A district level climate change vulnerability index for flood risks – Concept, implementation and results for the city of Kiel

1. Introduction

Climate change is already impacting and will continue to impact regions, cities and municipalities, whereby responding to climate change involves both mitigation to address the cause and adaptation as a response to the changes (e.g. IPCC 2007; EEA 2012; IPCC 2014; Revi et al., 2014). Local councils are key actors when it comes to the implementation of adaptation measures in order to improve the overall resilience of local territories in various fields such as water, energy, health and transportation. Thereby, increasing cities resilience to climate change impacts, is highly context specific, due to its geographical location, structure, institutions, inhabitants and operational capability (Cortekar et al. 2016).

Within our study we focus on climate change impacts regarding floods, whereby flood risk is most commonly defined as the interaction of the following influences: i) hazard (the probability that a flood event occurs), ii) exposure (the population and economic value of assets subject to flooding), and iii) vulnerability (the capacity of a society to deal with the event) (e.g. Kron 2005; IPCC 2012; Koks 2015; Rose and Wilke 2015). While research and understanding of hazards and exposure has improved recently, specific knowledge of vulnerability is often still seen as one of the biggest challenges in flood risk assessment (e.g. Mechler et al. 2014; Mechler and Bouwer 2014; Visser et al. 2014; Koks et al. 2015). In most studies dealing with flood risk and the feasibility of related management policies, the physical vulnerability of structures and goods is included as an indicator of flood risks (e.g. Filatova 2014; Jongman et al. 2014; Koks et al. 2015), not including the vulnerability of inhabitants. However, the capacity of households to adapt is equally important for the assessment of vulnerability and the implementation of policy measures (Koks et al. 2015).

In order to trigger adaptation measures from the decision-makers' point of view, the identification of points of weakness or an initial assessment of vulnerabilities is necessary (Queste and Lauwe 2006). These kinds of vulnerability assessments at the city level as well as at the district level are not novel and have already been carried out. However, the existing methods are mostly complex and have partly been done with extensive and expensive surveys of households in the districts (e.g. Bollin and Hidajat 2006; Birkmann 2013). In order to develop a less costly and less time-consuming approach, our study is based on already existing and freely available data from official statistics.

The development of a vulnerability index for the city of Kiel within our study is based on previous work, like the social vulnerability assessment of Koks et al. (2015) for the city of Rotterdam as well as a vulnerability index used by Rose and Wilke (2015) regarding climate change vulnerability and possible adaptation measures for the Free and Hanseatic City of Hamburg. Thereby we focus on the exposure, sensitivity and coping capacity of inhabitants and companies in order to provide decision-makers with a basis for the derivation of adaptation actions. The main research question is to identify which districts in the city of Kiel face the highest vulnerability, either because of a relatively high exposure to flooding (urban floods and storm surges), a relatively high sensitivity due to social and economic structures or a relatively low coping and adaptive capacity.

2. Data and methodology

Our approach is applied to the city of Kiel, the capital city of the northernmost German state of Schleswig-Holstein, with a population of about 240.000 inhabitants, located 90 kilometers north of Hamburg. Due to its location around the Kieler Förde – an approximately 17 km long inlet of the Baltic Sea, connecting the harbor of Kiel to the Baltic see – the city consists of both protected and unprotected areas, which makes it a potential hazardous area for flooding. Due to specificities regarding geographical location, structure, inhabitants and operational capability it is to be expected, that the vulnerability of districts differs substantially.

Generally, we refer to the concept and definition of vulnerability given in assessment report 4 of the Intergovernmental Panel on Climate Change (IPCC 2007). Thus, the degree of vulnerability of a system in general depends on three main factors, as follows: i) the exposure to climatic changes, ii) the sensitivity, depending on socio-economic (and cultural) factors, and iii) the coping and adaptive capacity.
In our paper, we defined and used detailed indicators regarding the district specific level of exposure, sensitivity (both the ability to evacuate and financial losses) as well as coping capacity, and finally integrate them within the overall vulnerability index. Thereby, we further developed the approach by Rose and Wilke (2015) regarding a district level climate change vulnerability index mainly by weighting the specific indicators using the method of calculating ratios instead of a simple ranging of districts.

