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The Analysis of the Ground Plan Variations of a Town Located in a Floodplain. The Case of Szeged, Hungary

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A B S T R A C T

Natural environment influences the life of the settlements even today. It directly affects the built environment. It can be better noticed in the mountainous areas but it is not negligible in case of the towns located in the lowlands either. In our research we numerically surveyed the variations of the built areas (ground plan) of a lowland town, Szeged, Hungary, and compared these results with the microrelief and hydrological characteristics. We determined that in the last about 230 years the ground plan of Szeged grew by 10.4 fold and its perimeter by 9.0 fold. The shape index grew by 2.8 fold between the end of the 18th century and the beginning of the 21st century, which refers to the fact that today the built area of the town is strongly fragmented and so it is better expelled to the environmental impacts. We investigated whether the timely change of the numerical indicators of the ground plan (perimeter, area, shape index) show any statistical coherence with the mean height of the ground plan above sea level. The rank correlation shows a weakly positive relation (r=+0.61). With the help of a digital relief model we localised those built-in areas where the microrelief and the hydrological relations indicate danger to the buildings and the population. Problematic areas can primarily be found in case of the lower located private house quarters in the Northern, Southern and Eastern parts of the city.

1. INTRODUCTION

Natural environment influences the life of settlements even today. It directly affects the technological facilities and indirectly the economy and society. The map illustration of the manmade residential and industry buildings and the technological and infrastructural facilities expels the ground plan of the settlement which, with its appearance, reflects in numerous cases the effects of the natural endowments. In the villages the location of the church or the direction of the street network are univocally determined by the characteristics of the relief, hydrology the soils and the micro climate. In the case of the greater towns this influence was only strong in the era around the establishment of the settlement, today their role is smaller. Earlier we researched macro relief impacts at other towns. We were curious whether any coherence can be detected between the microrelief and the expansion of the size of the built-in areas in certain towns. So we carried out a historical approach in the town of Szeged allocated on the floodplain of River Tisza.

The aim of the research is to numerically determine the ground plan development of the town and to examine whether there is a connection between the change of the ground plan and the microrelief or not. In the second part of the research we also impound in space those present and future areas where the natural endowments (first of all the high groundwater and internal water) could cause problems even today during the building in and the operation.

2. THEORY AND METHODOLOGY

The tossing for sides of the location of the settlements, their development or stagnation and deadening in many cases, even today, depend significantly on the natural endowments. The natural environment is the integrated unity of the on time stable and unstable factors. Their spatial exploration and map visualisation is of great importance. The elaborate cognition of the natural environmental relations and the settlement planning-purpose evaluation provide well utilisable information in the fields of town aesthetics, environment protection and technological questions and in the optimal allocation of the different establishments but we cannot neglect its hygienic and settlement sociological relations either [1], [2].

In the formation and development of the lowland settlements microrelief played an important role and the related hydrological relations as well. The flood free terraces and the high flood basin surfaces are clear from the demolition of the floods. The citizens of the settlements established on the edge of these areas could use easily the goods of the different surfaces. The reef belts are smaller in extent but play a similar function as well. Since the river regulations and flood exemptions this advantage has broken off but in the case of a possible dam break the higher surface could mean an advantage even today [3].

In the lowland in many cases the high level of ground water mean such restrictive factor as floods which can detain both agricultural activity and settling. That is why the positive microrelief forms are popular in order to develop the settlements. On the lowland areas the protective function is primarily connected to the hydrological endowments. The historical cores of numerous cities were settled on the islands of rivers or on peninsula-like formations of associating rivers [4].

In the study we present our researches executed in Szeged, the lowest situated town of Hungary in the former floodplain areas of River Tisza. Szeged is a city situated in the south eastern part of Hungary with a population of 161 837 persons [5], the transport, educational, cultural and industrial centre of the south eastern part of Hungary (fig. 1). It is the centre of Csongrád County from 1962. Szeged was an important intersection of the gold and salt transit route from River Maros even at the times of the Roman Empire (with the name of Partiscum).

The mineral resources discharged in its port were taken further on terrestrial routes. For the surveillance of the transport intersection military fortifications were built. In 1246 it received town rank. The town is allocated in the floodplain of River Tisza and Maros so during history the floods have been destroying it for several times. Its area is floodplain lowland with small height differences (fig. 2).

