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Abstract

Background Inconsistencies were found between residential greenness and the risk of gestational diabetes mellitus

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Background

Gestational diabetes mellitus (GDM), characterized by

during pregnancy ($n=1146$), maternal age at delivery younger than 15 or older than 50 years ($n=12$), gesta

plan, including Urban Employee Basic Medical Insurance (UEBMI), Urban-Rural Resident Basic Medical Insurance (URRBMI), New Rural Cooperative Medical Scheme (NRCMS), commercial insurance, or other social insurance programs) or no (fully self-paid). Other covariates included parity (nulliparous, multiparous), body mass

first two trimesters of pregnancy. There are strong positive correlations among NDVI-500 m and NDVI-1000 m with an estimate of 0.89 ($P < 0.001$). Strong positive correlations were also observed among air pollutants, particularly between $PM_{2.5}$ and PM_{10} ($r = 0.88$), CO ($r = 0.76$), and NO_2 ($r =$

during the 1st trimester (aOR=1.27, 95%CI: 1.09, 1.48) (Table S2).

No non-linear association was observed between residential greenness exposure and the risk of GDM across different gestational windows. The exposure-response (E-R) curves were approximately linear and tended to flatten at higher levels of residential greenness (Fig. 1). Exposure to PM_{2.5} during the 1st trimester also showed no non-linearity with GDM risks (*P* for non-linearity > 0.05) (Figure S5).

We detected the profound effect modification by socioeconomic factors in stratified analyses. During the first two trimesters, the association between NDVI-500 m and reduced GDM risk was more pronounced among unemployed women (aOR=0.70, 95%CI: 0.60, 0.82) than among those who were employed as workers and farmers (aOR=0.98, 95%CI: 0.90, 1.06). This association was also stronger among women with lower education levels, with aORs (95% CI) of 0.72 (0.63, 0.82) for middle school education or below, 0.83 (0.72, 0.97) for high school education, and 0.99 (0.91, 1.07) for college education or above. Similarly, women without health insurance showed a stronger negative association (aOR=0.76, 95% CI: 0.69, 0.84) compared to those with health insurance (aOR=1.01, 95% CI: 0.94, 1.10) (Table 3). Consistent trends were identified in NDVI-1000 m (Table 4). Although only a marginally significant effect modifica-

