1. Introduction

Many coastal cities are experiencing growing exposure to natural phenomena including sea level rise, heavy rainfall and storm surges (Chan, Chuah, Ziegler, Dąbrowski, & Varis, 2018). As the latest IPCC report (2014) postulates, particularly the risk of flooding in coastal megacities is rapidly rising. Ho Chi Minh City (HCMC), the largest city and economic powerhouse of Vietnam, provides an appropriate example for a location facing manifold challenges due to its notably high levels in current and future flood exposure and projected sea level rise (SLR) (ADB, 2010; Downes et al., 2016; Downes & Storch, 2014; Duy, Chapman, Tight, Linh, & Thuong, 2018; Nicholls et al., 2007).

Additionally, the city is confronted with an ongoing process of rapid industrialization closely related to the government’s political renovation policy and economic liberalization reforms (Doi Moi) since 1986 (Revilla Diez, 2016). Multiple local effects are induced by Vietnam’s transition from a state-planned to a market-oriented economy, e.g. the strong emergence of private firms since 2000 and the considerable growth of small- and medium enterprises (SMEs, including micro enterprises). As firms are already frequently located in flood-prone areas on the fringe of the city and are equipped with hard-to-change and immovable infrastructure, particularly firms in the manufacturing sector are at the frontline in terms of loss and damage caused by flooding (Neise, Revilla Diez, & Garschagen, 2018). Recently, there has been extensive research on the impact of flooding in HCMC (Arouri, Nguyen, & Youssef, 2015; Balica, Dinh, Popescu, Vo, & Pham, 2014; Dang & Kumar, 2017; Downes et al., 2016; Downes & Storch, 2014; Duy et al., 2018), mostly focussing on the impact of flooding on communities and households and risk-adapted land use planning. However, little research exists on firms’ exposure to future SLR inundation, although political frameworks such as the Sendai Framework for Disaster Risk Reduction 2015–2030 highlight firms and businesses as important actors for implementing an integrative and effective flood risk governance. Generally, private sector contribution is still rare, not adequately consulted and mostly realized by large multinational firms (BTU Cottbus & TU Dortmund, 2013; Neise & Revilla Diez, 2018). Therefore, there is a growing need to assist decision makers, policy makers, administrative bodies and other stakeholders on firms’ exposure to projected SLR in order to facilitate future adaptation efforts in HCMC’s urban area. Against this background, this study’s approach aims to:

(1) Assess the number and expansion of manufacturing firms in HCMC from 2005 to 2015;
(2) Identify future inundation areas in HCMC;
(3) Reveal the spatial distribution of all manufacturing firms exposed to future SLR and identify firms’ specifics due to firm type, main business activity and staff headcount in HCMC.
In order to assess these three empirical aspects, this study has developed a threefold methodology (1) mapping firms by geocoding, (2) revealing an initial estimate of future inundation areas by using SLR-projections and (3) displaying geocoded firms within inundation areas. In recent years, several techniques and methods in geographical information systems (GIS) have been developed that aimed to analyze and visualize exposure to environmental hazards (Kalogirou & Chalkias, 2014). As maps are an important medium to visualize spatial analysis, this study presents a Main Map of likely flood-exposed manufacturing firms that are located in future inundation areas and, thus, adds significant value to research and policy implication on flood exposure in HCMC, Vietnam.

2. Study area – Ho Chi Minh City, Vietnam

HCMC is situated in the southern part of Vietnam on the north-eastern edge of the Mekong River Delta and downstream of the Saigon-Dong Nai River. Major parts of the city are built on low-lying marshlands, being part of a complex river delta which makes the city extremely sensitive to various flood sources. Nowadays, more than 50% of the city is regularly affected by flooding caused by high tides, heavy rainfall and storm surges (Duy et al., 2018). As the southern parts of the city are directly connected to the East Sea, many districts (Quans) are projected to be exposed to SLR by 2070 (Hanson et al., 2011). About 60% of the main city is located below 1.5 m above mean sea level, nearly 40–45% of the land cover is 0–1 m and 15–20% is 1–2 m in elevation (ADB, 2010). Over the last 50 years, the sea level has increased by about 20 cm (MONRE, 2009) and is expected to continue rising (see 3.1).

