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FLOOD HAZARD AND ITS IMPACT ON THE RESILIENCE OF CITIES:

An Accessibility-Based Approach to Amenities in the City of Gothenburg, Sweden

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ABSTRACT

In the wake of climate change and its impact on increasing the number and intensity of floods, adaptability of cities to and resistance against the flood hazard is critical to retain functionality of the cities. Vulnerability of urban infrastructure and its resilience to flooding from different points of view have been important and worth investigating for experts in different fields of science. Flood hazards as physical phenomena are influenced by form of the cities and thus the magnitude of their impacts can be intensified by urban infrastructures such as street networks and buildings (Bacchin et. al, 2011). In this paper, we aim to develop a method to assess the resilience of a river city (the city of Gothenburg in Sweden), which is prone to flood events, against such disturbances and find out how the city reacts to river floods and to what extent the city retains its accessibility to essential amenities after a flood occurs. To do so, collecting required data; we, firstly, simulate flood inundation with two different return periods (50 and 1000 years) and then the impact areas overlay on the street networks. Evaluating the resilience of the city, syntactic properties of the street networks before and after flooding are measured at different scales. Additionally, accessibility and the minimum distance of the street networks to essential amenities such as healthcare centers, schools and commercial centers, at a medium distance (3 Km) is examined. The results show that flooding influences the city configuration at global scale more than the local scale based on comparison of syntactic properties before and after flooding. However, the results of accessibility and the minimum distance show that the impact of flooding on the functionality of the city is more limited to the riparian areas and the city is not affected globally.

KEYWORDS

Flood inundation, Resilience, Space syntax, GIS, Accessibility

1. INTRODUCTION

"Flood" is defined as a great overflow of water which especially submerges normally dry lands. Based on statistics from Centre for research on the epidemiology of disasters (CRED, 2015) in the period 1994- 2013 floods were the most frequent type of disasters and accounted 43 percent of all disasters and affected 55 percent of total population of the world during past two decades. When the flood plain includes the urbanized areas, such flooding has great impacts on both population and infrastructures and therefore, flood risk management in urban areas plays an essential role in preventing or reducing the impacts of flooding (Tucci, 2007).

In contrast to flood modelling and flood simulation which have a long history, urban resilience against flood hazard is still under development due to the complexity of the urban systems and urban drainage systems (Bacchin et al., 2011). It has been proven that urban forms and urbanization patterns are in close relationships and interaction with natural phenomena and the balance between them might break or disrupt with changing or damaging the physical structure of the cities (Herold et al., 2003; Alberti, 2009; Hillier and Hanson, 1984; Hillier et al., 2007).

In recent years, space syntax research and syntactic properties of the city combined with resilience concept have proposed different methods in assessment and reduction of the disaster risks which cover a range of possibilities from theory to practice at different scale of built environment from building to urban scales (Authors, 2017; Koch and Miranda, 2013; Carpenter, 2013; Cutini, 2013). Gil and Steinbach (2008) use properties of the road network such as connectivity, closeness and betweenness to show indirect effect of flood hazard on transport and socio-economic situations in London. In their paper areas of impact due to the level of separation from the rest of the city making islands, peninsula and peripheral areas and the degree of accessibility to the rest of the city were assessed. Carpenter (2013) used temporal data from before and after the Hurricane Katrina in 2005 and conducted syntactic properties on the street networks to identify specific syntactic and environmental parameters that had positive influences on the resilience of the city.

Flood hazards and river flooding as physical phenomena are influenced by the form of the cities and thus the magnitude of their impacts on urban infrastructures and human life can be intensified by urban infrastructures such as road networks and buildings (Bacchin et al., 2011). As such, one of the main spatial footprints of the flood impact is on the accessibility of the city (road networks for example) to different and essential amenities during the flood events. Comparing the accessibility to amenities before and after a flood event can provide important information about the adaptability of cities to flooding and resistance against the damages caused by flood hazard; an important issue that can be of interest for city planners and designers. In this research, we aim to measure the accessibility of the road network to amenities in the city before and after flood events and compare the results to illustrate if and how the city reacts to flood hazards and to what extent the city retains its functionality against such disturbance.

In this way, we firstly use available data of the city of Gothenburg trying to simulate flood risk with different return periods and represent the affected area of the city by different floods. Finding the most vulnerable area of the city in terms of integration values and the effect of flooding on the accessibility to different facilities offered by city is also of interest in this paper.

