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Urban Decay and Pediatric Asthma Prevalence in Memphis, Tennessee: Urban Data Integration for Efficient Population Health Surveillance

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ABSTRACT In this paper, we investigate the relationships between dwelling conditions and pediatric asthma prevalence, merging multiple data sources to unpack disproportionate pediatric asthma prevalence in Memphis, TN, USA. Using 32 097 pediatric asthma encounter data from a children's hospital, we map the patient distributions in Memphis. Connecting these data with 244 000 property quality data and census data, we show that pediatric asthma is disproportionately prevalent in the bad quality neighborhoods, even after controlling for ethnicity and poverty level. Furthermore, we show that the neighborhood inequality has a more negative effect than the overall neighborhood degeneration. Our novel data integration provides a unique opportunity to directly test the relationship between residential qualities and asthma prevalences at the macro-level, and to the best of our knowledge, this study is the first study that investigates the association between the detailed property quality and pediatric asthma with a relatively large sample size. Moreover, directly connecting health outcomes with the detailed housing quality data enables us to unpack how the inequality in living conditions yields disproportionate public health outcome distributions. To further improve public health decision making, the health issue should be approached with a more holistic view with taking into account environmental, residential, and social conditions. Integrating multiple data sources helps us not only discover the hidden links between quality of housing and childhood asthma in an urban community but also provide more efficient health surveillance guidelines to identify the population at risk. We show that neighborhood blight and inequality are closely associated with childhood asthma and other consecutive health problems, and therefore, any effective health intervention should also consider consolidation of housing policies and procedures. In addition, the detailed neighborhood level data helps us to reveal the pathways of social inequalities to health disparities and improve the public health through a properly designed surveillance system.

INDEX TERMS Health data analytics, health disparity, pediatric asthma, public health surveillance, social determinants of health, urban decay.

I. INTRODUCTION

Asthma is one of the most common chronic childhood diseases in the United States, result in morbidity higher than what has been reported in many other industrialized countries [1], [2]. According to the U.S. Centers for Disease Control and Prevention (CDC), 13.5% of the U.S. population experienced asthma ever in their lifetime and 8.6% of the population reported that they still had asthma in 2014 [3], resulting in tremendous social and economic burdens. It has long been noticed that there are evident disparities in asthma prevalence among different demographics [4], [5]. Asthma is a highly socio/environment-sensitive disease and the geographical variance has been extensively studied by health professionals [6]–[12]. According to the CDC's adult asthma data, the prevalence rates across different states vary greatly from 8.8% to 25.3% [5]. Asthma prevalence has increased more in urban than rural areas [13]. Although some studies suggest a genetic role in asthma development [14], [15], a family history of asthma is not a sufficient predictor of asthma development in succeeding generations [16]. Despite the importance of residential conditions in asthma, direct assessments on built and social neighborhood environment effects have not been thoroughly examined due to the complexity of its causal route, limited data availability, and heterogeneity of existing data sources. Systematic analyses of the prevalence of asthma in children, by examining the impacts of housing and neighborhood factors, can shed light on a better understanding of the etiology of the disease.

To design effective preventive and therapeutic interventions to reduce health and social burdens of chronic diseases such as asthma, we explore the influence of the neighborhood-level factors on the prevalence of asthma among children residing in and around urban areas in Memphis and Shelby County, TN. More than 750,000 Tennesseans are diagnosed with asthma in their lifetime according to the Tennessee Department of Health. Focusing on the socio-environmental determinants and risk factors influencing asthma prevalence in children, we compare pediatric patient distributions in Memphis geographically. Then, we examine whether residential disparity, housing inequality, and other neighborhood factors can help to explain disproportionate asthma prevalence in the city.

After summarizing existing literature on non-biological asthma determinants, we geographically map asthma prevalence in and around Memphis and study neighborhood variation in disease prevalence. Next, we statistically test if neighborhood quality is significantly associated with asthma prevalence with two sets of statistical analyses: the individual-level asthma severity and the neighborhood-level total asthma encounters in a zip code area. Finally, we conclude with a discussion of our results and findings and suggestions for future work.