Along with the SLR, the issues of substantial urbanization and socio-economic dynamics in HCMC over the last 20 years can be identified as crucial multipliers of flood risk and are expected to continue in the future (Storch & Downes, 2011). HCMC is the economic center of Vietnam and a logistic hub in South East Asia (SEA), well connected to domestic and international markets. The economic structure of the city has been changing since Doi Moi policy in 1986. Vietnam’s transition from a planned to a market economy was and still is driven by economic liberalization and, thus, massive Foreign Direct Investment (FDI) flows and an overall modernization of industry accompanied by the emergence of the private sector (Bloomberg, 2015; Mishra, 2011; Waibel, 2009). Since then, about 350,000 private companies are operating in a range of sectors from food processing, light manufacturing like garment and textile production and sophisticated financial services in Vietnam (Bai, Jayachandran, Malesky, & Olken, 2017).

The national Gross Domestic Product (GDP) reached about 20 bn USD (at current USD rates) in 2016 (The World Bank, 2016). To date, the HCMC region generates almost 40% of the country’s GDP and accounts for around 70% of its export revenue growing rate (Katzschner, Schwartz, Thanh, & Schmidt, 2016). The economic development of HCMC is notably attributed to the city’s location and its attraction for the labor force (Duy, Chapman, Tight, Linh, & Thuong, 2018). Moreover, FDI has been encouraged through a series of laws, policies and investments, primarily distributed within the South-east region including HCMC. Particularly the South-east offers a more market-friendly business environment, which has fostered faster economic growth (Nguyen & Revilla Diez, 2017). This economic growth is borne by SMEs which continue to play a major role and represent 96% of all manufacturing firms in HCMC (VEC, 2005, 2015). Although the SMEs sector is a key driver in the Vietnamese economy, it is facing additional challenges with an institutional setting that is biased in favor of larger firms such as multinational and state-owned firms (Nguyen, Le, & Bryant, 2013; Revilla Diez, 2016). In comparison to large firms, SMEs in Vietnam generally encounter an ineffective support from the government, a lack of financial accessibility and limited business capacity (JETRO, 2017). Moreover, poor strategic plans to achieve long-term goals may strengthen the exposure to future SLR inundation as SMEs often follow short-term plans and catch up temporary opportunities (Trinh & Thanh, 2017).

Despite the remarkable economic development, the economic planning in HCMC does not sufficiently consider topographic conditions. The economic infrastructure and industrial zones are continuously started up in and relocated to highly flood-exposed urbanizing zones such as wetlands and low elevated areas, which has presumably intensified forthcoming inundation (Katzschner et al., 2016). The industry in these areas often consists of firms in the labor-intensive manufacturing and processing sector, requiring significant numbers of manufacturing workers. Thus, the labor market has surged around these emerging industrial zones, which induce mostly young men and women from rural areas to migrate often large distances to HCMC (Arnold & Pickles, 2011; Seo & Kwon, 2017; Waibel, 2009). Over 70% of these migrants are between 15 and 30 years old (Seo & Kwon, 2017). Additionally, workers from household businesses formally registered their businesses or started self-employed micro firms after Doi Moi (McCaig & Pavcnik, 2013). Thus the competitiveness and viability of many manufacturing firms is closely connected to peoples’ livelihoods.

3. Data and methodological workflow

As this research seeks to indicate future tendencies of flood exposure by combining projected inundation
areas with the location of firms, three steps of analysis need to be applied in order to prepare a suitable dataset and comprehensive maps (see Figure 1).

The methodological approach is based on the understanding of exposure by Balica, Wright, and van der Meulen (2012), who define exposure to flooding as ‘the predisposition of a system to be disrupted by a flooding event due to its location in the same area of influence’. Thus, in the case of manufacturing firms in HCMC, exposure to flooding is defined by the location of firms and the predisposition of future inundation in this area due to SLR.

The Vietnam Enterprise Census Survey (VEC) of 2005 and 2015 is a micro-firm-level data set and provides detailed information on characteristics like the location of firms, legal ownership, business sector, labor information as well as business results such as turnover and capital resources of registered enterprises in Vietnam. The VEC is nationwide conducted by the General Statistical Office of Vietnam (GSO) and collects information of the preceding year. Due to the census, we use the 2007 Vietnam Standard Industrial Classification (VSIC) system to define ‘manufacturing & processing industries’ (for a classification of the business activities of ‘manufacturing & processing’ firms see Figure 2).

