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Impact of the residential green space environment on the prevalence and mortality of Type 2 diabetes mellitus

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Abstract. – OBJECTIVE: The residential green space environment plays a significant role in the progression of social, neuropsychological, behavioral, and public health. Green spaces are considered one of the most important components of healthy life events. This study investigated the impact of the green space environment on the prevalence and mortality of type 2 diabetes mellitus.

MATERIALS AND METHODS: In this study, 110 research articles were initially identified through search engines (Web of Science, PubMed, Medline, EMBASE, Scopus) using the keywords "green space, environment, prevalence, mortality, diabetes mellitus." Finally, out of 110, 16 (14.54%) original research publications were included in the analysis, and the remaining 94 (85.45%) articles were excluded. The sample size of these 16 studies was 4,615,359. These studies originated from China (4), Canada (3), the United States of America (2), Australia (2), and one study each from the United Kingdom, Hong Kong, Korea, Belgium, and Bangladesh. The data on prevalence and diabetes mellitus were recorded and analyzed.

RESULTS: Worldwide total of 16 studies met the selection criteria. The results showed that a high green space environment was significantly associated with a decreased prevalence of diabetes mellitus (13 studies; OR=0.875, 95% CI=0.859-0.891; $p<0.001$; $I^2=61.0\%$) and mortality (3 studies; HR=0.917, 95% CI=0.904-0.930; $p<0.001$; $I^2=75.4\%$). The findings support the hypothesis that a green space environment significantly reduces the prevalence and mortality of diabetes mellitus.

CONCLUSIONS: The residential green space environment significantly decreases the prevalence and mortality of type 2 diabetes mellitus. It is suggested to establish strategies to keep residential areas and living environment green and clean to minimize air pollution and fight diabetes mellitus.

Key Words:

Green space, Environment, Prevalence, Diabetes mellitus.

Introduction

The interaction between humans and their surroundings has a significant role in the social, behavioral, and psychological developments and the pattern of health and diseases[1]. The swift unplanned urbanization and industrialization have disturbed normal environmental proportions worldwide[2]. Environment and pollution are increasing international public health issues and causing 4.2 million deaths per year[3]. Environmental factors play a significant role in health, diseases, surveillance, and prevention[4]. The literature[5] highlights the relationship between environment, weather conditions, and metabolic disorders, including diabetes mellitus[5].

Diabetes mellitus (DM) has become a significant health issue in the 21st century. The most recent data demonstrates that 537 million people in 2021 had DM, which is estimated to increase to 643 million by 2030. DM caused 6.7 million deaths and 966 billion US dollars in health expenditures in 2021[6].

The etiopathology of DM has markedly changed over the recent years; the rapid growth in population and urbanization have resulted in an air polluted environment and minimized healthy and sustainable living environments[7]. The swift growth of industrialization has limited access to nature and increased exposure to air pollution. The green space environment mitigates air pollution and environmental hazards. Moreover, it provides healthy lifestyles, improves residents' wellbeing, and offers disease prevention[8,9]. Plants, parks, playgrounds, or vegetation in public and

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private spaces can give the residents healthy climate conditions and natural opportunities.

Worldwide, environmental pollution has become a leading cause of diseases and pandemics[10]. The rapid growth in population, urbanization, and industrialization reduces the green space areas and increases environmental pollution on the planet[11]. The literature highlights the various etiopathological linkages with diabetes mellitus, but it lacks establishing mechanisms and their association with green space environment and diabetes mellitus. This study investigates the impact of a green space environment on the prevalence and mortality of diabetes mellitus.

