Assessing the Effects of Greenness on Disability-adjusted Life Years (DALYs) for Depressive Disorder: a Global Analysis

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Abstract

By using country-level data collected from 183 countries worldwide, this ecological study aimed to investigate the association between greenness and depressive disorders globally. We used the normalized difference vegetation index (NDVI) to estimate greenness exposure. The disability-adjusted life years (DALY) provided by the World Health Organization was used as a proxy for health burden due to depressive disorders. A linear mixed model algorithm was used to assess the association after controlling for pertinent covariates. Stratified analyses were then conducted to determine the effects of greenness on different groups, stratified by age, sex, economic status, urbanization level, and continent, respectively. The main findings show a significant negative association between greenness and depressive disorders with an NDVI coefficient of -0.58 (95% CI: -1.06, -0.10) for change in DALY. The results from the subgroup analyses suggested significant beneficial effects of greenness on depressive disorders across sex, various age groups, and especially for those aged less than 49 years, with low-income and/or those living in highly urbanized countries as well as Asian, African, and American regions. In short, the findings can add additional evidence of the possible benefits of green exposure on mental health and further reduces the risk of depressive disorders.

Introduction

According to the World Health Organization (WHO), over 300 million people in the world suffer from depressive disorders[1], influencing their disability-adjusted life years (DALY) momentously. In other words, the population experiencing depressive disorders have increased years of life lost due to premature mortality (YLLs) and years of life lost due to time lived in states of less than full health. Based on the Global Burden of Disease (GBD) study in 2015, which covered the time period from 2005 to 2015, depressive disorders are the main leading causes of global age-specific disability-adjusted life years (DALY) for people aged 15–64 years[2].

Previous studies have confirmed the protective effects of greenness on psychological health. For example, greenness can mitigate the burden of psychological diseases such as depressive disorders[3,4]. Factors moderating the effects of greenness were also investigated, including residential proximity to greenness and time spent in greenness[5,6]. In other words, individuals who live close to greenness or spend more time in greenness have better psychological health than do their counterparts[7]. Although the beneficial effects of greenness have been demonstrated, greenness in living environments is expected to decrease due to urbanization. According to the statistics from the United Nations Department of Economic and Social Affairs[8], around 60% of the global population will live in cities by 2030. The flow of population into cities will have to sacrifice some spaces such as greenness in order to embrace more population, leading to increased risks of psychological diseases.

Although effects of greenness on depressive disorders such as major depressive disorder and dysthymia have been discussed in previous studies, the majority of them were conducted on a small-scale or focused only on one country, limiting the generalizability of findings[5,6]. A study on a large scale is needed to capture a big picture regarding the effects of greenness. Accordingly, this study investigates the association between greenness and depressive disorders with a focus on 183 countries in the world. More than examining the influence of demographics and socio-economics on the effect of greenness, this global study was able to make comparisons between continents. Results of this study not only provide evidence on a global scale but also help identify countries that should be further investigated.

Results

Descriptive statistics. Table 1 presents the descriptive statistics of each variable examined in this study. The average global burden due to depressive disorders was 5.62 years (standard deviation (SD) = 1.37 years) for the study period (2000, 2010, 2015, and 2016). The average DALY of malignant neoplasms, diabetes mellitus, cardiovascular diseases, and respiratory diseases was 32.09 (SD = 16.92), 9.68(SD = 6.95), 54.87(SD = 31.56), and 10.85(SD = 3.82) years, respectively. The average amount of greenness - NDVI was 0.49 (SD: 0.21) and $PM_{2.5}$ exposure was 19.45 μg/m^3 (SD = 16.10 μg/m^3). The average population of all selected countries was about 38 million people (mean ± SD: 37,992,370 ± 139,909,540 persons) and 50% of them were female and aged between 15 to 50. The rate of education, urbanization level, no religion, divorce, and smoking were 83.7%, 55.68%, 0.04%, 1.02%, and 18.6%, respectively. More than half of the countries included in this study had middle to high-income levels and were located in Asia and Africa.