II. THEORETICAL BACKGROUNDS AND THE STATE OF THE ART

In this study, we focus on the non-biological determinants of pediatric asthma. Although the biological causes of asthma, such as viral infection, is evident for asthma prevalence, including environmental factors can better account for regional prevalence variations [1]. Amongst non-biological determinants of asthma, socio-economic risk factors - race, poverty, immigration status, residential environment, and so forth - are known to significantly contribute to the prevalence of asthma [2], [7], [10], [13], [17]–[19].

Racial and ethnic disparities in asthma prevalence and mortality have been studied extensively [2], [20]–[26]. Despite the fact that asthma is not considered a racially-linked genetic disease [16], [27], [28], one can observe empirical disparities between African Americans and Whites. There have been conflicting findings on the trends of racial disparities in asthma prevalence in the U.S. [2], [20]–[26]. Winer *et al.* [23] argue that they could not find any statistical difference between racial/ethnic groups, according to their Asthma Call-back survey data from 2006 to 2008. However, many other researchers have obtained evidence supporting racial disparities in asthma prevalence and mortality [21], [24], [25]. For example, from 1995 to 2002, although the racial gap for the older population decreased, the disparity in mortality rate for children under the age of 10 is still evident, according to the National Hospital Discharge Survey Database [20]. Gold and Wright [2] argue that, based on data from four American cities, African American children are more likely to be diagnosed with asthma than White children. Bhan *et al.* [21] found that racial minorities face a greater risk for asthma morbidity, and the disparity between African Americans and Whites has significantly increased between 1999 and 2011. Also, Nelson *et al.* [25] showed that middle-class African American children are twice as likely to experience asthma than middle-class White children.

This conflicting empirical evidence demands further investigation. Moreover, some scholars have linked the racial disparities to economic inequality [11], [29]–[31]. Economic inequality leads to medical inequality and to the differing accessibility of medical insurance/care. In addition, poor living conditions and dwelling qualities can lead to drastic asthma disparities along the poverty line [11], [29–[31]. With Maryland hospital discharge data, Wissow and her coauthors found that African American children are more likely to be hospitalized due to asthma. However, after controlling for the level of poverty, the racial gap between African American and White children had become significantly attenuated [30].

These two factors - racial and economic disparities - exacerbate the problem when they cohabit. Geographically, asthma develops more in inner-city settings [2], [32]. Children dwelling located in inner cities are exposed to multiple disadvantages, including higher poverty rates, lower-quality housing, high crime rates, and alleviated stress levels, which are all associated with adverse health outcomes [33]. Additionally, inner-city residential conditions are often associated with lower hygiene and higher air pollution [34]–[36]. For example, air pollution measured as correlated with carbon monoxide (CO) levels has a significant effect on pediatric asthma prevalence, and children with lower socioeconomic status are more exposed to this form of pollution [36]. Particularly for pediatric asthma patients, Aligne *et al.* [7] found that the higher prevalence of asthma among African Americans is not directly related to race or poverty; rather, inner-city residency is what affects people most, especially children. Furthermore, Chen *et al.* [19] argue that higher levels of neighborhood problems are associated with greater asthma symptoms, based on their observational study of 78 pediatric asthma patients. They show that racial disparity and economic inequality are factored through different residential conditions [19].

Despite extensive studies on asthma, large-scale direct assessments on the effects of dwelling environments and neighborhood conditions on asthma have not been empirically examined, partly due to the scarcity and heterogeneity of the existing data sources. The integration between our health-related data set and various socio-environmental data sets, including the data provided by our partners on the housing conditions in Memphis and Shelby County, provides a unique opportunity to further study and examine the above-mentioned association at the macro level. According to the social determinants of health theory [37], in order to systematically analyze the prevalence of asthma in children and understand its underlying etiology, direct examination of the residential factor is crucial. In this paper, we statistically investigate the relationships between dwelling conditions and asthma prevalence by integrating multiple data sources, to further unpack disproportionate pediatric asthma prevalence in our target community.

