

# The Health Dividend of Urban Greenness: Impacts on Child Malnutrition and Mortality in India

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## Abstract

This study investigates the impact of urban green spaces on child nutritional health and mortality outcomes in Indian cities and towns. Using data from the National Family Health Surveys (NFHS-4 and NFHS-5), we integrate high-resolution satellite-derived Normalized Difference Vegetation Index (NDVI) values based on survey locations. Employing probit regression on a pooled sample, we find that increased urban green cover significantly reduces the risk of stunting, wasting, underweight, and child mortality in urban India, after controlling for socio-economic and demographic factors. To ensure robustness, we conduct additional analyses using alternative greenness indicator, quadratic regression models, interactions of NDVI environmental variables, and instrumental variable regression. The results reveal a nonlinear relationship between NDVI and child health, where the benefits of greenness emerge only beyond a certain threshold. Additionally, environmental factors such as temperature, precipitation, and air pollution (PM<sub>2.5</sub>) interact with NDVI, sometimes lowering its positive effects. These findings highlight the potential of urban greening initiatives in reducing child malnutrition and mortality risks while emphasizing the need to consider climatic and pollution-related factors in urban health policies.

**Keywords:** Urban Greenery; NDVI; Child Nutrition; Child Mortality; Environment; Probit Regression; IV Regression

## 1 Introduction

Urban greenness has emerged as a critical factor influencing public health outcomes, particularly in rapidly urbanizing regions like India, where environmental stressors such as air pollution and heat stress pose significant risks to child health. As cities expand, the loss of green spaces exacerbates these challenges, making it imperative to explore the role of urban vegetation in mitigating adverse health outcomes. Research indicates that exposure to green spaces contributes to improved maternal and child health, reduced air pollution-related risks, and overall enhanced well-being (Dadvand et al., 2012; Hystad et al., 2014). Study shows that exposure to climatic shocks such as heatwaves and droughts severely affects the child health and under-five mortality (Andriano, 2023, 2024). The role of urban vegetation in mitigating the adverse effects of environmental stressors, such as air pollution and heat stress, has been extensively studied (James et al., 2015; De Keijzer et al., 2017; Karimi & Shokrinezhad, 2020).

Green spaces are associated with lower mortality rates and better health outcomes. Studies in Spain and China suggest that long-term exposure to greenness significantly reduces

mortality risk (Kasdagli et al., 2021; Li et al., 2023). A systematic review and meta-analysis further confirm the positive impact of urban greenery on mortality rates (Rojas-Rueda et al., 2019). Additionally, tree-planting initiatives have been linked to reduced mortality in urban settings (Donovan et al., 2022). The benefits of urban greenness extend to birth and early childhood outcomes. Increased residential greenness has been correlated with improved pregnancy outcomes and reduced risks of adverse birth conditions (Dadvand et al., 2012; Villeneuve et al., 2022; Zhang et al., 2022). Exposure to green spaces in early life also positively affects neurodevelopment and cognitive functions in children (Jimenez et al., 2022; Liao et al., 2019).

Furthermore, greenness interacts with air pollution in complex ways, influencing child mortality. Studies in Europe and North America highlight how greenness can moderate the negative health effects of air pollution (Hill et al., 2019; McEachan et al., 2016). A longitudinal study in China confirms the protective effect of urban greenery against infant and under-five mortality (Zhang et al., 2024). Similarly, an analysis of greenness and under-five mortality worldwide emphasizes the global relevance of this relationship (Perin et al., 2022).

Urban greenness also plays a role in mental health and physical activity. Green environments have been associated with lower depressive symptoms, especially among vulnerable populations (McEachan et al., 2016). Urban greenness encourages physical activity, contributing to improved health outcomes (McMorris et al., 2015). Moreover, green space exposure has been linked to reduced insulin resistance in adolescents (Thiering et al., 2016), further demonstrating its broad health benefits. The need for policy interventions to expand urban greenery is evident. Studies in Europe and the U.S. indicate that increasing green spaces can help mitigate health inequalities (Barboza et al., 2021; Mitchell & Popham, 2008). Recent findings suggest that expanding urban greenness can positively impact childhood health metrics (Koebe, 2025).

Urban green spaces are increasingly recognized as critical for shaping environmental quality and public health, yet their role in influencing child health outcomes in India remains insufficiently understood. While cities worldwide have incorporated greenness into planning as a means of improving well-being, Indian cities show stark inequalities in access to open space. These variations, coupled with challenges such as air pollution, overcrowding, and heat stress, raise important questions about how urban greenery affects child health and mortality. This study therefore investigates the relationship between urban green spaces and child health in India, with the aim of generating evidence to advance demographic research and deepen the understanding of how urban environments affect vulnerable populations.

In the Indian context, this study contributes to understanding how urban greenness influences child health and mortality, considering the rapid urban expansion and associated environmental challenges. By employing remote sensing-based greenness indicators, it provides an empirical foundation for integrating urban vegetation into health-focused policy interventions. This research underscores the significance of sustainable urban planning to enhance child health outcomes in India's growing cities.

## **2 Data and Methods**

### **2.1 Child health and mortality**

We integrate two rounds of the National Family Health Survey (NFHS)—NFHS-4 (2015–16) and NFHS-5 (2019–21)—which form part of India's Demographic and Health Survey program (IIPS & ICF, 2017, 2021). Together, these rounds provide nationally representative

information on household, maternal, and child health for more than 1.2 million households, of which about one-third are urban. The pooled child sample includes 47,199 children from NFHS-4 (born 2010–2016) and 61,379 from NFHS-5 (born 2014–2021), yielding a decade-long perspective on urban child health.

Child health outcomes are assessed using four key indicators: stunting, wasting, underweight status, and under-five mortality. The child nutrition values are binarized using WHO growth standards. Under-five mortality is determined whether a child died before reaching the age of five.

