GIS for Sustainable Development

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**Urbanization-Induced Flood Risk: An Analysis of Spatial Inequalities and Vulnerabilities in Ho Chi Minh City, Vietnam**

**INTRODUCTION**

In recent years, processes of urbanization have drawn increasing attention from climate scientists and urban planners alike in light of their impacts on urban climate. The Ho Chi Minh City (HCMC) metropolitan area, the largest urban region in Vietnam, presents itself as an important study area into the process and implications of both urbanization and climate change; more than 8 million inhabitants live within and around the city directly north of the Mekong River Delta in Southeast Asia. In addition, HCMC is a major economic center in the region, contributing approximately 40% to Vietnam’s overall Gross Domestic Product (Katzschner et al., 2016). In the face of rapid urban growth and expansion in the past decade (Kontgis et al., 2014; Saksena et al., 2014), as well as coastal sea level rise, the city faces increasing flood risk: exposed area to regular flooding is projected to increase from 54% in 2009 to 61% by 2050, mostly due to impervious surfaces (Storch & Downes, 2011).

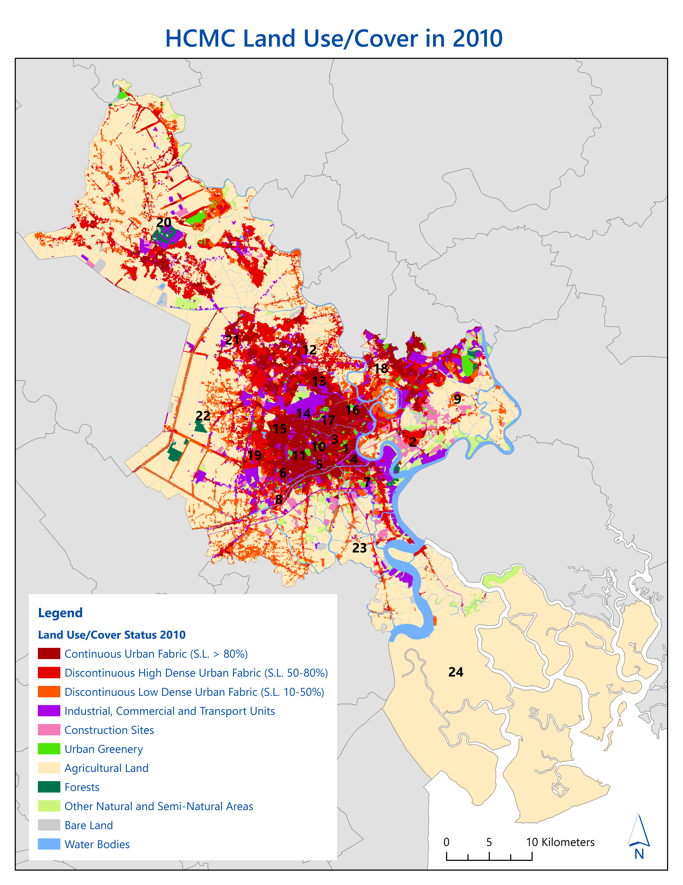
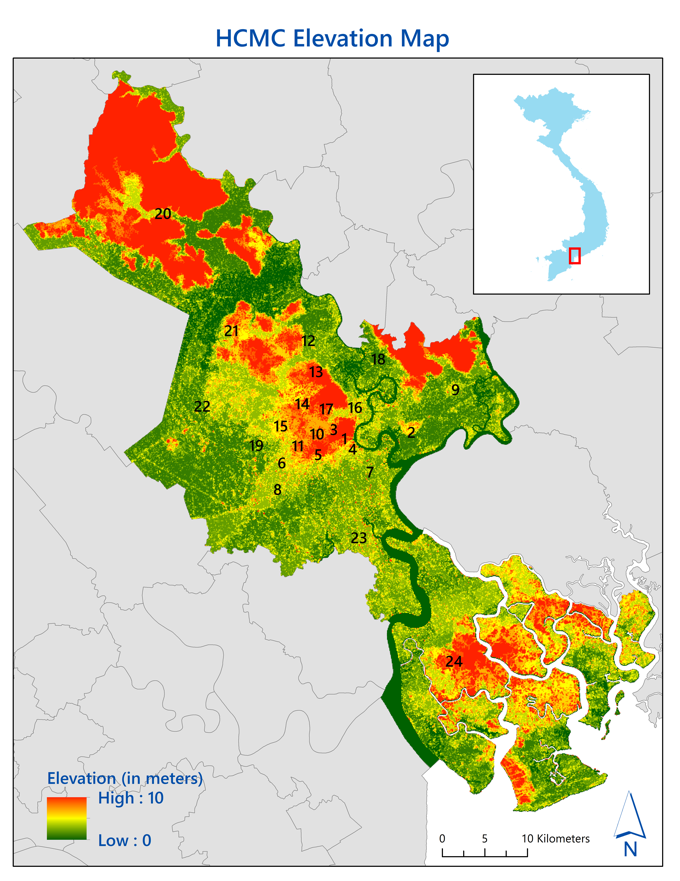
Yet the city’s inhabitants experience differing exposures and vulnerabilities to climatic disruptions across space. Spatial inequalities in resource distribution, in particular, potentially undermine the adaptive capacities of individuals in an urban region. In this study, I explore the relationship between the spatial distribution of flood risk (based on elevation and land cover)and the inequalities in resource distribution (healthcare and education)within HCMC’s boundaries. New insights on the distribution of the population and resources within the city would identify segments of the city most vulnerable in the event of extreme weather events. By integrating information on two socio-economic resources crucial to climate resilience, the resulting visualizations would inform more effective resilience approaches based on social equity by both state and non-state actors.

