TITLE

Green space, social inequalities and neonatal mortality in France

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Abstract

Background-Few studies considered environmental benefits to explain social health inequalities. Nevertheless, natural environments, that promote good health, might have an effect on socioeconomic health inequalities. In developed countries, the evidence that green spaces have health benefits for urban population is now strong. Moreover, recent studies suggest such positive effects on pregnancy outcomes.

Objective. To investigate the relationships between green spaces and the spatial distribution of infant mortality taking into account neighborhood deprivation levels.

Methods. The study took place in the Lyon metropolitan area, France. All infant deaths that occurred between 2000 and 2009 were geocoded at the census block level. Each census block was assigned greenness and socioeconomic deprivation levels. Using a spatial–scan statistic, we examined whether there were significant clusters of high risk of infant mortality according to these neighborhood characteristics.

Results. Our results highlight that infant mortality is not randomly spatially distributed, with clusters of high risk in the southeast of the Lyon metropolitan area (p<0.003). After adjustment on greenness level and socioeconomic deprivation, this cluster disappears (p=0.12), suggesting that these factors explain the spatial distribution of infant mortality. Our findings are discussed following a conceptual framework which proposes 3 hypotheticals pathways by which green space may have a beneficial effect on adverse pregnancy outcomes: (i) a psychological pathway, (ii) a physiological disruption process and (iii) an environmental pathway.

Conclusions. These results add some evidence to the link between access to green space and pregnancy outcomes but require further research for confirmation.
**KEY WORDS:** Greenness level, neighborhood deprivation, infant mortality, spatial analysis
Background

In developed countries, the leading causes of neonatal morbidity and mortality relate to various adverse pregnancy outcomes such as preterm birth [1], congenital malformations [2], low birth weight [1] and intrauterine growth retardation [3]. Moreover, socio-epidemiological research documented a social gradient of infant mortality and stillbirth[4, 5]. Infant mortality and its risk factors are both more common among women of low socioeconomic status [6, 7]. A wide literature describes various deprivation measures related to infant mortality and its determinants, including composite indices [6, 8] or proxy variables of socio-economic characteristics, such as income [9], education level [10, 11], unemployment [10], occupation category [10], percentage of persons below the poverty level [10], house ownership[12], percentage of immigrants [9]. However, few studies explored together the individual and contextual socioeconomic status [7, 13, 14].

Environmental factors have been recently proposed as determinants which could partially explain social health inequalities. The majority of these studies focused on environmental nuisances, e.g. ambient air pollution related to traffic and to industries [15–17], noise [18, 19]; few considered environmental benefits [20]. Nevertheless, several recent papers showed that access to natural environments may have a beneficial health effect [21, 22] and may relate to urban socioeconomic inequalities [20].

Two recent reviews reported that green space, defined as “open, undeveloped land with natural vegetation, parks or forest”, have beneficial health effect on morbidity [23] and on mortality [20]. The literature advances various ways by which a natural environment may promote heath, like increased physical activity [24, 25] and walking [26], reduced environmental nuisances(air pollution [27, 28]or noise [29]), and
increased social ties [30]. In addition, a large literature explored psychological benefits of green space. Through stress relief [31], natural environments positively influence people’s self-perceived health [32], emotional and mental health [33], well-being [26]. Beyond promotion of psychological health, several studies have shown that physical or visual contact with natural areas can be physiologically restorative. Numerous health benefits have been documented, such as on cardio-vascular diseases [34], overweight and obesity [35], and eventually mortality [20].

To our knowledge, only two teams in Spain and Portland investigated the effects of natural environments on adverse pregnancy outcomes [36–39]. An association was reported between living near a major green space and birth weight or gestational age. These recent findings highlight the need of new research on the relationship between the natural environment and pregnancy outcomes in order to improve our understanding of the underlying mechanisms.

Accessibility of natural environment remains unequal between different socio-economic groups. The Spanish study revealed a clear association between proximity to green space and birth weight or gestational age, but only among the lowest education level group [36]. Other authors also reported that people with greater access to green space were likely to be less deprived than those with little access to such areas [40, 41]. Thus, natural environments, that promote good health, might have an effect on socioeconomic health inequalities.