Table 1. Descriptive statistics of variables examined in this study, **(a)** continuous variables and **(b)** categorical variables

(a)

Variable	Mean	SD	Min	25^{th}	Median	75^{th}	Max
Burden of diseases and comorbidities– DALY (years/100 000 population)							
DALY loss due to depressive disorders	5.62	1.37	3.04	4.65	5.38	6.47	10.25
DALY loss due to malignant neoplasms	32.09	16.92	6.98	19.55	25.80	44.35	83.43
DALY loss due to diabetes mellitus	9.68	6.95	2.28	5.59	8.02	11.18	51.57
DALY loss due to cardiovascular diseases	54.87	31.56	13.63	35.80	45.48	61.31	185.16
DALY loss due to respiratory diseases	10.85	3.82	3.12	7.99	10.24	13.19	25.59
Environmental exposures							
Greenness (NDVI)	0.49	0.21	0.08	0.34	0.54	0.65	0.87
$PM_{2.5}$ (μg/m^3)	19.45	16.10	0.46	7.34	15.02	27.45	87.53
Covariates							
Population size ('000)	37 992.37	139 909.54	81.00	2 418.75	8 723.50	26 165.25	1 411 415.00
Sex (female, %)	49.95	3.05	24.17	49.77	50.32	50.92	54.21
Age 0-4 (yrs, %)	10.55	4.48	4.03	6.37	9.94	14.59	20.99
Age 5 - 14 (yrs, %)	19.17	6.42	8.04	13.22	19.05	25.53	31.28
Age 15 - 29 (yrs, %)	25.38	4.13	14.52	22.30	26.66	28.17	36.76
Age 30 - 49 (yrs, %)	25.30	5.26	15.77	21.07	25.94	28.70	52.04
Age 50 - 59 (yrs, %)	8.62	3.58	2.88	5.30	7.85	12.01	16.08
Age 60 - 69 (yrs, %)	5.89	3.29	1.14	3.16	4.62	8.59	14.30
Age ≥ 70 (yrs, %)	5.10	3.97	0.39	1.95	3.28	7.75	19.08
Education (%)	83.70	19.68	0.00	72.60	92.80	98.80	100.00
(Continued.)							
Variable	**Mean**	**SD**	**Min**	**25^{th}**	**Median**	**75^{th}**	**Max**
Covariates							
Urbanization level (%)	55.68	22.62	10.84	37.04	55.67	73.71	100.00
No religion (%)	0.04	0.10	0.00	0.00	0.01	0.02	0.77

Divorce rate (%)	1.02	1.11	0.00	0.00	0.80	1.72	5.95
Alcohol consumption (liters/population)	3.26	3.61	0.00	0.21	2.00	4.82	16.64
Smoking (%)	18.60	13.79	0.00	6.70	19.10	28.30	73.40
Mean systolic blood pressure (mmHg)	126.53	3.39	116.61	124.39	126.65	129.23	134.49

(b)

Variable	Number (countries)	%
Economic status		
Low-income	80	43.71
Middle-income	52	28.42
High-income	51	27.87
Continent		
Asia	46	25.14
Africa	54	29.51
America	34	18.58
Europe	39	21.31
Oceania	10	5.46

Various association models between greenness and depressive disorders. A significant negative association between global greenness and depressive disorders, with a coefficient estimation of NDVI of -0.58 (95% CI= -1.06, -0.10) was observed (Table 2). This finding indicates that exposure to greenness could significantly reduce the health burden due to depressive disorders. The associations between exposure to greenness and depressive disorders remain significant and in the same direction in the six models of sensitivity tests. With the consideration of four comorbid conditions, the results of models 7 through 10 showed the significant negative relationship between greenness exposure and depressive disorders. The coefficient estimation of NDVI for malignant neoplasms, diabetes mellitus, cardiovascular diseases, and respiratory diseases were − 0.59, -0.63, -0.52, and − 0.72, respectively.

Table 3 shows coefficients estimations of greenness by quartile. The results show the significant negative relationship between depressive disorders in countries with the highest exposure to NDVI (Q4), compared to those with the lowest exposure (Q1) (p-value < 0.05). Moran's Index was used to assess the effects of spatial auto-correlation in the model. As shown in Table S4, no statistically significant clustering effects (p-value > 0.05) were found in the developed models.

Table 2
Association between greenness exposure and depressive disorders in the DALY changes based on an increase in NDVI from 0 to 1 in both the main analysis and sensitivity analyses in the generalized linear mixed model.

