MUNICIPAL RESPONSES TO CLIMATE CHANGE EMERGENCIES

Municipal GIS Usage and Future Possibilities

TKK – Helsinki University of Technology
Antti Veijalainen, Jukka Krisp & Kirsi Virrantaus

As scientifically known and widely admitted, global warming and climate change are taking place. Average global surface temperatures have already risen, and the occurrence of extreme weather phenomena is anticipated to increase in the future. Despite a number of profitable effects of climate change, the benefits are usually outrun by a multitude of drawbacks, making climate change as a whole an unwanted phenomenon. Mitigation and adaptation are the two main, complementary approaches in responding to climate change. Even with the best mitigation strategies being and becoming implemented, further changing in climate and corresponding impacts cannot be avoided. Therefore, preparation for and adaptation to climate change in one way or another is inevitable. Adaptation to climate change is quite new as a political issue in many parts of Europe, having proceeded barely a couple of years into its full introduction at the moment. According to a survey, only a couple of national initiatives or programmes in different sectors, including coastal and flood protection, have been launched. Yet, adaptation should not be considered as a separate topic but as an integral component of all policies, even boosted by the need to poise with decisions between the precautionary basis and scientific evidence. Adaptation is a complex crosscutting issue, and needs to be addressed by all quarters of society. (IPCC 2007; Hilpert, Mannke & Schmidt-Thomé 2007)

In its Thematic Assessment (HELCOM 2007), Helsinki Commission enumerates likely climate change impacts in the Baltic Sea area. Many predictions refer to a warming trend of 3–5 ºC in the average annual temperature in the Baltic Sea area during this century, which would have a remarkable impact on, for example, precipitation and ice conditions. Especially in the Baltic Sea region, sea level rise together with alternating river runoff is one of the predominant consequences of climate change. Despite many geographical features of the Baltic Sea area mitigating heavy floods, the coastal zones are increasingly exploited for residential construction and other human needs, which inflates the possible costs and harm produced by floods. The Baltic Sea is a nearly closed basin, with the narrow Danish Straits as the only connection to other seas, which results in very slow water level variations and, prevailing winds permitting, also long periods of risen water level even locally. The average water level in the Baltic Sea has risen about 15 centimetres during the last 40 years and, as estimated by the IPCC and depending on the scenario, will rise 9–88 centimetres by the year 2100 (Tulvavahinkotyöryhmä 2006). When considering the effects from flooding, local circumstances usually play a crucial role. The vertical profile of the shore is an important factor, the formation of the shoreline another. Constructing and planning new regions on areas with a high flood risk is often taken for irresponsible. On the other hand, one could argue that the benefits from escaping flood damage should cover the expenses of safeguarding against them, which might sometimes make the aforementioned action a reasonable risk to run (Lilja 2008).

In emergency management, various organizations all have their domains of responsibility, and the collaboration necessitates a lot of information and understanding of the overall situation. The majority of all information being in some way spatial and mappable, Geographic Information Systems (GIS) have become increasingly significant tools for tackling and facilitating otherwise inconvenient complexes of emergency management issues. GIS provides means for organizing, analyzing and displaying data, as well as for cooperation, coordination and creating situational awareness, in all emergency management stages from planning through mitigation to recovery (Johnson 2000). The most significant deficiencies in using spatial data is often the lack of harmonization and the unavailability of data. The INSPIRE directive is an EU legislative instrument established to provide a framework for a Spatial Data Infrastructure, SDI, aiming to ease the availability of and information on spatial data. The SDI is expected to be fully in place by 2019. (EU 2007) In spite of these data standardization actions, many factors still impede a full-scale GIS implementation. In his study, Krisp (Krisp 2007) found the low level of GIS expertise and the heterogeneous use level of GIS in multilayered organizations as the major problems within the Baltic Sea region. All this weakens the possibilities GIS can provide for emergency management and other related issues.