In this context, the present study explores the effects of proximity to green spaces on infant mortality in the Lyon metropolitan area, France, between January 2000 and December 2009 and assesses the effect of socioeconomic level on these relationships. We conducted a spatial SaTScan analysis which is used in an increasing number of applications in the field of spatial epidemiology [42]. Our findings
are then confronted to a theoretical model we propose to explain the possible mechanisms through which green spaces and socioeconomic indicators might relate to adverse pregnancy outcomes.

**Materials and methods**

**Study Setting** - The study setting is an urban area of 515.96 km² located in east-central France, with a population of 1,340,155 inhabitants in 2009.

**Health data** - The dependent variable is infant mortality, defined as all death cases aged <1 year. Data come from the death certificates, collected by co-investigators of the present project “Equit’Area” ([www.equitarea.org](http://www.equitarea.org)) in all the local municipalities. Cases were geo-coded using the parent’s postal address with the CAZU software from the National Institute for Statistics and Economic Studies INSEE that assigns the street names and numbers to census blocks (counting 2000 inhabitants on average). Some cases could not be geo-coded because parents’ addresses were missing, incomplete or incorrectly written; 3.5% of all infant deaths were excluded from the study. Overall, we collected 715 infant death cases living in the Lyon metropolitan area between January 2000 and December 2009. The French National Commission for Digitalized Information and Liberty (CNIL) gave its consent to retrieve geocode and analyze the health data.

**Neighbourhood characteristics**

*Socioeconomic index* - Socioeconomic and demographic data were obtained from the 1999 national population census conducted by INSEE at a census block level. In order to characterize the neighbourhood socioeconomic level, we used a deprivation index and also an array of specific variables that compose this index (including education level, employment and occupation status, and housing characteristics).
Successive principal-component analyses were used to create the deprivation index based on Havard et al. [43]. The measure of neighborhood deprivation was categorized into three groups according to the tertiles of the index distribution (Table 1): low, moderate and high deprivation [44].

Green space index

Spatial land cover data sets for Lyon Metropolitan were sought and processed using ArcMap GIS software (ESRI) to produce the green space index. Our definition of green space included natural area (e.g. parks, forest...) as these are generally treated as green space in the literature. Our measure represented the geographic area (Km$^2$) of green space as a proportion of the total area within a census block. The greenness index, measured in each census block, was categorized into three groups defined according to the tertiles of the index distribution: low, moderate and high greenness.

Statistical analysis

Spatial methodology – Using cluster analysis, the spatial scan statistic implemented in the SaTScan software [45], we investigated the presence of spatial aggregation of infant mortality. This approach allows to explore the presence of high risk infant mortality clusters named “most likely clusters” and their spatial location. The number of cases in each census block is assumed to follow a Poisson distribution.

The procedure works as follows: a circle or windows of variable radius (from zero up to 50% of the population size [46]) is placed at every centroid of the census block and moves across the whole study area to compare the infant mortality rate in the windows with what would be expected under a random distribution. The identification of the most likely clusters is based on a likelihood ratio test [47] with an associated p-
value obtained using Monte Carlo replications [48]. The on-line appendix describes in more detail the analytical strategy.

**Results**

Figure 1A shows the spatial distribution of the socioeconomic deprivation index at the census block level. This map highlights that the most wealthy census blocks are located in the very central and periphery parts of the study area, while the most deprived blocks are in the central-east and south portions of the metropolitan area.

Figure 1B exhibits the spatial distribution of the greenness index, showing that the census blocks with the highest greenness levels are concentrated in the periphery and west parts of the metropolitan area whereas the census blocks with the lowest greenness levels are in in the central-east and south portions of the metropolitan area. Hence, the spatial variations of the deprivation and greenness index reveal similar patterns.

**Spatial analysis**

**Identification of high risk infant mortality clusters** - Figures 2A reveal the location of the most likely cluster in the southeast of Lyon metropolitan area, with an infant mortality rate 1.70 times higher than in the rest of the study area (p=0.003). This cluster is composed of 53 census blocks and hosts around 19401 inhabitants (Table 2, unadjusted analysis).

**Adjusted scan statistical analysis**

**Greenness level and spatial display of infant mortality** – After adjusting on greenness index, we found the same most likely cluster (Figure 2A), with a lower log likelihood ratio, which decreased from 12 to 10.06 (Table 2, adjusted analysis - stage2). We can conclude that greenness level explains only partially the excess of
infant mortality risk observed in the south eastern part of the Lyon metropolitan area[46]. However, the cluster is still significant after this adjustment (RR=1.52; p = 0.01), meaning that infant mortality risk is to be explained by other variables.