Model	Coefficient of NDVI[h] (95% CI)	*p*-value
Main Model [a]	**-0.58 (-1.06, -0.10)**	**< 0.05**
Sensitivity test adjusted for covariates		
Model 1[b]	-0.68 (-1.15, -0.21)	< 0.01
Model 2[c]	-0.69 (-1.17, -0.21)	< 0.01
Model 3[d]	-0.63 (-1.11, -0.15)	< 0.01
Model 4[e]	-0.63 (-1.11, -0.15)	< 0.01
Model 5[f]	-0.60 (-1.08, -0.12)	< 0.05
Model 6[g]	-0.57 (-1.05, -0.08)	< 0.05
Sensitivity test adjusted for comorbidities burden		
Model 7 (Model 6 + Malignant neoplasms)	-0.59 (-1.06, -0.11)	< 0.01
Model 8 (Model 6 + Diabetes mellitus)	-0.63 (-1.11, -0.15)	< 0.01
Model 9 (Model 6 + Cardiovascular diseases)	-0.52 (-1.00, -0.04)	< 0.05
Model 10 (Model 6 + Respiratory diseases)	-0.72 (-1.19, -0.24)	< 0.01

a. Control variables included population size, sex (% of females), age, year, $PM_{2.5}$, economic status, the prevalence rate of education, urbanization level, no religion, the prevalence rate of smoking, alcohol consumption, systolic blood pressure, divorce rate, and burden of comorbidities, continents.
b. Adjusted for population size, sex (% of females), age, and year.
c. Adjusted for population size, sex (% of females), age, year, and $PM_{2.5}$.
d. Adjusted for population size, sex (% of females), age, year, $PM_{2.5}$, economic status, and the prevalence rate of education.
e. Adjusted for population size, sex (% of females), age, year, $PM_{2.5}$, economic status, the prevalence rate of education, urbanization level, and no religion.
f. Adjusted for population size, sex (% of females), age, year, $PM_{2.5}$ exposures, economic status, the prevalence rate of education, urbanization level, no religion, the prevalence rate of smoking, and alcohol consumption.
g. Adjusted for population size, sex (% of females), age, year, $PM_{2.5}$, economic status, the prevalence rate of education, urbanization level, no religion, the prevalence rate of smoking, alcohol consumption, systolic blood pressure, and divorce rate.
h. Continuous variable – an annual average of NDVI.

Table 3
Coefficient estimations of greenness by quartile attributed to depressive disorders in multivariable-adjusted models.

Quartile of NDVI	Model 1[a]		Model 2[b]	
	Coefficient of NDVI [c] (95% CI)	p-value	Coefficient of NDVI [c] (95% CI)	p-value
Q1 (NDVI: 0.085–0.389)	Reference		Reference	
Q2 (NDVI: 0.390–0.524)	-0.188 (-0.369, 0.309)	0.46	-0.330 (-0.827, 0.168)	0.20
Q3 (NDVI: 0.525–0.622)	-0.460 (-0.946, 0.027)	0.06	-0.674 (-1.174, -0.173)	< 0.01
Q4 (NDVI: 0.623–0.808)	-0.601 (-1.088, -0.114)	< 0.05	-0.459 (-0.956, -0.003)	< 0.05

a. Additional adjustment for population size, sex (% of females), age, and year
b. Control variables included population size, sex (% of females), age, PM_5 exposures, economic status, the prevalence rate of education, urbanization level, no religion, the prevalence rate of smoking, alcohol consumption, systolic blood pressure, divorce rate, burden of comorbidities, continent, and year.
c. Continuous variable – an annual average of NDVI

Stratified analysis. After adjusting for covariates, the stratified analyses by sex, age group, economic status, urbanization level, and continent were conducted (Fig. 1). Significant beneficial effects of greenness on depressive disorders for both females and males were found, suggesting no sex-based inequality in relation to the impact of greenness on depressive disorders (Fig. 1A). Moreover, health burden due to depressive disorders had a negative association with greenness in all age groups, but significance only appeared in groups from age 0 to 49 (Fig. 1B). Regarding economic status and urbanization level, significant negative associations between greenness and depressive disorders were found in low-income countries and countries with high urbanization levels (Fig. 1C, Fig. 1D). Lastly, significantly negative relationships between greenness and depressive disorders were observed in Africa, Asia, and America (Fig. 1E).

