Preliminary Development of Composite Geospatial Indices to Evaluate Social Determinants of Health on Asthma Outcomes

Adam Quek, MSc[1], Mingren Toh, MMed[2], Ngiap Chuan Tan, FAMS[3,4] Chian Min Loo, FCCP[2,4], Marcus Eng Hock Ong, FRCS[2,4], Mariko Siyue Koh, MRCP[2,4], Sean Shao Wei Lam, PhD[1, 4]
[1] SingHealth HQ, Singapore; [2]Singapore General Hospital, Singapore; [3]SingHealth Polyclinic, Singapore [4]Duke-NUS Medical School, Singapore

Abstract
This study leverages geospatial informatics to examine how geospatial accessibility, urban density, and socioeconomic status (SES) influence asthma exacerbations in Singapore. Using patient data (n=10,234) and housing geospatial data (n=10,488), three composite indices were developed. Regression analysis found healthcare accessibility to be a significant predictor of the risk of exacerbation (RR=0.88, p<0.001. Findings highlight the importance for geospatial information in understanding risk factors associated with social determinants on health and provide insights on potential public health interventions to enhance asthma care and reduce disparities in urban populations.

Introduction
Asthma is a chronic respiratory disease influenced by both clinical and non-clinical factors, including environmental and social determinants. While medical treatment remains central to exacerbation control, housing conditions, urban density, and healthcare access play a significant role in asthma outcomes[1]. Singapore's public housing system offers a structured environment to examine these determinants, as it reflects socioeconomic gradients and spatial distribution of healthcare resources[2].

Prior studies have assessed asthma disparities by investigating socioeconomic status (SES) based on housing data[3], but few have explored their combined effects. The interaction between population density, transportation networks, and healthcare proximity may influence timely treatment access, particularly in a dense urban environment like Singapore[4]. This study aims to quantify these effects by developing three composite indices – Enhanced Singapore Housing Index (E-SHI), the Community Density Index (CDI), and the Access Index, representing healthcare accessibility. We evaluated the index on the hypothesis that geospatial accessibility and SES affect the risk of asthma exacerbation.

Methods
This cross-sectional study analyzed patient data from the SingHealth COPD and Asthma Data Mart (2016 – 2020)[5,6] alongside housing and geospatial data from Singapore's Housing Development Board (HDB)[7] and OneMap API[8]. The dataset comprised 10,234 asthma patients and 10,488 public housing blocks, with patient records linked to residential postal codes for spatial analysis. Asthma exacerbation was defined as an acute worsening of asthma symptoms requiring either an emergency department visit, hospitalization, or a prescription for systemic corticosteroids[6]. This study received IRB approval (CIRB Ref: 2024/2070), with de-identified patient data used for analysis.

Principal Component Analysis (PCA)[8] was used to construct three indices representing SES, urban density and healthcare accessibility. E-SHI served as an SES indicator, derived from housing prices, rental status and dwelling type. This index extends from an existing SHI index and is shown to be a suitable proxy for SES in Singapore[3]. CDI further captured urban density based on the total number of housing units per block and building height. The Access Index attempts to capture healthcare accessibility by computing distances to polyclinics, hospitals, and transport hubs. All variables were standardized via z-score scaling before performing PCA. Parallel analysis[10] was used to determine the number of principal components to retain. The final index score was normalized to a 1-to-5 scale for interpretability and cross-region comparisons.

Asthma exacerbation rates were modeled using a zero-inflated negative binomial (ZINB)[11] regression to account for overdispersion and the excess zero counts (patients with no exacerbations). Covariates included age, ethnicity and citizenship and comorbidities (COPD, allergic rhinitis). The level of significance was set at 0.05, where $p < 0.05$ was considered statistically significant.

Results
Three principal components explaining 59.4% of total variance were estimated. E-SHI correlated with socioeconomic advantage (r=0.40, p<0.05) but showed weaker associations with exacerbations. CDI indicated higher density in

Queenstown (CDI=3.03) vs. lower density in Changi (CDI=1.38). Access Index was highest in Marine Parade (4.67) and lowest in Changi (1.02), highlighting disparities in healthcare accessibility.

Higher Access Index was associated with lower exacerbation rates (RR=0.88, $p<0.001$). Similarly, higher CDI scores were associated with lower risk of exacerbations (OR=0.89, $p<0.05$), potentially reflecting better healthcare infrastructure in denser areas. E-SHI was not significantly associated with exacerbation frequency (RR=1.03, p=0.09), but higher SES showed increased exacerbation reporting (OR=1.10, $p<0.05$), possible due to greater healthcare engagement. Older age, allergic rhinitis, and COPD were significant risk factors for exacerbations ($p<0.001$).

Discussion

Findings suggest geospatial accessibility is a stronger effect on asthma exacerbation rates than SES. This implies that proximity to healthcare and transportation networks is more influential in asthma management than housing-based SES indicators. Contrary to common assumptions, higher urban density was associated with lower exacerbation likelihood[5]. This could be due to better healthcare infrastructure in denser area. However, high-density environments may also pose risks such as pollution and overcrowding, which warrant further study. SES as assessed using the E-SHI was not a strong predictor of exacerbation frequency but correlated with higher healthcare engagement. This underscores the need to ensure equitable access to primary care services to lower income populations, preventing underdiagnosis and undertreatment.

