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Flood risk and housing prices: evidence from Hungary

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Abstract

This study employs the hedonic property price method to analyze the flood risk effect on a rich set of data. The analysis is carried out on Hungary, but as the control variables are extremely elaborated, our results have general importance. The paper finds a significant reduction in housing prices accounted to ZIP code level flood risk even after controlling for a wide range of geographical and socio-economic features. This paper finds that flood risk reduces housing prices substantially. It turns out that the average elasticity is driven by being in close proximity of major rivers. While riverside areas have an overall price premium in Hungary, risky areas loose this advantage to flood risk. In ZIP code areas where the inundation depths are 10% higher, housing prices tend to be 1% lower on average plus another 1% lower along the major rivers.

JEL: Q51, Q54, R30, R31

Keywords: housing, hedonic pricing, flood risk, geography

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Árvízi kockázat és lakásárak Magyarországon

Békés Gábor - Horváth Áron - Sápi Zoltán

Összefoglaló

A tanulmányban a hedonikus módszer alkalmazásával elemezzük az árvízi kockázat hatását egy széleskörű lakásár-adatbázison. Az elemzést Magyarországra végeztük el, de eredményeink általános tanulságok levonására is alkalmasak. Az irányítószám-körzetek szintjén mért árvízi kockázatnak a lakásárakra szignifikánsan negatív hatása azonosítható a földrajzi és társadalmi-gazdasági változók széles körére történő kontrollálást követően is. A tanulmányban megállapítjuk, hogy az árvízi kockázat jelentősen csökkenti a lakásárakat. Az átlagos rugalmasságot leginkább a nagy folyókhoz való közelség befolyásolja. Miközben a folyópartmenti területeken árprémium mérhető, a kockázatosabb részek az árvízi kockázat miatt elvesztik ezt az előnyüket. Azokban az irányítószám-körzetekben, ahol az elöntési mélység 10%-kal magasabb, a lakásárak átlagosan 1%-kal alacsonyabbak, és még 1%-kal, ha nagyobb folyó mellett találhatók.

JEL: Q51, Q54, R30, R31

Tárgyszavak: lakáspiac, hedonikus árazás, árvízi kockázat, földrajz

Köszönetnyilvánítás

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INTRODUCTION

Understanding the consequences of natural disasters such as floods has become an important topic. Climate change is perceived to increase the likelihood of such events and as public policy is geared more towards intervention[1]. These events, even if not disastrous are associated with substantial costs. In particular risks of inundation may reduce housing prices thus destroying wealth of locals.

Flood events are a threat to life and cause countless economic losses, including the damage of properties. A recent report by The United Nations International Strategy for Disaster Reduction reveals, that floods affected 2.3 billion people and more than 150,000 individuals have died as a result of floods in the last 20 years worldwide. In summary it alone accounted for 47% of all weather-related disasters (UNISDR 2015). Moreover such natural disasters are likely to grow in Europe according to the European Environment Agency (EEA). Climate change will probably increase the occurrence and frequency of flooding hazards across Europe. More extreme weather results in local intense precipitation events which raise the frequency of flash floods and pluvial floods as well (EEA 2012). These facts motivate the investigation on the impacts of flooding on property valuation.

Flood risk is particularly important in Hungary. Due to its low-lying location and that most of its rivers are inflows from neighboring countries, it is highly endangered by flooding. Hungary has the largest flood protection system in Europe, followed by much larger countries (Italy, Ukraine) and the smaller Netherlands which makes only the latter comparable to Hungary (OECD 2008). These protected flood plains covers 23 percent of the country's territory (about 21 000 km^2), where more than 700 settlements and 30 percent of the national income located (ÁKK 2014 Konzorcium, 2015a).

Estimating the potential impact of floods is closely related to the analysis of how water proximity may affect housing prices. Proximity of water has a fundamental role in the housing value, and it affects the value of real estate through different channels. Historically, water had an essential role in industrial production and transportation. This technological importance lost strength, but cities on riverbanks kept their labor force and regional significance.

[1] Indeed, there seems to be an increased chance of flooding due to "greater water-holding capacity of a warmer atmosphere", chances are that "such events will continue to become more frequent" (IPCC, 2007, page 783). See also Daniel, Florax and Rietveld (2009) on the topic.

In this paper we consider a simple hedonic pricing model, where housing prices are driven by characteristics of the property and the flat or the house, features of first geography and socio-economic characteristics of the location. Most studies focused either on positive water amenities or flood risks, mostly focusing on a small geographical area.

Rouwendal, Levkovich, and van Marwijk (2016) estimates the value of proximity to water using matching of almost identical houses. Their result focuses on the bias that locations close to water may be selected by households with higher incomes who construct more luxury houses. They find that proximity to water increases the value of housing by 5% on average, but this effect decays quickly with distance. The study of Cho, Bowker and Park (2006) estimates the influence of proximity to water bodies and park amenities on residential housing values in Knox County, Tennessee, using the hedonic price approach. The authors find that a houses that are 10 percent closer to water bodies are on average 12% more expensive. Interestingly, distance to parks have almost the same effect of 1.1%. Water proximity nowadays is more valued as a sight. We found various attempts to valuate flood risks in the existing literature. Daniel, Florax and Rietveld (2009) gives a good review of them for their meta-analysis. Most of the studies use the actual selling price of the house as the dependent variable. They found that higher probability of flood risk of 1% in a year is associated with a difference in transaction price of an otherwise similar house of -0.6%.

Papers that investigate the effects of flooding are increasingly common in recent real estate literature due to climate change[2]. With the estimation of spatial hedonic regression models within a difference-in-differences framework Bin and Landry (2013) investigate the impact of flood risk on housing values after multiple storm events in Pitt County, North Carolina. They found that price differentials arise in the wake of two major storms (Hurricane Fran and Floyd): homes in flood zones sell for 5.7% less after Hurricane Fran and 8.8% less after Hurricane Floyd. More recent data that cover a period in which there were no significant storms reveal that price discount on homes in the flood zone is diminishing over time. Turnbull et al (2013) argue that perceived floor risk affects not just the selling price of housing but also its liquidity. Moreover the mix of capitalization in price relative to liquidity varies by type of flood risk as weak and strong phases of housing market. A broader flood entails a greater price and liquidity capitalization in the strong market compared to a more modest price decrease in a weak market. There is a more severe difference in capitalization

[2] Some of the environment and risk literature focuses on large, devastating events such as Hurricane Floyd in 1999 (Bin-Polasky 2004), Hurricane Ivan (Morgan 2004). Zhai, Fukuzono and Ikeda (2003) presented a case study of the 2000 Tokai Flood when a heavy rainfall inundated the Japanese city of Nagoya.

patterns in case of localized flood risks. Risks are fully capitalized into price in the weak market and liquidity in the strong market phase. Zhang (2016) reveals further heterogenity in the effects of flooding. With the application of spatial quantile regression Zhang shows that being located within a 100-year floodplain in Fargo-Moorhead Metropolitan Statistical Area has a negative impact on the price of residential single-family houses. In addition to that this discount is stronger among lower-priced homes, and weaker among higher-priced ones. The study also examines if a major flood in 2009 had an impact on the housing prices and it turns out that across quantiles it had more effect on lower-priced than higher-priced homes.