To capture long-term trends in urban child health, we pool data from NFHS-4 and NFHS-5, providing a comprehensive view of child nutrition and mortality patterns over the past decade. This approach enables a robust analysis of the association between urban environments and child health outcomes in Indian cities, where rapid urbanization and environmental challenges continue to shape public health trajectories.

## **2.2 Measures and exposure to urban greenness**

Urban greenness is quantified using the Normalized Difference Vegetation Index (NDVI), derived from high resolution satellite imagery (Landsat 7-9 Missions) from google earth engine for the period of 2009-2021. NDVI measures vegetation density based on the difference between near-infrared and red reflectance, ranging from  $-1$  (non-vegetated) to  $+1$  (dense vegetation). Higher NDVI values indicate greater surrounding greenery, including trees, gardens, and open spaces in both public and private areas. The exposure to urban greenery is based on the survey locations and for better understanding we have created 2km and 5km buffer zones.

## **2.3 Other explanatory variables**

Child nutrition and mortality in India are influenced by a range of socio-economic variables. To account for both proximate and distal factors, we control for Child Gender (Male, Female), Birth Order (First, Second, Third, Fourth or more), Mother's Age at Marriage, Institutional Delivery (No, Yes), Mother's Education (No Education, Primary, Secondary, Higher), Religion (Hindu, Muslim, Christian, Sikh, Others), Caste (No Caste, Scheduled Caste, Scheduled Tribe, Other Backward Caste), Wealth Quintile (Poorest, Poorer, Middle, Richer, Richest), Toilet Facility (Not Improved, Improved), and Water Source (Not Improved, Improved Source).

## **2.4 Heterogeneous effects and additional interaction variables**

To capture heterogeneity in the greenness–health relationship, additional variables describing the urban environment are included. These comprise air pollution ( $\text{PM}_{2.5}$   $\mu\text{g}/\text{m}^3$ ), temperature (mean land-surface temperature  $^{\circ}\text{C}$ ), and precipitation (annual rainfall mm). Interaction terms between NDVI and these indicators assess whether heat stress or pollution moderates the health benefits of urban greenness.

## **2.5 Statistical Methods**

All four outcome variables, i.e., stunting, wasting, underweight, and under-five mortality, are dichotomous. Thus, probit regression model is applied. The probit model uses the

cumulative distribution function of the normal distribution. The probit model used is specified as follows:

$$\Pr(Y=1 | \text{NDVI}_i, X_i) = \Phi(\beta_0 + \beta_1 \text{NDVI}_i + \beta_2 X_i)$$

where,  $\Phi$  is the standard cumulative normal distribution, NDVI is the Normalized Difference Vegetation Index, and  $X$  is the vector of other explanatory variables.

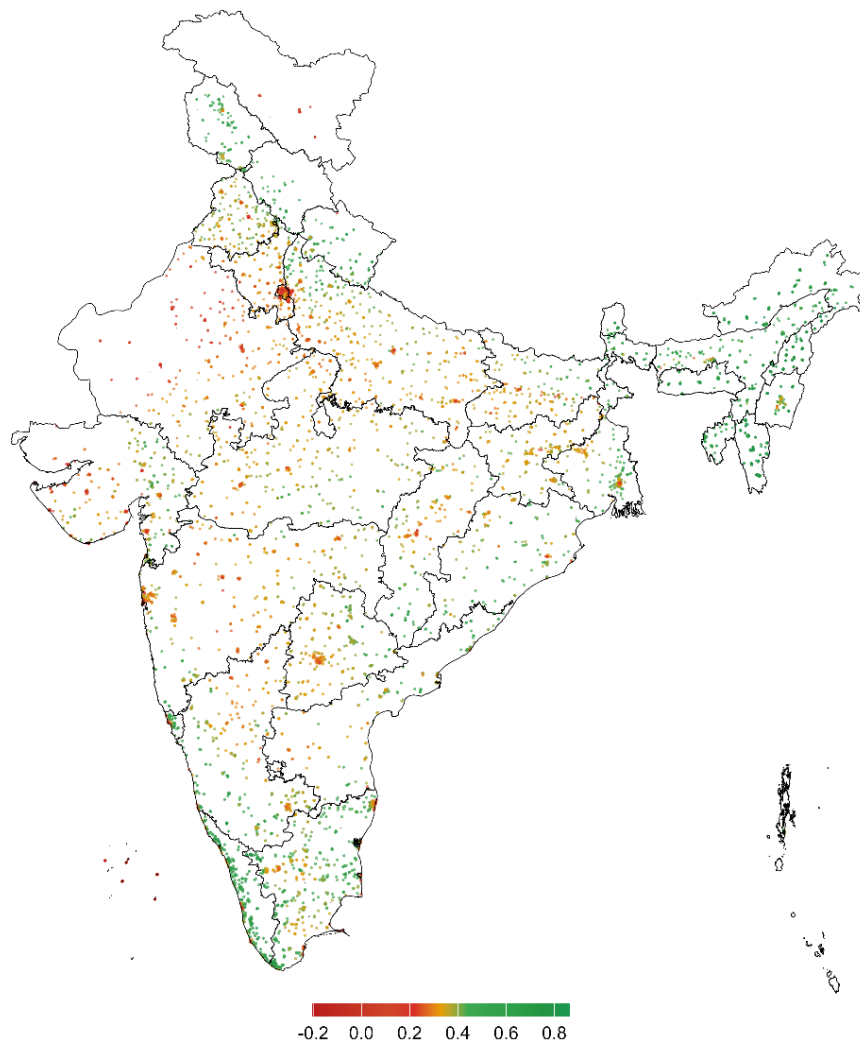
To account for possible non-linearity, a quadratic term of NDVI is included to identify threshold or saturation effects in the greenness–health relationship. Given potential endogeneity—since urban vegetation may correlate with unobserved socio-economic or planning factors—an instrumental-variable probit model is also estimated using natural geographic instruments such as elevation and slope. Further, interaction terms between NDVI and environmental stressors (temperature, rainfall, and  $\text{PM}_{2.5}$ ) assess whether heat or pollution moderates greenness benefits. Robustness is further tested using the Enhanced Vegetation Index (EVI), which refines dense canopy detection, though NDVI remains the principal measure for global comparability.