Positive-negative exposure and outcome controls. The results of the associations between positive or negative exposures and depressive disorders are shown in Table S5. First, a significant positive association was observed between CO_2 (i.e., a positive control) and depressive disorders. Second, the relationship between depressive disorders and wind speed (i.e., a negative control) did not show significance. Associations between exposure to greenness and positive or negative outcomes were also examined. A significant relationship between greenness and cardiovascular diseases (i.e., a positive control) was found, whereas a non-significant relationship between greenness and HIV (i.e., a negative control) was observed.

Discussion

Although the impacts of greenness have been studied, none of the studies have investigated on a global scale the effects of greenness on depressive disorder. To our knowledge, this is the first global ecological study to investigate the association between greenness and the health burden of depressive disorders across multiple countries. Consistent with prior studies, the main finding of this study showed that exposure to greenness was negatively related to depressive disorders. This finding was further confirmed by a series of sensitivity analyses. Further, the higher the greenness exposure, the lower the health burden due to depressive disorders. Lastly, findings of stratified analyses help discern the disparity in beneficial effects of greenness exposure. Accordingly, more efforts should be paid to disparate groups.

The findings of this study are reinforced by previous studies. For example, Sarkar et al. observed a protective effect of greenness on depressive disorders, with 4.0% lower odds of major depressive disorder per interquartile increment in NDVI (odds ratio 0.96, 95% CI 0.93–0.99; p = 0.004)[34]. Prior studies have also indicated the beneficial effects of greenness on the health burden due to comorbidities, including cardiovascular mortality[35], malignant neoplasms[36], diabetes mellitus[37], respiratory diseases[38], and metabolic system[39]. Given the coexistence of comorbidities and depressive disorders, individuals with comorbidities are suggested to take benefits from greenness exposure.

The association between greenness and depressive disorders did not show any significant difference between sex but age groups. Further, greenness exposure had protective effects to those younger than 50 regarding depressive disorders. This finding is partially supported by several studies suggesting that greenness can reduce risks of mental health burden among children and young to middle-aged adults[40–45], even during women's pregnancy[46]. Contrary to the previous findings[47], greenness exposure did not show protective effects on those aged 50 years and older. One possible reason for this may be the insufficient sample size of this age group. Nonetheless, it should be noted that greenness has protective effects on those aged younger than 50 who was considered as high-risk groups of depressive disorder. In the subsequent analyses, we found a significant negative association between exposure to greenness and depressive disorders in low-income and highly urbanized countries, respectively. Similarly, Tomita et al. also proposed the benefits of greenness for mental well-being in sub-Saharan Africa which has been experiencing rapid urbanization and economic transition[25]. Moreover, Hoffimann's study also confirmed that exposure to greenness has the potential to mitigate health inequalities associated with socioeconomic deprivation[48]. Accordingly, a certain percent of greenness should be conserved during the urbanization process, especially in low-income countries.

Negative correlations were observed in different regions between green space exposure and depressive disorder. Among them, only the results for Africa, Asia, and the Americas were statistically significant. The reason for this may be the small number of countries in these five continents (Table 1) and an additional cause may be the low degree of variability in the data. Nevertheless, prior research has illustrated the protective role greenness exposure plays in the relationship between greenness exposure and mental health in the Americas[24], Africa[25], Asia[26,27], Europe[6,28] and Oceania[29]. Furthermore, better mental health is associated with a lower risk of depressive disorders[30], which may explain why there is a beneficial association between greenness exposure and DALY from depressive disorders.

Several strengths are noted in this study. This is the first global study to investigate the association between greenness and depressive disorders across 183 countries worldwide. Findings could serve as a global baseline for future environmental development research studies. Moreover, several potential confounders with influence on the effectiveness of greenness in reducing the burden of depressive disorders were adjusted in models. A series of analyses were employed to confirm the robustness of the results.

This study has limitations. First, the benefits of mental health are attributed to the natural environments and their components[49]. A previous study has found there is negative association between biodiversity index and depressive symptoms[50]. However, due to the limited accessibility of vegetation species data, we did not adjust for the effects of biodiversity in our models. As such, we recommended that biodiversity be considered in future studies. Second, information for some important factors such as hereditary disease, health care quality index, and ethnicity, was not available on a global scale. It is suggested that the effects of the abovementioned factors on depressive disorders should be examined in future studies. Third, individual information was not applied in this global study. Although detailed information may be overlooked, this study provides a big picture about the impact of greenness on depressive disorder. It is suggested that more attention should be paid to those deprived countries or continents in future studies focusing on depressive disorders.