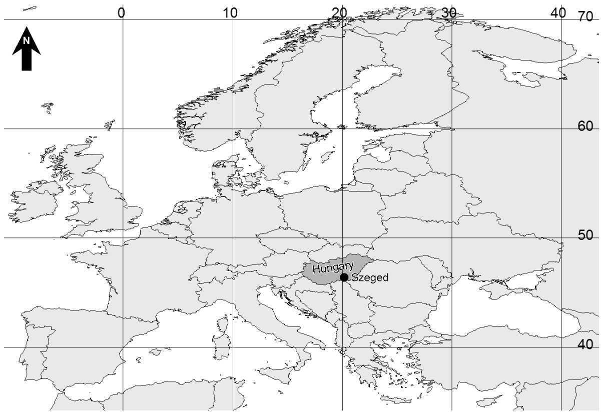

Fig. 1. The location of Szeged in Europe and in Hungary.

Fig. 2. Digital elevation model of Szeged and its surroundings.

For the analysis of the territory of the town we used military and civilian maps and aerial photographs from different ages. These were made in the following years: 1783 (1:28.800), 1861 (1:28.800), 1884 (1:25.000), 1950-51 (1:25.000), 1966-68 (1:25.000), 1980-84 (1:10.000), 2005 (1:10.000).

For the analysis of the ground plan extension of Szeged we used Idrisi and Cartalinx GIS programs. In the first step we scanned, than geo-referred the old military survey maps. In the second step we digitalised the contour of the built up areas of the town.

We have to clarify it here that we classified into the built up areas not only concrete buildings but roads, squares and gardens around the houses. This does not accord with the interior areas of the settlements.

In the third step we digitalised the contour lines from a 1:10 000 topographic map. From these we created a digital elevation model (DEM).

With the help of the Idrisi and Cartalinx programs we read out numerical information from the ground plans and the relief model. These are the area and perimeter and the mean height above sea level.

According to our preliminary expectations during the extension of the city it expanded from the higher flood plain reliefs to the lower area so the mean height above sea level and the perimeter and surface of the ground plan should show a reverse correlation.

For characterising the built up areas of the towns (ground plan) several indicators were already worked out [6], [7]. According to our opinion the relation between the settlement and the natural environment is well represented by the so called Shape Index used in ecology which studies the correlated value of area and perimeter. The shape, area and perimeter of the built up areas of the towns continuously changes due to the outward expansion and the denser built up of the internal areas. The so called Shape Index used in ecology was created for the reason to show the spread of an ecological patch from the ideally looked on circle [8], [9]. The circle possesses the possibly smallest perimeter compared to its area. From and ecological point of view the plant associations of the circle like plant patches can be considered to be the most stable, the most resistant to the external impacts. The Shape Index represents the deflection of a patch from the ideal circle. In the case of the circle the Shape Index puts on D=1 measure-free value. Its value can be not smaller than 1, but greater. We can use the following formula to its calculation for each of the patches one by one (where P = perimeter, A = area):

$$D = \frac{P}{2 \times \sqrt{A \times \pi}}$$

According to our point of view this index can be well used in order to characterise the built up areas of greater settlements as well.

3. RESULTS AND DISCUSSION

3.1. The reconstruction of the city's relief before the "great" flood and the analysis of its ground plan

The three core areas of the city have been established on the higher areas emerging from the floodplain, locally known as "islands": Felsőváros (Upper City), Belváros (Downtown) (castle) and Alsóváros (Lower City). Szeged has been demolished for several times by the middle age wars and the natural catastrophes. The rivers were not only important trade routes but they also meant danger for the residents due to their floods.

During the survey we elaborated the expansion map of the city showing the built up areas (fig. 3). At the time of the 1st and 2nd military survey showed a stringy elongated shape at the right bank of the Tisza with approximately 5 km length and 1-1.5 km width in a NE-SW direction. The Downtown and the castle have been compassed by a bailey on the map of the 1st military survey.