**Neighborhood deprivation level and spatial display of infant mortality** -

Adjusting on the deprivation index yielded the most likely cluster to be larger in size but located in the same zone (Figure 2B), now composed of 66 census blocks with about 21,907 inhabitant in a radius of 9258.9 meters (Table 2, adjusted analysis - stage2). The risk of infant mortality is 1.54 greater than in the rest of the metropolitan area; the log likelihood ratio decreases from 12 to 8.74 and the excess risk becomes borderline significant (p=0.06), indicating that these socio-economic characteristics explain a great part of the excess of infant mortality detected in the unadjusted analysis [46].

**Greenness level, neighborhood deprivation level and spatial display of infant mortality** - After adjustment for both greenness and deprivation levels (including their interaction), in stage 3 of the analysis (Table 2, adjusted analysis –stage3), the most likely cluster observed in the unadjusted analysis became not significant (p=0.12), yet in the same zone(Figure 2A); infant mortality rates did not vary when including the interaction term between deprivation and greenness levels, meaning that both factors had an independent effect, with no effect modification.

**Discussion**

To our knowledge, this is the first study to investigate spatial relationship between greenness, deprivation level and infant mortality. Our analysis reveals that infant mortality rates are not randomly distributed over the study area with a spatial aggregation of infant mortality located in the southwest of the Lyon metropolitan area.
After controlling for greenness levels and neighborhood deprivation, this cluster of high risk disappears, suggesting that these factors explain the excess risk of infant mortality, with no interaction.

Our finding is consistent with recent studies conducted at the individual level investigating adverse pregnancy outcomes that are well known risk factors of infant mortality. Two studies highlighted a reduction in the risk of small for gestational age [39] and low birth weight [36–38] associated with higher surrounding tree canopy [39] or greenness [36–38]. However, no association was observed with gestational age [37–39]. Recently, a paper documented that proximity to green space have various maternal benefits including decreased musculoskeletal discomfort, reduced incidence of muscle cramps and lower limb edema [49]. However, the exact mechanisms of these beneficial effects were not established.

The present study provides some additional empirical support for the potential role of access to green space on reduction of the risk of adverse pregnancy outcomes. We propose hereafter a conceptual model of the mediating variables associated with green space accessibility and of their hypothesized relation with pregnancy outcomes.

We propose hereafter 3 hypotheticals pathways by which green space may have a beneficial effect on adverse pregnancy outcomes.

**Psychological pathway as a plausible biological pathway**

The main mechanism by which natural environments might be associated with a favorable pregnancy outcome is stress reduction. A large number of experimental studies have produced strong evidence of the positive effect of nature on recovery from stress and attention fatigue [22, 31]. Contact with natural environments
promotes psychological restoration [50] and reduces stress and anxiety [51–53]. It is not only through wholesome landscape vision, but also by physical activities [54, 55] and by social support [30, 56], that green space has positive effect on stressful life events including mood and stress level.

In terms of mechanism, there is evidence of a direct impact of the perception of the natural environment on an individual’s brain and body through psychoneuroendocrine mechanisms, including the functioning of the hypothalamic pituitary adrenal axis which regulates cortisol secretion and whose disregulation is associated with a range of adverse pregnancy outcomes. This principal theoretical model for these responses, known as Ulrich’s psychoevolutionary model [52, 53] was confirmed by several experimental studies that revealed that being in or viewing green space was linked to reduced physiological manifestations of stress, including heart rate, blood pressure, skin conductance and muscle tension [53, 57]. Surprisingly, these findings were not reported in other papers [58].

Thereby, some beneficial green space effects would operate through reduction of maternal stress and the neuroendocrine and immune mechanisms which may alter feto-maternal exchanges [59, 60], yielding limited fetal nutrition and/or oxygenation, and subsequently fetal growth [61, 62] and preterm birth [63].

**Physiological disruption as a hypothetical pathway**

The second pathway posits that green space may be promoting maternal health by encouraging physical activity and facilitating social ties. Several hypothetical mechanisms may be underlying. Firstly, through physical exercise, access to green areas may enhance maternal cardiovascular activity [49, 64] which, by a number of biological pathways, may reduce blood pressure, decrease the concentrations of
proinflammatory cytokines and leptin in the peripheral circulation, reduce oxidative stress, improve plasma lipids and lipoprotein concentrations [64]. A large number of studies have produced strong evidence of these positive effects including reduction in the risk of hypertensive disorders [25, 65] and of the risk of preeclampsia [64, 66], both conditions that are associated with preterm birth [67], low birth weight [68] or infant mortality [69, 70].