Conclusion

Our findings demonstrate a significant negative association between exposure to greenness and the burden of depressive disorders, particularly in low-income and high-urbanized countries as well as in the continents of Africa, Asia, and America. This is the first study providing evidence between greenness and the health burden of depressive disorders on a global scale. The findings of this study could serve as a call to policymakers and communities to deploy environmental interventions in order to reduce the global health burden of depressive disorders, with the potential for positive repercussions for the world.

Methods

Health burden due to depressive disorders. The raw data for disability-adjusted life years (DALY) was used to represent the country-level disease burden due to depressive disorders. The data was provided by the World Health Organization (WHO) from the Global Burden of Disease (GBD) study database. Annual country-level estimations were available for the four follow-up years (i.e., 2000, 2010, 2015, and 2016) (http://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html). DALY, a summary metric of population health, included years lived with disability (YLD) and years of life lost due to premature mortality (YLL). The DALY data is available for the entire population and is grouped by various factors, such as sex and age (e.g., 0–4, 5–14, 15–29, 30–49, 50–59, 60–69, and ≥ 70 years). This study calculated the number of DALY per 100,000 persons for each country. Regarding depressive disorders, the International Classification of Diseases 10th revision codes (F32-F33, F34.1) for non-communicable diseases was applied to identified cases with depressive disorders. In total, 183 WHO member countries across five continents with depressive disorders data were analyzed. Figure S1 shows the spatial distribution of DALY lost due to depressive disorders after adjusting for population size.

Assessment of greenness. The Normalized Difference Vegetation Index (NDVI) measured by a Terra Moderate Resolution Imaging Spectroradiometer (Terra-MODIS) sensor with 1x1 km spatial resolution was used to estimate the presence of greenness in each country[9]. The data provided by the National Aeronautics and Space Administration (NASA) includes the monitoring and measuring of vegetation, plants, and biomass production, as well as components of greenness including chlorophyll, canopy structure, and leaf[10]. The monthly NDVI used in this study was MOD13A3 version 6 and for a given pixel has a range of values from − 1.0 to + 1.0. Positive values represent greener vegetation and negative values indicate limit vegetation[11]. Since recent studies have indicated an association between negative NDVI values and the proximity to water[12], pixels with negative values were excluded to avoid misclassification bias due to the effects of water. In this study, satellite images with an acquisition date closer to mid-season were collected for January, April, July, and October. In total, 292 MODIS NDVI images were used to assess levels of green coverage of 183 selected countries. For image integration, a monthly global green coverage map was generated by combining 292 images. Next, we established similar procedures to assess greenness for the four selected months. Finally, monthly greenness concentrations were calculated to estimate the annual average values of greenness for each country. In all, this process integrated a total of 4672 images across the four follow-up years (i.e., 2000, 2010, 2015, and 2016). The spatial distribution of greenness in each country based on the NDVI estimations is shown in Fig. 2.

Covariates. Based on the findings of previous studies, several potential variables were considered for model adjustments including demographics, education, economic status, urbanization level, religion, divorce rate, alcohol consumption, smoking, chronic diseases/comorbidity, $PM_{2.5}$, and continent (Table S1). Demographic covariates included population size, age, and sex because these factors were found to be associate with depressive disorders[13]. Moreover, the percentage of the educated population at a country-level was controlled because of its protective effect against depressive disorders[14]. Given economic status and urbanization level influence accessibility and affordability of medical care, these two factors were also included in the model[15,16]. Religion, divorce rate, blood pressure, and lifestyle behaviors including smoking and alcohol consumption were treated as covariates because they have been demonstrated to link with psychological health[17–21]. Given chronic diseases were found positively related to depressive disorders[22], this study included malignant neoplasms, diabetes mellitus, cardiovascular diseases, and respiratory diseases as comorbid conditions. Exposure to air pollution such as fine particulate matter ($PM_{2.5}$) was also assessed due to its negative effect on mental health[23]. Positive relationships between greenness exposure and mental health have been revealed for multiple continents, including both Americas[24], Africa[25], Asia[26,27], Europe[6,28] and Oceania[29]. In addition, better mental health may lower the risk of experiencing a depressive disorder[30]; thus, five continents were included so as to corroborate whether different regions have different impacts on depressive disorders resulting from degree of greenness exposure.

