. Even more so, because the satellite system can detect intensities between 0 and 256 for each of the green, orange, red and infrared wavelengths. In other words, each pixel in each of these 4 wavelengths represents a radiation intensity between 0 and 256. This means that, for example, no two pixels out of twenty million pixels have the same four-dimensional intensity vector. Even the slightest surface differences that are not visible to the naked eye can be isolated, defined or mapped with a high degree of confidence.

It is not only possible to include study areas in land use categories (such as forest, field, orchard, built-up area, water surface, field), but also in urban areas in zones with different functions, such as areas with weekend houses, garden suburbs, modern housing estates, densely built-up areas, industrial areas, transport areas, sports grounds, beaches, cemeteries - this is how the first satellite map of Budapest was created, as shown in Figure 6. In agriculture, a crop structure map can also be produced using GIS-processed satellite imagery. By recording study areas and measuring their pixels, the land use and crop structure of an entire county can be clustered: in addition to forests, water surfaces, built-up areas, the area sown to wheat, sunflower, grapes, alfalfa, and barley (Figure 9).

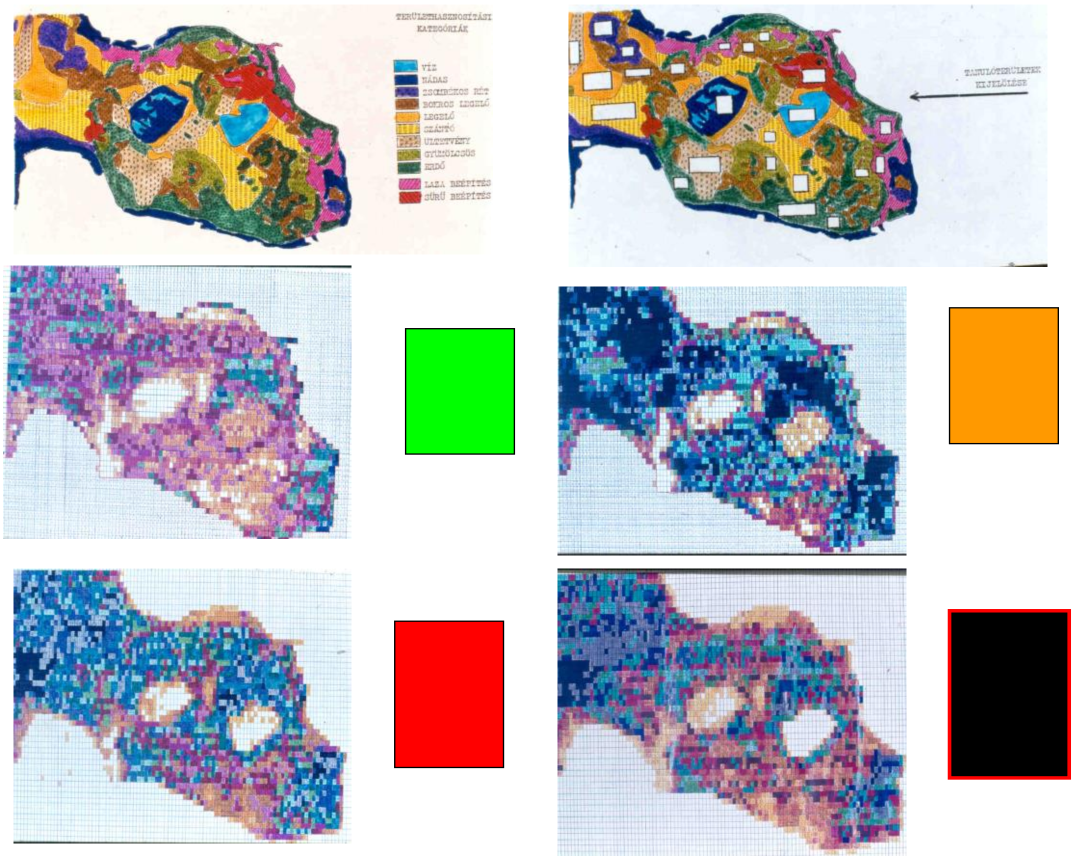

Figure 8. GIS processing of satellite images for the Tihany Peninsula in the Lake Balaton in Hungary. If a so-called study area (top right) is assigned to each land use category (top left), the average intensity and dispersion of its pixels between 0 and 256 intensity values can be measured in all four radiation bands (green, orange, red and infrared), so that each land use category can be mapped with high confidence in the whole (Transdanubian) area of the satellite image within one second. The Budapest map shown in Figure 6 and one of the Hungarian counties (Komárom County) crop structure map shown in Figure 9 are based on this GIS principle.

If there is no possibility to select study areas somewhere in the area represented by the satellite image and cluster the whole vast area represented by the satellite image on the basis of these study areas, it is of course also possible to have the GIS itself cluster the pixels (groups, classes) on the basis of their reflectance intensity measured in the four radiation bands. This is image processing without a learning domain, where the program identifies and plots surfaces of the same quality within, say, a city, but we don't know exactly what they are. In this case, we can also find out what land use categories or building types or what crop composition or crop structure the image represents by identifying each class afterwards. This is called calibration: if we know exactly what was on a given surface at the moment when the image was taken, then all the other sites will have the same quality that the program has assigned to the same class or cluster. These are shown in colour on the map as output GIS data.

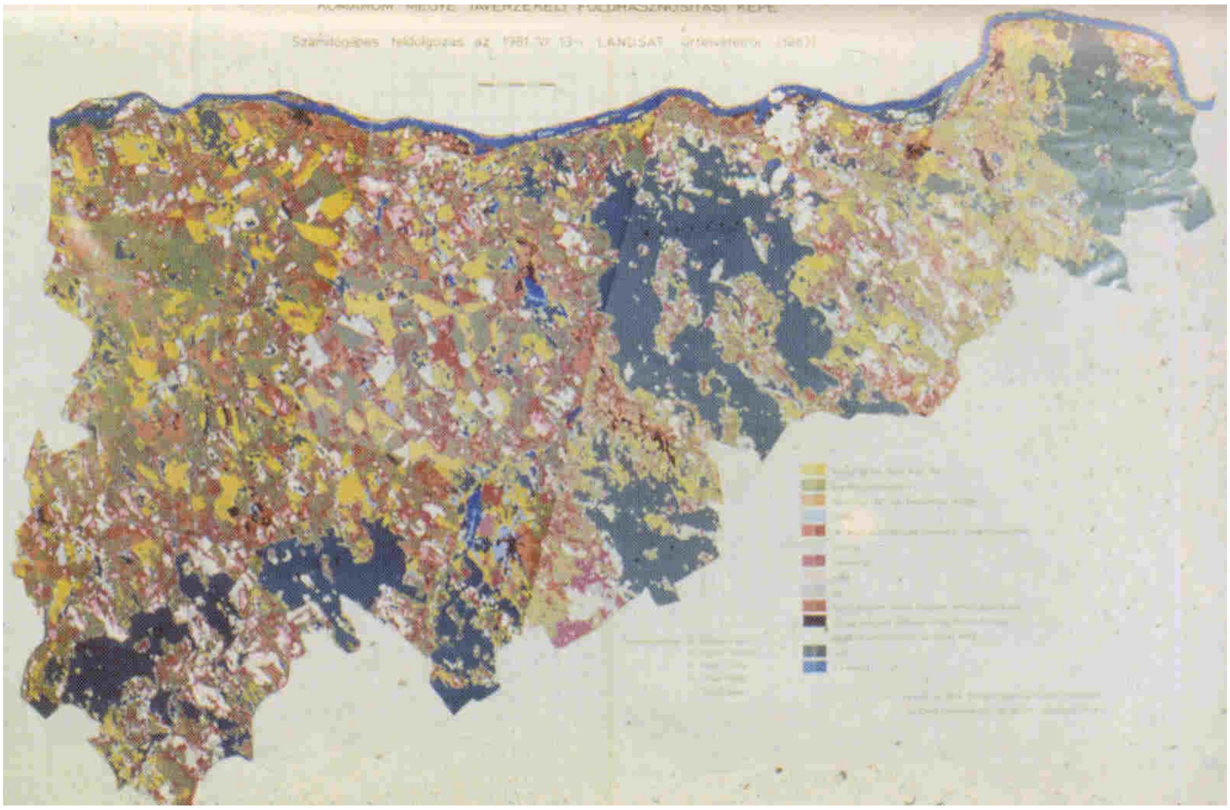

Figure 9. The first land use and crop structure map of Komárom-Esztergom County in Hungary, based on GIS processing of satellite imagery only (by Tózsa I. in 1983)

When researchers first made such maps in the 1980s, they assigned the red colour to the infrared range (see Figure 7), which is not visible to the naked eye but represents the maximum reflected radiation from green vegetation, and the other colours were necessarily assigned the remaining blue and yellow for the orange and green bands in the space images. The result was the so-called false colour image, i.e. the redder a surface is in a satellite image without a study area, the greener it is in reality. Figures 10 - 11 show such false colour satellite images without a study area or teaching area or training site, where the same colours represent the same surfaces, red represents green, black represents water, and the exact meaning of the other shades could be determined by calibration, if it is known what was exactly the case at the time the image was taken at a particular place where a particular shade of colour is visible.

Tool-oriented GIS processing can also play a significant role in the use of satellite imagery in smart urban planning, which is less known in Hungarian practice, although international and Hungarian scientific research has long recognised and applied these solutions. One of these is urban biomass mapping.

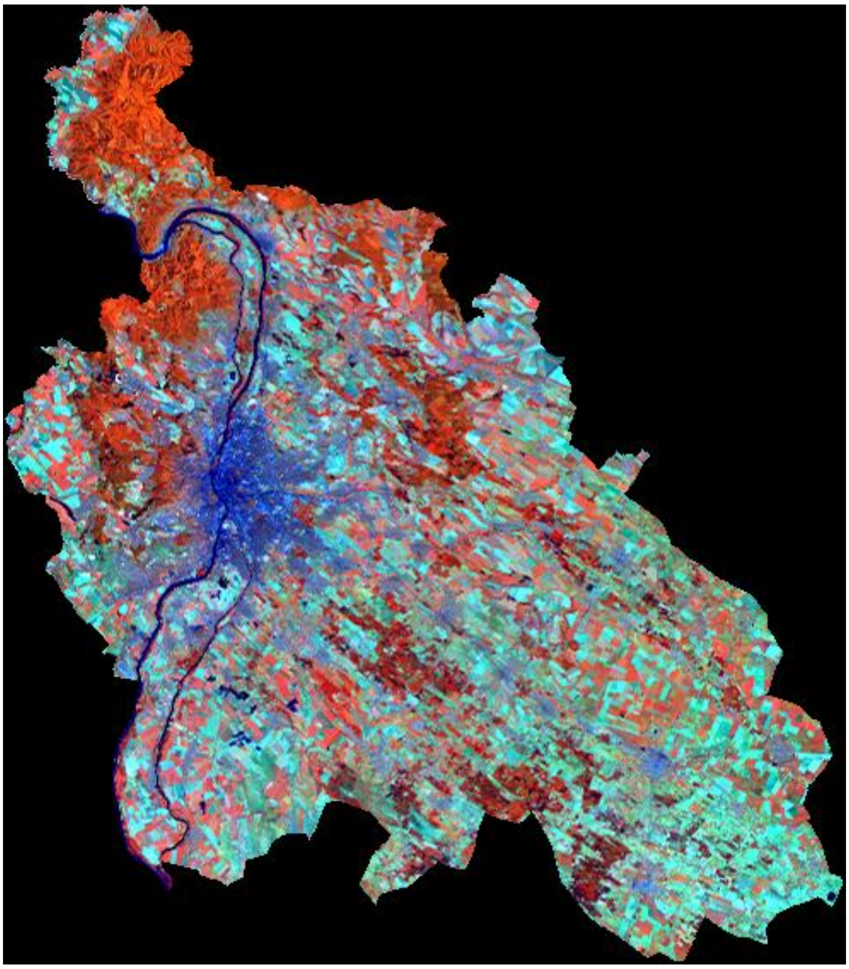

Figure 10. False colour satellite map of the centrally situated Pest County in Hungary, where the same colour shades indicate the same surface quality, but the meaning of the colour shades can only be determined by post-calibration.

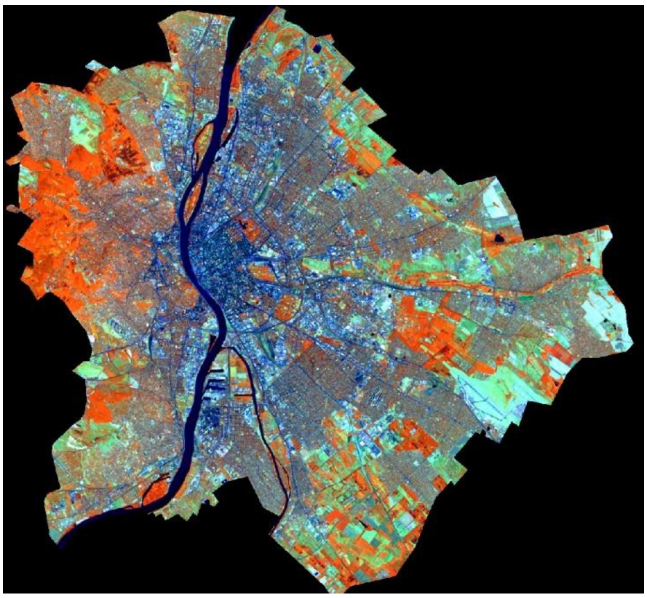

Figure 11. The image of the greater Budapest area and the administrative boundary of the city in a false colour image without a teaching or training area

Figure 7 shows that the near-infrared range carries the radiation reflectance values responsible for the "true" colour of vegetation. Therefore, if we look at the reflectance values for the Budapest area only in the infrared band, we can also cluster the pixel intensities of a single band into classes. Figure 12 shows that according to the frequency curve (histogram) of the distribution of pixel intensities from 0 to 256, 5 biomass intensity clusters can be distinguished in a processing without a teaching/training area/site.

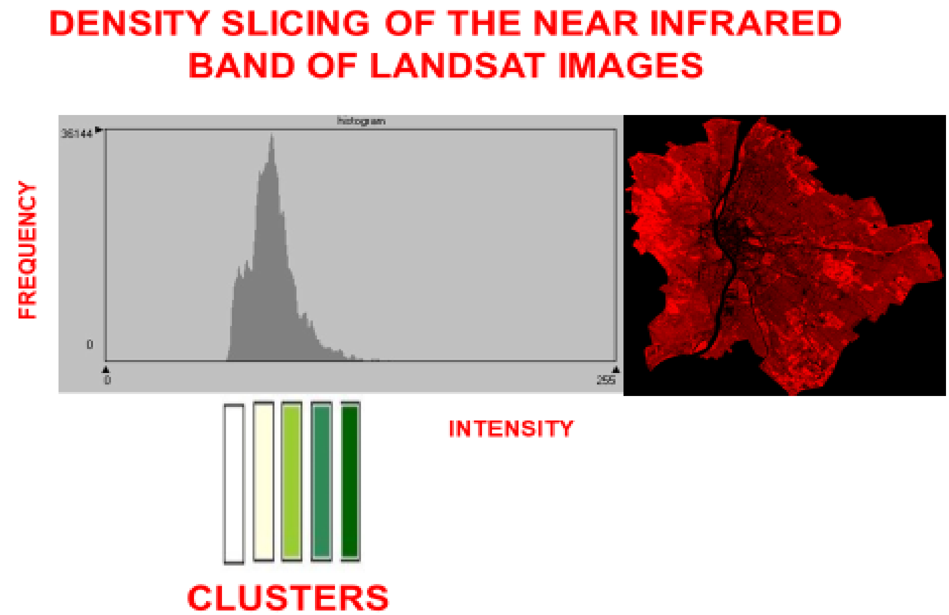

Figure 12. The classification of pixels into a cluster or group is called density slicing: here the distribution of biomass vitality is shown for Budapest

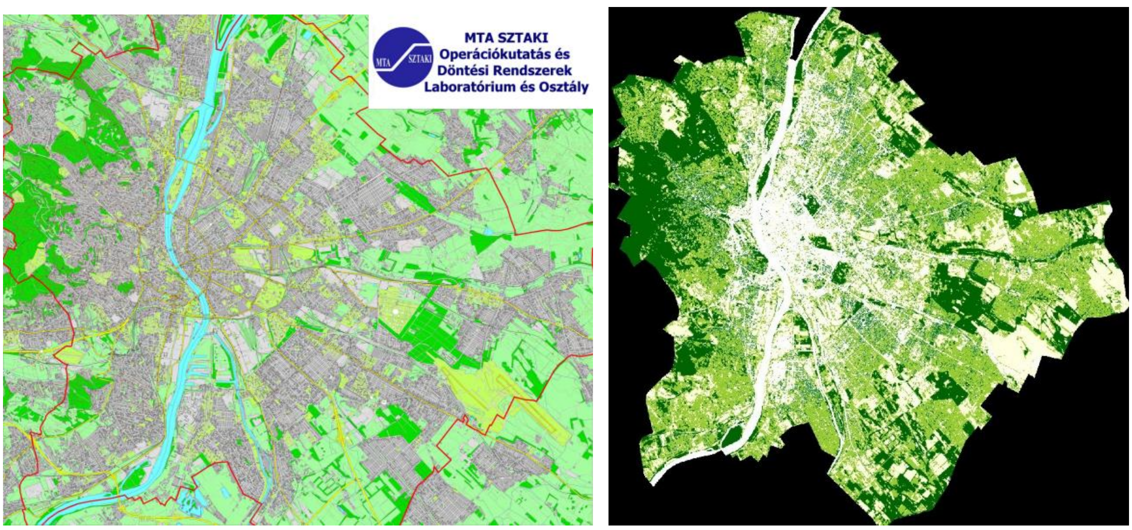

Figure 13. On the left, there is a conventional land use map showing the distribution of green space in Budapest, and on the right, the result of the GIS of the infrared density slicing shown in Figure 12: the latter shows the more nuanced and realistic quality of the latter

3. Decision Support GIS

This is the most intelligent form of GIS applications, where a question is asked to a system containing digital spatial data and the answer is given as the result of an algorithmic data processing that was not included in the input data. In municipal GIS applications, such systems can be the main tools for creative municipal management, as they can considering many factors when providing decision-supporting, decision-preparatory background information.

The structure of the decision support GIS type is illustrated in Figure 14. Data from a given area (Somogy County in Hungary in the picture) is input, which can be represented spatially on a number of overlapping map sheets. This creates a database. The formulation of the question is the formulation of an algorithm: where is the most and least favourable or unfavourable area for some use on a scale of 3 or 10? To do this, the factors that are relevant to the land-use classification must be weighted or correlated using some mathematical statistical method. The analysis is performed for each point (matrix unit or polygon - according to the data format) of the map, and each location-dependent matrix or polygonal area unit is assigned a certain score. The given point sets are then clustered using a histogram, and a map representation of the three or ten correspondence categories or clusters gives the resulting map, which classifies the area in terms of a particular utility.

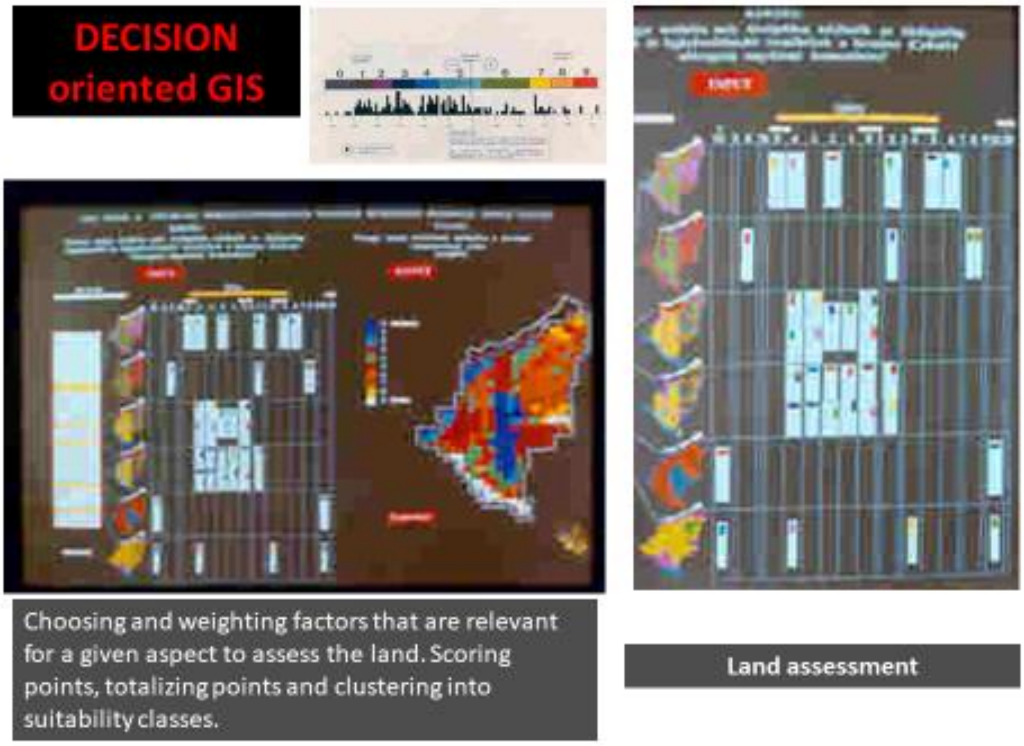

Figure 14. The decision support GIS structure (left): database, weighting table, and the result, the area classification map. The example shows the classification of the county area in terms of suitability for planting a particular orchard. On the right side, the weighting table is enlarged: the topography, soil type, soil structure, groundwater, climate (precipitation and temperature) are assigned weighting values by the algorithm based on horticultural knowledge, which are summed up to give the final result that the area along the Drava and the Kapos Rivers' valleys in Somogy County has the most favourable conditions for the plantation of the orchard in question.

In the case of a GIS for municipal decision making, it is obvious to assess all the environmental pollutants, to weight them and classify the area under study in aggregate. Even simple maps of a municipality, such as the distribution of CO or NO_x air pollution, the accumulated lead content in the soil, or the noise pollution of roads, are valuable background information for the environmental management of a municipality. However, GIS results such as the iron aggressivity of groundwater (by a combined assessment of free CO_2 content, iron ion concentration and chemistry) are a real decision support, because such spatial information can be used to plan the maintenance of underground iron pipelines exposed to groundwater, and to quasi-predict the probability of pipe bursts. The combined assessment of NO_x and humidity in the air, as well as temperature, produces smog hazard maps that can be used by city authorities to differentiate the application of smog warnings and to plan traffic restrictions, green space extensions, road watering, fountains - all interventions that can reduce air pollution in urban environments - on the basis of environmental science (Figure 15).

Figure 15. Map of Józsefváros (District VIII of Budapest) smog hazard (left) and the distribution of iron aggressivity of groundwater in Józsefváros (right)

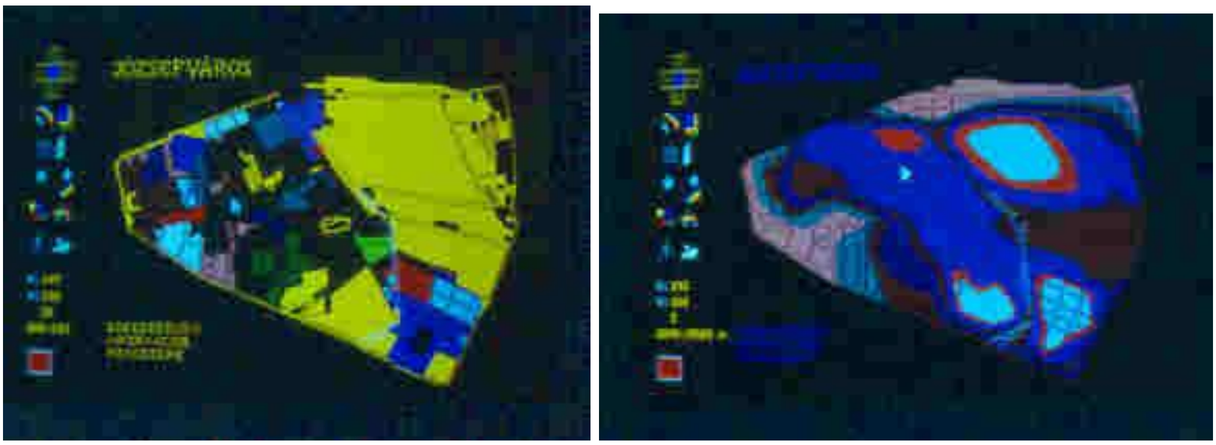

Figure 16. Patient traffic data and air CO pollution map of Józsefváros

The correlation of patient traffic data and maps of environmental pollutants can provide decision-support background information for the members of the health committee in addition to the environmental committee of the municipality (Figure 16).

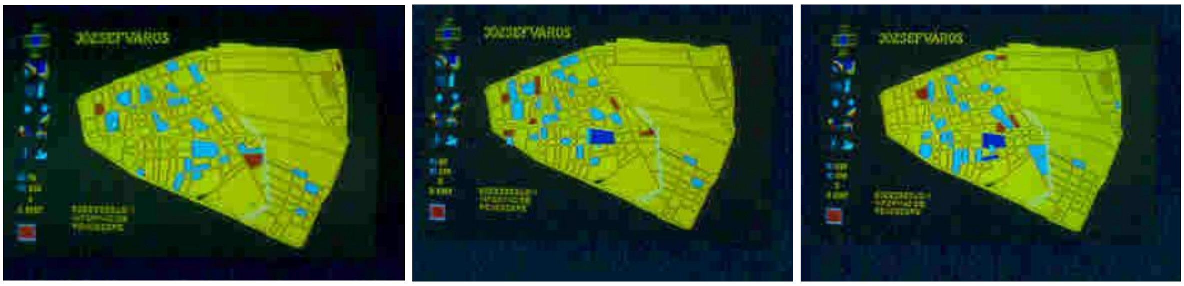

Figure 17. The correlation between the number of newly registered breast cancer cases and the background radiation intensity showing decreasing, stagnating and increasing trends in Józsefváros for 3 consecutive years

If the distribution map of an environmental pollutant or effect is correlated with the incidence of a disease - over a cross-section of years - then the relevant local authority can obtain "deadly serious" decision-support background information if an increasing, strengthening spatial relationship is found (Figure 17).

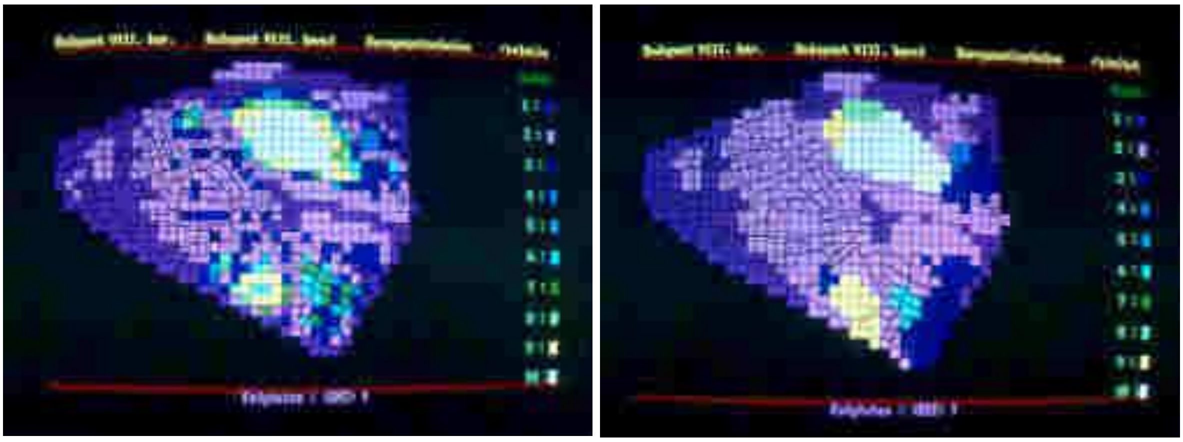

Figure 18. Exploring environmental trends in decision preparation by "smoothing" the mosaic result (left) to spatially well-defined locations (right)

A digital map of several environmental pressures (air pollution in terms of particulate matter, CO, SO_2, NO_2, lead contamination of soil and vegetation, chemical and biological contamination of groundwater, noise levels, background beta radiation levels from building materials, the condition of biological indicator plants) can be assessed in an integrated way from one perspective - by means of a medical expert weighting. In such cases, we ask the GIS to rate the urban environment from a human health perspective. The resulting map, if sometimes too mosaic, can be statistically smoothed. This makes it easier to define individual neighbourhoods according to their overall impact on human health, whether harmful, less harmful or beneficial, as in the case of Józsefváros in Figure 18. This facilitates the development of municipal environmental, health and environment protection strategies.

Examples of data-driven smart city management with a scientific basis are also shown in Figure 19. The aggregate number of cancer cases (per street block) can be correlated with the amount of background beta radiation from street pavement and building materials and can be planned for the amount and distribution of air pollution in different typical weather situations (e.g. calm or windy weather), which is caused by the wind ventilation effect of streets. It is interesting to note that streets with high vehicular traffic loads that do not make an angle with the prevailing wind direction have negligible air pollution in windy weather, while streets with similar traffic loads have higher air pollution the closer their alignment is to a 90-degree angle with respect to the prevailing wind direction. For example, at the two edges of Józsefváros, Rákóczi Road and Üllői Road both have a traffic volume of approximately 5,000 vehicles per day. In terms of air pollution, Rákóczi Road is far superior to Üllői Road. The reason is that while Rákóczi Road is at a sharp angle to the prevailing wind direction, Üllői Road runs in the prevailing N-NW wind direction, with negligible traffic air pollution. Thus, in an urban area, it is the run of the streets and the blocks that influence air pollution. Both air sampling, radiation and noise measurements, groundwater samples need to be measured at 30-40 locations at nearly the same time in a Józsefváros (District VIII) or Erzsébetváros (District VII) area to provide the environmental GIS with adequate input data.

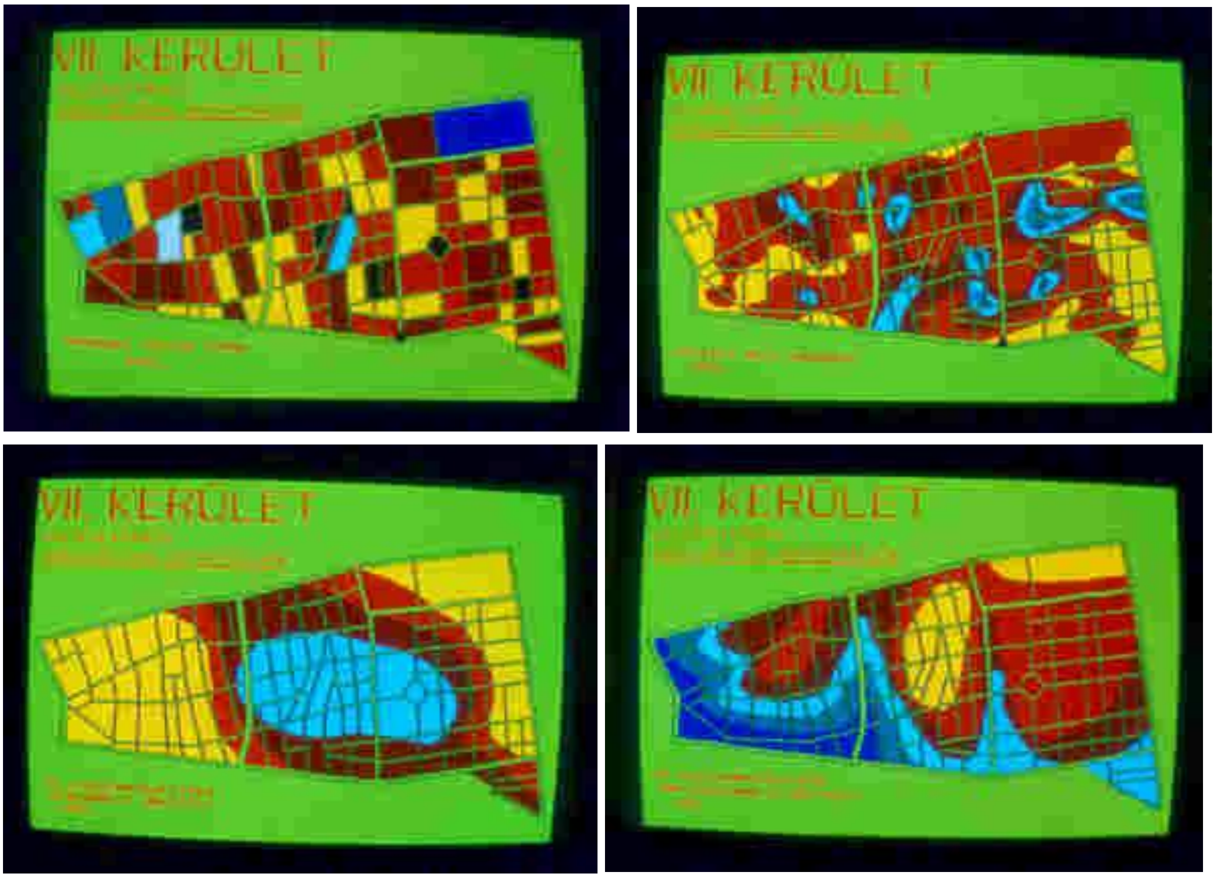

Figure 19. Input data of cancer incidence (top left) and background beta radiation levels (top right) for the spatial correlation calculation. Bottom left: distribution of CO air pollution in cyclone (windy) weather conditions; and bottom right: in anticyclone (calm) conditions. The high vehicular traffic impact of Erzsébet Blvd is clearly observed in the latter case, while the orientation of buildings and the wind ventilation of streets are responsible for the so-called "Almásy Square depression".

Decision-support GIS can also be used to assess and predict environmental risk. Measuring vehicle traffic, CO, SO_2 and NO_2 air pollution, falling dust, noise levels, background radiation, lichen indicators in a public space, the magnitude of the measured data can be used by specialists, including pulmonologists (lung) and oncologists (cancer). The average of their health risk factor weighting is the algorithm used to classify public areas using GIS (Figure 20).

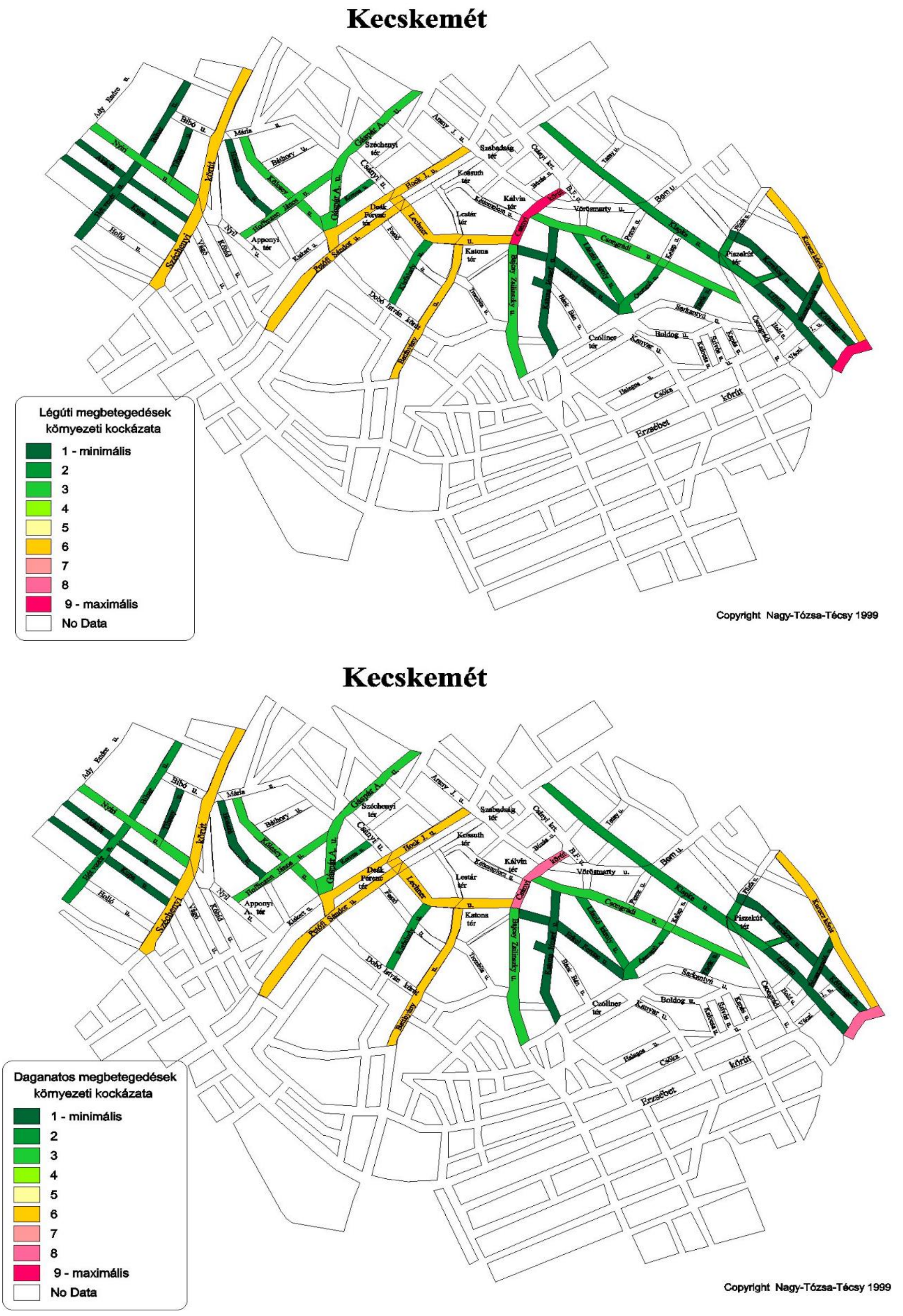

Figure 20. Decision-support GIS in Kecskemét (a city in the middle of Hungary) classifies the NW-NE-DW band of the city centre in terms of risk of respiratory diseases (top) and risk of cancer (bottom). Trends are similar, where traffic volumes are the same, but street orientation is 30 - 90 degrees to the prevailing wind direction, it is considered a riskier location.

Of course, the municipal authorities have a responsibility to make public the information shown in Figure 20, since publicly available information that the risk of a disease is higher in a given place in a city than elsewhere may adversely affect property prices there and may ruin the market chances of any development projects that may be started in that place. Thus, in a smart city, investors need to be informed in advance about the environmental health and suitability of a property for development. It is the responsibility of local authorities to make potential investors aware of this.

Figure 21. Result of the GIS processing of the Ferencváros Revitalisation district between Üllői Road, Ferenc Blvd. and Mester Street (District 9): general business case with the most and least favourable properties

Of course, decision-oriented municipal GIS applications can be used not only for environmental and environmental health analyses. Urban areas can also be classified according to various business and social aspects: where the environmental conditions are suitable for the establishment of a grocery store, a bakery, a fast-food restaurant, a car service station, or a kindergarten, a dance hall, a community centre, a doctor's surgery, or a home for the elderly.

In Figure 21, the inputs for the rating of a neighbourhood in Ferencváros (District IX) were the number of inhabitants, age composition, education level, tax capacity, solvent demand and purchasing power, pedestrian and car traffic intensity, number of parking spaces, distance to public transport stops, and property prices. The question was: at the property level, where are the most and least favourable properties within this area from a general business point of view, ranked from 1 to 9? The bottom row of Figure 21 shows the "smart" GIS answer to this question. To illustrate the reliability of the survey, the property rated most unfavourable (bottom right in the figure) was demolished in the months following the survey.

In the hands of municipal management, this kind of "smart" geographic information application is not only suitable for preparing decisions, but also for justifying decisions to the public and stakeholders, and for differentiating the local tax levy, if it is known how favourable or unfavourable a location is from a business point of view.

The English sister borough of Erzsébetváros (District VII) is London’s Islington. During a visit to Islington, the author of this article was present at a District Council committee meeting when councillors there were deciding whether an applicant could open a nightclub on a property in a particular part of Islington. After a brief discussion and consultation, the decision was ruled out because the *night club* would 'probably' increase the level of noise on the street at night with the traffic it would generate and would also introduce drug dealing in the vicinity, which would probably disturb residents. Justifying a refusal based on such assumptions is not necessarily worthy of the image of a smart city. How much more convincing would it have been if they had said: "we have considered your application; our local GIS, which considers all the environmental factors to be considered, has classified the property in question as a category 3 *nightclub* and such a licence can only be granted by the Council for properties in categories 7-8-9. Please find attached a rating map of the district in this respect and we draw your attention to the properties that have been rated as suitable for your business." Such a justification not only protects the interests of residents, but is also business-friendly, not necessarily just scares investors away from the district or the municipality.

4. GIS for public services

GIS is an essential "accessory" for the smart city. At the same time, geographic information support for urban services is an integral part of e-Government. Figure 22 illustrates the factors and linkages involved in the modernisation of municipal government operations. The services shown in the lower third of the figure for the smart city all use GIS tools. Utility services include public utilities (water and sewage systems), telecommunications and communication networks, and energy supply (electricity, heating and hot water). Real estate, population and property registry GIS provides up-to-date statistical and land registry data that are required by the local government and the decentralised bodies of the district administration for their operations in the fields of construction, tax collection, municipal planning, health, education and social services. The same can be said of statistical data at municipal level, data required for town and country planning and land registry data. Transport management in the local interest is only a task for municipalities by extension, but one of the hallmarks of the smart city is that passengers at bus stops should be able to obtain increasingly detailed information on traffic conditions, the position and timing of arrivals and departures, not only for trains and buses but also for metro and tram services. This is provided by asset-oriented GPS-based GIS. Finally, complex GIS systems for urban management and local environmental protection and urban health (primarily of the decision-support type) are still largely under development and are the most representative of the smart city.

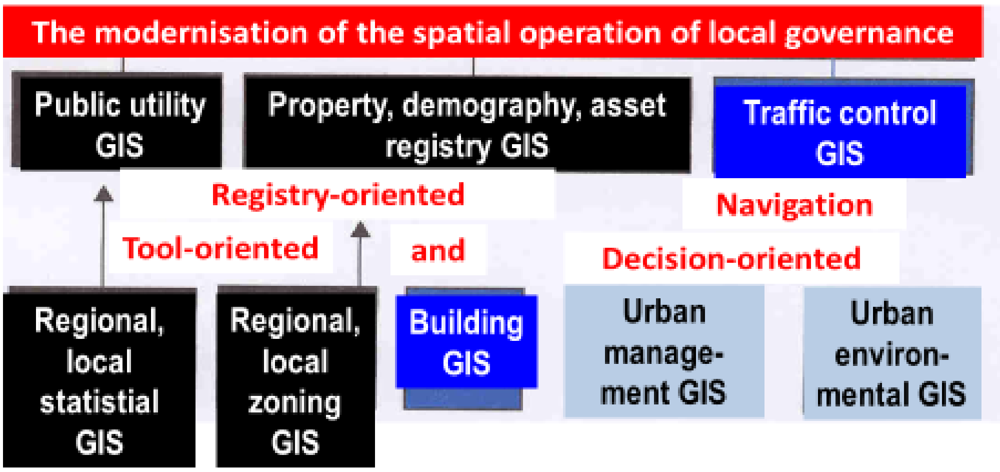

Figure 22. In the modernisation of municipal services, all three types of GIS-based tools are used: register-oriented in utility applications and property and asset registers; Tool-oriented in town planning, construction and transport; and Decision support GIS in complex urban management and environmental health systems. The black colour has been in use for some time, the dark blue colour is for recent developments, while the light blue is still under development - in Hungary.

Figure 23. A public utility and a property registration (database type) GIS application

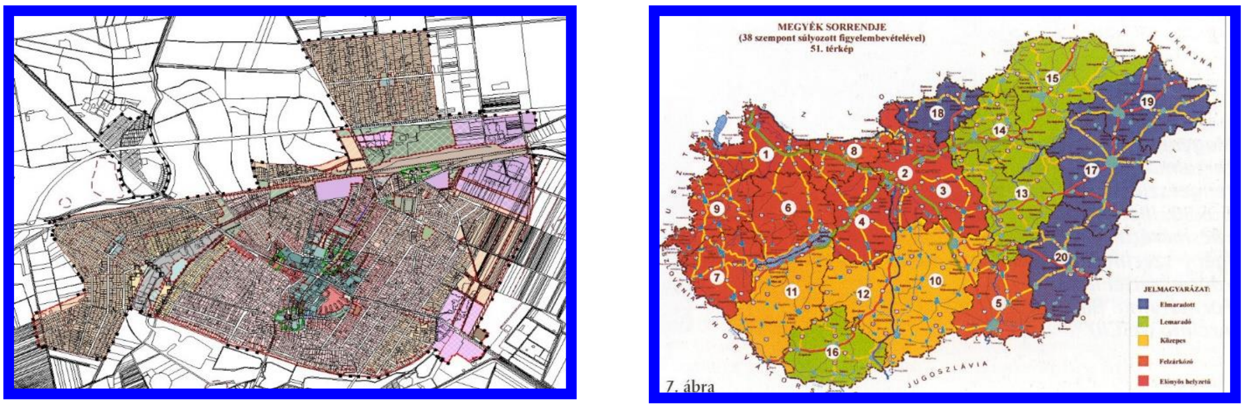

Figure 24. A spatial statistical database type and a spatial planning tool-oriented GIS application

Figure 25. Examples of tool-oriented GIS applications in the smart city: on the left, a building survey showing the real (aerial photo) and land registry (red line) locations of residential properties (such applications can be used for building fines, as they provide evidence of unauthorised construction). On the right, a tool-oriented GIS application for public transport combined with GPS.

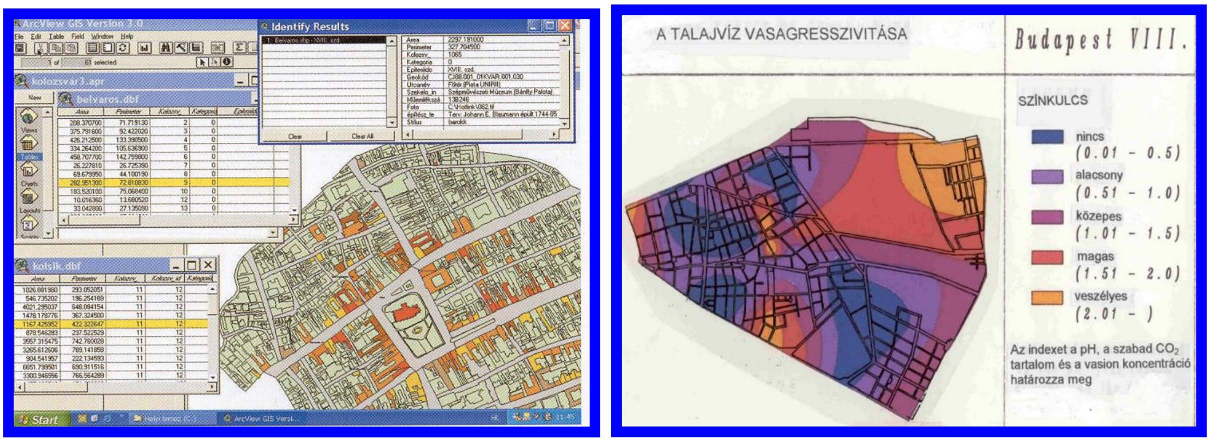

Figure 26. Examples of decision-support GIS applications in the smart city: on the left, an urban management GIS at the property level for technical infrastructure and land registry, with real estate market data; on the left, a typical urban health GIS with certification.

Interference between public services and e-Government does not necessarily have a spatial dimension. This includes most e-Government services, with online administration services and workflows for document offices and other specialised administrations (Figure 27: 4). The interference between GIS and e-Government includes online administration for building and other specialised administrations with a territorial dimension (3). The interference between GIS and public services is most extensive: public utilities, i.e. technical infrastructure services, online services with territorial relevance or relevance to human infrastructure. Finally, the group of services where GIS interferes with both public services and e-Government are: police, ambulance, fire brigade, disaster management, flood protection.

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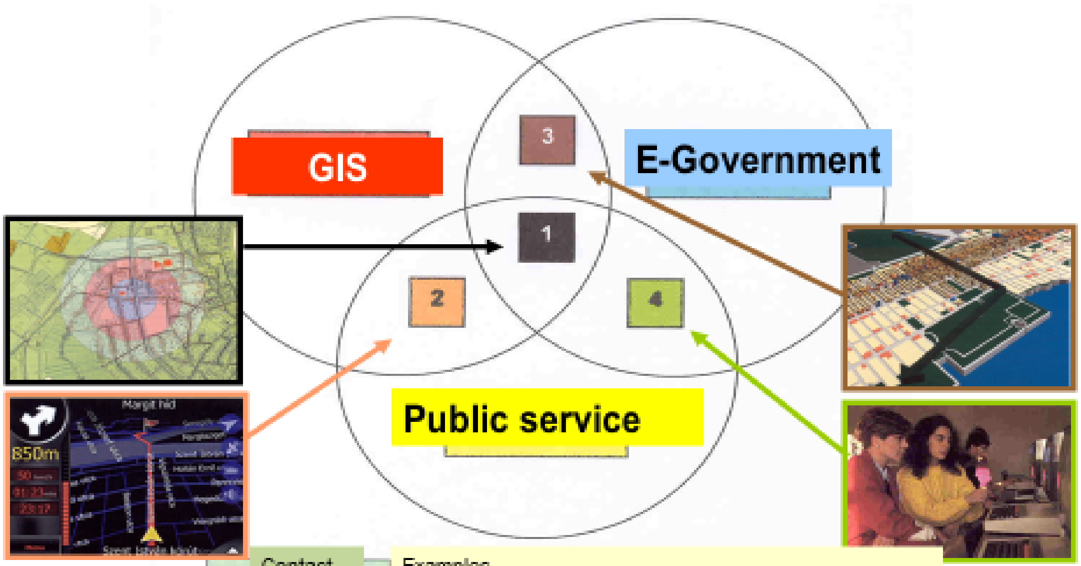

	Contact	Examples
1	GIS-Egov-P.s.	Defence services (police, fire, catastrophy management)
2	GIS-P.s.	Operation of transport, public utility, education
3	GIS-Egov	Building authority, reg and local development
4	Egov-P.s.	E-document management, e-taxation etc.

Figure 27. Embedding GIS (geospatial information systems) in smart city e-government and public services

Public services are in fact a combination of technical and human infrastructure. The infrastructure available in municipalities can be divided into eight broad areas based on the scientific classification of György Kőszegfalvi (Figure 28). They include service areas such as (1) housing, (2) human (health, education and social services), (3) technical (utilities, energy supply, communications), (4) consumption-related services, (5) urban health, (6) transport, (7) recreation (leisure, leisure, sports) and (8) urban governance.

1. Residential property management	**5.** Urban environmental services: sanitation, waste management, green areas upkeep, chimney sweep, fire protection, burial service, sewage water
2. Communal services, human infrastructure: education, health and social care	**6.** Logistic services: transport, traffic, carriage/shipping, storage
3. Public utility services: water, sewage, energy, ICT	**7.** Recreation: sports, holidaying, entertainment services, healthy living, nature conservation, environmental protection, cultural, community and art services
4. Consuming and personal services, commerce, maintenance	**8.** Urban management services, local development, master planning, building construction, public safety, catastrophe management, defence

Figure 28. Allocation of municipal infrastructure (public services)

The following is a visual representation of the GIS applications that creates a prerequisite for a smart city, which is essential for both the high-quality operation and use of municipal public services. The first major area is therefore housing and real estate management, where the application of municipal GIS cannot be ignored in the 21st century (Figure 29).

Figure 29. The housing, property and asset management GIS stores all technical, land registry, business and market data at the property level that can contribute to the proper management of housing in municipalities. Aerial photographs can be used to make these systems more visual, aesthetic and orientational for better clarity.

The technical term for human infrastructure is a set of community services. Its main components are primary, secondary and tertiary education, and, in the same subdivision, health care and administration, and social services. Although the use of GIS in these areas is not yet widespread in Hungary, there are examples, although mainly abroad, overseas.

In addition to transport, public utilities form an important segment of technical infrastructure. Public utilities consist of three parts. (1) Water utilities i.e. piped drinking water supply, waterworks operation, sewerage network and wastewater treatment. (2) Energy utilities, i.e. power plants, power lines, transformer houses for distribution, gas works and gas pipeline network, district heating and hot water supply. (3) Communications and telecommunications mean the operation and use of various wired and wireless networks in the form of radio, TV, fixed and mobile telephone, Internet, and cable TV networks. The operation of these also requires the application and use of GIS, especially record oriented, database driven GIS for spatial development, monitoring of operations and localization of troubleshooting.

Among the examples shown in Figure 31, the top left is a utility map of Gellért Square with the exact location of all the lines, and among the examples are a mobile network coverage map and electrical and water utility spatial information

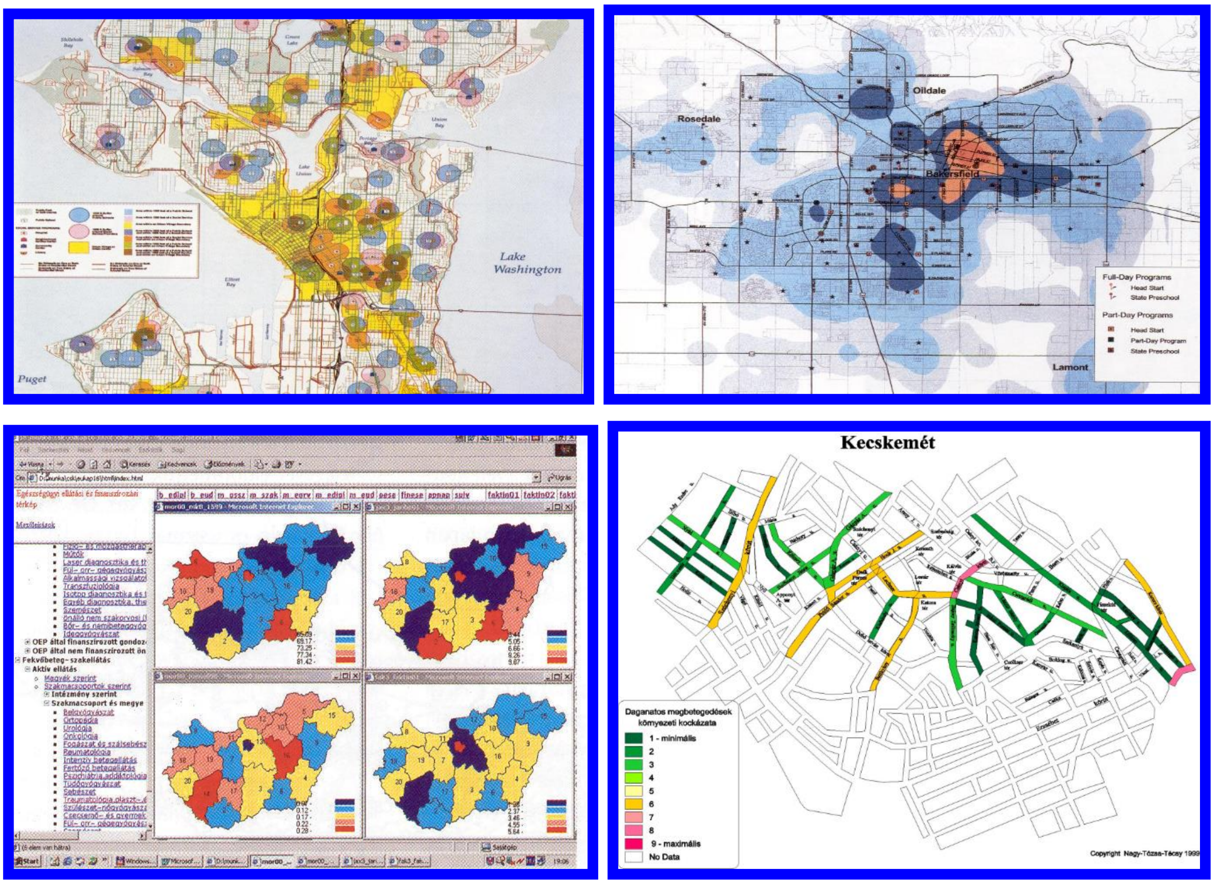

Figure 30. Examples of GIS applications that improve community services. The catchment areas and turnover data of social homes, schools and hospitals, doctors' surgeries can be plotted, occupancy and demand can be compared, and the utilisation of facilities can be planned using GIS. Statistical data can be used to visualise the quality of care, even at national level (bottom left), and to localise the environmental hazards mentioned above, which can be used in health management, to improve the health status of the population - by displaying location-dependent data and spatial information (bottom right), and which are already a type of decision-support GIS.

The difference between CAD and GIS is partly technical: CAD data input is vector-captured, so lines and polygons can be recorded to a high accuracy of centimetres, which is an essential database for design, construction, maintenance and troubleshooting. GIS data input, on the other hand, operates with raster points, a square grid, whose geographic accuracy depends on the resolution of the square grid. Obviously, a resolution of several square kilometres is only suitable for detecting geographical trends. For technical planning, construction, troubleshooting, GIS is of course not generally suitable, think of a road survey, where it is appropriate to know the exact location of underground pipelines, and not to do a random survey, for example, with an accuracy of a few metres or with inaccuracies. The advantage of CAD is therefore accuracy, but precisely because it operates with lines and polygons, polygons and polygons, it is much less suitable for multi-factor spatial classifications than GIS, where you can overlay any number of digital maps on overlapping raster grids, compare, weight and analyse them.