Materials and Methods

The current study explores the impact of the green space environment on the prevalence and mortality of type 2 diabetes mellitus. This study searched the literature with related keywords: green space, environment, diabetes mellitus, incidence, prevalence, and mortality in global databases. Based on the keywords, initially, 110 articles were found from various databases, including Web of Science, Pub-Med, Medline, EMBASE, and Scopus. During the search process, publications were selected without language restrictions. The studies that achieved the selection criteria were thoroughly examined. Finally, out of 110, 16 (14.54) original research publications were included in the analysis, while 94 (85.45%) articles were excluded. The sample size of these 16 studies was 4,615,359. These studies originated from China (4), Canada (3), the United States of America (2), Australia (2), and one study each from the United Kingdom, Hong Kong, Korea, Belgium, and Bangladesh. The data on prevalence and diabetes mellitus were recorded and analyzed based on perspectives, cross-sectional, cohort, and longitudinal community-based studies. They explored possible relations between the green space environment and its impact on the risk to develop diabetes mellitus and prevalence and mortality.

Suitability of the Articles

The data based on the sample size, green space outcome, prevalence, mortality, and risk estimates were investigated and analyzed. The appropriateness of articles was scrutinized and analyzed by the title and abstract of the study. Once eligible studies had been shortlisted, relevant findings were extracted by an investigator and verified by another investigator.

Inclusion and Exclusion Criteria

For this study, the criteria for selecting the studies were highly standardized. The studies had to: be published in peer-reviewed, PubMed and Web of Science indexed journals; be based on a human model; be original research; include cross-sectional, case-control, cohort, observational studies that investigate the impact of the green space environment on the prevalence and mortality of diabetes mellitus. However, studies published in not indexed journals in 'Pub-Med' and 'Web of Science' were excluded. Moreover, non-original research, review, editorial, and case reports were excluded. Furthermore, preprint papers indexed in Medline (MedRxiv) were excluded, as the literature was not peer-reviewed and unpublished. The study title, abstract, and detailed article information were evaluated and included. All the selected 16 original articles were carefully examined. The required data were recorded, including the authors' name, publication year, location, sample size, study outcomes, incidence, mortality, and 95% CI.

Statistical Analysis

The STATA software package was used to analyze the data. All results are shown as forest plots with 95% confidence intervals. To quantify the degree of heterogeneity between studies, the I^2 statistic was calculated. The analysis used a random-effects model, which is thought to be a more conservative approach suitable for cases of high heterogeneity. A p-value ≤ 0.05 was considered significant.

Results

Based on the primary keywords and studies published up to February 2022, we identified 110 articles in the different web engines, and finally, 16 studies were included. These studies originated from China (4), Canada (3), the United States of America (2), Australia (2), and one study each from the United Kingdom, Hong Kong, Korea, Belgium, and Bangladesh. The studies assessed and displayed the "impact of the green space environment on the prevalence and mortality of diabetes mellitus" worldwide. The data on prevalence and mortality of diabetes mellitus were recorded and analyzed. The data on the prevalence (Table I, Figure 1) and mortality (Table II,

Table I. Impact of Green space Environment on the prevalence of diabetes mellitus.