Variables reflecting the quality of water bodies or floodplain location could capture both amenity and disamenity effects of being closer to water bodies (Cho-Bowker-Park 2006). Indeed, as argued by Daniel, Florax and Rietveld (2009), the existence of water is associated with both negative and positive spatial amenities so a floodplain location signaling dummy variable may underestimate the value of the risk of river flooding.

Despite flood protection, inundation risk remains a concern for housing pricing. Studying Hungarian data will let us understand the costs of non-catastrophic events. Indeed, our core question is how a fairly permanent, non-catastrophic risk may be priced in housing values. In this paper we consider a simple hedonic pricing model, where housing prices are driven by characteristics of the property and the flat or the house, features of first geography and socio-economic characteristics of the location. In particular, we focus on proximity to major river and flood risk measured with the inundation depth of ZIP code districts. We use a cross-section of Hungarian housing transaction data merged inundation risk information that were calculated for us by General Directorate of Water Management in Hungary.

Hedonic method is the main technique of pricing heterogeneous products. The principle of the method is to statistically estimate the correspondence between the price and the attributes of the product (Coulson 2008). An important alternative of the model would be the repeated sales model – that is not possible given an important limitation of our data, we do not observe the actual address but the street only.

This paper finds that flood risk reduces housing prices substantially. It turns out that the average elasticity is driven by being in close proximity of major rivers. While riverside areas have an overall price premium in Hungary, risky areas lose this advantage to flood risk. In ZIP code areas where the inundation depths are 10% higher, housing prices tend to be 1% lower on average plus another 1% lower along the major rivers.

This result goes beyond evidence found in the literature as directly focus comparing positive and negative effects associated with proximity to water. Importantly, we considered socio-economic features such as average local income that allows to control for sorting of wealthy people away from risky areas.

As for the remained of the paper, section 2 presents key facts and figures on floods in Hungary, 3 introduces all the data used, section 4 presents the estimation method and results, while section 5 concludes.

1. FLOOD RISK IN HUNGARY

Previous studies argued that proximity to waterbodies capture both amenity and disamenity effects. Amenity effects include the value of open space (water view) and its recreational attractiveness, while disamenity effects could be associated with the risk of natural disasters, e.g. landfills, floods. In case of Hungary, flooding has always been the greatest hazard over its history, even today the risk of flooding is the highest in Europe. This can be traced back to the country's geographic and climatic features. Hungary is located in the drainage basin of the Danube river, in the deepest part of the Carpathian Basin. Most rivers of the Alps and the Carpathians flow into its two major rivers: the Danube and the Tisza. The majority of other rivers also spring in foreign countries, so their water flow is influenced by other countries, too. Besides that, almost two thirds of the country lie lower than 200 metres above sea level. In addition to that, climate also increase flood risks. Sudden melting of snow is common in the above mentioned mountains and a huge amount of the falling precipitation also result in flooding in Hungary. The combination of melting snow and precipitation often led to severe flooding (Rácz 2011).

River regulation date back to the 19th century and most of the floodworks were carried out at Tisza. The settlements along the Tisza and its tributaries were located in the socalled high floodplain, which had not been inundated even by the most devastating floods while in the meantime the ancient Tisza and its tributaries had flooded the lower flooplains of the Great Plains. As a consequence of various human intervention in nature (forest clearance, land cultivation, mining and quarrying activities within the basin) runoff had increased and the low floodplain was silted up gradually so an increasing number of settlements were endangered even in the higher areas near the Tisza. Risen high water levels had convinced decision makers to start a flood control and water regulation program in the middle of the 19th century.

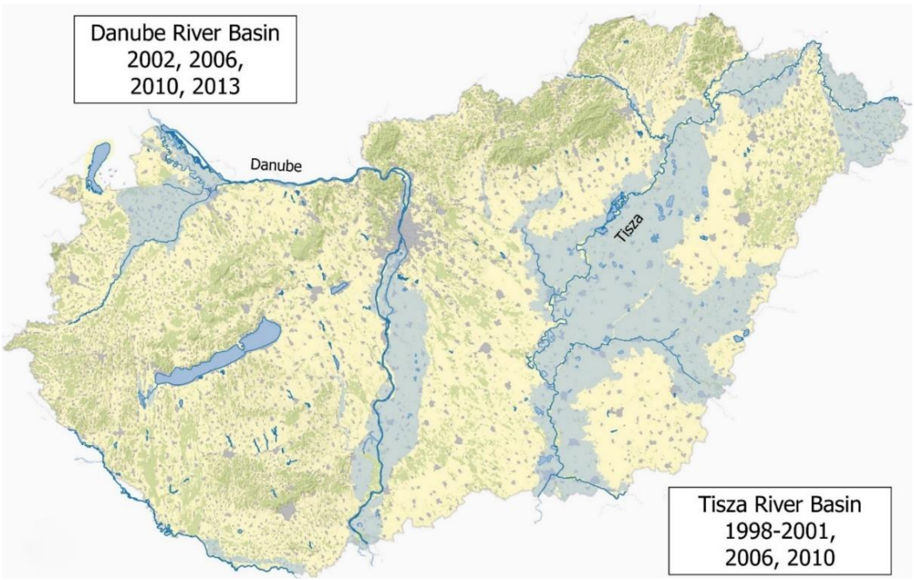
Construction of a system of embankments also involved the construction of artificial channels, cutting off meanders and reclamation of swampy areas through the operation of drainage canals. Water regulation also covered the Danube but constructions were more substantial at Tisza. These measure are still considered one of the most radical interventions in the natural conditions of Europe (Schweitzer 2009). With the regulation of Tisza its section has shortened by almost 500 km on the present-day territory of Hungary. The achieved results are fairly debatable: there has been a fourfold increase in population and the accumulation of wealth in floodplain has also multiplied near the Tisza while floods continue to occur (Nagy et al 2010).

In the 2000s due to the above mentioned causes many floods hit Hungary causing the evacuation of population from some heavily threatened settlements because hundreds of homes have become inhabitable.