### 3 Results

#### 3.1 Spatial variation of urban greenness in India

Figure 4.1 shows the comparative levels of urban greenness in India from 2009 to 2021. The maps present the urban clusters of both NFHS-4 and NFHS-5. The map indicates that urban areas in the northern and north-eastern hilly regions, as well as northern and eastern states with hilly terrain, have high exposure to urban greenery. In the plains, states such as Punjab, West Bengal, Odisha, northern Uttar Pradesh, and northern Bihar also show relatively high green cover. In contrast, other plain regions of Uttar Pradesh and Bihar, along with the western, central, and south-central dry zones, have medium to low urban greenery exposure. The three southern states—Tamil Nadu, Kerala, and Karnataka—show comparatively higher green cover across most urban areas. Some urban centers in Gujarat, Telangana, coastal Andhra Pradesh, and the central region around the tri-junction of Madhya Pradesh, Chhattisgarh, and Maharashtra also display good exposure to greenery, while other parts of these regions have only low to moderate greenness. Notably, most large urban agglomerations show very low exposure to greenery. Overall, urban greenness in India remains heavily influenced by natural landscape and climatic conditions.

Figure 1 Level of urban greenness (NDVI) in survey clusters



### 3.2 Effect of urban greenness on child health and mortality

Results from the probit regression models (Table 1) reveal a strong and statistically significant association between urban greenness—measured by the Normalized Difference Vegetation Index (NDVI)—and child nutritional outcomes in urban India. Higher NDVI values are consistently linked to lower risks of stunting, wasting, and underweight, with the strongest effects observed for underweight. A one-unit increase in NDVI reduces the probability of stunting and wasting by about 10–12 percentage points and underweight by 20–21 points, with results remaining robust across both 2 km and 5 km buffer zones.

Similarly, Table 2 shows a significant inverse relationship between NDVI and under-five mortality. A one-unit increase in NDVI is associated with a 1.1–1.4 percentage-point decline in the probability of death before age five. Although household and individual characteristics largely drive early-age mortality, children in greener urban areas exhibit improved survival outcomes—likely reflecting better air quality, reduced heat exposure, and overall healthier environments that also reinforce nutritional gains.

Table 1 Probit regression models show the marginal effect of NDVI on child nutritional status

| Variables               | Stunting              |                       | Wasting               |                       | Underweight           |                       |
|-------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                         | (1)<br>2-km<br>buffer | (2)<br>5-km<br>buffer | (3)<br>2-km<br>buffer | (4)<br>5-km<br>buffer | (5)<br>2-km<br>buffer | (6)<br>5-km<br>buffer |
| NDVI                    | -0.127***<br>(0.013)  | -0.123***<br>(0.013)  | -0.097***<br>(0.011)  | -0.105***<br>(0.011)  | -0.198***<br>(0.012)  | -0.210***<br>(0.012)  |
| Other control variables | Yes                   | Yes                   | Yes                   | Yes                   | Yes                   | Yes                   |
| Observations            | 94010                 | 94010                 | 92540                 | 92540                 | 94695                 | 94695                 |
| $\chi^2$                | 3290.839***           | 3287.828***           | 536.921***            | 552.991***            | 3516.974***           | 3558.358***           |

Note: Robust standard errors in parentheses; Significance: \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Table 2 Probit regression models show the marginal effect of NDVI on under five child mortality in urban India

| Variables               | Under-five mortality |                    |
|-------------------------|----------------------|--------------------|
|                         | (1)<br>2-km buffer   | (2)<br>5-km buffer |
| NDVI                    | -0.014*** (0.005)    | -0.011** (0.005)   |
| Other control variables | Yes                  | Yes                |
| Observations            | 97238                | 97238              |
| $\chi^2$                | 625.805***           | 622.700***         |

Note: Robust standard errors in parentheses; Significance: \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

## 4 Robustness checks

### 4.1 Quadratic effect of urban greenness

Figure 2 depicts the quadratic relationship between urban green space and child health outcomes. The results suggest that higher NDVI values are generally associated with a lower likelihood of stunting, wasting, underweight, and under-five mortality, though the threshold at which this effect emerges varies across outcomes. For stunting, the association is monotonic: increases in NDVI at any level are linked to a reduced probability of stunting. In contrast, reductions in wasting are only observed once NDVI reaches approximately 0.3, corresponding to average to good vegetation cover. For underweight, the threshold is lower, at around 0.2. Finally, reductions in under-five mortality become evident only above an NDVI of about 0.4, indicative of moderately healthy vegetation cover.

### 4.2 Impact of urban greenness on severe malnutrition and infant mortality

Table 3, applies stricter criteria for the outcome variables: for nutritional indicators, only severe cases are considered, defined as a height-for-age, weight-for-height, or weight-for-age z-score below  $-3$  standard deviations (SD) from the WHO Child Growth Standards; for mortality, only deaths occurring before one year of age are included. The marginal effects show that a one-unit increase in NDVI reduces the probability of severe stunting by approximately 5 percentage points, severe wasting by about 3.6 percentage points, severe underweight by around 7.3 percentage points, and infant mortality by roughly 1.3 percentage points. These effects are highly consistent across both 2-km and 5-km buffers, underscoring the robustness of the protective influence of urban green space on infant mortality.

### 4.3 Probit instrumental variable (IV) regression results

The NDVI of the surrounding area can be influenced by factors at both individual and community levels. Higher-income households often choose—and are able to afford—to live near green spaces. Likewise, government planning priorities within a given area or city can enhance the availability of green spaces near households. To address these potential endogeneity concerns, an IV probit regression model is employed, with results presented in Table 4. In this specification, NDVI is instrumented using elevation, soil moisture, and terrain aspect. The results indicate that, across all buffer zones and outcome variables, instrumented NDVI exerts a significant effect on the dependent variable. Specifically, higher instrumented NDVI values are associated with reductions in the probability of stunting, wasting, underweight, and under-five mortality. Model validity is further supported by the Conditional Likelihood Ratio test, the Anderson–Rubin test, and the overidentification test, all of which confirm the robustness of both the models and the instruments.

