UNIVERSITY OF PÉCS
Faculty of Sciences
Doctoral School of Earth Sciences

Practical applications of time-scale mapping

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Introduction

Humans meet with the nature of passing time from various aspects in everyday life. From time to time, especially at prominent life times, humans evaluate their antecedent life (Freitag 2006).

Over our daily activities, especially for modern mankind, time is extremely important; its shortage is probably the most crucial entity for civilized man, i.e. it is both valuable and indispensable. One of our most commonly asked questions are the followings: When was it? When is it going to be? How long does it take? How long will it last?

For several scientific topics, the fourth dimension (time) is essential; it is especially true for history and geography. The latter one primarily focuses on spatial attributes; however, besides the spatial prospective, temporal changes are also important issues in geographical, and generally in scientific research.

The Swedish geographer, Torsten Hägerstand significantly contributed to the evolution of spatio-temporal research. His research primarily focused on the spatial and temporal analysis of human careers. Hägerstand and his co-workers produced substantial scientific results on the correlation between micro-scale changes and population distribution patterns (Nemes Nagy 1998, Haggett 2006).

Time space analysis and mapping of time has a long history, as early maps and cartographic representations often (typically) used time for distance scales and units; time space was common base for travel guides used for Roman itineraries and later for military maps.

Both Hungarian and international literature on time-based mapping is scarce. There are very few researchers and research groups that specifically focus on time space research.

Materials and Methods

- Calculation of time space distances were based on the 2009 Pécs local and distance bus and coach service time tables.
- The automation of space-time transformation was facilitated with the use of GIS softwares (GRASS GIS 6.4, ArcGIS 10) and a unique program (a perl script)
- During the literature review and the individual research I have defined and introduced new cartographical terms in Hungarian
- The doctoral dissertation itself provides a methodological description for the generation of time-scale (time space) maps

Objectives

The main objective of the current dissertation is to present the generation and analysis of time space (time scale) maps, of particular importance of the followings:

1. Scientific interpretation of time space maps and determination of spatial location of inter-point sites on time space maps with the aid of adequate and relevant literature.
2. Defining the meanings of the following terms: time-distance, time scale, time space, time relief (time surface); scientific interpretation of the English terminology.
3. Elaboration of the methodology for time space paper-based and digital maps.

   The current dissertation provides a methodological description, through a case study, on the analytical methods and approaches used for time space map generation. During the main phase of the dissertation, through three case studies, I have focused on the following research problems:

   - The first case study discusses the major factors responsible for the spatio-temporal pattern of settlements;
   - The second case study focused on the spatio-temporal consequences of the asymmetrical behavior of travel times;
   - The third case study explores and exploits the advantages, drawbacks, limitations

and potentials of the various transformation procedures used during the generation of publicly available maps.

4. Mathematical description of time space maps, presentation of projection equations.
5. The ultimate goal of the presented research is the generation of a cartographed overview. traffic map where distances interpreted as time dimensions.
6. Elaboration of the legend for the aforementioned Pécs time map.
7. Analysis of the practical applicability of time space maps.

Results

In the present dissertation I have summarized the application concepts, history and methodology of time space maps. In the Materials and Methods chapter the potential tools for the implementation of the space-time transformation are presented. The basic properties of time-scale maps are shown through multiple examples, and with the generation of the time space map (TSM) for Pécs, I introduced the potential opportunities and general concepts for the development of time-based city maps.

1. *Interpretation of TSM, and determination of spatial location of inter-point sites on time space maps using adequate literature*
   Both national and international literature explores that the importance of the map presentation of time goes beyond the scope of cartographers. Conversion between geographic space and time is a recurrent topic of geography; nevertheless, this problem hitherto has not yet been completely solved. TSMs, as analytical tools have been present in science for a long period of time; however, they are usually inaccessible and unavailable to the everyday map users and the broader public.

