Natural environments and suicide mortality in the Netherlands: a cross-sectional, ecological study

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Summary

Background Natural outdoor environments, such as green spaces (ie, grass, forests, or parks), blue spaces (ie, visible bodies of fresh or salt water), and coastal proximity, have been increasingly shown to promote mental health. However, little is known about how and the extent to which these natural environments are associated with suicide mortality. Our aim was to investigate whether the availability of green space and blue space within people's living environments and living next to the coast are protective against suicide mortality.

Methods In this cross-sectional, ecological study, we analysed officially confirmed deaths by suicide between 2005 and 2014 per municipality in the Netherlands. We calculated indexes to measure the proportion of green space and blue space per municipality and the coastal proximity of each municipality using a geographical information system. We fitted Bayesian hierarchical Poisson regressions to assess associations between suicide risk, green space, blue space, and coastal proximity, adjusted for risk and protective factors.

Findings Municipalities with a large proportion of green space (relative risk 0·879, 95% credibility interval 0·779–0·991) or a moderate proportion of green space (0·919, 0·846–0·998) showed a reduced suicide risk compared with municipalities with less green space. Green space did not differ according to urbanicity in relation to suicide. Neither blue space nor coastal proximity was associated with suicide risk. The geographical variation in the residual relative suicide risk was substantial and the south of the Netherlands was at high risk.

Interpretation Our findings support the notion that exposure to natural environments, particularly to greenery, might have a role in reducing suicide mortality. If confirmed by future studies on an individual level, the consideration of environmental exposures might enrich suicide prevention programmes.

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Introduction

In high-income countries, a substantial proportion of the burden of mental illness is attributable to the high prevalence of suicide mortality,[1] which accounts for 1·4% of all deaths globally.[2] The increase in suicide rates in the Netherlands from 8·3 to 11·0 cases per 100 000 people between 2007 and 2015 makes suicide mortality in that country a vital public health concern.[3,4]

Suicide risk is generally recognised to be affected by sociodemographic, psychological, and clinical factors, lifestyle factors, and the availability of mental health services.[5–7] Findings are also mounting that environmental conditions and urbanicity serve as background factors that potentially trigger, reduce, or amplify suicidal motives.[8] However, the role that natural environments play in this constellation remains speculative.[9] Tentative links between suicide mortality and sunshine,[10] lithium in drinking water,[11] and air pollution have been reported.[12] Knowledge about other natural environmental factors is scarce.

Numerous epidemiological studies have examined how mental health, such as depression, is affected by natural environments, with green space, such as grass, forests, and parks, being the most prominent environment analysed.[13–15] Meta-analyses and reviews suggest that exposure to green space in a person's living environment has salutogenic effects on mental health.[16–18] As with greenery, blue space—ie, visible bodies of fresh or salt water[14,16,19,20]—and living next to the coast have been argued to have therapeutic effects,[20–22] although these effects have been scarcely researched.

Diverse explanations exist for the underlying aetiological mechanism.[18] For example, exposure to natural stimuli is thought to reduce negative thoughts and feelings, and to support stress recovery, which results in positive mental health outcomes.[18] These pathways have received gradual empirical confirmation,[17] although mostly from cross-sectional[14,19,21] rather than longitudinal research designs.[13,22]

It seems intuitively plausible that natural environments, including green space, blue space, and coastal environments, might also be protective against suicide mortality owing to their therapeutic effects on mental health. To our knowledge, no study has yet explored such associations. To address this research gap, our hypothesis-driven study aimed to disentangle the relationship between suicide mortality and these characteristics of natural environments. We generated the following guiding hypotheses: first, that a greater availability of green and

Research in context

Evidence before this study

Evidence is growing that suicidal behaviour is affected not only by individual characteristics, but also by environmental conditions where people live. Whereas evidence is mounting that green space is protective against several mental disorders, evidence for the health-supporting effects of blue space and coastal proximity is scarce; for suicide mortality specifically, the evidence for these is non-existent. Improvements in understanding how natural environments affect suicide mortality might contribute to the grand challenge of suicide reduction.

Added value of this study

This ecological study enhances knowledge of the associations between characteristics of natural environments (ie, green space, blue space, and coastal proximity) and suicide mortality in the Netherlands. For the first time, data suggested that green space was negatively correlated with suicide risk. The association was not moderated by urbanicity. Neither blue space nor coastal proximity appeared to be associated with suicide risk. Of similar importance, we found distinct spatial variation in suicide risk: areas in the south are at increased risk.