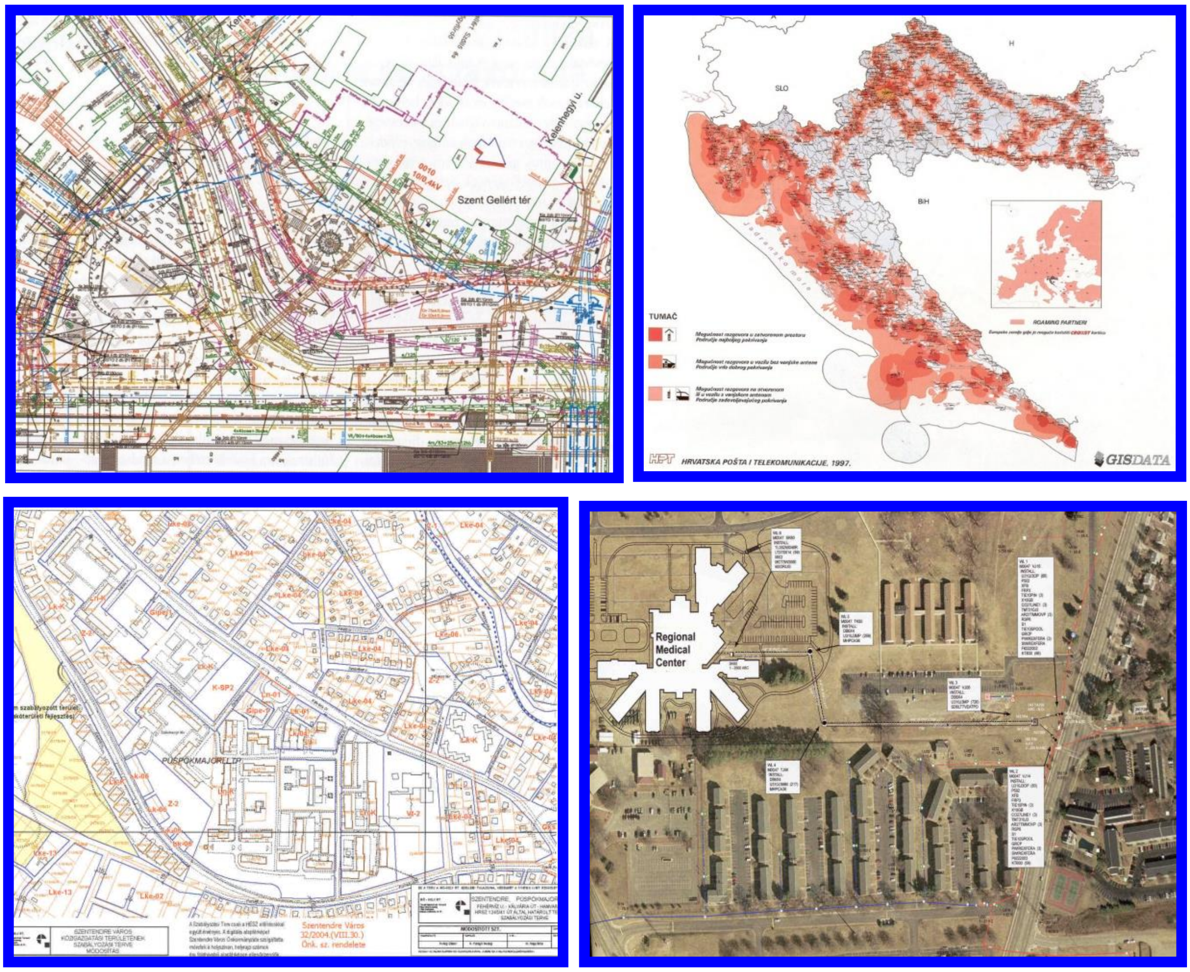

Figure 31. GIS used in utility services is primarily a database-driven, record-oriented geospatial information system that requires high spatial precision, namely that pipelines and facilities are exactly where they are depicted in the geographic space. These spatial information systems are known in the industry as CAD (Computer Aided Design).

Personal consumption and personalised services are dealt with by retail, maintenance, repair and services such as hairdressers, tailors, masseurs, body builders, beauticians, etc. Due to the nature of the service, only large hypermarkets, supermarkets, food and industrial retail chains and large banks in financial services use geospatial information technology in their operations. Banks and large supermarkets and shopping malls map their customer catchment areas by mapping their customers' places of residence and then extend this with spatial data on the wealth, consumption habits and transport conditions of the catchment consumer population. They can use the spatial information gathered from these data as decision-supporting background information for planning their commercial policy, expanding their range of products and timing their promotions. For the time being, these are not so much in the practice of traders and bankers, but rather in scientific research, both abroad and in Hungary.

Here we should note the following case, referring to the not necessarily correlation between GIS operating with scientific, environmental data and rigid business interest. In the mid-1900s, when Western chains and shopping malls were opening one after another in Budapest, the author of these lines, using the GIS methods of spatial classification developed at the Institute of Geographical Research of the Hungarian Academy of Sciences, noticed that, for example, the shops of Western fast food chains were often opened side by side, in the immediate vicinity of each other, at a single node or along a main road in the capital, while at the same time there were no shops in certain parts of the city where social and traffic environmental factors would have justified it. Therefore, the US headquarters of McDonald's, King Burger, KFC, Pizza Hut and the then existing Wendy's were approached with the following offer. Based on a weighted aggregation and area rating of the factors of the overall urban environment (number of local population, number of local offices, income level, intensity of local pedestrian and vehicular traffic, distance to public transport stops, number of parking spaces, real estate prices, distance and capacity of competitors, etc.), the neighbourhoods with the most favourable mix of assets for the maximum number of customers of a given fast food restaurant can be selected, even at the property level. Such applied research could be an attractive GIS challenge. After none of the restaurant chains responded to the "reasonable" prompt, someone commented to the author's puzzlement, "you think McDonald's is a restaurant chain?" This got the author to thinking yes, international *fast food* restaurants are in fact huge real estate investments in the most frequented, expensive properties in the world's major metropolises, and the restaurant industry business, franchising, is just a maintenance business. All of which belies the naive notion that the international fast-food chain's vocation is to provide a steady supply of food or to scientifically explore the busiest possible neighbourhoods. This is secondary to the price and preservation of the property depending on its location.

It is no coincidence, therefore, that GIS is less developed for highly business-driven consumer services, and is more limited to scientific research results, not even considering as a public service the basic food supply, where the state would have a responsibility, but this responsibility is shared among dozens of public administrations, mainly control bodies, and where the role of state intervention is the smallest among services.

The next municipal infrastructure area is the scope of municipal health services. This includes (1) Public sanitation (cleaning of public areas and snow and sleet removal); (2) Waste management (collection, transport, storage and disposal of household and hazardous waste and site remediation). (3) The management and maintenance of green areas. (4) Chimney sweeping and fire protection. (5) Funeral services. (6) Sanitation, which is a specialised term for the traditional domestic sewage disposal and the removal (siphoning) and disposal of this sewage. This municipal service is (would be) of particular importance because it is the most polluting residential activity, typically in suburban, unsanitary urban areas, as it often directly pollutes the lowest layer of the urban biosphere, the groundwater.

Traffic, together with transport and warehousing, is included in logistics services. Tool-oriented GIS is used in combination with GPS (global positioning systems) for route planning, navigation, planning of road routes, warehouse loads, capacity planning, traffic counts, planning of highways, railways, fleet management in transport. In urban public transport, to inform passengers and improve dispatching services. There is a growing number of driverless public transport vehicles, which are navigated using asset-oriented GIS and GPS combinations. And *Google car* is already foreshadowing a future in which GIS-based geospatial information will be the basis for safe road transport based solely on positioning, route planning and traffic intensity detection.

The combination of location-based GPS and GIS with mapped routes will put transport on a whole new footing in the future. In addition to helping vehicles navigate; on trains, boats, roads, airplanes, passengers will be provided with visual information by this tool-oriented GIS that will keep them informed - on a map - of their whereabouts, the trail of their route and the remaining travel time. This intelligent transport, public transport, traffic management and continuous passenger information is an essential feature of the smart city. GIS provides a flexible solution to route planning, re-planning the route in case of traffic congestion.

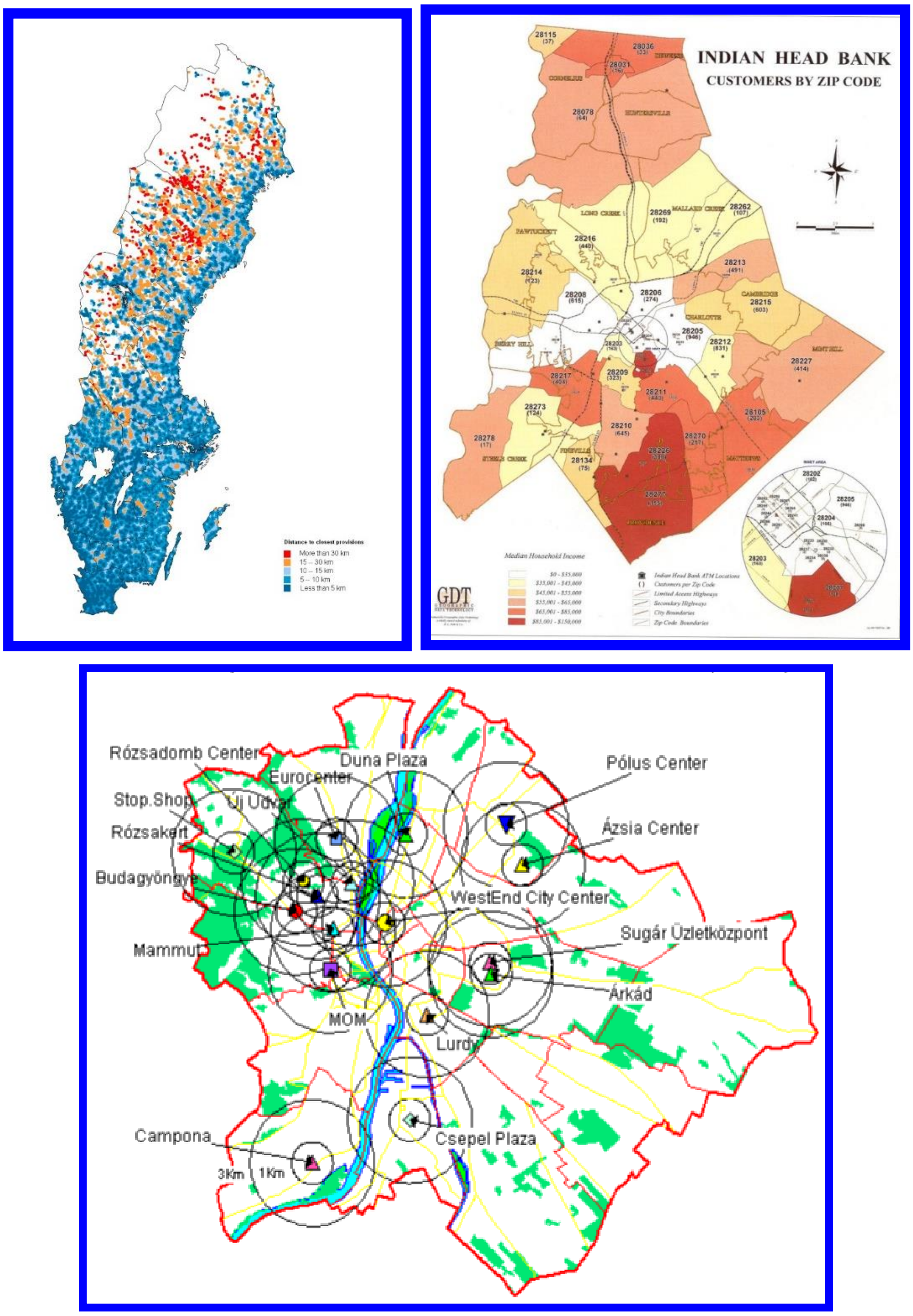

Figure 32. GIS applications related to consumption as a municipal service are so far more used in scientific research: the retail network of a country, the catchment area of a bank, or the catchment area of a mall in Budapest (Source: Sikos T. - Hoffmann I. 2004.)

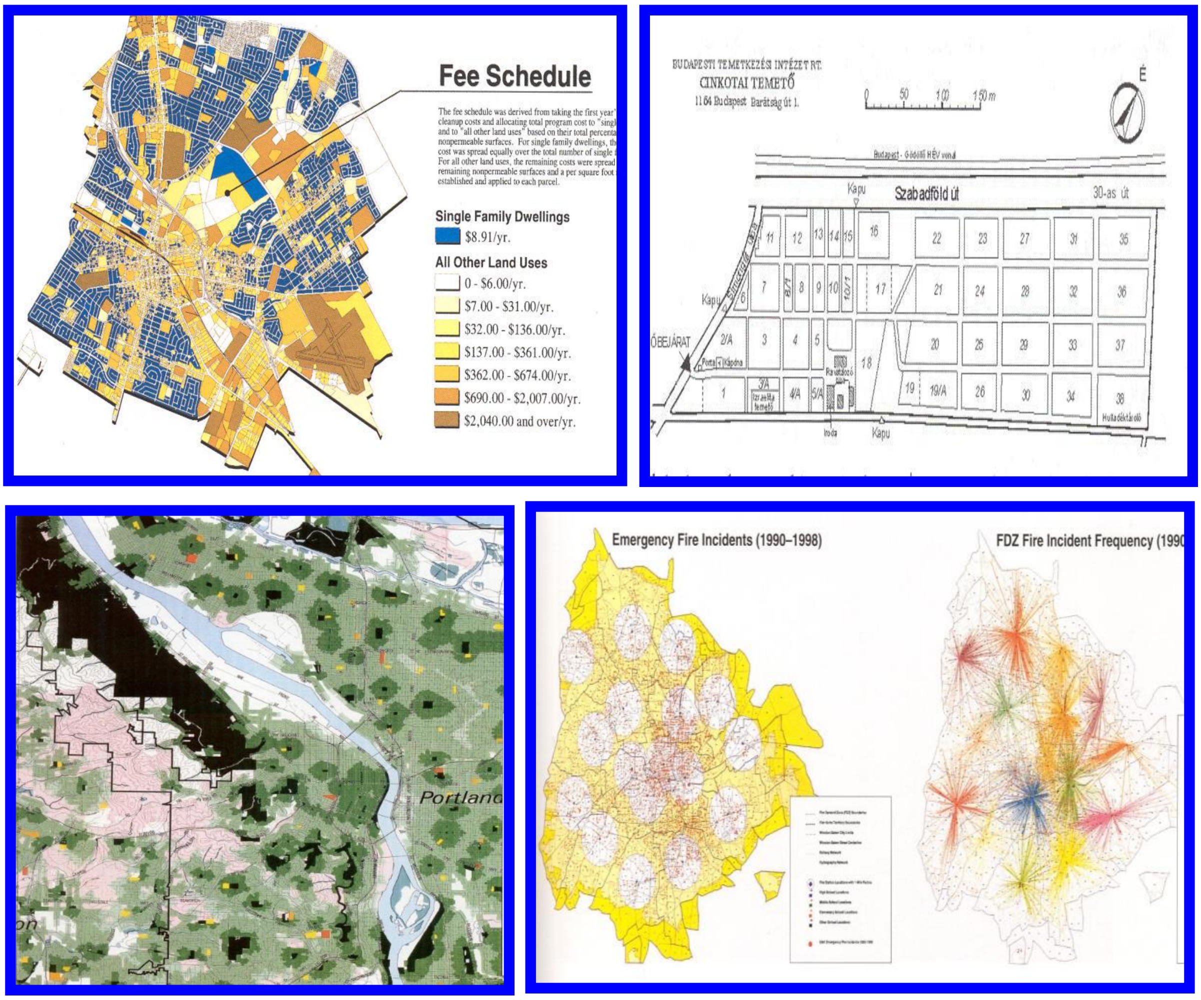

Figure 33. Some examples of GIS support for municipal health services: tariff zones for household waste collection (top left); digital parcel map of a cemetery (top right); green space register (bottom left); and fire management (with fire frequency register and response times).

Recreational municipal services include the management and operation of facilities hosting sporting events, the operation and programming of cultural and arts facilities, the provision of information on entertainment facilities (theatre, cinema, concert), community events and activities (on maps or interactive maps), and the spatial representation of information on nature walks, accommodation, spas, beaches. All this, alongside rich visual information, is of course, as in the case of transport, combined with online transaction facilities, ticketing, booking facilities. All these services, which are not public services, but are essential and very much used by the municipal infrastructure, clearly signal the need for a smart city in terms of geo-spatial information. Local authorities should therefore encourage all services that run interactive applications optimised for mobile devices and geo-spatial information, in order to raise awareness of the healthy lifestyle of local residents as an optional task. For example, the number of these services, which are used by incomparably more citizens and tourists than official public services such as document offices, could be one of the measures of the implementation of the smart city.

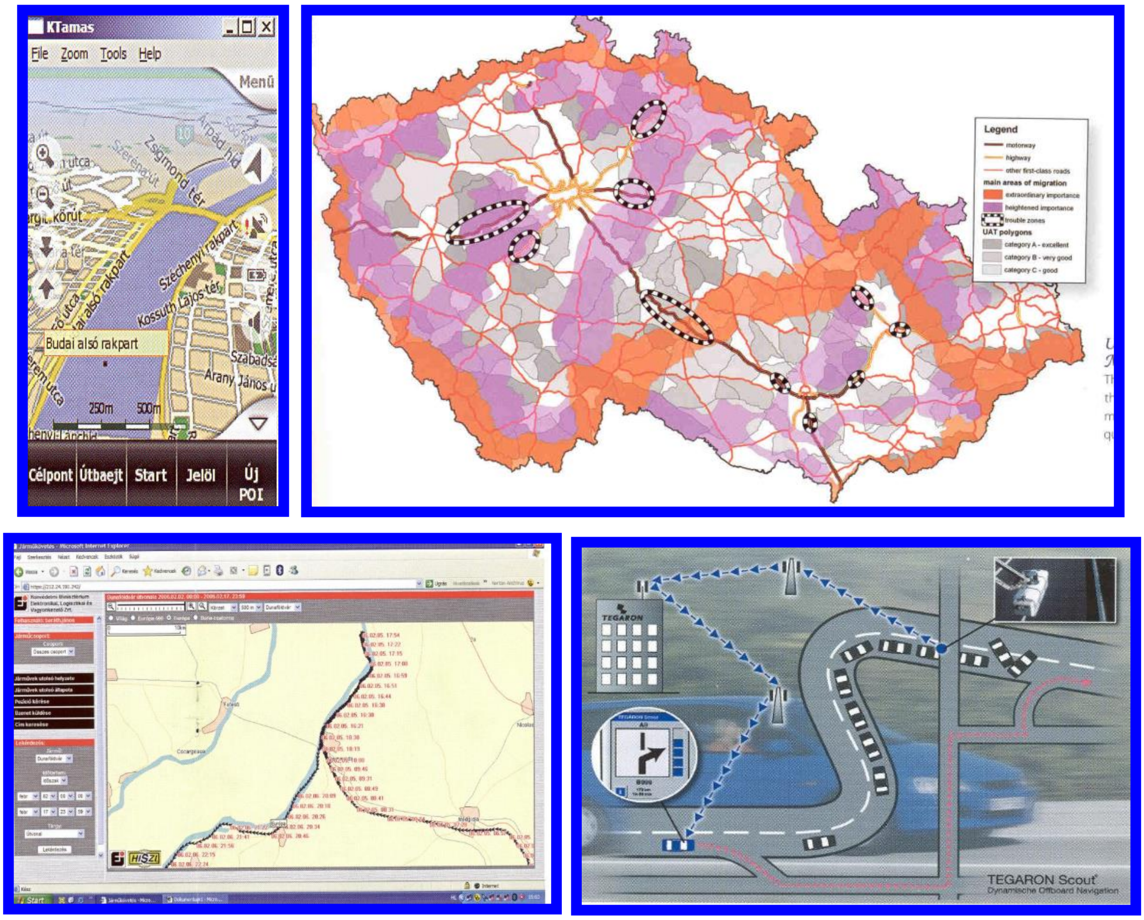

Figure 34. Some illustrations of GIS support for logistics services: navigation GPS, planning of motorway capacity in the light of expected traffic, transport fleet management for capacity utilisation and optimisation based on access times, and finally flexible route planning by continuously informing the traffic situation in case of sudden obstacles or accidents - just like Google maps continuously creates the traffic load on roads in real time based on the number of mobile devices passing through.

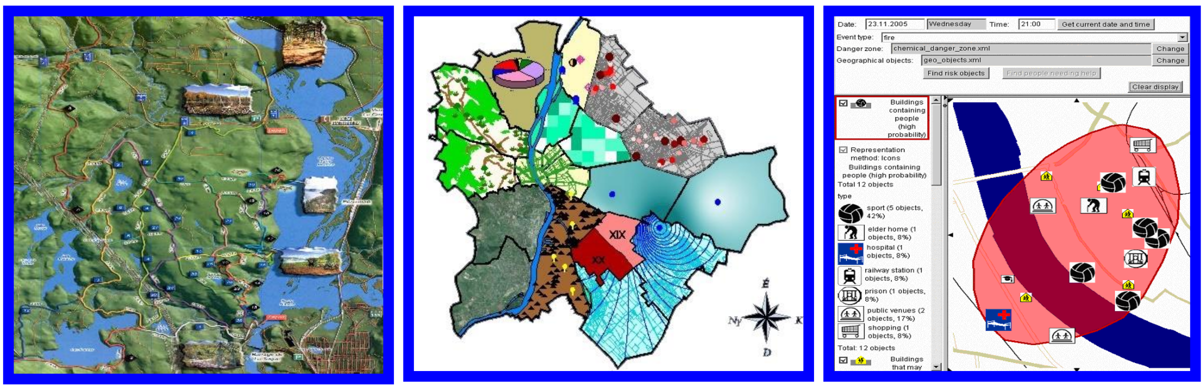

Figure 35. The implementation of healthy lifestyles at the municipal level is also supported by GIS, geospatial information systems, such as online tourist maps, environmental and nature conservation maps (in the Budapest Environmental Information System), or geospatial information systems for events in the vicinity of certain sports facilities.

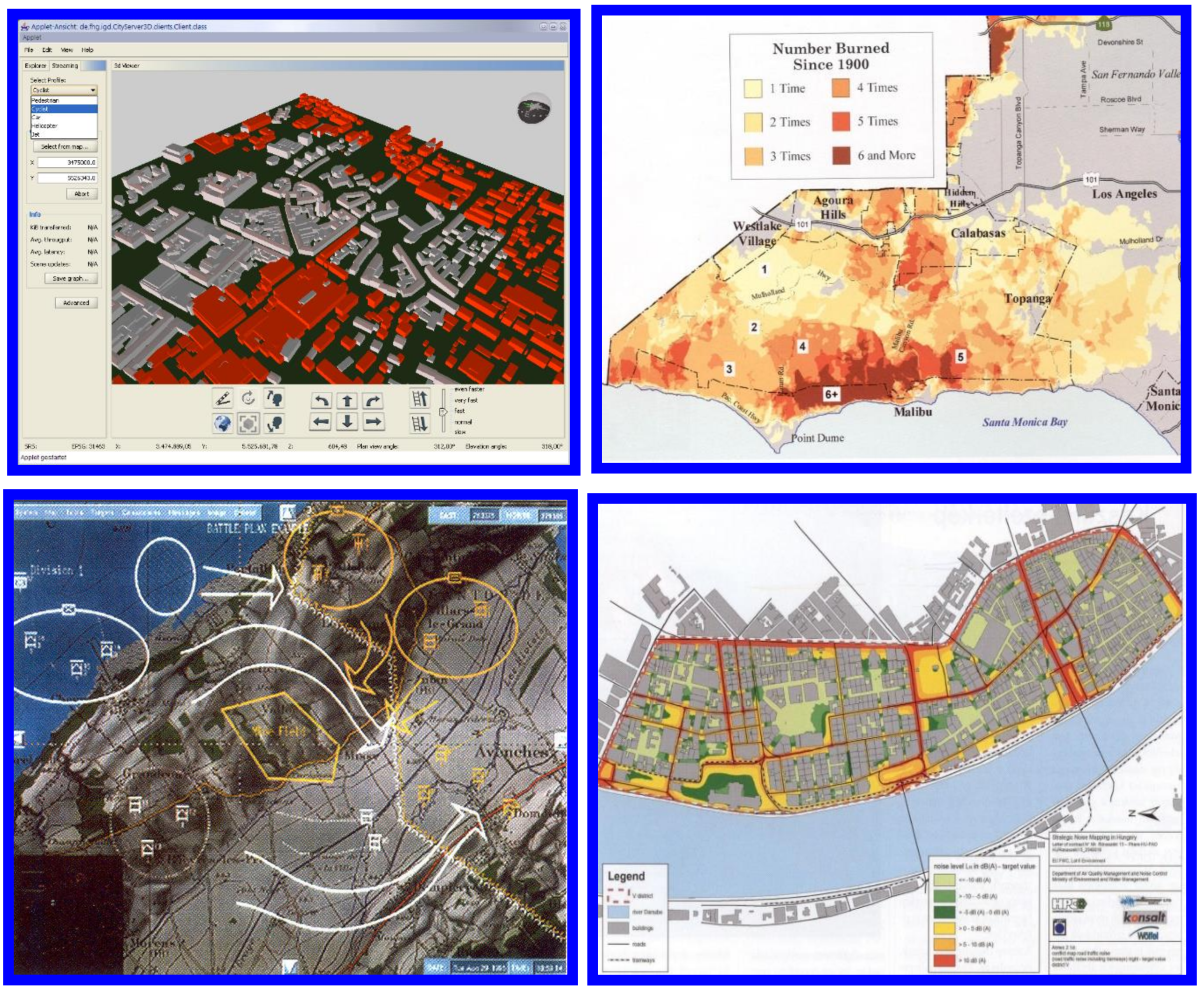

Figure 36. Some examples of municipal GIS applications. Three-dimensional images and simulations can also be used in urban planning; places at risk from specific disasters (e.g. forest fires) can be represented by public noise maps (bottom right, District V), or by specialised defence planning and implementation maps of the Defence Forces (bottom left)

Finally, the 8th major area of municipal infrastructure includes municipal management services. Here, the town and country structure plan, the land-use plan and the regulatory plan must be presented in an asset-oriented GIS format in a smart city. The maps of the land registry data can also be displayed independently on the municipal asset management maps or in the regulatory plans. Maps that promote local public safety could include a police or vigilante patrol map, which could be outlined based on the locations and frequency of various crimes. Disaster management in the event of flooding or nuclear radiation or terrorist attack should have GIS-based maps that allow evacuation planning and localisation of the individual protection tasks according to a plan of action required by the disaster situation. Lastly, the armed forces should also have maps that locate or depict in space the objects of defence interest, warehouses, shelters, wells, reserves, supply routes, accessibility, etc. in a settlement.

Figure 37. The structural plans of Tata and Tatabánya (two towns in Transdanubia, Hungary), as an example of tool-oriented GIS application in urban management.

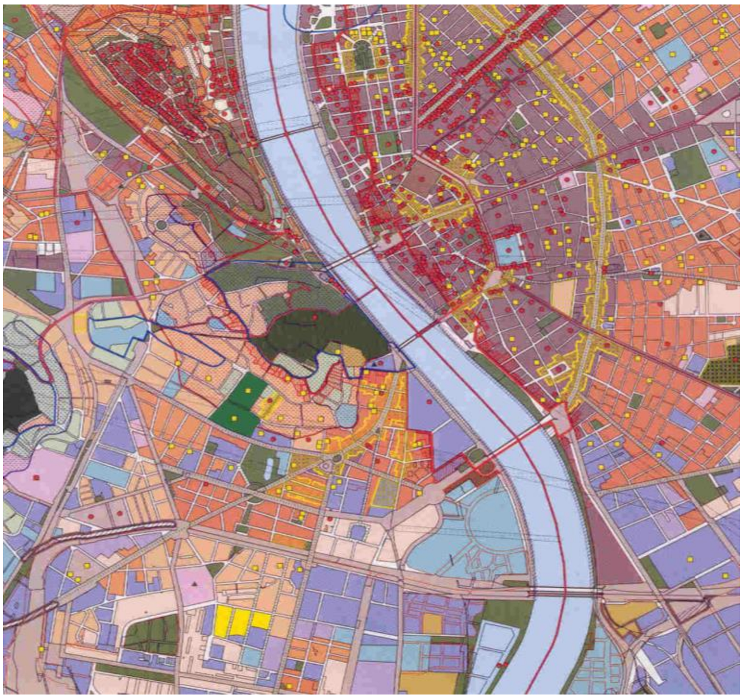

Figure 38. The regulatory master plan of the centre of Budapest as an example of a tool-oriented GIS for urban management. Technically, the input data overlays (maps) of such a map are building zone colours, street network, hydrography, pipelines, green spaces, signs, as well as property boundaries (if zoomed in) and land registry data associated with the property.

5. Outlook

In the European Union, the INSPIRE Recommendation (INSPIRE= Directive on the **IN**frastructure for **SP**atial **I**nfo**R**mation in the **E**uropean Community), launched in 2009 aims to make digitised maps compatible with GIS

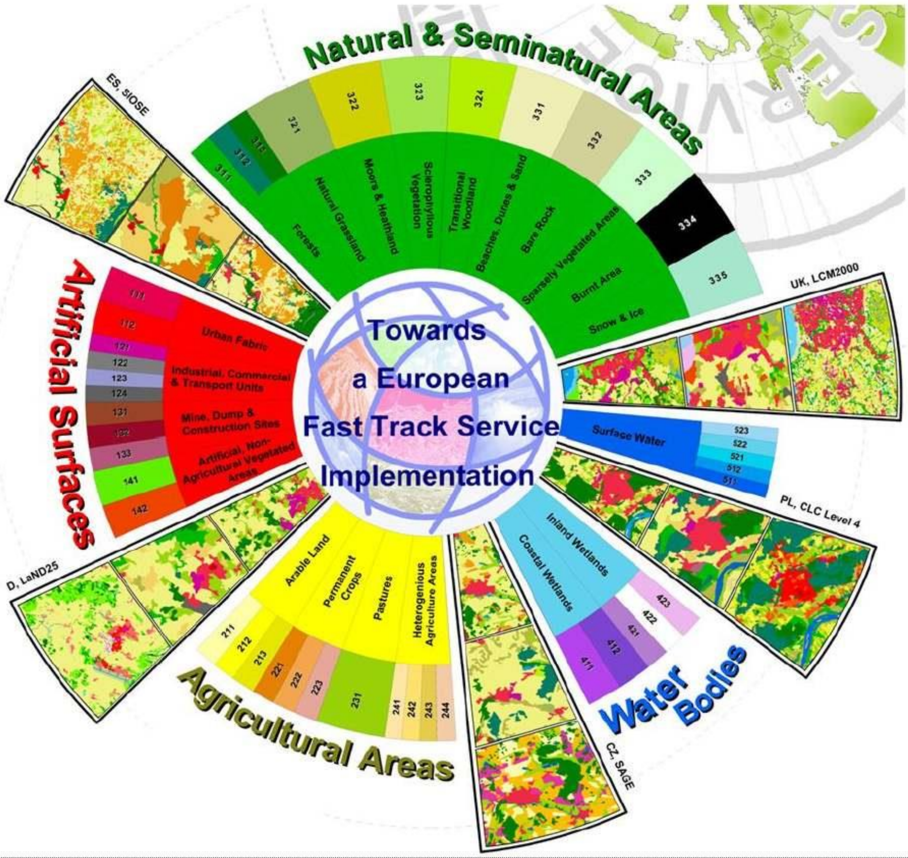

Figure 39. INSPIRE EU GIS domains: Natural and seminatural areas (11 categories); Artificial surfaces (11 categories); Agricultural areas (11 categories) and Water bodies (10 categories).

Figure 40. Al Gore, US Vice President, 1998: "I believe we need a Digital Earth. We need a high-resolution, three-dimensional representation of the planet into which we can embed huge amounts of stationary data."

In 20 years, Al Gore's vision has become a reality and mobile internet applications linked to the digital networking of the Earth are spreading to more and more areas of life. From banking to everyday shopping, from travel to entertainment and dining, from work to administration, more and more digital, online applications are available and have become part of people's lives; digital communities and visual friendships are being created. The web is transforming humanity. We also need to see that although the web exists in cyberspace, cyberspace has a real spatial dimension everywhere, i.e. GIS has become an integral part of most web applications.

Figure 41. Ákos Detrekői, former rector of the Technical University of Hungary and the most renowned expert in Hungarian GIS, said in 2006: 'The future of GIS depends on how quickly we can populate the Digital Earth with location-based data. The main drivers are Google, Microsoft, free data networks, intelligent transport, mobile internet and 3D technologies."

The above quote from Academician Detrekői is a response to the fact that the adequate tool for smart city urban development in the 21st century is GIS, with the spatial /virtual spatial/ processing of data, which opens the way to the development of physical urban space.

Figure 42. Smart city urban management, urban planning is nowadays in America, but in the future it will be worldwide, using the Internet and 3D process exploration, process planning and process management in GIS.

6. Closing words

The aim of this short, colourful and visual learning material was that when people working in urban management and operations come across the term GIS in the future, they should have an idea of what it means, how it is used in most municipal services, how widely it can be used and why it is an essential tool for smart city urban development. Anyone who works in municipal management and/or the operation of municipal public services will almost certainly have not only encountered but also used and applied some form of GIS on countless occasions. If nothing else, he or she has used a GPS, booked or bought a ticket at an institution selected from a map, identified an address on a map, looked up a route or timetable, but has not realised that they have actually used municipal GIS. This brief review on GIS application is expected to develop an attitude capable for using GIS in the process of implementing the smart city and managing the smart region.

7. Control questions

- **What is GIS?**
- **What are the three basic types of GIS?**
- **What is the difference between a database and an information system?**
- **What is the difference between data and information?**
- **What are the uses of tool-oriented GIS?**
- **How does decision-support GIS work?**
- **Give examples of decision-support GIS that can be used to protect the urban environment.**
- **What is CAD?**
- **What is the difference between CAD and GIS?**
- **What are the business uses of a decision support GIS?**
- **Give examples of register-oriented, tool-oriented and decision-oriented GIS applications in the modernisation of municipal management.**
- **Describe the areas of interference in geospatial information, public services and e-Government and give an example of each.**
- **How is a satellite image taken and why is it considered a GIS?**
- **What is the difference between producing a satellite image with and without a teaching/training site?**
- **Why is the satellite image in false colour?**
- **What are the possible applications of satellite imagery in urban management?**
- **How many large areas of municipal infrastructure are there? What are they?**
- **What functions can GIS perform in property management?**
- **What functions can GIS perform in the management of the human infrastructure of a municipality?**
- **What functions can GIS/CAD perform in the management of technical infrastructure?**
- **What functions can GIS perform in the area of municipal consumption services?**
- **What functions can GIS perform in the field of urban health services?**
- **What functions can GIS perform in the management of logistics services?**
- **What functions can GIS perform in recreation services?**
- **What functions can GIS perform in the field of urban management?**
- **Summarise why you think GIS is part of the Smart City.**
- **What do you think are the development perspectives for GIS?**

8. Sources of the figures:

Where the source of figures is not specifically noted, they are reproduced from the following publications:

- Tózsa I. 2000. A térinformatika alkalmazása a természeti és humán erőforrás gazdálkodásban. Szakkönyv. Aula Kiadó. The application of spatial information technology in natural and human resource management. Technical book. Aula Publishing House
- Tózsa I. 2008. Vizuális közszolgáltatás – térinformatika és e-government. Egyetemi tankönyv. E-Government Alapítvány – HVG Kiadó. Visual public services - geoinformatics and e-government. University textbook. E-Government Foundation - HVG Publishing
- Sikos T. - Hoffmann I. 2004. Typology of Budapest shopping centres = Geographical Bulletin 53. 1-2 pp 111-127.

II. The geographical space matters! How can we integrate the geographical space into the analysis of economic and social development processes?

Júlia Schuchmann[2]

This chapter focuses the spatial aspects of the economic activities, especially the interaction between the geographical location and the economic-social development processes. This part of the e-book will provide you theoretical and mostly practical knowledge about the territorial (regional) analysis. The chapter also teaches you about the most important sources of territorial (regional) database.

1. The role of the geographical space in the economics

Economic activities arise, grows, and develop in space. Firms, and economic actors in general choose their locations in the same way as they choose their production factors and their technology. Productive resources are distributed unevenly in space: They are frequently concentrated in specific places (regions or cities). While they are entirely or partly non-existent in others (generally in peripheral regions and remote areas). Quantitative and qualitative imbalances in the geographical distribution of resources and economic activities generate different factor remunerations, different levels of wealth and well-being and different degree of control over local development (Capello-Nijkamp, 2009).

Regional economics is a branch of economics which incorporates the dimension "space" into analysis of the workings of the market. It does so by including space in logical schemes, laws and models which regulate and interpret the formation of prices demand, productive capacity, levels of output and development growth rates, and distribution of income in condition of unequal regional endowments of resources (human, economic, infrastructural, natural). Furthermore, regional economics move from "space" to territory as the main focus of analysis when local growth models include space as an economic resource and as an independent production factor, a generator of static and dynamic advantages for the firms situated within it. Or in other words, an element of fundamental importance in determining competitiveness of a local production system. (Capello-Nijkamp, 2009).

As the famous Nobel prized economist Paul Krugman[3] wrote: "I have put the word "geography" into the title of these lectures, they won't be about mapmaking, or at least not about the kind of map that can be placed on a wall. What I will be talking about is the evolution of ideas in economics specifically, with the story of the two related disciplines of development economics and economic geography. (Krugman, 1998, 2.p). The history of economic

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[3] Paul Krugman (born 28, February, 1953-) american economist, In 2008, Krugman was the sole winner of the Nobel Memorial Prize in Economic Sciences for his contributions to new trade theory and new economic geography

geography of the study of the location of economic activity. The location of production is an obvious feature of the economic world. (Krugman, 1998, 5.p)

2. What? Where? Why?

If you want to understand the role of geographical location in economic and social processes, you need to ask three questions:
What type of economic or social phenomenon do you want to examine?
Where are these processes located in geographical space?
Why are the examined processes concentrated there? Are there any correlation between the geographical location and the examined phenomenon?
In this context the:
What refers to every type of economic and social activity
Where refers to geographical location of the examined economic social or environment phenomenon and involves questions of proximity, concentration, dispersion and similarity/disparity of spatial patterns.
Why refers to the correlation between the spatial patterns and the economic social processes,

2.1. The relevancy of the spatial context in the economic- socio- and environmental studies

As we already discuss, all the economic and socio-cultural activities take place int he geographical space. It means that, the geographical location has a strong impact on any activities, or phenomenon. The success of a business is strongly influenced by where it is located. It is located near to the main axes in the city, or not. The success of a city in the global competition concerning the FDI attraction is strongly depends on the geographical features as well. It depends on the geographical location of the city, especially the good accessibility.

As Capello wrote in his famous article (Capello, 2009), all the social and economic activities realized in the geographical space. The three great spheres of life: Economical, Socio cultural-political, and environmental sphere. All three spheres are closely interconnected and has specific geographical features (see 1 Figure.).

There is strong interconnectivity between the society and the economy, between economy and natural environment or the society and the natural environment. The common characteristics is all of them are embedded into the geographical spaces.

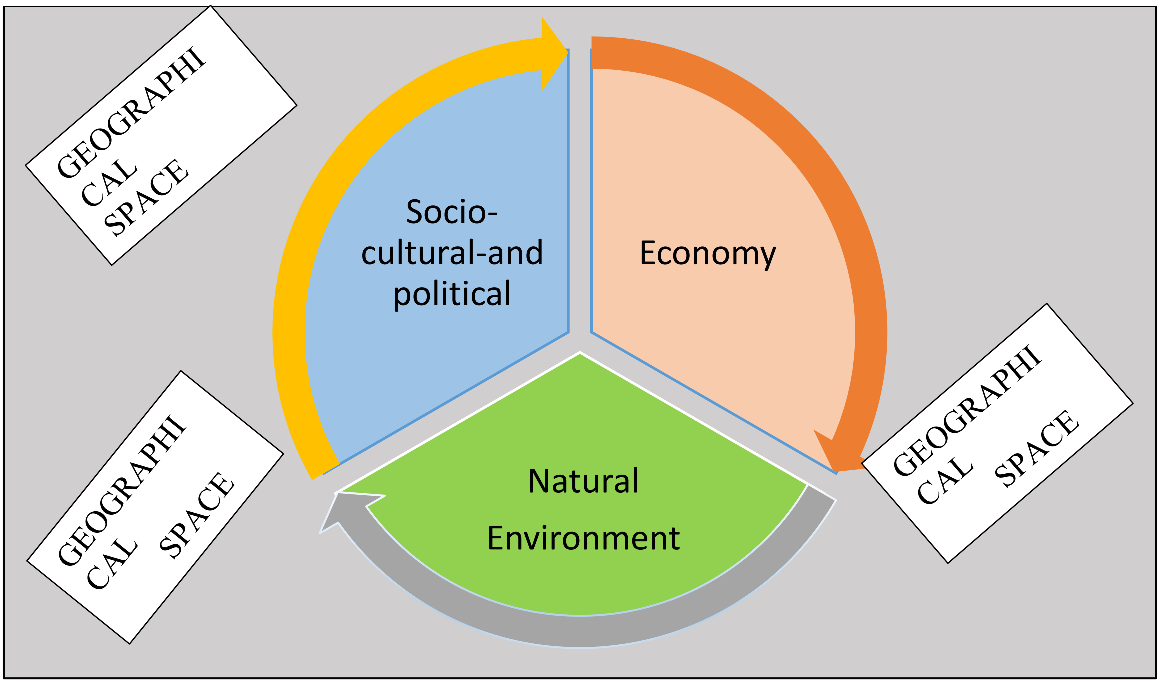

Figure 1. All areas of life are embedded into geographical space

Source: own edited

Table 1. The spatial approach in the economic analyses

Analysed issues	**research questions without spatial context**	**research questions with spatial context**
Changes in the labour market	How the proportion of people employed in the industry developed in Hungary?	How the proportion of people employed in the industry developed in the different regions (industrial, rural etc.) in Hungary?
Consumption habits	How does the Hungarian consumers environmentally conscious?	How environmentally conscious are urban and rural consumers?
Ageing societies	How aging affects labour market processes?	What are the regional differences in population aging?
Pollution	How the urban transport impacts the greenhouse gas emission?	Which parts of the city are the most polluted?
Climate change	How climate change affects household energy consumption and costs?	How climate change affects household energy consumption and costs in the poor and affluent communities
Environmental policies and strategies	How has environmental policy developed in Hungary over the past 30 years?	What are the different practices in environmental policies in Western and Central Eastern Europe?

Source: Own editing

3. Spatial analysis

3.1.Short history of spatial analyses

Spatial analysis began with early attempts at cartography and surveying. Land surveying goes back to at least 1,400 B.C in Egypt: the dimensions of taxable land plots were measured with measuring ropes. Many field of sciences have contributed to its rise in modern form. Biology contributed through botanical studies of global plant distributions and local plant locations. Ecological studies of spatial population dynamics, and the study of biogeography. Landscape ecological studies of vegetation blocks. Epidemiology contributed with early work on disease mapping, notably John Snow's work of mapping an outbreak of cholera, with research on mapping the spread of disease and with location studies for health care delivery. Most recently, geolocation data was essential to detect the spread of the Covid 19 pandemic. Statistics has contributed greatly through work in spatial statistics. Economics has contributed notably through spatial econometrics. (Spatial econometrics is the field where spatial analysis and econometrics intersect.)

3.1.1. Why spatial analysis could be important?

The spatial analyses can be important to understand better the spatial distribution of social-economic or environmental development processes and phenomenon. The spatial analyses can be a crucial tool, if we want to present the spatial patterns of the different forms of inequalities: social, cultural, economic, wealth, or environmental problems as well. The spatial analyses can be useful methods when we want to highlights the spatial inequalities between different countries, regions, micro regions or neighbourhoods, or local communities based on several social-economic or environmental data.

Spatial analysis includes a variety of techniques using different analytic approaches, especially spatial statistics. Classification of the techniques of spatial analysis is difficult because of the large number of different fields of research involved (urban studies, economics, environmental studies, social studies, political sciences etc.), the different fundamental approaches which can be chosen, and the many forms the data can take.

3.1.2. Variety of terms: Delimitation of the spatial units.

Places, areas, regions, territory, spatial units….When we intend to highlight the spatial inequalities in a special socio economic or environmental phenomenon, we need to define and delimit the analysed spatial unit. How can we do that? We have two choices: Firstly, we can use in our spatial analysis the existing administrative units (county, communes, regions, urban regions, territory of the countries). Secondly we need relevant spatial datas on our administrative spatial unites (for example: GDP/head on regional level)

For example the public administrative structure of Hungary contains 8 regions, 19 counties, 197 micro regions, 3155 settlements. See the next figure.

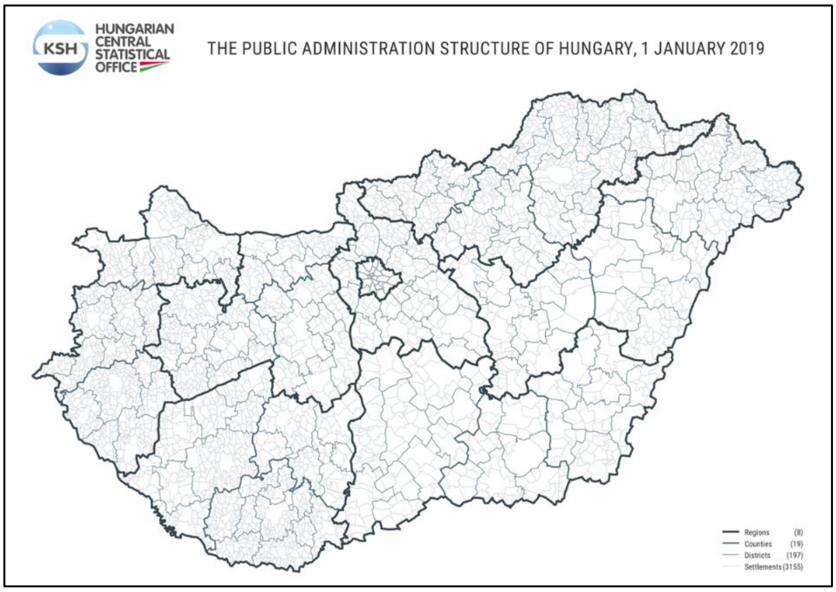

Figure 2. The public administrative division of Hungary

Source: HCSO (Hungarian Central Statistical Office)

If you intend to present the regional distribution of the different spatial level, you need the relevant spatial data. For example, you can highlight the regional distribution of GDP at purchasing power parity (2022). You can see the regional inequalities between the different regions in Hungary.

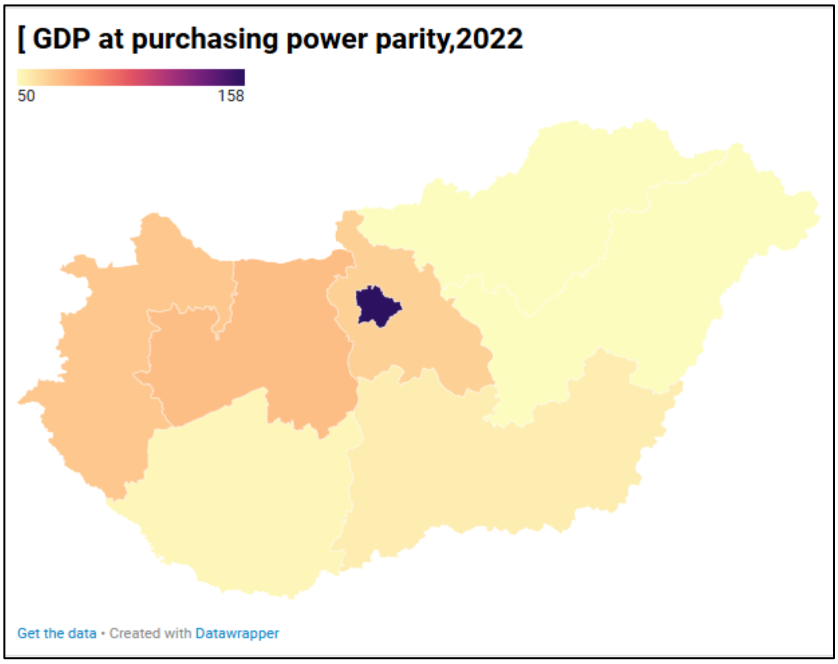

Figure 3. The regional distribution of the GDP at purchasing power parity in the Hungarian regions, 2022 (%)

Source: Own edited, by datawrapper

If you want to present the spatial inequalities on county level, you will need spatial data on county level. (See Figure 4. and 5).

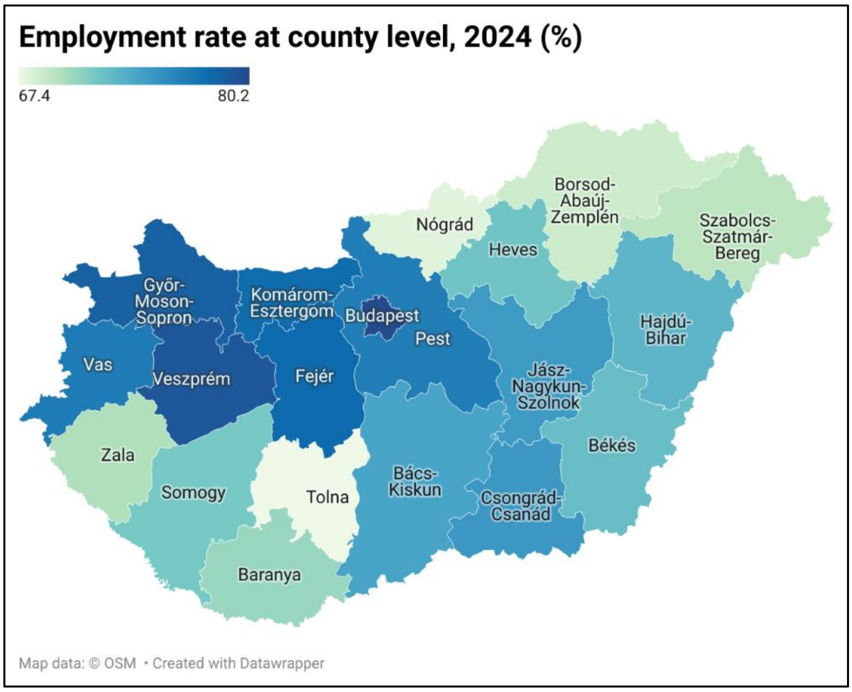

Figure 4. Employment rate at county level in Hungary (2024) (%)

Source: Own edited by Datawrapper

You can also highlight the differences among the districts as well. For example, let's see the population change in the 23 districts of capital city of Hungary, Budapest.

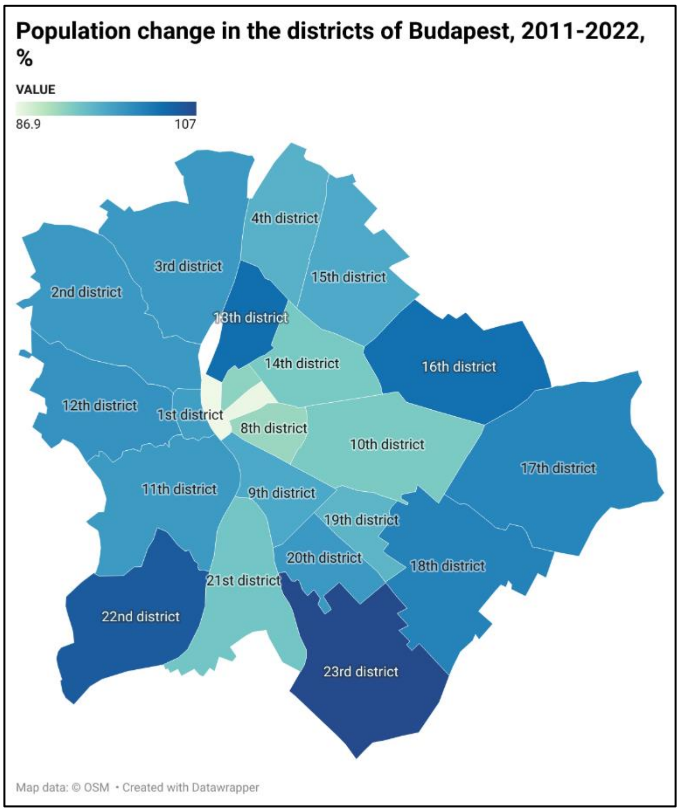

Figure 5. Population change n the districts of Budapest, 2011-2022 (%)

Source: own edited by Datawrapper

4. Spatial data resources

After you select the proper territorial level for your spatial analyses you will need the relevant spatial data as well. The analysed territorial unit can be an existing administrative unit (regions, counties, communes, districts) or the spatial unit can be defined and delimit by you (for example in a case of a commuter zone around a large city).

The second most important question to answer: are there any available and appropriate database for your spatial analyses or not?

4.1. National Statistical Offices

For first, you can get information from the websites of official national statistical offices. For example, in Hungary we have the Hungarian Central Statistical Office[4], and it has a website where you can find and collect spatial data on different spatial level, and administrative units. See the following screenshot from the website of HCSO.

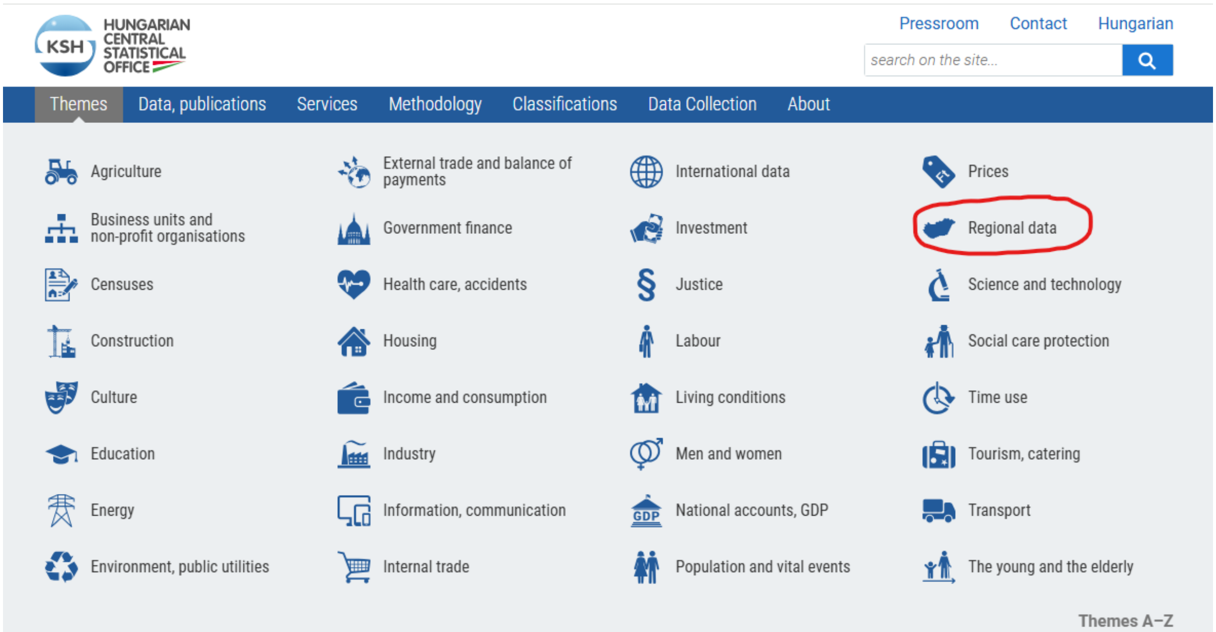

Figure 6. Homepage of the Hungarian National Statistical Office

Source: HCSO

"Regional statistics offers data relating to units of area, settlements, about economic, social and environmental phenomena, processes, respectively contributes to regional impoundment. The goal of regional statistics is to provide reference, information for users by making public regionally detailed data originating from the HCSO data collection system, as well as data and information taken over from external bodies. It incorporates detailed and comprehensive statistics about the situation and development of regions, counties, districts, settlements and units of area outside administrative boundaries (e.g. in-settlements georeferenced data)." (HCSO).[5]

You can find also annual settlements statistics database for all the Hungarian communes. For example, you can collect data on settlement level (Figure 7.).

[4] The website of the Hungarian National Statistical Offices: www.ksh.hu

[5] https://www.ksh.hu/regional-data

Annual statistical data

Settlements in Hungary

Accounts: Number of resident males at the end of the year (data calculated further from final data of the population census) (capita)

Update: Feb 27, 2025

Period of time	Geographic area
	County
Year	Budapest
2001. year	794 669
2002. year	784 610
2003. year	776 834
2004. year	773 120
2005. year	774 581
2006. year	773 384
2007. year	776 470
2008. year	781 124
2009. year	786 352
2010. year	792 788

Figure 7. The annual number of resident populations in Budapest.

Source: HCSO

4.2.EUROSTAT (The official database of the European Union)

The European Union has its own statistical database called Eurostat.[6] The mission of the Eurostat is to provide high quality statistics and data on Europe. Eurostat produces European statistics in partnership with National Statistical Institutes and other national authorities in the EU Member States. The EUROSTAT provide macro-economic statistics, social statistics, governments finance statistics, business and trade statistics, and sectoral and regional statistics.

You can find many statistics for the 27 member states on social, economic, or environmental topics.

Figure 8. Official logo of the EUROSTAT

Source: https://ec.europa.eu/eurostat/web/main/home

There are available data on national (country level), regional, and micro regional level, and local level.

[6] https://ec.europa.eu/eurostat/web/main/home

4.2.1. The EU territorial classification

The European Union has its own special territorial classification called NUTS. NUTS is mosaic word refers to the **N**omenclature of **T**erritorial **U**nits for **S**tatistics. The European Union developed this territorial classification for statistical and regional policy purposes. The NUTS divides each EU countries into 3 level. (see Figure 9.)

NUTS3: small regions (for specific diagnoses

NUTS 2: basic regions (for regional policies)

NUTS 1: major socio-economic regions

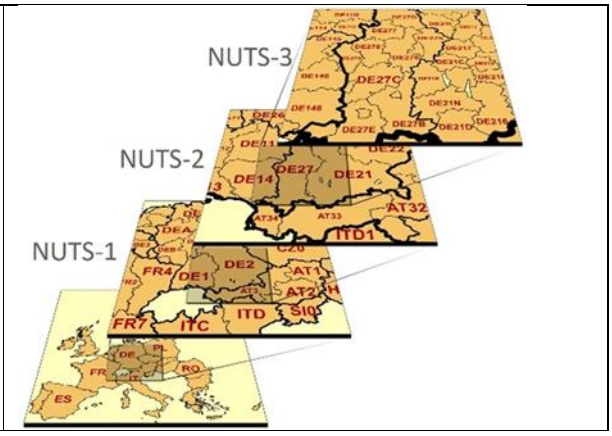

Figure 9. NUTS classfication
Source: https://ec.europa.eu/regional_policy/home_en

The NUTS classification contains 92 regions at NUTS 1, 244 regions at NUTS 2, 1165 regions at NUTS 3. NUTS classification is used for many purposes: collecting, developing and harmonising European regional statistics; carrying out socio-economic analyses of the regions. framing of EU regional policies. The EU regional policy is the main investment policy. It supports job creation, competitiveness, economic growth, improved quality of life and sustainable development. In order to reach these goals and address the diverse development needs in all EU regions, €392 billion – almost a third of the total EU budget – has been set aside for Cohesion Policy for the period 2021-2027. The regional (cohesion) policy has a territorial aspects. Cohesion Policy provides special care and investment tools to territories to address specific issues: Border regions, and cross border cooperation (Interreg), Urban areas, remote, islands, mountainous or sparsely populated areas, outermost regions. The eligibility for financial support from the cohesion policy have been defined at NUTS 2 level. And also he cohesion report have been prepared at NUTS 2 level.

The principles of NUTS classification. The NUTS classification has three principles:

1. **<u>NUTS system favours administrative divisions</u>**

For practical reasons the NUTS classification generally mirrors the territorial administrative division of EU countries. This helps to ensure that data are readily available and policies can be implemented effectively using these divisions.