2. *Elaboration of the methodology for time space maps in the case of paper-based and digital maps*
   In the methodological part, through three case studies, I have answered and solved the majority of the questions and problems that arose during the analysis for the generation potentials of TSMs.
   Characteristic points of objects found on the Earth's surface were presented on a projected plane, the time plane. Time space was defined as a plane, on which, during the space-time conversion (discussed later in details), the projected points, from a selected central point, were placed to a given time distance.
   The point set used during the mapping procedure, may be either complete (A), or limited through an arbitrarily selected viewpoint (*B*, *B*'):
   A) Each point of the reference plane is discretely and continuously assigned to the points of the projection surface
   B) Mapping is limited to discrete point sets
      B') Transformation of infinite number of points, although the reference plane is incompletely projected
      Calculation of travel time and the derived time-distance may be general (*C*) or special (*D*):
   C) Time-distance is interpreted as the shortest time between two discrete (selected) points covered by the fastest transportation mode, including multiple or combined transport tools.
   D) Shortest time between two discrete (selected) points covered with a selected transportation mode (predetermined transportation).

The geographic location of the projected (mapped) point determines the location of the pixels in the time space (E), where the access route has primarily role (F):

   E) The projection maintains its slope and direction compared to the central point

F) Time space identifies the location of the pixels along the access routes.

Combination of the above described conditions will provide various experimental maps that need to be further analyzed. The first and second case studies include conditions described in points *B*, *D* and *E*, while the third case study employs conditions depicted in points *B*', *D* and *E*.

In the first case study (travel time between the settlements of Baranya County to Pécs), the random-like pattern (Figure 1) follows form the lack of mathematical relationship between time-distance and the road (or as the crow flies) distance between two settlements. Time distance depends on the geographic environment in a complex way, including the direct accessibility, topography, road density and quality, etc.

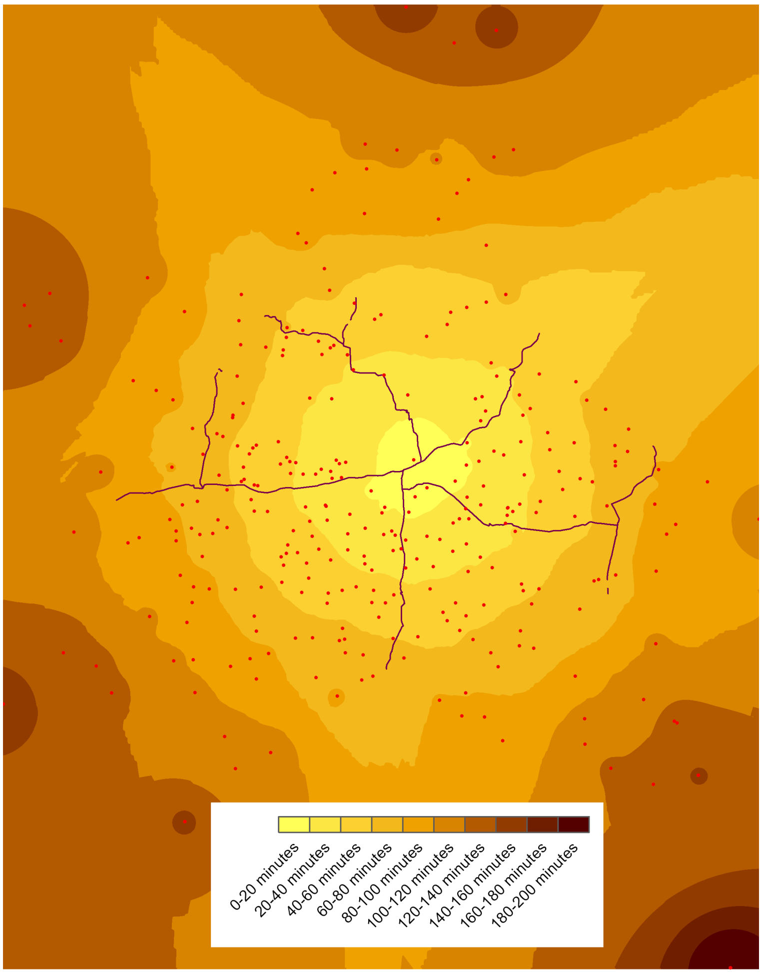

Figure 1. *Time relief map of Baranya County (SW Hungary), with the settlements located in the time space and showing the existing main roads (Compiled by the author, 2009)*

The second case study (Travel Times to the right and left banks of the River Danube) describes the asymmetry of the travel times, which roots in the dissonance of the two central (focal) points in the selected region (Figure 2). The second case study points out the importance of transformation direction during the map presentation of time space.