Measurement of the impact of flood risks is considered as a highly relevant topic nowadays. This statement is especially true for the countries located in the Carpathian basin. Map 1 shows the key floodplains in Hungary and several catastrophic flooding events in the past 20 years. Floods were more common and severe in the Tisza River catchment area where the majority of flood-prone areas (15 610 km²) are located. The Hungarian part of the Danube River is considered relatively safer, flood-prone areas cover a total of 5 590 km² (ÁKK 2014 Konzorcium, 2015a).

Map 1

Floodplains and flood events in Hungary in the past two decades

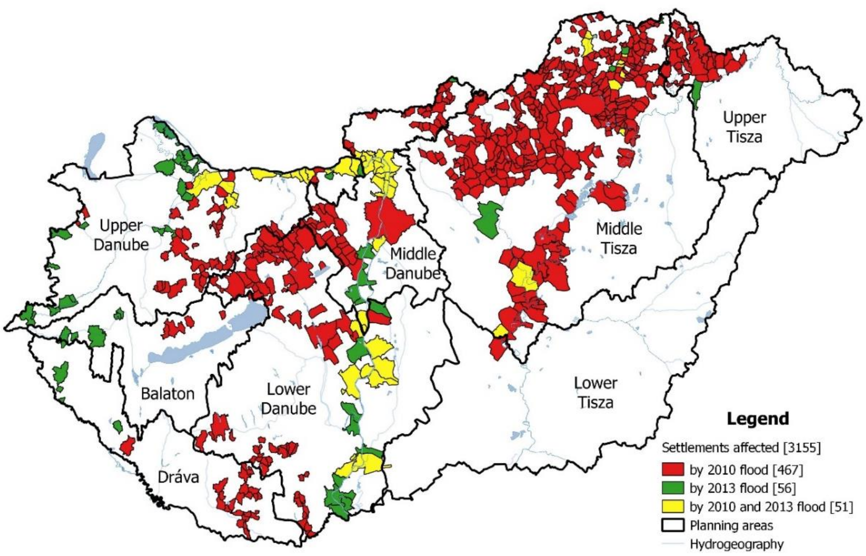


Source of the flooding events is the ÁKK 2014 Konzorcium (2015a)

Between November 1998 and March 2001 four flood waves moved down the Tisza River. In 1999 almost 2500 housing units and 150 municipality buildings were damaged as the result of the severe floods in Northern Hungary (Kapros 2002). The spring flood in 2006 caused a 135 billion HUF in damage overwhelmingly near Tisza (ÁKK 2014 Konzorcium, 2015a). In 2010 more than 300 housing units became unrecoverable and thousands of other buildings suffered reparable damage in Northern Hungary (KSH 2011). The most recent flood events in 2010 and 2013 affected 574 settlements in Hungary (Map 2). The disaster in 2010 was more extensive and caused serious damages in the right tributaries of Tisza. Heavy rain in the middle of 2013 in Central-Europe caused havoc in the Danube, the flood threatened about 200 thousand people in the Hungarian part of the river, of which 1570 have been evacuated[3]. Compared to Map 1 and 2 it can be clearly seen that not only those settlements were affected by the last 2 major hazards that locate in the floodplains but others located near smaller creeks as well. Settlements near those smaller creeks are heavily threatened by flash floods, when suddenly large precipitation pours down locally relatively quickly. In our work we only measure flood risk for those settlements which are located in a 100-year-floodplain. (The key risk measure of 1 in 100 flood risk will be shown in Map 4)

Map 2

Settlements affected by the 2010 and 2013 floods in Hungary



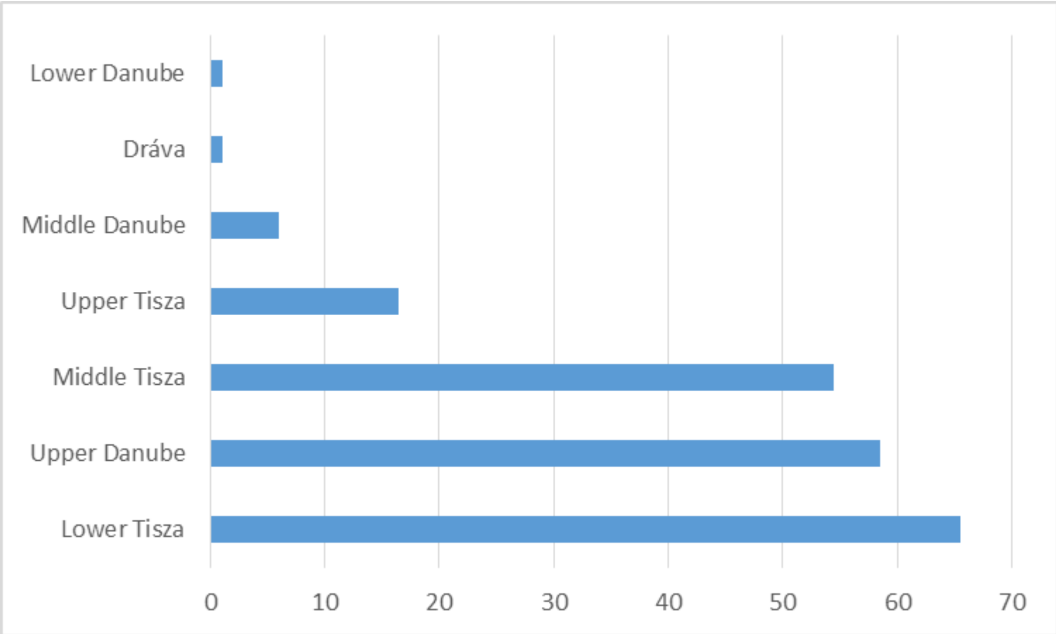
The data source is the National Directorate General for Disaster Management, Ministry of the Interior.

[3] http://index.hu/belfold/2013/06/15/36780_onkentes_10_millio_179_ezer_46_homokzsak/

In the last 10 years approximately 20 billion forints were spent on average annually on flood control. Middle and Lower Tisza and Upper Danube planning areas pose greater risks while Dráva and Lower Danube planning areas entail less risk. Based on the calculations by ÁKK 2014 Konzorcium, the Balaton planning area is completely risk free.