2. DATASETS AND METHODS

Although Sweden has been less destructed by floods, the location in the estuary of Göta River in the coast of Kattegat puts Gothenburg at high risk of rising water level in both sea and in the river causing in flooding in the city. Following a global trend, the rate of flooding in Gothenburg is increasing in recent years (Filipova et al., 2012; Herbring and Landenmark, 2011). Thus, measuring and estimating the flood risk, mapping and assessing potential damage and economical loss is not only of interest for researchers but are critical for city planners and other societies of the city dealing with flood hazard and city infrastructures (Fakta om Göta älv, 2015). Gothenburg with a population of 540000 is the second largest city in Sweden after the capital Stockholm (SCB, 2010, www.scb.se). Figure 1 shows a zoomed part of the city including main bridges on the river and the flow of Göta River. In this research, we limit the study area to that part of the river located inside the city (municipality border) and flood simulation and its potential impacts on the structure of the city are investigated in such area. Data required for this paper is obtained from the following sources:

- Digital elevation model (DEM) with a resolution of 2m which covers the whole study area provided by Lantmäteriet (downloaded from https://www.mapslu.se).
- Urban road network or road centre line of Gothenburg derived from open street map (OSM, downloaded from https://www.geofabrik.de/).
- Urban amenities including the location of commercial centres, healthcare centres, pre and primary schools collected from a project called "Dela[d]Stad" (Legeby et al., 2015) funded by Boverket/MISTRA Urban Futures.
- Hydrological data and measurements of the river flows for a period of 15 years collected from SMHI (http://vattenwebb.smhi.se/modelarea/)

Figure 1 - City and the flow of Göta River, sub-stream, bridges and tunnel

2.1 RESILIENCE AND THE WAY WE MEASURE IT

The term resilience was coined in ecology by Holling (1973, p.14) defined as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" is a fashionable term for researchers and authorities involved in disaster management. The main difficulties occur when efforts are devoted to formulate the concept in order to take the term out of a purely abstract and general form -applied interchangeably for sustainability- and advance it toward a specific characteristic in a measurable and functional form (Abshirini and Koch, 2017; Lhomme et al., 2010, Folke 2006). However, there are common definitions of resilience in urban planning and disaster management. Wilbanks (2007) defined urban resilience as "capability to prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to public safety and health, the economy, and security" and Lhomme et al. (2011) defined it as "the ability of a city to operate in a degraded mode (absorption capacity) and to recover its functions, despite the fact that some urban components are disrupted". UNSIDR (2009) defined resilience in disaster management as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." In this view, as Carpenter et al. (2001) noticed the main questions are resilience of what or resilience to what rather than the terminology itself.

Dating back particularly to the 9th international symposium of space syntax, the concept of resilience and the way to measure it in space syntax has recently been discussed in different research, proposing different methods for evaluating the resilience of a city based on comparing syntactic properties of its road network before and after a disturbance. Shedding some light on previous works, some of them are pointed out in this literature. As an example, investigating the influence of flood risk on the city of Turin, Esposito and De Pinto (2015) took advantage of angular segments properties at global and local radii and conducted a principal component analysis to compare the spatial configuration of the city before and after the flood event. Since the comparison of spatial properties before and after the flood showed very limited changes, they considered the city resilient against the flood disaster. In a recent work, Abshirini and Koch (2017) developed a method, firstly introduced by Koch and Miranda (2013) for the building scale, to be executable on the larger architectural scale like cities. They defined two measures derived from syntactic properties called similarity and sameness. Grounded in foreground network (Abshirini and Koch, 2017), similarity measures the extent of change in the size of foreground network before and after a disturbance and sameness measures the percentage of foreground network which remains the same after a disturbance by comparing the location of segments forming the foreground network before and after a disturbance.

According to the nature of flood hazard, one of the subjects highly affected by a flood is the ease with people while access amenities in a city, called accessibility. In this research, we try to measure the impact of flood on the accessibility to essential amenities. It is worth mentioning that such effect is mostly classified as *indirect impacts* of flood, addressing the areas not *inundated* though flooding. In this view, public services, hospitals and healthcare centres, emergency services, food shops, water supplies and importantly road networks as the main connectors of such services, which is spatially located in or around the flooded area, are also vulnerable to flood (Douglas et al., 2010; Stålhult and Andersson, 2014).

Therefore, evaluating the road accessibility to such amenities and comparing the results with the accessibility after a flood occurs can help understand the indirect impacts of the flood. In a recent work, Green et al, (2017) integrating flood modelling with network analysis tried to evaluate the impact of flood on the accessibility of emergency responders to the city district in Leicester, UK. The method they developed was to measure and compare the rescue time via road networks in normal situation and during the flood events. The results showed that 10 minutes rescue time with a full coverage during non-flood condition decreased by 66.5, 39.8 and 26.2 percent for the floods with intervals of 20, 100 and 1000 years respectively. In a similar work, Coles et al, (2017) tried to model emergency accessibility during flood events in York, UK using numerical modelling of flood and overlaying the flooded areas on the road networks to detect inaccessible areas according to a 10 minutes rescue coverage. The results showed the impact of flood events by both reducing in the coverage area and increasing in rescue time.