**METHODS**

The overall procedure involved producing and analyzing 3 key pieces of information, mainly maps of the city’s (1) flood risk based on elevation and urban land cover, (2) educational resource distribution, and (3) healthcare resource distribution. Two datasets on elevation (low-elevation coastal zone) and urban land cover (2010) were first obtained from the Center for International Earth Science Information Network (CIESIN) and the World Bank’s online Platform for Urban Management and Analysis (PUMA) respectively for the purposes of the flood risk analysis. Primary datasets on educational and healthcare resource by district[[1]](#footnote-1) were simultaneously obtained from the 2015 HCMC Statistical Yearbook published on the city government’s website.[[2]](#footnote-2)

1. **Flood Risk from Elevation and Urban Land Cover**

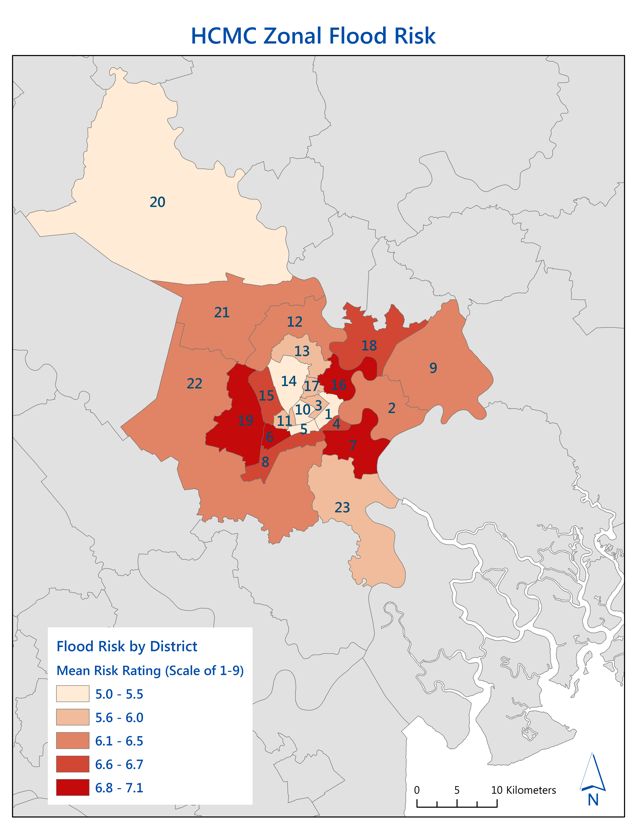
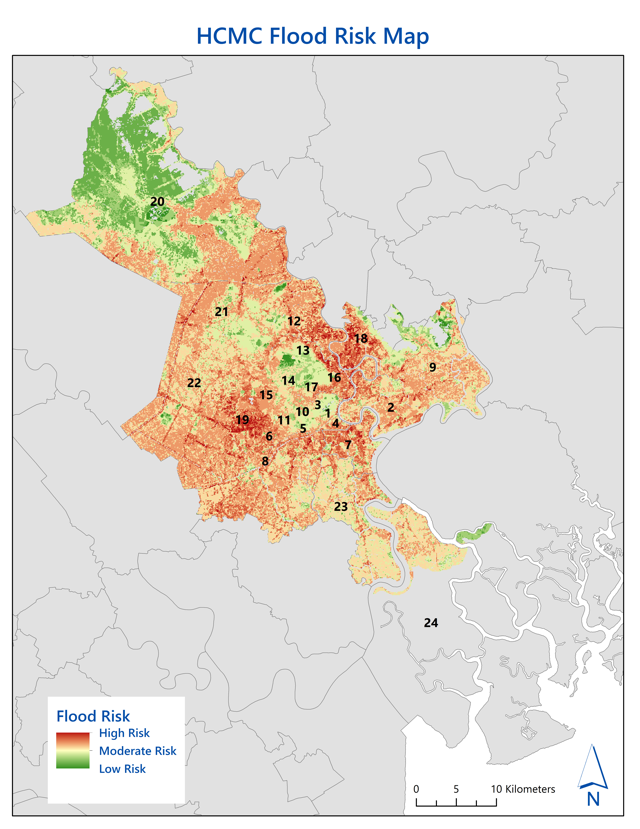
Regional raster elevation data (with individual cell values from 0-30 m) was first imported. Pyramids were created, with a ‘nearest neighbor’ pyramid resampling technique. The elevation data was subsequently delineated and clipped to the city’s level 3 administrative boundaries (with shapefiles from CIESIN). A color ramp with stretched values was then assigned to the elevation map, with a new scale from 0 to 10 m elevation (minimum-maximum on the green-red spectrum). For the purposes of visualization, elevations above 10 m were assigned maximum values and are denoted in red on the map, while oceanic water bodies have been excluded. Greater visual emphasis has been placed on the low-lying areas of the city, which mostly lies below an elevation of 5 m. In addition, the city’s districts have been numbered 1 to 24 (details in Appendix). The resulting map is shown in Figure 1.