2. **<u>Comparability by population size</u>**

The aim is to ensure regions of comparable size at each NUTS level, each level still contains regions with significant differences in population size.

3. **<u>Stability over time</u>**

The NUTS classification can be modified but generally not more frequently than every three years. The modifications are usually based on changes in the territorial structure of one EU country or more. If there is a major reorganisation of a country's administrative structure, amendments may be adopted at intervals of less than 3 years. This has only happened once, in 2014 for Portugal.

Table 2. The minimum and maximum population size of the regions

Level	Minimum	Maximum
NUTS 1	3 000 000	7 000 000
NUTS 2	800 000	3 000 000
NUTS 3	150 000	800 000

Source: EUROSTAT

4.3. Let's practice!

It's time to put theory into practice!

1. Go to the EUROSTAT homepage and collect data at regional level, NUTS 2 level
2. Collect data on number of populations at NUTS 2 regions in Hungary
3. Calculate the changes in the regional population dynamics between2015-2025? Which Hungarian regions gain population and which regions loose population?
4. Visualize the results by charts in Excel
5. Try to analyse the regional disparities concerning the population dynamics.

4.4. References

- Capello, R.-Nijkamp, P. 2009. Handbook of Regional Growth and Development Strategies, Edward Elgar Publishing, Inc., 2009, p. 525.
- EUROSTAT homepage: https://ec.europa.eu/eurostat
- Hungarian Central Statistical Office: https://www.ksh.hu/?lang=en
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III. Fundamental methods of territorial analysis

Attila Korompai[7]

1. Why do we need territorial analysis?

There are 3 basic motivations: (1) we want to know what is going on around us, (2) we want to manage some critical issue, (3) we want to change something in our activity or in our environment. Each one has territorial context. If you are living in a family house, you are interested in the accessibility or the operation of public utilities or their development in the area your house is located. While running a business you should know the location and accessibility of your potential suppliers, customers and competitors, as well as the local factors influencing your activity. In addition, if you want to survive, you must be familiar with your development opportunities in similar contexts. Therefore, your spatial analysis should involve the time dimension, the relevant past experiences, present conditions and tendencies, ideas or plans concerning the future.

However, though the territorial characteristics appear in the geographic space mostly connected to the surface of the Earth, and their physical appearance and relations are important, but all of them are highly influenced by the virtual spaces connected to the spheres of existence they are operating (Table 1.).

Table 1. Spatial components

Sphere	Spatial unit	Components
Nature	Landscapes	Terrain, hydrological elements, soils etc.
Society	Settlements	Individuals, Social groups
Economy	Economic districts	Economic units
Services	Attraction zones	Institutions
Culture	Cultural regions	Ethnic, language, cultural groups
Policy	Electoral-districts	Parties
Built environment	Settlements, networks	Buildings, constructive works
Public administration	Administrative units	Institutions of public administration
Integrations	Group of countries	Integration institutions
Regional policy	Regions	Partners, actors of regional policy

Source: Author's editing based on Nemes Nagy 2009

Each spheres have its own actors, resources, means and rules or some kind of regulation. These are different not only in their internal contexts (e.g. in economy in their sectoral characteristics)

[7] University lecturer of the Centre for Economic Geography and Urban Marketing, John von Neumann University, Kecskemét, Hungary

but also in their spaces, that influences their territorial differences, too. These territorial differences are connected to:

- Physical circumstances, natural resources
- Distance from markets / resources / centres
- Opportunities for co-operation
- Agglomeration advantages /disadvantages owing to nearby location (externalities)
- Limits to enter into a local market
- Local monopolies, local externalities, rents (e.g. water resources, public services, labour force etc.)
- Social conditions, traditions, customs and relations
- Growth has to start somewhere, and the distribution is a process

Key components to be analysed for territorial analysis

They are determined by the problem, the objective and purpose of the research task. The problem statement contains three elements:

(1) the problem itself,
(2) for whom and why studying the problem is important, and
(3) how the study will address the problem. This part of the problem statement is a precursor to the purpose statement.

The purpose statement specifies the study design, theoretical context, intent, variables or phenomenon, participants, and site.

Space and Time Categories

Categories of space are

- Point /
- Line/ network / edges / nodes / paths
- Area / extension / expansion / distribution
- Being in the same space / inclusion
- Next to each-other /borders
- Contact / separation
- Neighbourhood
- Widening / narrowing space

Categories of spatial movements are

- mobility
- migration
- diffusion
- expansion

Categories of time are

- Moment
- At the same time
- Before in time
- After in time
- Duration / Period
- Accelerating / slowing down time

Place is the intersection of space-time relations of all entities connected to one entity located within a relevant environment. These relationships are presented on Figure 1 where "HERE" may represent any territorial unit as a place. "THERE" represents all other places outside of "HERE". Arrows represent the direction of influencing forces in the system of relations.

Any kind of analysis is based on **data** that are representation of facts or observations. In the process of working on data **information** is produced that has interpretation adding meaning and values to data. Data which are sensible to any type of changes and characterize the state of affairs of an investigated object are called **indicators**. List of indicators based on international experiences for various economic and social phenomena are available at the homepage of the World Bank Group (https://data.worldbank.org/indicator?tab=featured).

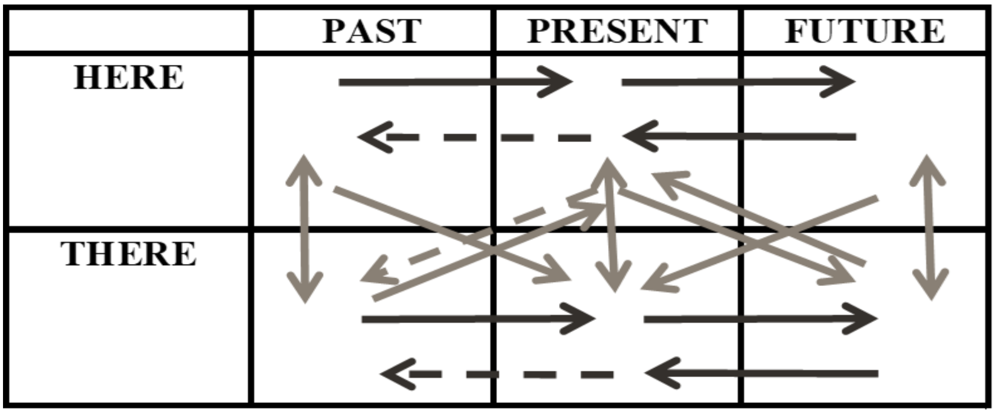

Figure 1. Spatial-temporal relations of objects

Source: Author's editing

The key components of any territorial problem may be identified in connection with:

- *resources* (factors contributing to satisfy human or social needs and ensure the continuous and safe operation of economy and society):
    - Natural resources
    - Capital
    - Labour
    - Knowledge
    - Information
    - Mental habit
- *Actors,* who maybe
    - People, population
    - Entrepreneurs
    - Companies
    - Governments
    - Institutions
    - Civil Organisations
- *Products* differentiated them by
    - Level of aggregation
    - Sectoral characteristics
    - Consumption conditions and characteristics
    - etc.
- *Regulation*, e.g.
    - Feed-back or feed-forward mechanisms
    - Laws
    - Norms
    - Traditions
    - Ethics

The characteristics whose values vary from one observation to another observation are called variables. In statistic formulas they are represented by various symbols (e.g. a, A, X, x, Y, y, σ). To distinguish different values of the same variable subscripts are used to denote (e.g. x_i, Y_r). Individual observations are presented in a table. Table 2 presents the values of k variables (e.g. population number, number of births, number of deaths etc.) in n number of territorial units (e.g. countries).

Table 2. Data of k variables in n territorial units

	Variable1	Variable 2	Variable 3	…	Variable k
Country 1	x_{11}	x_{12}	x_{13}		x_{1k}
Country 2	x_{21}	x_{22}	x_{23}		x_{2k}
Country 3	x_{31}	x_{32}	x_{33}		x_{3k}
…	…	…	…	…	…
…	…	…	…	…	…
Country n	x_{n1}	x_{n2}	x_{n3}		x_{nk}

Source: Author's editing

Requirements against data bases:

- Reliable, controlled resource
- Full data series or representative sample,
- Clear, relevant content of indicators
- Unambiguously localised data
- Basic data to calculate derived data (e.g. GDP and population instead of GDP/capita)
- Comparable in space and time – fixed points for comparison
- Easy to survey and manage, segmenting possibility
- Accessible for others
- Research and methodological steps are possible to follow, and they are repeatable

Control questions

- What are the key components to be investigated in the frame of territorial analysis?
- What are the requirements of data bases?
- What is the difference between data, information and indicator?

2. Measuring and sampling

Collected data are appropriate for different purposes based on their content and the range they cover concerning the full possibilities of observations representing the subject of our research. Some consequences are discussed in this chapter.

2.1.Levels of measurement

Data or variables can be categorized based on their applicability in mathematical operations. There are four main measuring levels:

1. *Nominal* – Data are categorized without a specific order. (e.g. Type of Bicycle (mountain bike, road bike, chopper, folding, BMX.), Gender, ethnicity (White British, Afro-Caribbean, Asian, Chinese, etc. (note problems with these categories) Smoking status (smoker, non-smoker).
2. *Ordinal* – Data are categorized with a meaningful order, but intervals between categories aren't equal (e.g., rankings, satisfaction levels, class of degree, degree of illness [none, mild, moderate, acute, chronic] opinion about something [very unhappy, unhappy, neutral, happy, ecstatic]).
3. *Interval* – Data have ordered categories with equal intervals, but no true zero (e.g., temperature in Celsius/Fahrenheit, Central tendency measures [mean, median, mode]).
4. *Ratio* – Like interval data, but with a true zero, allowing for meaningful ratios (e.g., height, weight, age, number of clients in a period, number of members in a community).

Each level supports different types of statistical analysis, with ratio being the most precise. This is reflected in another distinction:

- *Category or qualitative variables* can be measured on nominal scale. Their measuring on ordinal scale is based on another value system.
- *Quantitative variables* can be discrete or continuous. Depending on their level of measurement they can be measured on all levels.

Two types of quantitative variables should be distinguished:

- *Discrete variables* can take only specific, separate values—typically whole numbers. These values are countable. Examples include the number of students in a class or the number of cars in a parking lot. Their relevant graphical representation is in columns.
- *Continuous variables* can take any value within a given range and are measurable. They can include fractions and decimals. Examples include height, temperature, or time. Their relevant graphical representation is in continuous lines.

In short: Discrete variables are **countable** and have **gaps between values**, while continuous variables are **measurable** and can take on **any value within a range**.

Measuring opportunities are changing depending on the spatial components for territorial units. Some examples are summarized in the table 3.

Table 3. Measuring opportunities of spatial components of various spaces

Measuring level	Spatial components		
	Points	Lines	Territorial units
Nominal	Settlement network without hierarchical relations	Road network without hierarchical relations	Qualitative data of counties in a country
Ordinal	Settlement network indicating their hierarchical relations or other ranking values	Road network indicating their hierarchical relations or other ranking values	Counties of a country with their ranking values
Quantitative	Settlement network with relevant quantitative data (e.g. number of inhabitants)	Road network with data on their traffic	Counties of a country with relevant quantitative data (e.g. population)

Source: Translated and edited by the author based on Dusek, Kotosz 2016, 32

2.2.Sampling

There are situations in the research process when each item of the population belonging to the subject may be involved into the analysis. In this case it is proved that the total collection of units, elements or individuals, i.e. *the total population* that you want to analyse are available Examples to this are studying regions of a country, the number of settlements in a smaller area, number of residents, students, business units, institutions of a particular area etc. In this case the results of the analysis, the summary measures like mean, median, modus are the *parameters of the population.*

In other cases, it may be impossible or irrational to involve the total population into the research because of its size, large number of items, data collection would be too expensive or would take too much time, or checking all the transactions may become monotonous and lead to errors. In this case a sample must be selected from the total population that represents it, and it is hoped to draw valid conclusions about the larger group. A list or database from which a sample is drawn is the *sampling frame*. An accurate sampling frame is essential for probability sampling. The selected part of the population is called *sample*, and the process of selection is called *sampling*. The summary measures of a sample are known as *statistics*.

Therefore, it is important that the researcher carefully and completely defines the population, including a description of the members to be included. The characteristics of the sample should correspond to, or reflect, those of the original population or reference population. This is called representativeness. This is ensured by various methods of sampling process as the types of sampling. Each process is characterized by the number of populations, the sampling units, the sample size, the sampling interval, the tolerable error, bias and the level of confidence[8].

The types of sampling:

- Non-statistical sampling
    - Judgement sampling
    - Convenient sampling
    - Quota sampling
    - Snowball sampling
- Statistical sampling
    - Random sampling
    - Systematic sampling
    - Stratified sampling
    - Attribute sampling

Difference between non-probability/non-statistical and probability/statistical sampling

- Statistical sampling application has ability to measure sampling risk associated with the sampling procedure.
- The sample selection is more objective in statistical sampling and hence audit conclusions are more defensible.
- The sample size in statistical sampling will be smaller than the one in non-statistical sampling.
- Statistical sampling involves additional costs (a)in training the auditors (b) in designing individual samples and (c) in selecting item

2.2.1. Basic characteristics of sampling procedures

Non-probability sampling methods

Judgement sampling (also called expert, purposive or authoritative sampling)

- the sample members are chosen only on the basis of the researcher's knowledge and judgement, or based on usefulness to the purposes of the research,
- most effective in situations where there are only a restricted number of people in a population who own qualities that a researcher expects from the target population,
- also used where there is time-constraint for sample creation and the authorities involved would prefer relying on their knowledge and not on other sampling methods,
- advantages are that it is easy to conduct, takes minimum time for execution, allows researchers to approach their target directly, almost real-time results are available.
- researcher who takes up the responsibility of creating a sample using judgement sampling will have to be extremely confident in their own skills and understanding of the subject. The disadvantage of this sampling process is in researcher's proficiency.

Convenient sampling

- a convenience sample simply includes the individuals who happen to be most accessible to the researcher,
- an easy and inexpensive way to gather initial data,
- there is no way to tell if the sample is representative of the population,
- these samples are at risk for both sampling bias and selection bias,
- it can't produce generalizable results.

[8] Level of confidence reflects the representativeness (together with error terms) of your sample usually in % values. The confidence interval gives you a range where the actual population parameter is likely to be. E.g. a 95% confidence level means that if you repeated your study 100 times, the true value would fall within your calculated interval 95 times.

- A special type of this process is the **voluntary response sampling** when instead of the researcher choosing participants and directly contacting them, people volunteer themselves. It leads to self-selection bias.

Quota sampling

- It relies on the non-random selection of a predetermined number or proportion of units (the quotas).
- The aim is to control what or who makes up your sample, the investigated population is adequately represented.
- Researchers can achieve a balance that reflects the broader population, making it easier to analyse and generalize findings.
- The population is divided into mutually exclusive subgroups (called strata) sharing specific predetermined characteristics,
- evaluate the proportion of the population in which the subgroups exist and select the relevant sample size,
- then recruit sample units until you reach your quota.
- Don't survey full quotas; focus on completing surveys for each quota.
- It is one of the most cost-effective ways to gather insights from specific population subgroups (saves time and money, convenient, offers accurate representation of the population)

Snowball sampling (also called chain-referral sampling)

- Existing subjects provide referrals to recruit samples required for a research study.
- It starts from a primary data source nominating other potential data source that will be able to participate in the research studies.
- It is purely based on referrals therefore; it cannot be considered for a representative sample.
- This sampling technique can go on and on, just like a snowball increasing in size (in this case the sample size) till the time a researcher has enough data to analyse, to draw conclusive results.
- Extensively used where a population is unknown and rare and it is tough to choose subjects to assemble them as samples for research. Furthermore, for conducting qualitative research, with a population that is hard to locate.
- Advantages are: time and cost effective, it is easy and quick to find subjects, promotes to achieve sample hesitant subjects.
- Disadvantages are: lack of cooperation, have a potential sampling errors and margin of error that means a researcher might only be able to reach out to a small group of people and may not be able to complete the study with conclusive results.

Probability sampling methods

Random sampling

- Simple random sampling
  - It is considered a fair and unbiased sample selection method.
  - A complete and accurate sampling frame is available.
  - Every member of the population has equal chance, the selection of items entirely depends on luck or probability
  - In case of fairly homogeneous population
  - Based on table of random numbers
  - The sample size should ideally be more than a few hundred
  - Minimizes selection bias.
  - Easy to analyse statistically.

    - Disadvantages: Working with a large sample size isn't an easy task, and it can sometimes be challenging to find a realistic sampling bias frame, and it may become costly and time-consuming.
- Areal random sampling
    - Samples are representatives of locational variability
    - Selection of points based on random numbers in a coordinate system. The sample areas are around these selected sample points.

Systematic sampling (also called interval sampling)

- Selection is at regular intervals after a random start (e.g. each 10th item is selected)
- More uniform coverage of the population is ensured
- Random distribution of the population is supposed
- In case of any regularity in the distribution the systematic sample my be biased
- Sampling interval (I) is determined by the number of total population (N) and the planned number of samples (n): I=N/n
- Not truly random
- Easy and simple to create sample with relatively low risk factor

Stratified sampling

- When population can be divided into distinct subgroups (strata).
- When subgroups vary significantly.
- Ensures representation of all subgroups.
- Increases precision of estimates.
- Reduces variability in the sample.
- Requires detailed knowledge of the population.
- More complex to design and analyse.
- Time-consuming setup.

Attribute sampling (also called cluster sampling)

- dividing the population into subgroups, but each subgroup should have similar characteristics within the whole sample.
- Instead of sampling individuals from each subgroup, you randomly select entire subgroups.
- When studying hidden, rare, or hard-to-reach populations.
- When sampling frame is not available.
- Useful for network-based or sensitive topics.
- Efficient in small populations.
- Disadvantages are its strong selection bias, not generalizable, sample size and quality depend on initial participants.

Multistage sampling

- When large-scale, complex surveys are conducted.
- You can sample individuals from within each cluster using other techniques
- When direct access to the full population is not feasible.
- Highly flexible and adaptable.
- Can reduce cost and logistical effort.
- Allows combination of different techniques.
- Complex design and analysis.
- Greater potential for sampling error.
- Needs skilled personnel for implementation.

2.2.2. Summary

Sampling is a cornerstone of modern research and statistical analysis. It allows researchers to draw valid conclusions about populations without the need to collect data from every individual. The key to effective sampling lies in selecting the appropriate method based on the research question, population characteristics, and resource constraints.

Probability sampling offers more rigorous and generalizable results, while non-probability sampling is often more practical, especially in exploratory or qualitative research. Regardless of the method, understanding the principles of sampling ensures the reliability and validity of research findings.

A well-designed sampling strategy can mean the difference between insightful, actionable results and misleading conclusions. As such, mastery of sampling techniques is essential for any researcher or analyst aiming to produce high-quality, credible work.

Further detailed discussion on sampling is available at Lohr 2019.

Table 4. Summary Table of sampling methods

Sampling Method	**Conditions of Use**	**Advantages**	**Disadvantages**
Judgmental	Expert or specialized cases	Targeted, efficient	Subjective, limited generalization
Convenience	Limited time/resources	Fast, easy	High bias, low validity
Quota	Represent specific traits	Ensures diversity	No randomization, bias-prone
Snowball	Hidden/rare populations	Access to difficult populations	Non-random, hard to validate
Simple Random	Homogeneous population, full list	Unbiased, simple analysis	Needs full population list, not practical for large N
Systematic	Ordered population list	Easy to implement	Risk of periodic bias
Stratified	Population with distinct subgroups	More precise, subgroup representation	Requires detailed strata data
Cluster	Large, geographically spread population	Cost-effective	Higher sampling error
Multistage	Large-scale or multi-level surveys	Flexible, practical	Complex to manage

Source: Author's editing

Control questions

- Characterise the measuring levels
- What is the difference between qualitative and quantitative variables?
- When do you need to apply a sampling process?
- What are the basic categories of sampling?
- What is the difference between probability and non-probability sampling?
- What is the difference between judgemental and convenience sampling?
- What is the difference between quota and snowball sampling?
- What is the difference between simple random and systematic sampling?
- What is the difference between stratified and cluster sampling?
- What are the advantages and disadvantages of multistage sampling?

3. Descriptive statistics

Descriptive statistics in the first phase of analysis serve to identify the salient features, like frequency, dispersion, university or patterns of a given phenomenon, in territorial analysis their connection with territorial units or areal appearance. Data related to investigated variables may be obtained from primary sources (field research) or secondary sources (statistical offices, literature etc.).

As it was mentioned at the beginning of this part any analysis must start with problem and purpose identification. In this overview of statistical analysis methods, *the example problem* is that we want to intervene for decreasing territorial differences in economic performance of Hungarian counties. Our territorial units are county-level regions in their latest (2023) administrative borders. The period we are interested in is from the accession of Hungary to the European Union till latest available data – i.e. 2004-2023. Economic performance is measured by Gross Value Added[9] (GVA) in the mirror of relevant population.

GVA data are available at EUROSTAT Database, where you can filter the Hungarian county data at current prices in million Euro from data of all EU NUTS3 territorial units: https://ec.europa.eu/eurostat/databrowser/product/page/nama_10r_3gva__custom_16023485 Hungarian population data can be downloaded from the Summary Tables (STADAT) system of the Hungarian Central Statistical Office (HCSO) https://www.ksh.hu/stadat_files/nep/en/nep0034.html. The table contains the number of resident populations by sex and total and by NUTS 1, NUTS2 and NUTS3 regions. Because we are interested just in the total population at NUTS3 level, for our analysis unnecessary data must be filtered out. The filtered data are tabulated in Table 5.

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[9] **Gross Value Added** is a national account indicator. Gross value added at basic prices is the difference between gross output (at basic prices) and intermediate consumption (at purchasers' prices). **Gross Output** is the sum of goods and services that are produced within an institutional unit to be purchased by other institutional units and of those that are produced for own final use. It is valued at basic prices. **Intermediate consumption** consists of the value of the goods and services consumed as inputs by a process of production, excluding fixed assets whose consumption is recorded as consumption of fixed capital. The goods and services may be either transformed or used up by the production process. Intermediate consumption is valued at purchasers' prices.

Other related terms:

Gross domestic product (GDP) is a concept of value added. It is the sum of gross value added of all resident producers (institutional sectors or industries) measured at basic prices, plus the balance of taxes and subsidies on products, which cannot be divided among industries or sectors. So GDP is an aggregate value at market prices. GDP can be defined from three approaches: - by production approach it is: + the sum of gross value added at basic prices + taxes on products - subsidies on products - by expenditure approach it is: + final consumption expenditure of households + final consumption expenditure of government + final consumption expenditure of non-profit institutions serving households + gross fixed capital formation + changes in inventories + export - import - by income approach it is: + wages and salaries + employers' social contributions - other subsidies on production + other taxes on production + gross operating surplus and mixed income + taxes on products - subsidies on products.

Gross national income (GNI) (at market prices) equals GDP minus primary income payable by resident institutional units to non-resident institutional units plus primary income receivable by resident institutional units from the rest of the world.

Prices:

- **Basic price:** price used for the evaluation of production. It is the amount receivable by the producer from the purchaser for a unit of a good or service produced as output minus any tax payable and plus any subsidy receivable on that unit as a consequence of its production or sale.
- **Purchasers' price:** the price actually paid by the purchaser for the product purchased excluding any deductible VAT or similar deductible tax. (It means it excludes taxes on purchased goods and services thatare acquired for intermediate consumption and subsidies on products.)
- **Market price:** the consumer pays at the market.

Source: KSH Metainformationx

3.1.Frequency distribution

Key Concepts

1. **Territory**: The defined spatial unit (e.g., districts, census blocks, zip codes).
2. **Tabulation** (arranging data in a systematic form)
3. **Frequency**: Number of occurrences of a certain event within the territory, or the number of territories occurring as location of a phenomenon.
4. **Graphical representation** (to promote visual assessment and comparison)

Table 5. Filtered data for example analyses

			Resident number of populations			**GVA in million Euro at current prices**	
2	**County name**	**Level of territorial units**	**2004**	**2023**		**2004**	**2023**
3	**A**	**B**	**C**	**D**		E	F
4	Budapest	capital, region	1 705 309	1 671 004		24 915.33	65 198.71
5	Pest	county, region	1 124 395	1 328 790		7 143.21	20 130.16
6	Fejér	county	428 579	419 565		2 949.8	6 558.74
7	Komárom-Esztergom	county	315 886	301 492		2 474.87	5 233.49
8	Veszprém	county	368 519	338 342		2 036.84	4 612.92
9	Győr-Moson-Sopron	county	440 138	471 309		3 621.96	8 641.84
10	Vas	county	266 342	249 812		1 896.05	3 527.62
11	Zala	county	296 705	261 803		1 926.23	3 173.92
12	Baranya	county	402 260	355 315		2 070.73	4 313.07
13	Somogy	county	334 065	295 316		1 591.58	3 154.55
14	Tolna	county	247 287	208 044		1 223.35	2 535.74
15	Borsod-Abaúj-Zemplén	county	738 143	624 219		3 382.65	7 015.35
16	Heves	county	323 769	287 533		1 602.38	3 696.83
17	Nógrád	county	218 128	182 038		781.48	1 421.95
18	Hajdú-Bihar	county	550 265	520 656		3 085.82	6 704.07
19	Jász-Nagykun-Szolnok	county	413 174	356 388		1 873.31	3 934.98
20	Szabolcs-Szatmár-Bereg	county	583 564	527 968		2 337.17	5 389.83
21	Bács-Kiskun	county	541 584	494 563		2 700.23	6 509.06
22	Békés	county	392 845	314 380		1 755.45	3 106.85
23	Csongrád-Csanád	county	425 785	391 207		2 354.78	5 236.11
24	**Total**	**country**	**10 116 742**	**9 599 744**		**71 723.22**	**170 095.79**

Source: Author's editing based on EUROSTAT and HCSO data

3.1.1. Tabulation of data

Raw data arranged in a systematic form into **FREQUENCY DISTRIBUTION TABLE.** In order to create this table the whole range of the values of the variable are divided into smaller groups, known as **classes**, and note the number of observations falling into each class. The numbers are called as the **frequencies** of the particular classes. Each class has upper and lower **class limits**, and the difference between them is the **class interval**.

In **Ungrouped frequency distribution** there are no classes, but cases are connected to the fixed values of the given variable.

Requirements for frequency tabulation

- The class intervals should be kept equal unless there is some specific reason against it.
- *Theoretical number of classes* - k=1+3.3*lg(n),
- *Theoretical length of class interval* - h=(x_{max}-x_{min})/k,
- The class limits as well as class interval should be a multiple of 5, as far as possible.
- **Cumulative frequency** is the cumulated number of observations in a class adding the frequencies of all the classes preceding the given class from the maximum (more than type) or the minimum (less than type) class.

Hungarian example

- For Hungarian population in 2004 this theoretical number of classes:

k=1+3.3*LG(20) = 1+3.3*1.301=5.3

- The theoretical length of classes

h=(1 705 309-218 128)/5=297 436.

Consequently 5 classes of 300 000 of length are theoretically reasonable. Using this classification the distribution of counties is in table 6.

Table 6. Distribution of 20 Hungarian counties

Classes in thousands	-300	301-600	601-900	901-1200	1201-
Number of counties	4	13	1	1	1

Source: Author's edition

The problem of this classification that owing to the extremely high values of Budapest and Pest County most counties belong to one class (301-600 thousand). They are outliers is this observation (Budapest is the capital of Hungary and Pest County is mostly its agglomeration area). Therefore, it is reasonable to calculate the theoretical number of classes without their values. I.e. k_c=1+3.3*LG(18)=5.1. Consequently the 18 counties will be ordered into 5 classes plus one class for the outliers.

Fort the 18 Hungarian counties considered without outliers the class interval
h=(MAX(C4:C23)-MIN(C4:C23))/5=(738143-218128)/5=104003,
i.e our advised class interval will be 100 000 inhabitants starting with 300 000 and below
Consequently, for our example we will have 6 classes of 1000 inhabitants: below 300/301-400/401-500/501-600/601-800/more than 800.

Table 7. Frequency calculation functions

Row	Classes in 1000 inhabitants	Function
33	-300	=COUNTIF(C$4:C$23;"<"&300000)
34	301-400	=COUNTIF(C$4:C$23;"<"&400000)-C33
35	401-500	=COUNTIF(C$4:C$23;"<"&500000)-C34-C33
36	501-600	=COUNTIF(C$4:C$23;"<"&600000)-C35-C34-C33
37	601-800	=COUNTIF(C$4:C$23;"<"&800000)-C36-C35-C34-C33
38	800-	=COUNTIF(C$4:C$23;">"&800000)
39	Total	=SUM(C33:C38)

Table 8. Frequencies

Classes in 1000 inhabitants	Number of counties	Cumulative frequencies
-300	4	4
301-400	5	9
401-500	5	14
501-600	3	17
601-800	1	18
800-	2	20
Total	20	

Source: Author's edition

Calculating tables for comparing the distribution of different variables – feature scaling

The analysis of a single variable in one year rarely enough for presenting or evaluating the factors data of qualitatively and quantitatively different variables in different periods are required. In our case the population number is measured in persons, the GVA in Euros. In addition, during the 20 years there were significant changes in the content of data. Therefore, the classes describing the distribution of the initial year are inappropriate for the last year. To gain a relevant and comparable indicator the numeric data must be transformed into values independent from magnitudes and measuring units.

Feature scaling involves transforming the values of features in a dataset to a similar scale, ensuring that all features contribute equally to the analysis. It adjusts the range of the data without distorting differences in the values.

One of the most frequently used simple technics is the calculation of proportional scale representing the distribution in percent values. In this case the individual values of variables are related to the sum of variables. The proportional indices may be presented in percent values by multiplying them 100. The formula of proportional index calculation:

$$I_i=x_i/\sum x_i.$$

Where

I_i is the proportional index number of i variable

x_i is the value of i variable $\sum x_i$ is the summarised value of the i variable

Pay attention always to the number of decimal places. ROUND(number; number of digits) function specifies the number of digits in the calculated value. It is important because the calculated accuracy and the observation or relevant accuracy should be synced.

Calculating the relevant classes in this case is done in the above-mentioned way but in all cases in the 0 —˙1, or 0% — 100% range. Most frequently the advised number of classes is 5, but the length of classes depends on the minimum number.

Table 9. Calculation of percent distribution

1		**Resident number of population**		**Population %**
2	**County name**	**2004**		**2004**
3	**A**	**C**		**U**
4	**Budapest**	**1 705 309**		16,9%
5	**Pest**	**1 124 395**		11,1%
6	Fejé r	428 579		4,2%
	…			
	…			
21	Bács-Kiskun	541 584		5,4%
22	Béké s	392 845		3,9%
23	Csongrád-Csanád	425 785		4,2%
24	**Total**	**10 116 742**		100,0%

1		**Resident number of populatio n**		**Population %**
2	**County name**	**2004**		**2004**
3	**A**	**C**		**U**
4	**Budapes t**	**1705309**		=ROUND(U4/U$24; 3)
5	**Pest**	**1124395**		=ROUND(U5/U$24; 3)
6	Fejér	428579		=ROUND(U6/U$24; 3)
	…			
	…			
2 1	Bács-Kiskun	541584		=ROUND(U21/U$24 ;3)
2 2	Békés	392845		=ROUND(U22/U$24 ;3)
2 3	Csongrá d-Csanád	425785		=ROUND(U23/U$24 ;3)
2 4	**Total**	**10116742**		=ROUND(U24/U$24 ;3)

Source: Author's edition

Another way to prepare tables for comparable data of variables measured in different measuring units is the **min-max normalisation**.

$$\text{Normalized value} = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where:

- X_i is the raw value for a given variable.
- X_{min} is the minimum value for that variable.
- X_{max} is the maximum value for that variable.

This transformation scales all data points between 0 and 1, with 0 indicating the worst value of the variable and 1 representing the best.

Normalization is most effective in the following scenarios:

- When the distribution of data is not known or does not follow a normal (Gaussian) pattern.
- When the analysis is based on distances between data points to prevent features with larger scales from dominating the distance calculations.

Table 10. Normalisation

1	**Resident number of population**			**Normalised**	
2	**County name**	**2004**	%	value	formula
3	**A**	**C**	**D**	**E**	**E**
4	**Budapest**	**1 705 309**	16,9%	1,00	=(C4-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
5	**Pest**	**1 124 395**	11,1%	0,61	=(C5-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
6	Borsod-Abaúj-Zemplén	738 143	7,3%	0,35	=(C6-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
7	Szabolcs-Szatmár-Bereg	583 564	5,8%	0,25	=(C7-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
8	Hajdú-Bihar	550 265	5,4%	0,22	=(C8-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
9	Bács-Kiskun	541 584	5,4%	0,22	=(C9-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
10	Győr-Moson-Sopron	440 138	4,4%	0,15	=(C10-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
11	Fejér	428 579	4,2%	0,14	=(C11-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
12	Csongrád-Csanád	425 785	4,2%	0,14	=(C12-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
13	Jász-Nagykun-Szolnok	413 174	4,1%	0,13	=(C13-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
14	Baranya	402 260	4,0%	0,12	=(C14-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
15	Békés	392 845	3,9%	0,12	=(C15-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
16	Veszprém	368 519	3,6%	0,10	=(C16-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
17	Somogy	334 065	3,3%	0,08	=(C17-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
18	Heves	323 769	3,2%	0,07	=(C18-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
19	Komárom-Esztergom	315 886	3,1%	0,07	=(C19-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
20	Zala	296 705	2,9%	0,05	=(C20-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
21	Vas	266 342	2,6%	0,03	=(C21-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
22	Tolna	247 287	2,4%	0,02	=(C22-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
23	Nógrád	218 128	2,2%	0,00	=(C23-MIN(C$4:C$23))/(MAX(C$4:C$23)-MIN(C$4:C$23))
24	**Total**	**10 116 742**	100,0%		

Source: Author's editing

3.1.2. Graphical representation

Frequency distributions can be represented for a quick visual assessment generally in several types of graphs:

- Separated columns
- Histogram
- Frequency polygon
- Frequency curve shapes can be
  - symmetric / positively skewed (←) /
  - negatively (→) skewed /
  - J-shaped /
  - U-shaped)
- Cumulative frequency curve or ogive (more (↘) / less (↗) than type)

– Pareto distribution (ordered classes)
– Stem-and leaf (12,15,26,35,38,39)

Histogram is a column graph of frequency data by classes (Figure 2). Frequency polygon is obtained by joining the upper middle points of histogram columns with straight lines (Figure 2). The frequency curve (Figure 3) is obtained by connecting small class interval vertices with a continuous line. The two types of cumulative frequency curves are presented on figure 4.

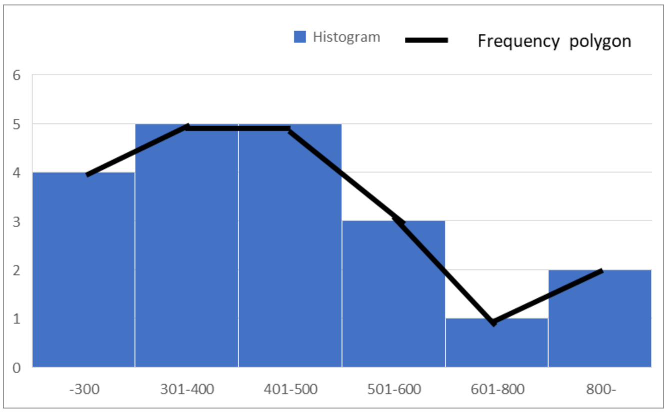
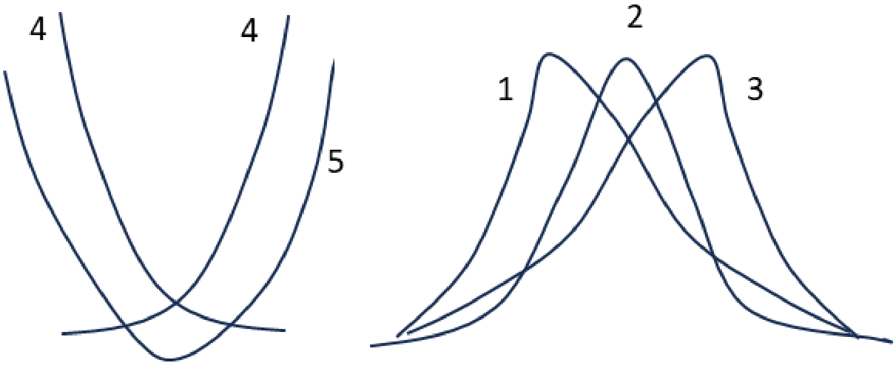


Figure 2. Histogram and frequency polygon of Hungarian population by counties (2004)

Source: Author's edition



4 J-shaped	1 positively skewed	2 symmetric
5 U-shaped	3 negatively skewed	

Figure 3. Frequency curve types

Source: Author's edition

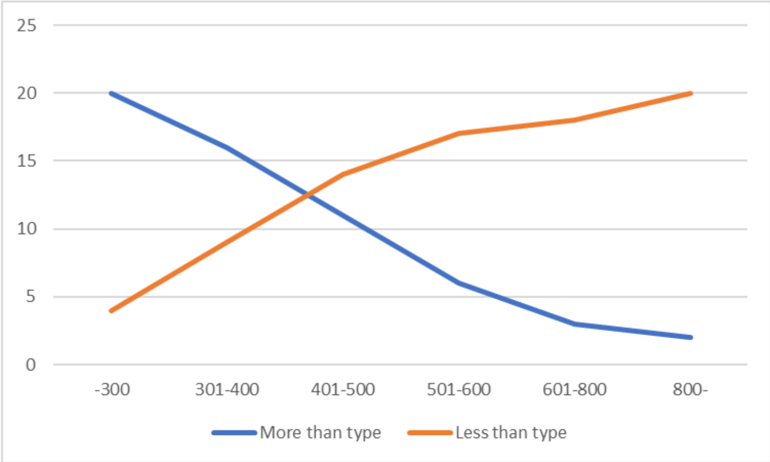


Figure 4. *Cumulated frequency curves of population of Hungarian counties (2004)*

Source: Author's edition

Notes to graphical representation

- The area of the constituent rectangles of a histogram is proportional to the number of observations falling into the corresponding classes
- If a perpendicular is drawn on the x-axis, the area between the x-axis and the frequency curve on the left-hand side is proportional to the number of observations, whose values are less, while the other side area to the observation with larger values
- In a cumulative frequency curve, a perpendicular erected from any (A) point of the x-axis will cut the curve at point (B) . A perpendicular from (B) to the y-axis cuts it at point (C), that is the number of observations whose value is less or greater than (A) depending on the type (less or more) of the curve.

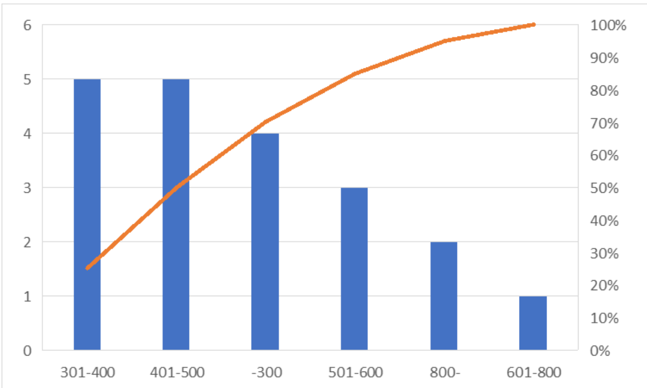


Figure 5. *Pareto chart of Hungarian population distribution by counties (2004)*

Source: Author's edition

Pareto chart or diagram is based on the ranked number of classes from the more frequent to the less frequent class. In this way the chart reflects that which situation, classes are more important or representing the highest share. Considering the population distribution in Hungarian counties in 2004, it is visible that most of the counties (10 out of 20 i.e. 50%) are in the range of 300-500 thousand inhabitants. The smallest share with one county has the class of 600-800 thousand inhabitants (Borsod-Abaúj-Zemplén, though it is the largest one except for the two outliers).

A template for creating graphs of frequency distribution is available from: https://asq.org/-/media/public/learn-about-quality/data-collection-analysis-tools/data-analysis.xls

3.2.Measures of central tendency

Mean – the average or aritmentic mean of the different values of a variable that is equal to the sum of values divided by the number of observations.

$$\bar{x} = \frac{\sum x}{n}$$

In case of grouped data with classes the middle values of each class should be summarised and divided by the number of observations.

Mean is susceptible to outliers or skewed data series, as it loses its ability to provide the best central location of data series.

Median – the middle most value of observations after arranging them in an ascending or descending order.

- M is the [(n+1)/2]-th value provided that n is an odd number
- M is the [n/2]-th value if n is an even number

In a distribution which has extremely large or small value(s) the arithmetic mean will either overestimate or underestimate the average position. The best representative measure of central tendency is the Median in this case, that is located in the middle of the ordered series of data.

Mode or modal value –the value which has the maximum frequency. Someties it is considered the most popular option. On the histogram it has the highest value. When the distribution is in the form of classes its value can be calculated on the basis of the following formula:

- **Mode** = *l*+((fm-f1)/(2*fm –f1-f2))*h
  - where *l*=lower limit of the modal class,
  - fm= maximum frequency
  - f1, f2 are frequencies of the classes preceding and following the modal class
  - h= the class interval of the modal class

Though it is easy to identify, it has several problems. In case of continuous data series it is hard to find exactly equal values. The highest occurence is not necessarily in the centre particularly in skewed data series. It also may occur that more mode can be identified. Owing to these uncertainties mode is rarely used in statistical analyses.

Quartiles (1st, 2nd, 3rd), **Deciles**, **Percentiles** are values dividing the observations rspectively into **4, 10, 100 equal parts**

In summary the best measures of central tendency with respect of different types of variables are summarised in Table 11.

Table 11. Best measures of central tendency by types of variable

Type of Variable	Best measure of central tendency
Nominal	Mode
Ordinal	Median
Interval/Ratio (not skewed)	Mean
Interval/Ratio (skewed)	Median

Source: Laerd content 2025

Example

For the population data of 2004 there are two classes with the same highest values (5) in the distribution of counties: classes 300-400 thousand and 400-500 thousand inhabitants. This means that two modes occur in our observation. In addition, owing to classes, the value of mode must be calculated based on the above formula. The values of outliers have significant impact on the value of the mean – the difference is more than 100 thousand. Altogether, from the above discussed central tendency indicators the median value seems the best one.

Table 12. Comparing the central tendencies of the population number in Hungarian counties

For 18 counties			For 20 counties (with outliers)		
Average/ Mean	=AVERAGE(C6:C23)	*404 835*	Average/ Mean	=AVERAGE(C4:C23)	*505 837*
Median	=MEDIAN(C6:C23)	*419480*	Median	=MEDIAN(C4:C23)	*407 717*
Mode	=300000+((D50-D49)/(2*D50-D49-D52))*300000	*445304*	Mode		*445304*

Source: The author's editing

Control questions

What is the content of Gross Value Added?
How can you solve feature scaling?
What is the interpretation of frequency?
What types of cumulative frequencies may be distinguished?
How you can characterize the positive and negative frequency skewness?
How do you interpret Pareto frequency diagram?
Create the frequency table of population and GVA of Hungarian counties in 2004!
Create the frequency table of population and GVA of Hungarian counties in 2023!
How can you create comparable frequency table of Population and GVA distribution?
Compare the measures of central tendency!

4. Measures of dispersion

Measuring central tendency does not specify sufficiently the distribution because it does not reflect the internal variations in the data of our investigated event. In the above example of table 10 it seems that including the counties of largest population the mean values are different. Though by analysing the means of various segmentations we may get information about the internal structure of population distribution there are opportunities for further specification. These are the measures of dispersion which measure the internal variability of the variables.

The measures of dispersion highly depend on the territorial division to smaller units of a larger one (e.g. changing the size of counties).

Range

$$P = x_{i,max} - x_{i,min}, \qquad P=MIN()-MAX()$$

Where:
$x_{i,max}$ = maximum value of x_i variable; $x_{i,min}$ = minimum value of x_i variable
$0 \leq P < \infty$; Measuring unit: the same as for the original data

Comments: Disadvantageous that the indicator is built on the extreme values, therefore in case of any extreme value P value may be incidental

Relative range

$$Q = (x_{i,max} - x_{i,min})/x_{i,avg} \quad , Q=(MAX()-MIN())/AVERAGE()$$

Where:
$x_{i,max}$ = maximum value of x_i; $x_{i,min}$ = minimum value of x_i;
$x_{i,avg}$ = average value of x_i.
$1 \leq Q < \infty$; Measuring unit: dimensionless

Comments: Appropriate to compare data series of different measuring units. Most frequently used in this group of indicators.

Range-proportion

$$K = x_{i,\, max}/x_{i,min}, \qquad K=MAX()/MIN()$$

Where:
$x_{i,max}$ = maximum value of x_i; $x_{i,min}$ = minimum value of x_i
$1 \leq K < \infty$; Measuring unit: dimensionless

Comments: It may be used with data measured on proportional scale where the minimum≠0, and having the same signs

Mean deviation

$$MD = (\sum(|x_i - x_{i,avg}|)/n \qquad MD=AVEDEV()$$

Where:
x_i = value of x_i variable; $x_{i,avg}$ = average value of x_i. variable;
n= number of observations
$0 \leq MD < \infty$ Measuring unit: the same as for the original data

Comments: It shows the average difference between observed and their average values of variables. The absolute values of differences are summarised because the sum of differences is equal to 0.

Standard Deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{i,avg})^2}{n}} \qquad \sigma=STDEV.P()$$

Where:
x_i = value of x_i variable; $x_{i,avg}$ = average value of x_i. variable;
n= number of observations
$0 \leq \sigma < \infty$; Measuring unit: the same as for the original data

It gives greater weightage to higher deviations about mean. In regional analysis it is used mainly for analysing inequalities of phenomena characterised with data of absolute volumes. Rarely used in case of relative indicators where weighting is necessary.

Relative Dispersion – Coefficient of Variation

$$CV = 100 \times \frac{\sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{avg})^2}{n}}}{x_{avg}} = 100 \times \frac{\sigma}{x_{avg}} \qquad CV= STDEV.P()/AVERAGE()$$

Where:
x_i = value of x_i variable; $x_{i,avg}$ = average value of x_i. variable;
n= number of observations
$0 \leq CV < \infty$; Measuring unit: %

Comments: Variability of variables measured in different units cannot be compared. The standard deviation is related to the average value of data, i.e. it is dimensionless. Therefore, CV is useful to compare the distribution of variables measured in different measuring units. The higher value of CV shows higher inconsistency, while the lower value shows higher consistency in the data.

Coefficient of skewness

$$SK = (\text{Mean - Mode})/\text{Standard deviation}$$

Alternative formula: $SK = [1/n] * \sum (x_i - x_{avg})^3/\sigma$ SK=SKEW.P()
Where:
x_i = value of x_i variable; $x_{i,avg}$ = average value of x_i. variable;
n= number of observations; σ = standard deviation

No limit to this measure, but generally it is $-1 \leq +1$ Measuring unit: dimensionless
SK = 0, if Mean=Mode

Here is a standardly used scale to interpret skewness intensity (Skewness calculator, 2025):

- A value of 0 indicates a perfectly symmetrical distribution.
- A value between -0.5 and 0 or between 0 and 0.5 indicates an approximately symmetric distribution.
- A value between -1 and -0.5 or between 0.5 and 1 indicates a moderately skewed distribution.
- A value between -1.5 and -1 or between 1 and 1.5 indicates a highly skewed distribution.
- A value less than -1.5 or greater than 1.5 indicates an extremely skewed distribution.

Weighted Standard Deviation

$$\sigma_w = \sqrt{\frac{\sum_{i=1}^{n} f_i(y_i - y_{avg})^2}{\sum f_i}}$$

$y_i = \frac{x_i}{f_i}$ *and* y_{avg} = weighted average value of y_i; $y_{avg} = \frac{\sum x_i}{\sum f_i}$

If $w_i = f_i / \sum f_i$, then $y_{avg} = \sum(w_i * x_i)$
Where:
f_i = weighting factor (e.g. population in GDP/capita); x_i = value of i variable
$0 \leq \sigma < \infty$; Measuring unit: the same as for the original data

Comments: Because only data of the same measuring units can be compared to each-other, this indicator is used particularly for time series analysis. In the frame of the analysis of income inequalities (like GDP/capita) the changes of this indicator are used to indicate the convergences or divergences (σ – convergence if the σ value is decreasing).

Weighted Coefficient of Variation

$$CV_w = 100 \times \frac{\sqrt{\frac{\sum_{i=1}^{n} f_i (y_i - y_{avg})^2}{\sum f_i}}}{y_{avg}}$$

$y_i = \frac{x_i}{f_i}$ *and* y_{avg} = weighted average value of y_i; $y_{avg} = \frac{\sum x_i}{\sum f_i}$

If $w_i = f_i / \sum f_i$, then $y_{avg} = \sum(w_i * x_i)$

Where:
f_i = weighting factor (e.g. population in GDP/capita); x_i = value of i variable
$0 \leq CVw < \infty$; Measuring unit: %

Comments: The weighted standard deviation is related to the weighted average value of data. Therefore, CV is useful to compare the distribution of weighted variables, measures in different measuring units.

Examples for measuring dispersion

Table 13. Measuring indicators of distribution based on Table 5 data

	WITHOUT OUTLIERS		
Nr	**Name**	**C**	**C**
27	MAX	738 143	=MAX(C6:C23)
28	MIN	218 128	=MIN(C6:C23)
29	Average/Mean	404 835	=AVERAGE(C6:C23)
30	Median	397 553	=+MEDIAN(L6:L23)
31	Mode (18)	340 000	340000
32	Range=MAX()-MIN()	520 015	=+C27-C28
33	Relative range	128,5%	=+C32/C29
34	Range proportion	3,38	=+C27/C28
35	Mean deviation	98 061	=AVEDEV(C6:C23)
36	Standard deviation (σ)	128 392	=STDEV.P(C6:C23)
37	Coefficient of variation	31,7%	=+C36/C29
38	Skewness	0,85	=SKEW.P(C6:C23)

Source: Author's compilation

Table 14. Calculation of weighted coefficient of variation for population in 2004 weighted by GVA distribution in Excel

	County name	Population 2004	GVA share 2004 (see Table 8.)	weighted population 2004	Weighting formula
		C	**D**	**E**	**E**
47	**Budapest**	**1 705 309**	0,35	592393	=+D47*C47
48	**Pest**	**1 124 395**	0,10	111983	=+D48*C48
49	Fejér	428 579	0,04	17626	=+D49*C49
50	Komárom-Esztergom	315 886	0,03	10900	=+D50*C50
51	Veszprém	368 519	0,03	10465	=+D51*C51
52	Győr-Moson-Sopron	440 138	0,05	22227	=+D52*C52
53	Vas	266 342	0,03	7041	=+D53*C53
54	Zala	296 705	0,03	7968	=+D54*C54
55	Baranya	402 260	0,03	11614	=+D55*C55
56	Somogy	334 065	0,02	7413	=+D56*C56
57	Tolna	247 287	0,02	4218	=+D57*C57
58	Borsod-Abaúj-Zemplén	738 143	0,05	34813	=+D58*C58
59	Heves	323 769	0,02	7233	=+D59*C59
60	Nógrád	218 128	0,01	2377	=+D60*C60
61	Hajdú-Bihar	550 265	0,04	23675	=+D61*C61
62	Jász-Nagykun-Szolnok	413 174	0,03	10792	=+D62*C62
63	Szabolcs-Szatmár-Bereg	583 564	0,03	19016	=+D63*C63
64	Bács-Kiskun	541 584	0,04	20390	=+D64*C64
65	Békés	392 845	0,02	9615	=+D65*C65
66	Csongrád-Csanád	425 785	0,03	13979	=+D66*C66
67	**Total**	**10 116 742**	1,00	**945737**	=SUM(E47:E66)
			Without outliers	**For 20 counties**	
68	Weighted mean =SUMPRODUCT(C47:C66;D47:D66)/ SUM(D47:D66)		436438	945737	=SUMPRODUCT(C47:C66;D47:D66)/ SUM(D47:D66)
69	Weighted standard deviation =SQRT(SUMPRODUCT((C47:C66-E68)^2;D47:D66)/SUM(D47:D66))		132033	597233	=SQRT(SUMPRODUCT((C47:C66-E68)^2;D47:D66)/SUM(D47:D66))
70	Weighted coefficient of variation		30,3%	63,2%	=+E69/E68

Source: Author's compilation

Conclusion: The value of CV_w is lower than that of CV for population, consequently the differences in GVA distribution decrease the differences in population distribution between

Hungarian counties. However, considering the outliers (i.e. Budapest and Pest County) the inequalities are doubling.

Control questions

- Which type of indicators are appropriate to compare the dispersion of variables measured in different measuring units?
- How can you compare the dispersion of population, GVA and GVA/capita?
- Evaluate dispersion indicators based on the calculation of range?
- What is the difference between standard deviation and coefficient of variation?
- How do you qualify the skewness intensity based on coefficient of skewness?

5. Measures of inequality

Territorial differences are necessary phenomena connected to territorial entities/units. Totally equal situation may only be exceptional. Territorial inequalities are closely connected to territorial differences, but the two concepts are not equal. Differences and differentiation may be connected to any kind of spatial phenomenon, but **inequalities are connected to phenomena with definite social value** (moral, political, discretional). Factors of geographic differences influencing territorial inequalities are listed in the first chapter of part 2.

The study and policy towards inequalities of different kinds have particular importance in regional policy. Therefore, the opportunities to measure the level and tendencies of various types of differences represent the first step to approach to inequalities. For the real evaluation of these indicators their connection to social values has to be clarified and included into the analysis.

The evaluation of inequalities requires:

- clear clarification and definition of the subject of research,
- selection of relevant and comparable measuring indicators and units,
- selection of appropriate territorial units,
- clear definition of the content and explanatory force of selected indicators,
- selection of relevant and comparable time scale,
- clarification of social and political aspects, particularly those of the value system

Most frequently applied indicators of territorial inequalities are

- Ranking
- Location Quotient
- Dual (Éltető-Frigyes) Index
- Hirschmann – Herfindahl Index of concentration
- Hoover Index or Index of Dissimilarity
- Shannon Index of diversity
- Gini Index of concentration
- Lorentz-curve
- Nearest Neighbour Index
- Potential/gravity models

5.1.Ranking

Ranking procedures in territorial analysis involve using various methods to order or prioritize different geographical areas or locations based on specific criteria or indicators. These rankings can be used for a wide range of purposes, including resource allocation, policy implementation, and monitoring progress towards various goals. However, rankings are not neutral tools, and their use frequently overlooks disparities in the starting conditions. There are widely known rankings on countries, cities, tourist places based on their economic performance, level of development, place in urban hierarchies, number of tourism facilities etc.

The simplest way of ranking is based on a single variable. In Excel this is easy to do by using the SORT tool in the DATA menu. Any complex analysis requires the consideration of several factors/variables. This can be done by using Multicriteria Analysis (Dean 2022). In this part only two simple technique is considered for the analysis of the settlement structure, particularly their role in their hierarchical system. In each case the first step is to transform the data into dimensionless form (percent distribution, normalisation or standardisation[10]).

5.2. Guttman-scale

Scaling is an ordinary measuring tool for ranking the smaller units of a larger one (e.g. the settlements of a district based on economic activities). By the application of Guttman-scale through summarisation most content of original information may be preserved. Its foundation is that the considered items (e.g. business units) as the indicators of a studied variable (e.g. attractivity, role of settlements, level of development) are able to reflect the strength of the variable.

Compiling the Guttman-scale starts in a table of territorial units with data characterising the studied variable (e.g. number of retail trade units by subsectors). After summarising the data both by settlements and by subsectors, both the rows and the columns are ranked based on the summarised values which are placed in the first column and first row of the table. In this way the table contains in the left upper corner those territorial units (settlements) having most of components of characterising items (e.g. retail trade subsectors) and most of individual items (retail trade units). The complex ranking will be visible after drawing a stepped line at cells where the large number disappear and zero values appear in the table.

Studying the table you can find holes (zero values) above the stepped line followed by non-zero values indicating missing components which may be filled up in the future or may operate in connection with other components (reflecting e.g. investment opportunities). You may also find numbers in the zero field of the table, representing a different situation. These represent components which may have difficulties in operation and probably soon disappear, or there is a special condition of its sustainability.

Example

Table 15 presents selected settlements located in a small district of Northern Hungary (in one of the poorest regions) and number of retailing shops in subsectors of retailing from the research aimed at ranking retail supply centres and unfolding potential market holes. The sectoral data have overlaps within one type of stores -e.g. the item Number of accommodation contains the beds for tourist accommodation (a lower class of supply). Their difference is the number of

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[10] **Standardisation** (also called z-score scaling) transforms data to have a mean of 0 and a standard deviation of 1. It refers first centring then scaling data. Its formula:

$$X_{std} = (X - \mu)/\sigma$$

Where:

- *X* is the original value,
- *μ (mu)* is the mean of the feature, and
- *σ (sigma)* is the standard deviation of the feature.

hotels in the area. This distinction is important from the aspect of tourism that is considered an important potential of regional development in the district. This is why the number of camping sites had also been involved in the research.

After summarising the data by settlements and by the type of shops (sectors) these total sums were used to rank the settlements and the sectors. The SORT tool in the DATA menu was used. Selecting the full range of data don't forget to click on the "My data has headers" icon and in the Options select first Sort top to bottom, and in the Sort by cell menu select the column containing the Total sum. After ranking by columns change in the Options Sort left to right, and in the Row select the row containing the Total values by rows. In both cases in the Order menu select Largest to smallest. The result is presented in table 15.

Evaluation
Grocery stores represent the basic supply, and they are available almost in each settlement. The second most important items are restaurants, bars and wineries, followed by industrial products stores. Accommodation is a concentrated special service discussed above. Considering the importance of tourism the lack of camping places is surprising (development opportunity?). The stepped line of available services gradually decreases with internal and external zero values reflecting development opportunities or difficulties of operation. The table offers still many directions for evaluation.