III. DATA SOURCES

We integrate multiple data sources with detailed information on residential and neighborhood quality, along with pediatric asthma patients' data from a local children's hospital in downtown Memphis from 2011 to 2016 (Pediatric Research Database). Asthma is the cause of 40 percent of the hospital's admissions. We merge the individual-level patient data with aggregated relevant neighborhood data such as residential quality survey data from the Memphis Property Hub (mempropertyhub.com, a private sector partner that collects data related to distressed and vacant properties in the City of Memphis), and basic demographic information (2010 U.S. Census).

A. HEALTH-RELATED DATA

With regard to asthma patient data, we have investigated localized pediatric asthma prevalence in 29 zip code areas in Memphis, combining with 32,097 encounter data from Le Bonheur children's hospital in Memphis. For the encounter data, we only considered patients aged between 0 to 21 who were living in Memphis from January 1st, 2011 to December 31st, 2016, with any diagnosis code related to asthma. All types of the encounters filed with asthma-related diagnosis codes are included, from Emergency Room (ER) visits to outpatient visits. At the individual level, we have the patients' zip code area and insurance class data, with four categories including *Medicaid*, *Medicare*, *Commercial,* and *Self-pay*. The total encounter data came from 14,821 patients with varying total visit numbers from 1 to 33. The majority of patients (n=8,631) visited the hospital only once between 2011 and 2016. No patient revisited the hospital with different zip code areas if they visited multiple times, which means either they didn't move at all, or they might have relocated their residences but not outside of their original zip code area. We only use the first time visit for each patient within the observation period. The mean patient age at visit is 6.83, with 39% female and 61% male. The sample is composed of 89.22% African American and 5.14% White patients. Other/unknown/unavailable/declined categories summed up to 4.61% and all other minority groups comprise the rest of the sample. The racial composition of the sample is highly skewed towards African American patients. It is worth mentioning that our sample is not a representative composition, considering the fact that the racial composition of the city consists of 53.5% African American and 42.0% White (2010 Census) and, therefore, much caution is needed when making inferences about broader contexts. Also, the patient insurance types are mostly Medicaid (82.65%). 15.18% of the patients have commercial insurance plans and 0.07% use Medicare.[1] Among 28,637 African American patient encounters, the ratio of patients who are covered by Medicaid exceeds other ethnic groups' propensity to be covered by Medicaid. Patients covered under Medicaid are more likely to have higher asthma risk compared to the patients who pay by other sources [30].

B. SOCIO-ENVIRONMENTAL AND NEIGHBORHOOD DATA

Integrating the individual level data with the unique neighborhood/environmental data, we link the individual level encounter data within the zip code area of patients' residency. We used Memphis survey data that explore multiple property unit qualities, provided by the Memphis Property Hub. In 2015, the survey teams went out to different neighborhoods in Memphis to gather the actual property quality data. Volunteers used a smartphone-based app to survey each parcel in Memphis and document the presence of blight, evaluating over 244,000 parcels to capture structural deficiencies. The quality control team tested a random sample of 200 units from each surveyor to check the reliability of their assessment. The dataset provides a rich and detailed record of the appearance of each property unit, such as the presence of broken windows, roof problems, mishandled trash, etc. Also, information about the overall quality of the property was captured with photos. Moreover, we used the 2010 census data on the neighborhood racial composition, the poverty level, and the population size.

Most patients in our sample are urban-dwelling African American children with Medicaid, who are considered to be in a more disadvantaged and vulnerable position according to [11] and [29]–[31]. Expanding the existing socioeconomic models, we explore the neighborhood effects on localized asthma prevalence, measured by the total number of pediatric asthma encounters observed in each zip code area.

IV. METHODS

We employed geostatistical analytics [38] to identify asthma indicators, detect high-risk groups, and validate socio-environmental determinants for asthma prevalence and severity, both at individual and population levels. First, we conducted individual level analysis to see if our data support the existing theories of non-biological asthma determinants discussed in the previous section. The individual level dependent variables are the total number of hospital visits and symptom severity varying from uncomplicated cases to acute ones, based on their International Classification of Diseases (ICD version 9 and 10) diagnosis codes.