### 3.1. Mapping manufacturing firms by geocoding

In a first step, we map manufacturing firms in HCMC by addresses on the basis of the VEC, 2015. In order to convert the addresses from text into geographic coordinates (latitude and longitude), we used Google Maps Geocoding API. Generally, the process of translating an address into the best matching geographic coordinates includes parsing the input addresses into different components (Zandbergen, 2008). In our case, we divided the addresses by information on the country, street name and building number. The geocoding was conducted with the package ‘ggmap’ in RStudio (3.4.3.). As an output, the addresses of 89.5% (117,655) of a total of 131,500 firms in 2015 were found and turned into geographic coordinates. Based on this output, we validated the data to the best of our knowledge on both the macro- and micro-level. First, we checked that about 70% of the geocoded addresses are located within the same district compared to the district code of the census. We verified that a large share of the remaining firms is situated close to the administrative border of districts. Second, we implemented a visual ground truthing. Therefore, we used the information from the census on a firm’s location within an industrial park (yes/no) and compared it with satellite data on a sample basis. Third, we randomly validated the given email addresses of the firms with their location published on their websites.

After the validation, we identified firms that where either established before 2005 or between 2005 and 2015 as reference years by merging the Vietnam Census datasets of 2005 and 2015. The final results of the development and spatial distribution of manufacturing firms in HCMC are presented in the Main Map (Map 1).

### 3.2. Identifying future inundation areas by SLR projection

In a second step, we carried out an elevation-based Geographic Information Systems (GIS) analysis in order to reveal the future SLR in HCMC. In hydrological modeling, GIS is often used to conduct flooding...
projection models and to analyze multi-source spatial data (Gallegos, Schubert, & Sanders, 2009; Merwade, Cook, & Coonrod, 2008). In the absence of an appropriate hydrological model, we used a free of charge digital elevation model (DEM) derived via Shuttle Radar Topography Mission (SRTM) 3.0 (2015, horizontal resolution of 30 meters) of HCMC to provide a basis to attain essential topographical information for SLR projection. As the SLR will probably increase the intensity, duration and area of future flooding (ADB, 2010), the results of elevation modeling are used to prepare a future inundation map.

The official projection of the SLR used by the Vietnamese government is 75 cm by 2100 (MONRE, 2009), but the planning parameter used by the National Target Programme to Respond to Climate Change is 100 cm SLR by 2100 based on IPCC A1FI emission scenario (Nicholls et al., 2007). This also corresponds with the RCP 8.5 (range of 52–98, 74 cm mean SLR) predictions of the newest IPCC report in 2014. However, in consideration to the large uncertainties of the assumed SLR, our analysis contains one amplitude of SLR based on the RCP 4.5 and RCP 8.5 scenario which have already been used for SLR simulation in HCMC by Scussolini et al. (2017). In order to ensure the transferability of our findings to policy development in Vietnam, we define a scenario with a rise of 50 cm respectively and combine it with a current tidal maximum of 150 cm, following Downes and Storch (2014).

In a third step, we join the location of manufacturing firms in 2015 with the SLR simulation to reveal the spatial distribution of exposed firms. In order to differentiate between the firm size, we use the definition of SMEs formulated by the recently established Vietnamese Law 04/2017/QH14 – Law on Support for Small- and Medium-sized Enterprises (National Assembly of Vietnam, 2017) which is based on the staff headcount (see Table 2) and the total turnover of the preceding year of firms which should not exceed VND 300 billion. The final results are presented in the Main Map (Map 2).

### 3.3. Data limitation

Regarding our methodology, some limitations in data and operationalization should be mentioned. First, the SLR has to be understood as one of many factors for exposure to flooding. Due to Phi (2013) and Duy et al. (2018), the exposure to flooding of HCMC is not only increased by the SLR, but also by manifold and self-enhancing processes. Data on e.g. pluvial and fluvial flooding, flood water velocity and flood duration would be a valuable supplementary to generate a comprehensive hydrological model. Moreover, due to the difficulty in acquiring spatially accurate data, the impact of observed land subsidence (e.g. Erban, Gorelick, & Zebker, 2014; Minh, Trung, & Toan, 2015) and flood protection measures in HCMC could not be included in this study.
Second, analyses based on digital elevation models derived via SRTM generally imply limitations due to the vertical resolution level (Elkhrachy, 2017; Hu, Peng, Hou, & Shan, 2017). As Storch and Downes (2011) have already pointed out, the known accuracy problems of SRTM data in built-up land distort the assessment results. Recent studies on localized assessment of DEM’s quality and accuracy reveal that the root mean square error ranges from five to eight meters in different land-cover classes (Elkhrachy, 2017; Santillan & Makinano-Santillan, 2016). In north-eastern Philippines, for example, it ranges from 5.91 m (for built up land) to 10.42 m (for bushland) (Santillan & Makinano-Santillan 2016). Testing for uncertainties as using check points obtained by GPS observation or using a geomorphology-based approach (see Tran, Raghavan, Masumoto, Vinayaraj, & Yonezawa, 2014) to improve the resolution of data is reasonable but costly in terms of time and effort. Against this background, we work with original SRTM data, being aware of limitations due to accuracy and reliability. As we are operating with a projection of 200 cm above mean sea level (AMSL), a vertical resolution between five and eight meters is rather coarse. Thus, we are commonly talking about areas and firms likely exposed to future SLR and provide an initial estimate of future SLR inundation.