Figure 2. Marginal effect of NDVI on Child Health Outcomes at different level of NDVI

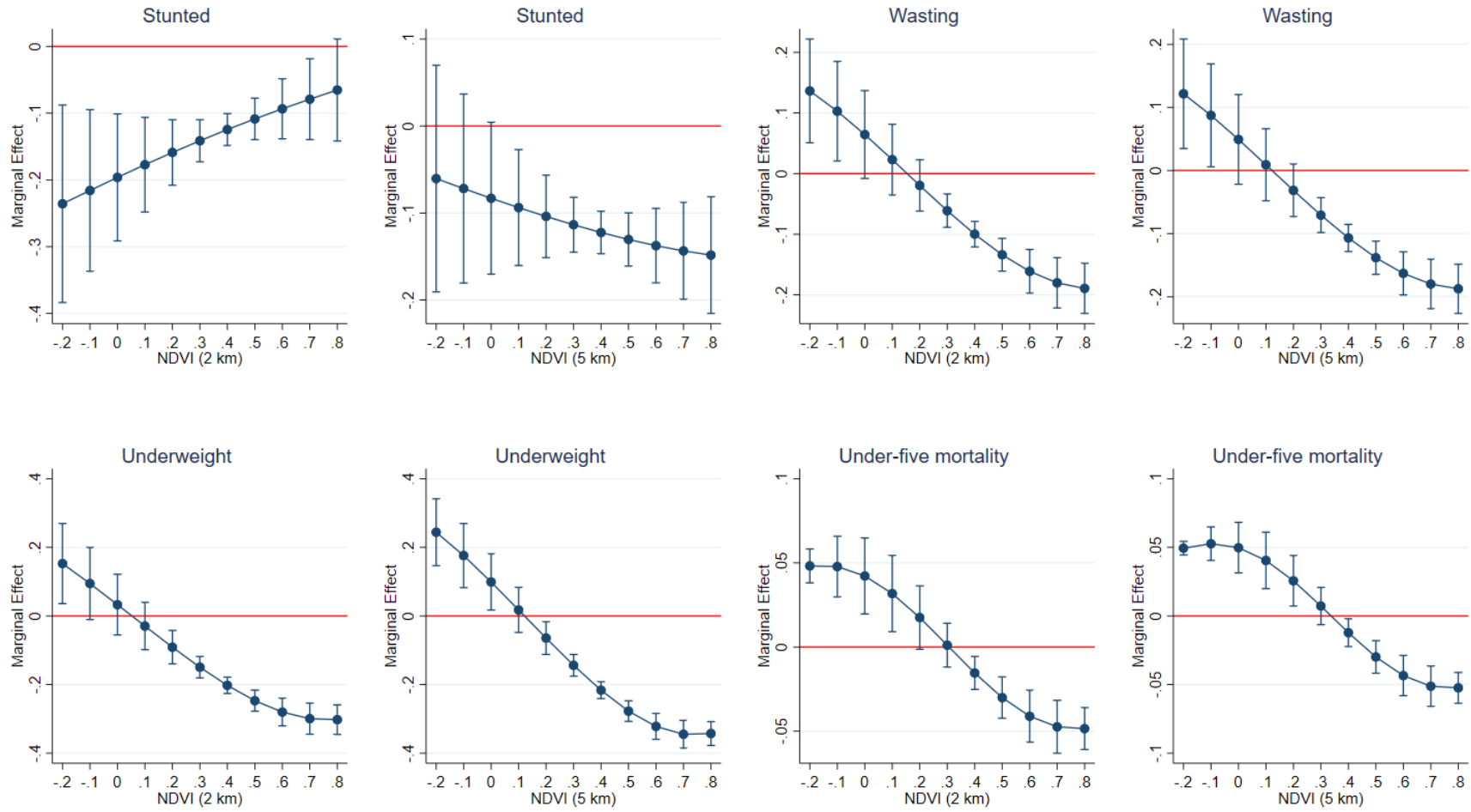


Table 3. Probit regression models show the marginal effect of NDVI on severe child nutrition and infant mortality in urban India

| Variables               | Severe Stunting      |                      | Severe Wasting       |                      | Severe Underweight   |                      | Infant mortality     |                      |
|-------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|                         | (1)                  | (2)                  | (3)                  | (4)                  | (5)                  | (6)                  | (7)                  | (8)                  |
|                         | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          |
| NDVI                    | -0.055***<br>(0.009) | -0.049***<br>(0.009) | -0.037***<br>(0.007) | -0.035***<br>(0.007) | -0.074***<br>(0.008) | -0.072***<br>(0.008) | -0.014***<br>(0.004) | -0.012***<br>(0.004) |
| Other control variables | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| Observations            | 94010                | 94010                | 92540                | 92540                | 94695                | 94695                | 97238                | 97238                |
| $\chi^2$                | 1837.977***          | 1832.348***          | 178.844***           | 177.250***           | 1335.593***          | 1334.687***          | 508.350***           | 505.709***           |