For the macro-level dependent variable, we use the number of encounters associated with a zip code area. For instance,

[1] The Medicare proportion is small because we are only looking at pediatric patients.

we can link the number of hospital visits by the residents from a zip code to the prevalence of asthma in that area (more visits indicate higher prevalence). For the neighborhood model, we introduce property blight, neighborhood quality, and inequality to test whether living conditions in a neighborhood have a significant influence on the degree of pediatric asthma prevalence.

$$\hat{y}_i = \alpha + x_{i1}\beta_1 + x_{i2}\beta_2 + \cdots + x_{ik}\beta_k + \varepsilon_i \quad (1)$$

We have run multivariable regression models (1) to account for asthma prevalence and its severity [39]. To control extreme outliers, we used robust regressions to predict asthma prevalence. In robust regression models, after running initial Ordinary least squares (OLS) as shown in the equation above, the new weights are assigned to original values according to their absolute residuals [40]. The more distance between the expected value and the actual value, the smaller weight is assigned to the value to minimize the effect of the outliers. Factors indicated by previous studies serve as controlling variables in the analysis. We used the population size of each zip code area as a control variable. As discussed earlier, poverty is known to have a positive association with asthma [11], [29]–[31]. Thus, we incorporate the poverty ratio, extracted from the U.S. census data, for each zip code area into the socioeconomic model. Lastly, we control for the percentage of African American population of each zip code, as they are considered to face a higher risk of asthma.[2] Correspondingly, we added the African American population ratio into the socioeconomic model to control for the unique composition of the urban area and our sample. For the geodisparity model, we introduce three variables that can describe the neighborhood quality of the patients at the zip code level. The blight variable is the number of abandoned properties within the zip code area. The neighborhood dilapidation variable and the neighborhood inequality measure are derived from the neighborhood quality survey data. We have utilized the question of the property quality in the Property Hub dataset, which offers a 5-point scale measure of the overall quality of the property. The property quality indicator in this study varies from 5 for an excellent condition and 1 suggesting the property is in a severely dilapidated condition. The average score of property qualities within a zip code area is used for the neighborhood dilapidation variable and the standard deviation score of the variable employed for the neighborhood inequality variable. Higher levels of neighborhood dilapidation means more severely damaged properties are present in the zip code area. Higher levels of the neighborhood inequality indicates that there is a greater variance in terms of housing quality within in zip code area. The variables and specific operationalization are summarized in Table 1.

[2]As the encounter data show, 86.2% of encounters are associated with African Americans.

V. RESULTS

First, we mapped the asthma prevalence in the Memphis, and then we compared it with the neighborhood quality map highlighting the blight prevalence. We found that asthma encounters are disproportionately distributed across different neighborhoods. Figure 1 represents all pediatric asthma encounters from 2011 to 2016 accumulatively and demonstrates the geographical distribution of patients in and around Memphis.[3] As mentioned before, our sample is mostly composed of highly vulnerable groups, the urban-dwelling racial minority covered by Medicaid. The geographical residential pattern of patients is widely spread over the urban areas in Memphis. A blight map, shown in Figure 2, represents the total number of abandoned units within a specific zip code area.[4] Comparing the blight phenomenon presented in Figure 2 with Figure 1, we observe striking overlap between regions with high asthma prevalence with high blight areas. The actual total encounter numbers (shown in Figure 1) and the total number of blighted properties (shown in Figure 2) correlate at the level of 0.76.