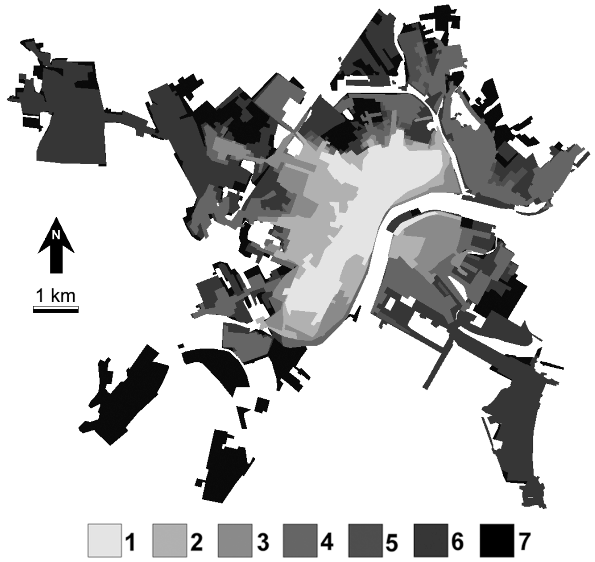

Fig. 3. The change of the ground plan of Szeged in the 18th-21st centuries: 1 = 1783, 2 = 1861, 3 = 1884, 4 = 1950-51, 5 = 1966-68, 6 = 1980-84, 7 = 2005

According to our measurements in 1783 the built up area of the city was 4.6 km² while its perimeter was 21.1 km. Both the two values have been growing significantly in the following 8 decades. The built up area by 1.8 fold, the perimeter by 1.5 fold (fig. 4).

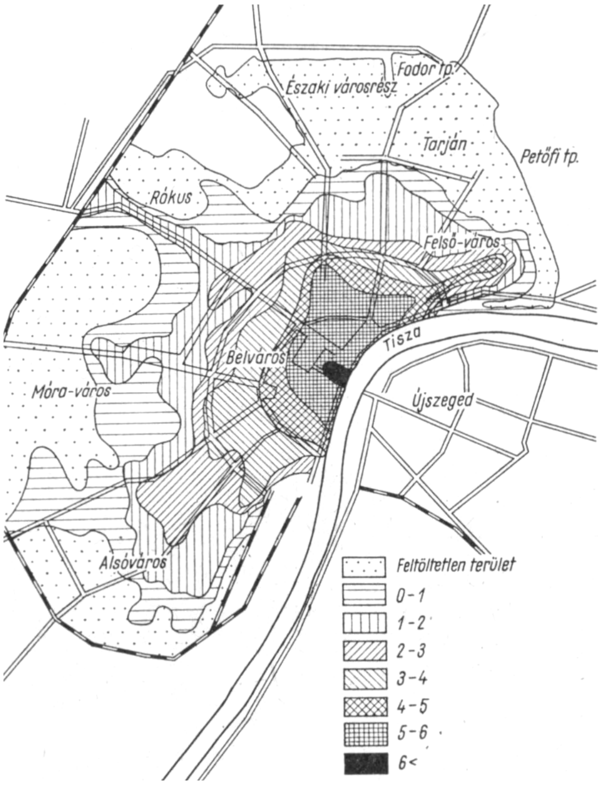

Fig. 4. The thickness of the artificial filling in Szeged [15].

We can draw the conclusion from the measured data that the increase of the built up area does not result the same amount of increase in case of the perimeter. However, since both of them characterises the relation with the neighbouring landscape and the natural endowments, it is worth following them side by side. The shape index shows for instance the defensibility of the city against military attacks and floods. The greater perimeter is associated to a certain size of area the given settlement is the harder to be defensible. In the 18th and 19th centuries the town possessed a rather low shape index with a value around 3, meaning specifically lower costs of defence against the environmental impacts. It was advantageous because of the recurrent floods.

With the GIS programs we estimated for every surveyed time the mean height above sea level of the built up areas (fig. 5).

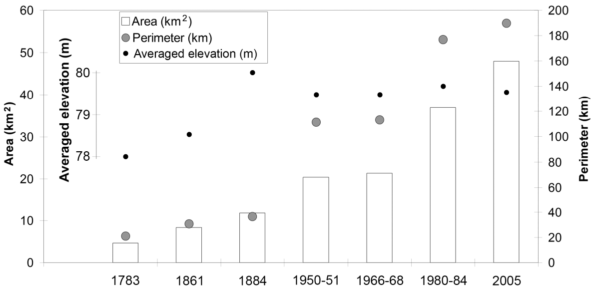

Fig. 5. The ground plan change of Szeged by area, perimeter and mean height above sea level.