In this research, we evaluate the resilience of the city based on two different properties: syntactic properties of the street networks including integration and choice values and accessibility value measured based on metric distance (3Km) and minimum distance to amenities. Accessibility is defined as the number of amenities located within a distance from each segment of the street networks and minimum distance is the shortest path to an amenity from a segment measured in metric unit. Comparing syntactic properties and accessibility measures before and after each disturbance reveals the impact of such disturbance on the city configuration and accessibility of street networks, providing quantitative measures to evaluate the resilience of the city against flooding. In this view, what makes this research different from the above-mentioned works is that we measure the accessibility to different amenities and do not limit the analysis to one specific amenity. Furthermore, in this research, we measures accessibility of the entire network to amenities and do not confine the analysis to few centres or limited area, resulting in a more comparative view of the city functionality and city adaptability against the flood event.

3. RESULTS

The results gained from different analyses are discussed in this section for 2 different situations: Flood inundation with a return period of 50 years and flood inundation with a return period of 1000 years which hereafter called *flood L* (low) and *flood H* (high) respectively, due to the degree of their impacts. The flood simulation process was grounded in a GIS platform using tools developed by ESRI and HEC- RAS. The delineation of the watershed and stream network and geometric data including cross sections, flow direction, bank areas and Manning coefficient are prepared and used as inputs to HEC-RAS to simulate potential water flow or flooding according to different return period of 50 and 1000 years (see Demir and Kisi, 2016; Khattak et al, 2016; Goodell and Warren, 2006 for more information) In the end, the results of flood simulation were overlaid on the road network as well as amenities maps to identify the areas of impact. The accessibility analysis is done by PST (Place Syntax Tool) developed by Ståhle et al. (2005) for MapInfo software.

The section starts with the comparison between syntactic properties (choice and integration values) of the city at different scales from local to global to show how such values changes before and after flooding. Then, it represents the accessibility to different amenities before and after the flood events and evaluates the resilience of the city regarding the flood impacts. It should be mentioned that due to the importance of flood H and higher effects of flood H on accessibility, thus the impacts of flood H is more analysed compared to flood L (Table 1).

Syntactic Properties	Geometric Distance (Degree)	Compared to original situation for
Normalised Angular Integration (NAIN)	180, 270, 360, 450, 900, 1200, 1800,3600,4500	Flood L & Flood H
Normalised Angular Choice (NACH)	180, 270, 360, 450, 900, 1200, 1800, 3600, 4500	Flood L & Flood H
Accessibility	**Metric Distance (Km)**	**Compared to original situation for**
Commercial	3	Flood L & Flood H
Healthcare	3	Flood L & Flood H
Preschool	3	Flood H
Primary school	3	Flood H
Minimum Distance	**Metric Distance (m)**	**Compared to original situation for**
Commercial	In Meter	Flood H
Healthcare	In Meter	Flood H
Preschool	In Meter	Flood H
Primary school	In Meter	Flood H

Table 1 - different analyses conducted on the street networks discussed in this research.

Before going to the main discussion, in Figure 2, we show the areas and the segments which inundated through different flooding.