Note: Robust standard errors in parentheses; Significance: \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Table 4. IV Probit regression models show the effect of NDVI on child nutritional status and mortality in Urban India

| Variables               | Stunting             |                      | Wasting              |                      | Underweight          |                      | Under-five mortality |                      |
|-------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|                         | (1)                  | (2)                  | (3)                  | (4)                  | (5)                  | (6)                  | (7)                  | (8)                  |
|                         | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          |
| NDVI                    | -0.647***<br>(0.079) | -0.713***<br>(0.086) | -0.246***<br>(0.078) | -0.223***<br>(0.070) | -0.625***<br>(0.073) | -0.637***<br>(0.075) | -0.872***<br>(0.158) | -0.951***<br>(0.171) |
| Other control variables | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| Observations            | 93994                | 93994                | 92527                | 92527                | 94679                | 94679                | 97222                | 97222                |
| $\chi^2$                | 3257.571***          | 3258.332***          | 465.873***           | 466.904***           | 3345.987***          | 3347.521***          | 607.747***           | 607.877***           |
| CLR test                | 69.11***             | 71.39***             | 10.14***             | 10.74***             | 77.19***             | 76.72***             | 31.25***             | 31.83***             |
| AR test                 | 71.57***             | 71.47***             | 10.16***             | 11.40***             | 77.53***             | 77.37***             | 31.47***             | 31.92***             |
| Overidentification test | 2.46                 | 0.08                 | 0.03                 | 0.66                 | 0.34                 | 0.65                 | 0.23                 | 0.09                 |

Note: Values reported are coefficients; Robust standard errors in parentheses; Significance: \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; NDVI is instrumented with Elevation, Terrain aspect and Soil moisture.

#### 4.4 Heterogeneous effect of urban greenness in various environments

Figures 3, 4, and 5 illustrate how the effects of greenness on child health outcomes vary depending on environmental conditions. The results show that the protective role of greenness is not uniform but highly sensitive to temperature, precipitation, and air pollution. In Figure 3, greenness reduces the probability of stunting at moderate levels of temperatures, but this benefit weakens under extreme heat. At very low temperatures in the 2 km buffer, and at both low and high temperatures in the 5 km buffer, the effect on stunting is negligible. Greenness also reduces the likelihood of being underweight, particularly when temperatures remain below 30°C, but the effect diminishes at higher temperatures. By contrast, the interaction with wasting is largely statistically insignificant across the temperature range. For under-five mortality, greenness is protective at very low temperatures, but this advantage steadily declines as temperatures rise, suggesting that extreme heat weakens the capacity of vegetation to buffer households against adverse health risks.

In Figure 4 greenness lowers the risk of stunting, wasting and underweight across most rainfall levels, highlighting its consistent nutritional benefits. However, at very high precipitation (around 3,000 mm per year), the effect on stunting disappears, likely reflecting the ecological stress of excessive rainfall on vegetation or the increased vulnerability of households in flood-prone areas. For under-five mortality, estimates of the impact of greenness are insignificant across the precipitation range.

Finally, the interaction with air pollution (Figure 5) shows that greenness consistently reduces stunting across the full range of PM<sub>2.5</sub> exposure. The effects on wasting and underweight are significant only when PM<sub>2.5</sub> levels remain below 90 µg/m<sup>3</sup>. Similarly, the protective effect of greenness on under-five mortality is strongest at low PM<sub>2.5</sub> levels but diminishes substantially as exposure increases, disappearing at the upper tail of the distribution. Taken together, these findings suggest that greenness delivers its largest health benefits in environmental conditions that are themselves favorable to vegetation—namely moderate temperatures, adequate rainfall, and lower levels of air pollution.