Essential GIS themes when considering flooding issues are terrain elevation and topography, as these have a direct connection to the extent of flooded areas. A digital elevation model, DEM, is an approximate digital representation of the terrain formations in raster-like, triangulated or other form. As water level can be conceived as horizontal, transforming the elevation model into contours or exploiting existing contour data serves best in defining the extent and boundaries of a flood. Besides static extent of a flood, contour data can also be applied to determining, for example, the progress of a flood from low to higher water levels.

The City of Helsinki has at the moment highly accurate and comprehensive flood map over the whole city area. This map has been acquired based on laser scanned elevation model. It shows, based directly on elevation contours, which areas would be covered under different flood water heights. So far the map is produced up to a flood level of +250 cm. The area of Helsinki is being repeatedly laser scanned according to a staggered schedule. The same areas are updated approximately at intervals of five years, making the flood map data fairly up-to-date.

GIS is a valuable asset to many novel approaches that can be taken advantage of in climate change issues. One such approach is graph theory and connectivity analysis of spatial networks. The basic idea is to consider, for example, a road network as a compilation of nodes and connections describing crossroads and road segments, respectively. Using graph theory, different measures can be mathematically calculated for each road element in order to present their criticality and importance in the whole network. The results show how vulnerable a network is in different locations in case, for example, flood water cuts off a section of road, and helps deciding which locations should get the most alert protection. The concept of critical networks in a spatial context has been studied in the Geoinformatics & Cartography research group at TKK in recent years, and the critical measures and procedure are thoroughly presented in (Demšar, Špatenková & Virrantaus 2008).

Emergency conditions are usually dynamic in many ways, which calls for corresponding methods in emergency management and analysis. Time can be seen as one main component of spatial data, as basically anything that happens, happens at a certain moment or period of time. Representing time in the context of spatial data contains many constraints and always requires some compromises. Spatiotemporal modelling focuses on storing and visualizing the change in a phenomenon, for example the diurnal locations of people, by time. Even this has been research at TKK, and the idea and some applications, including population density modelling, are presented in (Ahola 2006) and (Ahola et al. 2007).

Case Study: Helsinki Flooding

Critical network and spatiotemporal model methods were tested in practice as an imaginary, though simplified, future scenario was created. Helsinki was chosen as the case study municipality for flooding because of its societal importance and previous flood experience. The test area covered the downtown and some outskirts of Helsinki. Due to unexpected quality deficiency and availability problems, the intended elevation data had to be replaced with alternative contour data. The intended flood elevation level of 3 and 4 metres above average sea level also needed to be replaced with 5 metres. Despite this slight exaggeration in a practical sense, the aim was nonetheless in finding out and demonstrating the principle itself and feasibility of the methods.

The main part of the case study was based on calculating the vulnerability risk for all road network elements in both normal and flood situation. The so-called betweenness value and cut vertex feature were justifiably chosen to describe road segment centrality, as high betweenness value and cut vertex on the average suggest vulnerable locations. Betweenness describes the importance of the existence of the element along all possible connections in the whole network, whereas cut vertex – or cut element, in this case – represents a locations the removal of which cuts off all connections to a certain part of the network. The figure below shows a comparison between normal and flooding situations for a piece of the study area, with yellow depicting low and red high criticality values, and light blue the flooded land area.

Figure: ***The vulnerability risk of the road network in a) normal and b) flood conditions***

Some highly notable changes and distinctions are easy to perceive. The flooding water blocks significant routes in the western part of the map section and coerces traffic to alternative ones. This increases the relative importance of and strain on those routes, which is also reflected to a wide area further away from the flood. It is worth a note that only topology and no geometry information is used. Yet the roads with highest centrality values in normal situation coincide astonishingly well with most traffic arteries, which is an extra visual support for the competence of this method in flood situation preparedness.