Figure 1

Expected value of damage annually by planning areas in Hungary (billion HUF)

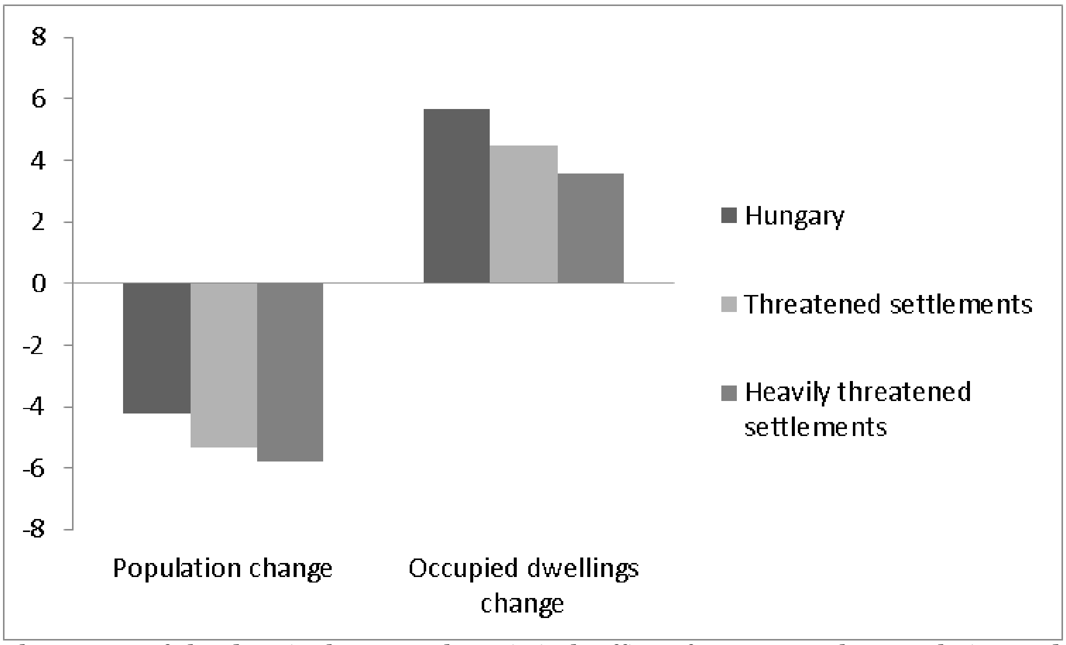


The data source is the General Directorate of Water Management (ÁKK 2014 Konzorcium, 2015b). Expected value of damage was calculated by the multiplication of inundation probability, the exposured areas' sensitivity to inundation and the local value at risk.

In parallel with this more frequent tragic disasters the number of residents who live in flood-prone areas has decreased which was accompanied by the increasing number of occupied dwellings in these settlements (Figure 2). The population of the country has been in decline since 1980 but the steady fall started after 1992. Between the censuses of 1990 and 2011 the nation's population shrank by 4.2% (437,000 persons). Settlements threatened by flooding lost 5.3% of their residents between 1990 and 2011 while the decrease of the heavily threatened region's (settlements where more than 50% of the built-up areas are inundated) population was slightly more severe (5.8%). Despite population decline the number of occupied dwellings increased in Hungary by 5.6% (209,000 housing units). It could be surprising that this growth is also prevailed in flood-prone areas, although the heavier the threat the lesser the increment (4.48% and 3.56%).

Figure 2

Population and occupied dwellings change between the 1990 and 2011 censuses



The source of the data is the Central Statistical Office of Hungary. The population and occupied dwellings change were calculated by the settlements data of the 1990 and 2011 Censuses. We labeled settlements as threatened if a 1 in 100-year flood inundate any part of their built-up areas. A settlement was treated as heavily threatened if more than 50% of the built-up areas would inundated.

2. DATA

In this paper, we use a cross section of 2012 and 2013 residential real estate transactions, after filtering out unreliable data. In this section we present housing prices, geography and other variables used as well as the construction of our main flood risk variable.

3.1. HOUSING PRICES

We used transactional data of the Hungarian housing market for years 2012 and 2013. The data covers all housing transactions in the country. The source of the data is the National Tax and Customs Administration of Hungary (NTCA) and has the following set of variables[4]:

- year of purchase,

[4] There are lot of potentially useful variables in the database related to real estate properties (number of rooms, the existence of balcony, year of construction etc.) that we cannot utilize because availability of these variables are below 10%.

- price (purchase price documented through transaction)[5],
- area,
- building type (detached house, terraced house, condominium or flat in a block of flats),
- location of the lot (based on ZIP codes).

Several rounds of data cleaning were necessary given large amount of missing observations in key variables and some anomalies of values --transactions with reliable data were kept only. We dropped those transactions where fractional ownership was transferred and we also had to remove observations which came with missing prices/location/purchase year. We only kept transactions of which type can be clearly identified. The minimum price limit was set to 10 thousand forints, so we dropped almost 300 observations which were less expensive.

In case of houses we only kept those ones where 2 differing area data (living area and lot size) was recorded. We also formed two groups in order to investigate the difference between flats where one or two area data was recorded. We also found statistically significant difference between those two groups and we do not know the reason for it so we dropped those flats where only one area data was found.

Finally, we would like to get rid of extremely small and large areas – the huge differences between the mean and median values suggest the presence of coding errors. We scanned pattern in the possible errors and analyzed correlations as well before setting the limits of dropping. The lower limit was set to 10 sqm while the upper limit was set to 1000 and 3000 sqm in case of living area and lot size, respectively. As a result, we dropped about 2000 observations.[6]

Despite pooling two years of transactions, almost two-thirds of the 3154 Hungarian settlements had no recorded transactions. The most important reason is that these are very small units (see Table 1). A map on the number of transactions may be found in the Appendix (Map A1).

[5] In case the NTCA didn't accept the reported purchase price and imposed the stamp duty based on higher price, we used the calculated value of the NTCA.

[6] For more details see the Technical Paper by Békés, Horváth and Sápi (2016)

Table 1

The distribution of settlements by number of transactions and inhabitants

Transactions / Inhabitants	0	1-4	5-25	25+	All
less than 1.000	1382	369	6	0	1757
1.000-10.000	473	595	175	12	1255
10.000-100.000	0	2	43	89	134
100.000+	0	0	0	7	7

The data source is the National Tax and Customs Administration of Hungary.
The population comes from CSO's T-STAR database, for year 2012.

An important additional decision is dropping the Budapest market. Hungarian capital Budapest has 18% of the country's population and 35% of its GDP, it has a large and sophisticated housing market. However, it also has its own flood defense system, different consumer base (foreigners), and identifying exact location would be more important. Hence, it has no real control group, making any identification rather unfounded. As a result, we dropped all Budapest transactions.