Table 15. Selected sample of the Guttman-scale for the Encs district in Hungary

Settlements	Encs district total	Encs	Krasznokvajda	Forró	Méra	Novajidrány	Keresztéte	Ináncs	Hernádvécse	Baktakék	Pere	Felsőgagy	Csenyéte	Hernádsztandrás	Pamlény	Hernádbüd	Szászfa	Kány
Sectors Total	472	194	77	43	36	30	22	21	18	10	10	3	2	2	2	1	1	0
Restaurants	87	39	4	11	10	7	0	7	2	3	3	1	0	0	0	0	0	0
Grocery stores	60	20	2	6	5	6	0	4	5	3	2	1	2	2	0	1	1	0
Stores of other industrial products	50	27	1	3	6	6	0	5	0	1	1	0	0	0	0	0	0	0
Accommodation beds	48	0	20	0	0	0	20	0	8	0	0	0	0	0	0	0	0	0
Bars, Wineries	43	19	3	4	2	5	0	4	2	2	1	1	0	0	0	0	0	0
Tourist accommodation beds	42	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Restaurants, Confectionaries	32	13	1	7	7	2	0	0	0	0	2	0	0	0	0	0	0	0
Clothing stores	16	15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DIY and building materials stores	15	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wholesaling stores	12	6	0	2	2	1	0	0	0	1	0	0	0	0	0	0	0	0
Second-hand shops	11	9	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Greengroceries	9	3	1	2	1	0	0	0	0	0	0	0	0	0	2	0	0	0
Auto-motor parts stores	8	3	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furniture stores	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Settlements	Encs district total	Encs	Krasznokvajda	Forró	Méra	Novajidrány	Keresztéte	Ináncs	Hernádvécse	Baktakék	Pere	Felsőgagy	Csenyéte	Hernádsztandrás	Pamlény	Hernádbűd	Szászfa	Kány
Private accommodation	5	0	2	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0
Book and stationery shops	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perfumeries	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petrol stations	3	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Private butcher shops	3	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Leather and shoe stores	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rental shop	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Household electrical appliances stores	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pensions	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Tobacco shops	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Private bottled drinks stores	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Camping sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author's edition based on HNSO data

5.3.Composite Development Index

The Composite Development Index is a composite measure that quantifies the level or quality of various sectors in a given location or region. It combines various factors like transportation networks, energy supply, communication systems, healthcare, and other essential services to provide an overall assessment of sectoral development and accessibility. It helps compare the development and quality of influencing components between different locations. By defining relevant components, collecting data, normalizing the data, and applying appropriate weights, you can create a comprehensive index that reflects the overall sectoral quality of a region.

Steps for calculating the Composite Development Index of health infrastructure supply.

1. Define the components
   - Research area: Counties of the South Plain Region in Hungary
   - Variables to explain the level of health infrastructure development:
     - General Practitioners (GPs)
     - Resident per GP and paediatrician
     - Hospital beds in operation
     - Number of hospital beds in operation per ten thousand population
2. Data collection

Gether data for each selected variable – in this case from Hungarian Central Statistical Office.

Table 16. Selected health infrastructure data of the Hungarian South Plain Region

Name of territorial units	Data			
	General Practitioners (GPs)	Resident per GP and paediatrician	Hospital beds in operation	Number of hospital beds in operation per ten thousand population
A	B	C	D	E
South-Plain Region				
Bács-Kiskun	233	1601	3 013	61,2
Békés	144	1654	2 293	73,7
Csongrád-Csanád	202	1486	2 932	75,4
SUM	579	1575	8238	69,1

Source: Author's compilation

3. Normalise the data using min-max normalisation.

Table 17. Normalised values of data from Table 16.

Name of territorial units	Normalised data			
	General Practitioners (GPs)	Resident per GP and paediatrician	Hospital beds in operation	Number of hospital beds in operation per ten thousand population
G	H	I	J	K
Bács-Kiskun	=(B6-MIN(B$6:B$8))/(MAX(B$6:B$8)-MIN(B$6:B$8)) = **1,00**	=(C6-MIN(C$6:C$8))/(MAX(C$6:C$8)-MIN(C$6:C$8)) = **0,69**	=(D6-MIN(D$6:D$8))/(MAX(D$6:D$8)-MIN(D$6:D$8)) = **1,00**	=(E6-MIN(E$6:E$8))/(MAX(E$6:E$8)-MIN(E$6:E$8)) = **0,00**
Békés	=(B7-MIN(B$6:B$8))/(MAX(B$6:B$8)-MIN(B$6:B$8)) = **0,00**	=(C7-MIN(C$6:C$8))/(MAX(C$6:C$8)-MIN(C$6:C$8)) = **1,00**	=(D7-MIN(D$6:D$8))/(MAX(D$6:D$8)-MIN(D$6:D$8)) = **0,00**	=(E7-MIN(E$6:E$8))/(MAX(E$6:E$8)-MIN(E$6:E$8)) = **0,88**
Csongrád-Csanád	=(B8-MIN(B$6:B$8))/(MAX(B$6:B$8)-MIN(B$6:B$8)) **=0,65**	=(C8-MIN(C$6:C$8))/(MAX(C$6:C$8)-MIN(C$6:C$8)) = **0,00**	=(D8-MIN(D$6:D$8))/(MAX(D$6:D$8)-MIN(D$6:D$8)) = **0,89**	=(E8-MIN(E$6:E$8))/(MAX(E$6:E$8)-MIN(E$6:E$8)) = **1,00**

Source: Author's compilation

This transformation scales all data points between 0 and 1, with 0 indicating the largest value of variable and 1 representing the smallest.

4. Assign weights and evaluate the quality contribution to individual component variables.

Different components might have varying levels of importance depending on the context or the region being analysed. Assign a weight (w_i) to each component based on its perceived importance. Ensure that the total of the weights adds up to 100% or 1.

Also evaluate the quality contribution of the variable for the total evaluation. For example the highest value of the number of practitioners may reflect better supply, while the higher number of residents per practitioners reflect worst. Therefore, the opposite value must be involved by taking the difference of 1-wighted value.

5. Calculate the Composite Development Index (CDI).

The formula:

$$\mathrm{CDI} = \sum_{i=1}^{n} (w_i \times Normalized\ Value\ of\ Component_i)$$

Where:

- CDI is the overall development index.
- w_i is the weight of each component variable.
- Normalized Value of $Component_i$ is the normalized value of the i-th component.

Table 18. Calculation of the Composed Health Infrastructure Index CHII)

Name of territorial units	Weighted normalised values					
	General Practitioners (GPs)	Resident per GP and paediatrician	Hospital beds in operation	Number of hospital beds in operation per ten thousand population	Composed Health Infrastructure Index CHII)	
M	N	O	P	Q	R	S
Weights	0,3	0,4	0,1	0,2		
South-Plain Region						
Bács-Kiskun	=+H6*H$4 = **0.30**	=1-(I6*I$4) = **073**	=+J6*J$4 = **0.10**	=(K6*K$4) = 0.**00**	=SUM(M6:P6) = **1.13**	=+Q6/Q$9 = **33.2%**
Békés	=+H7*H$4 = **0.00**	=1-(I7*I$4) = **060**	=+J7*J$4 = **0.00**	=(K7*K$4) = **0.18**	=SUM(M7:P7) = **0.78**	=+Q7/Q$9 = **23.0%**
Csongrád-Csanád	=+H8*H$4 = **0.20**	=1-(I8*I$4) = **1.00**	=+J8*J$4 = **0.09**	=(K8*K$4) = **0.20**	=SUM(M8:P8) = **1.48**	=+Q8/Q$9= **43.8%**
SUM	=SUM(M6:M8) **= 0.50**	=SUM(N6:N8) **= 2.33**	=SUM(O6:O = **0.19**	=SUM(P6:P8) = **0.38**	=SUM(Q6:Q8) = **3.39**	=+Q9/Q$9 = **100.0%**

Source: Author's compilation

6. Rank the individual counties by their health infrastructural development level.

In this example overview is easy due to the small number of units, therefore this step is not necessary

7. Evaluate your results

Csongrád-Csanád County has the best level of medical infrastructure in the region. This is closely connected with the university located in Szeged, the county seat. Bács-Kiskun County is on the second place against its first place in the number of practitioners and hospital beds. The poorest county is in the worst situation in medical infrastructure supply. Increasing the number of variables and/or changing the weights result in different CHII.

5.4.Location Quotient

The **Location Quotient (LQ)** compares the concentration of a particular economic activity in a region to the average of a larger territorial unit, e.g. to the national or global average. It is interpreted as **index of specialization**, too.

Formula:

$$LQ_{\mathrm{Ei}} = \frac{\frac{E_i}{\sum E_i}}{\frac{E_c}{\sum E_c}}$$

Where:

- LQ_{Ei} is the location quotient (the relative concentration) of E activity in region i (the specialization level of the i region for E activity)
- E_i is the economic sector activity in region i.
- $\sum E_i$ is the total economic activity in region i.
- E_c is the national-level economic sector activity.
- $\sum E_c$ is the total national economic activity.

An LQ greater than 1 indicates a higher-than-average concentration of that activity in the region. LQs are dimensionless, because they are ratios of the ratios. Therefore, data of various variables and territories are comparable to each-other. It does not require extensive data collection and easily understood.

Calculation of the Location Quotient

1. Define components

Research area: Counties of Northern Transdanubia Region in Hungary
Variables to explain territorial specialisation are selected economic sectors aggregated from Statistical classification of economic activities in the European Community (NACE Rev. 2). Values are Value Added in million Euro at 2020 price level in 2022.

2. Data collection

Source: Eurostat database

Table 19. Sectoral values of GVA in the Hungarian North-Transdanubia Region (million Euro at 2020 price level) (2022)

North-Transdanubia Region	Total	Agriculture	Manufacturing	Construction	Retail	Services	Other
Counties	B	C	D	E	F	G	H
Pest	16931,59	326,13	3 947	1596,62	3866,93	4336,04	2858,67
Fejér	6382,49	284,08	2 060	481,27	753,63	2159,02	644
Komárom-Esztergom	4136,68	187,32	1 649	271,77	630,68	912,08	486,12
Veszprém	4001,37	179,19	1 097	302,95	636,59	1181,87	603,49
Győr-Moson-Sopron	7315,02	355,89	2 618	471,46	1095,01	1834,19	940,65
Vas	3090,77	191,84	1 066	232,33	419,7	836,22	345,04
Zala	2838,1	188,45	564	238,63	542,27	931,5	373,12
Total	44696,02	1712,9	13001,27	3595,03	7944,81	12190,92	6251,09

Source: Author's compilation

3. Calculate the Location Quotient for each sector and county

Using the above formula

Table 20. Calculation of the Location Quotient for Northen Transdanubia based on Table 19.

	Total	Agriculture	Manu-facturing	Construction	Retail	Services	Other
	J	K	L	M	N	O	P
Pest	=+(B4/$B4)/(B$11/$B$11)	=+(C4/$B4)/(C$11/$B$11)	=+(D4/$B4)/(D$11/$B$11)	=+(E4/$B4)/(E$11/$B$11)	=+(F4/$B4)/(F$11/$B$11)	=+(G4/$B4)/(G$11/$B$11)	=+(H4/$B4)/(H$11/$B$11)
Fejér	=+(B5/$B5)/(B$11/$B$11)	=+(C5/$B5)/(C$11/$B$11)	=+(D5/$B5)/(D$11/$B$11)	=+(E5/$B5)/(E$11/$B$11)	=+(F5/$B5)/(F$11/$B$11)	=+(G5/$B5)/(G$11/$B$11)	=+(H5/$B5)/(H$11/$B$11)
Komárom-Esztergom	=+(B6/$B6)/(B$11/$B$11)	=+(C6/$B6)/(C$11/$B$11)	=+(D6/$B6)/(D$11/$B$11)	=+(E6/$B6)/(E$11/$B$11)	=+(F6/$B6)/(F$11/$B$11)	=+(G6/$B6)/(G$11/$B$11)	=+(H6/$B6)/(H$11/$B$11)
Veszprém	=+(B7/$B7)/(B$11/$B$11)	=+(C7/$B7)/(C$11/$B$11)	=+(D7/$B7)/(D$11/$B$11)	=+(E7/$B7)/(E$11/$B$11)	=+(F7/$B7)/(F$11/$B$11)	=+(G7/$B7)/(G$11/$B$11)	=+(H7/$B7)/(H$11/$B$11)
Győr-Moson-Sopron	=+(B8/$B8)/(B$11/$B$11)	=+(C8/$B8)/(C$11/$B$11)	=+(D8/$B8)/(D$11/$B$11)	=+(E8/$B8)/(E$11/$B$11)	=+(F8/$B8)/(F$11/$B$11)	=+(G8/$B8)/(G$11/$B$11)	=+(H8/$B8)/(H$11/$B$11)
Vas	=+(B9/$B9)/(B$11/$B$11)	=+(C9/$B9)/(C$11/$B$11)	=+(D9/$B9)/(D$11/$B$11)	=+(E9/$B9)/(E$11/$B$11)	=+(F9/$B9)/(F$11/$B$11)	=+(G9/$B9)/(G$11/$B$11)	=+(H9/$B9)/(H$11/$B$11)
Zala	=+(B10/$B10)/(B$11/$B$11)	=+(C10/$B10)/(C$11/$B$11)	=+(D10/$B10)/(D$11/$B$11)	=+(E10/$B10)/(E$11/$B$11)	=+(F10/$B10)/(F$11/$B$11)	=+(G10/$B10)/(G$11/$B$11)	=+(H10/$B10)/(H$11/$B$11)
Total	=+(B11/$B11)/(B$11/$B$11)	=+(C11/$B11)/(C$11/$B$11)	=+(D11/$B11)/(D$11/$B$11)	=+(E11/$B11)/(E$11/$B$11)	=+(F11/$B11)/(F$11/$B$11)	=+(G11/$B11)/(G$11/$B$11)	=+(H11/$B11)/(H$11/$B$11)

Source: Author's compilation

Table 21. The values of LQ for counties in North-Transdanubia Region

	Total	Agriculture	Manufacturing	Construction	Retail	Services	Other
	J	K	L	M	N	O	P
Pest	1,00	0,50	0,80	1,17	1,28	0,94	1,21
Fejér	1,00	1,16	1,11	0,94	0,66	1,24	0,72
Komárom-Esztergom	1,00	1,18	1,37	0,82	0,86	0,81	0,84
Veszprém	1,00	1,17	0,94	0,94	0,90	1,08	1,08
Győr-Moson-Sopron	1,00	1,27	1,23	0,80	0,84	0,92	0,92
Vas	1,00	1,62	1,19	0,93	0,76	0,99	0,80
Zala	1,00	1,73	0,68	1,05	1,07	1,20	0,94
Total	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Source: Author's compilation

4. Evaluate the result

Based on Gross Value Added except for Pest County all counties of the region are relatively (i.e. in relation to the regional average) specialised to agriculture. The highest level is at Zala and Vas Counties. At the same time while Zala is specialised in services, Vas in manufacturing.

Komárom-Esztergom and Győr-Moson-Sopron are the manufacturing centres of the region. Retailing is concentrated to Pest County.

5.5.Dual (Éltető-Frigyes) Index

The Dual Index (D) compares the average of those values of the variable which are above and below the average of the whole range of values. In this way it reflects the gap between those who belong to the highest and lowest part of the observed class characterised by the variable. The index is particularly applied to indicate the income gap between social groups or territorial units. The developers of this index (Ödön Éltető and Ervin Frigyes) aimed to reflect by this the inequalities between the rich and poor parts of the society.

$$D = x_{avg\_up}/x_{avg\_low}$$

Where:
x_{avg_up} = arithmetic average of values larger than the average of all x values;
x_{avg_low} = arithmetic average of values smaller than the average of all x values
$1 \leq D < \infty$; Measuring unit: dimensionless

Comments: In case of equal distribution D=1. The larger the values of D over 1, the inequalities are the greater (e.g. the scissor of income is wider).

Calculation of the Dual Index

1. Define components

Research area: Counties of Northern Transdanubia Region in Hungary
Variables to explain changes of territorial inequalities in the production of Gross Value Added (GVA) between 2004 and 2023, Values are Value Added in million Euro at current price level.

2. Data collection

Source: Eurostat database

3. Calculation of the Dual Index (D)

Table 22. Calculation of the GVA Dual Index of Hungarian North Transdanubia Region for selected years (million Euro at current price

3	TIME	2004	2023
4	GEO (Labels)	B	C
5	Pest	7 143,51	50 130,16
6	Győr-Moson-Sopron	3 651,96	8 641,84
7	Fejér	5 949,8	6 558,74
8	Komárom-Esztergom	5 474,87	5 533,49
9	Veszprém	5 036,84	4 615,95
10	Zala	1 956,53	3 173,95
11	Vas	1 896,05	3 557,65
12	Northern Transdanubia Total	31 109,56	82 211,78
13			
14	Mean (Average)=	=AVERAGE(B5:B11) = 4 444	=AVERAGE(C5:C11) = 11 745

3	TIME	2004	2023
15	**Dual Index=**	=(SUMIF(B5:B11;">"&B14)/COUNTIF(B5:B11;">"&B14))/(SUMIF(B5:B11;"<"&B14)/COUNTIF(B5:B11;"<"&B14)) = **2,36**	=(SUMIF(C5:C11;">"&C14)/COUNTIF(C5:C11;">"&C14))/(SUMIF(C5:C11;"<"&C14)/COUNTIF(C5:C11;"<"&C14)) = **9,38**

Source: Author's compilation

4. Evaluate the result

Though the values are at current prices the Dual Index is comparable because it is ratio. The inequalities of GVA production in the Northern Transdanubia region have more than tripled due to the intensive growth of GVA in Pest County.

5.6.Hirschmann – Herfindahl index of concentration

The **Hirschman-Herfindahl Index (HHI)** is a commonly used measure of market concentration, in regional research to measure the concentration or diversification of economic activity — such as employment, industry presence, or income — within a specific region. that helps assess the level of competition.

It is calculated by summing the squares of the market shares (expressed as percentages) of all firms in the market. The index ranges from close to **zero** depending on the number of observations (n) (its minimum value is (1/n*100) indicating a highly competitive market with many small firms) **to 100%** (a pure monopoly where one firm or territory holds 100% of the market). A higher HHI suggests greater market concentration and potentially less competition.

It is applied to assess industrial concentration in a region, to compare regional economies, to monitor economic evolution, to evaluate regional disparities. In spatial economics, HHI can reveal whether economic activity (like investment or job creation) is concentrated in a few regions or evenly spread across a country. **It helps to understand economic structure, resilience, and strategic vulnerabilities** of regions, providing critical insights for regional development strategies.

$$HH = \sum_{i=1}^{n} \left(\frac{x_i}{\sum x_i}\right)^2$$

Where

x_i = nominal data in natural measuring units

Value range: $1/n \leq HH \leq 1$ Measuring unit: dimensionless

If it is multiplied by 100, the values are in %.

Comments: The level of concentration is indicated by this index number in relation to equal distribution (1/n). HH>0.6 indicates very strong concentration. HH=1 means that all phenomena are located in one territorial unit. Because the minimum HH value depends on the number of territorial units the HH values of different territorial divisions are not comparable!

In this example of HHI calculation the data of Table 21 are used to calculate HHI.

Table 23. Calculation of the GVA concentration using Hirschman-Herfindahl Index (HHI)

TIME	**2004**	**2023**	**2004**	**2023**	**2004**	**2023**
GEO (Labels)	H	I	J	K	J	K
Pest	7 143,51	50 130,16	23,0%	61,0%	=+H5/H$12	=+I5/I$12
Győr-Moson-Sopron	3 651,96	8 641,84	11,7%	10,5%	=+H6/H$12	=+I6/I$12
Fejér	5 949,8	6 558,74	19,1%	8,0%	=+H7/H$12	=+I7/I$12
Komárom-Esztergom	5 474,87	5 533,49	17,6%	6,7%	=+H8/H$12	=+I8/I$12
Veszprém	5 036,84	4 615,95	16,2%	5,6%	=+H9/H$12	=+I9/I$12
Zala	1 956,53	3 173,95	6,3%	3,9%	=+H10/H$12	=+I10/I$12
Vas	1 896,05	3 557,65	6,1%	4,3%	=+H11/H$12	=+I11/I$12
Northern Transdanubia Total	31 109,56	82 211,78	1,000	1,000	=+H12/H$12	=+I12/I$12
HHI			16,8%	40,0%	=SUMSQ(J5:J11)	=SUMSQ(K5:K11)

Source: Author's compilation

Evaluation of results
HHI confirms the conclusion based on the Dual index. The concentration of GVA production has significantly increased within the North Transdanubia Region between 2004 and 2023 owing to the concentration of Pest County. Also worths to mention that the concentration to Győr-Moson-Sopron and Vas counties resulted a step forward change in their position within the region.

5.7.Shannon Diversity Index (SDI)

The Shannon formula, derived from Claude Shannon's work in information theory, is commonly used to quantify diversity and uncertainty. In regional analysis, it is particularly useful for assessing spatial and economic diversity, such as the variety of industries, land use types, or population distributions within a region.

$$SDI = -\sum_{i=1}^{n} p_i \, ln(p_i)$$

where:

- p_i is the proportion of the i-th category (e.g., land use type, industry, or population group) relative to the total,
- n is the total number of categories,
- ln is the natural logarithm.

Value range: $0 \leq \text{SDI} \leq \text{LN}(1/n)$ Measuring unit: dimensionless

This formula calculates the entropy or uncertainty associated with predicting the category of a randomly selected item. Higher values of SDI indicate greater diversity or complexity (totally equal distribution is indicated by LN(1/n), the maximum value), while lower values indicate the dominance of several or in case 0 one item (sector, territorial unit).

SDI is applied in territorial research for:

- *Land Use Diversity:* Planners use the Shannon index to assess how varied land uses are within a city or region. A high value suggests a balanced mix (e.g., residential, commercial, green spaces), which can indicate better sustainability and accessibility.

- *Economic Structure*: It measures industrial or occupational diversity within a region. A diverse economy (higher SDI) is typically more resilient to sector-specific shocks, helping policymakers design robust economic strategies.
- *Demographic Analysis:* The index can be applied to study ethnic, linguistic, or age-group diversity, supporting inclusive urban planning and social policy design.
- *Ecological and Environmental Studies:* In rural or mixed-use areas, it is used to evaluate biodiversity or land cover variation, relevant for conservation and land management.

Overall, the Shannon formula provides a quantitative framework for understanding complexity and heterogeneity, making it a valuable tool in regional planning, sustainability assessment, and policy development.

In this example of SDI calculation, the data of Table 23 are used to calculate SDI. Colum O of table 24 is equal to column J, and P to K in table 23.

Table 24. Calculation of SDI to show GVA diversity in Northern Transdanubia Region

TIME	2004	2023	2004	2023	2004	2023
GEO (Labels)	O	P	Q	R	Q	R
Pest	0,230	0,610	-0,338	-0,302	=+O5*LN(O5)	=+P5*LN(P5)
Győr-Moson-Sopron	0,117	0,105	-0,251	-0,237	=+O6*LN(O6)	=+P6*LN(P6)
Fejér	0,191	0,080	-0,316	-0,202	=+O7*LN(O7)	=+P7*LN(P7)
Komárom-Esztergom	0,176	0,067	-0,306	-0,182	=+O8*LN(O8)	=+P8*LN(P8)
Veszprém	0,162	0,056	-0,295	-0,162	=+O9*LN(O9)	=+P9*LN(P9)
Zala	0,063	0,039	-0,174	-0,126	=+O10*LN(O10)	=+P10*LN(P10)
Vas	0,061	0,043	-0,171	-0,136	=+O11*LN(O11)	=+P11*LN(P11)
Northern Transdanubia Total	1,000	1,000				
Shannon Diversity (SDI)			**1,851**	**1,345**	=-SUM(Q5:Q11)	=-SUM(R5:R11)

Source: Author's compilation

Evaluation of results
The territorial diversity of GVA production in the North Transdanubia Region has decreased owing to the greater dominance of Pest County. Overall, the regional economic performance of the Region became more sensible to changes in Pest County.

5.8.Hoover Index (HI)

In the analysis of income distribution, it is often called *Robin Hood Index* because of its interpretation. If income and population distributions are analysed the index is interpreted as HI percent of income (or population) must be redistributed for their equal distribution.

$$\mathrm{HI} = \frac{\sum_{i=1}^{n}|x_i - f_i|}{2}$$

where
$\sum x_i = 100$; and $\sum f_i = 100$; two partition coefficients in %
Value range: $0 \le \mathrm{HI} \le 100$ Measuring unit: %

Comments: The indicator is symmetric; therefore the role or order of the two distributions may be exchanged. The meaning of its value is that how many percent of the investigated x_i

phenomenon must be redistributed between territorial units for having the same distribution to f_i. In regional analysis usually the distribution of various social or economic indicators is compared to the territorial distribution of population.

The Hoover index has different interpretations in settlement /urban sociology:

a) it is called *dissimilarity index*, when the difference is measured in the location of two population groups. There is no segregation between two social groups if they are represented in the same proportion within each territorial unit. Consequently, the dissimilarity index shows the differences in the location of two social groups in relation to the segregation-free (equally distributed) location.
b) it is called *segregation index*, when the distribution of a selected population group is compared to the distribution of all other social groups (to the sum of all social group members minus the sum of the selected social group members). In this case the index shows the segregation of the selected social group within the total population.

The Hoover index may be used to compare the changes of territorial distribution in a time series.

a) In this case if in the denominator is 2t (t=the length of the period) instead of 2, then the value reflects the average change in one time unit (in case of yearly data in one year). This is particularly advantageous to compare changes of periods with different length.
b) Another possible modification of the Hoover index is when comparing the structural differences in two periods we divide with (i.e. we put into the denominator) 2n (n=number of territorial units) instead of 2. In this case the index reflects the changes of distribution for one territorial unit. This is particularly advantageous to compare the regional inequalities of countries with different number of administrative territorial units.

Steps for calculating the Hoover Index

1. Define components

To clarify how concentrated is the GDP in relation to the population in the Hungarian Northern Transdanubia Region the GDP values and population number is necessary by counties in 2023.

2. Data collection

Hungarian Central Statistical Office publishes the data on Resident population by sex, county and region, 1 January and Gross domestic product (GDP) by county and region [at purchasers' prices, million HUF]. From here the data must be filtered for the Region (Northern Transdanubia) and year (2023) we are interested in.

3. Process of calculation

Table 25. Calculation of Hoover index for Hungarian Northern Transdanubia in 2023

Name of territorial units	GDP 2023	POP 2023	GDP% 2023	POP% 2023	Diff	Diff
A	B	C	D	E	F	F
Pest	8 886 198	1 328 790	11,8%	13,8%	2,01 %	=ABS(D4-E4)
Fejér	2 895 269	419 565	3,9%	4,4%	0,51 %	=ABS(D5-E5)
Komárom-Esztergom	2 310 255	301 492	3,1%	3,1%	0,06 %	=ABS(D6-E6)

Name of territorial units	GDP 2023	POP 2023	GDP% 2023	POP% 2023	Diff	Diff
A	B	C	D	E	F	F
Veszprém	2 036 316	338 342	2,7%	3,5%	0,81 %	=ABS(D7-E7)
Győr-Moson-Sopron	3 814 828	471 309	5,1%	4,9%	0,17 %	=ABS(D8-E8)
Vas	1 557 220	249 812	2,1%	2,6%	0,53 %	=ABS(D9-E9)
Zala	1 401 088	261 803	1,9%	2,7%	0,86 %	=ABS(D10-E10)
Total	22 901 174	3 371 113	100,0 %	100,0 %	8,04 %	=SUM(F4:F10)
Hoover Index (HI)					**4,0%**	=+F11/2

4. Evaluate result

Based on the Hoover Index (HI) 4% of the GDP or population must be redistributed that their distribution would be the same. The difference is greatest for Pest County. Overall, the inequalities are relatively moderated in this aspect.

5.9.Lorentz-curve

Lorentz curve is a graphical representation of the relative concentration of two variables. Created from the ranked percentage distribution of two data series representing 2 variables arranged in a cumulated growing or decreasing order. In case of growing order, the curve is below the diagonal, in decreasing order the curve is over the diagonal. In territorial analysis the x axis represents the number of territorial units, the y axis represents the cumulated values of the investigated variable. In case of equal distribution, the curve coincides with the diagonal. The greater is the diversion of the curve from the diagonal the greater is the concentration of the phenomena. The territory between the diagonal and the Lorentz-curve as an indicator of concentration is measured by the *GINI index*.

Steps for calculating and drawing the Lorentz curve

In this example the data of Table 24 are used.

Table 26. Data transformation to draw the Lorentz curve - the relative concentration of GDP and population in the Hungarian Northern Transdanubia Region in 2023 Ranked Values

GDP% 2023	POP% 2023	Territorial units	Territorial units	GDP% 2023	POP% 2023
K	L	M	N	O	P
6,1%	7,4%	0,142857	0	0	0
6,8%	7,8%	0,142857	14%	6,1%	7,4%
8,9%	8,9%	0,142857	29%	12,9%	15,2%
10,1%	10,0%	0,142857	43%	21,8%	24,1%
12,6%	12,4%	0,142857	57%	31,9%	34,2%
16,7%	14,0%	0,142857	71%	44,5%	46,6%
38,8%	39,4%	0,142857	86%	61,2%	60,6%
100,0%	100,0%		100%	100,0%	100,0%

Formulas

Territorial units	Territorial units	GDP% 2023	POP% 2023
M	N	O	P
=1/7	0	0	0
=1/7	=+M4	=+K4	=+L4
=1/7	=+M5+N5	=+O5+K5	=+P5+L5
=1/7	=+M6+N6	=+O6+K6	=+P6+L6
=1/7	=+M7+N7	=+O7+K7	=+P7+L7
=1/7	=+M8+N8	=+O8+K8	=+P8+L8
=1/7	=+M9+N9	=+O9+K9	=+P9+L9
	=+M10+N10	=+O10+K10	=+P10+L10

Source: Author's compilation

After selecting data of N, O, P columns, select in the Insert/Charts menu of Excel the "X Y Scatter with smooth lines" graph to draw the Lorentz curve.

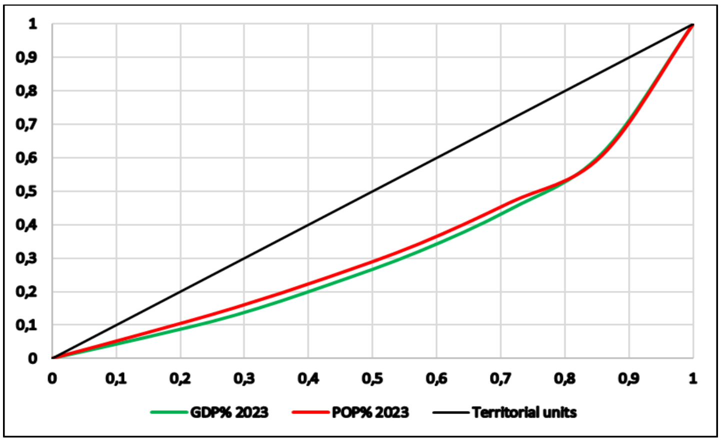


Figure 6. The Lorentz curve illustrating the territorial and relative concentration of GDP and population in the Hungarian Northern Transdanubia Region in 2023

Source: Author's edition

Strong relationship is in graphical interpretations of the Lorentz curve, the Hoover Index and the Gini Index (Figure 7)

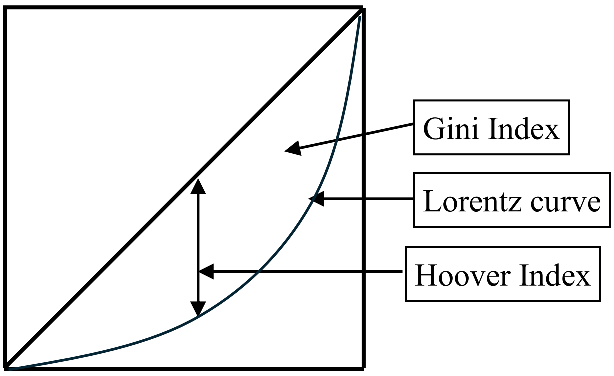


Figure 7. Relations between inequality indices

Source: Author's editing based on Nemes Nagy 2005

Evaluation of the result
Both the GDP and the population of the Hungarian North Transdanubia Region show relatively high concentration in 2023 confirming the result of Hirschman-Herfindahl Index, but in accordance with the result of the Hoover Index they show almost the same concentration in relation to each-other.

5.10. Gini-coefficient (Gini Index)

It measures inequality on a scale from 0 to 1, where higher values indicate higher inequality. This can sometimes be shown as a percentage from 0 to 100%, called the "Gini Index". A value of 0 indicates perfect equality: everyone has the same income. A value of 1 indicates perfect inequality. Frequent utilisation is for indicating income inequalities (Figure 7.). A special property of the Gini, compared to other inequality metrics, is that it is more sensitive to changes around the middle of the distribution than at the very top and bottom (Hasell 2023).

The Gini index captures how far the Lorenz curve falls from the "line of equality" by comparing the areas A (the internal area between the diagonal line and the line of the variable) and B (the external area), as calculated in the following way: Gini coefficient = A / (A + B).

There are several formulas to calculate:

$$G = \frac{1}{2x_{avg}n^2} \sum_i \sum_j \left| x_i - x_j \right|$$

where
$\sum x_i = 100$; and $\sum x_j = 100$; and $x_{avg} = \frac{\sum x_i}{n}$ (Nemes Nagy 2005, 116)

Alternatively, territorial Gini coefficient can be calculated from location quotients (LQ) (Dusek, Kotosz 2016):

$$G_t = \frac{1}{n(n-1)} * \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left| LQ_i - LQ_j \right|}{4\overline{LQ}}$$

where:
n= number of variables; LQ$_i$ and LQ$_j$ are the location quotients of i and j variables
Value range in all cases: $0 \leq G \leq 1$; Measuring unit: dimensionless

Advantages as a measure of inequality (

- The Gini coefficient's main advantage is that it is a measure of inequality by means of a ratio analysis, rather than a variable unrepresentative of most of the population, such as per capita income or gross domestic product.
- It can be used to compare income distributions across different population sectors as well as countries.
- The Gini coefficient can be used to indicate how the distribution of income has changed within a country over a period of time, thus it is possible to see if inequality is increasing or decreasing.

- The Gini coefficient satisfies four important principles:
    1. *Anonymity*: it does not matter who the high and low earners are.
    2. *Scale independence*: the Gini coefficient does not consider the size of the economy, the way it is measured, or whether it is a rich or poor country on average.
    3. *Population independence*: it does not matter how large the population of the country is.
    4. *Transfer principle*: if income (less than the difference), is transferred from a rich person to a poor person the resulting distribution is more equal.

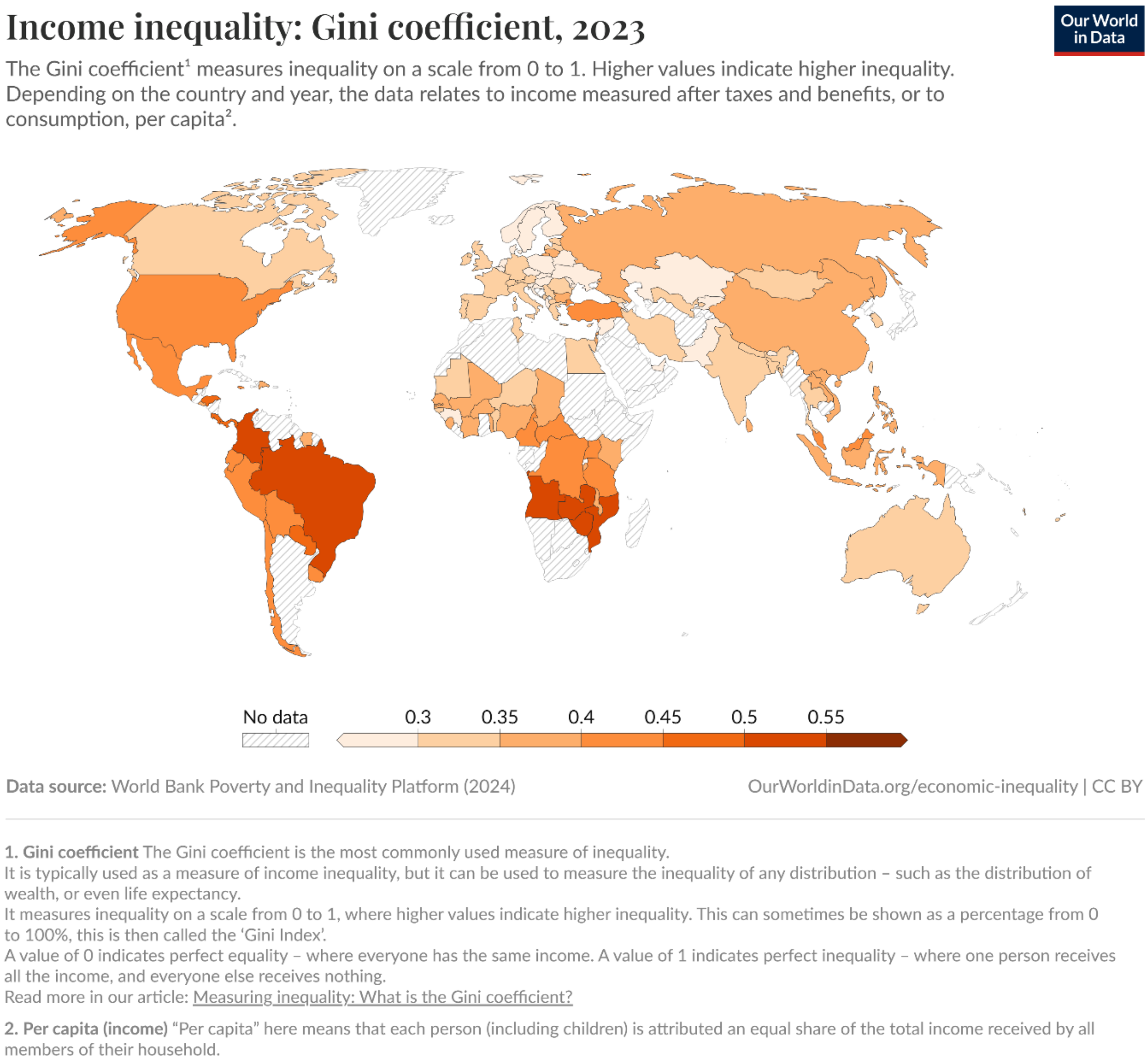


Figure 8. Gini Index of income inequality in the world (2023)

Source: Hasell 2023

Disadvantages of the Gini coefficient as a measure of inequality

- The Gini coefficient measured for a large economically diverse country will generally result in a much higher coefficient than each of its regions has individually. For this reason, the scores calculated for individual countries within the EU are difficult to compare with the score of the entire US.

- Comparing income distributions among countries may be difficult because benefits systems may differ.
- The measure will give different results when applied to individuals instead of households. When different populations are not measured with consistent definitions, comparison is not meaningful.
- The Lorenz curve may understate the actual amount of inequality if richer households are able to use income more efficiently than lower income households. From another point of view, measured inequality may be the result of more or less efficient use of household incomes.
- As for all statistics, there will be systematic and random errors in the data. The meaning of the Gini coefficient decreases as the data become less accurate. Also, countries may collect data differently, making it difficult to compare statistics between countries.
- Economies with similar incomes and Gini coefficients can still have very different income distributions. This is because the Lorenz curves can have different shapes and yet still yield the same Gini coefficient. As an extreme example, an economy where half the households have no income, and the other half share income equally has a Gini coefficient of ½; but an economy with complete income equality, except for one wealthy household that has half the total income, also has a Gini coefficient of ½.
- Too often only the Gini coefficient is quoted without describing the proportions of the quantiles used for measurement. As with other inequality coefficients, the Gini coefficient is influenced by the granularity of the measurements. For example, five 20% quantiles (low granularity) will yield a lower Gini coefficient than twenty 5% quantiles (high granularity) taken from the same distribution.

Example based on data of Northern Transdanubia (Table 25.)

1. Select data of territory, GDP and population in cumulative % distribution in the ranges of C1:Cn, D1:Dn and E1:En.
2. For calculating territorial Gini Index first use the SUMPRODUCT() function =SUMPRODUCT((C2:Cn)+(C1:Cn-1);(D2:Dn-D1:Dn-1)), that returns the sum of the products of corresponding ranges or arrays.
3. The Gini Index is calculated by the following equation:

$$G = 1 - 2 * (\text{SUMPRODUCT formula result})$$

4. The working table:

Table 27. Calculation of the GDP Gini coefficient to Northern Transdanubia Region (2023)

Name of territorial units	**Territorial units**	**GDP % 2023**	**POP % 2023**	**Territorial units**	**GDP% 2023**	**POP% 2023**
A	**N**	**T**	**U**	**N**	**T**	**U**
Pest	14,3%	6,1%	7,4%	0	0	0
Fejér	28,6%	12,9 %	15,2%	=+M4	=+K4	=+L4
Komárom-Esztergom	42,9%	21,8 %	24,1%	=+M5 +N5	=+K5+O5	=+L5+P5
Veszprém	57,1%	31,9 %	34,2%	=+M6 +N6	=+K6+O6	=+L6+P6

Name of territorial units	Territorial units	GDP % 2023	POP % 2023	Territorial units	GDP% 2023	POP% 2023
A	**N**	**T**	**U**	**N**	**T**	**U**
Győr-Moson-Sopron	71,4%	44,5 %	46,6%	=+M7 +N7	=+K7+O7	=+L7+P7
Vas	85,7%	61,2 %	60,6%	=+M8 +N8	=+K8+O8	=+L8+P8
Zala	100,0 %	100, 0%	100,0 %	=+M9 +N9	=+K9+O9	=+L9+P9
SUMPRODUCT()		-1,33846	-1,1021584		=SUMPRODUCT(($S5:$S10)+(S4:S9);(T4:T9)-(T5:T10))	=SUMPRODUCT(($S5:$S10)+(T4:T9);(U4:U9)-(U5:U10))
		GDP	**Population**		GDP	Population
Territorial Gini Index		**3,7**	**3,2**		=1-2*T12	=1-2*U12
GDP_POP Gini Index		**3,0**			=1-2*V12	

Evaluation of results

The concentration tendencies are confirmed by the Gini coefficients, reflecting relatively higher territorial concentration of GDP than that of the population, while they are less concentrated in relation to each-other.

5.11. The Nearest Neighbour Index

The **Nearest Neighbour Index (NNI)** is a spatial statistic used to quantify the spatial arrangement of points in a given area. The pattern of distribution ranges from

- regular clustered - irregular/random
- symmetric - asymmetric
- coherent - non-coherent (exclave - enclave e.g. Kaliningrad from the aspect of Russia - EU)

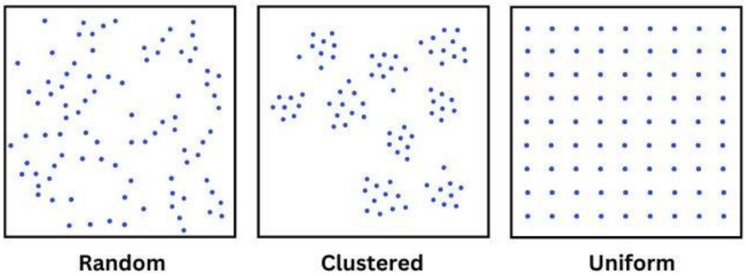


Figure 9. Distribution patterns

Source: GISGeography 2025

Nearest Neighbour Analysis produces an index (expressed as NNI) which measures the extent to which a particular pattern is clustered (nucleated), random or regular (uniform). It measures the deviation of any spatial pattern of the distribution of points from randomness.

Methodology

1. Select the area to be analysed. The area should include more than 30 points (e.g. settlements or plants in ecological research). With fewer than 30 points, it is difficult to say with any confidence that the distribution has regular distribution tendency, and the pattern may have occurred by chance. The NNI value lies within the yellow shaded area on the diagram below and therefore has a random distribution at the 95% probability level. The *NNI* value must lie outside the shaded area before a particular distribution pattern can be accepted as significant.

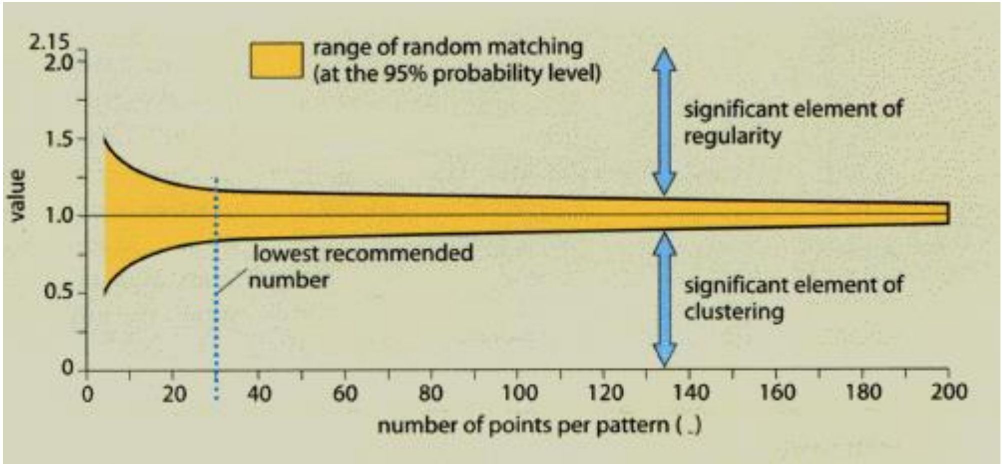


Figure 10. Interpretation of NNI statistic: significant values

Source: Barcelona 2025

2. Measure the distances between each point. For representing a region regional seat or gravity centre may be selected. Distances should be arranged into a distance matrix. This is asymmetric matrix where the elements are the pairwise distances of each point. Selecting the minimum values (MIN()) of columns, **the nearest distances (d_x)** for each point are identified. The minimum distance of two points is not necessarily the same for each one, because for point A the nearest neighbour may be B, but it occurs that for B a C point is the nearest neighbour. of point A from B.

There are different types of distances.

a. Geographical distance is measured between geographical points based on their geocodes (latitude, longitude), measured by km.
b. Travel distances on the road, railway, flight etc. networks measured by km or travelling time,
c. Economic distances measured by transport prices,
d. Virtual distances (psychological, cultural, etc.) are measured by relevant subjective units weighted with travel or economic distances.

3. With minimum distances calculate the Nearest Neighbour Index (NNI)
   a) Determine the density of points (m)

$$m = \frac{n}{T}$$ n = number of points; T = territory extension

Measuring unit: e.g. points/km^2

   b) Determine the expected average distance between points (D) in case of random distribution of points (Poisson distribution) (e.g. km)

$$D = \frac{1}{\sqrt{m}}$$

c) The average distance measured between the nearest neighbouring points (Dx)

$$D_x = \frac{\sum d_x}{n}$$

d) **The nearest neighbour index (NNI)**

$$NNI = \frac{D_x}{D}$$

Where

$$0 \leq \text{NNI} \leq 2.149$$

IF:

- NNI<1, then the distribution of points approaches to be clustered/concentrated pattern, at the value of zero the distance of each point is 0.
- NNI~1, then the distribution of points is random
- NNI>1, then the distribution of points approaches to be regular or uniform pattern, at value 2.149 means that each place is equidistant

Limits:

- minimum 30 points have to be included
- border situation has to be distinguished
- concentration may be around one or several points

Table 28. A sample of distance matrix selected from Csongrád-Csanád County (km)

		Algyő	Ambróz-falva	Apát-falva	Árpád-halom	Ásott-halom	Baks	Balástya	Bordány	Szeged	Area km²
A	B	C	D	E	F	G	H	I	J	K	L
1	Algyő		56	45	53	42	41	30	28	12	75,77
2	Ambrózfalva	56		30	40	92	95	84	80	66	11,22
3	Apátfalva	45	30		70	73	74	63	61	41	53,84
4	Árpádhalom	53	40	70		94	50	77	80	64	45,20
5	Ásotthalom	42	92	73	94		60	40	20	31	122,54
6	Baks	41	95	74	50	60		20	42	38	61,92
7	Balástya	30	84	63	77	40	20		20	24	110,00
8	Bordány	28	80	61	80	20	42	20		20	36,61
9	Szeged	12	66	41	64	31	38	24	20		280,84
10	Total	307	487	412	475	410	379	328	323	284	722,17
11											
12	Minimum	12	30	30	40	20	20	20	20	12	

Source: Author's compilation

For all settlements of Csongrád-Csanád County had been calculated using the above formulas.

This is presented in summary in the Table 29.:

Table 29. Calculation of the Nearest Neighbour Index for Csongrád-Csanád County

74	Csongrád-Csanád County territory (km^2)	4264,42	4264,42
75	Nr of Settlements	60	60
76	m (Nr/km^2)=	0,01407	=+C75/C74
77	D=	8,43052	=1/(SQRT(C76))
78	SUM(Dx)=	447	=SUM(C64:BJ64)
79	AVG(Dx)=	7,45	=+C78/C75
80	**NNI=**	**0,884**	=+C79/C77

Source: Author's compilation

Evaluation of results
The Nearest Neighbour Index of Csongrád-Csanád County is less than 1, indicating that there is a tendency for clustering. Against its peripheral location Szeged has the smallest average distance value, confirming that Szeged is the centre of county-level clustering.

5.12. Spatial Gravity Centre (SGC)

Spatial Gravity Centre (SGC) presents the weighted location of activities or items dispersed in a larger area. Weighting depends on the objective of the research: number of populations, size of production units, volume of production or consumption etc. SGC may be applied for demographic, economic, social, political purposes. The location on the map is determined by the geocoordinates of individual observation units.

Positioning is based on the weighted average of (geographic) co-ordinates (latitudes (x_i;) and longitudes (y_i)). The weights (f_i) are the indicators of investigated phenomena in percent/100 value.

$$x_s = \frac{\sum f_i x_i}{\sum f_i} \qquad y_s = \frac{\sum f_i y_i}{\sum f_i}$$

Types of spatial gravity centres:

- Geometric => based on the average of geo-coordinates
- demographic => geographic differentiation of population distribution
- economic => territorial concentration of the economic activity
- income => territorial inequalities of income structure
- market => territorial concentration of markets
- political => political power centres
- capital allocation => concentration of investments
- settlements => distribution of settlements by size or by numbers
- unemployment => territorial deficiencies of employment policy
- employment by industries / economic branches => distribution of key industries / branches

Comparing the changes of gravity centres connected to different periods reflects the changes in territorial distribution of the investigated phenomena.

Research process

1. Select the event/activity in accordance with your research objective. Identify the locations and weighting indicator.
2. Select data for weighting.
3. Identify the geocodes of selected locations. This can be done by using the geoapify link:

Geocoding tool

a) Go to https://www.geoapify.com/tools/geocoding-online/
b) Upload an Excel, CSV, or text file that contains addresses to be geocoded - Go to step 3 - /or copy&paste addresses to a text area, select „adress"; „Country"; „Language". – GO to step 5
c) Map columns to the address components (house number, street, city, and etc.)
d) Geocode addresses with Geoapify Geocoder
e) Download CSV file with results

4. Calculate the weighted average of geocodes

Insert csv file using Excel Data/Getdata menu and after inserting, select the columns of geocodes

Table 30. Geocoding table

Name	Latitudes x_i	Longitudes y_i	Weights f_i	$f_i *x_i$	$f_i *y_i$
i=1					
i=n					
Centre of gravitation =	**-**	**-**	**-**	**SUM() = Xs**	**SUM() = Ys**

Source: Author's compilation

5. Put the gravity centre into your map

Example

1. Research question: Where is the global gravity centre of copper mine production and refinery copper production in relation to population gravity centre of top producer countries? Countries are represented by their capital cities and their population.
2. Select data from databases and the geocodes of capital cities

Table 31. Leading countries in global copper mine and refined copper production.

M	N	O	P	Q	R	S	T	U	V	W
1		Copper mine producti on	Refined copper producti on	Copper mine producti on	Refined copper producti on	Capital	Populati on	Populati on		
2	Country	2020	2020	2020	2020				Lati-tude	Longi-tude
3	Canada	585	300	9,3%	4,9%	Ottawa-Gatineau	1363159	0,9%	45,416 6	-75,698
4	USA	12	918	0,2%	15,0%	Washingt on, D.C.	5206593	3,3%	38,895 1	- 77,0364
5	South Korea	0	671	0,0%	10,9%	Seoul	9963497	6,3%	37,568 3	126,977 8
6	German y	0	643	0,0%	10,5%	Berlin	3552123	2,3%	52,524 4	13,4105
7	Poland	393	560	6,2%	9,1%	Warszawa (Warsaw)	1767798	1,1%	52,229 8	21,0118

M	N	O	P	Q	R	S	T	U	V	W
1		Copper mine production	Refined copper production	Copper mine production	Refined copper production	Capital	Population	Population		
2	Country	2020	2020	2020	2020				Latitude	Longitude
8	Kazakhstan	552	515	8,8%	8,4%	Astana	1068113	0,7%	51,1801	71,446
9	Mexico	733	492	11,6%	8,0%	Ciudad de México (Mexico City)	21580827	13,7%	19,4273	-99,1419
10	Australia	885	427	14,0%	7,0%	Canberra	447692	0,3%	-35,2835	149,1281
11	Zambia	853	378	13,5%	6,2%	Lusaka	2523844	1,6%	-15,4134	28,2771
12	Peru	215	324	3,4%	5,3%	Lima	10390607	6,6%	-12,0432	-77,0282
13	Indonesia	505	269	8,0%	4,4%	Jakarta	10516927	6,7%	-6,2118	106,8416
14	China	172	10	2,7%	0,2%	Beijing	19617963	12,4%	39,9075	116,3972
15	Chile	573	233	9,1%	3,8%	Santiago	6680371	4,2%	-33,4569	-70,6483
16	Japan	0	158	0,0%	2,6%	Tokyo	37468302	23,8%	35,6895	139,6917
17	Congo Dem.Rep.	16	135	0,3%	2,2%	Kinshasa	13171256	8,4%	-4,3276	15,3136
18	Russia	810	104	12,8%	1,7%	Moskva (Moscow)	12409738	7,9%	55,755	37,6218
19	Total	6304	6137	100,0%	100,0%		157728810	100,0%		
20										
21	**Weighted geocodes**									

Source: US Geological Survey 2024

Table 32. Calculation of global gravity centres of copper mine and refinery production, and the population gravity centre of the capitals of producer countries

M	N	X	Y	Z	AA	AB	AC
1		Weighted with copper mine production		Weighted with refined copper production		Weighted with population	
2	Country	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
3	Canada	4,2145798	-7,02464	2,2201369	-3,700407	0,392509	-0,654214
4	USA	0,0740389	-0,146643	5,8181036	-11,52345	1,283919	-2,542954
5	South Korea	0	0	4,1075981	13,883348	2,373134	8,0210009
6	Germany	0	0	5,5032083	1,405076	1,182873	0,3020104
7	Poland	3,2560773	1,3099044	4,7659586	1,9173225	0,585383	0,2354967
8	Kazakhstan	4,4815062	6,2560584	4,2948919	5,9955499	0,346583	0,4838203
9	Mexico	2,2589167	-11,52776	1,5574762	-7,948153	2,658089	-13,56483
10	Australia	-4,953347	20,935655	-2,454954	10,37603	-0,10015	0,42328
11	Zambia	-2,085601	3,8262002	-0,949367	1,7416887	-0,24663	0,4524664
12	Peru	-0,410737	-2,627072	-0,635815	-4,066667	-0,79336	-5,074341
13	Indonesia	-0,497614	8,5588528	-0,272279	4,6831335	-0,41419	7,1239066

M	N	X	Y	Z	AA	AB	AC
1		Weighted with copper mine production		Weighted with refined copper production		Weighted with population	
2	Country	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
14	China	1,0888468	3,1758119	0,0650277	0,1896647	4,963607	14,477228
15	Chile	-3,041054	-6,421554	-1,270239	-2,682264	-1,41702	-2,992204
16	Japan	0	0	0,9188432	3,5964296	8,478001	33,183607
17	Congo Dem.Rep.	-0,010984	0,038867	-0,095197	0,3368643	-0,36138	1,278773
18	Russia	7,1639515	4,8340194	0,944846	0,6375537	4,386674	2,9599962
19	Total	11,53858	21,187698	24,518239	14,841719	23,31805	44,113043
20							
21	**Weighted geocodes**	**11.53858**	**21.18769**	**24.51823**	**14.84171**	**23.31804**	**44.11304**

Table 32 Formulas

M	N	X	Y	Z	AA	AB	AC
1		Weighted with copper mine production		Weighted with refined copper production		Weighted with population	
2	Country	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
3	Canada	=+V3*$Q3	=+W3*$Q3	=+V3*$R3	=+W3*$R3	=+V3*$U3	=+W3*$U3
4	USA	=+V4*$Q4	=+W4*$Q4	=+V4*$R4	=+W4*$R4	=+V4*$U4	=+W4*$U4
5	South Korea	=+V5*$Q5	=+W5*$Q5	=+V5*$R5	=+W5*$R5	=+V5*$U5	=+W5*$U5
6	Germany	=+V6*$Q6	=+W6*$Q6	=+V6*$R6	=+W6*$R6	=+V6*$U6	=+W6*$U6
7	Poland	=+V7*$Q7	=+W7*$Q7	=+V7*$R7	=+W7*$R7	=+V7*$U7	=+W7*$U7
8	Kazakhstan	=+V8*$Q8	=+W8*$Q8	=+V8*$R8	=+W8*$R8	=+V8*$U8	=+W8*$U8
9	Mexico	=+V9*$Q9	=+W9*$Q9	=+V9*$R9	=+W9*$R9	=+V9*$U9	=+W9*$U9
10	Australia	=+V10*$Q10	=+W10*$Q10	=+V10*$R10	=+W10*$R10	=+V10*$U10	=+W10*$U10
11	Zambia	=+V11*$Q11	=+W11*$Q11	=+V11*$R11	=+W11*$R11	=+V11*$U11	=+W11*$U11
12	Peru	=+V12*$Q12	=+W12*$Q12	=+V12*$R12	=+W12*$R12	=+V12*$U12	=+W12*$U12
13	Indonesia	=+V13*$Q13	=+W13*$Q13	=+V13*$R13	=+W13*$R13	=+V13*$U13	=+W13*$U13
14	China	=+V14*$Q14	=+W14*$Q14	=+V14*$R14	=+W14*$R14	=+V14*$U14	=+W14*$U14
15	Chile	=+V15*$Q15	=+W15*$Q15	=+V15*$R15	=+W15*$R15	=+V15*$U15	=+W15*$U15
16	Japan	=+V16*$Q16	=+W16*$Q16	=+V16*$R16	=+W16*$R16	=+V16*$U16	=+W16*$U16
17	Congo Dem.Rep.	=+V17*$Q17	=+W17*$Q17	=+V17*$R17	=+W17*$R17	=+V17*$U17	=+W17*$U17
18	Russia	=+V18*$Q18	=+W18*$Q18	=+V18*$R18	=+W18*$R18	=+V18*$U18	=+W18*$U18
19	Total	=SUM(X3:X18)	=SUM(Y3:Y18)	=SUM(Z3:Z18)	=SUM(AA3:AA18)	=SUM(AB3:AB18)	=SUM(AC3:AC18)
20							
21	**Weighted geocodes of gravity centres**	**11.53858**	**21.18769**	**24.51823**	**14.84171**	**23.31804**	**44.11304**

Source: Author's compilation

Gravity centre of copper mine production
Gravity centre of copper refinery production
Population gravity centre of capitals of copper producer countries

Figure 11. Gravity centres of global 18 copper mine and refinery production countries in relation to their population gravity centre represented by their capitals

Source: Author's edition

Evaluation of results
The spatial Gravity Centres of copper mine and refinery production are located in the middle and northern part of Africa. The refinery production centre is shifted to the north from the mine production indicating that refinery is located mostly in northern countries, while in mining the southern countries play important role. The difference indicates that in copper production transport activity and recycling is also important. In both activities relative symmetry is reflected because there is no shift in East-West direction. The shift of population gravity centres to eastward indicates that the capitals in the Eastern hemisphere have more population.