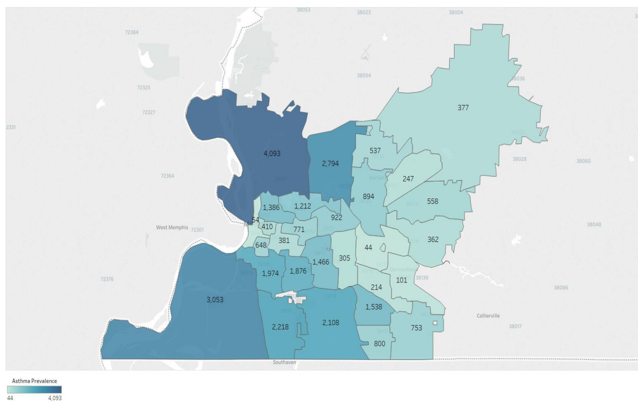

FIGURE 1. **Asthma Prevalence in Memphis, TN.**

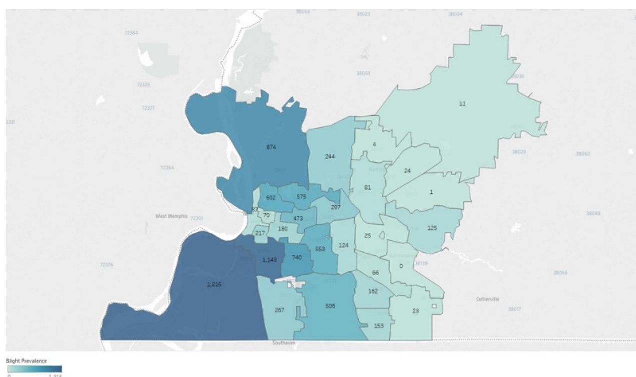

FIGURE 2. **Blight Prevalence in Memphis, TN.**

Additionally, when we parsed out the encounter data by year and graphed them together, we found that there is a

[3]When we project year by year data, maps are similar with Fig 1.

[4]When we depict the distribution of broken windows or other neighborhood bad quality indicators, their maps are similar to Fig 2.

TABLE 1. Variables and operationalization.

Variables	Measurement/Operationalization	Mean (SD / %)
Total Visits	Total number of hospitalizations	4.710 (4.897)
Symptom Severity	Degree of asthma symptom severity (ICD 9)	1.620 (0.619)
Age	Age of the patient	6.84 (4.68)
Medicaid	0: Non-medicaid Patient 1: Medicaid Patient	(83%)
African American	0: Not African American 1: African American	(89%)
Gender	0: Female 1: Male	(61%)
Asthma Prevalence	Total number of asthma encounters within a ZIP code area	1106.76 (1005.57)
Population	Population size of each ZIP code area	28884.62 (11993.1)
Poverty Level	Percentage of individuals under the poverty level residing within a ZIP code area	0.241 (0.156)
African American Population	Total number of African American residents within a zip code area	16464.69 (12869.48)
Blight	Number of unoccupied properties within a ZIP code area	304.897 (342.329)
Neighborhood Dilapidation	Mean of ratings of property qualities located within a ZIP code area (1: Excellent and 5: Severely Dilapidated)	1.748 (0.361)
Neighborhood Inequality	Standard deviation of housing quality data within a ZIP code area	0.714 (0.223)

clear year-on-year persistency of geographical disparities in asthma prevalence. In Figure 3, the ordinate represents the total number of encounters and the abscissa represents each zip code area. Each line shows asthma encounters for a specific zip code area per each year. We can see that the lines are closely overlapping each other, which means that the observed pattern is persistence in each area over the six years of this study. The figure suggests that the pediatric asthma prevalence is geographically disproportionate and the discrepancy is persistent in Memphis.

Table 2 shows the results of our individual level analysis. The individual level factors are statistically significant in our model at the 0.001 p-value level.

African American children experience asthma-related hospital visits more frequently than White children. Patients who are covered by Medicaid visit the hospital more often than patients who are covered by other types of resources (commercial, self-pay, and Medicare). When we use the symptom severity as the dependent variable for the individual level, the directionalities of predicting factors are consistent with the total number of visits analysis, but the Medicaid variable loses its statistical significance.

TABLE 2. Individual level robust regression models on asthma severity.