Table 2

Description statistics of our sample (2012-2013) without Budapest

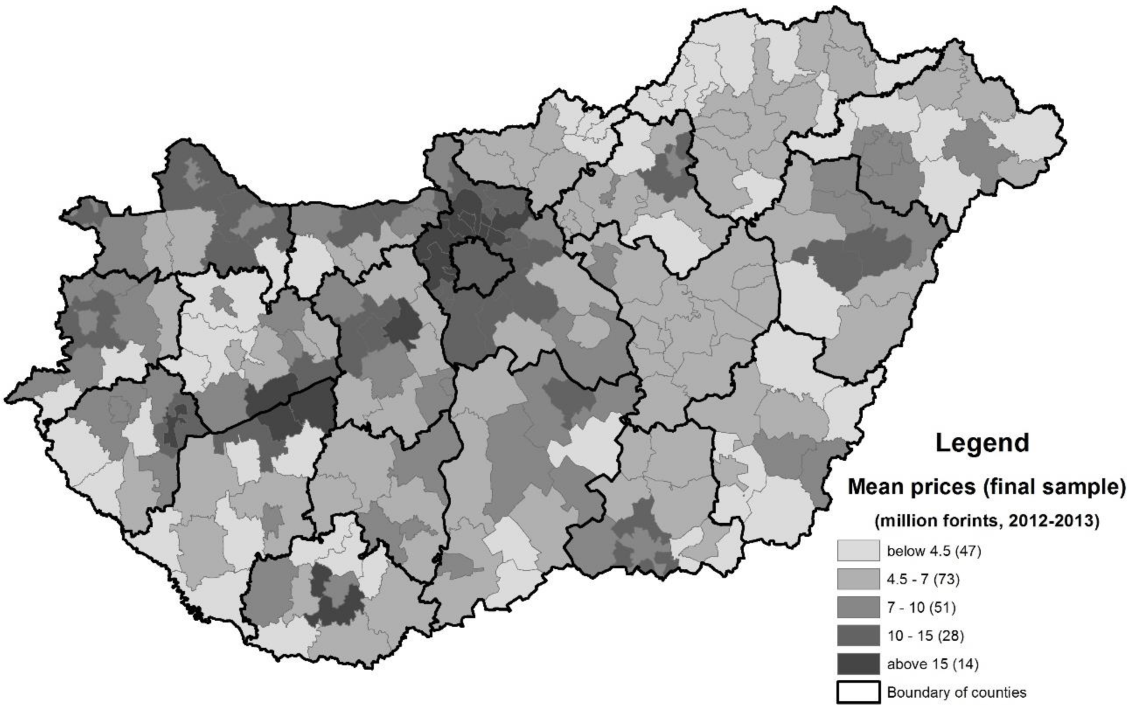
		Price		**Living size**		**Lot size**	
	Number of observations	Mean	Median	Mean	Median	Mean	Median
all	28,546	8.866	6.900	65.04	55	236.66	56
flat	22,593	8.149	6.790	56.08	54	60.28	54
house	5,953	11.590	8.000	99.02	80	906.07	779

The data source is the National Tax and Customs Administration of Hungary. Flat category comprises of condominiums and block of flats, house category consists detached and terrace houses. Price is measured in million forints and represents purchase price documented through transaction or the calculated value of the NTCA if the reported price was not accepted. Living size and lot size are measured in square meters.

Map 3 gives insight into the spatial differences of mean price. It varies greatly at the level of Modified Micro Regions. Three zones could be distinguished according to relative high prices: the big cities and their surrounding agglomerations (e.g. Győr, Pécs), micro regions that are close to Vienna and the territories near Lake Balaton. Prices are lower in the peripheral border regions in the southwest and northeast parts of the country, across much of the rural Great Plain and surprisingly between the more expensive areas of the western border and Lake Balaton.

Map 3

Mean prices in the final sample (2012-2013)



The source of the data is the NTCA. Mean prices were calculated for Modified Micro Regions or MMRs.

3.2. WATER PROXIMITY AND FLOOD RISK

As argued earlier, this paper aims at showing correlation of housing prices both with the positive amenity of proximity to water and the negative amenity value of floods.

Closeness to waterbody captures water related attractiveness well, so a dummy was constructed by using ZIP code boundary, settlement's built-up area boundary and waterbody map layers. We created a 1 km buffer in either direction around the main rivers (Duna, Tisza) and lakes (Balaton, Fertő, Lake Velence and Lake Tisza). We defined ZIP codes as near-water areas when part of the corresponding settlement's built-up area was overlapped by the waterbody buffers. We applied a slightly different method in case of the 7 region centres (including Budapest). These large cities comprise many ZIP code areas (Miskolc – 21), so we defined overlapping not for the whole built-up area, but for the ZIP code areas. Some locally important rivers (e.g. Rába, Sajó) were also used beside the main ones during the buffer construction process. As a result, 304 ZIP codes were defined as near-water areas out of which 238 is by rivers and 66 by lakes.

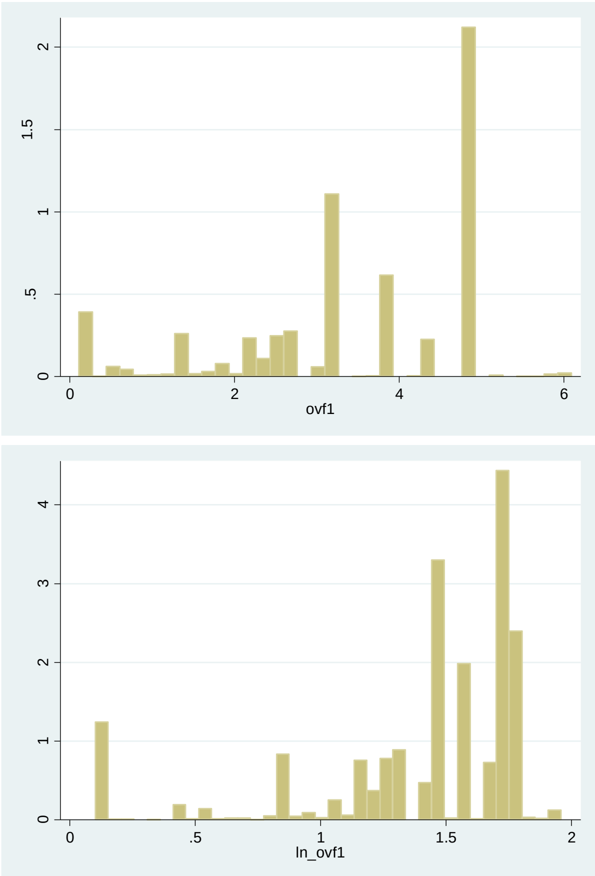
Evidence from the previous literature suggests that it is straightforward to assess the impact of flooding through a simulation of a flood event occurring with a certain probability in a year. In a recently finished project (Flood Risk Assessment and Hazard Mapping Data Production, funded by the European Union) the General Directorate of Water Management (Országos Vízügyi Főigazgatóság – OVF) mapped flood risk and calculated inundation depth with a Geographical Information System[7]. We obtained data for settlement and ZIP code levels derived from this project for a 1 in 100-year flood and used them for our analysis.