Authors, & country	Type of study	Sample size	Diabetes mellitus prevalence & confidence interval	Residing in green space and its outcomes
Lee et al[13] Republic of Korea	Cross-sectional	16,178 47 years	OR = 0.86 (0.75-0.99)	People live in areas with parks have a low risk of diabetes
Frank et al[15] Canada	Cohort studies	22,418 and 11,972	OR = 0.63 95 % CI: 0.47 0.84)	Park availability was linked with low diabetes prevalence.
Doubleday et al[16] USA	Prospective cohort study	6,814	21% less risk of DM per IQR rise in green space HR: 0.79 95%, CI 0.63-0.99	Green space provides protective impact on the development of diabetes.
Khan et al[17] Bangladesh	National Survey, Cohort study	2,367 aged ≥ 35 years	Greenness is associated with low odds of diabetes. 0.805 95%, CI 0.693-0.935	Greenness is adjacent to living areas associated with lower diabetes prevalence.
Li et al[18] China	Population-based cohort study	39,019	Green space causes a low risk of T2DM: 13.4% OR 0.866 95% CI: 0.830-0.903	Green space was beneficially associated with T2DM and fasting blood glucose levels.
Qu et al[19] China		5,237 pregnant mothers	Increase one IQR NDVI 1000m related to 3% low risks for GDM RR=0.97 95% CI 0.97-0.97	GDM risk was decreased with greater NDVI. Greenness provides effective intervention to reduce GDM.
Yang et al[21] China	Cross-sectional	15,477 adults	Green space is linked to low odds of DM 0.88 (95% CI 0.82-0.94)	igher residential greenness Hassociated with low prevalence of DM
Lee et al[22] USA	Longitudinal study	4,010	0.70 CI: 0.41-1.19	Green space has a relation to low BMI, fasting glucose, obesity, and diabetes
Clark et al[23] Canada	Cohort	380,378 45 to 85 years	Adjusted odds ratio = 0.90 CI (0.87-0.92)	Green spaces have a protective impact against T2DM.
Dalton et al[25] United Kingdom	Cohort study	23,865 Age 59 years	HR 0.81 95% CI 0.67, 0.99.	Living in the greenest areas had a 19% lower risk of diabetes
Fan et al[28] China	Cross-sectional study	4,670	Greenness associated with low diabetes prevalence OR 0.92 95% CI 0.86, 0.99	The prevalence of DM was 11.6%. Rural areas with high greenness are linked to low DM
Astell-Burt et al[29] Australia	Cohort study	267,072	OR 0.87 95% CI 0.83-0.92	T2DM was 9.1% with 0-20% green space dropped to 8% with 40% green area
Paquet et al[30] Australia	Cohort study	3,205 More than 8 years	People who have access to green spaces have a relatively low risk of DM = 0.75 (0.69-0.83)	Pre-diabetes & diabetes were lower among people who live in open green space areas with walkability.

Abbreviations: Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI); Odds Ratio (OR); Confidence Interval (CI); Type 2 Diabetes Mellitus (T2DM); Interquartile range (IQR); Hazards ratio (HR); Adjusted odds ratio (AOR); Relative risk (RR).

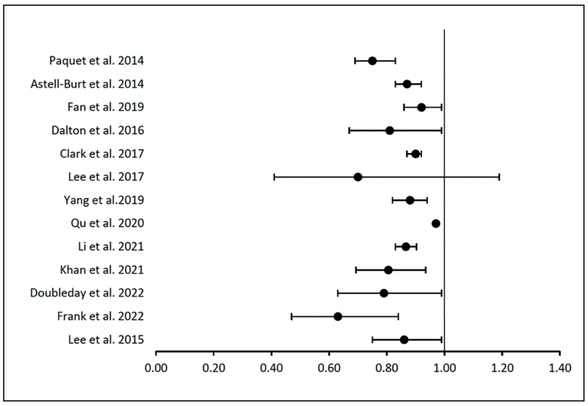

Figure 1. Forest plot showing the impact of the green space environment on the prevalence of diabetes mellitus.

Figure 2) due to diabetes mellitus were recorded and analyzed. Table III demonstrates the pooling aggregate data on the impact of the green space environment on prevalence, and Table IV shows mortality rates due to diabetes mellitus using the common effect inverse variance model.

A green space environment was linked to a decreased prevalence (Figure 1) and mortality (Figure 2) of diabetes mellitus in various countries. All the 110 studies are original findings on the topic of these studies; 13 studies established a substantial relationship between green space environment and prevalence of diabetes mellitus, and 3 studies demonstrate the mortality. The STATA software package was used to analyze the data. All results are shown as forest plots with 95% confidence intervals. To quantify the degree of heterogeneity between studies, the I^2 statistic was calculated. A random-effects model was used, which is thought to be a more conservative approach suitable for cases of high heterogeneity.

The results showed that a greenspace environment was associated with a decreased prevalence of diabetes mellitus (13 studies; OR=0.875, 95% CI=0.859-0.891; $p<0.001$; I^2=61.0%) and mortality (3 studies; HR=0.917, 95% CI=0.904-0.930; $p<0.001$; I^2=75.4%).