Conclusion

This study highlights the importance of spatial accessibility in asthma management, emphasizing how urban form and healthcare proximity can influence asthma outcomes. Our approach offers a novel, integrative framework that captures the multifaceted social and geospatial determinants of asthma exacerbations in a dense urban context. The ZINB regression revealed key insights that could guide public health interventions to address geospatial disparities. Future research can extend their application to other chronic conditions and settings, enabling policymakers and planners to reduce health inequities and optimizing care delivery across urban communities.

Acknowledgements

The authors would like to thank Weiqiang See for his expertise in project management. This research was supported by funding from Population-based, Unified, Learning System for Enhanced and Sustainable Health (PULSES) Grant (Ref: CGFeb24S05) and Pitch for Fund (PFF) Award Grant (Ref: 03/FY2024/P2/26-A148).

References

1. Bryant-Stephens TC, Strane D, Robinson EK, Bhambhani S, Kenyon CC. Housing and asthma disparities. *J Allergy Clin Immunol*. 2021;148(5):1121-1129. doi:10.1016/j.jaci.2021.09.023
2. Low LL, Wah W, Ng MJ, Tan SY, Liu N, Lee KH. Housing as a Social Determinant of Health in Singapore and Its Association with Readmission Risk and Increased Utilization of Hospital Services. *Front Public Health*. 2016;4. doi:10.3389/fpubh.2016.00109
3. Lim DYZ, Wong TH, Feng M, Ong MEH, Ho AFW. Leveraging open data to reconstruct the Singapore Housing Index and other building-level markers of socioeconomic status for health services research. *Int J Equity Health*. 2021;20(1):218. doi:10.1186/s12939-021-01554-8
4. Labban M, Chen CR, Frego N, et al. Disparities in Travel-Related Barriers to Accessing Health Care From the 2017 National Household Travel Survey. *JAMA Netw Open*. 2023;6(7):e2325291. doi:10.1001/jamanetworkopen.2023.25291
5. Koh M, Lam S, Xu X, et al. Patient Characteristics, Management, and Outcomes of Adult Asthma in a Singapore Population: Data from the SDG-CARE Asthma Registry. *Pragmatic Obs Res*. 2024;Volume 15:209-220. doi:10.2147/POR.S477225
6. Lam SSW, Fang AHS, Koh MS, et al. Development of a real-world database for asthma and COPD: The SingHealth-Duke-NUS-GSK COPD and Asthma Real-World Evidence (SDG-CARE) collaboration. *BMC Med Inform Decis Mak*. 2023;23(1):4. doi:10.1186/s12911-022-02071-6
7. Luo Y. A Study on Singapore's HDB System: A Model of Public Housing Policy. *Adv Econ Manag Polit Sci*. 2025;147(1):144-149. doi:10.54254/2754-1169/2024.GA19144
8. Singapore Land Authority. OneMap Application Programming Interface. Published online 2024. Accessed March 11, 2025. https://www.onemap.gov.sg/apidocs/
9. Jolliffe IT, Cadima J. Principal component analysis: a review and recent developments. *Philos Trans R Soc Math Phys Eng Sci*. 2016;374(2065):20150202. doi:10.1098/rsta.2015.0202
10. Franklin SB, Gibson DJ, Robertson PA, Pohlmann JT, Fralish JS. Parallel Analysis: a method for determining significant principal components. *J Veg Sci*. 1995;6(1):99-106. doi:10.2307/3236261
11. Lee KH, Pedroza C, Avritscher EBC, Mosquera RA, Tyson JE. Evaluation of negative binomial and zero-inflated negative binomial models for the analysis of zero-inflated count data: application to the telemedicine for children with medical complexity trial. *Trials*. 2023;24(1):613. doi:10.1186/s13063-023-07648-8