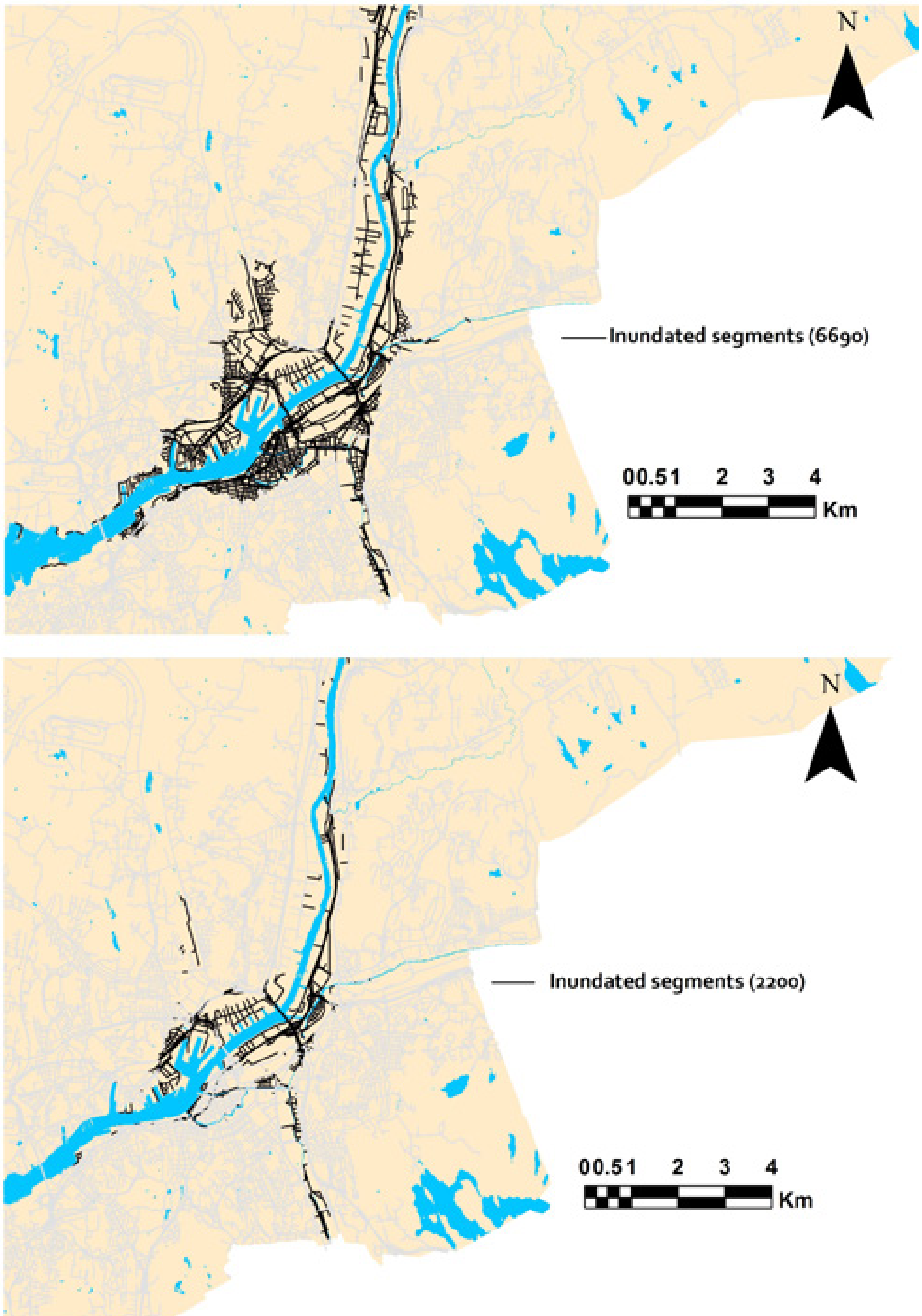

Figure 2 - segments inundated by flood H (upper) and flood L (lower). The number of inundated segments comes in parenthesises.

3.1 SYNTACTIC PROPERTIES

Figure 3 shows the normalized angular choice (NACH) and normalized angular integration (NAIN) values at the global scale (angular analysis in 4500 degrees is considered as global). As an interesting point it can be seen that after flood L and flood H, maximum NACH values are a bit increased while it is obvious that the segments with the high values (coloured in red) are almost disappeared from the centre and around the river. This situation in NAIN values shows that after flood L and flood H, the maximum values are dramatically reduced and segments with high values are intensely disappeared from the city centre and around the river. Having a better understanding of changes after flooding at different scales, Figure 4 and Figure 5 show differences in mean and maximum values of integration and choice properties compared to original properties (before flooding) at different geometric scales (different degrees).

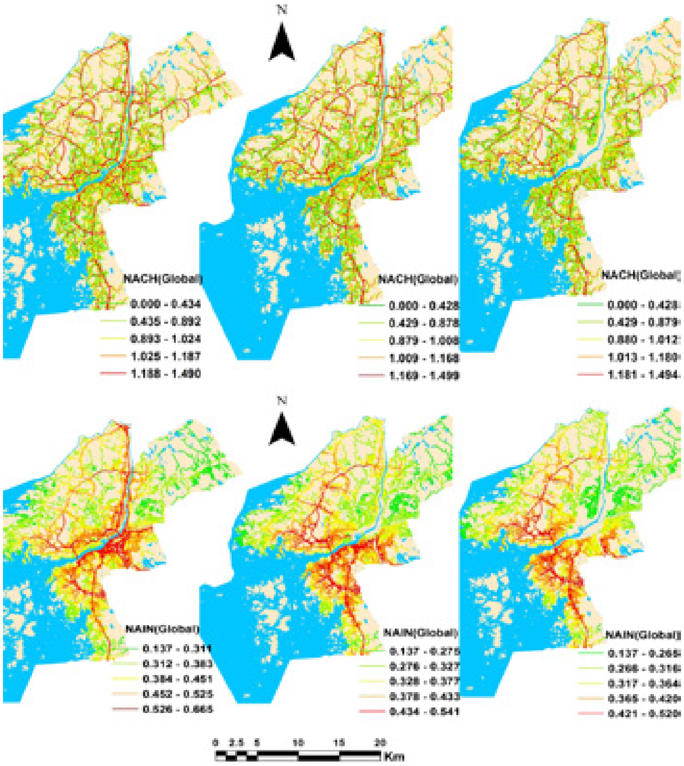

Figure 3 - Upper row: Normalized angular choice (NACH) at global scale. Lower row: Normalized angular integration (NAIN) at global scale. From left to right: Original situation, Flood L, Flood H.