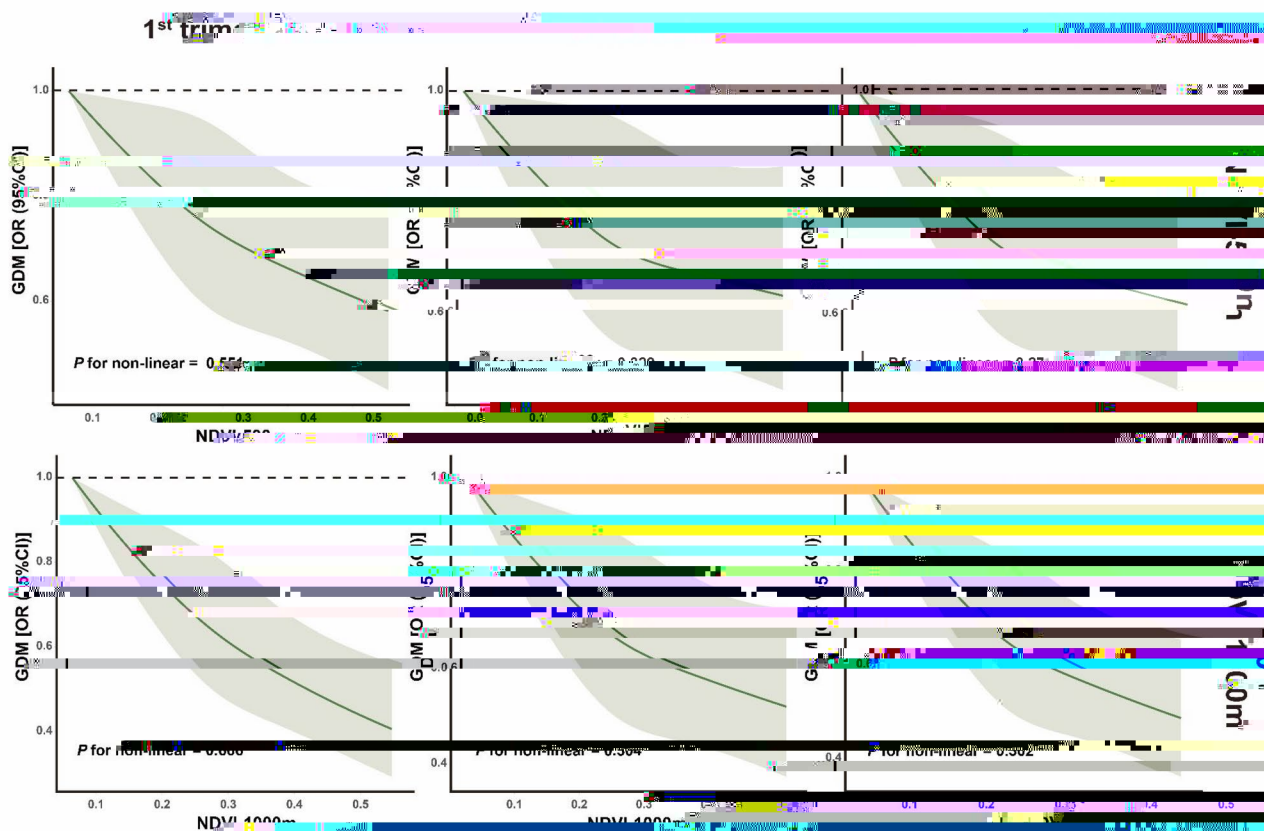


Fig. 1 Exposure-response curves for the association of NDVI-based residential greenness during the first two trimesters of pregnancy with odds of GDM. GDM, gestational diabetes mellitus; OR, the odds ratio; NDVI, normalized difference vegetation index. All models were adjusted for maternal age at delivery, BMI at an early stage of pregnancy, occupation, educational level, health insurance status, parity, year of conception, season of conception, infant sex, ambient temperature, and humidity

in both the 500 m and 1000 m buffers (Table S6). During both the preconception and extended periconceptional periods, residential greenness was consistently associated with a reduced risk of GDM, whereas PM_{2.5} exposure was not significantly associated with GDM during either period (Tables S7-S8). Additional air pollutants (PM₁₀, NO₂, and CO) exhibited generally similar associations with GDM as PM_{2.5} across various exposure windows (Table S9). Notably, NO₂ and CO also demonstrated significant mediating effects on the association between residential greenness and GDM, particularly during early pregnancy (Table S10). After further adjustment for these air pollutants, the protective association between residential greenness exposure and GDM remained robust (Table S11).

Discussion

In this multicenter study in Shanghai, we identified a notable inverse association between residential greenness and GDM risk. Furthermore, our analysis revealed that the protective effect of urban greenness on the risk of GDM was particularly pronounced among

socioeconomically disadvantaged women, highlighting the amplified benefits of green spaces for these vulnerable populations. Additionally, we found that the reduction in PM_{2.5} levels mediates 16.4% of the negative association between NDVI-500 m during the 1st trimester of gestation and GDM, suggesting one potential pathway through which greenness may exert its protective effect.

Recently, the influence of greenness on GDM has increasingly garnered attention, but the results remain inconclusive. In line with our findings, three previous studies in China suggest that greenness may protect against GDM [15, 17, 21]. For example, a multicenter study with 5237 pregnant women from Guangdong Province, China, identified that interquartile increases in NDVI within 250 m, 500 m, and 1000 m buffers were associated with decreases in GDM risk by 13%, 8% and 3% [15]. However, some other studies, mainly conducted in the U.S. and Europe, have reported null results [18–20]. Young et al. estimated the total square kilometers of recreational green spaces roughly using residential ZIP codes and reported no significant association with

GDM [20]. Among 61,640 women in the U.S., Choe et

The distinct exposure-outcome patterns observed for residential greenness and $PM_{2.5}$ may reflect their different mechanisms and timeframes of impact on GDM risk. Regarding $PM_{2.5}$, its association with GDM was limited to the first trimester, suggesting that early pregnancy represents a critical window of vulnerability. This finding is consistent with many previous studies [33–35], which

greenness on GDM. However, their specific mechanisms remain unclear and require further elucidation.

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Data availability

The dataset generated and/or analyzed in the current study are not publicly available but can be obtained from the corresponding author on a reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the principles outlined in the Declaration of Helsinki and received ethical approval from the Institutional Review Boards of the Xinhua Hospital Center affiliated to Shanghai Jiao Tong University School of Medicine (XHEC-C-2016-095). Written informed consent was obtained from the participants in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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