Implications of all the available evidence

We provided evidence in response to calls from WHO for a better understanding of the risk and protective factors related to suicide aetiologies. This study suggests that natural environments, particularly greenness, in people's residential municipalities is associated with reduced suicide risk. When health agencies develop place-based suicide prevention programmes, they should involve spatial and community planning because these landscape interventions might affect health outcomes in large populations.

blue space within the municipality where people live is associated with lower suicide risk. Second, that living close to the coast also reduces the risk of dying by suicide. The Netherlands provided an ideal setting to investigate these hypotheses because Dutch studies had already confirmed the mental health-supporting characteristics of the country's natural environments.[14,23]

Methods

Study design

This cross-sectional study employed an ecological research design. The 403 municipalities in the Netherlands in 2014 were chosen as the spatial units because they are the most detailed administrative units in the Netherlands that allow access to suicide data. Five municipalities that are not on the mainland (eg, the island of Texel) were excluded to avoid complicating the spatial analyses. Therefore, we assessed 398 municipalities.

Ethical approval (FETC17-060) for the Dynamic Urban Environmental Exposures on Depression and Suicide (NEEDS) study was obtained by the Ethics Review Board of Utrecht University.

Suicide and environmental data sources

We obtained officially registered suicide deaths per municipality for 2005–14. When a person dies in the Netherlands, a certificate is completed by the attending physician and submitted to Statistics Netherlands, which maintains the mortality and population registers. Because causes of death comply with the tenth version of the International Classification of Diseases, suicide cases coded X60.0–X84.9 were extracted from the registers. The detailed geographical scale made aggregation of the suicide data for a 10-year period obligatory to comply with privacy regulations. Despite this aggregation, 16 municipalities had no more than five suicide cases; as a result, these data were censored by Statistics Netherlands to ensure privacy.

The Dutch land-use database[24] provides the most accurate data with a spatial resolution of 25 m × 25 m on greenery and waterbodies for 2007. Because the thematic differentiation is comprehensive, the original land-use classes were merged into two indicators.[14] First, the proportion of green space per municipality (calculated as a percentage) was computed using a geographical information system (GIS). Greenery includes agricultural and natural areas as well as man-made greenery (eg, parks), which is the most common type in cities. The following land-use classes were combined:[14] 1–6, 9–12, 30–43, 45, and 61–62. Second, the proportion of blue space per municipality (calculated as a percentage) was determined by considering cells classified as freshwater or saltwater (classes 16–17). Third, a variable reflecting the distance in km from each municipal office along the road network to the shoreline was compiled. This index is founded on a GIS-based closest facility analysis and was calculated using shoreline data collected for 2015 from the National Oceanic and Atmospheric Administration and street data for 2008 obtained from the Environmental Systems Research Institute. Because the three variables were skewed, we classified them as low (≤25%), mid (>25% to ≤85%), and high (>85%).

Covariates

Variable selection was guided by literature reviews,[25] but limited by data availability. Data on covariates were acquired, if not otherwise mentioned, from Statistics Netherlands for 2005. To adjust for gender differences in suicide, for which men are at higher risk,[6] the proportion of men was used. Because traumatic life events increase the likelihood of suicide,[6] the proportion of divorced people based on the population aged 15 years or older was incorporated into the model. Because the absence of labour market participation relates to material losses and

diminished social status, the unemployment rate, calculated on the population aged 15–75 years, was also considered.[25] The economic deprivation or wealth of areas was represented through average housing values (in €1000). General practitioners (GPs) are the first point of contact in Dutch mental health care. We used the distance in km to the nearest GP to adjust for the availability of health services.[11] We controlled for the sociocultural conditions of the so-called Dutch Bible belt, where the majority of orthodox Protestant groups live, potentially resulting in a reduced suicide risk.[26] The proportion of voters for the Reformed Political Party (SGP) for the House of Representatives in 2003 served as a proxy variable.[27] Finally, due to urban–rural differences in suicides,[8] urbanicity was considered through a population-based regional dummy variable developed by the Organisation for Economic Cooperation and Development. To transform all continuous covariates on the same scale, variables were standardised.

Statistical analysis

We used descriptive statistics to summarise the data and to explore urban–rural differences in suicide mortality and the availability of natural environments. We calculated crude standardised suicide ratios and used Wilcoxon tests to investigate urban–rural differences in standardised suicide ratios, green space, blue space, and coastal proximity.