The analysis by the General Directorate of Water Management (OVF) is based on the following model: Take a 50x50m raster on the country and consider how rare but large floods – one that would happen once every 100 years would play out. Using maps, flood defense information and past data, simulate various scenarios and average them. Then create map based on expected inundation depth. Figure 3 shows the distribution of values of average inundation depth.

[7] http://www.vizugy.hu/index.php?module=vizstrat&programelemid=145

Figure 3

Conditional histograms of average inundation depth (nominal (LHS) and log scale (RHS))



The data source is the General Directorate of Water Management (OVF).
Conditional means (for settlements and ZIP code level inundation variable being above zero).

The database contains the size and proportion of flooded built-up area, the average, minimum and maximum values of inundation depth both for settlement and ZIP code levels (Table 3) conditional on the inundation depth variable being different from zero. Almost 500 Hungarian settlements (about every seventh) are threatened by a 100-year flood. The average inundation depth is 1.7 meters which could cause serious damage in the concerned properties. Figures are generally the same for ZIP code level, maybe slightly more severe as some ZIP codes in an otherwise threatened settlement are not inundated at all. The existence of ZIP level data allows us to make a more in-depth investigation so we will use this level for further analysis. As a result, almost 8000 transactions were identified as threatened by flood risk. The average inundation variables are fairly larger because most of the transactions occurred in bigger cities.

Table 3

Description statistics of the flooding variables

	Settlement level			ZIP-code level			Transaction level		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Inundated built-up area	499	1.6	3.7	552	1.4	2.2	7988	6	5.2
Proportion of inundated built-up area	499	49.7	35.5	552	52.3	35.9	7988	70.7	33.4
Average inundation depth	499	1.7	1.1	552	1.8	1.2	7988	2.8	1.3
Minimum inundation depth	499	0.4	0.7	552	0.4	0.7	7988	0.5	0.6
Maximum inundation depth	499	3.5	2.3	552	3.6	2.3	7988	6	2.7

The data source is the General Directorate of Water Management (OVF). Conditional means (for settlements, ZIP code and transactional level inundation variable being above zero). Inundated built-up area is measured in million square meters while inundation depths are measured in meters.

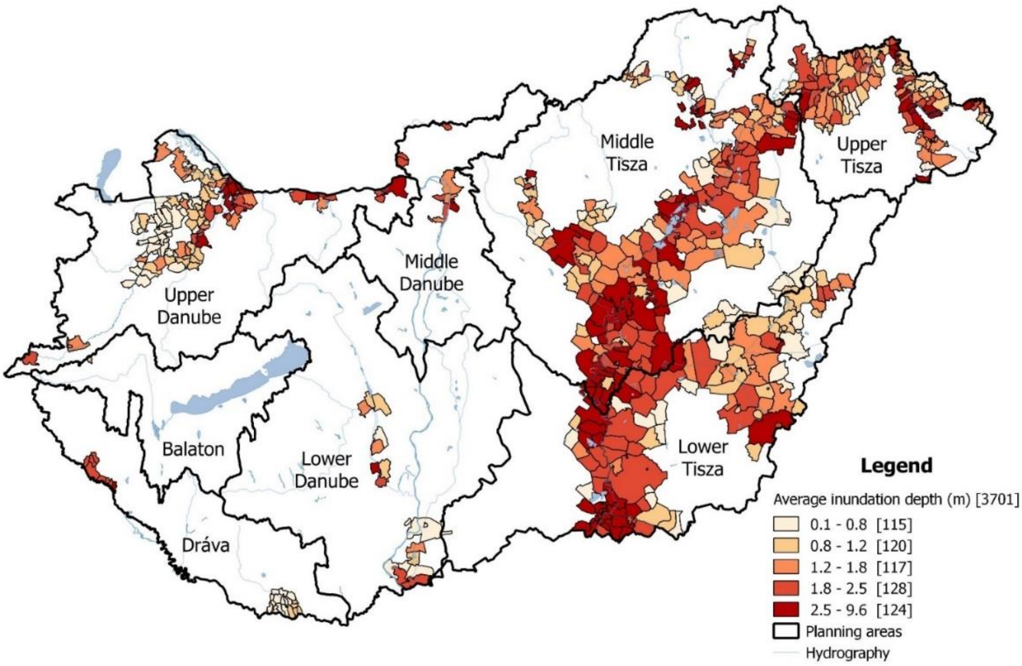
In terms of our transactions, the inundation risk variable non-zero about 20% of settlements, and its non-zero values: mean is 2.9m (SD 1.6).

Map 4 presents the value of our variable of interest: the inundation size (in meters) of a 1 in 100 years flood. Variation of this risk within cities, made us use flood variables at ZIP code level rather than aggregated at the settlement level.

The most endangered territories are located in the Tisza River Basin where the majority of the floodplains are inundated by 100-year flooding. Vulnerability is especially pronounced in the middle of the Great Plains, where the Hármas-Körös River flows into the Tisza River. Here a major flood event would deluge the majority of the surrounding settlements. Compared to Tisza River, Danube River Basin could be considered relatively safe. Starting from the northern border of the capital, Budapest, the river is regarded secure, except from the southernmost Hungarian part of it. From the state border to Budapest, Danube is more dangerous and the surroundings of its right tributaries (Rába, Rábca) are also exposed to risk.

Map 4

Average inundation depth in Hungary by ZIP areas



The data source is the General Directorate of Water Management (OVF). Inundation depth was calculated by using 1 in 100 years flood risk for built-up areas.

Only two of the major cities are threatened heavily by flooding: Győr and Szeged. Győr is located in the confluence of three rivers: Danube, Rába and Rábca. Half of its postal districts would be inundated more than 80 percent of the ZIP area by 100-year flooding. The most vulnerable major city is Szeged which sits below the confluence of the Tisza and Maros rivers. All but one of its ZIP areas would be completely flooded by a 1% flood.[8]

3.3. GEOGRAPHY AND SOCIO-ECONOMIC VARIABLES

Elevation data was created using NASA's high resolution (30m/px) SRTM-data. The Shuttle Radar Topography Mission launched in 2000, and it obtains near-global high-resolution database of the Earth's topography. [9] We argue that the terrain changes so slowly, that this data should be considered as up-to-date. The data covering the entire Hungarian territory

[8] Another related but less comonly used variable would be the *share* of built environment reached – see Map A1 in Appendix.
[9] NASA's Shuttle Radar Topography Mission, retrieved from: http://www2.jpl.nasa.gov/srtm/mission.htm

comes in two pieces, therefore we joined them[10]. After that we superimposed our ZIP-code boundary layer on the drawn up digital elevation model (DEM). With the Zonal Statistics Tool in Arcmap we calculated the maximum and average height of each ZIP area. We considered a ZIP area as mountainous area if the maximum height is more than 250 meters.