Exposure
Concerning the district specific exposure to floods, we used the relative share of the potential flood area within a district as an indicator. For this purpose the expected surface of a future flooding at 3.5 m above normal zero has been analyzed by means of an interactive flood map and measuring tool.
Flooding can also be caused by heavy rain events. Nevertheless, for the city of Kiel no district level data is available regarding such events. However, in the case of heavy rain, the degree of soil sealing is of great relevance, since it reduces the infiltration ability of rainwater. Therefore, we use the degree of sealing in the districts as an indicator of a possible risk of exposure to heavy rain. For this purpose, the specific transport, recreation and agricultural areas are used and placed in relation to the total district area.
Finally both factors are taken into account within the overall exposure indicator, whereby the surface sealing due to its slightly lower importance is weighted by 40%. The relative shares of the potential flood area are rated at 60%. As a result (figure 1), the districts “Altstadt” and “Vorstadt” show the highest exposure in terms of a high relative share of potential flood areas as well as the high degree of soil sealing seal. In contrast, the districts ”Suchsdorf”, “Pries”, “Schilksee”, “Wellingsdorf” and “Wilk” show the lowest exposure.

Sensitivity (ability to evacuate, financial losses)
Regarding the district specific sensitivity we take into account the ability to evacuate (and thus the protection of inhabitants) and the financial losses of inhabitants and companies separately. Thus, both aspects are assigned a higher weighting and each form one of the four overall levels of the vulnerability Index (figure 1).
The health risks caused by floods are particularly high for specific groups in communities, like elderly people, disabled people and children. This is accompanied by the ability to evacuate, which is of high relevance with regard to the protection of the population. It is becoming increasingly important in the context of expected demographic change. Within our study, the absolute number of people aged over 65 years as well as the number of children younger than 10 years within the districts have been taken into account as indicators. As a result, the ability to evacuate is – due to the high number of elderly people and children – at their lowest in the districts “Wik” and “Gaarden-Ost” (figure 1).
The financial losses consist of the average value of the indices for i) inhabitants as well as ii) companies. The potential economic loss for inhabitants is indicated by the number of registered motor vehicle as well as the number of existing residential buildings. The potential financial losses for companies are indicated by the number of workplaces in different sectors. In total, the potential overall financial losses are at their highest for the districts “Wik” and “Südfriedhof” as well as lowest for the districts “Friedrichsort”, “Altstadt” and “Düsternbrock” (figure 1).

Coping capacity

Coping capacity relates to the assessment of the possible social coping and adaptive capacity. Thereby it is assumed, that the coping capacity increases with a higher amount of financial resources. Indicators within our study are the use of governmental transfer payments in accordance with the German Social Security Statute Book (Sozialgesetzbuch - SGB), the right to receive housing benefits, as well as benefits for old-age provision and disability. The data shows that in the district "Gaarden-Ost" almost 50% and in the district "Düsternbrock" about 6.5% of all inhabitants receive payments regarding to one of the three services. As a result, the coping capacity is at their lowest in the districts "Gaarden-Ost", "Neumühlen/Dietrichsdorf", "Ellerbek" and "Wellingdorf" (figure 1).

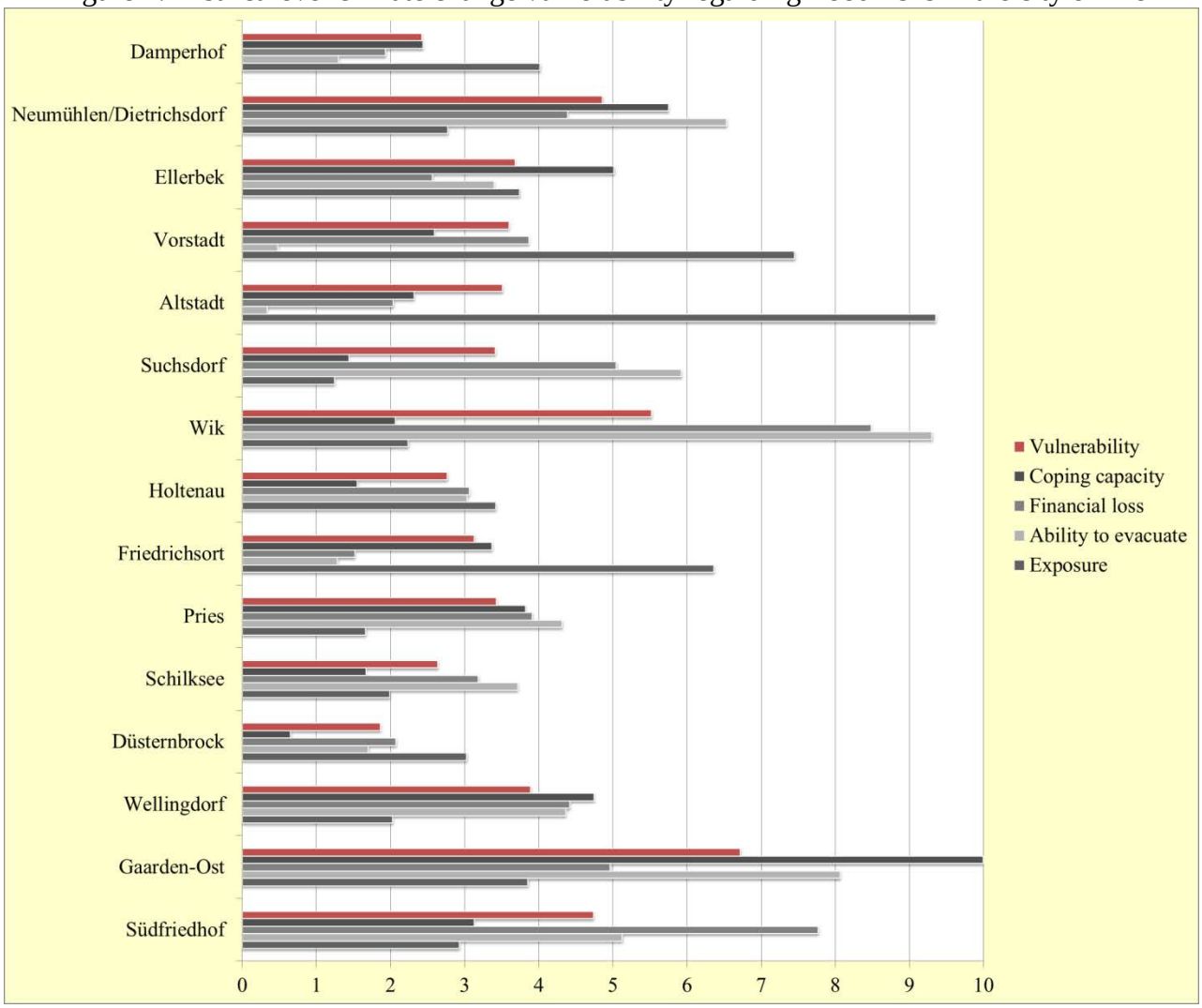
3. Overall results – the vulnerability index