Third, it is important to recognize that merely 89.5% of firms’ addresses could be localized by geocoding. The coarse validation of the referenced addresses indicates that our data is more reliable for revealing spatial patterns rather than accurate, micro-scale analysis. Additionally, it has to be mentioned that our analysis is based on the given information of the census. We were not able to eliminate errors occurring during data collection. We assume that the census does not observe some of the very small and self-employed micro firms that for example are not officially registered.

4. Results and observations

Due to the overall economic growth of HCMC, it is observed that the number of manufacturing firms in HCMC increased considerably in total from 6,405 in 2005–19,680 in 2015 (+207%). The comparison of firm identification numbers (IDs) within the datasets from 2005 and 2015 reveals that only 2,986 firms can be found both in 2005 and 2015. This suggests that 53% (3,419) of the manufacturing firms have been closed, consolidated or changed business or products. However, 13,275 of 19,680 firms in 2015 have been newly established, relocated or changed fundamentally as they were given a new firm ID during the period of observation.

Following the recently established Vietnamese definition of SMEs, 96% of manufacturing firms in HCMC can be defined as SMEs, which consist of micro firms (64%) and small and medium firms (32%). Due to the number of employees, 4% of all manufacturing firms are considered as large firms. In respect of the firms’ turnover, only 2% of all firms are defined as large firms with a total turnover of more than VND 300 billion. The greatest share of the manufacturing firms is domestic and private owned (86%) and 13% are either state-owned enterprises (SOE) or firms partially shared by state sector with still existing linkages to state authorities. Only 1% of the manufacturing firms is defined as foreign firms (incl. FDI).

Regarding the main business activity of manufacturing firms in HCMC, garment production (14%) has the highest share of the total amount of firms in 2015, followed by the production from prefabricated metal (13%), the production from rubber and plastic (8%) and the production of food (7%) which all have increased in importance. The emergence of manufacturing firms is primarily concentrated within the inner city and in the north, east and parts of the southern urban fringe (see Main Map (Map 1)).

Based on the assumption of 2 m AMSL, the total area of inundation is 45% (about 975,807 km²) of HCMC province, whereby we have not distinguished between built-up and non-built-up areas. It could be assumed that the share of inundated industrial built-up areas would be minor. However, the projected inundation is concentrated in some hotspot areas mainly of lower elevation and situated circularly around the city center. Due to the percentage of the inundated area (inundated area/total area), the highest inundated districts are the western districts Binh Tan (51%) and Binh Chang (58%) and the districts Quan 2 (58%) and Quan 7 (52%), located east of the central business district (CBD). Situated close to the river in the south of HCMC, about 50% of the area of Nha Be will also be inundated by future flooding.

The GIS analysis indicates that about 15.7% (2,441 firms) of the total geocoded manufacturing firms in 2015 are located in future inundation areas. 80% of the exposed firms were established after 2005. Concerning the spatial distribution of the exposed firms in HCMC, the Main Map (Map 2) clearly shows that some districts likely exposed to flooding also have a high concentration of firms. Overall, two hotspots of exposed firms could be identified. First, situated close to the city center, the western districts Binh Tan, Quan 6 and Tan Phu with respectively in total 633, 105 and 122 exposed firms have the highest number and density of exposed firms per km². Second, closely situated to the Saigon River (Song Sai Gon), the eastern districts Binh Than, Thu Duc and Quan 7 with respectively 191, 252 and 159 exposed firms have a high number of total exposed firms, although the density of firms is rather minor (see Table 1).
The analysis reveals that more than half (53%) of the future flood-exposed firms are located in only five of 24 districts in HCMC, creating a belt around the city center. To some extent the exposed firms are located within areas that are characterized by high immigration rates, such as Thu Duc and Binh Tan. These districts registered high rates of population growth, respectively, +64% and +58% from 1999 to 2005 (GSO, 2010). Whereas manufacturing firms located around the city’s core of Quan 1 (mainly Quan 3, Quan 4, Quan 5, Quan 10, Quan 11, Phu Nuan, Tan Binh) are less exposed to future flooding due to SLR. Only 74 of a total of 3,851 manufacturing firms within those districts are exposed to flooding, which amounts to 2%.