A key variable of interest will be income that comes from The National Land Development and Land Regulation Information System (TeIR) and within that the source is the NTCA database. The NTCA does not publish directly proper income data, so we calculated it in the following way: Total taxes was subtracted from the combined tax base, and the result was divided by the number of tax payers. We argue that this estimation reflects well the settlement's average income conditions. The average yearly income in our sample is 1,24 million forints. Not surprisingly the average income is greater in the cities than in the villages, but the highest average income values belong to villages agglomerating the capital: Telki, Budajenő and Üröm.

Table 4

Descriptive statistics of the geography and socio-economic variables without Budapest

	Total sample		**Cities**				**Villages**			
	mean	*SD*	*mean*	*SD*	*min*	*max*	*mean*	*SD*	*min*	*max*
Elevation	166.29	76.82	151.46	85.32	73.53	968.17	169.27	74.64	74.17	903.7
Population density	743.4	537.5	1461.9	653.5	269.6	4219.3	598.4	368.8	22.5	3636.4
Income per taxpayer	1.24	0.29	1.46	0.25	0.96	2.39	1.2	0.27	0.36	3.33

Elevation comes from the NASA's high resolution (30m/px) SRTM-data, measured at ZIP code level, in meters. The population density comes from CSO's T-STAR database, for year 2012 and it was calculated by the division of resident population by built-up area. It is measured at settlement level, in persons per square kilometers. Income data comes from TeiR's NTCA database, for year 2012. Income is calculated as the difference of combined tax base and total taxes and then divided by the number of taxpayers. It is measured at settlement level, in million forints.

[10] We used the Mosaic To New Raster tool in Arcmap.

Average income varies both by settlement type and regionally. Settlements of the Western and Central Transdanubia and Central Hungary looks wealthier in terms of average income per taxpayer. In the eastern part of Hungary, the average income is lower.

3. ESTIMATION MODEL AND RESULTS

To understand the role of proximity to water as well as flood risk, we estimate a cross section OLS model at the transaction level on the whole country.

$$p_{i|r} = \alpha + \beta \boldsymbol{H}_i + \gamma GEO_r + \mu ECO_j \delta_1 River_r + \delta_2 Flood_r + \delta_1 RiverXflood_r \quad (1)$$

Our dependent variable is the log price of the property i in area r. $\boldsymbol{H}$ is a vector of transaction specific variables, including the size of flat or house, the size of the lot, a house dummy, a house*size interaction variable, and dummy of blocs of houses. Estimates of these variables are available in the appendix. *GEO* is a vector of geography variables, including a dummy for lake-side (it is especially important for settlements around Lake Balaton), the log value of average elevation measured at settlement level. When available, we use ZIP code data for geographic variables. Settlement level data is used for population density.

ECO is a vector of socio-economic variables at the settlement level. It includes dummies for settlement types (city, village), population density and income. Population density is measured as log of number of inhabitants over settlement's built-up area, income is the log average wage of inhabitants of the settlement (excluding commuters).

Flood risk is measured by average inundation depth values. Out of 28,524 transactions, 6,259 took place in areas (ZIP codes) with non-zero inundation risk.

Equation (1) is measured by OLS, with standard errors clustered at settlement level. The data is combination of 2012 and 2013 transactions. This combination is necessary to increase the number of observations and hence, increase the coverage of small settlements with infrequent transactions. Although this period was quiet in terms of price dynamics, we included a 2013 year dummy. Data excludes Budapest, for it is a very specific area, with a rather different data structure.

The first table presents basic results with different functional forms ways of modelling inundation. In the first column, we have the nominal value, while columns 2-3 present log value – preferred specification. Column 3 includes an interaction term between inundation and major rivers.

Table 5

Estimation results

	(1)	(2)	(3)
Population density (log)	0.515**	0.512**	0.515**
	(0.0425)	(0.0421)	(0.0424)
Elevation (log)	-0.109	-0.111	-0.0912
	(0.0593)	(0.0594)	(0.0593)
Major river (Dummy)	0.0954	0.0984	0.187**
	(0.0609)	(0.0609)	(0.0698)
Lake (dummy)	0.894**	0.891**	0.907**
	(0.159)	(0.159)	(0.159)
Average inundation	-0.0646**		
	(0.0113)		
Average inundation (log)		-0.164**	-0.0576
		(0.0285)	(0.0313)
River X inundation			-0.212**
			(0.0475)
Constant	225.6**	224.5**	218.8**
	(33.83)	(33.80)	(34.77)
Observations	28,542	28,542	28,542
R-squared	0.438	0.438	0.443

Controls include, size of living area, lot size, blocks dummy, house dummy, house-size interaction terms. Budapest excluded. Robust standard errors clustered at settlement level are in parentheses. ** p<0.01, * p<0.05

These results suggest significantly negative correlation between housing prices and average inundation risk of an area. In particular, let us compare properties that have the same key features (size, type of housing), and the same basic urban environment (population density) and geography (elevation). Results in specification (2) suggests that in ZIP code areas with 10% higher inundation risk, housing prices tend to be 1.6% lower on average.

However, specification (3) suggests that this feature is closely associated with the housing being situated by major riverways. Indeed, it shows that house prices with no inundation risk are 18% higher by major riverways, but this advantage may become a disadvantage should inundation risk become an issue. Specification (3) suggests that the risk affects housing prices almost entirely along major rivers, where a 10% higher inundation risk is associated with 2.1% lower house prices.

The next table repeats this exercise, but now adding income per capita at settlement level. This variable reflects sorting pattern of people – more well-off people may have an easier time selecting better locations, may move away from flooded properties. Furthermore, settlements in richer areas will have more funds to cover flooding costs thereby potentially reducing the elasticity on house prices. Extended results are presented in Table 6.