To be consistent with the results, in all cases the values of original situation is subtracted from the flood situations. As a general trend, the differences in the mean value for flood L and flood H and for both choice and integration measures are positive, meaning that the mean values reduces after disturbances and differences increase as the scale of angular analyses increase toward the global scale. As seen in Figures 4, the differences generally increase for the mean NACH, although differences at the middle scales (900 and 1200 degrees) slightly reduce. Such pattern is not seen for NAIN measure as it shows steady increase in the differences while increasing the scale of analysis. In this view, the maximum difference for NACH measure is seen in 4500 degrees for flood (H) which is equal to 0.025 followed by 0.018 for flood (L). The maximum difference in the mean NAIN value is also seen in 4500 degrees for flood (H) equal to 0.084 which followed by 0.067 and 0.50 for the flood (L) accordingly. The results show that NAIN measures compared to NACH measures are more affected by disturbances.

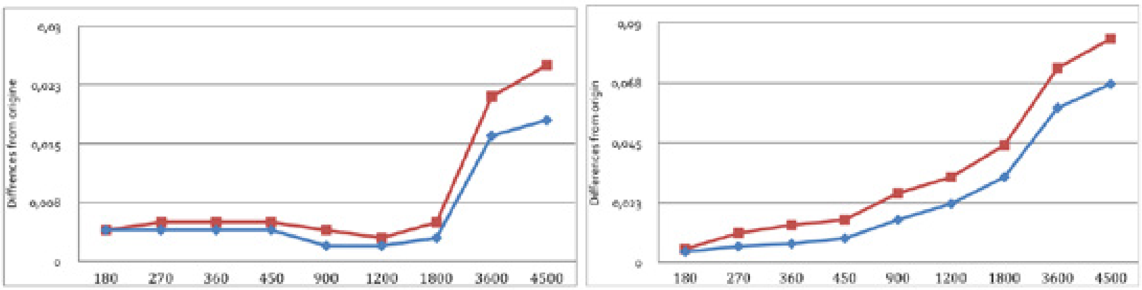

Figure 4 - Differences for mean choice (left) and mean integration (right) values after flood L and flood H

Figure 5 shows differences for the maximum values of NAIN and NACH properties on diagrams. As seen, differences for NAIN measure follow the same trend as the mean value. The maximum difference is seen in 4500 degrees for situations, where it is 0.144 for flood (H) and 0.124 for flood (L). However, differences for NACH measure follow a complex trend and do not show an explicit trend. In this case, the differences are zero at the local scales (180, 270, 360 and 450 degrees) for all conditions while taking negative values at the middle scales (900 and 1200 degrees) for flood H while flood L is still zero until 1800 degrees. However, at the global scales (3600 and 4500 degrees) sea-level rise is positive, while both flood H and flood L show positive values in 1800 and 3600 degrees and negative values in 4500 degrees. As a conclusion for this part, we can state that disturbances such as flood inundations influence syntactic properties of the city structure by generally decreasing the values for the integration and choice properties, less at the local scales and more at the global scales, both for the mean and the maximum values.

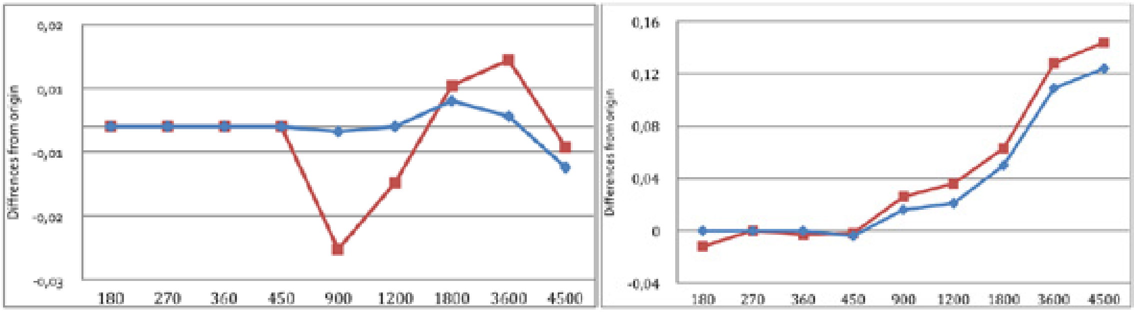

Figure 5 - Differences for maximum choice (left) and maximum integration (right) values after flood L and flood H

3.2 ACCESSIBILITY TO AMENITIES

3.2.1 COMMERCIALS

In Figure 6 the percentage of difference between original situation and flood situations is shown. As seen, the area of difference for flood L is distributed asymmetrically to the both sides of river but centralised in the middle of the river. As an interesting point, the riparian areas in the southern side are less affected by flood L compared to the northern side. The most affected area in the southern side occurs along the sub- stream river (coloured in red). The condition for flood H is different, as the riparian areas in the both sides are highly affected and the total area (number of segments) of influence is increased (Table 2).