5.13. Spatial Gravity Models

Spatial interaction modelling has been one of the most important strands of the modern human geographic modelling literature. Spatial interaction models illustrate how different locations are functionally interdependent. The degree of spatial interaction (e.g. commuting, migration, trade flows) reflects Tobler's First Law of Geography that 'everything is related to everything else, but near things are more related than distant things.' The process of spatial interaction is therefore a key mechanism for creating the spatial structures underlying human societies.

Spatial Gravity Models are based on the physical analogy of gravity interaction of masses. Spatial interaction (TI_{ij}) of territorial objects represented by mass indicators (M_i, M_j) (e.g. population, number of entrepreneurs, GDP, capital, produced goods, retailing capacity etc.) depends on the distance (d_{ij}) (measured by km, traveling time, transport cost, etc.) according to the classical gravity equation:

$$TI_{ij} = G * \frac{M_i * M_j}{d_{ij}^{ß}}$$

Where G= Gravity constant, and ß indicates the strength of the impact of distance

Movements connected to physical events can be explained by mechanistic causal relations, but in case of economic, social events the teleological habit of actors must be considered.

The value of G for social or economic events is usually one or could be important to reflect the numeric value of movement intensity.

The value of ß parameter is influenced by the type, motivation, direction of movement.

- ß<2
  - travelling from periphery to the centre
  - leaders, functionaries, high-educated employee
  - travelling to holiday
- ß>2
  - travelling from the centre towards the peripheries
  - in case of physical workers
  - women employees
  - travelling to primary or grammar school

5.13.1. Territorial Gravity Potential (TGP)

It is supposed by the model that those places or territories are in the best position (have the greatest potential) which concentrate great economic power or are located nearby to most important power centres. They have the best accessibility to targeted markets or to potential partners for cooperation. It is measured by the relation of a territorial unit to the sum of all other units in the socio-economic space.

$$TGP_i = \sum_{j=1}^{n} \frac{M_j}{d_{ij}^{ß}}$$

Where TGP_i is the Territorial Gravity Potential of the i territorial unit
M_j is the mass of all other j territorial unis considered
d_{ij} is the distance between i and j territorial unit
ß reflects the strength of the impact of distance (usually equal to 2)
n is the number of territorial units considered

Steps for calculating TGP

1. Define components

What is the interaction potential of 4 cities with population and distances of table 33.

Table 33. Sample city data

City	Population
City1	50000
City2	100000
City3	80000
City4	75000

Distance matrix				
	City1	**City2**	**City3**	**City4**
City1		120	200	180
City2	120		200	180
City3	200	200		21
City4	180	180	21	
Total	500	500	421	381

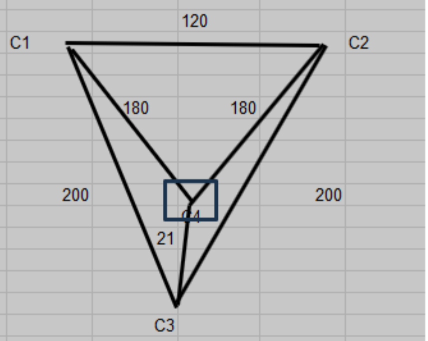
2. Calculation process of TGP

Calculate the level of interaction (TGP) of individual cities using the formula for coordinates of table 34.:

$$TGP_{1,2} = \$C\$1 * (D4 * E4) / (F4 \wedge \$C\$2)$$
$$TGP_1 = \sum_j TGP_{1j}$$

Table 34. TGP calculation in Excel with graph of location and distances of sample cities

	A	B	C	D	E	F	G
1		G=	0,001	= for 1000 inhabitant			
2		beta=	2				
3		Region A	Region B	Pop A	Pop B	Distance (I	Interaction
4		City1	City2	50000	100000	120	347
5		City1	City3	50000	80000	200	100
6		City1	City4	50000	75000	180	116
7							**563**
8							
9		City2	City1	100000	50000	120	347
10		City2	City3	100000	80000	200	200
11		City2	City4	100000	75000	180	231
12							**779**
13							
14		City4	City1	75000	50000	180	116
15		City4	City2	75000	100000	180	231
16		City4	City3	75000	80000	21	13 605
17							**13 953**
18							
19		City3	City1	80000	50000	200	100
20		City3	City2	80000	100000	200	200
21		City3	City4	80000	75000	21	13 605
22							13 905
23							



Source: Author's compilation

The sum of individual TGP values represent the total potential of the relevant city.

3. Evaluate the result

Though city 2 has the largest number of populations City4 has the largest potential against its almost smallest population number. It is due to its smallest distance from all other cities and close location to the second largest city. They together form the centre of the region composed of the 4 cities. This is illustrated on the graph. It worths to call the attention to the special positions of City 1 and City2. They are equally distant from all other cities but owing to the difference in their population number their potential is different, reflecting the impact connected to their internal market.

5.13.2. Gravity Attraction Borders and movements between points

The border of attraction between two territorial units is at the point where their power of attraction (PA_i=PA_j) is equal. Based on the gravity equation of two points it can be proved that

$$d_{ix} = \frac{d_{ij}}{1+\sqrt{\frac{M_j}{M_i}}} \qquad (1)$$

Where d_{ix} is the distance from i till the equal point of attraction
d_{ij} id the total distance between i and j
M_i and M_j are the masses of i and j respectively

Replacing this d_{ix} value into the gravity equation the potential scale of movements between individual territorial units can be calculated.

$$PA_i = \frac{M_i M_j}{d_{ix}^{ß}} \qquad (2)$$

Example

1. Research questions: Where are the borders between the cities of table 31? How many commuters are generated potentially due to the potential differences of these cities?

Step1. Calculate the border of attraction zones using equation (1)

Table 35. The modified distance matrix

	Distance matrix d_{Ax}			
	City1	**City2**	**City3**	**City4**
City1		**50**	**88**	**81**
City2	**70**		**106**	**96**
City3	**112**	**94**		**11**
City4	**99**	**84**	**10**	
Total distances	281	178	116	107

Formulas of Table 33

	Distance matrix d_{Ax}			
	City1	**City2**	**City3**	**City4**
City1		**=+C$5/(1+SQRT($F6/$F$5))**	**=+D$5/(1+SQRT($F7/$F$5))**	**=+E$5/(1+SQRT($F8/$F$5))**
City2	**=+B$6/(1+SQRT($F5/$F$6))**		**=+D$6/(1+SQRT($F7/$F$6))**	**=+E$6/(1+SQRT($F8/$F$6))**
City3	**=+B$7/(1+SQRT($F5/$F$7))**	**=+C7-D16**		**=+E$7/(1+SQRT($F8/$F$7))**
City4	**=+B$8/(1+SQRT($F5/$F$8))**	**=+C8-E16**	**=+D8-E17**	
Total distances	=SUM(B16:B18)	=SUM(C16:C18)	=SUM(D16:D18)	=SUM(E16:E18)

Source: Author's compilation

Step 2. Evaluate the result
The borders of potentials are closer to smaller cities. Note that the rank of cities based on the total distances of potential borders is different from the rank order based on population.

Step3. Calculate the potential movements (commuters) between cities

- Let's suppose that the commuting average rate in the region represented by the above cities is 20% in B21 cell.
- Replace the border distance into the equation (2)
- G=0,00001 = for 100 000 inhabitants in B1 cell
- beta= 2 in B2 cell

Table 36. Calculation of the number of potential commuters

Average commuting rate of total population	**20,0%**	**61000**				
	Number of potential commuters					
	City1	**City2**	**City3**	**City4**	**Total number of potential inward commuters**	**Balance of potential commuters**
City1		**8579**	**7798**	**15153**	*31529*	**-9469**
City2	**17157**		**22291**	**21539**	*60988*	**13037**
City3	**12476**	**17833**		**15488**	*45797*	**1188**
City4	**11365**	**21539**	**14520**		*47424*	**-4756**
Total number of outward commuters	*40998*	*47951*	*44609*	*52180*	**185738**	**0**
Number of commuters if the regional average share of commuters =				**20,0%**		
City1	0	2817	2561	4977	10355	**-3110**
City2	5635	0	7321	7074	20030	**4282**
City3	4097	5857	0	5087	15041	**390**
City4	3732	7074	4769	0	15575	**-1562**
Total number of outward commuters	**13465**	**15748**	**14650**	**17137**	**61000**	**0**

Step 4. Evaluate the results
City1 and city 4 potentially have negative balance of commuting. The greatest level of outward commuting is from the smallest city, while the highest inward to the largest city. City3 has nearly balanced number of commuters against its relatively small size but favourable location. The peripheral location of City4 is reflected in its negative commuting balance.

Control questions

- How can be made distinction between differences and inequalities?
- What are the requirements to evaluate inequalities?
- How can you evaluate a ranked table of Guttman-scale?
- Describe the process of calculation of a Composite Development Index?
- What is the content of the Location Quotient and how is its evaluation?
- Characterise the Dual Index!
- How is the concentration measured by Hirschmann-Herfindahl Index?
- What is diversity and how can it be measured?
- How is the concentration measured by the Hoover Index?
- Describe the relation of inequality indices on Lorentz-curve!
- What are the advantages and disadvantages of the Gini Index?
- How quantifies the Nearest Neighbour Index the spatial arrangements?
- What kind of spatial gravity centres may be distinguishes and how?
- How can you apply for analysis the various spatial gravity centres?
- How influence various types of movements the ß parameter of spatial gravity models?
- What kind of relations are reflected in the territorial gravity potential?
- How can be the borders of attraction determined?
- What kind of factors influence the movements between territorial units in a gravity model?

Formulas of Table 36.

Average commuting rate of total population			**0,2**	**=B21*F9**		
	Number of potential commuters					
	City1	**City2**	**City3**	**City4**	**Total number of potential inward commuters**	**Balance of potential commuters**
City1		**=+$B$1*(($F6*$F5)/(1+SQRT($F6/$F$5))^2)**	**=+$B$1*(($F7*$F5)/(1+SQRT($F7/$F$5))^2)**	**=+$B$1*(($F8*$F6)/(1+SQRT($F8/$F$5))^2)**	***=SUM(B25:E25)***	**=+F25-B$29**
City2	**=+$B$1*(($F6*$F5)/(1+SQRT(F5/F6))^$B$2)**		**=+$B$1*(($F7*$F6)/(1+SQRT($F7/$F$6))^2)**	**=+$B$1*(($F8*$F6)/(1+SQRT($F8/$F$6))^2)**	***=SUM(B26:E26)***	**=+F26-C$29**
City3	**=+$B$1*(($F7*$F5)/(1+SQRT(F5/F7))^$B$2)**	**=+$B$1*(($F6*$F7)/(1+SQRT($F6/$F$7))^2)**		**=+$B$1*(($F8*$F7)/(1+SQRT($F8/$F$7))^2)**	***=SUM(B27:E27)***	**=+F27-D$29**
City4	**=+$B$1*(($F8*$F5)/(1+SQRT(F5/F8))^$B$2)**	**=+$B$1*(($F6*$F8)/(1+SQRT($F8/$F$6))^2)**	**=+$B$1*(($F7*$F8)/(1+SQRT($F7/$F$8))^2)**		***=SUM(B28:E28)***	**=+F28-E$29**
Total number of outward commuters	***=SUM(B25:B28)***	***=SUM(C25:C28)***	***=SUM(D25:D28)***	***=SUM(E25:E28)***	**=SUM(F25:F28)**	**=SUM(G25:G28)**
Number of commuters if the regional average share of commuters =				**=+B21**		
City1	=+(B25)*($C$21/$F$29)	=+(C25)*($C$21/$F$29)	=+(D25)*($C$21/$F$29)	=+(E25)*($C$21/$F$29)	=SUM(B32:E32)	**=+F32-B$36**
City2	=+(B26)*($C$21/$F$29)	=+(C26)*($C$21/$F$29)	=+(D26)*($C$21/$F$29)	=+(E26)*($C$21/$F$29)	=SUM(B33:E33)	**=+F33-C36**
City3	=+(B27)*($C$21/$F$29)	=+(C27)*($C$21/$F$29)	=+(D27)*($C$21/$F$29)	=+(E27)*($C$21/$F$29)	=SUM(B34:E34)	**=+F34-D$36**
City4	=+(B28)*($C$21/$F$29)	=+(C28)*($C$21/$F$29)	=+(D28)*($C$21/$F$29)	=+(E28)*($C$21/$F$29)	=SUM(B35:E35)	**=+F35-E$36**
Total number of outward commuters	**=SUM(B32:B35)**	**=SUM(C32:C35)**	**=SUM(D32:D35)**	**=SUM(E32:E35)**	**=SUM(F32:F35)**	**=SUM(G32:G35)**

6. Time dimension in spatial analysis

6.1.Main points for analysing regional time series data

Empirical time series are data (observed values of events) connected to territorial units and several dates or periods which follow each-other in equal or other intervals. For statistical analysis the periods should be equalised. In different dates the events may take different values owing to the impact of various factors, therefore their behaviour is like a probability variable (Y_t). The series of these probability variables are called theoretical time series. The empirical time series data are one possible realisation (the realised values) of these theoretical time series. These observations are used to calculate the data and parameters of theoretical time series for analysing their characteristics and to prepare forecasts to help the orientation of interventions into the targeted processes. However, it is important to keep in mind that the calculated values and parameters are reflecting the conditions of the period which had been used to calculate them. The minimum required number of observations is 10-15 for each component!

Therefore, all conclusions and forecasts depend on probabilities connected to the calculation procedure. In addition, in the equations the only influencing factor is time, that concentrates in itself all other, not identified components. Furthermore, using the forecast for the future, there are many uncertainties concerning the future but there is one point that is sure, and it is *that the future will be different from the past*. Consequently, as the estimated parameters reflect the past conditions in their utilisation for the future peculiar consideration is needed.

6.2.Components of time series:

- *Trend component (T)* – is the durable tendency indicating the basic direction of changes of the time series. It is influenced by factors having crucial impact on the event for a long-time. In territorial analysis this is the most frequently analysed component.
- *Cyclical component (C)* – is a durable long-term (more than one year long) fluctuation in the time series. It can be identified and filtered out based on differences from the trend values and/or by using moving average procedure in which the included number of periods is the length of the cycle. The length of cycles is influenced by the length of the gestation period (the period from fertilisation till birth or sexual maturation, or from capital mobilisation till the beginning of production). Most important cycles for territorial processes are the demographic cycles, business cycles, technological cycles, innovation cycles, reproduction cycles etc.

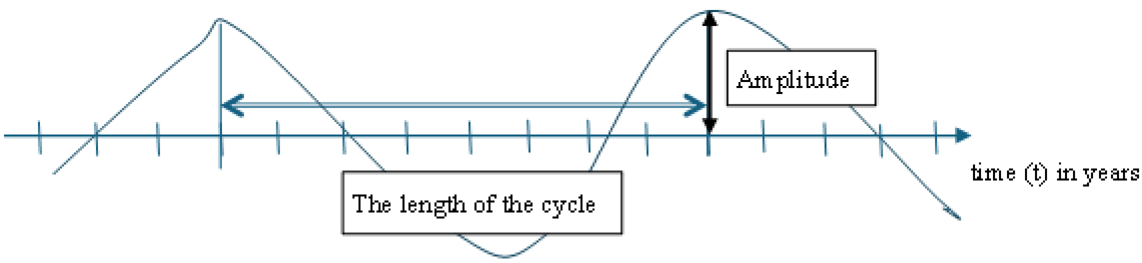


Figure 12. Cycle parameters

Source: Author"s edition

- *Seasonal component (S)* – is a regular fluctuation of stable length but within one year (short-term fluctuation). In case of constant seasonal impact, the deviation is constant from the trend line; in case of variable seasonal impact the deviation varies. Typical seasonal changes are for fashion industry , in animal husbandry, in urban services etc.
- *Random fluctuation (R)* – is the irregular change in the time series caused by the cumulated impact of unexpected events, non-significant, short term influencing forces. This component could be indicated for the past periods but can't be forecasted.

Composing time series components two approaches are used:

Y = T * C * S * R (multiplicative) or Y = T + C + S + R (additive)

Utilisation of the multiplicative approach is more flexible, because in this case the changes do not depend on the magnitude of the event, they are proportional.

6.3.Basic types of trends

Each territorial unit has its own development path characterised by its own long-term durable tendency, its baseline graphically represented by its development curve. This development path is influenced by internal and external factors reflected by the curve. Radical changes, internal or external interventions in these factors can generate the transformation of this characteristic development path. This process can be analysed and visualised around the breaking points of trends.

In the following equations t represents the time as the key influencing factor that reflects everything that operates during the period of the selected time unit (decade, year, quarter, week, day etc.). Its purposeful calibration starts with "0" (at the initial date) either at the beginning of the series of data or "0" in the middle of the series.

There are two ways in Excel to estimate the parameters of basic trend equations: (i) most simple is to add a trendline to a chart or (ii) by using Excel functions (formula based). For the visual + equation solution after selecting the data in the table of time series go to Insert/Insert Line/Line with markers in the menu. In the chart klick on the line with right button and select Add trendline and in trendline options select the type you are estimating the best fit. For evaluation select Display equation on chart and Display R-squared[11] (coefficient of determination) value on chart.

6.3.1. Linear trend

$$Y_t = \alpha + \beta * t$$

Where
α – the intercept, a constant parameter. Its value is the calculated value of Y at the t=0 point of the series.

[11] The value of R-squared indicates the strength of relationship between the variables. In % it indicates that how much % of changes are explained by the equation. ($0 \leq R^2 \leq 1$)

β – the slope, shows the absolute average changes in the volume of Y during one period that was used for calibration. Its measuring unit is the same as the measuring unit of Y at the calculation of the parameter.

In a chart on nominal scale the linear trend is a straight line. If the value of m is positive, then there is growth, if the value is negative, there is decrease in the process represented by the trend line. When the equation is used for forecasting, the t values are fitted to the length of forecast and replaced in the equation.

Linear trends gradually approach to the limits of the system with equal steps. In the long-term they may produce unrealistic values (e.g. the forecasted increase (or decrease) of individual smaller territorial units together may result extremely high (or low) values for the territorial unit which includes them. Owing to the constant magnitude of m parameter the growth rate is decreasing over several period.

In case of values for intertemporal comparability data must be transformed to the same price levels.

For formula-based solution
Y (observation) -values in B2:B10 and
X (time) -values in A2:A10):

=SLOPE(B2:B10, A2:A10) → returns the slope (m)

=INTERCEPT(B2:B10, A2:A10) → returns the intercept (b)

In Excel you can insert the line graph with lines representing the original data and after selecting the line of relevant data select in the chart elements menu trendline, linear trendlines with equation and R-squared value.

See more details: https://mathinsight.org/linear_function_one_variable

Example
In this example data for Northern Transdanubia are selected at constant (2020) price level.

The lines of observations reflect that the national GVA had decreased after the economic crisis of 2008, and after 2012 it shows gradual increase, that was stopped after 2019, by the COVID crisis. The m parameter of the trendline is negative indicating an average of 3 million Euros decrease during the whole period in each year. However, the coefficient of determination (R^2) value of the equation warns that very small variation is explained by the equation. This can be explained by the high amplitudes in the observed values, appearing also in the residuals.

Looking at the curve and trendline of the data on Northern Transdanubia it can be concluded that the region was less sensible to the crisis, even there was 8 million Euro increase during the period in each year. The coefficient of determination is also very small.

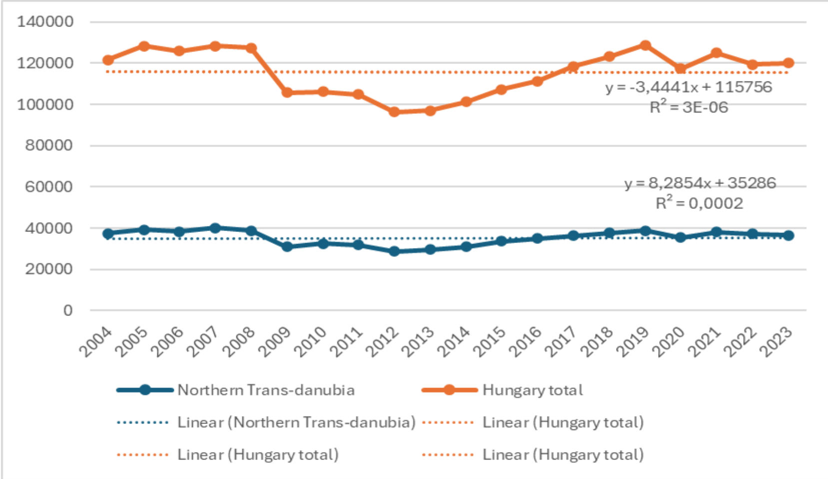


Figure 13. Gross value added at basic prices in Hungary and Northern Transdanubia Region (2020 prices, million euro)

Source: Author's edition

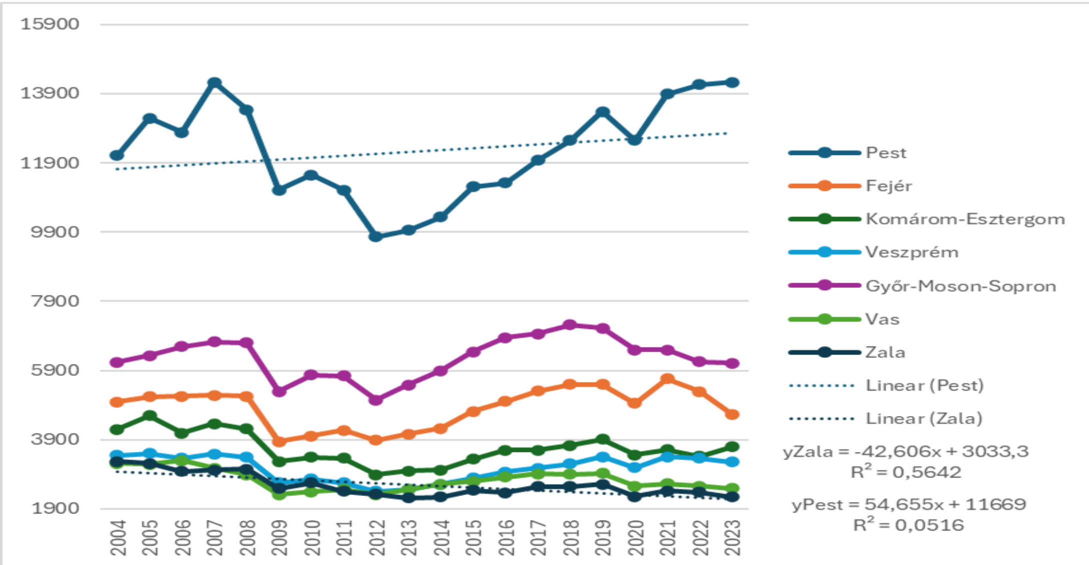


Figure 14. GVA values of N-Transdanubian counties (2020 prices, million euro)

Source: Author's edition

The detailed analysis based on county-level data (figure 14) enlightens the intraregional differences both in the level of GVA and in the sensibility to crisis phenomena. The low level of R^2 of Pest linear equation is the consequence of the error term due to higher sensibility to the crisis period. In case Zala the lowest level of GVA the differences are smaller, therefore the R^2 value is higher, indicating a better explanatory power. Pay attention to the tendencies indicated by the slope.

6.3.2. Exponential trend

When relative changes in time series show stability the best approach to them is the use of exponential function.

For formula-based solution the functions of SLOPE() and INTERCEPT() can be used but the logarithm (LOG() or Natural logarithm function =LN()) values of the observation must be replaced into the functions!

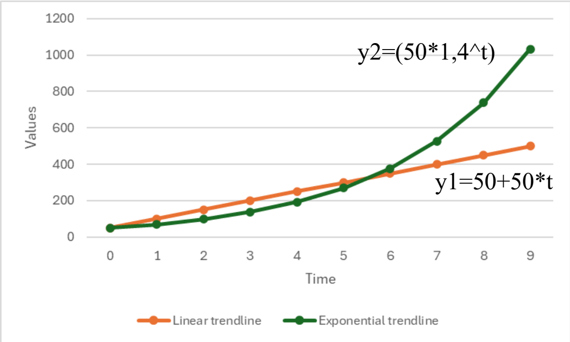


Figure 15. The exponential and linear trendline

Source: Author's edition

Task: Look at the graph when you change the values axis to logarithmic scale!

Table 37. Data for linear and exponential functions (figure 15)

t	*Linear line y1*	*Y1 growth rates (r= previous year=1)*	*Exponential line y2 (r=0.4)*
0	*50*		*50*
1	*100*	*1,00*	*70*
2	*150*	*0,50*	*98*
3	*200*	*0,33*	*137,2*
4	*250*	*0,25*	*192,08*
5	*300*	*0,20*	*268,912*
6	*350*	*0,17*	*376,4768*
7	*400*	*0,14*	*527,0675*
8	*450*	*0,13*	*737,8945*
9	*500*	*0,11*	*1033,052*

Source: Author's edition

The equation of exponential function

$$Y_t = \alpha * \beta^t$$

Linearized for calculation:

$$LN\ (Y_t) = LN(\alpha) + t * LN\ (\beta)$$

Where

α – constant parameter. Its value is the calculated value of Y at the t=0 point of the series.

β – shows the relative average changes in the volume of Y during one period. If $\beta>1$ the tendency is growth, if $\beta<1$ the tendency is decay, if $\beta=0$ there is no change.

The (β — 1 = r) value is the *growth rate*. Its multiplied value by 100 is its percent (p%) value.

The trend approaches to the limits of the analysed phenomena faster, with proportionally higher volumes. The doubling time of the growth is widely used indicator to characterise the speed of changes. This is the length of the period during which the value of the variable doubles. The classical environmental example to illustrate the importance of this indicator is the proliferation of water lily in a lake that endangers oxygen supply of lake animals. On the first day you put one lily into the lake that doubles itself by the next day. The question is: how many days do you have to save the lake when a quarter of the lake is covered by the lily?

The transformed function to calculate the doubling time:

$$t = \frac{LN\ (2)}{LN(1+\frac{p}{100})}$$

In connection with environmental, economic and social processes growth rates are often preferred indicators of changes. Exponential growth is a typical tendency for processes characterised by positive feedback. By comparing the growth rates of different regions conclusions can be made concerning their convergence or divergence, the growing or decreasing differences or inequalities. Looking at the doubling time of processes conclusions can be made on the approaches to local absorbent capacity ceiling, on the ceilings of local environmental assimilation capacity etc. Consequently, similarly to linear trends the exponential trends will change after several periods.

See more details: https://mathinsight.org/exponential_function

6.3.3. Parabolic trend

Changes of linear and exponential trends are supposed to be constant (volumes or rates respectively) during the whole investigated period. When changes are variable polynomial functions fit better to the original data series. However, in this case the opportunity for direct interpretation of parameters (α,β_1,β_2…), like in case of linear or exponential trends, is less possible. In Excel the quadratic polynomial function is available to characterise the trendline.

$$Y_t=\alpha+\beta_1 t+\beta_2 t^2$$

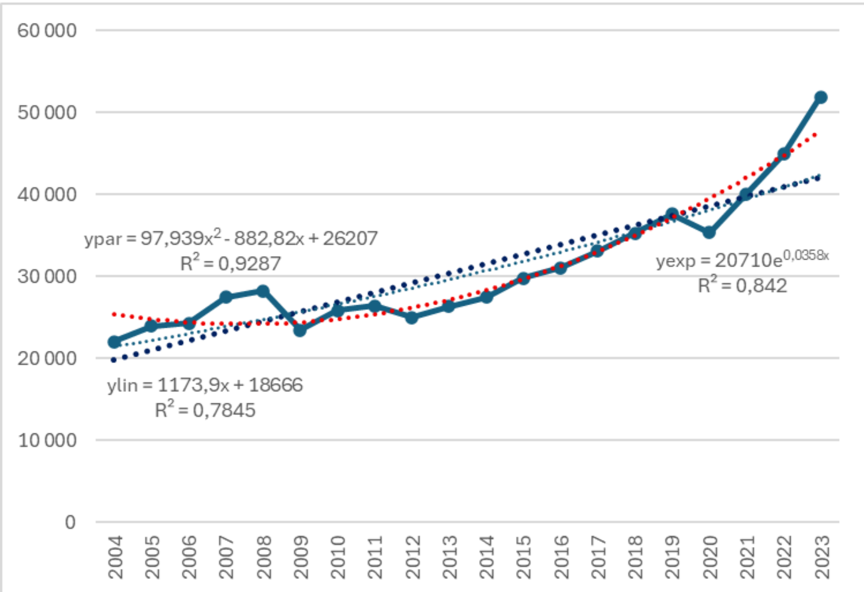


Figure 16. Linear (ylin) exponential (yexp) and parabolic (ypar) trendlines of GVA changes in North Transdanubia region based on current prices (million Euro)

Source: Author's edition

The explanatory power of equations is lowest for the linear and highest for the parabolic (quadratic polynomial) trend. This last one follows best the original data series. However, at the beginning and at the end of the series the error term is growing. Consequently, its utilisation for forecasting needs careful evaluation like in case of the other trendlines. Particular attention must be paid to the price changes, because the data are at current price level. The lines are just for illustrating the different trends. In case of the linear trend the growth difference is 1174 million Euro in each year, and the exponential trend indicates 3.6% growth rate per year.

6.3.4. S-shaped curves, the logistic trend

S-shaped curves describe phenomena that start slowly, accelerate, and then slow down as they approach to a maximum limit or saturation point. Various types of S-shaped curves play important role in characterising ecological, economic and social processes, but also territorial ones. Widely known is the innovation curve or the curve describing the consumption of durable goods. In settlement or infrastructure development or describing population changes they may be useful approaches to characterising the processes. The curves have two asymptotes: the zero value and the value of saturation (k), where capacity or sustainability limits are attained or a stock had been exhausted. Saturation occurs in a region when it can no longer sustain further expansion, growth, or development in a particular area without significant changes or interventions.

An S-shaped curve has three phases and three distinct points. The *Initial phase* characterised *by* slow growth rate, that is followed by the *Accelerated phase* with dynamic take-off in the processes. In the *Saturation phase* processes become matured with limited growth. The first transition period is at *the lower elbow point* also called *lower turning point* (A), where the growth begins noticeably to accelerate. This is the period when the former linear growth could be replaced by exponential growth curve. The second, less visible but crucial important transition point is the point where the increasing growth rate begins to decrease. This is called *inflection point* (B) that can be identified at the top of the derivative line of the growth. The derivative of the classic logistic curve is the bell-shaped Gauss-curve which has its maximum point at the half of the minimum and maximum value (k/2). This is the phase, which can be described by the end of the exponential curve, a dynamic linear curve or the beginning of a concave or parabolic curve. The *upper turning point* (C) is at the period when the growth rate noticeably begins to decrease, also called *upper elbow point*. This part is best described by a concave curve.

The equation of the logistic curve:

$$Y_t = \frac{k}{1+e^{\alpha+\beta t}}$$

Where:
k – saturation level (the curve approaches to it but never reach it)
e = 2.718.., the Euler number, ln(e)=1
α, β – parameters
t – time
A – lower turning point
C – upper turning point
B – inflexion point (in classic logistic curve B is at k/2)

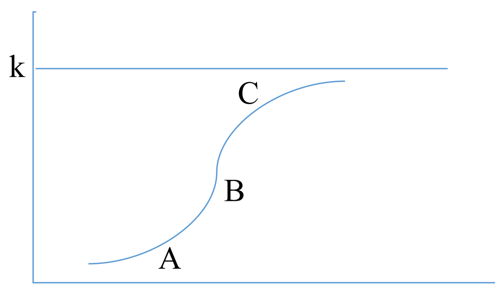


Figure 17. The logistic curve
Source: Author's edition

For t period the relative level of unsaturation can be expressed by

$$\frac{k - Y_t}{Y_t} = e^{a+bt}$$

The estimation of the logistic equation parameters typically requires the use of maximum likelihood estimation (MLE). Procedures can be found in statistical software packages.

Qualitatively different phases of development may be represented by S-shaped curves following each-other and covered by **lower and upper envelope curves**. Lower envelop curve connects the lower turning points of consecutive S-shaped curves; upper envelop curve connects the upper turning points of consecutive S-shaped curves. If there is a delay in starting the new development process represented by a new consecutive S-shaped curve, the envelop curve reflects a slow-down in development. The point where the curve of the new development crosses the curve of the previous one is called **break-through-point**. After this point a new development process or a new level of development will dominate the process.

In territorial analysis the consecutive phases of urban or infrastructural development, their relation to technological or industrial development may be analysed.

6.4.Index series in territorial analysis

Index numbers reflect relative changes of variables either in time or in space. They may reflect

- the changes of a certain phenomenon:
  - value-index series ($GDP_t * P_t$) (at current prices or constant - t_0 - prices)
  - price-index series (P_t)
  - volume index series (GDP_t)
  - the order of relationship
  - base-index series (basis is a selected t date –e.g. year, or a territorial unit)
  - chain-index series (previous period – e.g. year – is = 100)
  - the way of weighting
  - fix-weighted index series
  - variably weighted index series
  - ***Purchasing Power Parity (PPP)***is a rate for converting national deflators and currencies, thus eliminating the differences in the price level of different countries and enabling quantitative comparisons of different GDP components and price level comparisons as well. (Source: https://www.ksh.hu/docs/eng/modsz/nzt_meth.html)

Calculation of base indices from chain indices:

$$\frac{q_1\,p_1}{q_0\,p_0} \times \frac{q_2\,p_2}{q_1\,p_1} \times \frac{q_3\,p_3}{q_2\,p_2} \times \frac{q_4\,p_4}{q_3\,p_3} = \frac{q_4\,p_4}{q_0\,p_0}$$

The intensity of changes in a series of time is characterised with the average of changes between individual periods.

- The *average absolute change* is the arithmetic average of differences between neighbouring periods ($d_t=y_t-y_{t-1}$) or territorial units:

$$d_{avg} = \frac{\sum_{t=1}^{t} d_t}{t-1} = \frac{y_t - y_1}{t-1}$$

This is used, if the value of changes seems to be the same from one period to the next in the series.

- The average relative change is the geometric average of quotients (chain indices) of data for neighbouring periods ($r_i = \frac{y_t}{y_{t-1}}$):

$$r_{avg} = \sqrt[t-1]{\prod_{t=2}^{t} r_i} = \sqrt[t-1]{\frac{y_t}{y_{t=1}}}$$

Where r_{avg} – is the average rate of growth / decrease

Example

Table 38. The distribution and changes of GDP in 2 counties (r1, r2) of a region (R)

A	B	C	D	E	F	G	H
Év	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
CPI							
Previous year=100	102,4	102,8	103,4	103,3	105,1	114,5	117,6
2020=100	91,1	93,6	96,8	100	105,1	120,3	141,5
GDP (purchaser's prices, million HUF)							
GDP_r1	14 316 253	15 847 139	18 043 594	18 120 648	20 523 020	24 401 520	28 781 131
GDP_r2	3 975 263	4 434 554	4 985 627	5 216 977	6 180 114	7 840 686	8 886 198
GDP_R	18 291 516	20 281 693	23 029 221	23 337 625	26 703 134	32 242 206	37 667 329
GDP distribution (%)							
GDP_r1	78,3%	78,1%	78,4%	77,6%	76,9%	75,7%	76,4%
GDP_r2	21,7%	21,9%	21,6%	22,4%	23,1%	24,3%	23,6%
GDP_R	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
GDP (2020 prices, million HUF)							
GDP_r1	15 719 667	16 926 678	18 639 033	18 120 648	19 527 136	20 277 232	20 337 255
GDP_r2	4 364 956	4 736 645	5 150 153	5 216 977	5 880 223	6 515 472	6 279 144
GDP_R	20 084 623	21 663 322	23 789 185	23 337 625	25 407 359	26 792 704	26 616 399
GDP growth rate (in relation to previous year)							
GDP_r1		7,7%	10,1%	-2,8%	7,8%	3,8%	0,3%
GDP_r2		8,5%	8,7%	1,3%	12,7%	10,8%	-3,6%
GDP_R		7,9%	9,8%	-1,9%	8,9%	5,5%	-0,7%
GDP growth (2017=100)							
GDP_r1	100	107,7%	118,6%	115,3%	124,2%	129,0%	129,4%
GDP_r2	100	108,5%	118,0%	119,5%	134,7%	149,3%	143,9%
GDP_R	100	107,9%	118,4%	116,2%	126,5%	133,4%	132,5%
GDP distribution (share) change (%)							
GDP_r1	100	99,8%	100,1%	99,2%	98,2%	96,7%	97,6%
GDP_r2	100	100,6%	99,6%	102,9%	106,5%	111,9%	108,6%
GDP_R	100	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%

Source: Author's compilation based on HCSO data

Table 38 Formulas

A	B	C	D	E	F	G	H
Év	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
CPI							
Previous year=100	102,4	102,8	103,4	103,3	105,1	114,5	117,6
2020= 100	=C4/(C3/100)	=D4/(D3/100)	=E4/(E3/100)	100	=+F3/100*E4	=+G3/100*F4	=+H3/100*G4
GDP (purchaser's prices, million HUF)							
GDP_r1	14316253	15847139	18043594	18120648	20523020	24401520	28781131
GDP_r2	3975263	4434554	4985627	5216977	6180114	7840686	8886198
GDP_R	18291516	20281693	23029221	23337625	26703134	32242206	37667329
GDP distribution (%)							
GDP_r1	=B8/B$10	=C8/C$10	=D8/D$10	=E8/E$10	=F8/F$10	=G8/G$10	=H8/H$10
GDP_r2	=B9/B$10	=C9/C$10	=D9/D$10	=E9/E$10	=F9/F$10	=G9/G$10	=H9/H$10
GDP_R	=B10/B$10	=C10/C$10	=D10/D$10	=E10/E$10	=F10/F$10	=G10/G$10	=H10/H$10
GDP (2020 prices)							
GDP_r1	=B8/(B$4/100)	=C8/(C$4/100)	=D8/(D$4/100)	=E8/(E$4/100)	=F8/(F$4/100)	=G8/(G$4/100)	=H8/(H$4/100)
GDP_r2	=B9/(B$4/100)	=C9/(C$4/100)	=D9/(D$4/100)	=E9/(E$4/100)	=F9/(F$4/100)	=G9/(G$4/100)	=H9/(H$4/100)
GDP_R	=B10/(B$4/100)	=C10/(C$4/100)	=D10/(D$4/100)	=E10/(E$4/100)	=F10/(F$4/100)	=G10/(G$4/100)	=H10/(H$4/100)
GDP growth rate (in relation to previous year)							
GDP_r1		=(C18/B18)-1	=(D18/C18)-1	=(E18/D18)-1	=(F18/E18)-1	=(G18/F18)-1	=(H18/G18)-1
GDP_r2		=(C19/B19)-1	=(D19/C19)-1	=(E19/D19)-1	=(F19/E19)-1	=(G19/F19)-1	=(H19/G19)-1
GDP_R		=(C20/B20)-1	=(D20/C20)-1	=(E20/D20)-1	=(F20/E20)-1	=(G20/F20)-1	=(H20/G20)-1
GDP growth (2017=100)							
GDP_r1	100	=C18/$B18	=D18/$B18	=E18/$B18	=F18/$B18	=G18/$B18	=H18/$B18
GDP_r2	100	=C19/$B19	=D19/$B19	=E19/$B19	=F19/$B19	=G19/$B19	=H19/$B19
GDP_R	100	=C20/$B20	=D20/$B20	=E20/$B20	=F20/$B20	=G20/$B20	=H20/$B20
GDP distribution (share) change (%)							
GDP_r1	100	=C13/$B13	=D13/$B13	=E13/$B13	=F13/$B13	=G13/$B13	=H13/$B13
GDP_r2	100	=C14/$B14	=D14/$B14	=E14/$B14	=F14/$B14	=G14/$B14	=H14/$B14
GDP_R	100	=C15/$B15	=D15/$B15	=E15/$B15	=F15/$B15	=G15/$B15	=H15/$B15

Evaluation

The GDP of county r2 grows faster within the region in the observation period, therefore, there is a slight structural change reflected in the % distribution.
More information: F. Dorin, D. Perrotti and P. Goldszier, 2020. and O'Neill, R. 2015.

6.5.Convergence indices

One of the central objectives of the regional cohesion policy of the European Union is to decrease the differences between its territorial units. The σ-convergence and the β-convergence indicators are the most frequently referred indicators for the evaluation of the process.

6.5.1. σ- convergence

Calculate the standard deviation (σ) of data (e.g. GDP/capita) in each territorial unit for selected periods (years), and look at their changes:

$$\sigma_{t1} / \sigma_{t0}$$

Where σ_{t1} and σ_{t0} is the standard deviation in t1 and t0 period respectively

Evaluation

- $\sigma_{t1} / \sigma_{t0}$ > 1 there is divergence in the time series of data, consequently, inequalities are growing,
- $\sigma_{t1} / \sigma_{t0}$ < 1 there is convergence in the time series of data, therefore, inequalities are decreasing,
- $\sigma_{t1} / \sigma_{t0}$ ~ 1 there is no change in the scale of differences in the data of the time series, therefore inequalities are stabilised.

However, the standard deviation depends on the magnitude of observations. Therefore, comparing different territorial units with highly different magnitudes of data the decreasing σ values do not necessarily sign the convergence of the regions. For two territorial units an opportunity is the evaluation of growth rates in relation to the original share of their volumes. If the rate is higher than the original share of the values of the two regions, then the convergence occurs. Another opportunity is the use of the relative standard deviation, that is independent of the magnitudes, but it is not considered officially a convergence indicator.

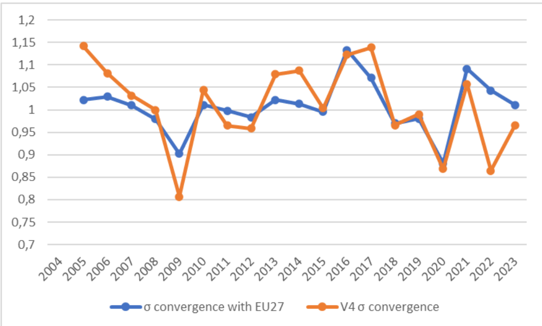


Figure 18. The σ- convergence of V4 countries between 2004 and 2023
Source: Author's compilation

Values
- above 1 indicate divergence,
- below 1 indicate convergence

6.5.2. β-convergence

Unconditional beta convergence is observed when the growth rate of the investigated variable (GDP/capita) in territorial units is negatively related to the starting levels of the variable (GDP/capita) regardless of structural characteristics. This type of convergence implies that poorer economies eventually catch up with richer ones, by growing faster. Hence the parameter β in equation (1) is expected to be negative and statistically different from zero.

$$\frac{1}{T} LN\left(\frac{Y_{it1}}{Y_{it0}}\right) = \propto + \beta * LN(Y_{it0}) + \epsilon_i \qquad (1)$$

where

Y_{it0} and Y_{it1} are values of Y variable in *i* territorial unit in t=0 and t=1 period respectively

T is the number of periods between t=0 and t=1

β is the convergence coefficient

ϵ_i is the error term reflecting the random disturbance with mean zero and constant variance, uncorrelated with Y_{it-1}

Evaluation:

- If β < 0 and statistically significant → there is β-convergence.
- This implies that poorer regions grow faster than richer ones, supporting convergence.

Conditional β-Convergence accounts for heterogeneity in steady-state incomes across economies due to different structural characteristics (like education, investment, policy, etc.).

$$\frac{1}{T} LN\left(\frac{Y_{it1}}{Y_{it0}}\right) = \propto + \beta * LN(Y_{it0}) + \gamma_i * Z_i + \epsilon_i$$

Where

Z_i is the vector of control variables (e.g., human capital, savings rate, population growth)

Example

Is convergence between Visegrad counties considering their GDP/capita values (USD) between 2004 and 2023?

Table 39. Convergence of Visegrad counties between 2004-2023

Country, group of countries	**2004**	**2023**	**growth rate= 1/19*LN(2023/2004)**					
Czechia	21047	49 347	0,04485					
Poland	14326	46 412	0,06187					
Hungary	18581	43 567	0,04485					
Slovakia	16268	42 170	0,05013					
EU27_2020	27782	56 964	0,03779					
SUMMARY OUTPUT								

Regression Statistics								
Multiple R	0,88296							
R Square	0,77961							
Adjusted R Square	0,70615							
Standard Error	0,00485							
Observations	5,00000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	0,00025	0,000250137	10,61245	0,047214481			
Residual	3	7,07E-05	2,35702E-05					
Total	4	0,000321						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept (α)	**0,0775911**	0,00937	8,2809190	0,0036889	0,047772022	0,10741	0,047772	0,10741
2004 (β)	**-0,0000015**	4,65E-07	-3,2576755	0,0472145	-2,9948E-06	-3,5E-08	-3E-06	-3,5E-08
Speed of convergence=	7,97E-08	USD/year						

Source: Author's compilation

Evaluation
Though the rate is slow and statistical indicators reflect low probability particularly due to the small number of observations but based on the negative value of β parameter (-0,0000015) the GDP/capita values of Visegrad countries show convergence between 2004 and 2023.

Control questions
- What are the components of time series?
- What are the conditions of using time series for forecasting?
- Interpret the parameters of a linear equation!
- Interpret the parameters of an exponential equation!
- Interpret the parameters of a logistic curve!
- What is the difference between volume, value and price indices?
- How can you make comparable the value data of different periods and countries?
- What is the difference between conditional and unconditional β-convergence?
- What is σ-convergence, and how do you evaluate it?

7. Shift-Share Analysis

The shift-share analysis is used to shed light on components influencing changes of an indicator. The application needs minimum two dimensions of data - mostly territorial and sectoral data. It is used e.g. to enlighten the role of concentration of regional employment by industry and the growth rate of that industry in the competitive effect. Another application is the role local factors and sectoral structure in the growth of a macroeconomic indicator like GDP or GVA.

The components:
v_{ij0} – the value of i sector in j territorial unit during time t=0.

v_{ij1} – the value of i sector in j territorial unit during time t=0.

$V_{i0} = \sum_j v_{ij0}$ – the total value of i sector in all territorial units during time t=0.

$V_{i1} = \sum_j v_{ij1}$ – the total value of i sector in all territorial units during time t=1.

$V_{0j} = \sum_i v_{ij0}$ – the total value of all sectors in j territorial unit during time t=0.

$V_{1j} = \sum_i v_{ij1}$ – the total value of all sectors in j territorial unit during time t=1.

$V_{000} = \sum_i \sum_j v_{ij0}$ Total value of all sectors and all territorial units during time t=0.

$V_{001} = \sum_i \sum_j v_{ij1}$ Total value of all sectors and all territorial units during time t=1.

$r_{ij} = \frac{v_{ij1}}{v_{ijo}}$ the growth rate of i sector in j territorial unit.

$R_{00} = \frac{V_{001}}{V_{000}}$ the total growth rate of all sectors and territorial units.

$R_{i0} = \frac{V_{i1}}{V_{io}}$ the total growth rate of i sector in all territorial units – total sectoral growth rate

$R_{0j} = \frac{V_{1j}}{V_{0j}}$ the total growth rate of all sectors in j territorial unit. – total territorial growth rate

$S_{aj} = S_{vj} + S_{lj}$ the total shift is the sum of the sectoral and local shifts.

$S_{vj} = V_{i1} – (V_{i0} * R_{i0})$ the sectoral shift is the difference between the measured total sectoral value at t=1 time and the multiplication of the measured total sectoral value at t=0 time with the total sectoral growth rate. This is the difference between the measured sectoral value at the end of the period and the fictive sectoral value that were realised if the growth were equal to the total sectoral growth.

$S_{lj} = V_{1j} – (V_{0j} * R_{0j})$ the local shift is the difference between the measured total local value at time t=1 and the multiplication of the measured total local value with the total local growth rate. This is the difference between the measured total local value at the end of the period and the fictive local value that were realised if the growth were equal to the total local growth.
Saj = V001 – (V000 * R00) the total shift is the difference between the measured total value of all sectors and all territorial units during time t=1 and the multiplication of the measured total value of all sectors and territorial units at time t=0 with the total growth rate of all sectors and territorial units. This is the difference between the total measured sum of sectoral and local values at the end of the period and the fictive value that were attained if the growth were on the total growth rate of all sectors and territorial units.

There are 8 possible outcomes

Table 40. Possible combinations of total, local and sectoral shifts

Nr	Total	Local	Sectoral	Nr	Total	Local	Sectoral
1	+	+	+	5	-	+	+
2	+	+	-	6	-	+	-
3	+	-	+	7	-	-	+
4	+	-	-	8	-	-	-

Source: Authors editing

Each one of combinations has specific policy implications.

1. indicates the positive shifts in both components accompanied with positive total growth referring to further utilisation of available advantages but taking care of the danger of overutilisation.
2. The positive local shifts may compensate the negative shifts due to the problems in sectoral structure. Pay more attention to sectoral policy.
3. The positive shifts owing to favourite sectoral structure may compensate the negative local factors. Pay more attention to the modification or utilisation of local factors.
4. Against the negative shifts in both involved influencing factors the positive total shift indicates the importance of other, not considered factors.
5. Against the positive shifts in local and sectoral factors there are not considered factors (e.g. external factors) that hinder the total growth. It reflects sensibility to unconsidered influencing factors.
6. There is inconsistency between the favourite local shifts and the sectoral and other unconsidered factors. Look for harmonising the sectoral structure with local factors.
7. The favourite sectoral advantages are unable to create positive total shift owing to unfavourable or inconsistent local factors. Pay more attention to local policy.
8. All shifts result negative outcome, consequently radical changes are required to step forward.

Example

In the example data for Northern Transdanubia are selected at constant (2020) price level. Using the information of the linear trend (figure 13.) it seems that the level of 2004 was attained by 2022. However, the line of development indicates significant changes during this period. Shift-share analysis helps to enlighten the role of local and sectoral factors in attaining again the level of 2004. The territorial units are the counties of Northern Transdanubia Region. The sectoral structure is aggregated using the statistical classification of economic activities in the European Community (NACE Rev. 2). The starting year is 2004 and the last year is 2022 (Table 41).

Table 41. Sectoral structure of GVA production in counties of the Northern Transdanubia Region of Hungary (2004, 2022) (million Euro)

	TIME	2004										
		Total	Agr	Man	Const	Ret	Info	Fin	Sci	Pub	Art	Other
HU 12	Pest	12119.1	470.1823	2999.232	848.677	2578.232	757.0573	141.9207	957.4818	1594.566	216.6096	1555.145
HU 211	Fejér	5003.171	333.0578	1870.255	274.7405	656.7943	98.65303	83.07802	334.4305	744.8719	79.72236	527.5674
HU 212	Komárom-Esztergom	4197.321	195.6452	2089.577	194.3063	487.3504	55.24976	51.97884	191.8997	542.8713	50.14848	338.2946
HU 213	Veszprém	3456.279	196.4926	855.5748	227.1002	588.071	75.95995	70.46887	254.0472	706.9766	67.85891	413.7292

	TIME	2004										
HU 221	Győr-Moson-Sopron	6143.13	313.7034	2258.885	428.4399	920.7729	153.6316	132.9723	306.7718	843.9655	127.227	656.7604
HU 222	Vas	3215.434	195.8316	1181.853	177.0196	466.5724	54.9786	59.24944	173.9181	559.3276	81.34934	265.3344
HU 223	Zala	3268.108	200.1363	962.0746	194.2724	567.7337	70.53666	55.30061	198.4924	639.5245	86.51842	293.5186
HU 2	Northern Transdanubia	37402.55	1905.049	12217.45	2344.556	6265.526	1266.067	594.9688	2417.042	5632.103	709.4341	4050.35
	Hungary	121698.9	6187.516	26946.92	6496.135	21232.98	6148.349	4628.964	9698.621	22636.9	3476.413	14246.08
	TIME	2022										
		Total	Agr	Man	Const	Ret	Info	Fin	Sci	Pub	Art	Other
HU 12	Pest	14069.85	271.0083	3280.054	1326.763	3213.351	532.6015	117.5757	1435.264	1259.719	258.0117	2375.504
HU 211	Fejér	5303.737	236.0655	1712.231	399.9269	626.2532	150.9396	49.44345	360.3056	1135.762	97.65705	535.1526
HU 212	Komárom-Esztergom	3437.508	155.6596	1370.049	225.8361	524.0839	33.86253	34.16168	232.326	401.9212	55.65089	403.9571
HU 213	Veszprém	3325.068	148.9037	911.8203	251.7461	528.9951	49.54317	43.82601	275.0967	532.9422	80.70501	501.4895
HU 221	Győr-Moson-Sopron	6078.652	295.7383	2175.362	391.7749	909.934	101.7122	86.91244	404.0901	801.3163	130.1485	781.6635
HU 222	Vas	2568.375	159.4157	885.528	193.0621	348.7633	26.15101	38.12547	155.751	404.2064	70.65012	286.7221
HU 223	Zala	2358.411	156.5986	468.7821	198.2973	450.6168	37.94265	43.90911	148.5464	475.164	68.49787	310.0561
HU 2	Northern Transdanubia	37141.6	1423.39	10803.83	2987.406	6601.997	932.7528	413.9539	3011.38	5011.031	761.3211	5194.545
	Hungary	119323.1	4543.072	24145.35	7561.399	20655.67	6004.903	4385.102	12123.74	19907.25	3226.031	16770.58

Source: Authors compilation based on EUROSTAT data

The next step is to calculate the indices of change (growth rates) (*value of 2022/value of 2004*). For detailed analysis it worths to calculate the indices for each county and the total sectoral values by counties, as well as the total county and regional values by sectors. In the frame of the shift-share analysis the GVA data of 2004 and 2022 will be used to calculate shifts multiplying with total sectoral and total county and regional indices of change (Table 42.).

The indices of sectoral changes reflect great variability in the counties. Pest and Fejér seems the most dynamic in most sectors. At regional level the most dynamic sectors were the construction, the sectors aggregated in others, the science, the arts and the retailing sectors. The GVA value of all other sectors has decreased. Surprisingly, the greatest decrease is in finance.

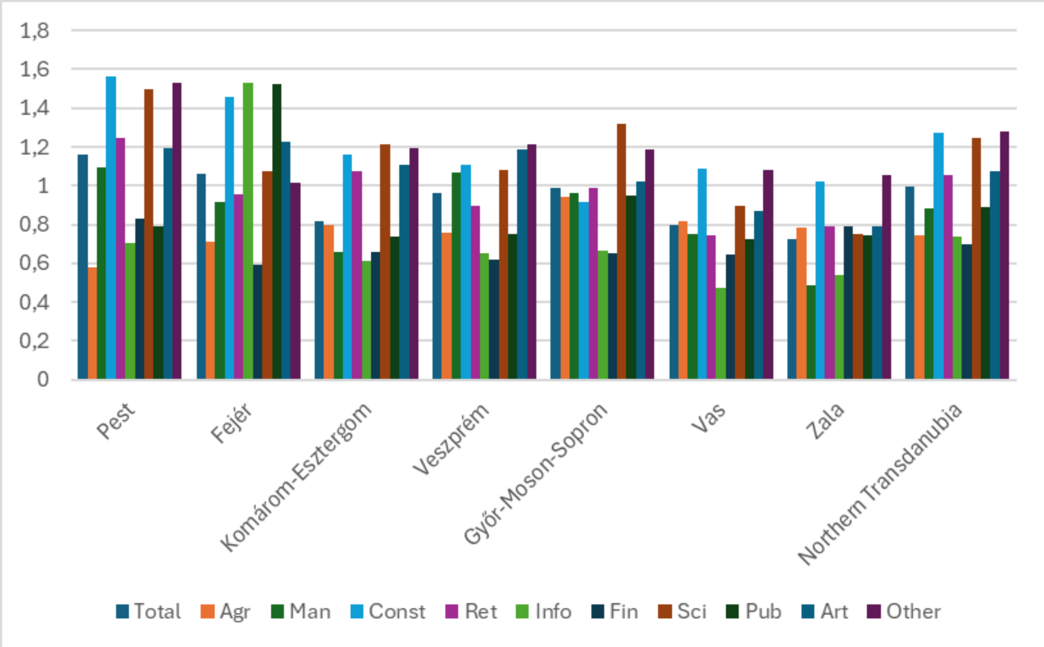


Figure 19. Changes of GVA by economic sectors in Transdanubian counties (2022/2004)

Source: Author's edition

Table 42. Indices of GVA change by counties of Northern Transdanubia Region

	2022/2004										
TIME	Total	Agr	Man	Const	Ret	Info	Fin	Sci	Pub	Art	Other
Pest	1,160 965	0,576 39	1,093 631	1,563 331	1,246 339	0,703 515	0,828 46	1,498 999	0,790 008	1,191 137	1,527 513
Fejér	1,060 075	0,708 782	0,915 506	1,455 653	0,953 5	1,530 005	0,595 145	1,077 371	1,524 775	1,224 964	1,014 378
Komárom-Esztergom	0,818 977	0,795 622	0,655 659	1,162 268	1,075 374	0,612 899	0,657 223	1,210 664	0,740 362	1,109 722	1,194 099
Veszprém	0,962 037	0,757 808	1,065 74	1,108 524	0,899 543	0,652 227	0,621 92	1,082 857	0,753 833	1,189 306	1,212 12
Győr-Moson-Sopron	0,989 504	0,942 732	0,963 025	0,914 422	0,988 228	0,662 053	0,653 613	1,317 234	0,949 466	1,022 963	1,190 181
Vas	0,798 765	0,814 045	0,749 271	1,090 626	0,747 501	0,475 658	0,643 474	0,895 542	0,722 665	0,868 478	1,080 607
Zala	0,721 644	0,782 46	0,487 262	1,020 718	0,793 712	0,537 914	0,794 008	0,748 373	0,742 996	0,791 714	1,056 342
Northern Transdanubia	0,993 023	0,747 167	0,884 295	1,274 189	1,053 702	0,736 733	0,695 757	1,245 895	0,889 726	1,073 139	1,282 493

Source: Author's edition

The local shifts are calculated by *taking the sum of differences between the county value of 2024 and the calculated fictive sectoral growth* (county value of 2004 multiplied with the regional level growth rate of the relevant sector).

The total shifts are calculated by *taking the difference between the total value of county GVA and the calculated fictive total value county GVA* (multiplying the county total value of GVA in 2004 with the total regional change).

The sectoral shifts are the differences between the total shifts and the local shifts.