	Total Visits		Symptom Severity	
Age	-.024	***	-.009	***
Medicaid	.629	***	.002	
African American	.841	***	.121	***
Gender	.193	***	.025	***
Constant	2.088	***	1.552	***

NOTE: *p<.05; **p<.01; ***p<0.001

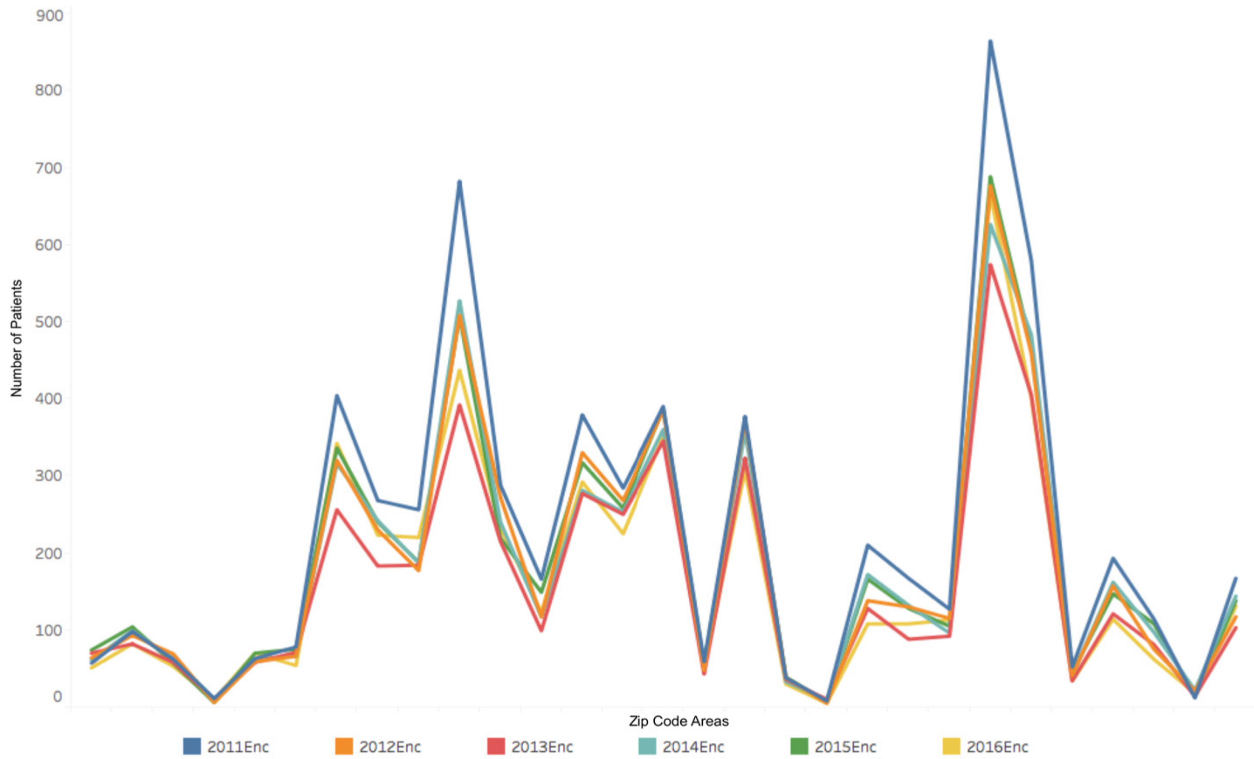

FIGURE 3. Asthma Persistency within the Zip Code areas in Memphis, TN.

Moving next to the macro level, to predict the prevalence, we run multivariable regression models at the neighborhood level. The results are summarized in Table 3. The baseline model agrees with previous studies showing that the poverty level is positively associated with the asthma prevalence and the percentage of African Americans is positively associated with the asthma prevalence [2], [20]–[26]. Consistent with existing studies, both variables are statistically significant in our results. The population size of each zip code area has a positive relationship to the asthma prevalence; although in contrast to the other independent variables, it is not statistically significant.

In the neighborhood models, the blight phenomenon is positively associated with asthma prevalence, at a statistically significant level, even after controlling for all other socioeconomic variables. In the blight model, the level of poverty and the proportion of the African American population of the neighborhood are statistically significant as well. Next, in the neighborhood inequality model, we replaced the blight variable with neighborhood quality variables such as neighborhood dilapidation and neighborhood inequality. What is interesting in this model is that neighborhood inequality in the overall neighborhood quality is statistically significant in predicting the asthma prevalence, but not the mean average of neighborhood quality. We show that neighborhood inequality has a stronger effect on the overall neighborhood degeneration. It is not a simple matter of quality - whether one is living in a bad neighborhood or not - rather, the relative inequality within the neighborhood that has a statistically significant relationship to the pediatric asthma prevalence.