To assess the relationship between comorbidities and depressive disorders, Spearman correlation analysis was performed (Table S2). The reason to examine the correlation between comorbidities and depressive disorders was to ensure whether or not the selected comorbidities were eligible for covariates.

Statistical analysis. A series of statistical analyses were conducted to examine the effects of greenness on depressive disorders and the robustness of results, including descriptive analysis, GLMM, sensitivity test, stratified analysis, positive-negative exposure, and outcome controls. Descriptive analysis was performed to present country-level characteristics of all covariates examined in this study, including DALY of depressive disorders, demographic factors (population size, sex, and age), the prevalence rate of education level, economic status, urbanization level, the prevalence rates of populations without religion, divorce rate, lifestyle behaviors (alcohol consumption and smoking), blood pressure, and health burden due to chronic diseases, environmental exposures (greenness and $PM_{2.5}$), as well as by continent.

The main model with adjustment for the above-listed covariates was developed by using the Generalized Linear Mixed Model (GLMM) with a penalized quasi-likelihood (PQL) algorithm to determine the relationship between exposure to green coverage and depressive disorders. The GLMM accounts for both fixed and random effects and provides a flexible approach for analyzing health outcomes. Given that the high number of variables adjusted for might affect the clustered spatial patterns[31], an additional random effect of the country was considered in the GLMMPQL calculation to minimize biases due to the spatial autocorrelation effect. A residual test was employed by using Spatial Autocorrelation Global Moran's I to confirm whether or not statistical significance was affected by spatial autocorrelation. Furthermore, generalized variance-inflation factors (GVIFs) were applied to examine multicollinearity across covariates. The GVIFs value was less than 4 for all covariates. Hence, all variables were included in the model adjustment (Table S3).

To evaluate the robustness of findings, a sensitivity test was applied. Different covariates in ten separate models were adjusted to discern the change in coefficient estimation and significance. Model 1 adjusted covariates, including population size, sex, age, and year. Covariates were added gradually from model 2 to model 6. From model 7 to model 10, different comorbidity was added. Moreover, a stratified analysis was conducted based on the level of greenness in quartiles to assess differences in the impact of greenness on depressive disorder. Subgroup analysis was then applied to assess the association between greenness and a reduction in the burden of depressive disorders, stratified by sex, age groups, economic status, urbanization levels, and continents. Lastly, positive-negative exposure and outcome controls were performed. In the analysis of positive exposure control, the same outcome variable was used but exposure to greenness was replaced. Given a prior study found CO_2 to be highly correlated with an increased risk of depression[32]. The relationship between CO_2 exposure (i.e., positive exposure control) and risks of having depressive disorders were checked. For the negative exposure control, the assumption that no relationship exists between wind speed and depressive disorder was examined. Previous studies have found that greenness exposure is negatively associated with prevalence of cardiovascular diseases (CVD)[33]. Because of this, the associations between exposure to greenness and the burden of disease due to CVD, the positive outcome control, and Human Immunodeficiency Virus (HIV), the negative outcome control, were included in the analyses of positive-negative outcome controls.

All of the spatial and statistical analyses were performed using ArcGIS 10.7.1 (Esri Inc., Redlands, California, United States) and R version 3.6.3 (The R packages Foundation for Statistical Computing, Vienna, Austria). Coefficient estimates with 95% confidence intervals (CI) were reported and p-values < 0.05 were considered statistically significant.

Declarations

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Author Contributions

Conceptualization, A.KA., S.C.C.L., H.J.S., C.D.W., and J.D.S.; methodology, A.K.A., H.J.T., W.C.P., Y.L.G., and C.D.W.; formal analysis, A.K.A., and W.C.P.; writing—original draft preparation, A.KA., H.J.T. and C.D.W.; writing—review and editing, A.K.A., H.J.T., H.Y.L., H.T.C., P.Y.W., W.C.P., Y.L.G., C.P.Y., C.S.W., H.J.S., S.C.C.L., C.D.W., and J.D.S.; supervision, C.D.W., S.C.C.L., and H.J.S.; funding acquisition, C.D.W., H.J.S., and S.C.C.L.