Table 43. The GVA shifts of North Transdanubian counties and their character (2022/2004)

		Total shifts	Structural shifts	Local shifts	Character (Structural/Local)	
	TIME	Stj	Spj	Skj	N-Transdanubian relation	Hungarian relation
HU12	Pest	2035,30	262,07	1773,23	+/+	+/+
HU211	Fejér	335,47	-51,39	386,86	-/+	-/+
HU212	Komárom-Esztergom	-730,53	-126,31	-604,22	-/-	-/-
HU213	Veszprém	-107,10	34,20	-141,30	+/-	-/-
HU221	Győr-Moson-Sopron	-21,62	-34,60	12,98	-/+	-/+
HU222	Vas	-624,63	-60,74	-563,88	-/-	-/-
HU223	Zala	-886,90	-23,23	-863,67	-/-	-/-
	Northern Hungary	0,00	0,00	0,00		

Formulas

	Total shifts	Structural shifts	Local shifts	Character (Structural/Local)	
TIME	Stj	Spj	Skj	N-Transdanubian relation	Hungarian relation
Pest	=+'GVA 2020price'!N6-('GVA 2020price'!C6*Changes!$C$14)	=+C7-E7	1773,22	+/+	+/+
Fejér	=+'GVA 2020price'!N7-('GVA 2020price'!C7*Changes!$C$14)	=+C8-E8	386,85	-/+	-/+
Komárom-Esztergom	=+'GVA 2020price'!N8-('GVA 2020price'!C8*Changes!$C$14)	=+C9-E9	-604,21	-/-	-/-
Veszprém	=+'GVA 2020price'!N9-('GVA 2020price'!C9*Changes!$C$14)	=+C10-E10	-141,29	+/-	-/-
Győr-Moson-Sopron	=+'GVA 2020price'!N10-('GVA 2020price'!C10*Changes!$C$14)	=+C11-E11	12,98	-/+	-/+
Vas	=+'GVA 2020price'!N11-('GVA 2020price'!C11*Changes!$C$14)	=+C12-E12	-563,88	-/-	-/-
Zala	=+'GVA 2020price'!N12-('GVA 2020price'!C12*Changes!$C$14)	=+C13-E13	-863,67	-/-	-/-
Northern Hungary	=SUM(C7:C13)	=+C14-E14	=SUM(E7:E13)		

Source: Author's design

The impact of sectoral and local shifts is visually presented on figures 20. and 21. The column diagram shows the total, the sectoral and the local shifts by counties. The scatter diagram shows the places of individual counties in the space of local and sectoral shifts.

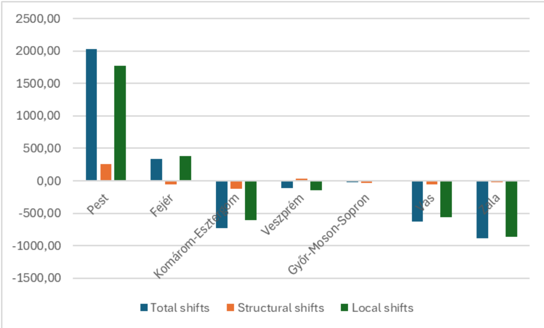


Figure 20. The role of structural and local factors in GVA shifts in Transdanubian counties (2004-2022)

Source: Author's edition

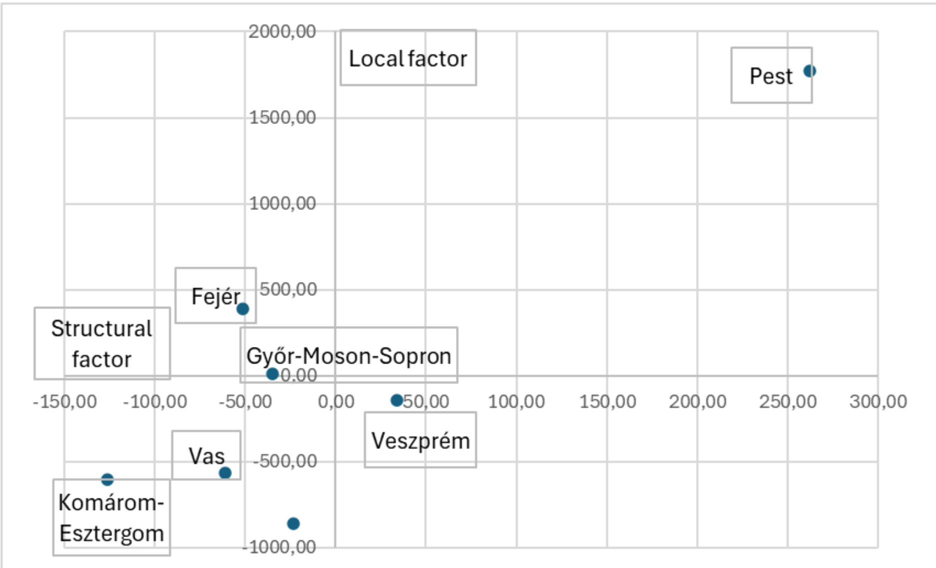


Figure 21. The shift diagram of structural and local factors in GVA changes in Transdanubian counties (2004-2022)

Source: Author's edition

Evaluation

Only the development of Pest County had been promoted both by the sectoral changes and the local changes. It has the most favourite position considering both influencing factors. The local factor has positive contribution to changes in Fejér and Győr-Moson-Sopron counties. The sectoral factor has positive impact only in Veszprém County. The contribution of arts is among the highest probably in connection of activities connected to the cultural capital of Europe developments. Both sectoral and local shifts are negative for Komárom-Esztergom, Vas and Zala counties. Vas and Zala counties are least developed peripheric counties in the region. The location of Komárom-Esztergom County on the axis of Budapest Vienna near Budapest seems to be favourable but the inner parts are less connected in a hilly area. In addition, the sectoral structure of the county was hit by crisis but the dynamic sectors in the indices of change were unable to compensate the losses in GVA. Their further analysis is highly advised.

8. Regression analysis in territorial research

Regression analysis serves as a fundamental statistical tool to quantify relationships between spatial phenomena. It is a technique of studying the dependence of one variable (called *dependant variable or* explained variable, predictand, response and endogenous variable), on one or more independent variables (called *explanatory variable*(s), regressor and exogenous variable(s)), with a view to estimate or predict the average value of the dependent variable in terms of the known or fixed values of the independent variable(s). The aim may be the estimation of the relationship between the dependant and explanatory variables, the estimation of the effect of the independent variables, or the estimation on the future of the dependent variable due to changes in the influencing variables.

In regression analysis, the data used to describe the relationship between the variables are primarily measured on interval scale. The chief advantage of using the interval level of measurement is that such data make it possible to describe the relationship between variables more exactly through employing mathematical equation. This in turn allows more accurate prediction of one variable from the knowledge of the other variables, which is one of the most important objectives of regression analysis.

Types of regression analysis:

- Based on the number of explanatory variables
  - Simple regression model consisting of one dependent(Y) and one independent (X) variable
  - Multiple regression model, consisting of one dependent and two or more explanatory variables
- Based on the type of equation
  - Linear model
  - Non-linear model

Example for simple *linear model equation*

$$Y = \propto + \beta X$$

Where

α - parameter has mathematical interpretation

β – parameter is the *regression coefficient,* and it means that one unit change of the explanatory variable causes β unit change in the dependent variable.

Example for multiple non-linear *exponent model equation*:

$$Y = \propto * X_1^{\beta_1} * X_2^{\beta_2}$$

They should be transformed for using least squares estimation method to estimate the parameters

$$LN(Y) = LN(\propto) + \beta_1 LN(X_1) + \beta_2 LN(X_2)$$

Where
α - parameter has mathematical interpretation
β_1 – parameter is the regression coefficient of X_1 variable. Its interpretation is that one percent relative change of X_1 variable causes β_1 percent change in the dependent (Y) variable on the condition that there is no change in the other variables.
β_2 – parameter is the regression coefficient of X_2 variable. Its interpretation is that one percent relative change of X_2 variable causes β_2 percent change in the dependent (Y) variable on the condition that there is no change in the other variables.

β_1 and β_2 parameters in this type of equation are **elasticity coefficients** reflecting the responsiveness of the dependent variable to changes of independent variables.

Assumptions of the linear regression:

1. Linear Functional form
2. Fixed independent variables
3. Independent observations
4. Representative sample and proper specification of the model (no omitted variables)
5. Normality of the residuals or errors
6. Equality of variance of the errors (homogeneity of residual variance)
7. No multicollinearity
8. No autocorrelation of the errors
9. No outlier distortion

Variable selection procedures:

- *Forward Selection* starts with no independent variables, than adding variables one at a time as long as a significant reduction in the error sum of squares (SSE) can be achieved.
- *Backward Elimination* begins with a model that includes all the independent variables the modeler wants considered. It then attempts to delete one variable at a time by determining whether the least significant variable currently in the model can be removed because its p-value is less than the user-specified or default value. Once a variable has been removed from the model it cannot re-enter at a subsequent step.
- *Stepwise Regression*, where predictor variables are entered into the regression equation one at a time based upon statistical criteria. At each step in the analysis the predictor variable that contributes the most to the prediction equation in terms of increasing the multiple correlation (R), is entered first. This process is continued only if additional variables add anything statistically to the regression equation.
- *Iterative;* one independent variable at a time is added or deleted Based on the F statistic
- F Test - To test whether the addition of x2 to a model involving x1 (or the deletion of x2 from a model involving x1and x2) is statistically significant
- The p-value corresponding to the F statistic is the criterion used to determine if a variable should be added or deleted

Regression models are frequently applied to estimate infrastructure demand and population growth, analysing parallel development paths in urban planning (Batty, 2009). Land use studies benefit from regression when analysing agricultural expansion and environmental degradation. Socioeconomic inequality can be assessed by correlating spatial attributes with income and education (Rey & Janikas, 2005). Transportation models predict travel time or accessibility based on urban form and transport networks. In risk analysis, regression estimates exposure to hazards like floods or landslides based on physical geography and population density.

9. Key concepts of Network Analysis

Networks may comprise roads, railways, airlines, telephone links, social relations etc. Whatever form of network can be transformed into **graphs** and can be portrayed as a **connectivity matrix**.

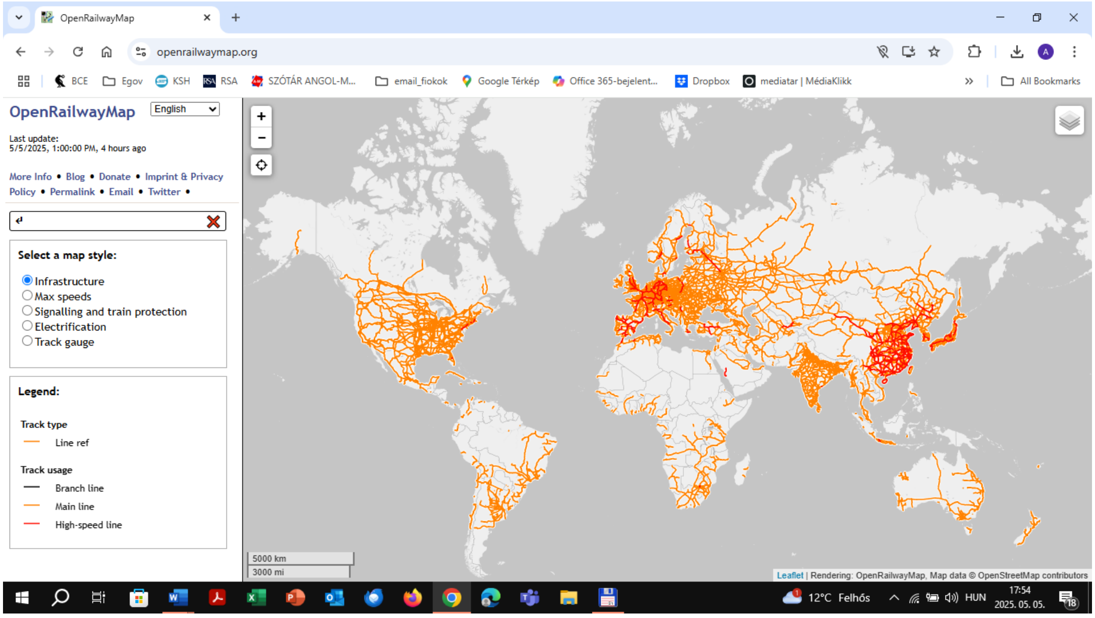


Figure 22. Global railway network

Source: Openrailwaymap

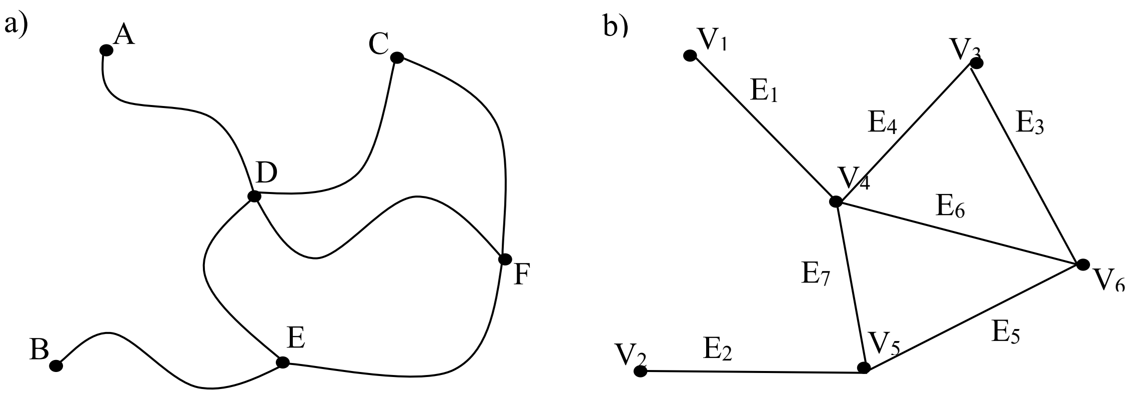


Figure 23. Conversion of a network (a) into a graph (b)

Source: Author's edition

Any ordinary graph representing a network will consist of the following elements:

1. Vertex (V) – the point where more than one route meet (**crossing**) or a road terminates (**terminus**) - nodes
2. Edge (E) – the route (line) joining two vertices
3. Sub-Graph (ρ) – the number of subsidiary graphs
4. Circuits – is a path starting from a particular Vertex, and comes back to the same Vertex without crossing any of the edges more than once

The elements of a connectivity matrix (a_{ij}) are either 0 or 1 depending on the direct connection between i and j Vertexes. The value a_{ij}=0 means that there is no direct connection (no direct road) between i and j vertexes. The value a_{ij}=1 means that there is direct connection (direct road) between i and j vertexes.

Table 44. Connectivity matrix of 23/b graph

Vertex	V_1	V_2	V_3	V_4	V_5	V_6
V_1	0	0	0	1	0	0
V_2	0	0	0	0	1	0
V_3	0	0	0	1	0	1
V_4	1	0	1	0	1	1
V_5	0	1	0	1	0	1
V_6	0	0	1	1	1	0

Source: Autor's edition

Note that all the diagonal elements (a_{11}, a_{22}, a_{33}...) are zero as a place does not require a connection to itself!

9.1.Topological measures of graphs

1) **Cyclometric number (μ)** indicates the number of circuits in a network:

$$\boldsymbol{\mu = E\text{-}V+\rho}$$

In our example E=7; V=6; ρ=1 (we have only one graph), therefore

$$\mu = 7-6+1=2$$

2) **Alpha index (α)** is the ratio of factual number of circuits and the maximum number of possible circuits in the network.

$$\boldsymbol{\alpha = \frac{E-V+1}{[(V^2-V)-(V-1)]^{1/2}}}$$

In our example b)

$$\alpha = \frac{7-6+1}{[(6*6-6) - (6-1)]^{1/2}} = 0.2$$

3) **Beta index (β)** is the ratio of edges to vertex

$$\boldsymbol{\beta = E/V}$$

Where
β = 1 – network with only one circuit
β < 1 – disconnected graphs; or trees with several branches but no circuits
β > 1 – complex networks with greater number of edges than vertices

In our example b): β =7/6=1.17

4) **Gamma index (γ)** is the actual number of edges (routes) to the maximum possible number of route connections or edges. It varies between 0 (no connection) and 1 (all possible connection $[(V^2-V)/2]$ is present), and reflects the connectivity of the graph.

$$\gamma = E/(V^2-V)/2]$$

In our example b): $\gamma = 7/[(6^2-6)/2] = 0.467$; i.e. we have only 46.7% of possible routes in our network

5) **Eta index (ή)** is the average length of edges.

$$ή = m/E;$$

where m is the total length of existing edges (e.g. km/edge)

Higher eta index indicates lower development of transport network and vice versa.

6) **Theta index (Θ)** is the average length of edges per vertex (V) (e.g. km/vertex)

$$\Theta = m/V\ ;$$

where m is the total length of existing edges (e.g. km)

The index takes care of length, structure and also the degree of connectivity simultaneously. The higher the eta index the worth is the connectedness of the road network.

7) **Road density (Dn)** is the length of road per unit area (e.g. km/km^2)

$$Dn=m/T;$$

where m is the total length of existing edges (e.g. km);
T is the size of the territorial unit (e.g. km^2)

8) **Centrality (Centr) index** is the ratio of the actual number of connections (Ev) of a vertex to the maximum possible number of its connections $\mathbf{[(V^2-V)/V]}$.

$$Centr = Ev/[(V^2-V)/V]$$

E.g. the centrality of V_4 in our example is $CentrV_4= 4/[(6^2-6)/6] = 4/5=0.8$ that is 80% of possible connections are available from V_4. At the same time the centrality of V_2 is $CentrV_2=1/5=0.2$ i.e. only 20% of connections are available.

Those networks are centralised in which one or several vertices have extremely high centrality value. In case of a decentralised network the centrality values are balanced / more-or less equal.

9) **Flow matrix** portrays the magnitude and the direction of flows between vertices (from – the origin of flow by rows; to – the destination of flows by columns).

10) **Network quotient** is the ratio of ETA indices (ή) calculated on the basis of two types of distances (e.g. railway and air – or road – network distances).

GRAPH Definitions

1) empty graph – no edges
2) circle – closed line of vertices and edges
3) full graph – Each pair of vertices are connected directly by one edge
4) line graph or chain – non-closing line of vertices and edges
5) connected graph – each vertex is connected to at least one other vertex.

Control questions

- What kind of relations are the outcomes of shift-share analysis and what may be their political interpretations?
- How to select variables for regression analysis?
- What is the relationship between graphs and matrices?
- What are the components of graphs?
- Which networks are centralised?
- What is indicated by the cyclometric number of a network?

10. Participatory and qualitative methods

Participatory and qualitative methods bring in local knowledge, values, and experiences that are crucial for understanding territorial state of affairs and dynamics in social and cultural terms, and contribute to the elaboration of objectives for changes, as well as may create motivation to the realisation of intended changes. Participatory mapping, for example, involves community members in the mapping process, allowing for the inclusion of non-official data or place-based meanings that are often overlooked in formal analyses. Furthermore, the involvement of professional experts and competent decision-makers promotes the foundation of innovative, future oriented, realisable proposals.

Techniques such as focus groups, interviews, and stakeholder workshops are used to gather qualitative insights into territorial issues, such as land-use conflicts, perceptions of development, or cultural heritage. These methods are especially valuable in planning contexts where local buy-in and legitimacy are important.

While these methods enhance the depth and inclusivity of territorial analysis, they are time-consuming and sometimes difficult to integrate with quantitative findings. Additionally, participatory methods may be influenced by power dynamics, requiring careful facilitation and ethical considerations.

Qualitative research is an exploratory investigation of a complex social phenomenon conducted in a natural setting through observation, description, and thematic analysis of participants' behaviours and perspectives for the purpose of explaining and/or understanding the phenomenon.

Qualitative studies usually use *nonprobability sampling*, also called *purposive sampling* to identify those who can provide data for the study. Critical issues in this process:

- Clear *definition of research objectives*
- establishing *criteria for choosing study participants* and
- describing a *strategy for determining that selected participants meet the established criteria*.

The researcher may play different roles depending on its involvement into the targeted group or population:

(1) Complete participant
(2) Participant – Observer
(3) Observer – Participant
(4) Complete Observer

Successful participatory research has to meet several selection criteria:

- Define *terms for selection* based on the purpose of research.
- *Eligibility criteria*. Look closely at the research question and then identify the characteristics needed of study participants to answer that research question.
- *Feasibility* requires that there is a sufficient number of people meeting your participant criteria available to you and that you truly can access them.
- Qualitative *sampling is based on relevance*, rather than representativeness.
- *Relevant professional knowledge / experience / competence* level.
- Sensibility to changes / future.
- Decision on the *structure of panel members*
    - Homogeneous panel
    - Heterogeneous panel
    - Avoid possibility of dominance
- *Readiness to participate*

Table 45. Summary of Qualitative Research Design Specifications

Qualitative Design	Major Purpose	Unit of Analysis	Primary Data Collection
Case study	Describe behaviour of a bounded unit in relation to a phenomenon	Bounded unit	Multiple sources
Ethnography	Describe behaviour of a cultural group in relation to a phenomenon	Cultural group	Immersion in culture for an extended time period; multiple sources
Phenomenology	Describe themes and patterns of lived experiences across individuals in relation to a phenomenon	Individuals sharing a common experience	Interviews
Narrative	Describe individual stories in relation to a phenomenon	Individuals	Interviews
Grounded theory	Develop theory	Unspecified	Interviews

Source: Burkholder et al. 2019, 88.

See further details in Burkholder et al. 2019.

Great variety of methods have been elaborated for participative and qualitative research. In this short insight only some of the most frequently used are summarised.

10.1. Interviewing

In qualitative research, the interview method is a technique used to gather in-depth, detailed information from participants about their experiences, thoughts, beliefs, and feelings. It is a flexible, conversational approach that allows the researcher to explore complex issues that cannot be captured through structured surveys or quantitative methods. It is advised to use when the research question involves understanding meaning, experience, or perspective, also in exploratory research where little is known about the topic, and when studying sensitive or personal issues.

Types of Interviews in Qualitative Research:

1. Structured Interviews
    a. Use a fixed set of questions.
    b. Minimal deviation from the script.
    c. Rare in qualitative research; more common in quantitative studies.
2. Semi-Structured Interviews
    a. Use a guide with key questions or topics.
    b. Allows flexibility to explore new ideas that emerge during the conversation.
    c. Commonly used in qualitative research.
3. Unstructured (or In-Depth) Interviews
    a. Open-ended and conversational.
    b. No fixed questions—just a broad topic or theme.
    c. Useful for exploring complex or deeply personal issues.
4. Focus Group Interviews
    a. A group discussion guided by a moderator.
    b. Useful for exploring social norms, group dynamics, or community views.
5. Key Features
    a. Open-ended questions: Encourage participants to express themselves freely.
    b. Participant-centred: Focuses on the participant's perspective and experience.
    c. Flexible and adaptive: The interviewer can probe or follow up on interesting topics.
    d. Rich, narrative data: Results in detailed descriptions rather than numerical data.
6. Advantages
    a. Provides deep insights into human behaviour, motivation, and context.
    b. Captures emotions, tone, and non-verbal cues.
    c. Can uncover unexpected findings.
7. Disadvantages
    a. Time-consuming to conduct and analyse.
    b. Requires skilled interviewers.
    c. May introduce bias through interviewer influence.

Preparing for an interview requires knowledge about the theme, the habit, the attitude to the topic, the experiences, relations of the interviewee. Also advised to prepare a detailed preliminary interview protocol (see a sample in table 46).

Table 46. Sample interview protocol

INTERVIEW PROTOCOL

Date of interview:

Location of interview:

Start time: End time:

Name of interviewee:

Name of interviewer:

Recording mechanism:

Introduction:

Thank you for taking your time to meet with me today. As you know, this interview will contribute information for a research study intended to [state purpose of the study]. You have signed an informed consent form, but, as a reminder, you may decline to answer any question you do not wish to answer or withdraw from the interview at any time. This interview will take approximately [X] minutes. With your permission, I will be making an audio recording of the interview and may take notes. Do you have any questions before we begin?

Interview Questions	Interviewee Responses	Interviewer Observations/Reactions
1. [List the interview questions, one per row.]	[Do not notate verbatim response, but notate some thoughts that jump out at you.]	[Notate observations, such as "The interviewee has drawn back in her chair and crossed her arms," and personal reactions, such as "I'm wondering if my question has offended or challenged her."]
2.		
3.		
Etc.		

Potential probes:

- Please tell me more about . . .
- How did you know . . . ?
- What kind . . . ?
- What was the best approach among those you named?

Conclusion:

Thank you for your time today. I very much appreciate your contributing to this study. [State the next steps, such as member checking.] May I contact you if I need any clarifications?

Source: Burkholder et al. 2020, 151.

Interviews are frequently used in situation when representative sampling is not possible, or it would be too expensive. Therefore, particular attention must be paid to avoid pitfalls either in the preliminary preparation phase or during the interview or in the final evaluation phase. Several pitfalls, their reason that why are they problems, and suggestions to avoid them are listed by Burkholder et al. 2020, cited in table 45. Useful practical information is available in other referred literature, too, like Creswell 2018, Patton 2015.

Table 47. Interviewing Pitfalls and Potential Solutions

Interviewing Pitfall	Why Problematic	Ways to Avoid This Pitfall
Rushing the informed consent/explanation of steps process	Interviewees feel confused and pressured to complete the interview	Carefully plan the informed consent process. Be sure to present information in a calm and relaxed way. Be sure it is clear to interviewees that it is their choice to participate and they can withdraw at any time.
Rushing the interview	Limited data lacking rich information to answer the research questions	Continue the calm, relaxed, and pleasant approach. Because many people tend to talk quickly, overtly trying to slow down a bit can be helpful.
Too many facial expressions/reactions	May close responses or influence the nature of responses	Find a comfortable, neutral facial expression and maintain it. If you tend to be naturally facially expressive, practice managing that in practice interviews. You want to be very careful not to express surprise, agreement, pleasure, or offense in reaction to the interviewee.
Frequent nodding	May influence the nature of responses as it indicates agreement	Limit nodding.
Lack of probes and follow-up questions	Limits the richness of data	Plan possible probes and use them to urge a participant to expand or more directly answer the question.
Only hearing and documenting part of the responses	Affects the integrity and validity of data	Audiotape or document verbatim. Listen to transcripts following the interview and/or review the notes.
Being unprepared for emotional responses	Unethical to have participants feeling vulnerable without follow-up or support	Have references available for counseling for emotionally laden interviews.
Too connected to the interviewee	Interviewees could be eager to please, and this can affect the integrity and truth of data	It is best not to interview people you are connected to in some way.
No rapport with the interviewee; being distant or robotic	Can limit responses	Make sure you are natural, with normal eye contact and responses, so the interviewee is comfortable.
Ordering of questions not well planned	If more intrusive questions are asked first, can limit responses	Start with more innocuous questions—such as demographic, factual-type questions—and build to the deeper questions.
Questions include presuppositions	Can be leading and influence the integrity of data	Use a direct preface. For example, instead of "How has this changed your life?" first ask, "Has this had an impact on your life?" Then ask, "How?"
Inappropriate use of "why" questions	Can be leading because there may not be a known "why"; "why" questions can lead to defensiveness	Make sure that the interviewee is likely to have an explanation of why. For example, with children, why questions are often confusing. Reword the question to avoid the use of "why."
Incompletely transcribing interviews	Makes data invalid and biased	Use software to slow down recording and transcribe completely. Consider hiring a transcriptionist.
Not audio recording interviews or documenting verbatim	If verbatim information is not available, can cause data to be limited and invalid	Audio record interviews, and be prepared to document verbatim on site if the interviewee refuses to be audiotaped.
Issues of power not considered	If the interviewee perceives the interviewer as a person of "power," can influence or limit what is reported	When meeting with the site contact, be sure to describe your role and background. Inquire as to whether the site contact foresees any issues.

Interviewing Pitfall	Why Problematic	Ways to Avoid This Pitfall
		This information helps in protocol preparation and planning the data collection process.
Issues of culture not considered	Every environment has a culture, and specific people have cultures. If this is not considered, the researcher can intrude or offend unintentionally and limit the nature of the data reported.	The interviewer needs to gather information from the site on cultural considerations for both the environment and the people interviewed. Special consideration for ethnic norms should be made (e.g., eye contact, appropriateness of shaking hands).

Source: Burkholder et al. 2020, 155.

10.2. Brainstorming

Brainstorming is a group creativity technique designed to generate a large number of ideas for the solution to a problem. For increased efficiency small number (maximum10) of participants are preferred in one group. The discussion should be intensive and short (preferably maximum 15 minutes – Philips 6x6 e.g. takes 6 minutes per group).

The process starts with clear articulation of the problem or challenge. This is followed by the selection of participants, where the preferred principle is to convene a differentiated, inhomogeneous group. At the beginning of the session emphasize the need for open-mindedness, defer judgment, and encourage wild ideas. The contribution of each participant is free; they are expected to raise any (even wilde) ideas that comes into their mind. They may raise new ideas or continue or build upon other's ideas. However, new ideas are preferred. All ideas are recorded without evaluation.

After the session combine and improve the raised ideas, review and assess them for feasibility. Choose the most viable ideas for implementation or further development.

Advantages of brainstorming: It helps to generate a wide range of new ideas, encourages, creativity, promotes collaboration, inclusive participation, enhances communication, contributes to team cohesion.

Disadvantages of brainstorming: Sitting in a small group there may be pressure to conform and suppress unique, controversial ideas. Hierarchical relation of members or assertive participants can overshadow quieter members. Not all members may contribute equally or feel valued. Without strong facilitation the discussion may be diverted, losing the focus or the discussion runs out of time, losing ideas. (See Osborn 1979, Paulus Brown 2003

10.3. Focus group

A focus group is a qualitative research method where a small group of people (typically 6–10 participants) are guided through a discussion by a trained moderator to gain insights into their perceptions, opinions, beliefs, and attitudes about a product, service, concept, or idea.

Steps to Conduct a Focus Group:

1. Define the Objective:
    - Clearly determine what you want to learn from the group.
    - Develop research questions or key topics for discussion.
2. Select Participants:
    - Choose a diverse or targeted sample depending on the research goal.

    - Participants should share relevant characteristics (e.g., age group, occupation, user type) based on the research purpose.
3. Recruit Participants:
    - Use invitations, ads, social media, or databases.
    - Offer incentives (e.g., gift cards, refreshments) to encourage participation.
4. Prepare Discussion Guide:
    - Create a semi-structured guide with open-ended questions.
    - Include warm-up questions, main discussion topics, and closing questions.
5. Choose a Moderator:
    - Use a skilled moderator to lead the discussion without bias.
    - The moderator should encourage participation and keep the group focused.
6. Set Up the Environment:
    - Use a quiet, comfortable setting with seating in a circle or around a table.
    - Record the session (audio/video) with participants' consent.
    - Provide name tags and notepads if necessary.
7. Conduct the Session:
    - Start with introductions and ground rules.
    - Follow the discussion guide but allow natural flow.
    - Ensure everyone has a chance to speak.
8. Record and Transcribe:
    - Audio or video recordings should be transcribed for analysis.
    - Take observational notes during the session.
9. Analyse the Data:
    - Identify key themes, patterns, and quotes.
    - Compare responses across different focus groups if multiple are conducted.
10. Report Findings:

- Summarize insights with supporting quotes.
- Highlight implications and recommendations for decision-making.

Advantages of Focus Groups:

- Rich, Detailed Data: Offers deep insight into participants' feelings, opinions, and motivations.
- Group Interaction: Participants can build on each other's ideas, leading to new insights.
- Quick Results: Compared to surveys or in-depth interviews, focus groups can be conducted and analysed more rapidly.
- Flexibility: Moderators can probe and clarify responses in real time.
- Cost-Effective: Less expensive than large-scale surveys or experimental methods, especially for exploratory research.

Disadvantages of Focus Groups:

- Limited Generalizability: Results are not statistically representative of a larger population.
- Groupthink Risk: Dominant voices may influence others, suppressing individual opinions.
- Moderator Bias: The quality of data heavily depends on the moderator's skill.
- Logistical Challenges: Requires careful planning, recruitment, and scheduling.
- Data Complexity: Analysing qualitative data from conversations can be time-consuming and subjective.

10.4. Surveying

It provides *verbal and quantifiable description* of attitudes, opinions or trends, data determining and reflecting the status of the total or the sample of a selected group of population as per that time with respect to one or more variables. It can be *cross-sectional* descriptive, exploratory and explanatory research, *longitudinal* research based on cohorts and/or panels at different points in time. In the application of any surveying method one of the most critical points is the decision on sampling. The rate of responses or the exclusion of a group of people (e.g. using internet for surveying total population) significantly influences the quality of the survey.

- Surveying methods[12]:
    - Questionnaires
    - Structured interviews
    - Face-to-face surveys
    - Telephone surveys
    - Internet surveys
    - Mail surveys

- Other classification of methods:
    - Descriptive survey (survey testing method, questionnaire survey method, Interview survey method);
    - Analytical survey (Documentary frequency, Observational survey, Rating survey, Critical incident, Factor analysis);
    - School survey
    - Genetic survey

The questions may be oriented to collect *quantitative data* when the answer could be yes-or-no or multiple-choice allowing more responses to a question. These answers could be counted and tabulated and further analysed with various statistical techniques.

Researchers can also ask more complex questions with more complex answers that require short essay responses. Anonymity is generally a critical ethical issue but in case of these types of questions, which usually aim at subjective, personal information is of particularly sensitive issue to get honest information. These are *qualitative data* that is harder to organise, classify and tabulate. However, their value is special for understanding and utilising motivations. An overview of the types of questions in a survey is available through the table 48.

[12] Details of individual methods are discussed in Burkholder et al. 2020 or Creswell 2018 and in wide range of the sociological literature.

Table 48. Types of questions in a survey

• The Dichotomous Question	• Multiple Choice Questions	• Rank Order Scaling Question	• Text Slider Question
• Likert Scale Question	• Semantic Differential Scale	• Stapel Scale Question	• Constant Sum Question
• Comment Box Open Ended Question	• Text Question	• Contact Information Question	• Demographic Question
• Matrix Table Question	• Side-by-Side Matrix Question	• Star Rating Question	• Max Diff Question
• Push to Social Questions	• Visual Analog Question	• Image Question	• Net Promoter Score (NPS) Question
• Van Westendorp-Price Sensitivity Question	• Date/Time Question	• CAPTCHA Question	• Calendar Question
• Interactive Maps Question	• Reference Data Question	• Lookup Table Question	• Store Locator Question
• TubePulse Question	•	•	•

Source: https://www.questionpro.com/article/types-of-questions-question-types.html

There are some common errors in writing survey questions and statements that are advised to avoid (Burkholder et el. 2020):

- ***Ambiguity**:* Ambiguity refers to questions and statements that are vaguely written. Ambiguous questions and statements lead to confusion because respondents must try to make sense of the researcher's meaning of a survey item.
- ***Biased wording:*** Biased wording refers to words within a question or statement that may trigger an emotional reaction. Biased words may influence a respondent's answer in a way that is not intended by the survey item.
- ***Leading questions and statements:*** To lead a question or statement refers to words that lead a respondent to favour or disfavour a particular perspective. For example, a question such as "Don't you agree that recycling plastic is important?" may lead a respondent to expect that a particular response is desired from the researcher.
- ***Double-barrelled questions and statements:*** Double-barrelled refers to questions and statements that ask for responses to two or more things or constructs within the same item. For example, the statement "I think it is important to recycle plastic and conserve water" reflects two different topics: (1) recycling plastic and (2) conserving water. A respondent may wish to answer one way about one of the topics and differently for the other topic.
- ***Complicated skip patterns***: Skip patterns are instructions that direct respondents to skip questions or statements that do not apply and proceed to items elsewhere within the

survey. If the skip patterns are overly complex, it may be difficult for respondents to follow them.

Here are some *tips to avoid common errors* in writing survey questions and statements (Burkholder et al. 2020):

- Provide respondents with clear instructions.
- Write questions and statements that are clear, simple, and as short as possible.
- Write in complete sentences; for example, write "What is your gender?" and not "Gender?"
- Avoid using biased or leading words that may cause an emotional response or lead a respondent to favour or disfavour a particular perspective.
- Avoid using double negatives.
- Avoid using "and" in questions and statements to ensure that only one topic is being measured in each item.
- Avoid complicated skip patterns that can be difficult for respondents to follow.
- Pre-test questions and statements for clarity by asking others to read them aloud and record any issues that arise to inform potential revision.

Main steps to prepare a survey include (figure 23):

- Determining the factors associated with the construct or phenomenon of interest. Pay attention to the objective of the research
- Selecting a method of administration to follow and manage the process
- Determining the sample to be studied
- Selecting a sampling plan
- Writing questions or statements
- Writing response scales
- Pilot testing
- Evaluate the pilot result and either return to one of the previous steps or step forward
- Doing the survey
- Evaluation of results
- Writing report / communication

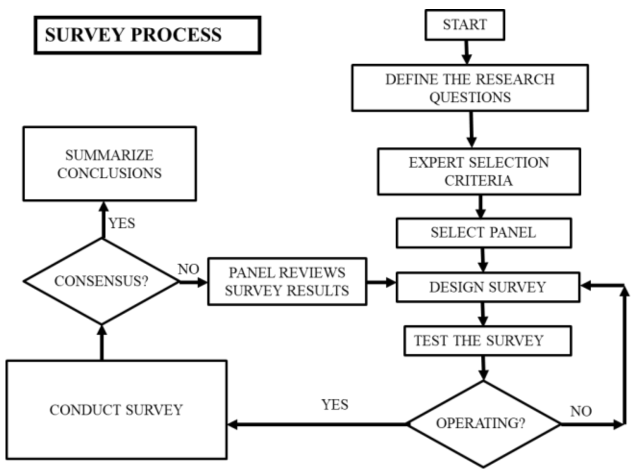


Figure 24. The survey process
Source: Author's edition based on Burkholder et al. 2020

- Advantages of surveying:
  - they provide information on large groups of people,
  - with relatively little effort, and
  - in a cost-effective manner
  - allows to assess a wider variety of behaviours and other phenomena
  - best utilized when control of dependent and independent variables is not easily achievable or desirable
- Drawbacks of surveying:
  - controlling against sample bias which can greatly compromise generalization
  - dependency on the cooperation of the respondents
  - information that is not known by the respondents can hardly by unearthed and
  - the information that is personal or secretive may easily be inaccurate

10.5. Delphi method

The method has its name from the ancient Greek sanctuary of Delphoi where Pythia was consulted about the consequences of decisions in the future. Originally it was elaborated at the RAND Corporation (USA) by O. Helmer for technological forecasting. In our days its further developed variants are used for a wide range of topics in future studies, among others in regional foresight concerning the possible territorial development scenarios.

It is a systematic, interactive forecasting method based on the opinion of a panel of experts. They provide opinions independently and anonymously to reduce the effect of dominant individuals and groupthink. The process involves multiple rounds of questionnaires. After each round, a summary of the group's forecasts and reasons is provided, and participants are encouraged to revise their earlier answers.

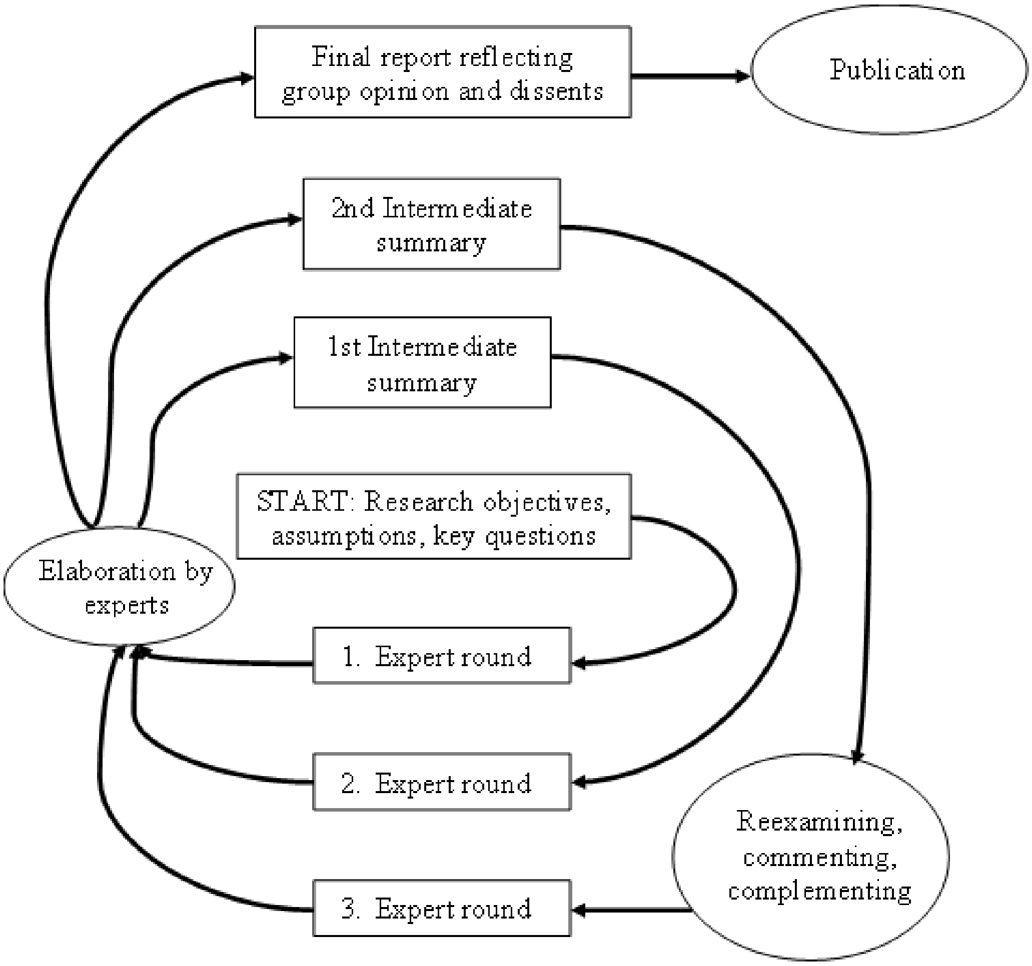
The first round collects general creative ideas depending on the objective of the research. In several cases this turn is replaced by brainstorming or in written form in brainwriting. These ideas are the basis of questions oriented to the possibilities or probabilities of events and processes in the second round. The third round is controlled feedback, where participants receive a statistical summary (like median and interquartile range) of the previous group response, promoting convergence toward consensus. They are expected to indicate that they accept or nor the common opinion of the group, and why they insist to their different previous opinion or change it. These answers are particularly important, because these experts may have special information representing an emerging or disappearing process. Results are quantitatively aggregated to inform final conclusions.

Advantages of Delphi method:

- Reduces influence of dominant individuals
- Allows for geographically dispersed participants
- Facilitates consensus on complex problems

Limitations of the Delphi method:

- Time-consuming
- Risk of attrition between rounds
- Consensus does not always equate to correctness



11. Closing remarks

This chapter aims to give a practice-oriented overview of elementary methods for territorial analysis to be utilised in working in the field of regional development planning. The discussion concentrates on the application. The Excel is selected and not any other statistical package, because it is supposed to be available for students coming from various fields of knowledge and level of knowledge. However, even this target-oriented discussion supposes some general statistical knowledge background. There are many other, more sophisticated techniques serving detailed analysis and approach to various themes from different aspects. These are available in theoretical and practice-oriented literature on urban and regional analysis. In addition, the cooperation either in development planning or management requires the cooperation of experts representing wide range of relevant co-sciences from physical sciences to economic and other social sciences. They all have their own special methodologies and methods, therefore, capacity for openness and adaptability as well as readiness to studying further is an elementary requirement.

Control questions

- How to select participants for participatory research (aspects of sampling)?
- What are the advantages / disadvantages of surveying?
- What are the advantages / disadvantages of interviewing?
- What are the typical errors in surveying
- What are the advantages / disadvantages of using focus group technique?

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IV. The Basics of GIS and thematic mapping

Júlia Gutpintér[13]

Összefoglalás

This chapter introduces Geographic Information Systems (GIS) and thematic mapping, covering key concepts, methods and some historical background. Furthermore, it covers spatial data types, spatial analysis, coordinate systems, map design principles, and the types of thematic maps.
During the practice sessions we are going to use the following tutorial: Frank Donelly (2023) Introduction to GIS with QGIS[14], available here: https://raw.githubusercontent.com/Brown-University-Library/geodata_pdf_tutorials/main/qgis/intro_qgis_apr2024.pdf
The data for the practice session is available here: https://drive.google.com/uc?export=download&id=1uUKsthKepeKd8d82Iz7Eb8ip_CAV3Cnf

1. The basics of GIS

1.1.GIS definitions and concepts

Although the first chapter of this textbook has already introduced the definition of GIS, here we reiterate once again. GIS stands for Geographic Information Systems which is an integrated framework of software, hardware, data, methodologies and people who use these to capture, store, analyze, manage, and visualize spatial or geographic data.

The narrow definition of GIS focuses on the software and data, while broader definitions include hardware (where the data and software are stored), metadata (data describing the data), as well as the individuals who are part of the system and interact with it as contributors. Another definition describes GIS as a (visual) system that organizes information around the concept of location, which can be used for geographic analysis, mapping, database management, and geospatial statistics. (Donelly, 2023)

GIS enables users to interpret and understand spatial relationships, patterns, and trends by linking data to specific locations on the Earth's surface. GIS combines spatial, location data (where things are) with various descriptive information (what things are). This serves as a basis for mapping and analysis, widely applied in science and numerous industries. It enables users to explore patterns, relationships, and geographic context.[15].

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[14] Creative Commons Attribution - NonCommercial- No Derivatives - 4.0 International License (CC BY-NC-ND 4.0)
[15] https://www.esri.com/en-us/what-is-gis/overview#planning-for-the-future

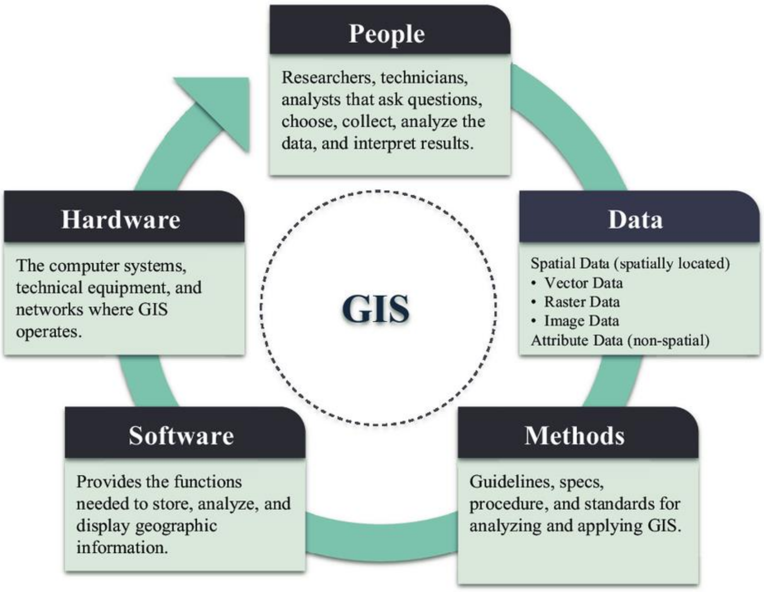

Figure 1. The 5 main components of GIS

Source: https://www.researchgate.net/publication/369245369/figure/fig1/AS:11431281126948586@1678889256970/The-five-components-of-a-GIS-system-This-figure-was-reproduced-based-on-a-figure-by-the.png

1.2. The evolution of GIS

The history of Geographic Information Systems (GIS) began with cartography used for exploration, strategy, and urban planning. However, the development of modern GIS was only made possible by the advancements in spatial analysis, computing, and data visualization from the mid-20th century onwards. The main driving force of the evolution of GIS was technological progress and the increasing need to analyze complex geographical patterns.

The beginnings

One of the earliest examples of spatial analysis was **Dr. John Snow's** cholera map from **1854**. During the cholera epidemic in **London in 1854**, Snow marked the cholera occurrences on a city map. His analysis revealed a concentration of cases around a **public water well on Broad Street**. By removing the pump handle, the spread of cholera declined, demonstrating the power of spatial analysis in public health. Snow's work is often considered a **precursor to GIS** as it showed how geographic data could be used to identify patterns and solve real-world problems[16].

Early Thematic Mapping and Manual GIS (19th–Mid 20th Century)

Following Snow's discovery, cartographers and scientists began using maps for various analytical purposes: Charles Minard (1869) created a famous map illustrating Napoleon's invasion of Russia with the integration of multiple data layers like troop movements and temperature changes. Patrick Geddes (1900s) laid the foundation of systematic urban and regional planning, his work (particularly mapping and data collection) influenced the spatial analysis methods used in modern GIS. Based on Geddes pioneering work Jacqueline Tyrwhitt "introduced her overlaying technique in 1950, which became the foundation for the integrating and analytical capacities of geographical information systems (Nijhuis, 2015; Shoshkes, 2006, 2016 In: Hein és van Mil, 2020 p. 155)". Early spatial data analysis – in the absence of

[16] https://learn.arcgis.com/en/projects/map-a-historic-cholera-outbreak/

computers – was done manually using paper maps, overlays, and statistical calculations. This method was slow and prone to errors.

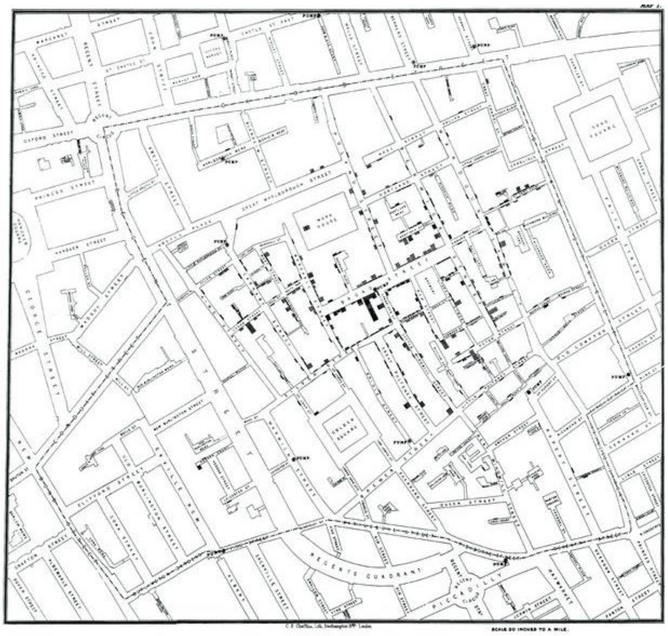

Figure 2. John Snow's cholera map from 1854
Source: https://upload.wikimedia.org/wikipedia/commons/thumb/2/27/Snow-cholera-map-1.jpg/958px-Snow-cholera-map-1.jpg

The Birth of Modern GIS (1950s–1970s)

The age of the Modern GIS can be divided into four distinct periods: "the pioneer period from the mid-1950s to approximately 1975; (ii) the government-supported, experimental period beginning in the mid-1970s and ending in the early 1980s; (iii) the commercial period from the early 1980s to 1990; and (iv) the user dominance era starting in 1990". (Waters, 2017 p. 2.) First period focused on the conceptual developments of GIS. The most remarkable and important development was the creation of the overlay model for the organization of geographical data and the geographical data matrix in which the columns represented places, and the rows represented their attributes. Later when this model was incorporated into the early GIS softwares this structure was transposed to align the geographical matrix with standard database technology (Waters, 2017)

Roger Tomlinson developed the first authentic GIS system in Canada during the year 1963. The Canada Geographic Information System (CGIS) was developed by Tomlinson to organize data concerning land use and natural resources. Tomlinson earned the title "Father of GIS" through his development of digital geographic data storage and analysis methods. During the 1970s universities and government organizations developed GIS tools which included the Harvard Laboratory for Computer Graphics and Spatial Analysis that produced early GIS software. The U.S. Census Bureau initiated GIS development by beginning the digitization of census maps which assisted urban planning efforts[17].

The United States initiated its GPS network by launching Navstar I satellite in 1978[18].During the 1980s commercial GIS software emerged with Esri's ArcInfo in 1982 becoming the industry standard for spatial analysis. The development of better satellite imagery systems along with

[17] https://www.esri.com/en-us/what-is-gis/history-of-gis
[18] https://www.esri.com/en-us/what-is-gis/history-of-gis

GPS technology and database management systems substantially improved GIS functionality and created new potential for its application. During the 1990s, GIS became broadly available because of ArcView which brought graphical user interfaces (GUIs) to simplify map creation and analysis[19].

Modern GIS systems combine artificial intelligence with cloud computing and remote sensing to support real-time data acquisition. GIS technologies support operations in smart cities and disaster management while contributing to climate change research and business intelligence operations (see chapter 1 for further details). The capabilities and necessity of GIS technology have reached unprecedented levels in today's world. GIS technology enables users to generate billions of maps each day. A GIS course or program exists in over 95% of universities. Most Fortune 500 corporations together with national and local government agencies and nonprofit organizations integrate GIS into their operations[20]. GIS plays a crucial role in the global market, as it is widely utilized across various industries. According to Data Bridge Market Research, the geographic information system market was valued at USD 9,160.02 million in 2021 and is projected to grow to USD 22,518.38 million by 2029, with a CAGR (Compound Annual Growth Rate) of 11.90% during the forecast period from 2022 to 2029[21].

1.3.Data Models and Structures in GIS

To start using GIS software first we should understand the basic data types we are going to apply. Geographic Information Systems (GIS) uses structured data models to store, manage, and analyze spatial information. These data models define how geographical features are represented, organized, and processed within GIS software. Basically, the data model translates reality into the language of the computer. The two main types of GIS data models are **vector data** and **raster data**, each suited for different applications. GIS also uses other data types besides raster and vector data, like tables, geodatabases, web services and special structures such as **topology, attribute tables, and spatial databases**.

Vector data[22]

The vector data model is a framework for representing specific features on the Earth's surface by assigning attributes to them. It is commonly used to store data with well-defined boundaries, such as country borders, land parcels, and roads.

Vectors consist of discrete geometric locations (x, y coordinates) called **vertices** (singular: vertex), which define the shape of a spatial object. The arrangement and minimum number of vertices determine the type of vector: point, line, or polygon. Vector data is always associated with so called **attribute data** which describes the attributes of the feature (spatial unit). This data can be numeric and text data as well.

[19] https://en.wikipedia.org/wiki/ArcInfo
[20] https://www.esri.com/en-us/what-is-gis/history-of-gis
[21] https://stratoflow.com/what-is-gis/
[22] https://datacarpentry.github.io/organization-geospatial/02-intro-vector-data.html
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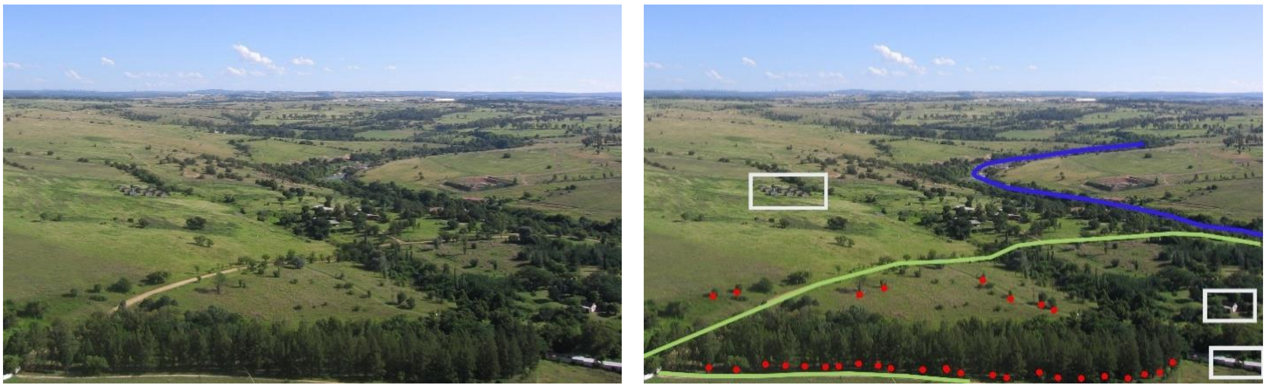


Figure 3. Example of how vector models represent features on the Earth's surface
Source:https://docs.qgis.org/3.34/en/docs/gentle_gis_introduction/vector_data.html

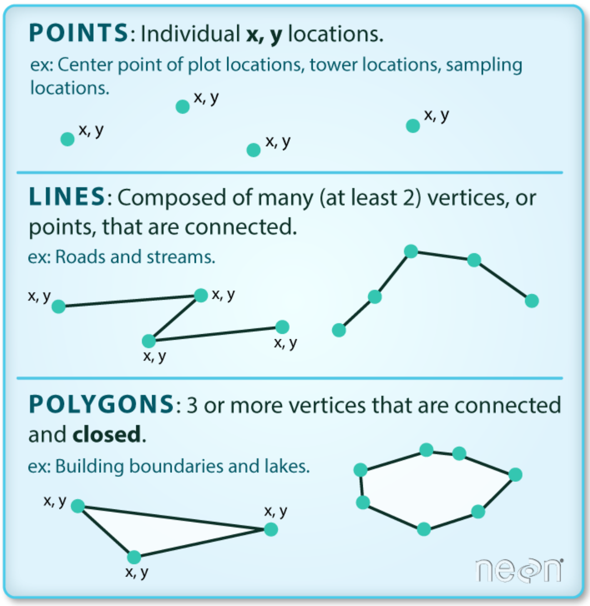


Figure 4. The three types of vector data
Source: https://datacarpentry.github.io/organization-geospatial/02-intro-vector-data.html

The three types of vector data:

- **Points**: A point is represented by a single vertex with (x, y) coordinates. A vector point file can contain multiple points. Examples include sampling sites, individual electric poles.
- **Lines**: A line consists of at least two connected points (vertices). The starting and ending points are different. Features such as roads or rivers are often depicted as lines, with each curve or bend defined by a vertex with specific (x, y) coordinates.
- **Polygons**: A polygon is a closed shape (that is, the starting and ending points are the same) formed by three or more connected vertices. Common examples include the boundaries of states, countries, lakes, areas with different types of soil.

Shapefiles

The most common and widely used vector file format is the *.shp*. Despite its many limitations and the availability of more modern and better alternatives, it remains the most widely used format for storing vector data. A shapefile can only contain a single geometry type and consists of multiple files (which can cause problems when moving them). The maximum size of a shapefile is limited to 2 GB, and there is a limit of 255 attributes and attribute names restricted to 10 characters. GeoJSON, OGC GeoPackage (GPKG), SpatiaLite file formats are some of the more up-to date alternatives of shapefiles.