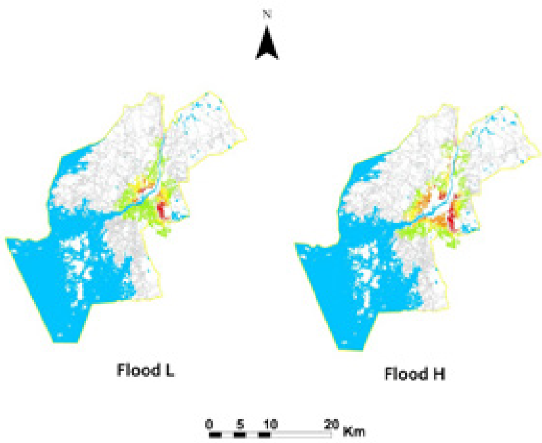

Figure 6 - Accessibility difference between original situation and flood L and flood H situations (commercial centres): grey colure = no differences, green and yellow colours = low differences, orange and red colours= high differences.

However, the asymmetrical distribution of accessibility differentiation is yet seen and same as flood L, the area along the sub-stream river is highly affected as the area of influence is extended to the both sides of the sub-stream.

	Flood L	Flood H
Amenities	Accessibility	Accessibility
Commercial	20780	23603
Healthcare	12060	14994
Preschool		14453
Primary school		10336
	Total number of segments: 100556	

Table 2 - Number of segments of which accessibility is affected (only indirect impacts) after flood L and flood H for different amenities separately.

3.2.2 HEALTHCARE CENTERS

In Figure 7, the difference in accessibility to healthcare centres in two situations, flood L and flood H is illustrated. Same as accessibility to commercial centres for flood L, distribution of influenced areas is asymmetrical and non-equal as it is more extended in the southern part of the river alongside the sub-stream. Eastern part of the sub-stream is more affected but less distributed while the western part, contrariwise, is more distributed and less affected.

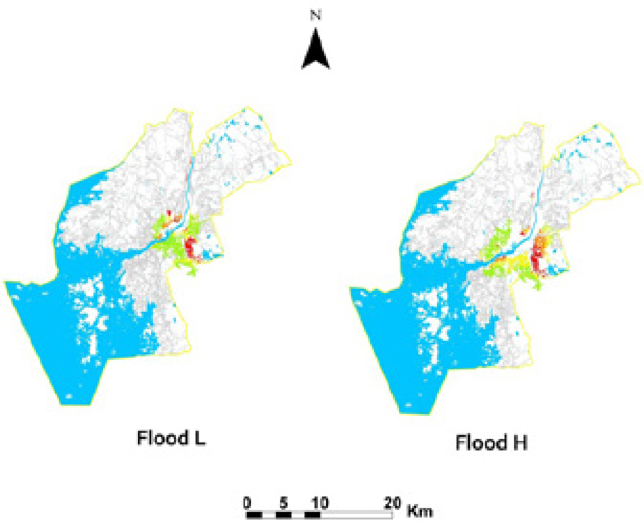

Figure 7 - Accessibility difference between original condition and flood L and flood H conditions (Healthcare centres): grey colure = no differences, green and yellow colours = low differences, orange and red colours= high differences.

The condition in the northern part of the river shows that riparian areas spatially close to the bridge is more influenced by flood L, but generally, the northern side is less affected than the southern side. Looking at Figure 7, three different distributions are recognised. A more affected but less distributed area is located in the eastern part of the sub-stream, a low to mid affected but more distributed in the western part of the sub-stream and a low affected and less distributed area located in the northern part of the main river. Riparian areas in the southern side of the river are generally more affected than areas in the northern side of the river. Table 2 shows the number of segments which their accessibility changes (reduces) after flooding.

3.2.3 PRESCHOOLS AND PRIMARY SCHOOLS

In Figure 8, we investigate the accessibility to preschools and primary schools only after flood H due to the more importance and bigger effects that flood H causes. Despite similar trend and asymmetrical distribution to the other amenities in general, there are yet differences in their distributions. As seen, affected areas, when analysing preschools, are totally more distributed compared with primary school. This can be seen on both sides of the river. However, the extent of changes shows a higher impact of flood H on the accessibility to primary schools than to preschools, represented by more areas highlighted in red for primary schools. Table 2 also shows that the number of segments with a reduced accessibility for preschools is higher than for primary schools. Furthermore, accessibility of riparian areas to preschools is less affected (green in Figure 8) than similar areas for primary schools (yellow in Figure 8).