Competing Interests Statement

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Data Availability Statement

The data set from this study is publicly available. Data used in this study was acquired from the World Health Organization (WHO), who provided the metrics, i.e. disability-adjusted life years (DALY) database to estimate the global health burden of depressive disorders; the National Aeronautics and Space Administration (NASA), which provided global greenness - NDVI data (MOD13A3); the Atmospheric Composition Analysis Group, which provided global $PM_{2.5}$ data; the United Nations Agency, which provided demographic data; and the World Bank Group, which provided the provisions of economic status, the prevalence rate of smoking, alcohol consumption and risk factor data at a country-level.

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Figures

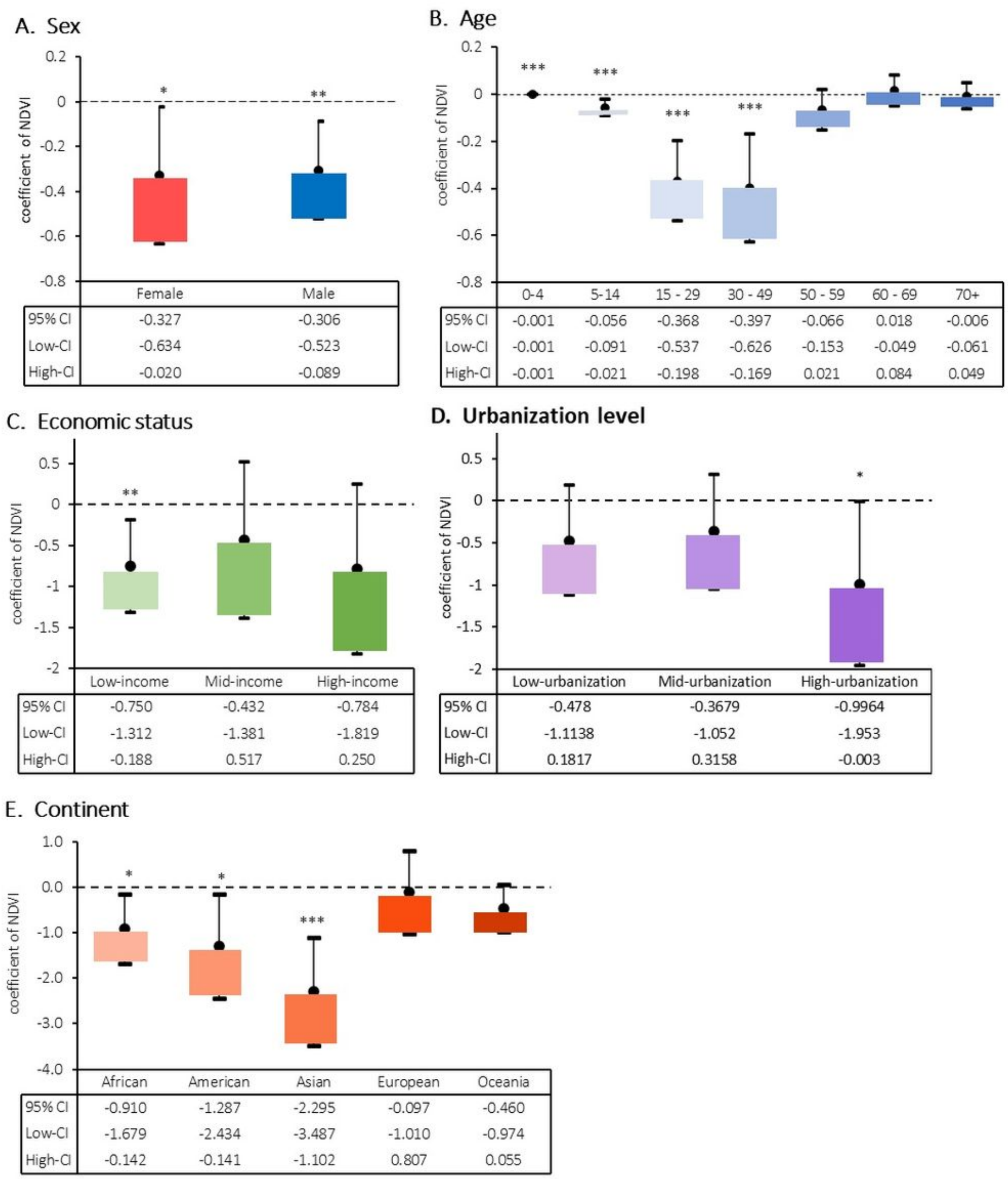

Figure 1

Stratified analysis by (A) sex, (B) age groups, (C) economic status, (D) urbanization levels, and (E) continents for greenness in relation to depressive disorders in the DALY changes based on an increase in NDVI from 0 to 1.