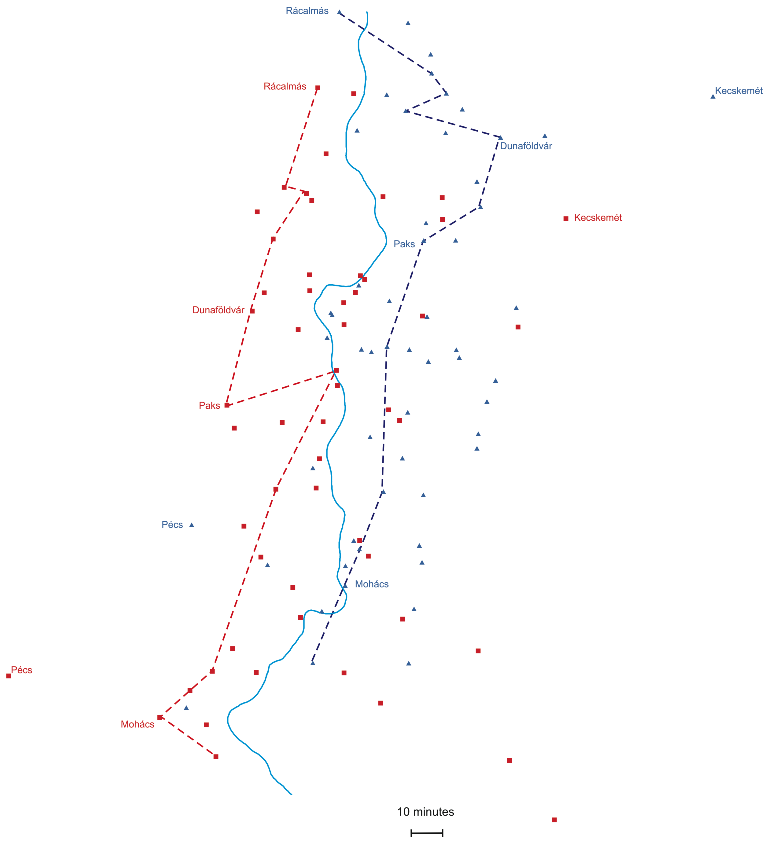

Figure 2. *Location of selected settlements in Southern Hungary with Pécs (red) and Kecskemét (blue) as origins for the map presentation. The apparent location of the Danube denoted with the appropriate color. (Compiled by the author, 2009)*

The third case study (the reduced Pécs road time space map) analyzes the advantages, drawbacks, limitations and potentials of various transformation methods. Data processing that employs various databases is not fully automated yet in that case, when relationship among the grid points is characterized with multi-functional, complex graphs. Nonetheless, automated data processing application from databases has been developed for those cases when direct relationship exists among the individual grid points (e.g.: underground or air traffic maps).

Line network that is directly related to the grid points (e.g.: bus stops with bus service according to pre-determined time tables) has been converted from space to time coordinates using various transformation methods and is visualized on the Pécs TSM.

A unique program for a given transformation problem

The problem described here ((Bus stop and road density of Pécs) included such unique boundary conditions that made it inappropriate to be solved with general transformation methods. In this case map pre-processing and presentation could not be achieved in a sufficiently short time frame, thus its time efficiency would have been low compared to the obtained results.

Use of GIS
The use of GIS softwares could be considered as convenient tools for mapping purposes as they usually offer a plethora of built-in functions that may serve as ideal tools for the solution of space-related problems. However, many of this function operates as ‘black boxes’ for the general GIS users, providing no analytical conclusions about the results: such problem was encountered during the use of the Rubber Sheet function.

Rubber Sheet = Space stretching
This function provides a fast and spectacular solution in most space-time conversion applications; however, the number of control points strongly influences the quality of the output. It is suitable for use and is easily applicable when there is no chronological relationship among the plotted data, or only very low time-related correlation exists among the individual data points. It may serve as significant advantage when profoundly generalized map objects (e.g. contour lines) are transformed; on the other hand, in other cases they may provide miscalculated and misleading solutions and results.

Space-time conversion with precisely described, arbitrarily parameterized interpolation
This procedure can be tested and validated with the visualization of time relief maps (Figure 3) Employing the parameters automatically offered by the software, the accuracy and quality of the calculation could be increased, and high-quality grid refinement may be achieved.
Digital visualization of the map did not form the focal point of the current dissertation. This could be achieved by the high-degree automation of the transformation procedure from a given origin (focal point), but this application, as mentioned above still requires further studies and insight into the problem and may serve as future direction for the current research.