*Figure 1: Elevation map of HCMC (0-10 m) Figure 2: Land use map of HCMC (2010)*

2010 urban land use/cover data from the World Bank’s PUMA was next mapped. 11 land types have been identified and classified based on the relative percentages of soil sealing in the urban fabric (Schneider et al., 2015). The layer, in vector form, was first similarly clipped to city boundaries (Figure 2). Due to a lack of data in PUMA, district 24 (Can Gio) was assumed to be agricultural land based on descriptions of the district’s functions and satellite imagery (Mather et al., 2013). The overall layer was subsequently rasterized using the Polygon to Raster tool (cell center, cell size 0.0005) prior to the production of the final flood risk map.

Utilizing the weighted overlay tool, the elevation layer was overlaid with the rasterized urban land cover layer (assuming a 50-50 influence of both elevation and land cover) to produce an overall raster flood risk map (Figure 3). On a scale of 1-9, low elevation and highly dense/continuous urban fabricwere both assigned the highest flood risk (value 9), while decreasing raster values of risk were progressively assigned to higher elevations and less covered land (with bare land receiving the lowest flood risk).[[3]](#footnote-3) District 24 and water bodies were excluded from the analysis (assigned ‘no data’).

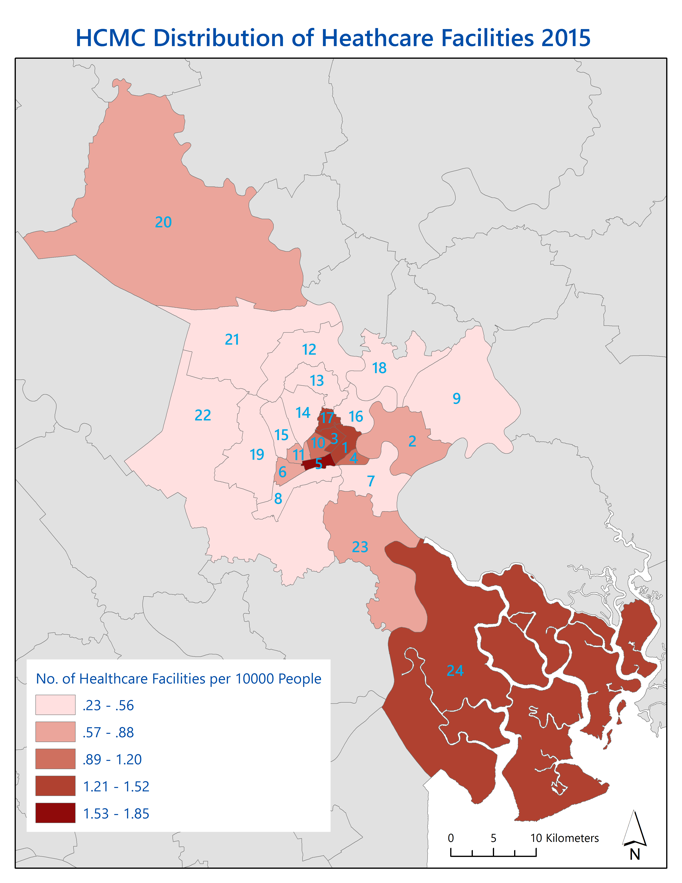
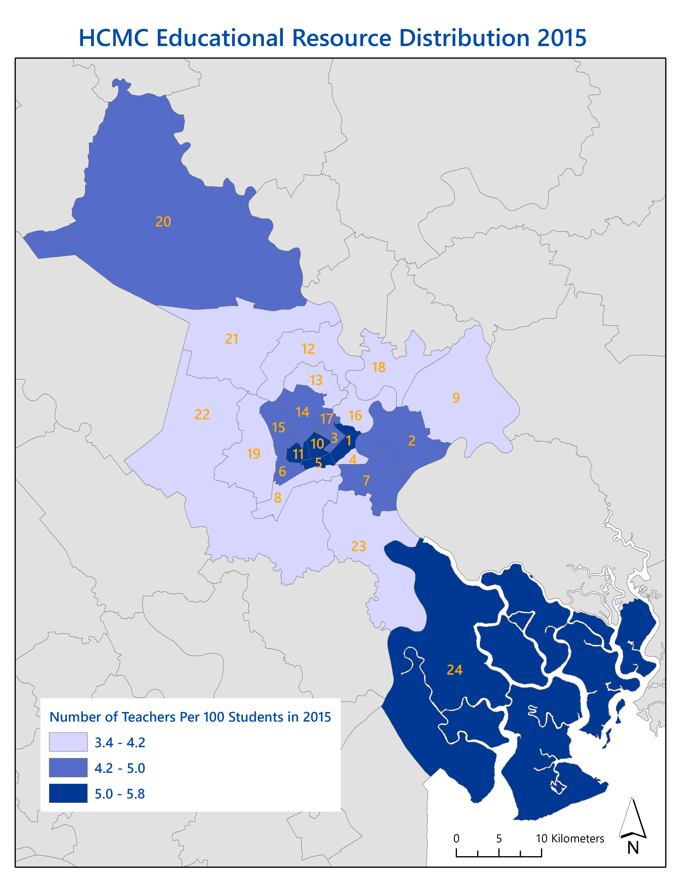


*Figure 3: Overall Flood Risk (Ratings 1-9) Figure 4: Mean Flood Risk by District (Ratings 1-9)*

Further analysis with the zonal statistics to table tool produced a zonal flood risk map (Figure 4) that assigned a flood risk rating (on a scale of 1-9) based on mean risk values to each of the 24 districts in the city.

1. **Resource (Educational and Healthcare) Distribution**

Educational and healthcare statistics were first obtained from the 2015 HCMC Statistical Yearbook and tabulated for each of the 24 districts. These include the 1) number of students in general education[[4]](#footnote-4) by district, 2) number of teachers in general education by district, 3) number of healthcare facilities[[5]](#footnote-5) by district, and 4) total population by district.

*Figure 5: Educational resource distribution Figure 6: Healthcare resource distribution*

Education resource densities (number of teachers per 100 students) by district were subsequently calculated, mapped onto administrative districts, and classified according to equal intervals with 3 classes (choropleth, Figure 5). A similar procedure was carried out for healthcare resource densities by district (number of healthcare facilities per 10000 population), with data classified according to natural breaks and into 5 classes (Figure 6).