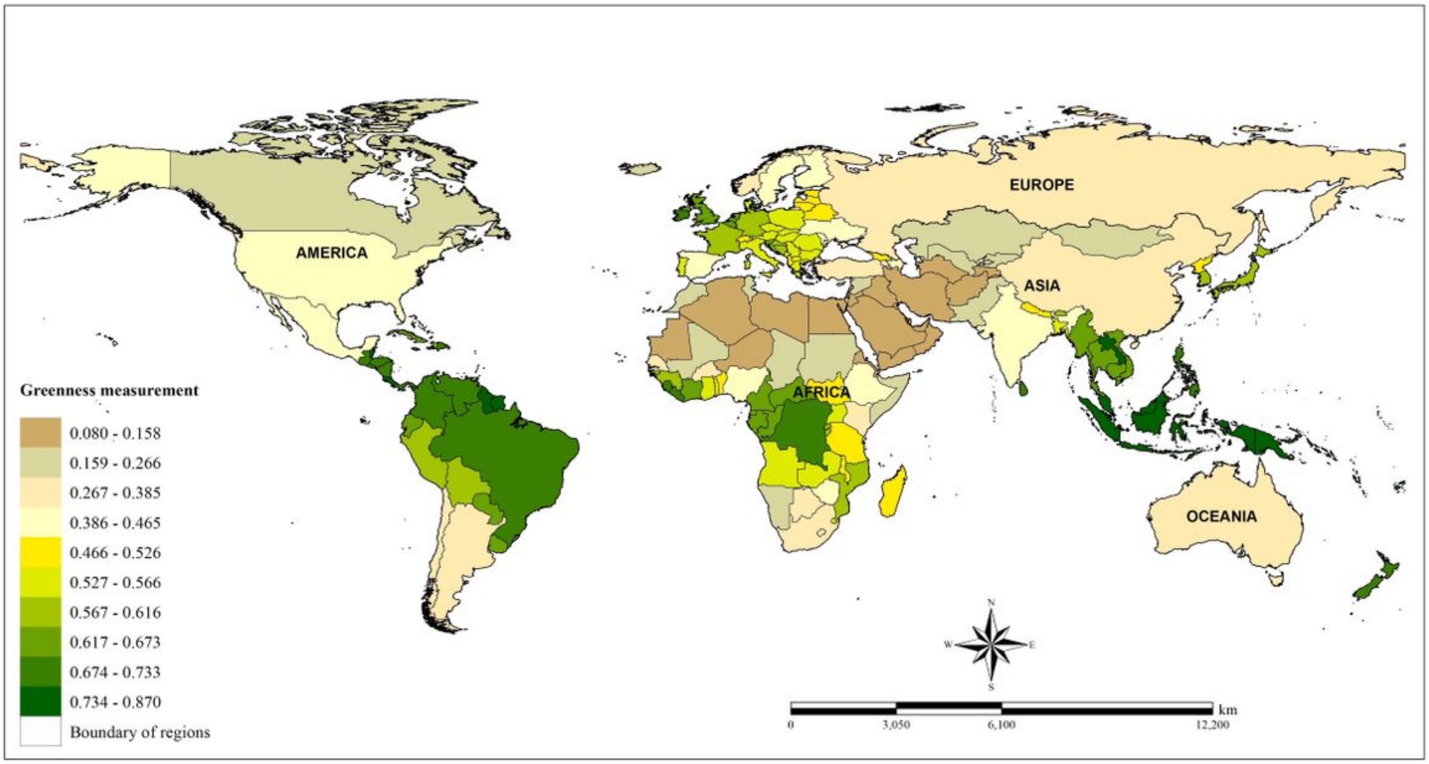

Figure 2

Spatial distribution of global greenness based on NDVI measurement in 2000 - 2016.

Supplementary Files

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