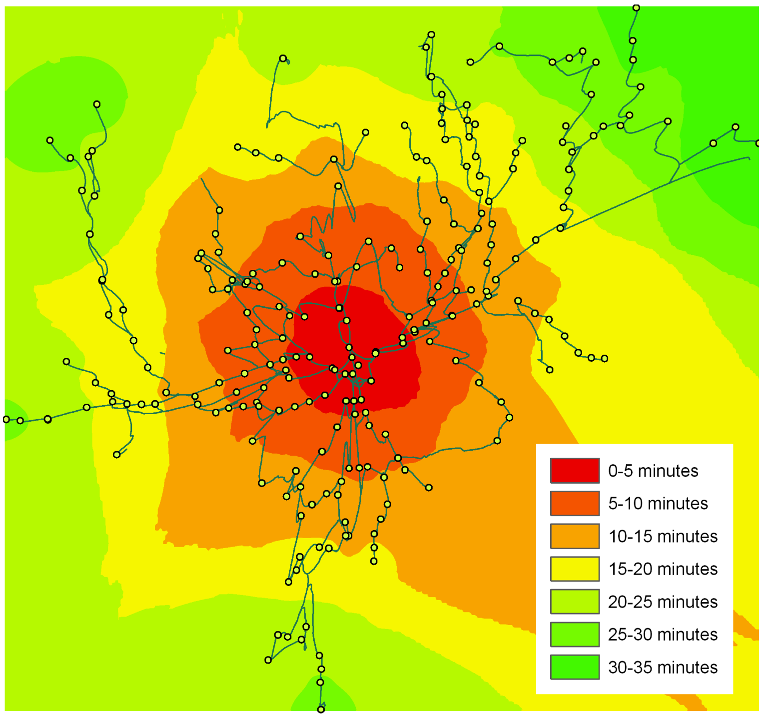

Figure 3. *Time relief map of Pécs showing a reduced (simplified) road network (Compiled by the author, 2009)*

3. **Mathematical presentation of the maps, and description of the projection equations:** The principle for mathematical equations describing the projection transformation lies in the continuous, finite regular description potential of the calculations (Győrffy 2012). If mutually unequivocal direct relationship can be defined among the data points of the basal plane and the visualized plane, it is considered as a projection equation. This definition remains unfulfilled during the imaging procedure, as the mathematical correlation between the time-distance and the original spatial coordinates is low or entirely inexistent and in most cases can only be approximated or estimated.

   Mathematical correlations have been defined for the employed space-time transformations; however these equations are not projection equations as their calculated results do not produce a projection in its technical sense.

   If the space, on which the transformation is carried out, considered being a plane, then the coordinates of the transformed points are the followings:

$$x' = x_0 + \frac{(x_0 - x)}{\sqrt{(x_0 - x)^2 + (y_0 - y)^2}} \cdot t ,$$

$$y' = y_0 + \frac{(y_0 - y)}{\sqrt{(x_0 - x)^2 + (y_0 - y)^2}} \cdot t ,$$

   where (x_0, y_0) the coordinates of the origin and t is the time-distance that belongs to point (x, y). If the transformed space is not a plane, or not considered being a plane, then spherical distances need to be used for calculations, then the coordinates of the transformed points are determined with the following equations:

$$\Phi' = \Phi_0 + \frac{(\Phi_0 - \Phi)}{d} \cdot t$$

$$\Lambda' = \Lambda_0 + \frac{(\Lambda_0 - \Lambda)}{d} \cdot t$$

$$d = R \cdot \arccos\left(\cos\left(90^\circ - \Phi_0\right)\cos\left(90^\circ - \Phi\right) + \sin\left(90^\circ - \Phi_0\right)\sin\left(90^\circ - \Phi\right)\cos\left(\Lambda_0 - \Lambda\right)\right) ,$$

   where (φ_0, Λ_0) are the spherical coordinates of the origin, t is the time distance that belongs to coordinate point of (φ, Λ).

4. The ultimate goal of the current doctoral dissertation is the generation of a cartographic overview traffic map (hereafter 'Pécs time map'), where distances interpreted as time dimensions.

Here, in this chapter, the main tasks included the data collection, data analysis and data homogenization, linear transformation of street network, generation of the primary map mock-up, design of the legend, digitalization of the map elements, and the quality control of the cartographic, drawing and content objects.