The indicators described above provide a district specific evaluation regarding the levels of exposure, sensitivity – in terms of the ability to evacuate, and financial losses – as well as coping capacity. The vulnerability index is created by an equal consideration of the four different indicators (figure 1).

Thereby it has to be pointed out that within our study we used the method of weighting the specific indicators by calculating ratios. Within the scope of the index, above-average values are considered to be unfavorable. For example, a high number of workplaces or motor vehicles within a district are assumed to be negative regarding the specific vulnerability, since the potential economic damage – or financial loss – is very high. Indicators where a high number would generally be positive – like a high proportion of recreational area and thus fewer surface sealing areas or a higher amount of financial resources – are converted accordingly. The highest value thus corresponds to 100% and is automatically assigned the value 10 in the scale. The percentage and scale values of the other districts therefore always refer to the highest value. In other words, a relatively high number in the four indicators as well as the overall vulnerability index shows a relatively high vulnerability for a specific district – a relatively high exposure, a relatively high sensitivity or a relatively low coping capacity – compared to other districts in the city of Kiel.

The results clearly highlight, that the specific vulnerably of the districts is very different. For example, the vulnerability of the districts "Vorstadt", "Altstadt" and "Friedrichsort" are generally moderate, but the relatively high specific exposure has a decisive influence on the overall vulnerability. The districts "Gaarden-Ost", "Wik", "Neumühlen/Dietrichsdorf" and "Südfriedhof" are relatively vulnerable, while "Düsternbrock" appears to be only slightly affected. The example of the district "Gaarden-Ost" shows, that its exposure is relatively low, but mainly due to the limited ability to evacuate and the low coping capacity, its overall vulnerability is at their highest compared to all other districts. Regarding the districts "Wik" and "Südfriedhof", the relatively high level of financial losses is responsible for the high overall vulnerability.

Figure 1: District level climate change vulnerability regarding flood risks in the city of Kiel



4. Conclusion and practical relevance

Urban governments play a key role in climate change adaptation, as it depends on local assessments and the integration into local investments, policies, and regulatory frameworks. Therefore, a scientific evidence base on local risk and vulnerability assessments, information and data is essential for appropriate adaptation action. Our study provides insights into climate change related risks, by the development and application of a district level climate change vulnerability index, which comprises all three main factors of vulnerability. It is a tool to identify the most vulnerable areas in a city, and highlights the reasons for their vulnerability. As it is based on freely available data from official statistics, it can be transferred to other cities or/and applied to other climate change related risks, like urban heat.

However, regarding the transfer of our approach to other cities, it has to be considered, that cities like the city of Kiel are state capital cities, so that a good data quality and availability can be assumed. However, the availability and quality of data will probably decrease for smaller cities and municipalities. Also digital flood maps might not be available for all cities. Therefore, in such cases, additional methods of data collection would have to be applied.