Because suicide counts were recorded as population level aggregates, we fitted non-spatial Poisson regressions to examine the relationships between natural environmental correlates and suicide mortality, taking covariates into account. Owing to the privacy protection for counts of five or fewer, a censored Poisson distribution was adequate. Due to varying suicide risk over the life course,[6] the expected suicides were obtained through indirect, age-adjusted standardisation. We tested multicollinearity among the covariates with generalised variance-inflation factors (GVIFs);[28] GVIFs higher than 4 are thought to be problematic. We tested for residual independence with Moran's *I* statistics. Pseudo p values were obtained from 9999 Monte Carlo simulations against the null hypothesis of spatial randomness. Significant Moran's *I* values support the application of spatially explicit models such as Bayesian hierarchical Poisson regressions.[29]

Our Bayesian models facilitated the introduction of geographical correlations between adjacent municipalities that have similar risk and helped to smooth the residual relative risk (RR) estimates. Because ignoring the spatial patterning of suicide risk might have led to biased inferences,[29] a spatially structured random effect was imposed by an intrinsic conditional autoregressive scheme to incorporate spatial dependency among adjacent municipalities, and we used a Gaussian random effect to adjust for uncorrelated extra variability.[29–31] Municipalities that share a common border were conceptualised as neighbours. Model details are provided in the appendix.

To test our hypotheses, we fitted the following spatial models with an increasing degree of adjustment. Model 1 represented the baseline, testing the associations between suicide and green space, blue space, and coastal proximity. Model 2 also controlled for risk and protective factors. Finally, we extended model 2 with an additional interaction term between significant environmental variables and urbanicity.

To judge the models' goodness-of-fit given their complexity, we used the Watanabe-Akaike information criterion (WAIC); lower WAIC scores correspond to superior models. The models were fitted with integrated nested Laplace approximation (INLA).[32] Statistical analyses were carried out with the R–INLA library in R version 3.3.1.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

A total of 16 105 suicides were registered in 2005–14. The crude standardised suicide ratios showed considerable variation, ranging from 0·393 to 1·856 with a median of 0·957 (SD 0·260). Descriptive statistics for each variable are given in the appendix. Of the suicides, 65% were

	Model 1	Model 2
Green space (*vs* low)		
Mid	0·831 (0·762–0·907)	0·919 (0·846–0·998)
High	0·760 (0·681–0·849)	0·879 (0·779–0·991)
Blue space (*vs* low)		
Mid	1·033 (0·961–1·111)	0·990 (0·927–1·057)
High	0·996 (0·908–1·093)	0·937 (0·861–1·019)
Coastal proximity (*vs* low)		
Mid	0·951 (0·878–1·029)	0·965 (0·898–1·035)
High	0·964 (0·838–1·107)	0·932 (0·823–1·052)
Covariates		
Urbanicity (*vs* rural): urban	..	0·947 (0·887–1·012)
Male	..	0·978 (0·950–1·008)
Divorced	..	1·032 (0·985–1·081)
Unemployed	..	1·043 (1·001–1·086)
Housing prices	..	1·001 (0·963–1·039)
Availability of general practitioners	..	1·034 (0·995–1·074)
Orthodox Protestant	..	0·922 (0·890–0·954)

Data are relative risk estimates (95% CrI). Continuous covariates were standardised. Relative risk estimates were obtained from the posterior distributions together with the 95% CrIs. If the 95% CrI does not include 1, a covariate is considered to be significant. We mapped the unexplained residual spatial variation in suicide risk per municipality relative to the nationwide risk. CrI=credibility interval.