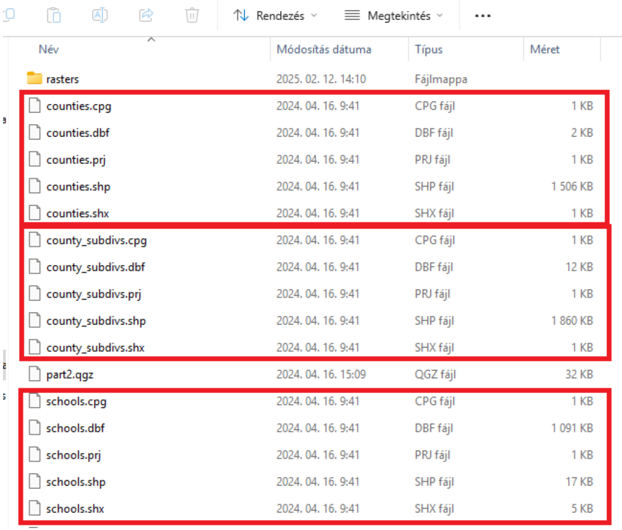


Figure 5. Shapefiles consist of multiple files. Pay attention to each of them while copying. Every part should be moved together in order the file to be readable!

Raster data

Raster data is primarily used in GIS applications to represent information that varies continuously across an area and cannot be easily separated into distinct features. [23] For instance, the aerial image below shows variations in color and vegetation density. While it is possible to create individual polygons for different areas, much of the surface detail would be lost by simplifying the features into distinct polygons.

Raster data can be defined as a pixelated (or gridded) data where a specific value is assigned to every pixel, which is displayed as a specific color[24]. The value of a pixel can be continuous (e.g.elevation) or categorical (e.g. land use). Raster files are similar to digital photos, except that they are georeferenced. This means that every pixel is tied to an actual geographical location. The two most important attributes of a raster file are **extent** (refers to the spatial boundaries of the dataset, defining the area it covers on the Earth's surface) and **resolution** (represents the area on the ground that each pixel of the raster covers)[25].

This data model can be considered primarily as a digital format for aerial and satellite imagery, as well as scanned paper maps. There are many different raster file formats, common ones are TIFF (.tif), JPEG (.jpg) and PNG (.png)

[23] https://docs.qgis.org/3.40/en/docs/gentle_gis_introduction/raster_data.html
[24] https://ucsbcarpentry.github.io/ucsb-geospatial/01-intro-raster-data/index.html
[25] https://datacarpentry.github.io/organization-geospatial/01-intro-raster-data.html

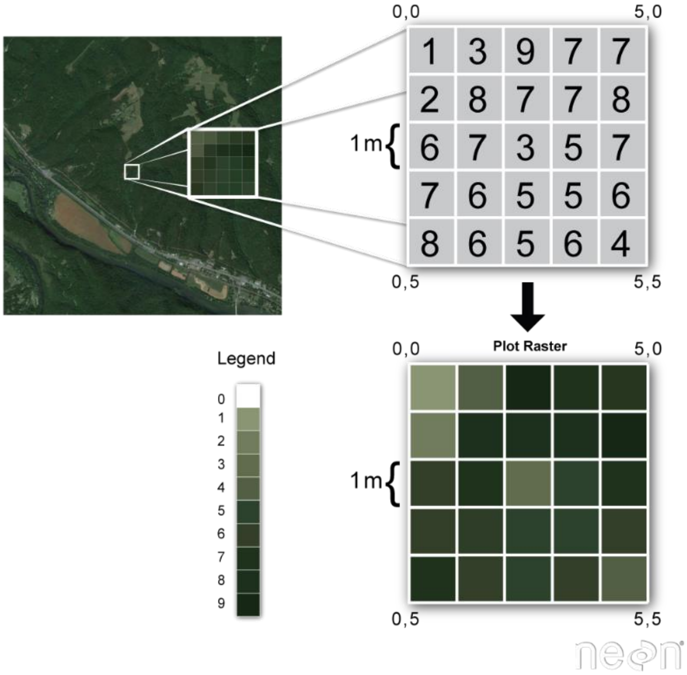


Figure 6. Simplified logic of the raster model
Source: https://datacarpentry.github.io/organization-geospatial/fig/dc-spatial-raster/raster_concept.png

Other data types
Data tables can contain location-related data that can be converted into GIS data/files and mapped. If a data table includes longitude and latitude coordinates, a vector file can be created from it. Data tables can also be linked to existing vector data if both contain a unique identifier corresponding to a specific row or element. They are usually stored in text files such as CSV, TXT, or xlsx, as well as in database files (Donelly, 2023).

Geodatabases are "container files" (for example, ESRI file geodatabase (.gdb), Spatialite files (.sqlite) that can store related raster, vector, and tabular data. They are excellent for organizing data, performing spatial queries, and conducting analyses (Donelly, 2023).

GIS applications can access content published on the internet through **web services**. Instead of downloading data, users can connect to web-based layers and display them directly in their GIS application. Layers are rendered using Web Mapping Services (WMS), which display layers as rasters, while Web Feature Services (WFS) provide vector data and allow attribute visualization and management. Web Map Tile Services (WMTS) and XYZ Tiles are popular open standards for displaying raster maps (Donelly, 2023)

Attribute Data and Spatial Databases
In GIS, attribute data is always linked to spatial features, which provides additional information about each feature. These attributes are stored in tables within a database. Every GIS software or system uses databases to store and manage data.

According to the Oracle "a **database** is an organized collection of structured information, or data, typically stored electronically in a computer system"[26]. Its main purpose is to organize, store, and retrieve large amounts of information efficiently. There are different relationships,

[26] https://www.oracle.com/database/what-is-database/

constraints/conditions between the data which make data management possible. The database is to be understood as the combination of the stored data and the managing system.

GIS softwares almost always use relational databases. A **relational database** is a type of database that stores data in a structured format using rows (records) and columns (attributes or fields), which are organized into **tables**. These tables are related to one another through **keys** (unique identifiers), allowing for efficient storage, retrieval, and manipulation of data. To put it differently a relational database is a collection of one or more tables which can be connected to each other through keys.

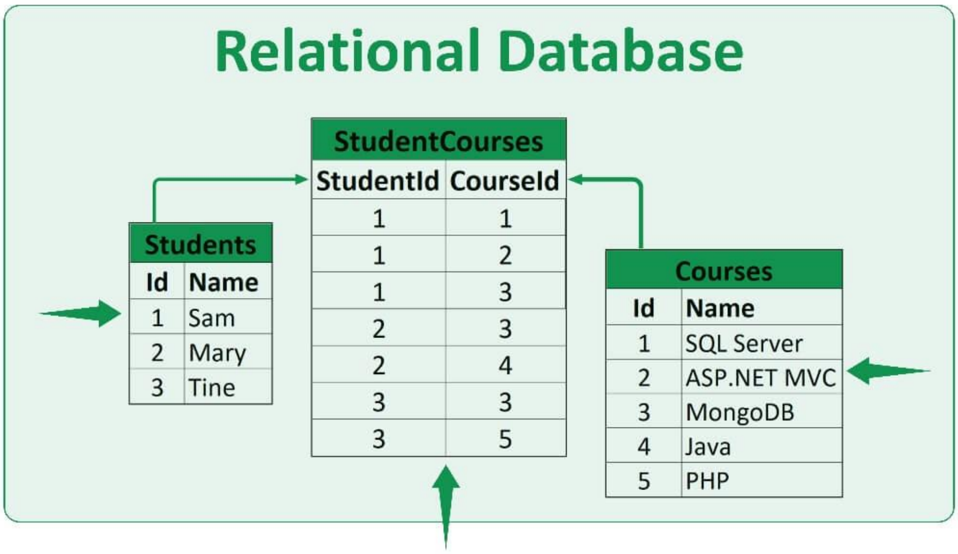


Figure 7. A simplified model of a relational database
Source: https://www.pragimtech.com/blog/mongodb-tutorial/relational-and-non-relational-databases/

Key elements of a relational database

- **Tables**: Data is stored in tables, which consist of rows (records) and columns (attributes or fields). Each table represents a specific entity, such as “Regions” or "Countries", “Cities”
- **Primary Keys**: Each table typically has a primary key, a column (or set of columns) that uniquely identifies each row in the table. For example, a country code or a NUTS code could serve as the primary key in a vector file.
- **Foreign Keys**: Tables can be related to one another through foreign keys. A foreign key in one table points to the primary key in another table, establishing a relationship between the two. For example, a "Locations" table might have a "RegionID" column that relates to the "RegionID" in the "Regions" table.

Data types

In a database each attribute must have a pre-defined data type. Attribute values can only be within this data type. For example, if we set integer (whole) as data type we will not be able to write a decimal number in that particular field. Data types ensure that the correct type of data is stored in each column.

Data type	Meaning
INTEGER, INT	whole numbers (without decimals)
FLOAT, DOUBLE	decimal numbers
DECIMAL	exact numeric values with a fixed number of digits before and after the decimal point
DATE	date values, typically in the format YYYY-MM-DD
TIME	time values, usually in the format HH:MM:SS
CHAR	fixed-lenght text (up to 255 character)
VARCHAR, TEXT, STRING	variable-length character strings (0-65535 character)
BOOLEAN	True/False

Figure 8. Most common data types in databases

Topology in GIS

Topology is a set of rules that defines how vector features (points, lines, and polygons) connect and interact with each other. In other words, it describes the spatial relationships between the features[27]. Depending on the vector type there could be several different rules. Figure 9. presents the point, the polygon and the line topology rules.

Topological or topology-based data are useful for detecting and correcting digitising errors (e.g. two lines in a roads vector layer that do not meet perfectly at an intersection). Topology or topological correctness is inevitable for carrying out some types of spatial analysis, such as network analysis. Topological errors break the relationship between features. [28]

[27] https://pro.arcgis.com/en/pro-app/latest/help/data/topologies/topology-basics.htm
[28] https://docs.qgis.org/3.40/en/docs/gentle_gis_introduction/topology.html

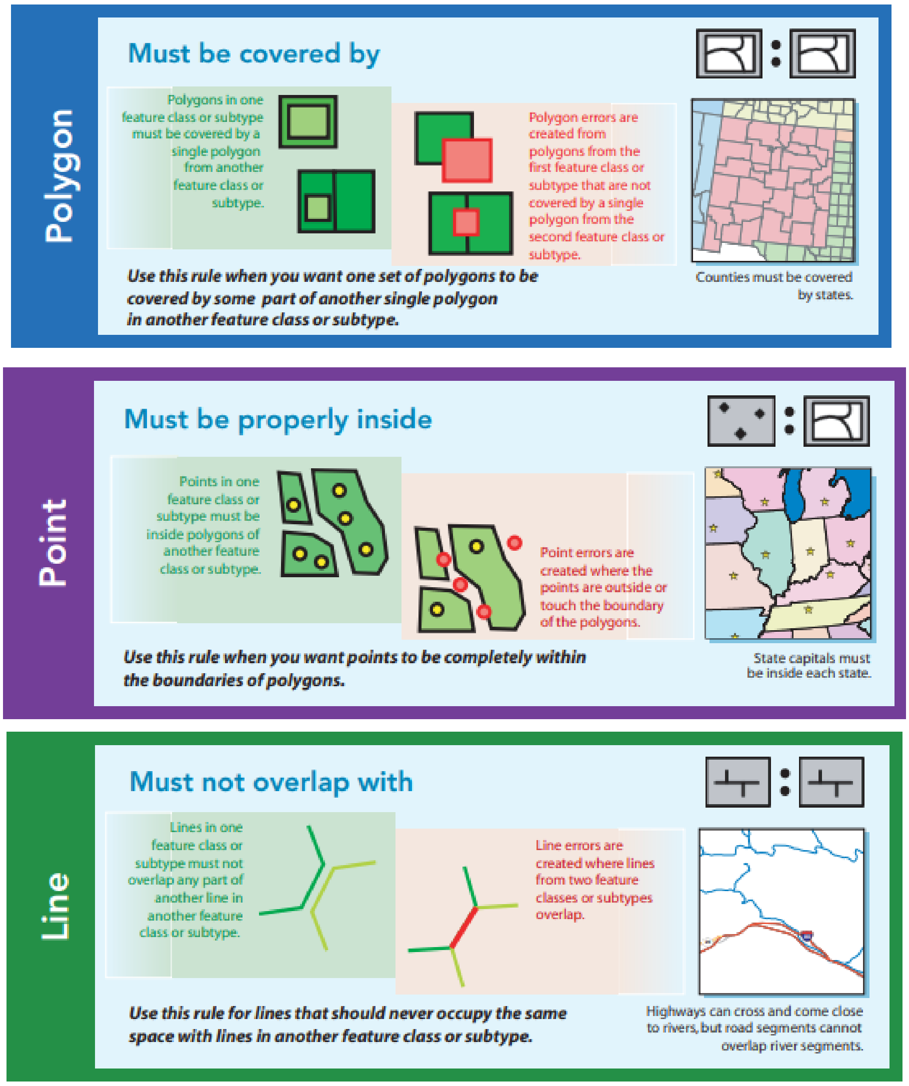


Figure 9. Examples of topology rules

Source: https://pro.arcgis.com/en/pro-app/3.2/help/editing/pdf/topology_rules_poster.pdf

GIS softwares

There are several different GIS softwares available which differ from each other in their abilities and accessibility. Despite their differences their core operational principles and logic remain similar. GIS softwares are broadly categorized into proprietary (licensed) programs and Free Open Source Software (FOSS).

Proprietary GIS softwares or licensed programs require purchasing a license for use. The most widely used proprietary GIS software globally is ESRI ArcGIS, which is considered the "industry standard". (Other popular proprietary softwares are MapInfo, Global Mapper.) The ArcGIS software was developed by ESRI, the leading GIS software company. (Previously it operated under different names like ArcInfo, ArcMap.) It is the most advanced software with the most (cutting-edge) functions. It is also the most popular proprietary GIS software, particularly used in government agencies, universities, and large organizations. It offers a comprehensive toolset including advanced spatial analysis, mapping, geodatabase management, and cloud integration. Although it is very powerful software, it could be expensive for individual users or small organizations.

Open Source GIS Software (FOSS), on the other hand, is free to use, modify, and distribute. The most popular open-source GIS software is QGIS, which has gained significant traction due to its accessibility and versatility. It is also a reasonably mature and capable software which can handle all fundamental GIS tasks. It is relatively easy to use compared to other GIS software. The main advantage of QGIS its strong global user and developer community which ensures its continuous improvement.

Since most GIS platforms share common functions and underlying principles, transitioning from proprietary GIS software (such as ArcGIS) to open-source alternatives (such as QGIS) is relatively straightforward and easy. Users familiar with one GIS platform can typically adapt to another with minimal learning effort, especially since there are hundreds of free learning materials available.

Check your knowledge!

- What is GIS?
- What was the first known application or precursor of GIS?
- What are the two primary types of GIS data models?
- Explain the difference between these two data models!
- Name the different vector types!
- What is attribute data?
- What is topology?
- What are the two most popular GIS softwares? What are their main differences?

2. Spatial analysis[29]

According to the ESRI's GIS dictionary spatial analysis is "the process of examining the locations, attributes, patterns, and relationships of features in spatial data to address a question or gain useful knowledge that goes beyond the scope of simple visual analysis[30].

The addressed questions are „where" questions. Where is the location(s) with the highest rate of green areas within a city? Where has hydrological change occurred? Where is the best location for a new store? Spatial analysis helps to answer these questions and support decision making through solving complex location-oriented problems, exploring and understanding data from a geographical perspective, determining relationships, detecting and quantifying patterns, assessing trends, and making predictions.

Using spatial analysis, you can combine spatial data from many sources and derive new information by applying a set of spatial operators. Statistical analysis, for example, can determine whether the patterns that are visible on maps are statistically significant. Spatial

[29] https://libguides.tulane.edu/geographicinformationsystems/spatialanalysis
https://support.esri.com/en-us/gis-dictionary/spatial-analysis
https://docs.qgis.org/3.34/en/docs/gentle_gis_introduction/vector_spatial_analysis_buffers.html#more-spatial-analysis-tools
https://pro.arcgis.com/en/pro-app/3.3/help/analysis/introduction/spatial-analysis-in-arcgis-pro.htm
https://pro.arcgis.com/en/pro-app/3.3/help/analysis/geoprocessing/basics/what-is-geoprocessing-.htm
30 https://pro.arcgis.com/en/pro-app/latest/help/analysis/introduction/spatial-analysis-in-arcgis-pro.htm

analysis can be used to calculate the suitability of a place for a particular activity, or using image analysis, you can detect change over time. The types of spatial analysis that are applied vary according to subject areas. In water management and research (hydrology) users will most likely be interested in analyzing terrain and modelling water as it moves across it. In wildlife management users are interested in analytical functions that deal with wildlife point locations and their relationship to the environment.

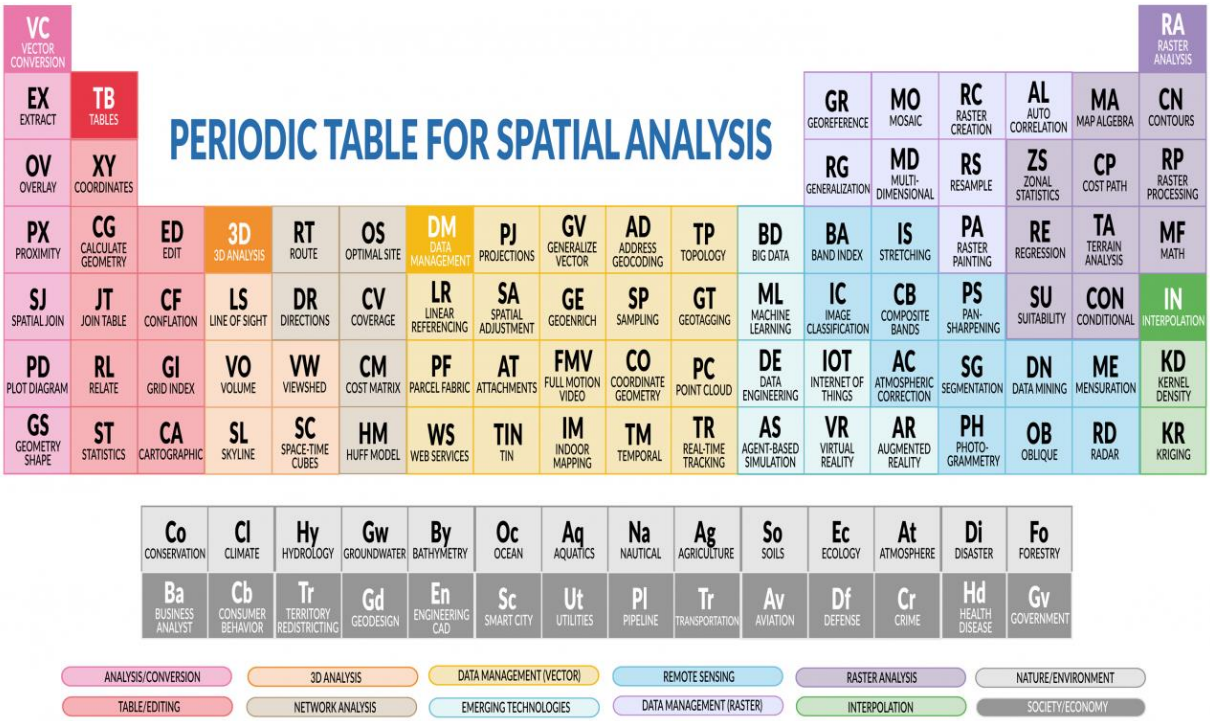


Figure 10. Spatial analysis operations

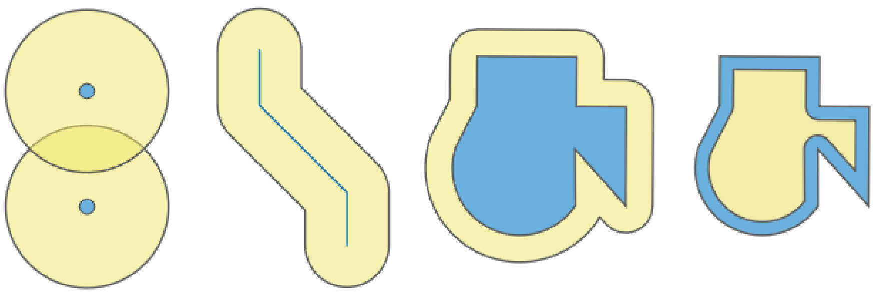
Source: https://gisgeography.com/wp-content/uploads/2021/05/Spatial-Analysis-Periodic-Table-1265x751.png

Geoprocessing

Geoprocessing is a framework or a set of tools for handling geographic and related data, as well as performing spatial analysis. A typical geoprocessing tool processes a dataset — such as a feature class, raster, or table — and generates a new output dataset. For instance, the Buffer tool takes input features, creates buffer zones around them based on a specified distance, and saves these buffer areas as a new dataset.

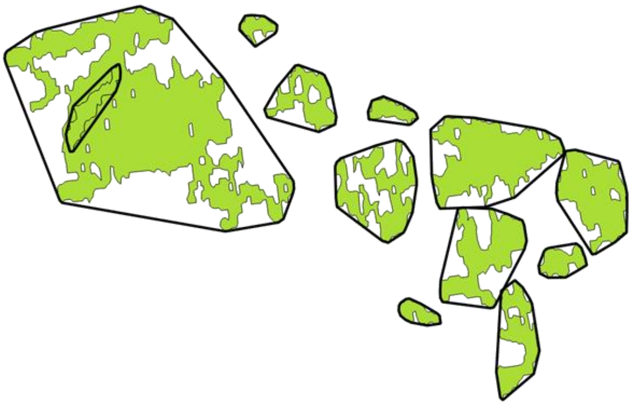
QGIS offers the following geoprocessing tools:

- Buffer - it creates a polygon at a set distance surrounding the features.



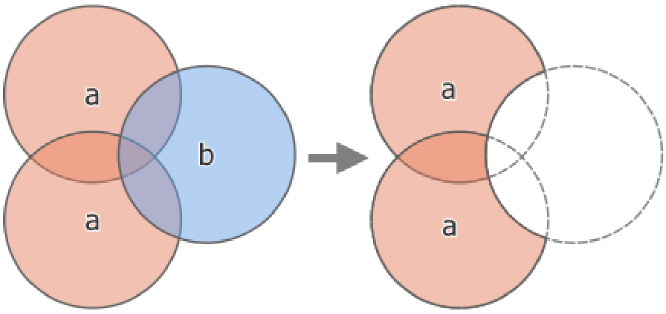
Source: https://docs.qgis.org/3.40/en/_images/buffer1.png

- Clip - cuts out an input layer to the extent of a defined feature boundary. The result of this tool is a new clipped output layer. It is like using a cookie cutter on a layer.
- Convex Hull: **A convex hull** is the smallest convex shape that encloses a given set of points in a plane or space. It can be visualized as the shape formed by stretching a rubber band around the outermost points of a dataset.



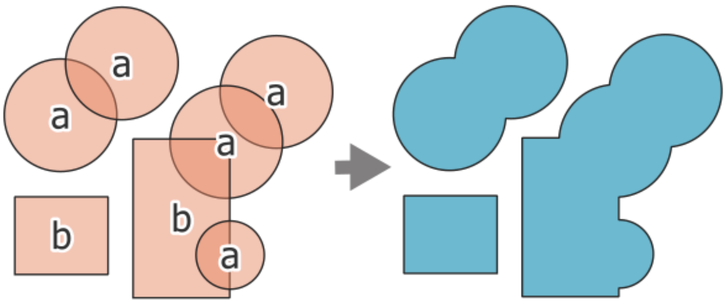
Source: https://docs.qgis.org/3.40/en/_images/convex_hull.png

- Difference - subtracts areas of one layer based on the overlap of another layer



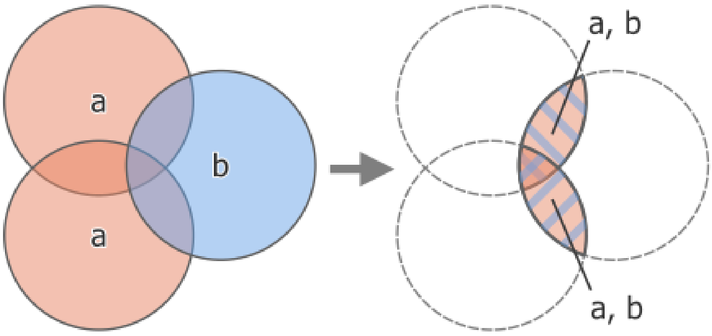
Source: https://docs.qgis.org/3.40/en/_images/difference.png

- Dissolve - takes a vector layer and combines its features into new features based on common attributes e.g. unification of West and East Germany



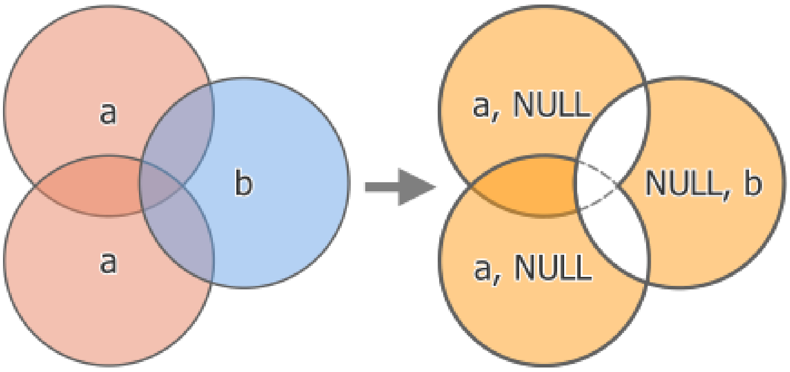
Source: https://docs.qgis.org/3.40/en/_images/dissolve.png

- Intersection - creates a new layer based on the area of overlap of two layers. It is similar to the clip function except it preserves attributes from all the data sets that overlap each other in the output.



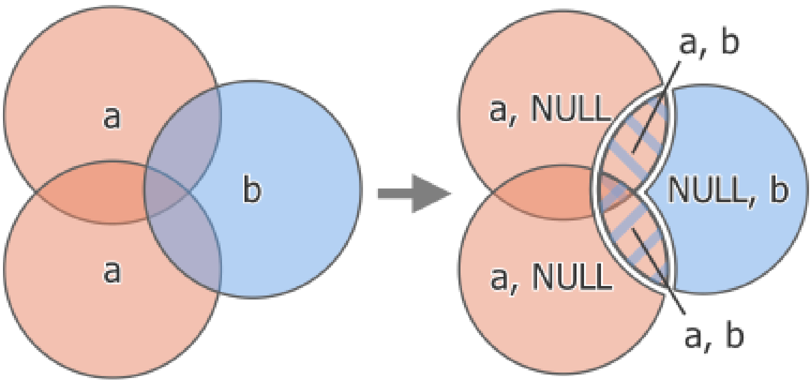
Source: https://docs.qgis.org/3.40/en/_images/intersection.png

- Symmetrical Difference - creates a new layer based on areas of two layers that do not overlap



Source: https://docs.qgis.org/3.40/en/_images/symmetrical_difference.png

- Union - melds two layers together into one while preserving features and attributes of both



Source: https://docs.qgis.org/3.40/en/_images/union_with_overlay.png

- Eliminate Selected Polygons - merges left-over or misformed geometry with neighboring features.

More on geoprocessing tools: https://gisgeography.com/geoprocessing-tools/ , https://docs.qgis.org/3.40/en/docs/index.html

Check your knowledge!

- What is spatial analysis?
- Why is it useful?
- What is geoprocessing?
- Name 3 geoprocessing tool and explain their function!

3. Basics of mapping

3.1.Reference systems and maps

A **map** is scaled down, generalized representation of the natural and artificial objects and phenomena (of a portion) of the Earth's surface graphically displayed on a planar (flat) surface, generally a sheet of paper or a display.

How can we graphically display the Earth's surface on a piece of paper or on a computer display? First, we need a shape which is relatively easy to describe or model mathematically. When we imagine the Earth, usually a perfect sphere shape that comes to our mind. In reality, the Earth's shape is nearly spherical, with a radius of about 3,963 miles (6,378 km), but its surface is very irregular. Mountains and valleys make measuring this surface impossible because an infinite amount of data would be needed[31].

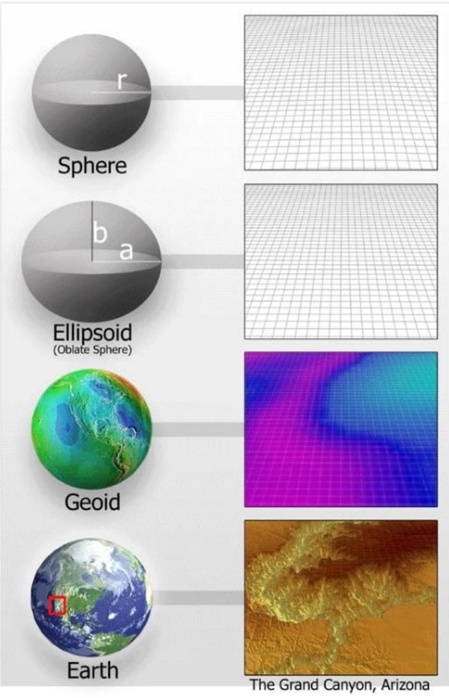


Figure 11. The different shapes and models of the Earth
Source:https://oceanservice.noaa.gov/education/tutorial_geodesy/media/geo03a_700.jpg

[31] https://oceanservice.noaa.gov/education/tutorial_geodesy/geo03_figure.html

The **geoid** which is a simplified shape of the Earth, is the hypothetical surface of the Earth that represents the mean sea level across the globe, considering variations in gravity (differences in strength of the Earth gravitational force distorts the shape of it.) It is an idealized shape that is often used as a reference for measuring elevations and depths. But it is still a complex shape, so geodesists use a theoretical mathematical surface called the **ellipsoid**[32]

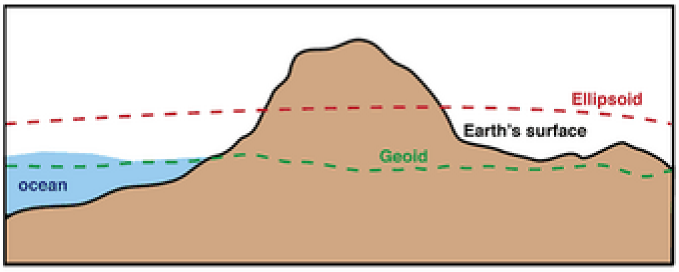


Figure 12. The surface of the geoid, the ellipsoid and the Earth in cross-sectional view
Source: https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/styles/side_image/public/thumbnails/image/geoid.png?itok=38q8gWzn

For historical reasons, numerous ellipsoids have been created in different periods and regions. A particular ellipsoid can be selected for use in a specific geographic area, because that ellipsoid does an exceptionally good job of representing the geoid for that part of the world. One of the most widely used today is the WGS-84 ellipsoid, which serves as the foundation for the GPS positioning system[33].

Since there are different ellipsoids, an additional factor should be considered. This is the **datum** which is a set of information for attaching the chosen ellipsoid to the surface of the Earth. A datum is built on top of the selected ellipsoid and can incorporate local variations in elevation[34].

After defining a model for the Earth's shape, we can develop a system to encode any location on its surface and assign coordinates to it. The integration of a **coordinate system** with a datum is known as a **coordinate reference system** (CRS)[35].

A coordinate reference system could be geographical or projected depending on the geometry it uses. **Geographical coordinate systems** use a spherical geometry in which the location of every point is defined by two angular values: latitude and longitude. Lines of equal latitude are called parallels, while lines of equal longitude are called meridians[36].

Geographical coordinate systems have their places, but for smaller regions and for performing tasks like measuring distances and areas or making a map the use of a planar geometry is more suitable. In order to this we must project the surface of a three-dimensional ellipsoid into a two-dimensional flat surface and create a **projected coordinate system**. Unlike a geographic coordinate system, a projected coordinate system maintains lengths, angles, and areas across two dimensions. A projected coordinate system is always derived from a geographic coordinate system, which is based on a sphere or spheroid. In a projected coordinate system, locations are

32 https://oceanservice.noaa.gov/education/tutorial_geodesy/geo03_figure.html
https://www.usgs.gov/faqs/what-a-geoid-why-do-we-use-it-and-where-does-its-shape-come
33 https://volaya.github.io/gis-book/en/Cartography.html
34 https://desktop.arcgis.com/en/arcmap/latest/map/projections/about-the-geoid-ellipsoid-spheroid-and-datum-and-h.htm
35 https://volaya.github.io/gis-book/en/Cartography.html
36 https://volaya.github.io/gis-book/en/Cartography.html

represented by x and y coordinates on a grid, with the origin at the center of the grid. Each point is identified by two values referencing its position relative to the central point: one for its horizontal position (x-coordinate) and the other for its vertical position (y-coordinate). In this system, the coordinates at the origin are x = 0 and y = 0[37].

A **projection** is a mathematical system that transforms a three-dimensional ellipsoid into a two-dimensional flat surface[38]. This inevitably results in distortions. The popular analogy is that a projection is like peeling and orange. To create a map of an orange's surface, we need to find a way to lay its peel flat onto a piece of paper or a computer screen. However, since the orange is a sphere, this can only be done by stretching or cutting the peel in certain areas. As a result, this stretching inevitably leads to distortion[39].

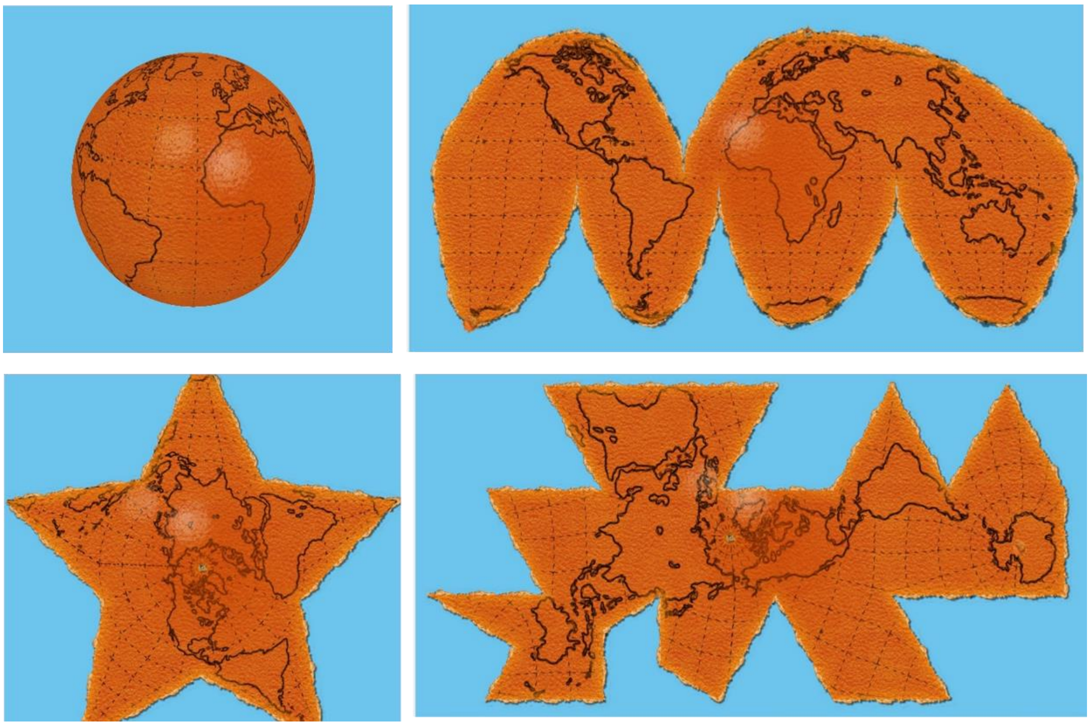


Figure 13. „Projection is like peeling an orange"
Source: https://www.esri.com/arcgis-blog/products/arcgis-pro/education/earth-peel

Projections are usually constructed to preserve certain properties. They can show one or more — but never all — of the following correctly: directions, distances (equidistant), areas (equal area), shapes, angles (conformal). Projections can also be grouped based on their geometric basis (cylinder, cone, plane), shape, special properties, projection parameters.

One of the often-seen projections is the Mollweide projection which is an equal-area, pseudo-cylindrical map projection commonly used for world maps. It prioritizes accurate area proportions over the preservation of angles and shapes, making it suitable for maps that illustrate global distributions. In this projection, the equator appears as a straight horizontal line, perpendicular to the central meridian, which is half the length of the equator. It is particularly

[37] [37] https://volaya.github.io/gis-book/en/Cartography.html
[38] https://desktop.arcgis.com/en/arcmap/latest/map/projections/about-map-projections.htm
[39] https://ceiengineers.com/about/news-media?id=34025/how-is-a-map-projection-like-an-orange-peel

useful for thematic and other world maps where maintaining correct area proportions is essential[40].

Figure 14. The Mollweide projection
Source: https://desktop.arcgis.com/en/arcmap/latest/map/projections/GUID-4631E648-FDD8-43DF-9ECB-C4AC56022484-web.png

Mercator is a conformal cylindrical map projection that was created by Gerardus Mercator in 1569 to display accurate compass bearings for sea travel. Directions, angles, and shapes are maintained at infinitesimal scale. On the other hand, the area is increasingly distorted toward the polar regions. For example, although Greenland is only one-eighth the size of South America, it appears to be larger than South America in the Mercator projection. Another expressive example is Australia and Antarctica. The latter is only 1,8 times bigger than the smallest continent, yet it seems huge on this projection. The Web Mercator variant of the projection is the de facto standard for web maps and online services[41].

Figure 15. The Mercator projection
Source: https://desktop.arcgis.com/en/arcmap/latest/map/projections/GUID-7B6CCF16-E2D0-4AAB-8376-A1EF08346E08-web.png

[40] https://desktop.arcgis.com/en/arcmap/latest/map/projections/mollweide.htm
[41] https://desktop.arcgis.com/en/arcmap/latest/map/projections/mercator.htm

There are projections that are better suited to different latitudes, continents, regional sizes or shapes. The shape of the countries or the areas to be mapped may dictate which projection is worth choosing to have a single, but sufficiently low distortion zone suitable for mapping. Countries that extend in a north-south direction (e.g. Chile, Portugal) have chosen the transverse Mercator projection, while for states that extend in an east-west direction (such as Belgium or Estonia) the Lambert projection is suitable.). In Hungary this is the Egységes Országos Vetület (EOV). This is an oblique, conformal, so-called recessed cylindrical projection. Its base surface is the HD72 datum (Hungarian datum 1972) which is based on the IUGG 67 ellipsoid.

More on map projections: https://pubs.usgs.gov/gip/70047422/report.pdf

Why is it important for us to learn a little about reference systems and projections? Reference systems are impossible to get around while using GIS software. It determines the results of different calculations, or the use of geoprocessing tools and the choice of projection fundamentally affects the appearance of our map. Although the underlying mathematics is very complicated, switching between reference systems and projections is relatively easy and straightforward in every GIS software.

3.2.A few basic concepts of cartography

We have already established the definition of the map at the beginning of this chapter. The definition reveals two key concepts that require detailed explanation: **scale and generalization**. Generalization is the process of simplifying the representation of geographic features on a map. Since maps are limited in space and scale, not all details from the real world can be included. Generalization involves selecting, reducing, or simplifying information to make a map clearer and more readable, while still maintaining its accuracy and usefulness for the intended purpose and on the chosen scale.

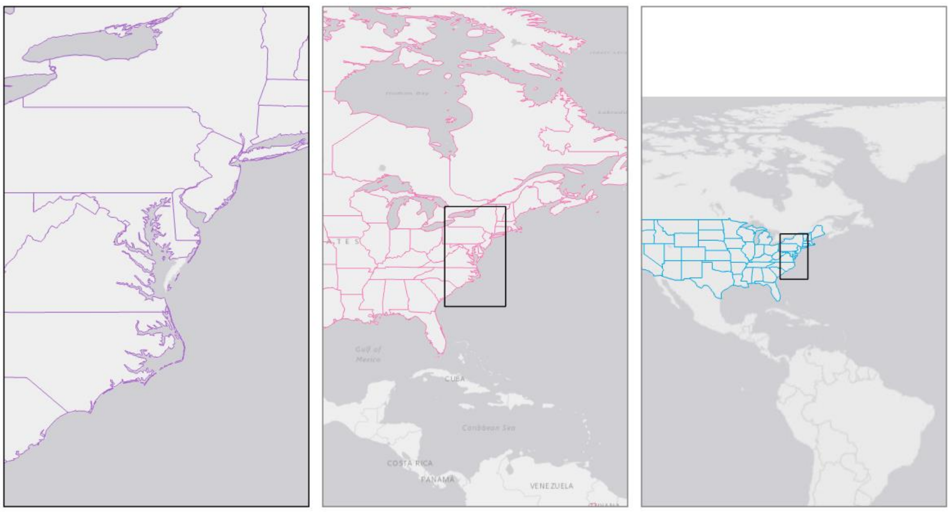


Figure 16. Natural Earth data through scale: 1:10m (left), 1:50m, (center), 1:110m (right)

Source: Cary Anderson© Penn State is licensed under CC BY-NC-SA 4.0(link is external). Data Source: Natural Earth, Esri (basemap from ArcGIS). https://www.e-education.psu.edu/geog486/node/912

This leads us to the other key concept in cartography which is scale. Simply defined, scale is the relationship or ratio between distance on the map and distance on the Earth. For example, a scale of 1:10000 means that 1 cm on the map represents 10 000 cm in reality. The larger this number is, the smaller the scale of the map. This could sound confusing, but it is quite logical. If 1 cm represents 10 000 cm (which is 100 m) on a map that means its level of detail is very high compared to a map with a scale of 1: 1 000 000 where 1 cm shows 10 kilometers. Let's see another example. A map covering an area of 100 kilometers by 100 kilometers drawn at a scale of 1:10 000 would be 10 meters by 10 meters in size. To make this map more practical, either the scale must be reduced, or the area covered must be smaller. If the scale is reduced to 1:50 000, then 1 centimeter on the map represents 500 m on the surface. This means that an area of 100 kilometers by 100 kilometers would fit on a sheet that is 2 meters by 2 meters which is still an unmanageable size. In order to be usable probably the size of the map should be reduced. A map covering an area of 50km *50 km with a scale of 1:50000 results in a 1m*1m map. (Whether the level of detail of the map meets the intended purpose is another very important question)

Based on their scale there are different map categories:

- Large scale maps (high level of detail): < 1:10 000 (e.g. city maps)
- Medium scale maps (medium level of detail): 1:10 000 – 1:200 000
- Small-scale maps (low level of detail): >1:200 000 (e.g. world maps)

We have already established that maps can be categorized according to their scale and projection as well. They can also be categorized according to their format (digital, paper) or their content or purpose.

- **Reference maps**: Provide general information about the geographical conditions, administrative divisions, and other physical characteristics of an area. Examples include administrative, relief, transportation, or topographic maps. A **topographic map** is a detailed and accurate representation of natural and human-made features on the ground. What makes it unique is that it shows elevation using contour lines, which indicate the shape and height of the land.
- Navigation maps: Contain specialized information for air and water navigation.
- Cadastral maps: Large-scale maps representing property and land boundaries.
- **Thematic maps** (see below)

4. Thematic maps

While traditional maps (e.g. reference maps) represent geographic features such as roads, rivers, and political boundaries, the purpose of thematic maps is different. Thematic maps are designed to illustrate the spatial patterns of different social or natural phenomena, such as population density, climate, economic activity, disease spread etc.

Thematic mapping is a special and efficient way of data visualization, helping to communicate complex spatially relevant information in an accessible and visually appealing way. By using colors, symbols, and different mapping techniques, thematic maps are able to reveal relationships and trends that might not be immediately visible from raw data alone. This subchapter explores the different types of thematic maps and their most important design principles.

4.1. Types of thematic maps

4.1.1. Area maps: unique value and graduated colors/ choropleth maps

This is the simplest thematic mapping method which shows data in areas or different spatial units. An area map can be created with **unique value** method when each category is associated with a different color. Common examples include habitat types, planning zones, voting preferences, and soil classifications. The unique values map contains qualitative data, highlighting the fundamental differences between features.

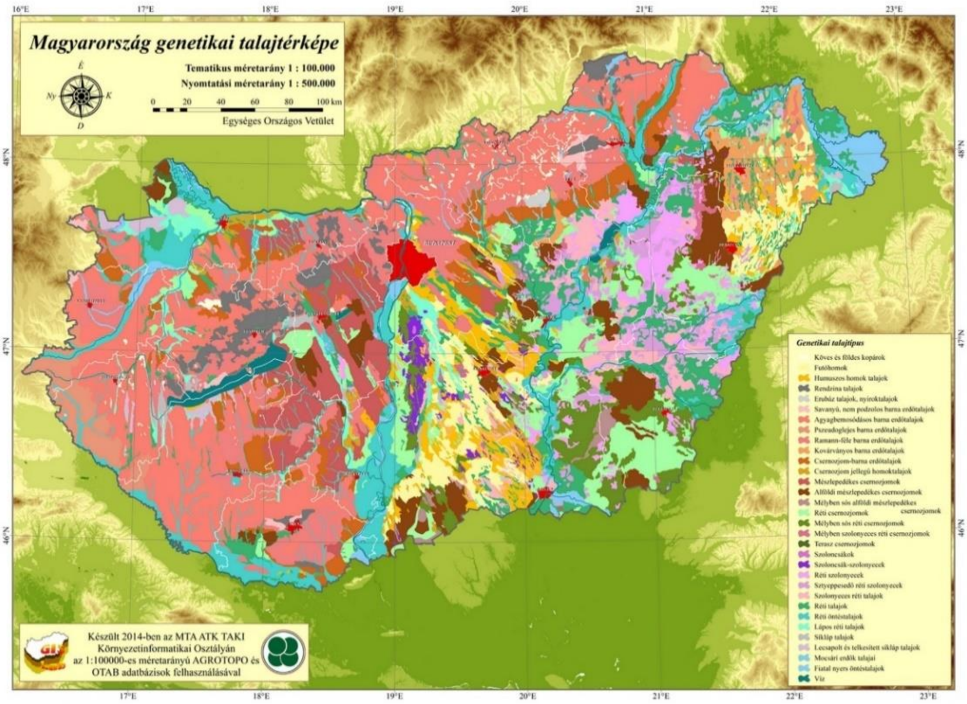


Figure 17. Soil types in Hungary – every soil category is represented with a different colour
Source: https://agrobio.hu/images/images/2048x2048/140637591054b8f39e8dbc7.jpg

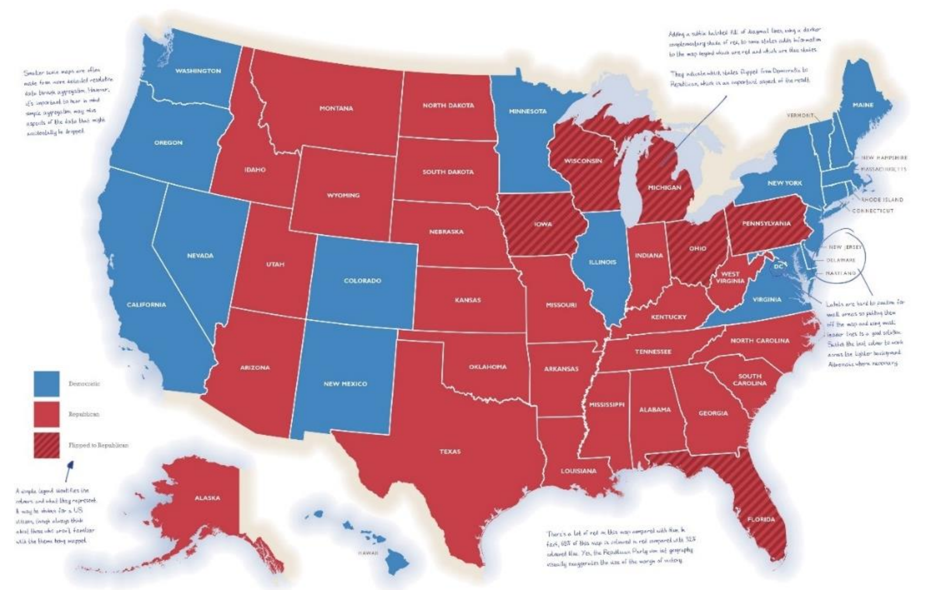


Figure 18. A unique value map showing the result of the 2016 presidential election in the USA
Source: Field, 2022 p. 28.

Choropleth (or graduated colors) maps are the most common and popular thematic mapping technique although they are not so fancy from the perspective of today's data visualization trends. It represents predominantly quantitative data for areas by variations in shading or patterns. Data normalization is essential when creating coropleth maps to handle the unevenness of population and geography (Field, 2022). It means that the values should be expressed in in the percentage of something (e.g. population or another variable). With the classification of data choropleth map can reveal areas with similar characterisctics which can draw out meaningful spatial patterns. A **continuous color scheme** is usually selected to apply varying shades of the same color, with lighter shades representing lower values and darker shades indicating higher values.

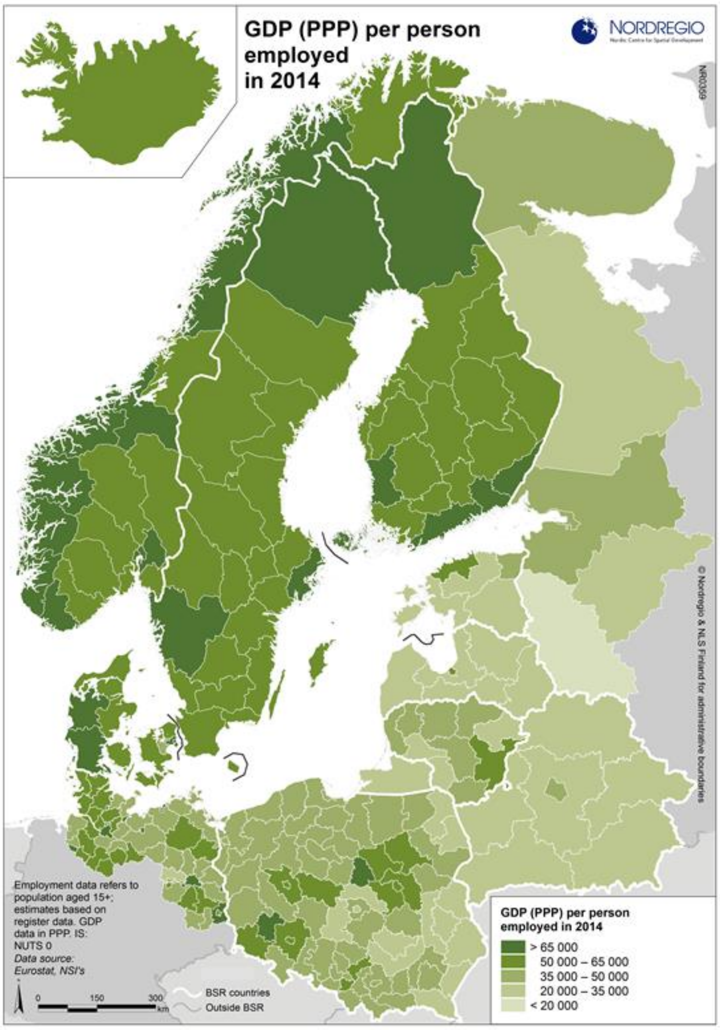


Figure 19. A coropleth map with a continuous color scheme

Source: https://nordregio.org/wp-content/uploads/2018/03/GDP_PPP_per_person_employed_Nordic_2014.png

On the other hand, there are several cases when the dataset has an inflection point at a central value (usually 0, but it can be the average as well). Common examples are population growth rate or temperature. Instead of using a continuous color scheme where a midrange color represents values near the central value, you want to emphasize that the central value is a key inflection point in the data distribution (Field, 2022). This can be achieved by introducing a break in that symbol class and applying a **diverging color scheme**.

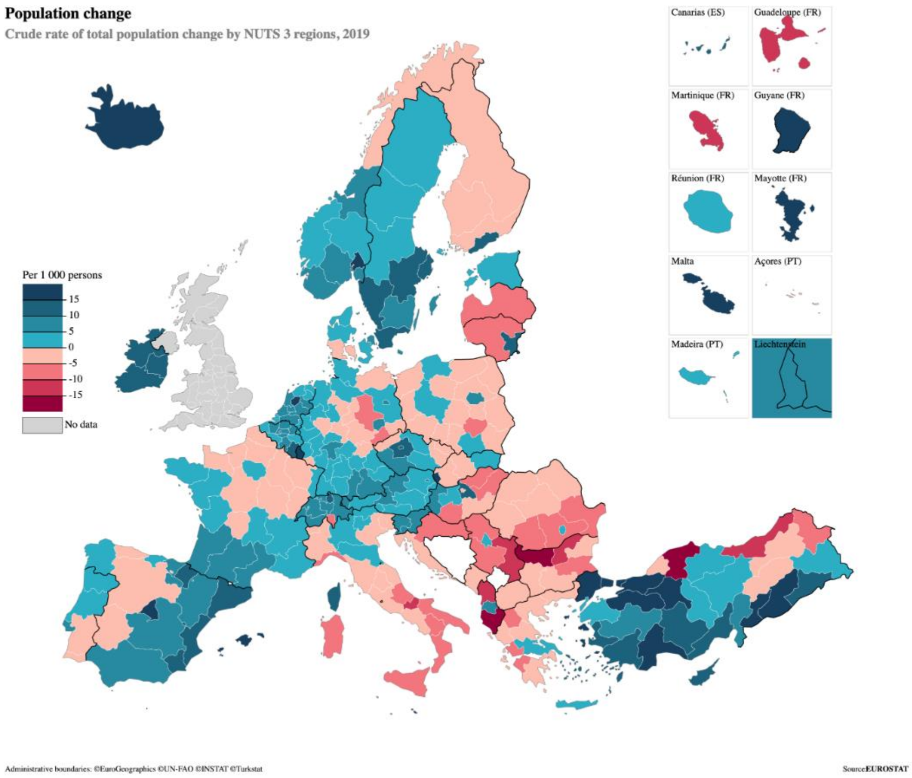


Figure 20. A coropleth map with diverging color scheme
Source: https://data.europa.eu/apps/data-visualisation-guide/choropleth-maps

Choropleth maps can also be used to show categorical data instead of numerical.

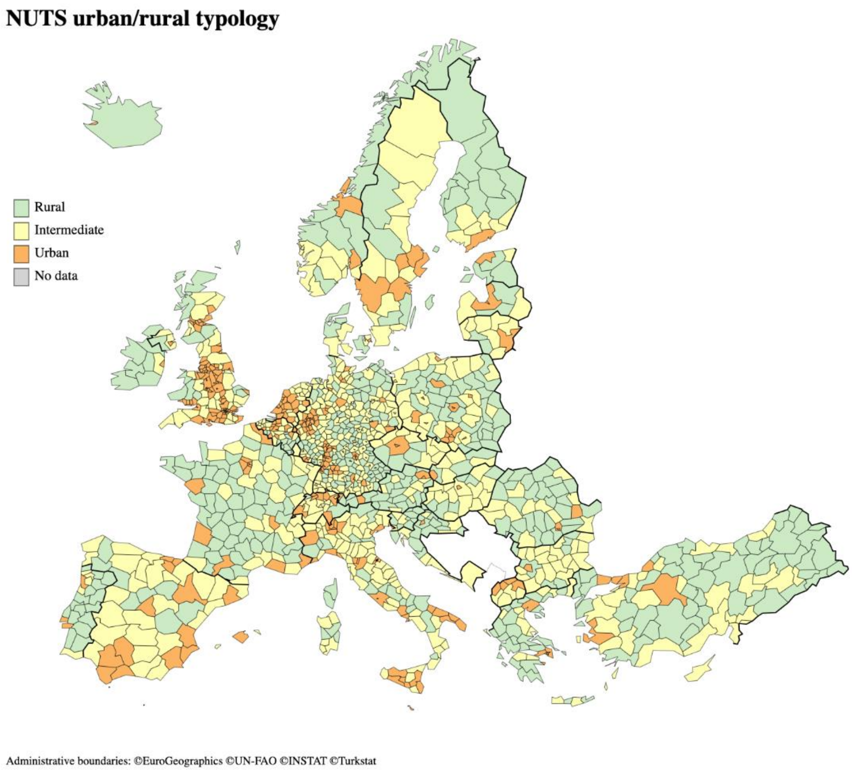


Figure 21. A choropleth map showing different categories
Source: https://data.europa.eu/apps/data-visualisation-guide/Maps%20e22d0627fc944d47be79a1d1a4f8acef/categorical-choropleth.png

A special type of choropleth maps, called bivariate choropleth map allows to illustrate the relationship between two different data variables. This is usually done using a grid where each axis represents one of the variables. For example, when mapping GDP alongside life expectancy, we can identify countries that are both wealthy and have high life expectancy, as well as those with more contrasting profiles. They allow us to compare and analyze multiple datasets at once, making it easier to spot clusters, outliers, and correlations that might otherwise go unnoticed[42]. On the other hand, because of their visual complexity they can be hard to read or interpret.

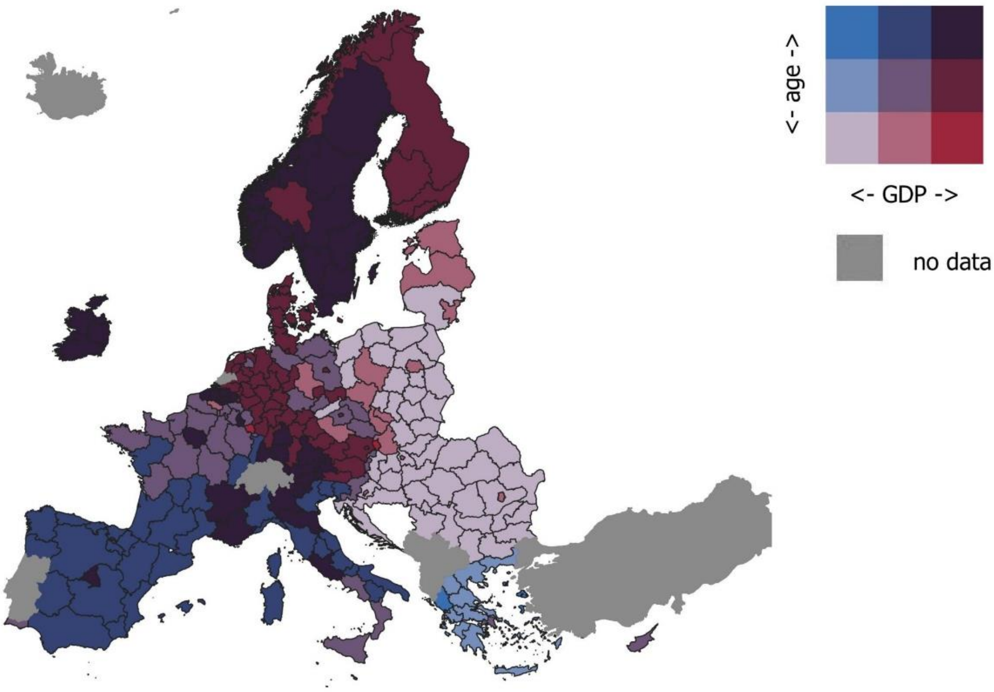


Figure 22. A bivariate choropleth map
Source: https://geoawesome.com/wp-content/uploads/2024/09/Output-2048x1448.jpeg

4.1.2. Point maps: graduated symbol, proportional symbol, dot density maps

Area maps are useful, but their major drawback is that the solid filled space creates the impression that values are uniform across the entire area (Field, 2022). In fact, it is a point-based, one-dimensional value, which can also be displayed using a point-like symbology. There are two main methods to symbolize data that represent aggregated counts for areas as point-based objects or a series of points: graduated symbols and proportional symbols.