Before 1879 the area of the town was situated lower. It is true however that the houses of the residents were built on the higher areas, the islands, but this group of islands could escape from the submergence only at smaller floods. The area of the town has been banked up after the 1879 flood, so a relief model cannot be used which is made out of the contour lines of today's maps in order to model the former statuses. That is why we created the modified relief model. For this we used the map of [10] (fig. 5) which showed the measure of the banking up based on the results of soil drillings. This measure in the area of the downtown reaches even 6 metres. We drew off the height of the banking up from the present relief data. After these processes we can state that between 1783 and 1861 the mean height above sea level of the built up areas of the city grew from 78 metres to 78.5 metres.

The elevation histogram created with GIS programs provides more detailed information from the mean values (fig. 7). In the era of the first two military surveys the settlement possessed areas between 75 and 81 metres above sea level. So the maximum altitude of the "islands" emerging from the floodplain was 81 metres. However, the greatest amount of built up areas were allocated between the heights of 77-80 metres, but there were buildings also at the riverside, frequently flooded lower surfaces.

A considerably great change has taken place in the built up areas of the city between the dates of the 2nd and 3rd military surveys. This catastrophic change was due to the 1879 flood which basically destroyed the town.

3.2. The ground plan change of Szeged in the last 130 years

River Tisza is one of the rivers in Europe with the smallest gradient so the floods of the tributaries easily swell back the water of the Tisza. Before the regulations the flood area of the river was approximately 20,000 km² out of which 5 000 has been covered by lakes, moors and marshes. In 1846 the regulation, the pushing between dikes of the river at the upper section has started. This process raised the elevation of the flood waves in the lower sections. In 1879 the flood of the Tisza, the Körös Rivers and the Maros reached the area of Szeged at the same time. The dikes protecting the city burst one after the other in the stormy weather between the 5th and the 12th of March and the town has been flooded with the water. The approximately 33 million m³ of estimated water covered the city for approximately 3 months demolishing almost all of its buildings. The depth of the water at some places reached even 3-4 metres. Until 1879 the houses were dominantly built from cob so they could not resist against the flood. Out of the 5,600-5,700 buildings before the flood only 300-400 remained. Approximately 60,000 people became homeless [11].

According to our estimations, the 759 mm maximum water level in 1879 means that the water level of the Tisza topped up till 81.3 metres, reaching and even exceeding the highest point of the town (see fig. 2). If we project this flood level to the present situation than 90.4% would have been flooded of the 2005 built up areas.

The present structure of Szeged has been formed after the 1879 great flood. The areas of the town that should be newly built up have been filled up with 16.1 million m³ soil. In the central areas it raised the surface with 5-6 metres and in the external parts with 1-2 metres. The round bank has been finished around the town which protects the internal city districts from even 10 metres high flood levels. Later the banks at the shores of the Tisza have been raised to 10.8 metres [12].

The castle's building material that has been battered down in 1880 was used again for reconstruction. In the first 5 years 9300 houses were built with state support. After the reconstruction the system of avenues and boulevard were developed which determine the borders of the internal districts even today [13], [14]. Szeged merged with Újszeged (New Szeged), allocated on the other part of the river, in 1880. The pages of the 1884 3rd military survey show the reconstructed town after the "great" flood. It area grew by 1.4 fold and perimeter by 1.7 fold compared to the 1861 status. The mean height above sea level of the built up areas suddenly grew due to the filling and became 80.0 metres. However, the distribution of the mean height above sea level has significantly changed. The majority of the buildings are situated between 79-81 metres, but in the centre of the city we can also find built up areas higher than 83 metres. Out of the researched dates this is the only one when there are no built up areas under 77 metres.

By the 1950s and 1960s the built up areas of the town extended even the round banks. The area grew by 170% and the perimeter by 300% of the 1881 status. This is also has taken along the deterioration of the shape index, growing to 7. However, the mean height above sea level decreased to 79.5 metres. We can see from the actual histogram that the town decisively built the areas allocated between 76 and 81 metres since the higher surfaces along the river banks were completely built up earlier.