Discussion

The neighboring environment has a significant impact on human health. The present study findings reveal that the green space environment significantly decreased the prevalence of mortality of diabetes mellitus. The results support the hypothesis that plants, trees, and vegetation provide a healthy living environment and reduce the risk of developing diabetes mellitus. The green space environment is essential for biological productivity, environmental eminence, and overall human health[12]. Green spaces encourage physical activities, social interaction, and psychological restoration, providing fresh air and healthy living[13].

Frank et al[15] demonstrated that green space areas, including parks, were linked to low odds of diabetes mellitus. People living in walkable neighborhood areas with greater park availabili-

Table II. Impact of Green space Environment on the mortality of diabetes mellitus.

Authors, & country	Type of study	Sample size	Diabetes mellitus prevalence & confidence interval	Residing in green space and its outcomes
Rodriguez-Loureiro et al[14] Belgium	Census-based cohort study	2,309,236	1.2% DM-related deaths HR 0.93 (95% CI: 0.91-0.95)	Green spaces reduce the risk of diabetes-related mortality regardless of social setting.
Crouse et al[31] Canada	Cohort study	126,5000 ≥ 19 years	Cardiovascular and diabetes 0.911; 0.895-0.928	Greenness is associated with reduced risks of death among urban Canadians
Xu et al[32] Hong Kong	Cohort study ≥ 20 years	238,441	RR = 0.72 95% CI = 0.60-0.92	Greater green space had a significant protective association with diabetes allied mortality

Abbreviations: Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI); Odds Ratio (OR); Confidence Interval (CI); Type 2 Diabetes Mellitus (T2DM); Interquartile range (IQR); Hazards ratio (HR); Adjusted odds ratio (AOR); Relative risk (RR).

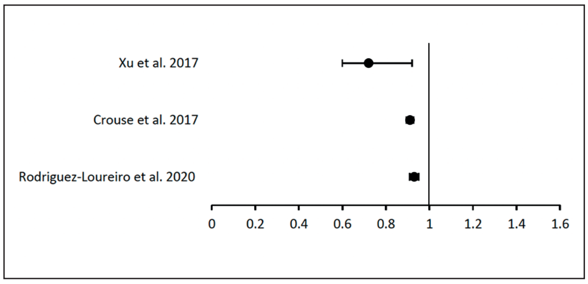

Figure 2. Forest plot showing the impact of the green space environment on the mortality of diabetes mellitus

ty were associated with low diabetes prevalence. In another study, Doubleday et al[16] reported a 21% decrease in the risk of developing diabetes per interquartile range increase in green space. Similarly, Rodriguez-Loureiro et al[14] reported a positive perception that neighborhoods with green spaces reduce the risk of diabetes-related mortality. Of 2,309,236 individuals, 1.2% died from DM during the follow-up. After adjusting for social factors, the residential greenness was inversely related to diabetes-related mortality.

Khan et al[17] conducted a study in Bangladesh and found that greenness adjacent to living areas tends to be associated with lower diabetes prevalence in the surrounding population. Moreover, Li et al[18] performed a study in China with a sample size of over 39,000 people and found that green space was associated with low fasting blood glucose levels and a 13.4% low risk of T2DM. The authors found that the quartile range increase in Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) were significantly associated with decreased risk of T2DM. The findings suggest that residential green space was beneficially associated with low fasting blood glucose levels and T2DM.

In China, another study was conducted by Qu et al[19] on 5,237 pregnant mothers who lived in or near green space regions. The authors reported that one interquartile increase in vegetation index was related to lower gestational diabetes mellitus (GDM) risks. The risk for GDM was a decrease of females living in or near green areas. Correspondingly, Liao et al[20] found green space reduced respectively 0.06, 0.09, and 0.06 mmol/L maternal fasting glucose, 1-hour glucose levels, and 2-hours glucose levels. The authors further demonstrated that living with higher levels of green space was significantly associated with decreased maternal blood glucose levels and attenuated risks of incident maternal IGT and GDM.