Table: **Results of the regression models with different adjustment levels**

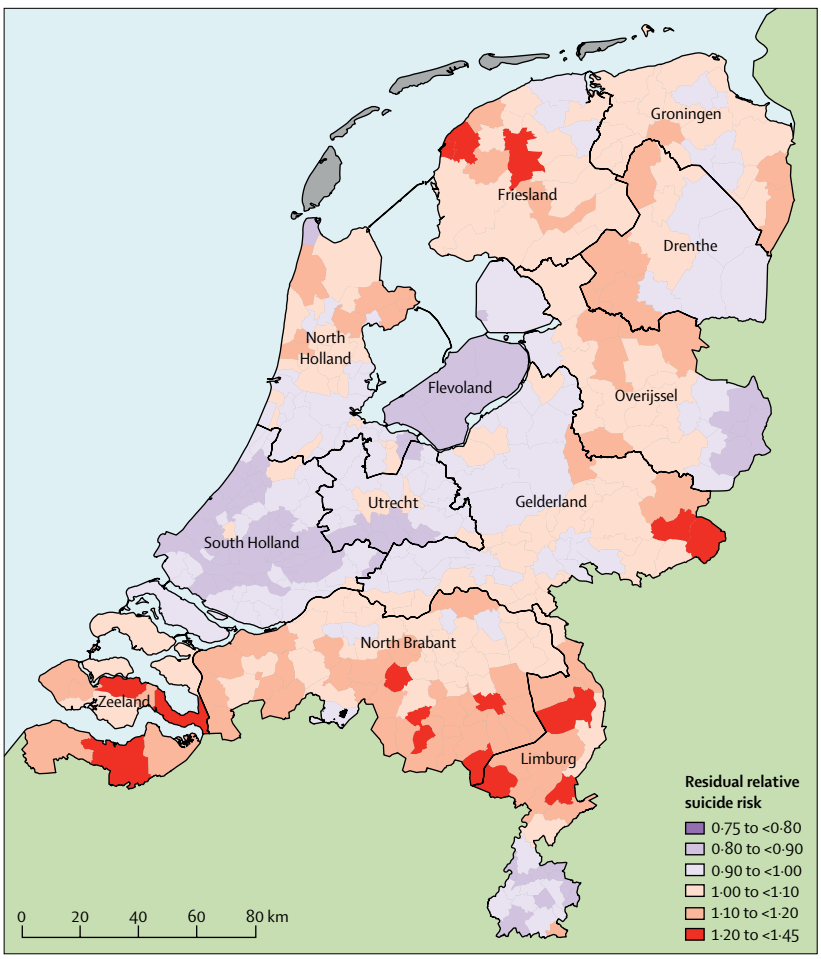

Figure: **Results of model 2**
Dark grey lines delimit provinces. Dark grey areas indicate excluded municipalities that are not on the mainland.

in rural areas with, on average, more green space (73% [SD 18·3] *vs* 58% [24·3]), less blue space (4% [5·1] *vs* 7% [5·1]), and greater distances to the coast (49 km [39·5] *vs* 25 km [27·9]) than urban areas. Wilcoxon tests showed mean differences between urban and rural areas in the crude standardised suicide ratio (p=0·060), green space (p<0·0001), blue space (p<0·0001), and coastal proximity (p<0·0001).

With the largest GVIF of 2·413, we found no evidence for multicollinearity among the variables. The residuals of the non-spatial regression were significantly auto-correlated (Moran's *I* 0·146; p=0·0001), thus suggesting the use of spatial models. Whereas model 1 had a WAIC score of 2520, the WAIC values declined to 2501 in model 2 (sensitivity tests for this model are reported in the appendix). No further improvement in fit was noticeable after including interaction terms (WAIC 2502; model results are shown in the appendix), thus favouring model 2, which we use to discuss the results.

Model 2 suggests that municipalities with a larger proportion of green space (RR 0·879, 95% credibility interval 0·779–0·991) or a moderate proportion of green space (0·919, 0·846–0·998), have a lower suicide risk than those with a small proportion of greenery (table). Neither blue space nor coastal proximity was associated with suicide in model 2. Because green space was the only associated environmental exposure, we tested an urbanicity–green space interaction, but found no evidence to support this interaction (appendix).

In terms of the covariates, we found no urban–rural differences in suicide risk. The proportion of men and divorced people, the availability of GPs, and housing values were not related to suicide mortality (table). Higher unemployment rates translated into an increased suicide risk, and belonging to an orthodox Protestant group reduced suicide risk (table).

When geographically plotting the residual RR not explained by the covariates, we observed striking patterns, with an increased risk (>1·1) in the south of the country (figure). Compared with the nationwide risk, the Randstad area (eg, the provinces of South Holland and Utrecht) is at low risk. Robustness checks with various prior specifications and a different neighbourhood specification confirmed the reported results (appendix).

Discussion

Our objective to investigate the associations between characteristics of natural environments and suicide mortality was novel. Consistent with our first hypothesis, we were able to show in the multivariate models that the higher the exposure to greenery within a municipality, the lower the suicide risk. Although urban settings are generally characterised by less greenery than rural settings, we found no interaction between residential greenery and urbanicity in relation to suicide.[8,33] We can thus exclude urbanicity being a surrogate for less greenery.[23]

Congruent with prior studies,[14] we assumed that all types of greenery support health; however, others argue that the quality of greenery also matters.[15,34] As confirmed for Austria[11] and Germany,[35] we also found substantial differences in suicide risk across the Netherlands, with municipalities in the provinces of Zeeland, North Brabant, and Limburg showing an amplified suicide risk.