**RESULTS & DISCUSSION**

The results primarily highlight differing exposures to flood risk as a result of urban land cover and elevation. According to the city elevation map (Fig. 1), most land in the city sits below 5 m in elevation, leaving much of the population exposed to risks of coastal flooding. Areas with the highest flood risks, as a result of a combination of highly dense and continuous urban fabric and low elevation, are predominantly peri-urban[[6]](#footnote-6) and are located beyond the city center (districts 6-8, 15, 16, 18, 19) (Fig. 3). In contrast, rural districts (20-23) were generally of lower flood risk as compared to the urban core. As a result of higher elevation, districts 1, 5, 10, 14 (within the urban core) and 20 (rural) were shown to have the lowest risk ratings. Mean risk ratings for the districts of highest risk were in the range of 6.6 to 7.1, while those of lowest risk were in the range of 5.0 to 5.5 (Fig. 4). While the analysis of overall flood risk assumes equal influence by urban cover and elevation, and disregards influence by other factors (such as proximity to waterway locations and population density), the final maps produced serve to visually emphasize the unequal distribution of risk arising as a result of current geographies.

Yet educational and healthcare resources are unequally distributed across the city: peri-urban districts beyond the city center have on average 30% fewer teachers (3.4-4.2 teachers/100 students, Fig. 5) and 77% fewer healthcare facilities(0.23-0.56 healthcare facilities/10000 people, Fig. 6) as compared to the highest concentrations in the urban core. The highest densities of teachers are located in districts 1, 5, 10, 11 (within the urban core) and 24 (Can Gio, which has the lowest population density with most people concentrated in the north) with 5.0 to 5.8 teachers per 100 students in general education. Similarly, the highest concentrations of healthcare facilities are located in districts 1, 3, 5 and 17 (within the urban core) with 1.21 to 1.85 healthcare facilities per 10000 residents – approximately 5 times the concentrations found in peri-urban districts.

The results highlight the spatial inequalities inherent in the distinction between the urban core and the rural. The urban core, in particular areas with continuous and dense urban fabric, has historically been the center of commerce and economic activity associated with higher per capita wealth. Educational and healthcare facilities have thus been concentrated in relatively wealthier districts, such as District 1 and 5, within the city center.

These spatial inequalities foreground existing infrastructural inadequacies that may compromise adaptive capacities in the face of extreme weather events. Educational and healthcare resources are crucial for effective disaster management education, preparedness, and response. The goal of enhancing city-wide resilience to extreme weather events thus entails more equitable distribution of such resources spatially and socio-economically. While mitigation measures such as the enhancements in drainage systems may potentially reduce risk in high-risk zones, approaches that advocate a more spatially equitable distribution of educational and healthcare resources would serve to promote social equity and just outcomes in the long term. On this basis, the number of facilities, educators and healthcare professionals should thus be augmented in areas of higher flood risk beyond the urban core to ensure more adequate and equitable coverage of climate resilience efforts.

**CONCLUSION**

Ho Chi Minh City faces emerging pressures as a result of rapid urbanization and a changing climate. Apart from issues with air pollution and traffic congestion, flooding exacerbated by urbanization and sea level rise continuously pose significant risk to the day-to-day activities of the city’s inhabitants. Yet the analysis of flood risk in relation to the spatial distribution of educational and healthcare resources reveals potentially differing vulnerabilities and adaptive capacities to flood events across the city; the densest urban core with a higher elevation is less vulnerable to flooding than the low-lying peri-urban regions. In addition, existing education and healthcare facilities are concentrated within the dense urban core, while peri-urban districts remain relatively less endowed with resources. In light of achieving just outcomes through urban climate resilience efforts, this study thus advocates more socially and spatially equitable approaches by placing greater emphasis on resource and facility development beyond the city’s core.

**DATA SOURCES**

Center for International Earth Science Information Network (CIESIN), Columbia University and ISciences. Low Elevation Coastal Zone (LECZ) elevation data. Available at <http://sedac.ciesin.columbia.edu/gpw/lecz>.

Ho Chi Minh City Statistical Yearbook 2015. Available at <http://www.pso.hochiminhcity.gov.vn>.

The World Bank Platform for Urban Management and Analysis (PUMA), derived from Schneider, A., Mertes, C. M., Tatem, A. J., Tan, B., Sulla-Menashe, D., Graves, S. J., . . . Dastur, A. (2015). A new urban landscape in East–Southeast Asia, 2000–2010. *Environmental Research Letters,* ***10***(3), 034002.