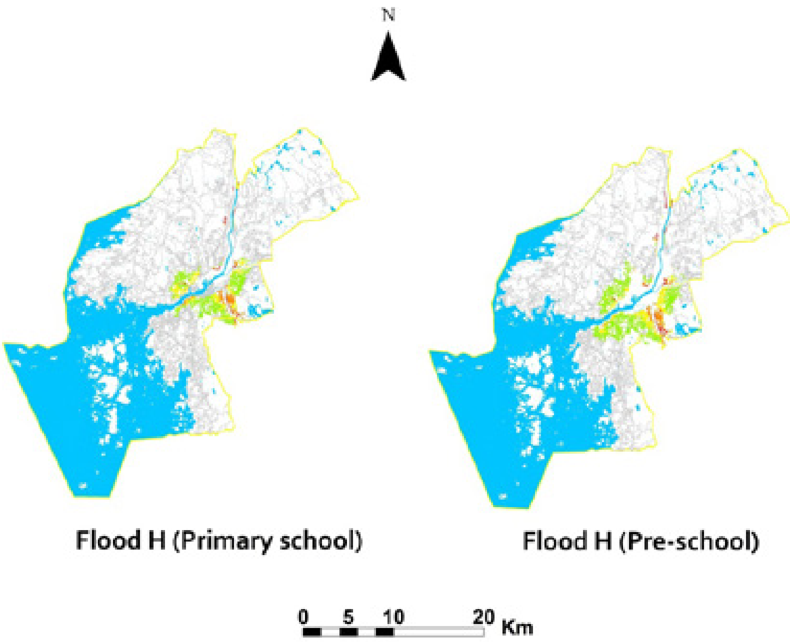

Figure 8 - Accessibility difference to preschools and primary schools only after flood H: grey colure = no differences, green and yellow colours = low differences, orange and red colours= high differences.

3. 3 MINIMUM DISTANCE TO AMENITIES

One of the important parameters that reveal the impact of flood events on the city structure is changes in the minimum distance to amenities. In this view, areas with a higher impact usually show increases in the distance to the closest amenity. In Figure 9, the percentage of change (increase) in the minimum distance to different amenities is illustrated separately. It should be noted that due to the very little change in the minimum distance after flood L, we illustrate the results only for flood H.

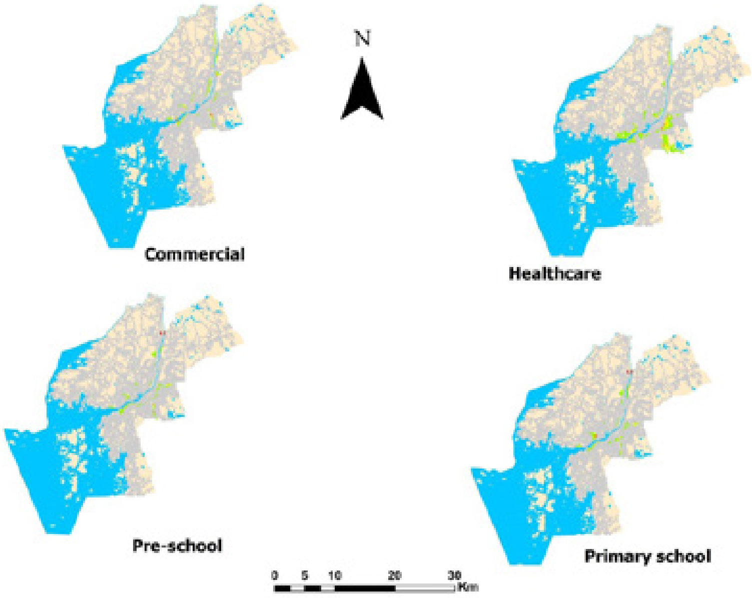

Figure 9 - Changes (increase) in the minimum distance to different amenities after flood H. grey colure = no differences, green and yellow colours = low differences, orange and red colours= high differences.

As a general trend in Figure 9, the effect of flood H on the minimum distance to amenities is low and mostly limited to few segments in the riparian areas of the main river, while their distributions are not symmetric and do not follow the direction of main river. Based on Figure 9 and Table 3, we can find that the minimum distance to healthcare centres is more affected by flood H compared with the minimum distance to the other amenities, as it is extended to the area around the sub-stream. As such, commercial centres are the least affected amenities among all. Additionally, as a different tendency between the preschools and primary schools, we can say that the minimum distance for primary schools is more affected by flood H spatially on the northern side of the river.

	Flood L	Flood H
Amenities	Accessibility	Accessibility
Commercial	737	547
Healthcare	2748	3788
Preschool		818
Primary school		1205
	Total number of segments: 100556	

Table 3 - Number of segments of which minimum distance is affected (only indirect impacts) after flood L and flood H for different amenities separately.

In the end, as a possible explanation to the observed trends in the minimum distance to different amenities and that the minimum distance is not highly affected by flood events, we can say that the reason seems to be related to the distribution of the amenities themselves within the city (Figure 10). Such asymmetrical distribution of amenities along with the small number of inundated amenities after flooding (Table 4), compared to the total number of amenities, can be resulted in the small changes in the minimum distance of segments to the amenities.

	Total	Removed by flood L	Removed by flood H
Segments	100556	2188	6680
Commercial	4612	176	1329
Healthcare	147	5	28
Preschool	566		18
Primary school	180		6

Figure 4 - Number of segments and amenities which are inundated by floods

Furthermore, as an explanation to the fact that the southern side of the river is more affected after flooding we can add that, besides the asymmetrical distribution of amenities in the city, distribution of street networks or density of street networks, existence of the sub-streams in the southern part of the river (Figure 1) which affect the accessibility and differences in the natural topography of different parts of the city might be the other reasons, causing the southern part of the river shows the greater impacts after flooding.