Bus time table, used for the calculation of time-distances, as well as data for the road network and bus stop locations in Pécs (both being basic components of the TSM) were generated in 2009. Thus the TSM reflects and represents the 2009 traffic and transportation conditions of Pécs.

5. Elaboration of the legend of the TSM

This part of the dissertation was considered as the most important part of the current research, as the primary goal of the study was the generation of the TSM for Pécs. The general look of the map is identical to a conventional city/road map, however it also comprises significant differences that appeared during the transformation and preprocessing procedures. It also needs to be easily understandable and interpretable for the general public, as it is intended for

everyday use in the Pécs public traffic services. The compilation of the legend was based on the legends of former local historical maps.
The conventional traffic categories for the following items were further emphasized:

1. The ones that significantly contribute to the easy understanding of the interpretation of time-distance (generation of reference grid, digitization of bus stops, see Figure 4)
2. Some map items, that formerly appears on the original map, and deteriorate the easy interpretation and readability of the resulted TSM were omitted or partially replaced. Items that are hard to be precisely presented and projected in the TSM were also omitted. Items of these types include topographical background, land use types and buildings.

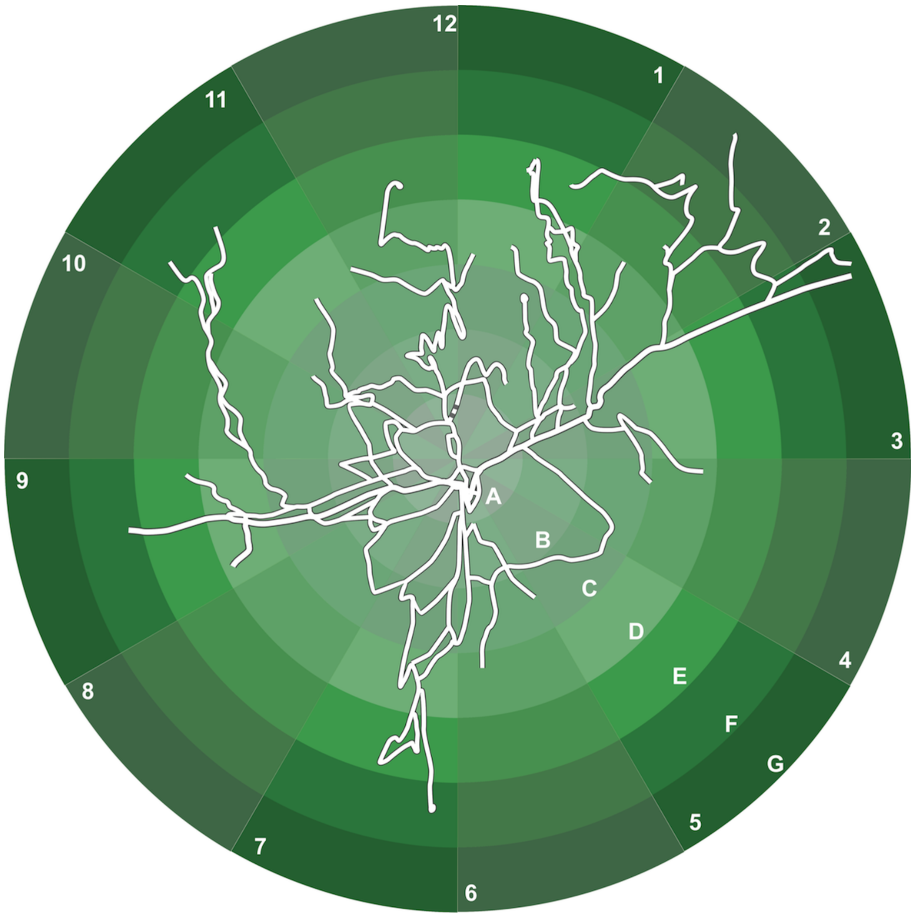

Figure 4. *Reference grid of TSM (Compiled by the author, 2012)*

Future research directions

Future Research prospective will target two main directions: firstly, the generation of paper-based and publicly available TSM for various transportation means in Pécs. Secondly, the currently available TSM will be validated and integrated into the first-generation Pécs TSM. According to the validation results, the current and future TSM will be calibrated for the various transportation means. Results of these future research plans will contribute to and facilitate the automation of the data assimilation, homogenization and processing procedures. Obtained TSMs and their everyday usability will be tested through public surveys.
A Future research venue will comprise the development of other specific, time-distance based maps, where time is the primary parameter. Such maps would include historic maps, or hydrologic runoff maps, where time of concentration may be of primary importance rather than distances within the watershed.