Figure 3 Marginal effect of NDVI on child health in different temperatures

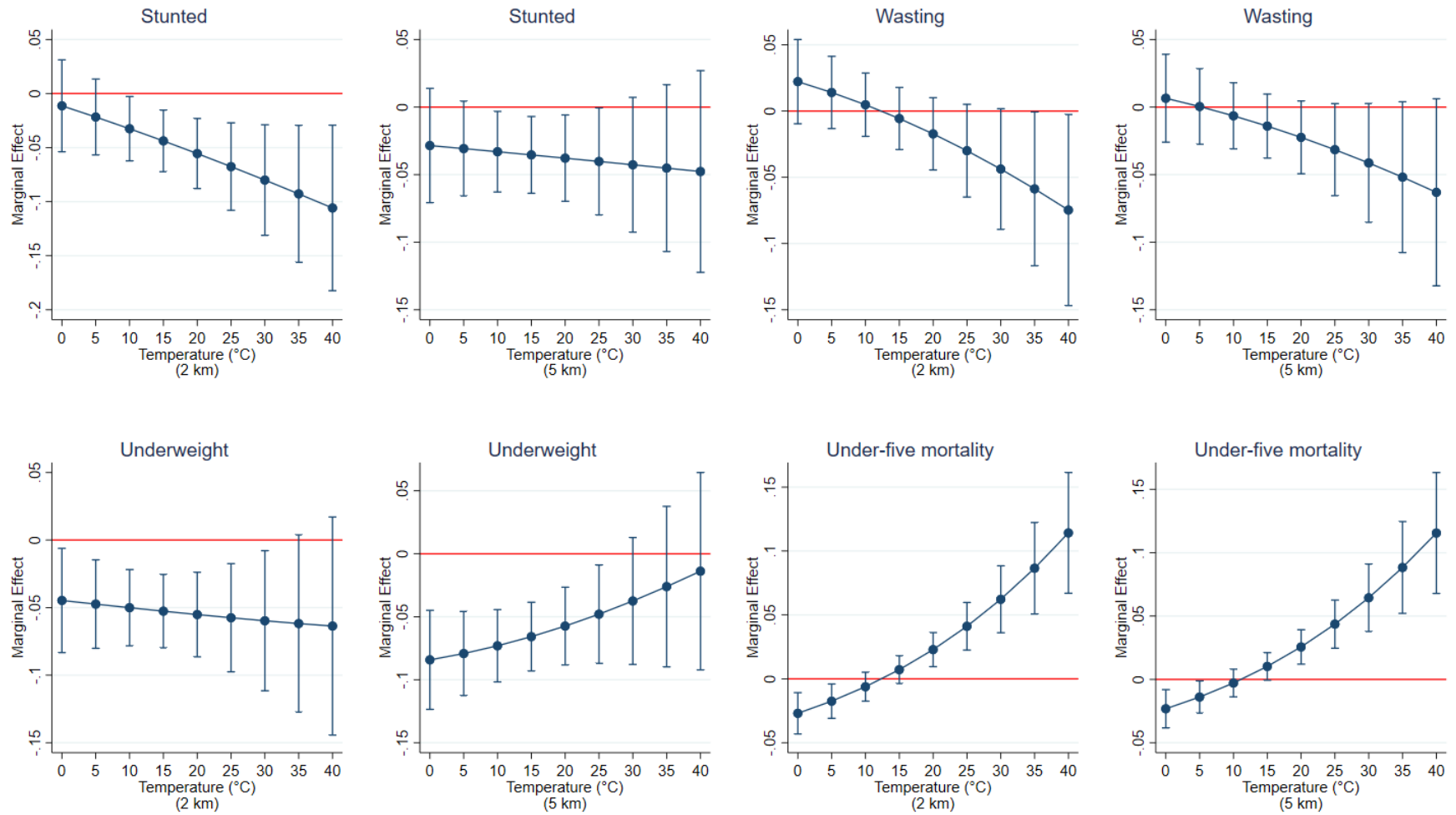


Figure 4 Marginal effect of NDVI on child health in different precipitation level