Table 6

Estimation results (2)

	(4)	(5)	(6)
Population density (log)	0.339**	0.337**	0.343**
	(0.0484)	(0.0481)	(0.0487)
Elevation (log)	-0.219**	-0.220**	-0.208**
	(0.0556)	(0.0557)	(0.0568)
Major river (Dummy)	-0.0960*	-0.0939*	-0.0474
	(0.0426)	(0.0426)	(0.0591)
Lake (dummy)	0.972**	0.970**	0.976**
	(0.149)	(0.148)	(0.149)
Average inundation	-0.0545**		
	(0.0109)		
Average inundation (log)		-0.136**	-0.0862**
		(0.0284)	(0.0327)
River X inundation			-0.101*
			(0.0474)
Income pc (log)	1.483**	1.481**	1.446**
	(0.166)	(0.167)	(0.169)
Constant	185.1**	184.3**	182.6**
	(32.19)	(32.11)	(32.42)
Observations	28,542	28,542	28,542
R-squared	0.491	0.491	0.492

Controls include, size of living area, lot size, blocks dummy, house dummy, house-size interaction terms. Budapest excluded. Robust standard errors clustered at settlement level are in parentheses. ** p<0.01, * p<0.05

Results in specification (5) suggests that when comparing properties located in comparable income areas, in ZIP code areas with 10% higher inundation risk, house prices tend to be 1.36% lower on average – a slightly lower point estimate, compared to specification (2). Regarding the interaction term in model (6), 10% higher inundation risk is associated with 0.086% lower house prices on average and in addition to this, another 1% reduction is visible along major rivers.

This extended model suggests some selection effect, but core results remain unchanged: there is a negative correlation between housing in very similar areas but different inundation risk, and this relationship is exacerbated along major rivers.

Note that by no means can we claim causality. While reverse causality is unlikely, an important missing variable would be details of housing: we only observe the size and location but not its features. It is possible that housing in flood-risk areas would be of higher quality. Note that such omitted variables, would bias our results upward. Note that there may also be a selection bias as some houses may be located in very risky areas that prevent a transaction happening. This would generate a downward bias of our estimates.

Overall, we showed that a strong negative correlation of housing prices and local flood risk. Cost of flood risk are substantial and are concentered in areas along major riverways.

4. CONCLUSION

The research was conducted on a very detailed and elaborated Hungarian database. 30 thousand transactional house prices were used as left-hand side variable. Since Hungary is heavily threatened by flooding, very detailed inundation data is available at the authorities. Beyond the key explanatory variable, rich set of control variables are used during the impact assessment. The calculated effect of flood risk is valid for locations identical in geographical and socio-economic characteristics. It turns out that the average elasticity is driven by being in close proximity of major rivers. While riverside areas have an overall price premium in Hungary, risky areas lose this advantage to flood risk.

Our analysis estimated that flood risk reduces housing prices substantially. In ZIP code areas with 10% higher inundation risk, house prices tend to be 1.36% lower on average. The mean value of log inundation is 1.27 for areas with non-zero risk. Comparing zero risk and the mean non-zero risk property gives an expected price difference of around 17%. Multiply with this 8.8m HUF average property value and 3.5m properties (outside Budapest), the housing cost of flood is around 900bn HUF (3bn euros).

Based on our results, cost-benefit analyses of protection against flood risks can be more established. Effect of flood risks on housing wealth has been scarcely used so far, our calculations support this part of the policy decisions.

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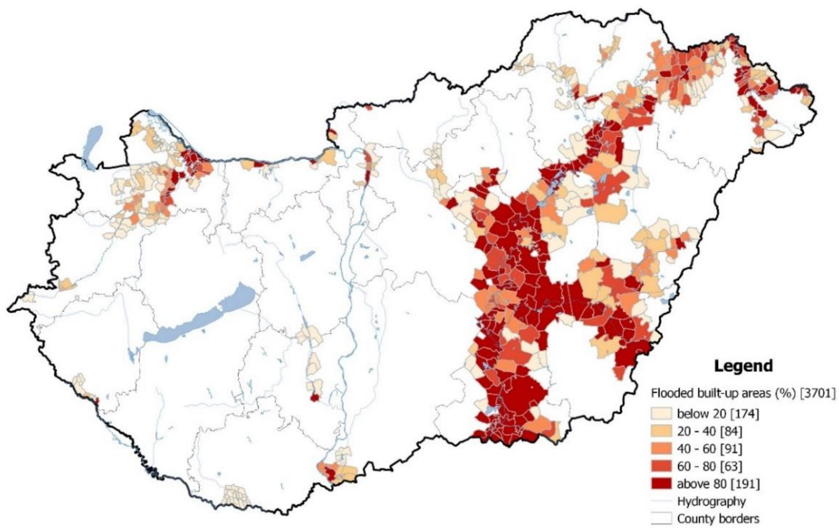
6. APPENDIX

Map A1 shows the inundated settlements and the severity of flooding as the proportion of flooded built-up areas per ZIP code area. In Hungary, there are two major rivers, Duna and Tisza, and smaller rivers would join up with these two. In Map A2 we can see the number of transaction in the Hungarian settlements in 2012 and 2013.

Map A1

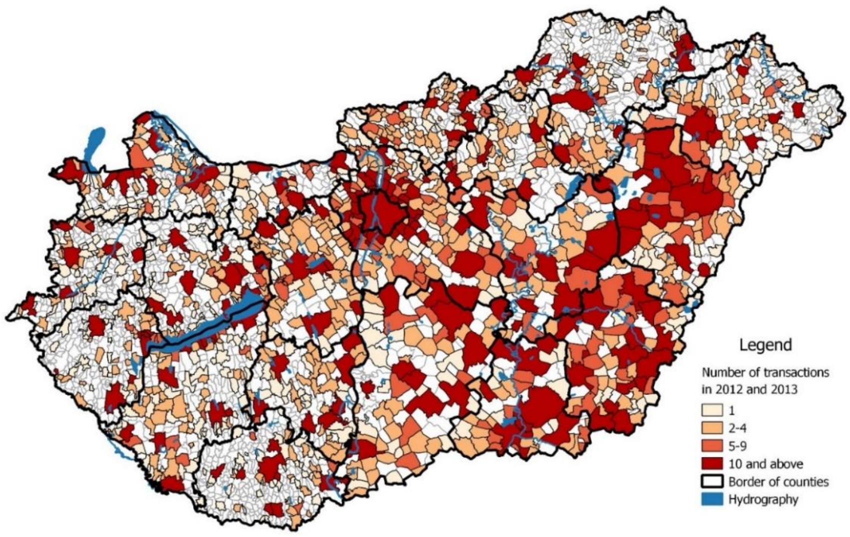
Flooded built-up ZIP areas by 100-year flooding in Hungary



Built-up areas attached to the 1 in 100 years flood risk. The data source is the General Directorate of Water Management (OVF).

Map A2

Number of transactions in the Hungarian settlements in 2012 and 2013



The source of the data is the NTCA.