Publications

Articles and book chapters on which the thesis is based

1. Baby, S. – **Balassa, B**. – Nagyváradi, L. (in press): *Choropleth Mapping Interpolation Technique to Analyze the Demographic Influence in Altering Kuwait's Coastal Morphological Landscape.* – In. GEO Enviromental Consultation, Al- Surra, Kuwait.

2. **Balassa B**. – Gyenizse P. – Pirkhoffer E. 2010: *Különböző kartográfiai és geoinformatikai módszerek alkalmazási lehetőségei Magyarország településsűrűségének vizsgálatára.* – In: Kovács I. P. – Trócsányi A. (szerk.): Tér – Tálentum – Tanítványok I. IDResearch Kft. – Publikon Kiadó, Pécs, pp. 27– 36.

3. Czigány Sz. – Pirkhoffer E. – **Balassa B**. – Bugya T. – Bötkös T. – Gyenizse P. – Nagyváradi L. – Lóczy D. – Geresdi I. 2010: *Villámárvíz, mint természeti veszélyforrás a Dél– Dunántúlon*. – In: Földrajzi Közlemények. 134:(3), pp. 281– 298.

4. **Balassa B.** – Bugya T. 2009: *Egy régi térábrázolás felújítása: az időléptékes térképek szerkesztése*. – In: **Geodézia és Kartográfia** 61:(9), pp. 3– 36.

5. **Balassa B. –** Bugya T. – Gyenizse P. – Nagyváradi L. 2009: *Tanulmány az időléptékes térképi ábrázolásról*. – In: Fábián Sz. Á – Kovács I. P. (szerk.): Az édesvízi mészkövektől a sivatagi kérgekig. Tanulmánykötet a 70 éves Schweitzer Ferenc professzor úr tiszteletére. (Geographia Pannonica Nova; 6.), PTE TTK Földrajzi Intézet, Pécs, pp. 185– 193.

6. Nagyváradi, L. – Szebenyi, A. – Gyenizse, P. – **Balassa, B**. 2009: *Modelling of interactions between urban development and physical environment an example the new town Kozarmisleny S– Transdanubia, Hungary.* – In: Aubert A – Csapó J (eds.): Differentiating Spatial Structures in the Central– European Region. PTE TTK Földrajzi Intézet, Pécs, pp. 118– 129.

7. Elekes, T. – **Balassa, B**. 2008: *The social effects of mining mine closure is Baranya county (Sw Hungary)* – In: Burny, P. – Petrescu, D.C. (Eds.): Environmental economics (Studies and Research). Gembloux– Cluj- Napoca, pp. 97– 110.

8. Gyenizse P. – **Balassa B.**– Elekes T. – Nagyváradi L. – Pirkhoffer E. 2008: *Lakossági igények szerinti településminősítés geoinformatikai módszerekkel Pécs példáján*. – In: Területfejlesztés és Innováció, PTE TTK Földrajzi Int. 2. évf./2 pp. 13– 25.

9. **Balassa, B**. – Gál, V. – Németh, K. 2008: *The way the world is seen*. – In: Lóczy, D. – Tóth, J. – Trócsányi, A. (eds.): Progress in Geography in the European Capital of Culture 2010. Geographia Pannonica Nova 3. Imedias Publisher, Pécs. pp. 105– 115.

10. **Balassa, B.** 2007: *Topográfiai alaptérképek Magyarországon*. – In: Gál V.– Szabó A. (szerk.): Tanulmányok Dr. Becsei József 70. születésnapja alkalmából. (A pécsi Földtudományok Doktori Iskola hallgatóitól.) PTE TTK FI, PTE Földtudományok Doktori Iskola, Pécs, pp. 23– 30.

Conference proceedings and abstracts on which the thesis is based

11. **Balassa B**. – Bugya T. – Czigány Sz. – Gyenizse P. – Nagyváradi L. – Pirkhoffer E. 2009: *Társadalmi igények felmérése és geoinformatikai elemzése Pécsett*. – In: HunDEM 2009, GeoInfo 2009, Miskolc, pp. 1– 17.