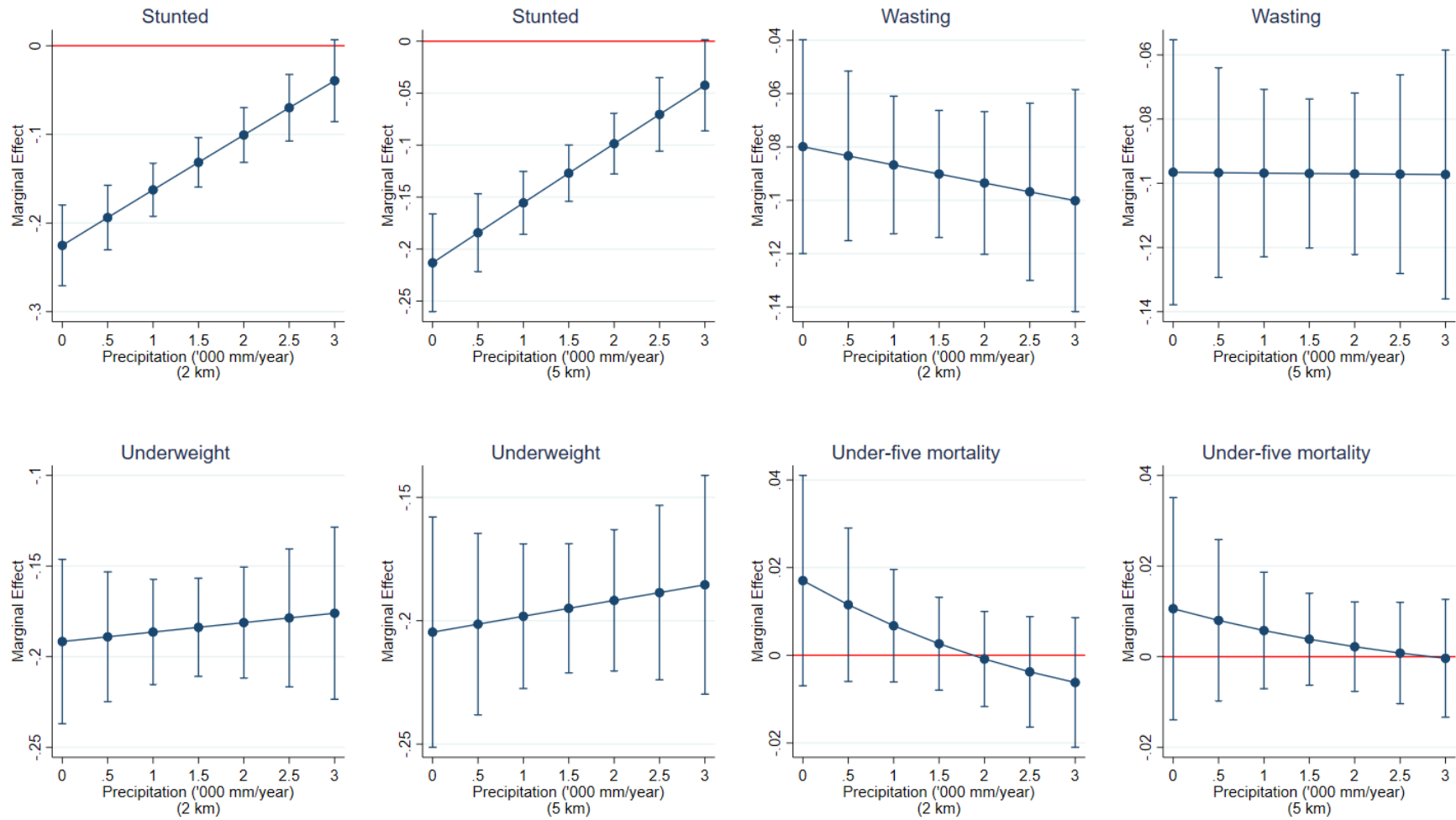


Figure 5 Marginal effect of NDVI on child health in different PM2.5 level

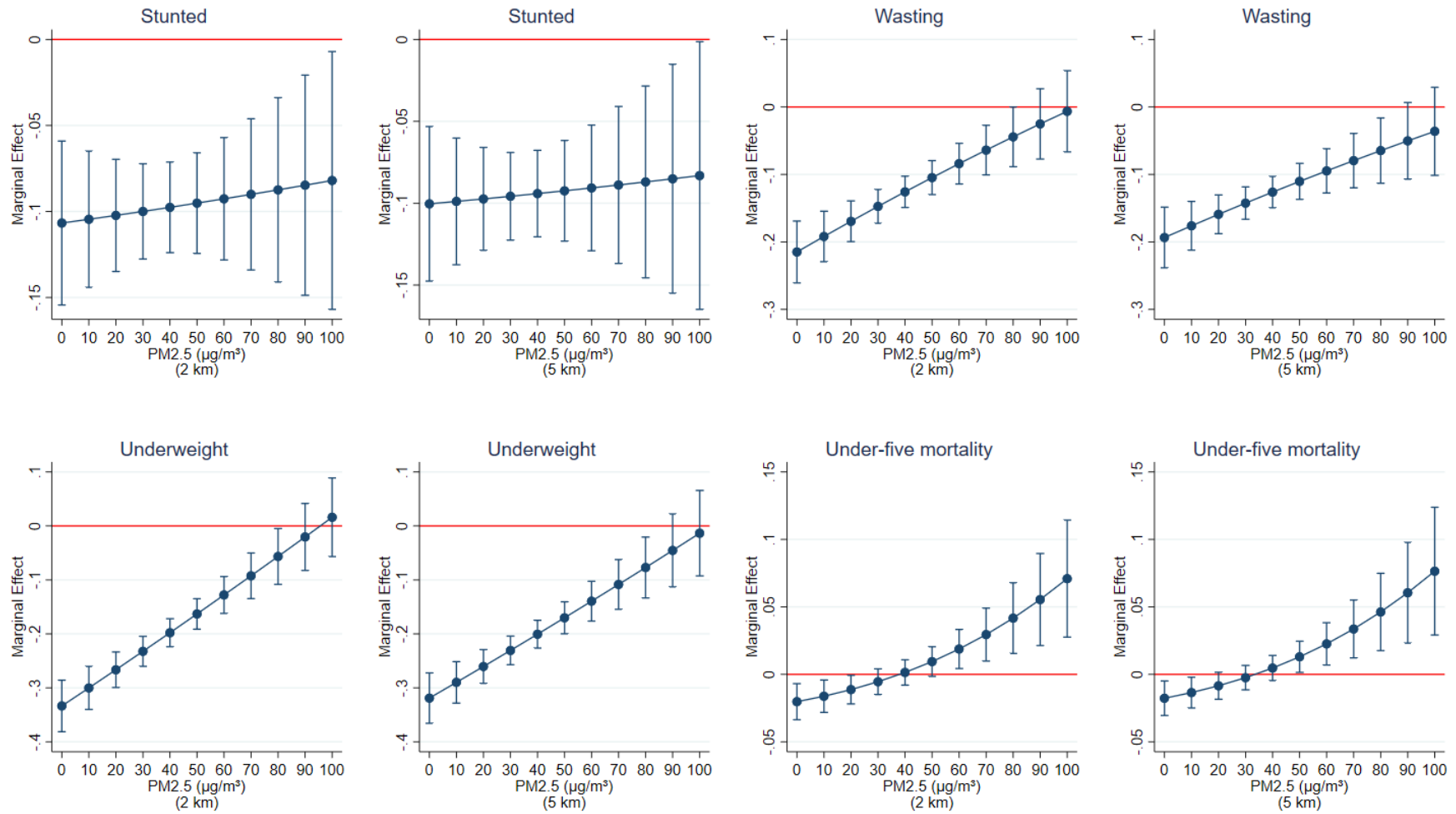


Table 5 Probit regression models show the effect of EVI as an alternative greenness measure on child nutritional status and mortality in Urban India

| Variables               | Stunting             |                      | Wasting              |                      | Underweight          |                      | Under-five mortality |                    |
|-------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|--------------------|
|                         | (1)                  | (2)                  | (3)                  | (4)                  | (5)                  | (6)                  | (7)                  | (8)                |
| Panel A                 | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer        |
| EVI                     | -0.198***<br>(0.021) | -0.195***<br>(0.022) | -0.182***<br>(0.018) | -0.207***<br>(0.019) | -0.334***<br>(0.020) | -0.368***<br>(0.021) | -0.015*<br>(0.008)   | -0.012<br>(0.008)  |
| Other control variables | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                |
| Observations            | 94010                | 94010                | 92540                | 92540                | 94695                | 94695                | 97238                | 97238              |
| $\chi^2$                | 3276.440***          | 3273.375***          | 552.750***           | 578.433***           | 3510.048***          | 3555.977***          | 619.668***           | 617.932***         |
| Panel B                 | Severe Stunting      |                      | Severe Wasting       |                      | Severe Underweight   |                      | Infant mortality     |                    |
|                         | (1)                  | (2)                  | (3)                  | (4)                  | (5)                  | (6)                  | (7)                  | (8)                |
|                         | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer          | 2-km buffer          | 5-km buffer        |
| EVI                     | -0.080***<br>(0.015) | -0.072***<br>(0.015) | -0.071***<br>(0.012) | -0.073***<br>(0.012) | -0.122***<br>(0.013) | -0.123***<br>(0.013) | -0.015**<br>(0.007)  | -0.013*<br>(0.008) |
| Other control variables | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                |
| Observations            | 94010                | 94010                | 92540                | 92540                | 94695                | 94695                | 97238                | 97238              |
| $\chi^2$                | 1830.317***          | 1825.725***          | 185.162***           | 187.235***           | 1325.803***          | 1329.321***          | 502.189***           | 500.649***         |

Note: Robust standard errors in parentheses; Significance: \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01

#### 4.5 Robustness check using alternate measure of greenness

NDVI, while widely used, is sensitive to dense vegetation, aerosols, and atmospheric scattering, which can generate mixed pixels from different land uses. By contrast, the Enhanced Vegetation Index (EVI) is less sensitive to these limitations and incorporates atmospheric adjustments to more accurately capture vegetation greenness. To assess the robustness of the baseline findings, EVI is employed as an alternative vegetation measure, with results reported in [Table 5](#).