Regarding the size of firms by staff headcount, the largest share of the 2,441 exposed manufacturing firms ranges from micro- (59%) to small- and medium (36%) firms (see Table 2). It is expected that the number of micro firms not reached by the census, particularly informal and self-employed firms, is much higher. Additionally, 106 large firms with in total 65,612 employees are located within areas of future inundation.

Although the highest share of turnover is also generated by large firms, SMEs contribute to 30% of the total turnover and engage 37% of total employees (see Table 2). Generally, the exposed firms in HCMC are economically and socially important, employing 104,100 persons who might be severely affected by the viability of firms.

Concerning the type of firm, similar to the total share of manufacturing firms in HCMC, 86% of the exposed firms are domestic and private owned (2,094). 13% are SOE or at least partially shared by the state sector (338) and only 1% (9) of the exposed firms is foreign. Regarding the main business activity of exposed firms, production from prefabricated metal (16%) represents the highest share, followed by the production from rubber and plastic (11%) and garment (11%, see Figure 2).

5. Conclusions and outlook

The Main Map presented in this study document both the spatial distribution and development of manufacturing firms from 2005 to 2015 and future flood-exposed firms due to SLR inundation within the urban area of HCMC. We demonstrated that the ongoing process of rapid industrialization in HCMC is characterized by a strong increase in manufacturing firms within the last decade. This increase is spatially spread over the city and induces people to migrate from rural areas to HCMC, e.g. to Thu Duc and Binh Tan, in order to find employment particularly within the manufacturing and processing sector. Several of the manufacturing firms are located in two hotspot areas in the western and eastern districts, that will probably experience inundation due to SLR in the future. At this point, the analysis shows that domestic, private owned micro- and small firms which are engaged in labor-intensive industries like the production from prefabricated metal, rubber, plastic and garment represent the largest share of the exposed firms. Due to manifold reasons, e.g. limited access to finance and capital resources, limited capabilities and lack of experience, particularly micro- and small firms seem to be overwhelmed with the implementation of individual, long-term adaptation measures or the relocation of business premises. Accordingly, future flooding endangers their competitiveness, and many jobs within the manufacturing sector are threatened, affecting directly peoples’ livelihoods.

Against this background, our analysis revealed that the exposure of firms to SLR inundation is still an underemphasized but important issue, often neglected by policy makers, and even scientific discourse. This paper underlines an initial estimate of future exposure to future SLR of manufacturing firms in urban HCMC and, thus, provides useful information for both the private sector (e.g. firm owners and stakeholders) and public administration in terms of future planning policies and the support of long-term adaptation measures. Following Katzschner et al. (2016), all relevant national and local governmental agencies support the process of relocating industrial factories from inner city districts to the urban fringe. Regarding this policy agenda, our findings emphasize the importance of keeping the issue of flood exposure and the protection of relocated firms in mind.
Furthermore, the findings could be used for public discussion on the impact of potential SLR as the increasing intensity and frequency of flooding are generally seen as a barrier to future prospects and the economic development of the city. This study provides a first step of flood analysis and represents a promising methodology for further investigations, which should focus on estimating eventual losses by SLR inundation according to production specifics and suitable adaptation strategies.

Summarizing the methodology implemented, our research processed a dataset of firms in HCMC which offers different opportunities for further spatial analysis on the exposure of firms to environmental hazards. As our data is currently limited by lacking a comprehensive hydrological model, supplementary data on flooding indices could easily be combined with the geocoded dataset in order to estimate the exposure to recurring and present-day flood events. Moreover, by mapping firms on the basis of the VEC dataset, we are prospectively able to conduct various kinds of spatial analyses to answer scientific questions due to other natural hazards besides the issue of flooding.

**Software**

We used Google Maps Geocoding API for the geocoding of the Census data. The ‘ggmap’ package in RStudio (3.4.3.) was used for further data processing and calculation. The production of the final map was performed with ArcGIS (10.5) by ESRI and Adobe Illustrator CC with MAPublisher (10.1) extension.

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