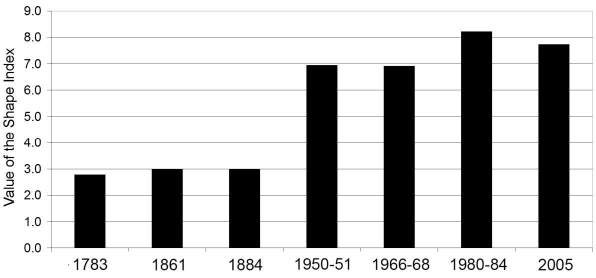

Fig. 6. The change of the shape index of Szeged between the 18th and 21st centuries.

In 1973 Szeged was attached with several nearby settlements living strongly together with the city (e.g. Gyálarét, Kiskundorozsma, Szőreg and Tápé). Their built up area practically became adherent with the area of Szeged in the 1980s. The area of the town showed a further 1.7 and the perimeter a 1.6 fold increase. At this time the shape index of the town reached the highest value (8.2) which is due to the building of the new block of flats residential areas and the industrial firms. The mean height above sea level rose to 79.7 metres because of the attached higher situated town districts.

In the next two decades primarily the significant growth of the built up areas can be experienced (30%) coupled with a moderate increase (7%), so the value of the shape index decreased to 7.7 because of the more dense built up. The mean height above sea level hardly changed (79.6 m). Based on the elevation histogram we can say that the minimum height above sea level of the built up areas has not grown but the maximum value grew a little bit parallel with the built up of the higher floodplain sand ridges. Further on the areas with medium heights (78-81 m) are dominating. Between the heights of 79-80 m we can see a decrease in the histogram due to the relatively smaller gradient between the low and the high floodplain areas.

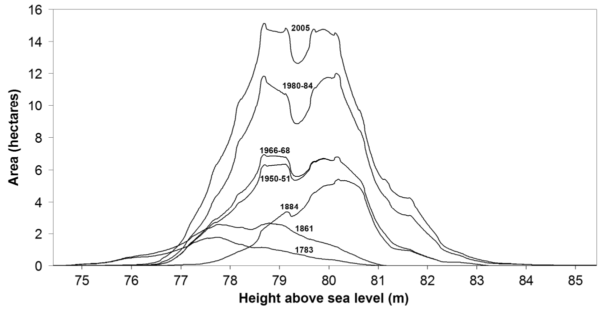

Fig. 7. The elevation distribution of the built up areas in Szeged in the researched dates.

3.3. Is there any relation between the features of the ground plan and the height above sea level?

In the previous chapters we read through several numerical characteristics of the built up areas of Szeged with GIS programs.

On the whole we can determine that in the last approximately 230 years the ground plan of Szeged grew 10.4 fold and its perimeter by 9.0 fold. The shape index between the end of the 18th century and the beginning of the 21st century grew 2.8 fold, referring to the fact that the built up areas of the city today is stronger fragmented and so it is better exposed to the environmental impacts. Such impacts are for instance the floods and internal waters obtaining the lower allocated, not yet filled areas.

It appeared as an interesting topic that how much the only measured physical factor, the height above sea level, can influence the measurable characteristics of the ground plan. Since we have statistical data for 7 dates we could only use rank-order correlation. We surveyed the correlation between the mean height of the built up areas and the area of the ground plan and the correlation between the height and perimeter and the height and the shape index. The value of this was in every case r=+0.61 which means a weak correlation with 92% significance. So there is a relation between the factors but weak. In general terms it is true that when the mean height is increasing than the area of the ground plan, its perimeter and shape index increases as well. This slightly contradicts with the presumptions according to which expanding from the “islands” lower and lower areas would be built up so the correlation should be inverse. However, when creating the pre-concept we avoided the impacts of the filling up of the area after the 1879 flood and the impact of the villages enclosed to Szeged. As an interesting topic we mention that when we take into consideration only 5 data after the filling up of the ground than we receive a r=-0.1 negative correlation.

The correlation between the perimeter and area of the built up areas is r=+1 besides 100% significance. However this strong correlation is modulated the detailed analysis of the indicators which we introduced earlier.

3.4. Present and future problematic areas

Great floods were running along the Tisza in the last decades as well, but fortunately these did not cause such destruction as in 1879 in and around Szeged. The so far measured highest flood reached Szeged on 21st April, 2006. AT this time the water level was 83.79 metres between the dams. In a flood hazardous period of time the smaller water courses also swell back. At such springs where precipitation is higher the internal water causes also huge problems. Primarily on the agricultural lands around the city but in some cases at the lower allocated built up areas as well. So the analysis of the natural features, such as the microrelief is actual even today.