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Kontgis, C., Schneider, A., Fox, J., Saksena, S., Spencer, J. H., & Castrence, M. (2014). Monitoring peri-urbanization in the greater Ho Chi Minh City metropolitan area. *Applied Geography,* ***53***, 377-388. doi:10.1016/j.apgeog.2014.06.029

Mather, R., Wyatt, A., & Weerapong, D. (2013). Building Resilience to Climate Change Impacts: Coastal Southeast Asia, Can Gio District, Ho Chi Minh City, Viet Nam. Retrieved November 25, 2016, from <https://cmsdata.iucn.org/downloads/bcr_factsheet_can_gio_final.pdf>

Saksena, S., Fox, J., Spencer, J., Castrence, M., Digregorio, M., Epprecht, M., . . . Vien, T. (2014). Classifying and mapping the urban transition in Vietnam. *Applied Geography,* ***50***, 80-89. doi:10.1016/j.apgeog.2014.02.010

Storch, H., & Downes, N. K. (2011). A scenario-based approach to assess Ho Chi Minh City’s urban development strategies against the impact of climate change. *Cities,* ***28***(6), 517-526.

**APPENDIX**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **District Number** | **District Name** | **District Number** | **District Name** | **District Number** | **District Name** |
| **1** | Quarter 1 | **9** | Quarter 9 | **17** | Quarter Phú Nhuận |
| **2** | Quarter 2 | **10** | Quarter 10 | **18** | Quarter Thủ Đức |
| **3** | Quarter 3 | **11** | Quarter 11 | **19** | Quarter Bình Tân |
| **4** | Quarter 4 | **12** | Quarter 12 | **20** | Củ Chi |
| **5** | Quarter 5 | **13** | Quarter Gò Vấp | **21** | Hóc Môn |
| **6** | Quarter 6 | **14** | Quarter Tân Bình | **22** | Bình Chánh |
| **7** | Quarter 7 | **15** | Quarter Tân Phú | **23** | Nhà Bè |
| **8** | Quarter 8 | **16** | Quarter Bình Thạnh | **24** | Cần Giờ |

Table 1: District Numbers and Names

Table 2: Raster Values Assigned for Elevation and Land Cover Type in Weighted Overlay

|  |  |  |  |
| --- | --- | --- | --- |
| **Elevation (in meters)** | **Raster Value**  **(1 – Low Risk, 9 – High Risk)** | **Land Cover Type (Soil Sealing Density)** | **Raster Value**  **(1 – Low Risk, 9 – High Risk)** |
| 0 | 9 | Continuous Urban Fabric (S.L. > 80%) | 9 |
| 1 | 9 | Discontinuous High Dense Urban Fabric (S.L. 50% - 80%) | 8 |
| 2 | 8 | Discontinuous Low Dense Urban Fabric (S.L.: 10% - 50%) | 7 |
| 3 | 7 | Industrial, Commercial and Transport Units | 6 |
| 4 | 6 | Construction Sites | 5 |
| 5 | 5 | Urban Greenery | 4 |
| 6 | 4 | Agricultural Land | 4 |
| 7 | 3 | Forests | 3 |
| 8 | 2 | Other Natural and Semi-Natural Areas | 2 |
| 9 | 1 | Bare Land | 1 |
| > 10 | 1 | Water Bodies | No Data |
| Oceans | No Data |  |  |

1. Ho Chi Minh City consists of 24 districts (5 rural huyện and 19 urban quận) and is on a similar administrative level as a province. [↑](#footnote-ref-1)
2. Further details on data sources are listed at the end of the report. [↑](#footnote-ref-2)
3. Raster values assigned for flood risk ratings are attached in the Appendix. [↑](#footnote-ref-3)
4. General education includes primary, lower secondary and upper secondary education, across both public and private schools. [↑](#footnote-ref-4)
5. Healthcare facilities included all hospitals, regional polyclinics, preventive medicine centers and medical service units in communes. [↑](#footnote-ref-5)
6. Peri-Urban: "areas characterized by patchwork development and mixed land use, with large amounts of land still in agricultural use." In Vietnam, 71% of the communes in Vietnam were rural, 18% were peri-urban, 3% were urban, and 4% were urban core (Saksena et al., 2014). [↑](#footnote-ref-6)