Yang et al[21] reported that higher greenness was significantly associated with lower fasting and 2-hours glucose levels, 2-hours insulin level, lower insulin resistance, and higher β-cell function. The increased residential greenness is associated with a low prevalence of DM. This association might be due to glucose and insulin metabolism and pancreatic β-cell function. The present study findings agree with the earlier studies[23,24] exploring the association between green space exposure and diabetes mellitus. These studies reported that diabetes tends to be lower in greener areas. The analysis performed by Lee et al[22] identified a negative association between the people residing in green spaces and fasting blood glucose levels, finding that higher green space lowers the fasting blood glucose levels.

Table III. Pooling aggregate data on the impact of green space environment and prevalence of diabetes mellitus using the common effect inverse variance model.

Study	Effect	95% Confidence Interval		% Weight
Lee et al 2015[13]	0.860	0.750	0.990	1.80
Frank et al 2021[15]	0.630	0.470	0.840	0.76
Doubleday et al 2022[16]	0.790	0.630	0.990	0.80
Khan et al 2021[17]	0.810	0.690	0.940	1.65
Li et al 2021[18]	0.870	0.830	0.900	21.1
Yang et al 2019[21]	0.880	0.820	0.940	7.18
Lee et al 2017[22]	0.700	0.410	1.190	0.17
Clark et al 2017[23]	0.900	0.870	0.920	41.4
Dalton et al 2016[25]	0.810	0.670	0.990	1.01
Fan et al 2019[28]	0.920	0.860	0.990	6.12
Astell-Burt et al 2014[29]	0.870	0.830	0.920	12.8
Paquet et al 2014[30]	0.750	0.690	0.830	5.28
Overall	0.875	0.859	0.891	100.0

Note: Test of overall effect = 0: z = 106.699, $p = 0.000$.

Table IV. Pooling aggregate data on the impact of green space environment and mortality of diabetes mellitus using the common effect inverse variance model.

Study	Effect	95% Confidence Interval		% Weight
Rodriguez-Loureiro et al 2020[14]	0.930	0.910	0.950	40.3
Crouse et al 2017[31]	0.910	0.895	0.928	59.1
Xu et al 2017[32]	0.720	0.600	0.920	0.63
Overall	0.917	0.904	0.930	100.0

Note: Test of overall effect = 0: z = 141.635, $p = 0.000$.

Similarly, studies from Canada (Clark et al[23], Ngom et al[24]) and from the United Kingdom (Dalton et al[25]) revealed that people living in or near green areas had a lower risk of developing diabetes mellitus. Moreover, Bodicoat et al[26] reported the results, consistent with the present study findings, that the people benefited more from the protective effect of greenness than the general population.

Dadvand et al[27] found an inverse relationship between time spent in natural green spaces and FBG levels. Approximately 1.83 hours spent in the green space regions were linked to a -0.5 mg/dl change in FBG levels. The authors also observed a reduced risk of impaired fasting glucose (IFG) with time spent in natural green spaces. Similarly, Fan et al[28] reported that residing in areas with greenness was associated with decreased risk of DM. Few significant interactions were found between green space areas and reduced prevalence of DM in Asian studies[27,28].

Overall findings show that people in greener surroundings have a lower risk of T2DM. Astell-Burt et al[29] reported that T2DM was 9.1% among participants living in neighborhoods with 0-20% green space. The prevalence rate dropped to 8% for participants with over 40% green space within their residential areas. In another study, Paquet et al[30] from Australia reported the risk of pre-diabetes and diabetes was lower among people residing in areas with larger open spaces, green spaces, and more walkability. All these studies support the notion that a green space environment positively reduces diabetes mellitus.