12. **Balassa B**. – Nagyváradi L. – Bugya T. 2009: *Az időléptékes térképek kapcsán felmerülő kérdések.* – In: Pajtókné Tari I. – Tóth A. (szerk.): Változó Föld, változó társadalom, változó ismeretszerzés. Tudományos Konferencia. Eger, EKF Földrajz Tanszék, pp. 169–174.

13. **Balassa B**. 2008: *Geográfia és a térképek (Térképek földrajzos szakdolgozatokban)*. – In: Kovács– Pálffy P. – Zimmermann K. – Verebiné Fehér K. – Kopsa G. (szerk.): A Föld éve 2008. (A földtudományok az emberiségért) Budapest. p. 74. (poszter)

14. **Balassa B**. – Nagyváradi L. – Szebényi A. 2007: *Study of the realationship between traffic and suburbanization in Budapest agglomeration with GIS methods*. – In: Traffic influence on the regional development of Bosnia and Hercegovina and neighbouring contries in the process of approaching European Union. Book of Abstracts, Tuzla. p. 22.

Other articles and book chapters

1. Gyenizse P. – Nagyváradi L. – Szebényi A. – **Balassa B**. – Bugya T. – Pirkhoffer E. – Czigány Sz. 2011: *A Bátaszék területén fekvő puszták történeti földrajza*. – In: Bokor L. – Szelesi T. – Tésits R. (szerk.): Dimenziók térben és időben: Tanulmánykötet a 60 éves Rudl József tiszteletére. (Geographia Pannonica Nova; 9.) Idresearch Kft. – Publikon Kiadó, Pécs, pp. 35– 43.

2. Gyenizse P. – Ronczyk L. – **Balassa B**. 2009: *A helyi energiák hatása a Mecsek és Villányi– hegység közötti alacsony dombság településeinek életére*. – In: Aubert A. – Tóth J. (szerk.): A Kárpát- medence és etnikumai. Tanulmánykötet Pozsár Vilmos tiszteletére. PTE Földtudományok Doktori Iskola, Pécs, pp. 79– 93.

3. **Balassa B**. – Szabó-Kovács B. 2009: *A feketeszén- bányászat és a bányabezárások néhány fontosabb környezeti és társadalmi hatása a Közép- és Kelet-Mecsekben*. – In: Szabó-Kovács B. – Tóth J. – Wilhelm Z. (szerk.): Környezetünk természeti– társadalmi dimenziói. Tanulmánykötet Fodor István tiszteletére. Molnár Nyomda, Pécs, pp. 147–165.

Other conference proceedings and abstracts

4. Gyenizse P. – Nagyváradi L. – **Balassa B**. 2010: *Dombóvár településfejlődésének geoinformatikai vizsgálata.* – In: Lóki J. – Demeter G. (szerk.): Az elmélet és a gyakorlat találkozása a térinformatikában: Térinformatikai konferencia és szakkiállítás. DE Kossuth Egyetemi Kiadó, Debrecen, pp. 357– 364.

5. **Balassa B.** – Bugya T. – Czigány Sz. – Gyenizse P. – Nagyváradi L. – Pirkhoffer E. 2009: *Domborzati modellek használata a Pécs környéki geoinformatikai vizsgálatokban*. – In: HunDEM 2009, GeoInfo 2009, Miskolc, pp. 1– 18.

6. **Balassa B**. – Nagyváradi L. – Szebényi A. 2008: *A településfejlődés sajátos útja Kozármislenyben*. – In: Sitányi L. (szerk.): II. Terület- és vidékfejlesztési konferencia. Dél-Dunántúli Regionális Fejlesztési Ügynökség Kht. – Kaposvári Egyetem, Kaposvár, pp. 120– 124.

7. **Balassa B.** – Hegedüs V. – Kopári L. 2007: *Az egészséges életmódra nevelés az erdei iskolákban, az egészségturizmus és az ökoturizmus összefüggésrendszere*. – In: Kárpát–medencei környezettudományi konferencia. Kolozsvár, pp. 68– 74.

8. **Balassa, B**. 2000: *A Tourist Map for Children*. – In: ICA Conference on Teaching Maps for Children: Theories, Extperiences and Berspectives beginning the 3RD millennium. Budapest. pp 51– 52.