Where can we find at the moment in Szeged the most imperiled built up areas? We reclassified the relief model created with the Idrisi GIS program and with its help we created elevation categories by every 2 meters (fig. 8). The darker tones indicate the deeper areas. The most imperilled built up areas are found at the edge of the town at the family house districts. In the "A" frame of Fig.9 we can see the so called Petőfitelep situated NE from the round dam. The offcut of the 1783 military survey map well demonstrates that in this area earlier swampy areas were allocated along the Baktói-stream and the Tápéi-stream. The deeply allocated area was parcelled out after the 1st World War for the dwelling houses. Here and north from here at some certain parts of the Baktó district the high internal water frequently hold it to be impossible to cultivate the gardens and made damages in the buildings as well. The "B" offcut of Figure 9 shows the Marostő district which is surrounded by the oxbow of the River Maros. In the era of the 1st military survey here swamps and a lake was situated. This area was built up in the last decades. At present one of the districts of Szeged with "American style" villas, family houses and row houses are allocated there. In the "C" frame of Figure 8 we can see the low situated Klebelsberg-yard district. Earlier in this area close to River Tisza there were swamps and a lake. The area started to be inherited in the beginning of the 20th century. Due to the closeness of the train station mainly railway employees were living here. The district possesses even today high groundwater levels but according to the experiences it is appropriate for garden cultivating.

How much microrelief influence the future investments and constructions? Let's compare the constructions at the external parts of the city with the microrelief situation. (We do not deal with the investments in the central areas of the town this time.) Based on the experiences of the past years we can state that the industrial and trade investments near to the edge of the city primarily were established near the major roads. On the contrary the expensing of the living quarters was independent from this process. We indicated the number of the most important roads to Fig.10 and marked the locations of the investments at the brink of the town.

a). Along main road 5, at the vent SW from the town we find a trading area with great shopping centres (TESCO, Aldi, Lidl, JYSK, etc.) and a housing estate. Expectedly it will generate further investments to the area in the future. Insomuch as since the construction of highway 5 (M5) the traffic of main road 5 decreased and so from this direction only a few customers can be expected, the multinational department stores were endeavoured to allocate near the internal living quarters. Both the department store and the living quarters can be considered as green field investments since because of the deep allocation and the humid soil it was a wooded and grassy land. This area inside the round dam became appropriate to building constructions only after significant landscaping.

b). The traditional industrial park of Szeged is situated along the outlet section of road 5,55 and 5408. In the last years significant brown field investments were realised here. In the relations of Szeged the area can be considered as having average height above sea level with small internal water irritability. In the future the industrial park can be expanded towards route 502 as well. In the latter years on the agricultural areas towards the west internal water appeared at many occasions.

c). In the borders of Szeged the M5 and M43 highways were handed over in 2005. These were also influencing the investments at the edge of the town. Along the outlet section of main road 5, towards the NW, numerous industrial firms established by brown and green field investments, storage bases, logistical establishments and shopping centres (Auchan, Cora, Metro, Decathlon, etc.) were established. This area, concerning its natural characteristics, belongs also to one of the most advantageous surfaces.

d). On the northern parts of the Szabadságtelep district new parcels were disposed for private houses. The area is moderately affected by the internal waters.

e). The living spaces are also expanded on the northern parts of the Tápé district. At the slightly higher areas compared to the formerly introduced Petőfitelep the high internal and ground waters cause less problems.

f). Out of the living quarters the most dynamically the south eastern Marostő district is growing even today. On the lower allocated area the built up of the former plough lands, reedy and woody areas is taking place. For this living quarter the proximity of main road 43 is having positive impacts only partially. Along the outlet sections of route 47 and 4519 there are only a few constructions and investments today in the areas near to the city.

So the built up areas of Szeged increases continuously even today. One has to take into consideration the characteristics and phenomena of the environment in the development plans. Since the 2006 flood the strengthening of the dams at Szeged and especially the downtown walls are having a highlighted role in the national and city budget. Besides the promenade at the shores of the Tisza a mobile dyke system will be built out of 2.2 billion HUF [16].