Graduated symbol maps illustrate quantitative differences between mapped features by adjusting symbol size. The data is distributed into ranges, or distinct classes with each range or class assigned a specific symbol size. For example, if there are five data classes, five different symbol sizes will be used, while the color remains the same. This method offers precise control over symbol size since it is not directly tied to individual data values.

[42] https://geoawesome.com/understanding-bivariate-maps-a-how-to-guide/

In contrast, when symbol size is directly proportional to data values, this is known as the **proportional symbol** method. Proportional symbols visually represent quantitative data using unclassified symbols, scaled according to each specific value.

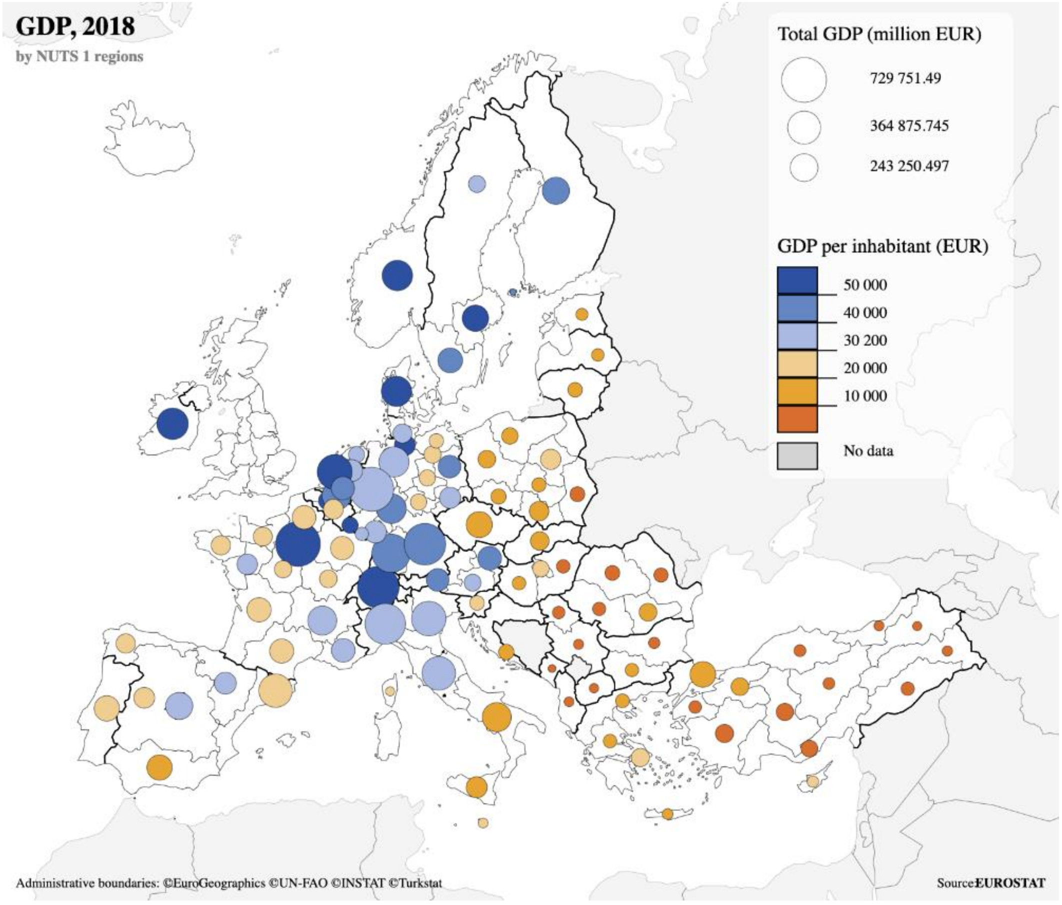


Figure 23. A proportional symbol map

Source: https://data.europa.eu/apps/data-visualisation-guide/Maps%20e22d0627fc944d47be79a1d1a4f8acef/proportional-symbol-choropleth.png

Although geometric shapes (circles, squares) are the most widely chosen symbols in these methods because the connection between the values and the area of the shapes is understandable enough. Basically, the symbol can be anything even abstract features like logos (Field, 2022) Proportional symbol method allows to use diagram as well, which method is particularly useful for visualizing more than one component.

A dot density map (distribution map) represents spatial distribution and density of a quantifiable phenomenon within a spatial unit (polygon) with a collection of point symbols, where each dot represents the same constant value, but the placement of the dots is random and not linked to specific locations within the area. The dots are equally sized. A famous map of this type is the “Rouge map of Hungary” prepared for the Trianon treaty by Paul Teleki to illustrate the distribution of nationalities in the Carpathian Basin.

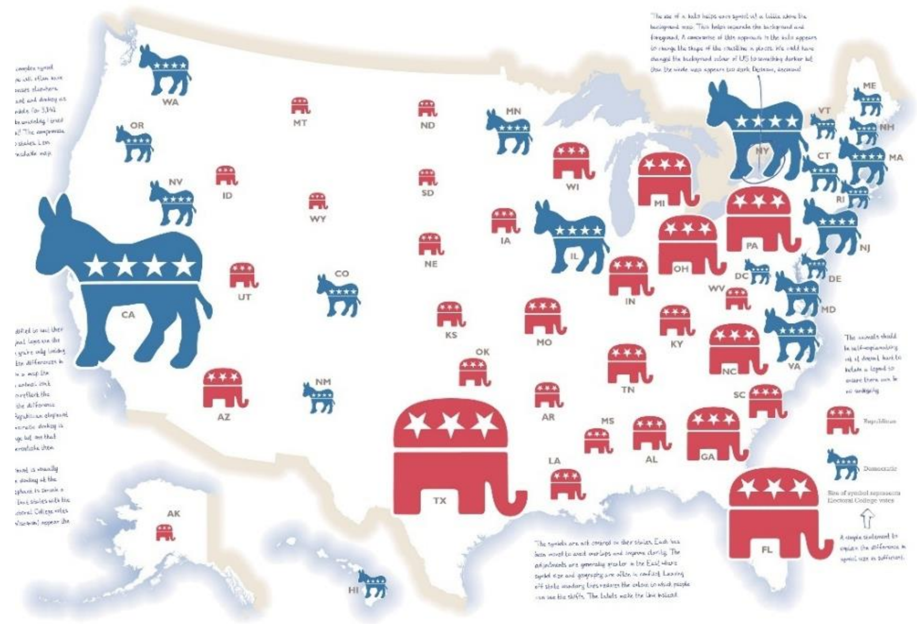


Figure 24. A proportional symbol map using logos as symbols

Source: Field, 2022 p. 54.

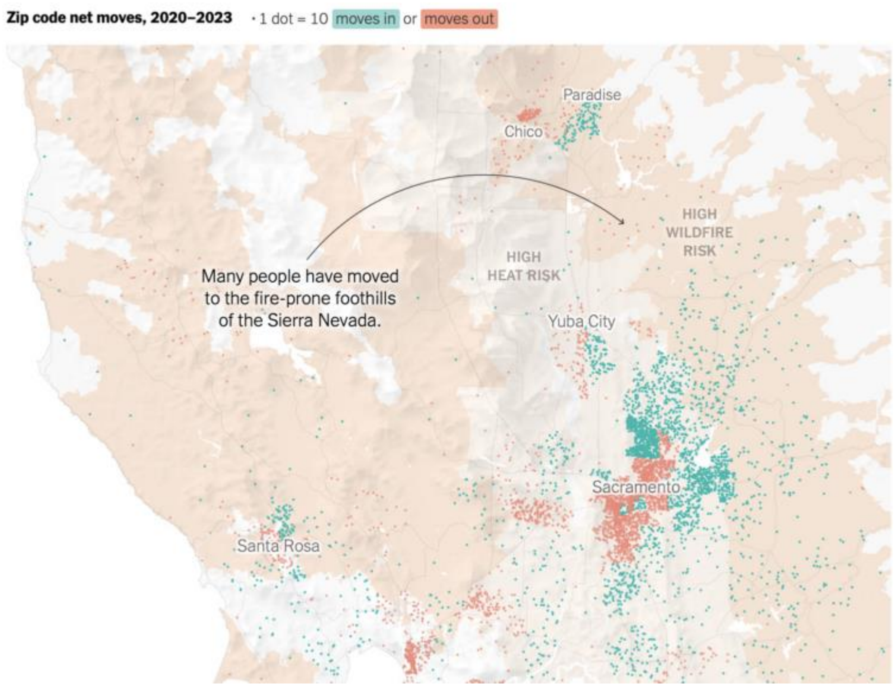


Figure 25. Dot density map of migration out of cities in the USA

Source: https://flowingdata.com/2024/10/03/migration-cities/

4.1.3. Line maps: flow maps, isopleth maps, heath maps

Line maps are usually used for displaying specific thematic data (often related to physical geography features) like temperature or atmospheric pressure.

A **flow map** shows spatial change or movement of tangible or non-tangible phenomenon from one location to another. The flow is represented by lines, often varying in width to indicate differences in the flow's quantity or magnitude. There are three primary types of flow maps: radial, network, and distributive. On a radial flow map locations and features are mapped in a nodal fashion, with one place serving as a common origin or destination. Network flow maps display the connections and exact routes between places, usually focusing on transportation or communication links. Distributive flow maps commonly show how a phenomenon flows from origins to multiple destinations.[43] They show the exact start and end points, while they do not represent the precise route[44].

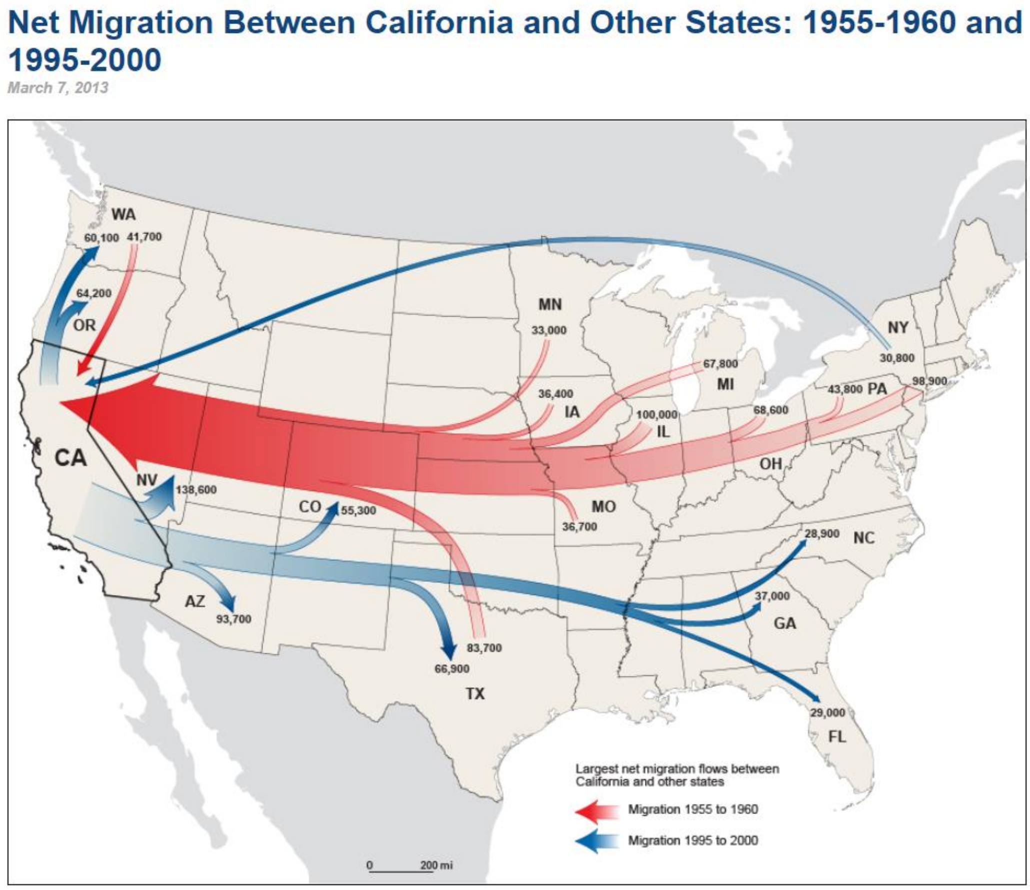


Figure 26. A distributive flow map

Source: https://www.e-education.psu.edu/geog486/sites/www.e-education.psu.edu.geog486/files/Lesson_05/Images/5.8.1.PNG

An isopleth map represents phenomena by connecting points with the same value using lines (isolines). Space in between lines is shaded as a single class similar to choropleth maps. This method creates a more organic and fluid appearance and eliminates the MAUP (modifiable area unit problem) which refers to phenomena when the structure and the borders of the administrative units fundamentally shapes the view of the data (see later) (Field, 2022).

43 https://www.esri.com/arcgis-blog/products/arcgis-desktop/mapping/creating-radial-flow-maps-with-arcgis
44 https://www.e-education.psu.edu/geog486/node/859

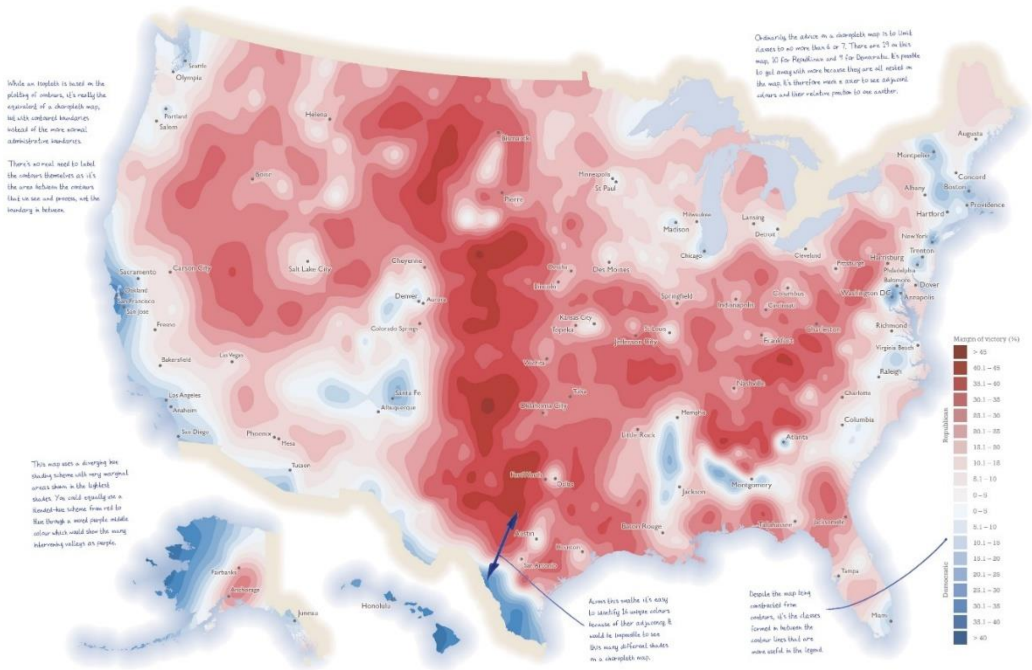


Figure 27. An isopleth map showing the margin of victory in the 2016 presidential election in the USA

Source: Field, 2022 p.93

Area maps	Point maps	Line maps
• unique value • choropleth (graduated colors) • bivariate choropleth	• graduated symbol • proportional symbol • dot density	• isopleth map • flow map

Figure 28. Summary of map types

4.2.The question of classification

Classification is crucial while making a thematic map, especially creating a choropleth map. Depending on the chosen classification method, the results can be very different, and the maps tell us a whole different story. In the following, we will review the most widely used classification methods, which are also offered by GIS software.

Quantile
Quantile classification is ideal for linearly distributed data, as it ensures that each class contains the same number of data values. This method prevents empty or disproportionately large or small classes. However, because features are evenly distributed among classes, the resulting map may sometimes be misleading. Similar values might be placed in different classes, while very different values could end up in the same class. To reduce this distortion, increasing the number of classes can be helpful[45].

Equal Interval Classification
This method divides the range of attribute values into equal-sized intervals. You specify the number of classes, and the software automatically determines the class breaks based on the data range. For example, if a dataset ranges from 0 to 300 and you choose three classes, the intervals would be 0–100, 101–200, and 201–300. Equal interval classification works well for data with familiar scales, such as percentages or temperatures, emphasizing the relative magnitude of values[46].

Natural Breaks (Jenks) Classification
This method identifies natural groupings within the data by creating class breaks that best cluster similar values together while maximizing differences between classes. Since it is tailored to the specific dataset, it provides a meaningful representation of the data's distribution. However, this approach is not ideal for comparing multiple maps based on different datasets, as the class breaks will vary depending on the underlying data[47].

Manual intervals
Setting intervals manually is often arbitrary but in specific cases automatically applied classification needs to be manually adjusted (e.g., assigning a separate category for 0 or ensuring that negative and positive numbers are not grouped together).
It is important to note that there is not a single best method to classify data. Classification depends on the purpose of the map, the intention of its creator and even the map reader's needs. So, the main question we must answer when choosing a classification method is what do we want to tell and which method is best suited to the data distribution.

Number of classes
The next question is how many classes we should use. With too few classes, the map cannot show any meaningful detail or spatial pattern, too many classes on the other hand make the map unreadable or hard to interpret (Field, 2022). Since the limit of readability or human perception is at around eight colors/categories, the optimal number is somewhere five to seven classes. There is a more scientific approach, however, to define the optimal number of classes. The equation below can help to define the upper limit of classes depending on the number of spatial units (ELTE Regionális Földrajzi Tanszék, 2005).

$$k = 1+3,3*\log n$$

where
k= number of classes
n= spatial units

[45] https://pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm
[46] https://pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm
[47] https://pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm

Cartograms

As we mentioned before, the most important requirement towards a thematic map is that it should make comparison possible. In a paradox way, geography often compromises this through its unevenness (Field, 2022). The area of the spatial units is uneven just like the population or any other phenomenon in space. This causes perceptual and cognitive difficulties in the comparison of spatial units. Cartograms remove the inherent visual biases of geographic maps by altering the original geometry (size, shape). They represent geographic space in a diagrammatic way, thereby losing the connection to actual geographic coordinates (Field, 2022). In other words, on a cartogram, the size of features (spatial units) is adjusted to be directly proportional to a chosen variable, such as population or gross national income[48], while their original shape and/or position can be modified or distorted accordingly. Too much distortion and modification can compromise readability, so it is advisable to keep either the original shape or adjacency.

Figure 29. A cartogram showing the world population

Source: https://ourworldindata.org/cdn-cgi/imagedelivery/qLq-8BTgXU8yG0N6HnOy8g/4e03e8ca-8d4d-4cba-e600-695f98fb6700/w=1350

48 https://en.wikipedia.org/wiki/Cartogram

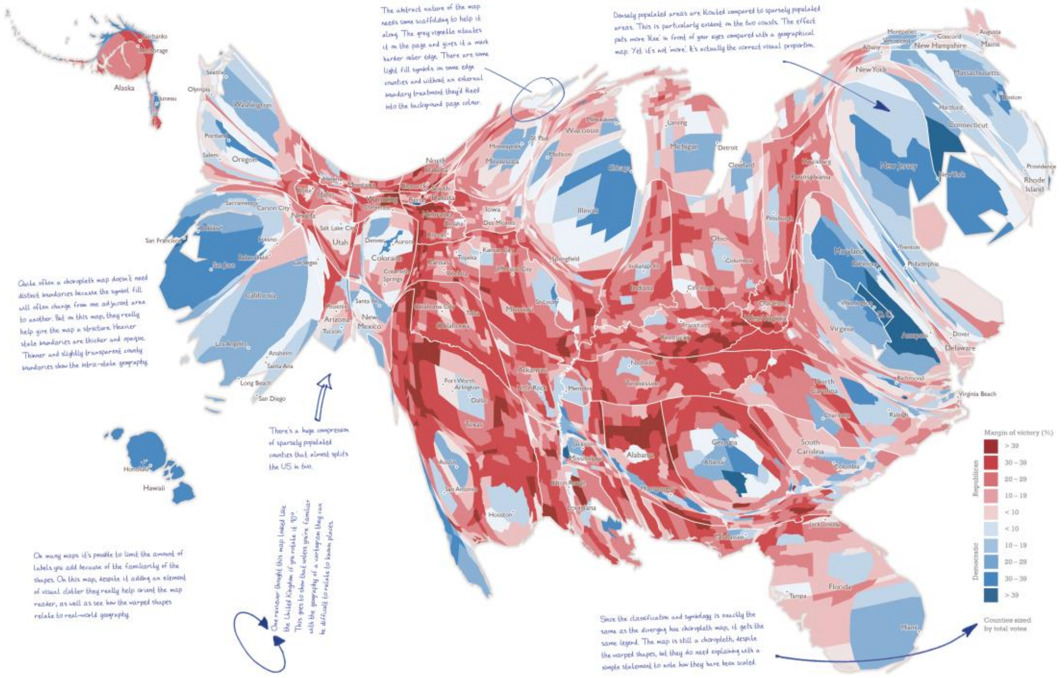


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Figure 30. A Population density–equalising cartogram also known as Gastner-Newman cartogram

Source: Field, 2022

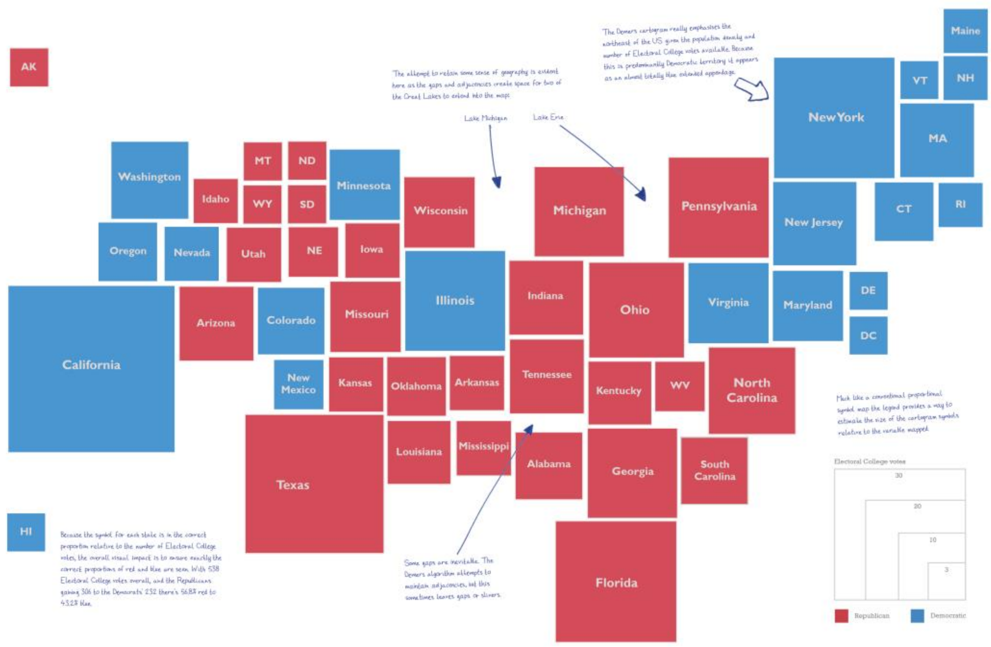

Figure 31. A Demers cartogram maintains adjacent relationships while changing the original shapes to proportional squares

Field, 2022

4.3.Important considerations when creating a map

While there is no single best way to create a map, there are quite a few considerations that need to take into account. We have collected some of them below.

First, **choosing the appropriate projection** is very important. As we discussed earlier it fundamentally depends on the area (country, region, continent) that you wish to display on the map. The other very important aspect regarding the projection is that you must choose an equal area projection for thematic mapping. On of the main tasks of a thematic map is to compare the different areas to each other. Geography often makes this comparison difficult because there could be large differences in the area of each territorial unit. Choosing a projection which is not an equal area one makes this even worse by distorting the areas of spatial units.

Data availability, especially the level of spatial units, determines the process of thematic mapping. Mapping methods should be chosen according to the nature of the data and the available spatial level. For example, at the level of Hungarian settlements, of which there are about 3200, we do not use proportional symbols.

Choosing the **right colours and colour scheme** is essential. Color itself has obvious connotations that most people are familiar with (e.g. the Republican Party is red the Democrats are blue, or high temperatures are red low temperatures are blue, water is also blue). If color has a particular meaning, you should take it into consideration and emphasize that meaning. In other cases, it is better to choose a neutral color palette. Websites or applications like Color Brewer[49] can help to choose an appropriate and aesthetic color scheme.

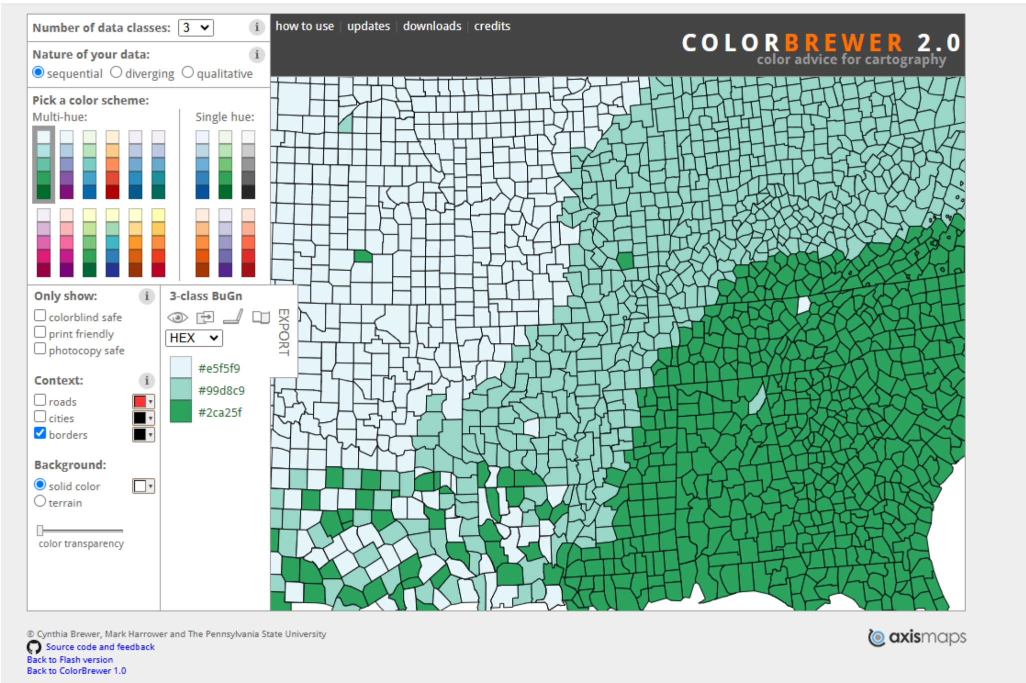

Figure 32. Screenshot of the ColorBrewer application

Strive for simplicity in design and in content as well. Use soft colors and clean font to create a map which is easy to read and good to look at.

[49]https://colorbrewer2.org/#type=sequential&scheme=BuGn&n=3

When creating a map, it is **important to consider the format** in which the map will appear (in print or digitally.) For example, if your map appears in a grayscale in a journal, you may choose a different color scheme. Digital format allows greater freedom, and you can even display changes in time as well with the appropriate methods, or display labels and other contextual information in a switchable layer

You must always **keep in mind the *modifiable areal unit problem*** (MAUP), which fundamentally affects how your map looks and what story it tells. MAUP arises from the fact that we use artificial boundaries or units on continuous phenomenon which results in an artificial spatial pattern (Field, 2022). Different boundaries result in different maps and different spatial patterns. (A well-known, infamous example of this problem is gerrymandering in election mapping. Which is the intentional modification of electoral districts for political gain.) „MAUP always imbues your map with inherent bias, because the spatial patterns you map, are controlled by how the boundaries were drawn" (Field, 2022 p. 22.). MAUP is hard to eliminate in area maps, but by using a detailed spatial division it is possible to weaken its effect. The smaller the spatial unit we display, the more detailed spatial pattern will emerge. Isopleth maps can fix this problem because they do not work with artificial boundaries, but they can be problematic because of the availability of data which is usually collected and recorded in definite (and artificial) spatial (often administrative) units.

"Cartography is always a compromise, or else there would be a single best way to make the map" (Field, 2022 p. 34)

4.4.Sources

- Websites and online sources are shown in footnotes, only scientific and other publications which has intertextual references are listed here.
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V. Next-Level 3D Spatial Modeling Powered by XR Tech

Ágnes Jenei[50]

1. Spatial and Immersive Analytics: An Overview

Spatial analysis refers to the examination of the locations, attributes, and relationships of features in spatial data. It is a methodological approach applied in fields such as urban planning, navigation, geography, Geographic Information Systems (GIS), statistics, and environmental science. Spatial analysis enables the understanding of patterns, the prediction of trends, and informed decision-making processes (Goodchild, 1987; Fotheringham et al., 2000; Shekhar & Xiong, 2008; Longley et al., 2015). Foundational work by Ben Shneiderman (1996) on information visualization, including the "Visual Information-Seeking Mantra," laid important principles for data exploration and analysis that underpin spatial data visualization.

“Immersive analytics” refers to the visualization of abstract datasets in an immersive 3D environment. In this sort of immersive analytics, visualizations are designed in advance, and users primarily have the goal of foraging: examining the dataset visually to find items, clusters, or trends of interest (Matees et al., 2019; Skarbez et al., 2019). Chris North's research has been influential in advancing 3D visualization and interaction techniques, making significant contributions to the conceptual and empirical foundations of immersive analytics and spatial data exploration (North, 2006).

This section reviews earlier research that established the technical, perceptual, and interactional foundations of immersive analytics, referencing Matees et al. (2019), who synthesized insights from previous works into a clear and practical definition of the field. Finally, we discuss some key publications from 2019 onward that have expanded or refined the definition and scope of immersive analytics.

Bowman et al. (2003), Henry and Polys (2010), Hossain et al. (2012), Bacim et al. (2013), Radics et al. (2015), Kwon et al. (2016), and Cordeil et al. (2017a) laid the basis for applying immersive technologies to data exploration, contributing to the conceptual and empirical foundations of immersive analytics using different approaches. Bowman et al. (2003) and Polys et al. (2010) explored the use of immersive environments (e.g., CAVE systems and VR head-mounted displays) for data visualization. Several empirical studies, including those by Henry and Polys (2010), Bacim et al. (2013), and Kwon et al. (2016), have investigated how immersion affects user performance when interpreting data in three-dimensional spaces, examining the impact of spatial layout, visual encoding, and interactivity on insight generation.

Works by Hossain et al. (2012), Radics et al. (2015), and Cordeil et al. (2017) presented systems for immersive network visualization, multidimensional data interaction, and collaborative analytics in 3D virtual environments. These studies contributed to understanding how

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immersive interfaces support analytical reasoning. An early comprehensive survey by Isenberg et al. (2017) provided a critical synthesis of immersive analytics research up to that point, highlighting challenges and opportunities in the field.

Matees et al. (2019) offered a concise operational definition of immersive analytics: "Immersive analytics refers to the visualization of abstract datasets in an immersive 3D environment. In this sort of immersive analytics, visualizations are designed in advance, and users primarily have the goal of foraging: examining the dataset visually to find items, clusters, or trends of interest." This definition highlights the use of predefined visualizations rather than generative or highly interactive systems. The focus is on visual foraging as the main analytic activity, enabling users to explore spatialized information in search of patterns, anomalies, or structures.

Saffo et al. (2020) introduced a taxonomy based on two main dimensions: how data is spatialized within immersive environments (spatial presentation) and the arrangement of visual elements around the user (visual positioning). This work shifted its focus from simply defining immersive analytics to systematically organizing its design space.

Klein, Sedlmair, and Schreiber (2022) offered a refined definition: "Immersive analytics is concerned with the systematic examination of the benefits and challenges of using immersive environments for data analysis, and the development of corresponding designs that improve the quality and efficiency of the analysis process." This approach emphasizes a systematic approach and frames immersive analytics as both a research agenda and a design challenge, focusing on improving analytical effectiveness through immersive technology.

Elmqvist (2023) broadened the scope further by advocating for mobile and ubiquitous analytics; for analytics environments that are not bound to traditional VR headsets. It advocates for a future where immersive, spatial, and context-aware analysis can happen anywhere, reframing immersive analytics as an experience that is device-flexible, mobile, and adaptive, integrating with AR, MR, and real-world contexts.

Despite its promising potential, immersive analytics faces several challenges and limitations, including the high cost and technical complexity of immersive hardware, user fatigue during prolonged use, difficulties in designing intuitive interaction techniques, and the need for standardized evaluation methods to assess effectiveness across diverse application domains. Addressing these issues is essential to fully realize the benefits of immersive environments for spatial data analysis and decision-making.

2. 3D Spaces and Immersive Environments

To prevent terminological confusion, as seen in the literature, it is important to distinguish between 3D spaces and immersive spaces. 3D, or three-dimensional, refers to objects or images that have width, height, and depth, representing the three spatial dimensions found in the physical world. In computing, a 3D image is a computer-generated graphic that provides a sense of depth, similar to real-world objects. This is achieved by mathematically modeling objects in a virtual space using geometric data, often expressed as Cartesian coordinates, which define their shape, size, and position (Bowman et al., 2003). These models are typically created and manipulated with software tools like CAD systems, allowing designers to interactively build and modify spatial forms (Donath, 1999).

We perceive 3D through stereoscopic vision, where the brain combines slightly different images from each eye to interpret depth (Angelaki & Cullen, 2008). Similarly, 3D graphics simulate this by using techniques such as perspective projection, shading, and lighting to create the illusion of depth on flat screens.

Immersive spaces are environments—either physical or virtual—designed to fully engage and envelop the participant, creating a strong sense of presence and emotional connection. The goal of developing an immersive environment is emotional and psychological immersion, not merely visual realism. Immersive spaces stimulate multiple senses (sight, sound, sometimes touch, and smell) (Slater & Sanchez-Vives, 2016), fostering a feeling of "being-in-the-world" that sets them apart from standard 3D visualizations. While all immersive spaces use 3D environments, not every 3D space qualifies as immersive. Achieving immersion demands additional design and technology to fully engage the senses and emotions, often enabling users to navigate and manipulate the environment intuitively, sometimes through gestures within the space itself (Cordeil et al., 2017a; Paes, Arantes, & Irizarry, 2017).

3. The Spectrum of Immersion

Immersive technologies offer users new ways to perceive, interact with, and interpret three-dimensional digital environments. These include Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—collectively referred to as Extended Reality (XR). The term XR serves as an umbrella concept that encompasses the full spectrum of immersive environments, from fully virtual to contextually augmented (Saffo, Johnson, & Lee, 2020).
The level of immersion refers to the extent to which technology engages the user's senses and creates a sense of presence, which varies across different modalities. Rather than discrete categories, these technologies exist on a continuum of immersion (Klein, Smith, & Zhao, 2022).

1. Virtual Reality (VR): VR offers the highest level of immersion. It fully replaces the user’s physical environment with a computer-generated one. Using head-mounted displays (HMDs), hand controllers, and motion tracking, users can explore and manipulate entirely virtual 3D spaces. This creates a strong sense of presence and embodiment, enabling users to perceive scale, depth, and spatial relationships as if they were physically present in the scene (Bowman, Kruijff, LaViola, & Poupyrev, 2003).

Figure 1. Enjoying Virtual Reality
Forrás: https://www.techlearning.com/features/what-is-virtual-reality

2. Augmented Reality (AR): AR overlays digital information—such as text, images, or 3D models—onto the real-world environment. While traditionally considered less

immersive, AR can still provide contextual immersion when digital elements are spatially aligned and interact with the user's perspective. AR allows users to remain aware of their physical surroundings while gaining additional layers of spatial information. Modern AR applications, particularly those utilizing head-worn displays (e.g., Microsoft HoloLens), are increasingly blurring the line between augmentation and immersion (Elmqvist, 2023).

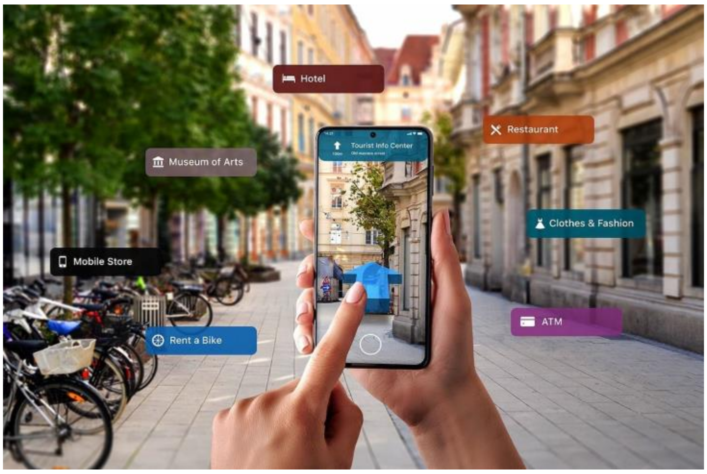

Figure 2. Looking at Augmented Reality
Forrás: https://mobupps.com/blog/augmented-reality-ads-in-action

3. Mixed Reality (MR): MR combines elements of both VR and AR, enabling digital and physical objects to coexist and interact in real-time. It allows users to manipulate virtual elements anchored in the real world and receive real-time feedback. MR often utilizes advanced spatial tracking and occlusion handling, resulting in a more integrated and interactive experience. In practice, MR usually occupies a middle ground, offering immersive capabilities that are similar to those of VR but within a physical context, much like AR (Saffo et al., 2020).

Figure 3. Communicating in Mixed Reality
Forrás: https://azure.microsoft.com/en-us/solutions/mixed-reality/

Together, these technologies form a dynamic spectrum of immersive experiences, each offering unique ways to engage users and transform their perception of digital and physical spaces.

4. Cognitive and Behavioral Aspects of Spatial Perception and GIS in Immersive Environments

Spatial perception — the ability to perceive, interpret, and interact with the spatial features of one's environment—is a complex mental process integrating visual, vestibular, and proprioceptive information. The brain synthesizes these multimodal inputs to form a cognitive map, relying on specialized neural circuits such as hippocampal place cells and entorhinal grid cells (Angelaki & Cullen, 2008; Burgess, 2008; Moser, Kropff, & Moser, 2008).

Key components of spatial cognition include:

- **Spatial memory**: encoding, storing, and retrieving spatial layout information (Burgess, 2008).
- **Distance estimation**: judging relative or absolute distances, influenced by visual fidelity and perceptual calibration in virtual environments (Loomis & Knapp, 2003; Mohler, Creem-Regehr, & Thompson, 2010).
- **Environmental awareness**: recognizing landmarks and spatial configurations (Epstein & Vass, 2014).
- **Wayfinding and orientation**: navigating and maintaining direction, with immersive environments offering high ecological validity for training and assessment (Wolbers & Hegarty, 2010; Parush, Gopher, & O'Toole, 2011; Wang et al., 2023).

Immersive technologies such as VR, AR, and MR significantly enhance spatial perception by simulating interactive 3D spaces that surpass traditional 2D media and flat-screen GIS interfaces (Slater & Sanchez-Vives, 2016; Kim & Billinghurst, 2021).

A Geographic Information System (GIS) interface allows users to view, manage, and analyze spatial data. Traditional flat-screen GIS applications display data on 2D monitors, limiting spatial understanding.

In contrast, 3D and immersive GIS systems incorporate the vertical (z) dimension, enabling detailed modeling of terrain, buildings, infrastructure, and natural features in three dimensions (Bowman et al., 2004; Esri, 2025; Lasecki, Lages, & Yu, 2017; Zhao & Chen, 2023).

Immersive GIS environments allow users to dynamically experience scale, distance, and depth through bodily movement, digital interaction, and real-time feedback from virtual agents. These affordances support embodied spatial learning—also known as experiential spatial cognition—by engaging motor and sensory systems to deepen understanding and memory retention (Ruddle & Lessels, 2006; Krokos, Plaisant, & Teylingen, 2019; Liu & Wu, 2024).

Interaction design and multisensory integration play crucial roles in maximizing the effectiveness of immersive GIS. Incorporating haptic feedback, spatialized audio, and intuitive gesture controls enhances presence and spatial comprehension. However, challenges such as hardware costs, user fatigue, and designing natural interaction techniques remain significant (Wang & Lin, 2021; Thompson et al., 2024).

5. Benefits of Immersion in Spatial Perception

Studies have consistently demonstrated that immersion offers multiple cognitive and behavioral benefits in spatial perception. These include:

- Improved spatial memory retention, especially evident in VR-based architectural walkthroughs and navigational tasks (Waller et al., 1998; Smith & Jones, 2021).
- Enhanced depth perception and egocentric/allocentric switching, facilitating flexible spatial reference frame use (Klatzky et al., 1998; Nguyen et al., 2022).
- Fostering an intuitive understanding of abstract spatial data, particularly within immersive analytics environments where complex multidimensional data can be spatially represented (Bowman et al., 2004; Lee et al., 2023).
- Supporting visuomotor coordination in training environments, such as surgical simulations and engineering tasks, where immersive feedback improves skill acquisition and transfer (Seymour, 2008; Patel & Kumar, 2024).

Moreover, behavioral responses in immersive spaces—such as fear of heights on virtual planks or instinctive obstacle avoidance—demonstrate how the brain treats well-designed virtual stimuli as functionally real (Harris & Menzies, 1998). This functional realism has opened new possibilities in behavioral research, clinical therapy (e.g., phobia exposure and PTSD treatment), and training scenarios where real-world risks are minimized while cognitive and emotional realism is preserved (Parsons & Rizzo, 2008; Chen et al., 2023).

As immersive technologies rapidly evolve, understanding the cognitive-behavioral mechanisms underlying spatial perception in virtual environments is increasingly crucial. This knowledge informs the design of more effective systems for education, design, simulation, and analytics, ensuring that immersive experiences maximize learning, engagement, and transfer to real-world tasks (Dede, 2009; Garcia et al., 2025).

Additional considerations
Recent research also highlights the importance of individual differences (e.g., spatial ability, susceptibility to motion sickness) in modulating immersion benefits, as well as the role of multisensory integration (including haptics and auditory cues) in deepening spatial presence and memory (Wang & Lin, 2021; Thompson et al., 2024). Furthermore, the integration of AI-driven adaptive systems in immersive environments shows promise for personalized spatial training and analytics (Zhao et al., 2022).

6. The Evolution of Virtual Reality: A Comprehensive History

Virtual reality (VR) has undergone a remarkable transformation, evolving from simple optical devices into complex, immersive digital ecosystems that are reshaping how we interact with information, environments, and one another. This section presents a detailed narrative of VR's development, weaving together historical milestones, technological breakthroughs, and the expanding impact of VR across various industries, with in-text citations in the author-year format.

Early Foundations (1838–1930s)
The origins of VR can be traced back to the 19th century, when Sir Charles Wheatstone introduced the stereoscope in 1838. This device demonstrated the principle of stereopsis, showing that the human brain can merge two slightly different images from each eye to create a sense of depth—a foundational concept for all modern VR displays (Wade, 2012).

Wheatstone's invention not only fascinated Victorian audiences but also laid the groundwork for future explorations into immersive media.

In 1935, the concept of VR took a leap forward in the realm of imagination with Stanley Weinbaum's short story "Pygmalion's Spectacles." Weinbaum envisioned a pair of goggles that could transport users into fictional worlds, engaging all the senses and foreshadowing the multisensory ambitions of later VR technologies (Weinbaum, 1935).

The Birth of VR Technology (1950s–1970s)

The mid-20th century saw the first technical attempts to create immersive environments. In 1956, cinematographer Morton Heilig developed the Sensorama, a machine that delivered a multisensory experience by combining 3D visuals, stereo sound, vibrations, and even scents. Heilig's vision was to create the "cinema of the future," immersing users in short films that stimulated all the senses (Heilig, 1962).

Building on this, Heilig patented the Telesphere Mask in 1960, the first head-mounted display (HMD) to provide stereoscopic 3D images and stereo sound, though it lacked motion tracking (Heilig, 1960). Just a year later, engineers at Philco Corporation developed Headsight, the first HMD with motion tracking, originally intended for remote military surveillance rather than entertainment (Philco Corporation, 1961).

In 1965, computer scientist Ivan Sutherland articulated the concept of the "Ultimate Display"—a virtual world indistinguishable from reality, where users could interact with computer-generated objects as if they were real. Sutherland's vision laid the conceptual groundwork for interactive VR and inspired generations of researchers (Sutherland, 1965).

Sutherland, together with Bob Sproull, realized part of this vision in 1968 by creating the "Sword of Damocles," the first computer-driven HMD. This device could render simple wireframe graphics and track head movements, though it was so heavy it had to be suspended from the ceiling (Sutherland & Sproull, 1968).

The 1970s expanded VR's horizons. In 1977, MIT's Aspen Movie Map allowed users to virtually navigate the city of Aspen, Colorado, using photographs and interactive controls—a precursor to modern mapping systems like Google Street View (MIT Media Lab, n.d.).

Expansion and Commercialization (1980s–1990s)

The 1980s marked a turning point as VR began to move from laboratories into commercial and entertainment realms. Jaron Lanier, founder of VPL Research, coined the term "virtual reality" and developed pioneering equipment such as the DataGlove and EyePhone HMD, laying the foundation for modern VR systems (Lanier, 2017). These innovations made it possible for users to interact more naturally with digital worlds.

In 1991, the Virtuality Group launched VR arcade machines that featured networked multiplayer and real-time immersive 3D graphics, bringing VR experiences to a broader public (Virtuality Group, 1991). However, early consumer devices often struggled with technical limitations. For example, Nintendo's Virtual Boy, released in 1995, was the first portable console to display 3D graphics but failed commercially due to its monochrome display and ergonomic issues (Kent, 2001).

The Digital Age and Mainstream Adoption (2000s–2020s)
The 21st century ushered in a new era for VR, marked by rapid technological advancement and mainstream adoption. In 2007, Google launched Street View, revolutionizing spatial visualization and enabling users to virtually explore cities worldwide (Vincent, 2007). By 2010, Google had introduced a stereoscopic 3D mode for Street View, further enhancing immersion.

A pivotal moment arrived in 2010 when Palmer Luckey, an 18-year-old entrepreneur, created the first prototype of the Oculus Rift headset. Featuring a wide field of view and high-quality computer-driven graphics, the Oculus Rift reignited public and industry interest in VR (Luckey, 2012). The subsequent Kickstarter campaign raised $2.4 million, demonstrating strong demand for immersive experiences.

Facebook's $2 billion acquisition of Oculus VR in 2014 marked a significant turning point, providing the resources needed to accelerate VR development and expand its reach (Constine, 2014). That same year, Sony announced the PlayStation VR, and Google introduced Cardboard—a low-cost, do-it-yourself stereoscopic viewer for smartphones—making VR more accessible than ever before.

The HTC Vive, launched in 2016, introduced room-scale tracking, allowing users to physically move and interact with virtual environments. This leap in immersion set a new standard for consumer VR (HTC, 2016).

The Modern Era: Mixed Reality and Beyond (2020s)
The 2020s have seen VR evolve into a broader ecosystem that includes augmented and mixed reality. In 2023, Apple announced the Vision Pro, a mixed-reality headset combining VR and AR capabilities, signaling the entry of another major tech giant into the immersive technology market (Apple Inc., 2023).

The following year, Meta and Pico released new headsets—the Meta Quest 3S and Pico 4 Ultra—emphasizing mixed reality, improved hand-tracking, and enhanced comfort. These developments reflect the industry's shift toward more accessible and versatile devices that blur the boundaries between the virtual and physical worlds (Meta, 2024; Pico Interactive, 2024).

VR's Role in Spatial Analysis and Professional Applications
Today, VR is more than just a tool for entertainment; it is a transformative technology in spatial analysis, urban planning, architecture, and environmental science. Platforms like ArcGIS VR and BIM workflows enable professionals to intuitively explore and analyze complex three-dimensional environments, supporting better decision-making and collaboration (Esri, 2023; Autodesk, 2022). By allowing users to "step inside" data, VR facilitates a deeper understanding of spatial relationships and patterns that are difficult to grasp on traditional 2D screens.

Conclusion
From Wheatstone's stereoscope to Apple's Vision Pro, the evolution of virtual reality is a testament to human ingenuity and the relentless drive to create immersive, interactive experiences. Each technological milestone has built upon the last, bringing us ever closer to seamless integration of virtual and physical worlds. As VR continues to advance, its impact on society, industry, and daily life will only deepen, opening new frontiers for exploration, communication, and understanding.

7. Immersive Technologies in Spatial Analysis: Industry Leaders

Immersive spatial analysis tools have revolutionized the way professionals interact with complex datasets. Leading companies such as Esri, Varjo, and Microsoft develop cutting-edge hardware and software platforms that enable detailed, accurate spatial interaction in fully virtual or mixed-reality environments.

Esri's ArcGIS platform supports immersive spatial analysis through VR and AR, offering tools like ArcGIS Reality Studio and ArcGIS Runtime. These enable creation, editing, and exploration of geospatial data in interactive 3D environments, featuring advanced LiDAR integration and mesh editing for urban modeling. Integration with game engines such as Unity and Unreal Engine empowers developers to build diverse immersive applications spanning urban planning, environmental monitoring, and design.

Varjo provides ultra-high-resolution VR headsets tailored for industrial applications, including aerospace and automotive design, delivering exceptional visual fidelity. Microsoft's HoloLens leads in mixed reality, combining spatial computing with enterprise applications in architecture, engineering, and GIS.

Consumer and enterprise hardware ecosystems include:

- **Meta (Oculus Quest series)**: Accessible standalone VR headsets that support spatial exploration.
- **HTC Vive and Vive Pro**: room-scale VR favored in professional and consumer markets.
- **Sony PlayStation VR**: gaming-focused immersive experiences.
- **Pico**: strong presence in enterprise and education, especially in Asia.
- **Apple Vision Pro**: premium mixed-reality headset merging AR and VR for spatial computing.
- **Valve Index**: high-fidelity VR experience.
- **Magic Leap**: an enterprise mixed reality solution with a smaller market share.

Despite rapid advancements, immersive spatial analysis faces challenges: high hardware costs, user fatigue during extended use, complex interaction design, and a lack of standardized evaluation methods across domains (Elmqvist, 2023; Klein, Sedlmair, & Schreiber, 2022). Addressing these challenges, alongside ethical considerations such as data privacy and user consent, will be crucial to harnessing the full potential of immersive technologies.

8. 3D and Immersive VR Applications for Enhanced Spatial Awareness and Analysis

Virtual reality is increasingly utilized across disciplines to provide immersive means of understanding space, structure, and systems. From geospatial analysis to anatomy and engineering, VR enables intuitive, interactive engagement with information.

ArcGIS CityEngine VR enables urban planners to explore 3D city models in an immersive environment. Users can assess spatial effects, such as shadowing, density, and visual changes, by virtually navigating proposed developments. The platform supports public engagement, mobility, infrastructure planning, and environmental impact assessments, such as green space distribution and noise analysis (Esri, 2025).

Figure 4. ArcGIS CityEngine VR

Forrás: https://www.esri.com/en-us/arcgis/products/arcgis-cityengine/overview?rmedium=www_esri_com_EtoF&rsource=/en-us/arcgis/products/esri-cityengine/overview

Urban Immersive offers interactive 3D virtual tours with real-time voice communication, making them ideal for virtual property walkthroughs. It’s used in real estate, tourism, education, and community planning to explore spaces together with live guides. The platform combines immersive navigation with live interaction, enhancing engagement and collaboration.

Figure 5. Urban Immersive

Forrás: https://www.urbanimmersive.com/

Google Earth VR allows users to explore the entire planet in fully immersive 3D, from cityscapes to natural wonders. With a VR headset, users can fly over mountains, walk through streets, or glide across oceans, all with stunning realism. It's an ideal tool for education, virtual tourism, and spatial awareness.

Figure 6. Google Earth view

Forrás: https://store.steampowered.com/app/348250/Google_Earth_VR/

In medical education, [Virtual Anatomy VR](#) offers immersive anatomical learning with interactive body systems, allowing users also to explore blood vessels virtually.

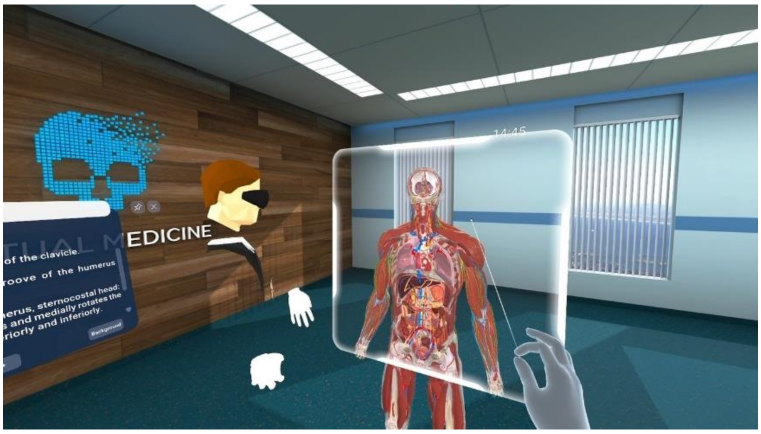

Figure 7. Virtual Anatomy VR

Forrás: https://www.medicinevirtual.com/

[Osso VR](#) focuses on medical training and surgical simulation, offering realistic practice scenarios for medical professionals.

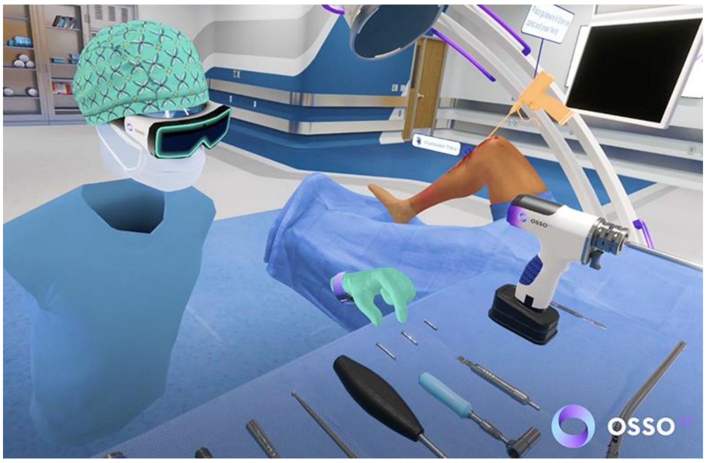

Figure 8. Osso VR

Forrás: https://www.massdevice.com/osso-vr-launches-controller-free-option-for-its-surgical-training-vr/

ORamaVR empowers content creators and medical institutions to mass produce high fidelity medical simulation content through MAGES Software Development Kit (SDK).

Figure 9. Orama VR

Forrás: https://schon.ch/oramavr-medical-vr-training/

Flight simulators in VR provide a realistic flight simulation environment**.** When combined with a motion simulator, the experience becomes even more immersive and intense, enabling users to enhance their situational awareness and decision-making skills in various conditions.

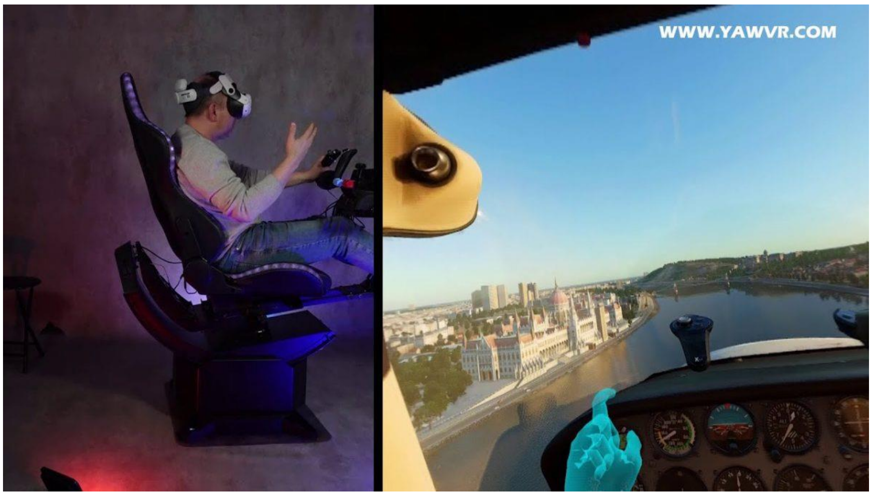

Figure 10. Flight simulation VR

Source: https://www.yawvr.com/

VIVED Learning offers an interactive 3D learning platform covering a variety of subjects, including Anatomy, Chemistry, Science, and Carpentry. Through virtual dissections, chemical simulations, scientific models, and practical carpentry training, VIVED enhances understanding and engagement, making it a valuable tool for both general education and vocational training.

SimLab VR Studio offers comprehensive vocational training solutions using immersive VR. It enables realistic and interactive learning environments across various industries, such as electrical work and HVAC. Users can create multi-user VR sessions without programming skills.

Figure 11. SimLab VR Studio
Forrás: https://www.simlab-soft.com/use_cases/simlab-vr-mechanical-cad.aspx

History comes alive through immersive VR experiences, such as Horizon of Khufu, which allows users to explore the Great Pyramid of Giza virtually. This educational VR experience offers a detailed, interactive journey into ancient Egypt, allowing users to walk through the pyramid's chambers, decipher hieroglyphs, and witness historical events within a fully immersive environment.

Figure 12. Horizon of Khufu
Forrás: https://horizonkheopsexperience.com/atlanta/

Similarly, **VR Tours Official** in Budapest's Buda Castle offers an immersive walking tour using 360° scenes to recreate 700 years of history. By combining real-world movement with geolocated VR.

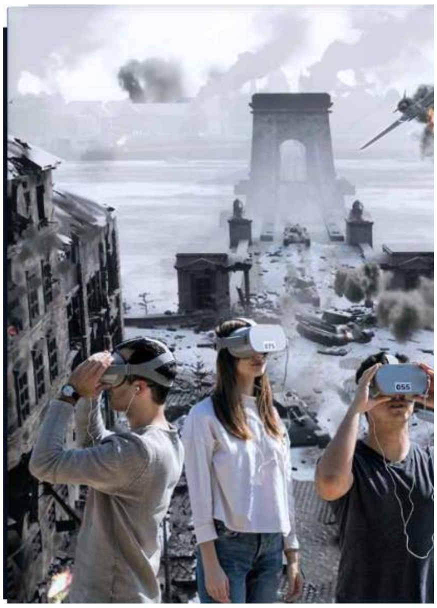

Figure 13. VR Tours Official Budapest
Forrás: https://vrtoursofficial.com/

These few examples, by no means exhaustive, illustrate the transformative power of immersive VR in enhancing spatial understanding across various fields. As VR technology advances, improving user interaction design and overcoming current limitations will be crucial to fully realizing its benefits in spatial cognition and real-world applications.

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