Plausible explanations for why greenery is protective are provided by stress reduction theory and attention restoration theory.[18] Simply put, both theories argue that greenery affects people's psychological functioning by making them less vulnerable to stressful life events, is stress relieving, and supports their reflection about life,[18] which might translate into fewer suicidal thoughts (although we recognise the multifactorial nature of the aetiology of suicidal thoughts and behaviour). As we are unaware of any similar study, we discuss our findings in a broader mental health context. Two studies[14,23] in the Netherlands, for example, found that depression, a well established risk factor for suicide mortality,[36] is negatively correlated with greenery. Although neither

study adjusted for people's genetics and environmental confounders due to residential self-selection, a US twin study[37] confirmed these cross-sectional findings that more greenery is associated with reduced depression risk.

Previous research has suggested that blue spaces have beneficial characteristics similar to those of greenery.[18] We considered blue space in combination with greenery rather than individually.[14] Blue space was associated with suicide in the expected direction in the fully adjusted model, although the associations did not attain significance. Contradicting our hypothesis, the results indicate that coastal proximity was not related to suicide mortality. Because we believe this to be the first study of its kind,[17] we do not know whether these findings are specific to our case study. However, our finding that blue space is not necessarily associated with mental health is supported by a cross-sectional analysis.[19] The reasons why green space is related to suicide risk and blue space is not are difficult to establish and require additional research. Whereas the health-promoting properties of coastal proximity found in England are based on Euclidean distance categories,[21,22] our study used more realistic street distances without categorisation. This advanced operationalisation might be the reason for our contradictory finding.

Our study had several strengths. To our knowledge, this is the first study to explore associations between suicide and natural environments. Both green space and blue space information was extracted from objectively measured land-use data, ensuring high-quality variables and allowing their correlations with suicide to be investigated. For future studies, green space and blue space should not be studied in isolation but in tandem with other environmental factors, such as air pollution.[12] Instead of districts,[11] this study used detailed municipal-level data, which increased the number of observations needed for robust results with considerable statistical power while reducing ecological bias. Using the latest advances in spatial analytics, data censoring due to privacy regulations was handled effectively. We addressed the methodological limitations of previous studies by incorporating geographical dependencies between adjacent areas, which otherwise would have caused biased estimates.[29] Our models also smoothed the RR estimates, which led to more reliable estimates than crude standardised suicide ratios, thus allowing policy makers to develop place-based suicide prevention strategies.

Some limitations should be considered. To adhere to privacy regulations, data were pooled over time; as a result, the analyses failed to reflect the increasing suicide rates since 2007.[3] The detailed analysis scale on the municipality level prevented us from stratifying suicides by gender. Although the covariates referred to 2005, green space and blue space data were for 2007. However, significant changes in such data are unlikely on a municipal level in the short term. Our study considered natural exposures within the municipality where people live. This assumption disregards the lengths of stay and exposures over people's residential life course.[9,13] Suicidal behaviour is also affected by many other factors, such as alcohol abuse, social disconnection, and depression prevalence.[6] Confounding cannot be precluded. Our results should be replicated in other countries, and verification merits further research. Finally, the general shortcomings of cross-sectional and ecological studies remain: although exploration of suicide–environment mechanisms is valuable, no conclusions about causality or for individuals can be inferred. Future longitudinal research on an individual level is required.

This study took an important step towards a better understanding of how natural environments might be associated with suicide mortality. Our results indicate that exposure to greenery could have a role in the reduction of suicide risk. We found no evidence that the green space–suicide association is further moderated through urbanicity, and we could not confirm that blue space and coastal proximity are associated with reduced suicide mortality. Whereas the relationship between suicide and green space indicated only minor variation across space, substantial geographical variation was found for suicide risk. If replicated by future studies, the suicide risk-relieving characteristics of natural environments, particularly green space, could potentially inform prevention programmes in the long run.

Contributors

MH developed the research idea and study design, carried out the statistical analysis and the interpretation, and drafted the manuscript. PPG and DdB supported the variable selection and contributed to the interpretation. MH collected the data. M-PK and RCO'C supported the interpretation. All authors read and approved the final manuscript.

Declaration of interest

We declare no competing interests.

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