There are some important points to consider in the context of this method, maybe the most significant of which is the topological consistency of the data. Road segments should be continuous from one crossroad to another. Double lines are at some places used to represent parallel roadways, which affects the calculated measures. One could even contemplate the definition of a “connection”, as in reality official roads and paths are usually not the only passages to move from one place to another. Also how the network is demarcated is of great significance, in case it represents only a section of a real-world network. In addition, it has to be noted that the burdening or cutting effect of the flood in this case is calculational, as a low layer of water is seldom a real obstacle for moving by foot or car. However, even with all the points of weaknesses inherent with the method, it gives good general estimates on critical locations and provides a good basis for further research.

The secondary part of the study included a partial utilization of the spatiotemporal population model when building data including computed and estimated population for different times of day was overlaid with both normal and flood situation water coverage data. This enabled the determination of the proportional change of the number of people in flooded and dry areas. The table below shows the population on the test area at different times of day. Whereas the variation in normal situation numbers seems logical for a bare eye knowing approximately what kind of buildings and activities are located in each neighborhood, some interesting details stand out in crisis situation numbers. The clearly lowest numbers in flooded areas occur in the night-time and on Sundays. One could reason that the flooded areas include less residential areas than the calculatory average over whole test area would suggest. So, even if broad coastal areas are being and will be built for residential buildings, relatively few of these are actually unshielded from flooding, at least in terms of population number. On the other hand, the flooded areas are most populated on weekday afternoons and evenings and Saturdays in the daytime, which would partly suggest that shopping and other services are relatively often located in flooded areas, partly supporting that flooded areas include more workplace than residential areas in proportion to the distribution in the whole test area. In this case the spatiotemporal model is only vaguely applied and is rough and generalizing at the most, but delivers some interesting patterns about population movements even as such.

Table: ***The number of people present at different points of time***

	Inhabit	WeekNight	WeekMorn	WeekDay	WeekAfter	WeekEven	WeekMidn
Normal situation	110626	162808	162562	149390	151683	172811	162179
Above water	87973	140506	136122	120923	120747	143595	139299
Under water	22653	22302	26440	28467	30936	29216	22880

	SatNight	SatMorn	SatDay	SatEven	SunNight	SunMorn	SunDay	SunEven
Normal situation	161179	166336	164898	161942	161179	162179	160790	161627
Above water	138649	142232	133645	136751	138649	139299	137238	138367
Under water	22530	24104	31253	25191	22530	22880	23552	23260

Suggesting Notes

On the basis of this case study as well as other observations and background knowledge, GIS use should be heavily reformed in both flood-prone and flood-free municipalities. On the average, especially smaller municipalities lack GIS expertise, whereas bigger cities are usually in possess of more extensive resources and already have a somewhat full-scale GIS implementation within several municipal sectors. The problem is not unfortunately uncommon, as the number of employees particularly in smaller municipalities is more or less limited, and their time and knowledge can only cover a certain amount of branches. Important here is that GIS be crossing organizational structure borders instead of separate unconnected components. Additionally, the availability of a right kind of data is essential for the functionality and also reliable results and decisions in any context.

The methods presented above are and should not be limited to flooding only but may be applied to many other uses. The Helsinki case is but an example and maybe not even the best subject of application, which holds true for both methods. Critical network analysis is an intriguing and, at its best, very usable method for defining the most vulnerable locations in the context of flooding as well as other threatening factors. There are naturally several points in the method needing adjustment and definitions, but the basic simplicity of the method will make it worth putting an effort to in near future. As the spatiotemporal model may fall a bit short when applied to flooding, the idea of people's whereabouts is nonetheless of essential significance what comes to emergency rescue. Even in this kind of application vague approximations are much better than nothing and provide at least indicative information about the situation. The most important issues here include how to represent the distribution of population as accurately and reliably as possible, and how to exploit more new data to include in the model. One suggestion is the use of cellular phone base station data for determining people's locations. The availability of this data however, owing to privacy issues, is possibly troublesome and still mostly uncharted.

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