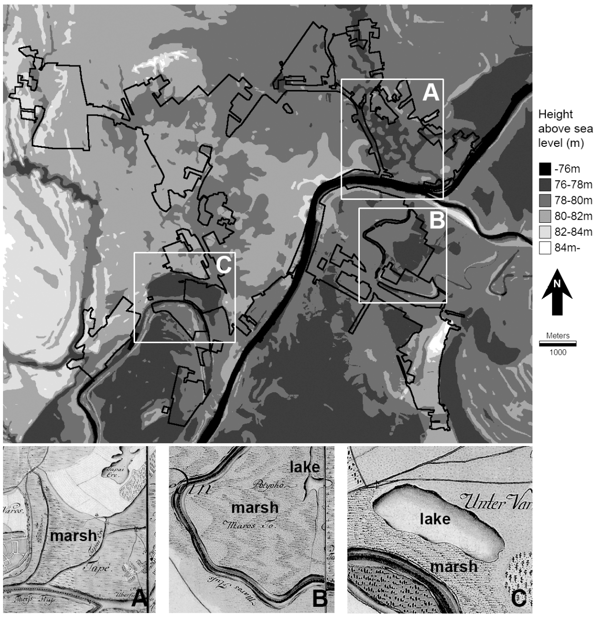

Fig. 8. The microrelief levels of Szeged created from DEM *(The legend for the framed areas can be found in the text).*

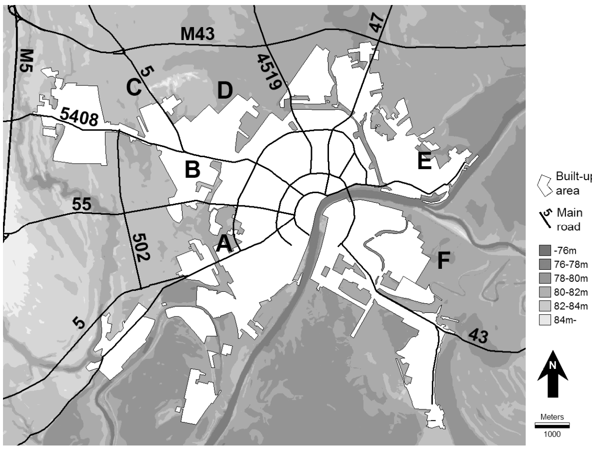

Fig. 9. The areas that will be built up in a greater measure in the near future and their relief relations in Szeged *(Explanations can be found in the text).*

The development of the drain system diverting the internal waters is also an important problem, especially at the external districts, which out of national and European Union supports were already in a large measure renewed and built during the public utility developments in the recent years, but in certain districts (e.g. Kiskundorozsma) their configuration is still deficient.

4. CONCLUSION

During the research we numerically analysed the change of the built up areas (ground plan) of Szeged and compared these results with the microrelief and hydrological endowments. With the help of military and civilian maps and aerial photographs we provided an overview about the numerical changes of the town's ground plan. We assessed that in the last approximately 230 years the ground plan of Szeged grew by 10.4 fold and its perimeter by 9.0 fold. Between the end of the 18th century and the beginning of the 21st century the shape index grew 2.8 fold referring to the fact that the built up areas of the town at present fragmented more strongly and so it is better exposed to the environmental impacts. Such impacts are for instance the flood and internal waters reaching the deeper allocated areas. We investigated whether the timely change of the numerical indicators of the ground plan (perimeter, area, shape index) show any statistical correspondence with the mean height above sea level of the ground plan. The rank correlation shows a weakly positive (r=+0.61) relation. It did not confirm our preliminary expectations.

In the second half of the analysis, with the help of a digital relief model, we localised those built up areas where the microrelief and the hydrological relations mean problematic areas. We assessed that since the beginning of the 20th century again there are such low allocated living spaces where, because of the low allocation, the ground and internal waters cause problems (the districts of Petőfitelep, Baktó, Marostő and Klebelsberg-yard – see fig. 8). With the analysis of the locations of the present constructions with industrial, trade and living purposes we demonstrated that the natural and transport endowments primarily make possible the problem free development of the north western industrial areas. In the northern and eastern living spaces the high ground and internal water level can further on cause problems.

The greatest contingency of danger is further along the flood of the River Tisza but we hope that the defence system, maintained and renewed by great costs, will function properly in the future and such demolition will not reach the city similar as the flood in 1879.

5. ACKNOWLEDGEMENTS

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