Panel A of [Table 5](#) shows that improvements in vegetation greenness, as measured by EVI, are consistently associated with significant reductions in child malnutrition across all indicators. A one-unit increase in EVI reduces the probability of stunting by 19.8 and 19.5 percentage points in the 2 km and 5 km buffers, respectively. For wasting, the corresponding reductions are 18.2 and 20.7 percentage points, while for underweight the effects are larger—33.4 and 36.8 percentage points, respectively. In the case of under-five mortality, EVI lowers mortality by 1.5 percentage points in the 2 km buffer, although the reduction of 1.2 percentage points in the 5 km buffer is not statistically significant. These magnitudes are economically meaningful, highlighting the substantial role of local vegetation in reducing child nutritional deprivations.

Panel B of [Table 5](#) extends the analysis to severe forms of malnutrition and infant mortality. Increases in EVI significantly reduce severe stunting (by 8.0 and 7.2 percentage points in the 2 km and 5 km buffers, respectively), severe wasting (7.1 and 7.3 percentage points), and severe underweight (12.2 and 12.3 percentage points). EVI is also negatively associated with infant mortality, reducing the probability by 1.5 and 1.3 percentage points in the 2 km and 5 km buffers, respectively. These findings demonstrate that the protective role of greenness is robust to alternative measures of vegetation and in line with previous results.

## 5 Discussion

The study is the first of its kind to analyze the impact of urban greenness on child health in Indian urban areas. It finds a strong correlation between urban greenness and child health outcomes, suggesting that increased greenness can help prevent child malnutrition and mortality. The study makes three key contributions: first, it addresses child health and mortality in urban areas and evaluates urban greenness as a potential mitigation strategy; second, it measures greenness exposure more precisely using cluster locations; and third, it examines the heterogeneity in the impact of urban greenness across environmental variables and severity levels of child health outcomes.

The study considers two dimensions of child development: malnutrition and mortality. Although there is a substantial rural–urban gap in under-five malnutrition and mortality, significant spatial variation exists within urban areas across the country. This variation is also reflected in socio-economic parameters, and urban greenness itself exhibits a heterogeneous pattern in India. The study finds a positive impact of urban greenness on child health regardless of socio-economic conditions. Across all three indicators of child malnutrition—stunting, wasting, and underweight—urban greenness demonstrates a beneficial effect. While exposure to urban greenery positively influences all three nutritional parameters, its impact is slightly stronger for underweight. Previous studies also show that exposure to urban green cover increases birthweight irrespective of economic conditions, which is directly linked to reduced underweight prevalence among children under-five ([Dzhambov et al., 2014](#); [Ebisu et al., 2016](#)). Although exposure to urban greenness is often associated with higher socio-economic households, this study, along with others, shows that its benefits for child health are

independent of social or economic status (Dzhambov et al., 2014). Exposure to green cover such as playground, parks and natural vegetation cover improve children’s balance and motor coordination of children (Fjørtoft, 2004), increase physical activity for children (Lovasi et al., 2011), enhance sleep quality (Söderström et al., 2013), support healthy BMI (Koebe, 2025) and promote overall health & well-being (Feng & Astell-Burt, 2017). These factors collectively contribute to improved nutritional status. In cases of severe malnutrition, the results align with previous findings. Under-five and infant mortality also show a negative association with urban green cover. Although the impact of greenness on child mortality is slightly lower than its effect on nutritional outcomes, there is still a strong association between increasing urban greenness and reduced child mortality, consistent with global studies (Schinasi et al., 2019; Zhang et al., 2024).

The improvements in child nutrition are not uniform across all levels of greenness or NDVI. Beneficial effects require a minimum level of greenness. The results show that for wasting and underweight, positive impacts occur only when NDVI reaches 0.2 or higher within 2 km and 5 km of cluster locations (Figure 2), representing moderate to high greenness (Earth Resources Observation & Science (EROS) Center, 2018). For stunting, the relationship is more linear, but significant differences emerge only after NDVI exceeds 0.2. Under-five mortality similarly improves only after this NDVI threshold. These patterns are consistent for severe malnutrition and infant mortality, indicating that a minimum level of greenness is necessary to affect child health outcomes.

Previous research indicates that increasing urban greenness can mitigate urban heat island effects and reduce air pollution levels (Li et al., 2025; Schwaab et al., 2021; Wong et al., 2021). This study shows that high temperature and PM2.5 levels can hinder the beneficial effects of urban greenness on child health. Temperature and greenness exhibit a dual relationship: extreme temperatures are generally associated with low vegetation cover, although increased urban greenery—through artificial irrigation or other sustainable methods—can lower temperatures by regulating the urban microclimate. Similarly, urban greenery can reduce PM2.5 levels (Cardinali et al., 2024; Chaudhuri & Kumar, 2022; Diener & Mudu, 2021), which in turn decreases child malnutrition and mortality. Precipitation, which has a unidirectional positive effect on vegetation, also benefits child health through increased urban greenness. When these conditions deteriorate, the protective impact of greenness on child health is weakened. Thus, although heterogeneity exists in the role of greenness in reducing malnutrition and mortality, this variability can be managed. Importantly, however, urban greening has the potential to simultaneously mitigate both local heat and air pollution, which implies that investments in green infrastructure can reinforce multiple protective pathways, amplifying its long-run role in improving child health outcomes. Urban greenery offers a practical solution to mitigate the adverse effects of high temperatures and air pollution, serving a protective role in child health (Nowak et al., 2006; Ramyar et al., 2021; Zhou et al., 2023).

## 6 Conclusion

The findings highlight the significant role of urban greenness in improving child health outcomes in urban India. Higher NDVI values are consistently associated with lower risks of stunting, wasting, underweight, and under-five mortality, with effects persisting across different buffer zones and after accounting for key socioeconomic and demographic factors. However, the relationship between NDVI and child health is nonlinear, as only after certain level of greenness increasing NDVI provides benefits. Moreover, environmental factors such as temperature, precipitation, and air pollution interact with NDVI, sometimes diminishing its positive effects. These results underscore the potential of

urban greening initiatives in mitigating child malnutrition and mortality risks and highlighting the need to consider the green in urban health, pollution and climate change policies.

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