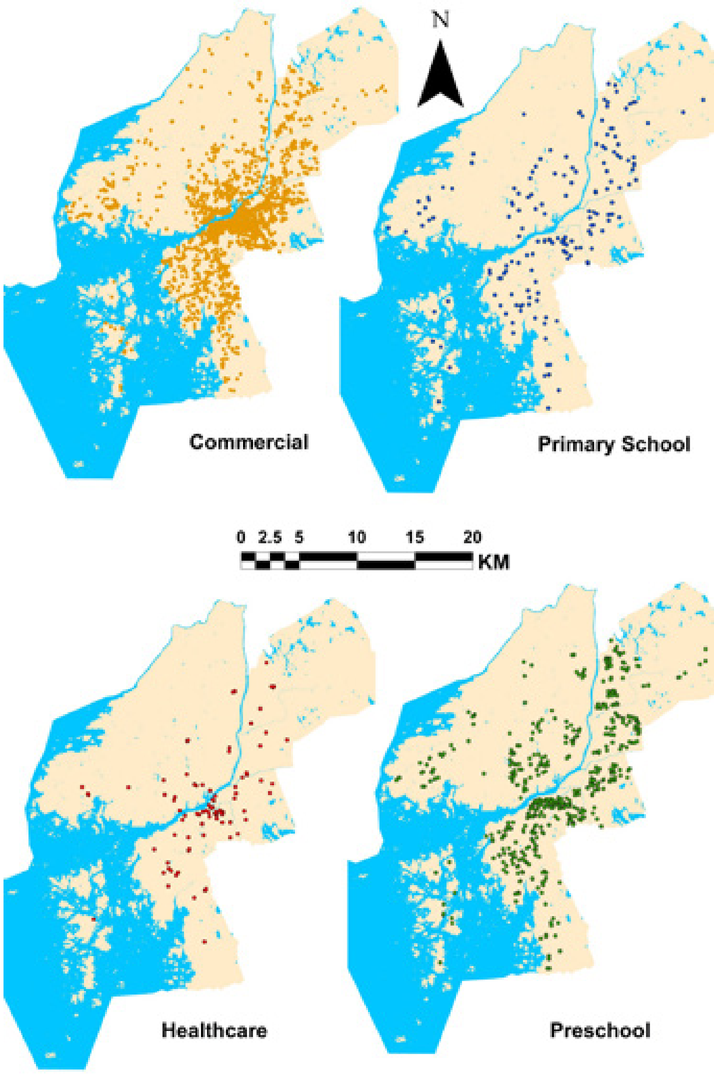

Figure 10 - Unequal distribution of different amenities in the city

4. CONCLUSIONS

Flooding as natural disasters, which occurrence has been rapidly increasing, has great impact on structure of the cities and on the city networks. Thus, study the impact of such disasters, conducting vulnerability assessment and determining sensitive and high- risk areas of the city are essential in order to manage and reduce the risk of dealing with such disasters. In this paper the resilience of the city of Gothenburg against river-flooding is investigated. The methods applied in this research are comparing syntactic properties of the street networks and accessibility measurement. Analysis of the syntactic properties (NACH and NAIN) shows that the city configuration is influences by flooding and the degree of such influence is bigger at global scale rather than at local scale and stronger for NAIN values rather than for NACH values. In the accessibility analysis, two parameters are measured; accessibility to different amenities in the city within 3 kilometres, and the minimum metric distance to amenities. The result of accessibility analyses shows that the city after flood L is more accessible than after flood H which is expected since the number of amenities and segments indirectly affected by flood H is higher than flood L. Furthermore, the influence of the accessibility is asymmetrically distributed in the city as the southern part of the city is more influenced after flooding compared to the northern part.

For the minimum distance, the numbers of *indirectly* affected segments, and the difference in the total length of their shortest distance to amenities, were examined. The result shows that although the impact of flooding on the minimum distance is relatively low, the healthcare centres show the maximum influence and the commercials show the minimum distance. It is also discussed that the reasons for such influence might be considered in the asymmetrical distribution of amenities, density of street network, topography of the city and existence of the sub-streams.

However the result shows that flooding (especially low-intensity flood) does not have a big effect on the minimum distance to amenities and from this perspective the city is highly resilient against the flood events. What should be noticed; however, is that the current results obtained from the analyses focused to measure the *indirect* impact of the flood events on the structure of the city. Therefore, the resilience of the city is examined only on the remaining part of the city and it does not consider *directly inundated* areas (Buildings and plots). In this view, more analyses of the street networks including the investigation of changes in the size of foreground networks, changes in accessibility of residential locations (address points) and examination of the other types of amenities are suggested in order to have a better understanding of impacts of such disturbances in the structure of the city, emphasizing that the resilience of a city depends on a set of many different parameters and cannot be confined to one or two parameters.

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