VI. DISCUSSIONS

Overall, we found that patterns of asthma prevalence are disproportionately distributed within the city. Some neighborhoods are more vulnerable compared to the other neighborhoods at the statistically significant level. Our results suggest that neighborhood blights and living conditions are among major health determinants and therefore should not be avoided during public health decision making and policy development. As our future work, we aim to incorporate these results to implement a knowledge-based urban population health observatory (UPHO) to facilitate urban health surveillance and public health planning. An integrated knowledge-based system [41] will be able to analyze the causal pathway [42] of the disease, answer questions on how changes in upstream causal risk factors and determinants (e.g., social determinants of health, the built environment, remediating neighborhood blight and housing improvement, education, and other factors) can lead to health gains and narrow racial and socioeconomic disparities and compare and evaluate [43] the related programs, intervention and policies.

The complexity of pediatric asthma causal pathway demands comprehensive, coordinated, and coherent

TABLE 3. Neighborhood level robust regression models on asthma prevalence.

	Baseline Model		Blight Model		Neighborhood Inequality	
Population	.013		.009		.012	
Poverty level	1898.914	**	863.588	*	285.279	
African American	.044	***	.033	***	.049	***
Blight			.927	***		
Neighborhood Dilapidation					281.051	
Neighborhood Inequality					970.289	*
Constant	496.784	**	-55.856	**	-23.398	*

NOTE: *p<.05; **p<.01; ***p<0.001

solutions. To design effective preventive interventions to reduce social and financial burdens of asthma prevalence in the U.S., we need to integrate housing policy to the health policy more closely. Our results show that the interventions targeting treatment of asthma in children should be tailored according to where the patients live, as the living conditions are significantly influence the prevalence of pediatric asthma.

Inference of our findings is constrained with some limitations and the results must be interpreted based on the scope condition. Although we investigate a large number of pediatric patients in and around Memphis, some asthma patients may have visited different hospitals, which are not captured in the data. We utilize the medical records from one hospital. Though we are confident in our findings, the exact prevalence could be slightly different from our data. Additionally, the granularity of zip code has been considered for studying our neighborhoods. Although a zip code level was the most micro-level details we could access data for the current study, it might not be the finest granular to capture detailed social gradients [44]. In our case, the zip code level works relatively well, given the low population density in the subject area. Population density in Memphis is 2,072 people per a square mile (U.S. Census 2010). If, for instance, we conduct the same study in New York City, where the population density is 28,211, we would use a finer grid than a zip code. How to analyze data for studying a neighborhood can vary depends on the kind of specific characteristics one is looking for and the kind of residential conditions one is investigating on.

VII. CONCLUSION

In the present study, the integration of multiple data sources allows us to systematically unpack asthma prevalence patterns and broaden our comprehension of the pediatrics asthma epidemic in an urban area. Pediatric asthma is disproportionately prevalent in poor and bad quality neighborhoods. Directly connecting health outcomes with detailed housing quality and census data enables us to reveal how inequalities in living conditions yield disproportionate public health outcome distributions. Using socio-environmental indicators, public health organizations can implement intelligent surveillance systems for neighborhood-level monitoring of major determinants of health and risk factors.

Health is a social matter as much as a biological matter. In fact, that the social conditions heavily influence health outcomes at the individual and population levels. Understanding the pathways of how social inequalities are channeled to health disparities is a matter of supreme import and the neighborhood is the key unit of the mechanism. Different aspects of urban decay can leave long-lasting impacts on the overall wellness of individuals and families living in a community. As presented in this paper the health conditions are not only reflecting whether one's absolute living condition is good or not but also the relative condition within the neighborhood.

Detailed neighborhood level data helps us to reveal the pathways of social inequalities to health disparities. Public health intervention design, therefore, should pay more attention to improve the conditional inequality as well. More comprehensive data integrations with other types of social factors (e.g. crime data, transportation, food and grocery purchase, etc.) are strongly encouraged for future investigations.

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