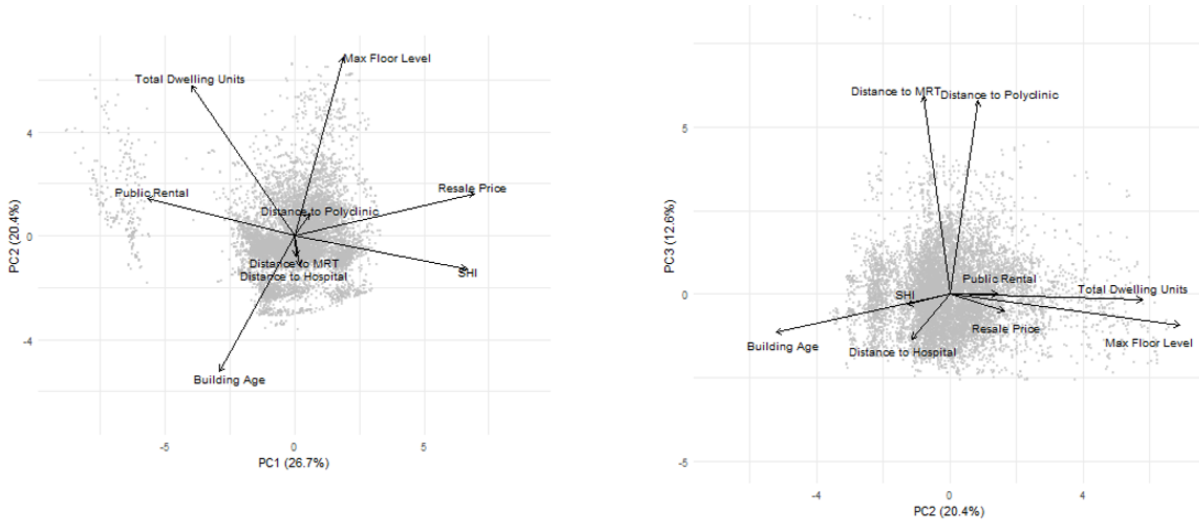

Figure 1: PCA biplots for PC1 vs PC2 (left) and PC3 vs PC3 (right). PC1 describes E-SHI, PC2 describes CDI and PC3 describes Access Index.

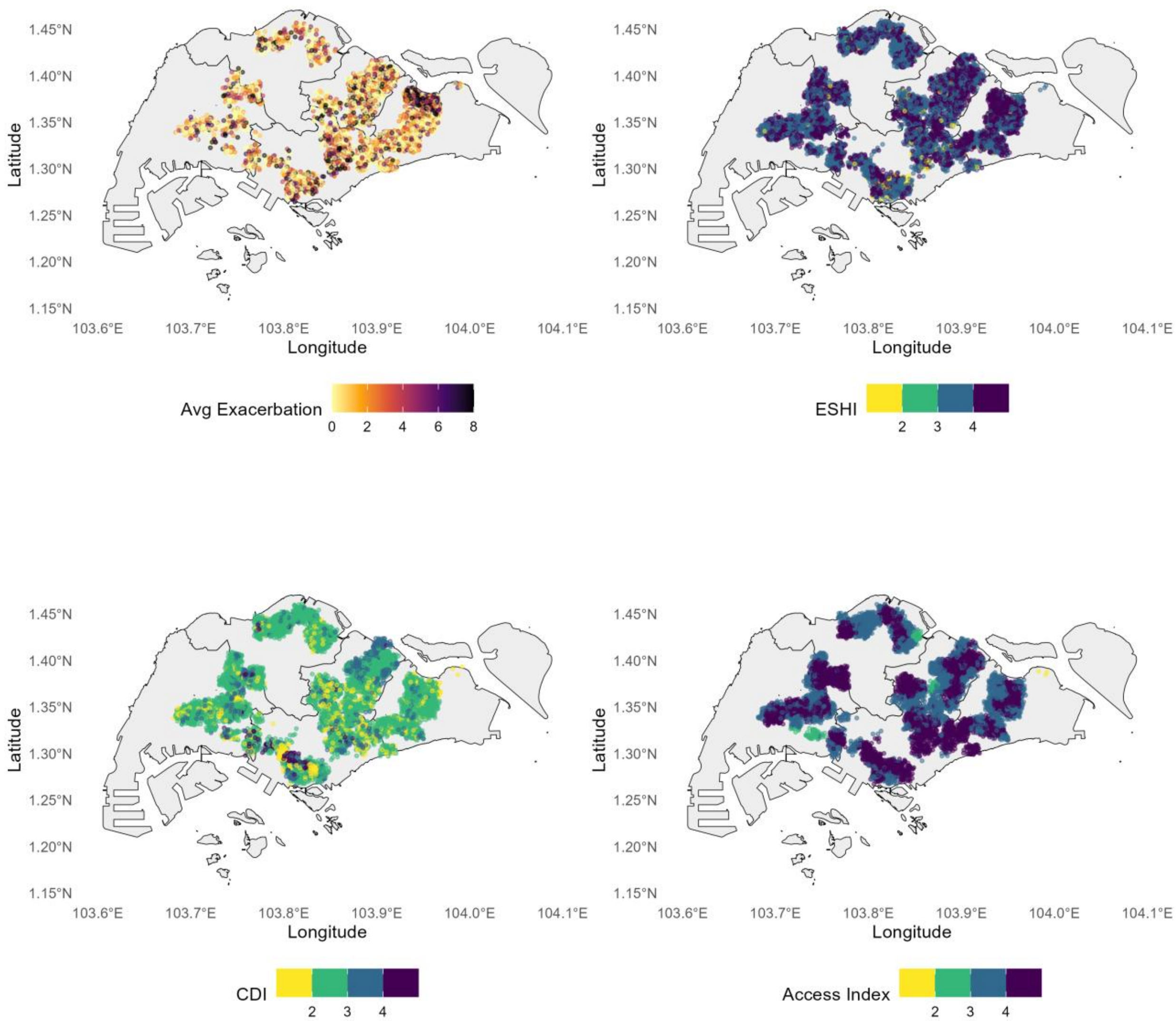

Figure 2: Heatmap for exacerbation counts and indices.