Possible Mechanisms to Understand How the Green Space Environment Reduces the Diabetes Mellitus

The present study findings are consistent with several potential mechanisms to understand the impact of the green space environment and its association with a lower prevalence of DM. The

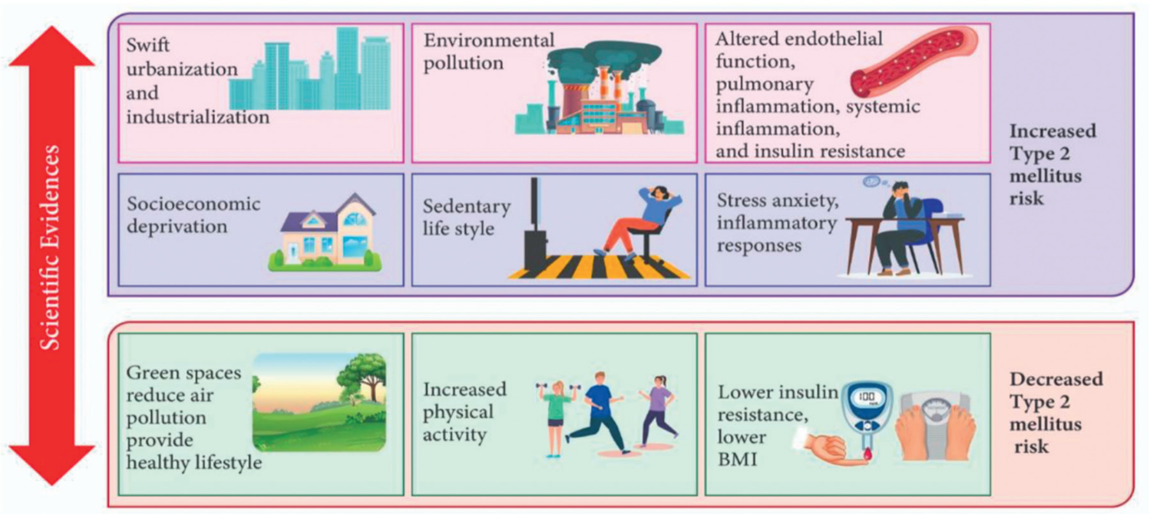

Figure 3. Mechanisms involved in the occurrence and minimizing the risk of diabetes.

first mechanism shows that the green space environment, trees, and plants leaves absorb air pollutants and minimize environmental pollution[33] (Figure 3). The second mechanism is related to the lungs' exposure to air pollutants, which can cause lung injuries due to oxidative stress, cause macrophage dysfunction, and a disrupted epithelial barrier. These factors increase lung inflammation and cause systemic inflammation, insulin resistance, and DM[34-36]. These facts support the hypothesis that the green space environment reduces stress and provides fresh air, relaxation, sports, and physical activities. These pieces of evidence support the premise that the green space environment plays a role in reducing the prevalence of DM.

Study Strengths and Limitations

This study highlights the impact of the green space environment on diabetes mellitus. The first strength of this study is that data is based on 16 original studies worldwide. Secondly, this study enhances the knowledge of how the green environment minimizes air pollutants and reduces diabetes mellitus. This study's limitation is the lack of actual data on the people's lifestyles that may contribute to diabetes; the second limitation is there is no similarity in the types of studies.

Conclusions

It is concluded that a green space environment significantly decreases the prevalence and mortality of type 2 diabetes mellitus. This study's findings convey that planning, promoting, and maintaining green spaces are essential in multisector initiatives addressing the T2DM epidemic. The current study's findings are in keeping with calls for town designers and policymakers to provide more green spaces to fight diabetes mellitus regionally and globally.

Conflict of Interest
The Authors declare that they have no conflict of interests.

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Ethics Approval
No direct involvement of subjects; hence ethical approval was not required.

Data Availability
Data may be provided on a reasonable request to the corresponding author.

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Authors' Contribution
SAM: study concept, writing and editing; TAK, MA: literature review, data collection, and analysis.

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