Secondly, through promotion of physical activity, green space may have positive effects on metabolic disorders including weight gain [25] and diabetes [71] during pregnancy. The pregnancy weight gain has significant health implications on the newborn [72]. Both maternal obesity and sedentary lifestyle during pregnancy have been associated with a preterm birth [25, 73] and increased risk of congenital anomalies, a leading cause of stillbirth and infant mortality, and important contributors to preterm birth and early childhood morbidity [72].

A recent meta-analysis and epidemiological studies documented that women who are physically active during pregnancy have a 24% lower odds of developing gestational diabetes than inactive women [71] and that the risk of spontaneous preterm birth increased with increasing levels of pregnancy [74].

And thirdly, through an association between physical activity [75, 76] or social support [33, 77] and mental health, including well-being, mood and depression/insomnia during pregnancy, green space may reduce mental disorders and their effects on adverse outcomes [25, 78, 79].

**Environmental pathways, as an indirect pathway** - The third hypothetical pathway that we suggest is the effect of green space on the maternal environment of life.

Recent studies documented that green areas had beneficial effects on environmental
factors of adverse pregnancy outcomes among which (i) ambient pollution, (ii) noise levels and (iii) temperature.

Green space is associated with lower personal exposure to particulate matter (PM$_{2.5}$) [37]. Broad leaved woodland reduces ambient air pollution, and streets with trees have around a quarter of the particles’ concentrations of those without [80, 81]. Other studies showed that urban trees, particularly low VOCs emitting species, can reduce urban ozone levels [82–84]. In 2000, Nowak [85] describes four main processes by which vegetation may affect air quality: (i) temperature reduction and other microclimatic effects, (ii) removal of air pollutants, (iii) emission of volatile organic compounds and tree maintenance emissions, (vi) energy effects on buildings. Overall, vegetation may play various roles as a physical filter for harmful gases and particulate matter [80, 81]. Through affecting air temperature, radiation and absorption, tree transpiration and tree canopies can improve air quality because the emissions of many pollutants, including ozone-forming chemicals, are temperature dependent. Also, through reduced building energy use and pollutant emissions from power plants, trees improve air quality [86, 85]. Therefore, by these various mechanisms which reduce maternal exposure to hazardous air pollutants, proximity to green space may have positive effects on pregnancy outcomes [87].

Exposure to noise during pregnancy has been associated with a higher risk of preterm birth [88, 89] and of low birth weight [90, 91]. We suggest that by reduced environmental noise, green space may promote a better psychosocial maternal environment that reduces the risk of adverse pregnancy outcomes. Although there is little research establishing the actual benefits of urban green space as a distance barrier to environmental noise, recent papers suggest that green space, particularly trees and large shrubs have the ability to mitigate noise in urban areas by providing a
barrier to screen out noise [92, 93]. "Noise buffers" composed of trees and shrubs may achieve noise reductions of up to 15db [81]. It is also suggested that trees in urban areas may absorb some traffic noise [29]. In addition, perceived intrusion of noise from traffic can be reduced by vegetation obscuring the noise source and associated traffic movement [81]. In 2007, Gidlöf-Gunnarsson and Öhrström proposed a brief conceptual model involving the role of green space on noise annoyance, behaviors and perception of the residential soundscape related to road traffic noise [94].

Our hypothesis highlights the complexity of the mechanisms which link green space to pregnancy outcomes, and suggest that other factors may interact to promote or impede the beneficial effects of a natural environment. Among them, the socio-economic status of pregnant women [20, 31]. Several studies describe disparities in the accessibility to green space according to personal or area-based socio-economic status. In general, deprived neighbourhoods in urban settings have inferior provision of park and walking trails, and poorer access to green space in comparison with non-deprived ones [40, 41, 95, 96]. Proximity and usage of green space depend on the education level, or on income [97]. Although this general observation has been challenged by other authors, residents in deprived neighbourhoods are less likely to make use of green spaces because of less positive perceptions [98, 99].

Because of the ecological nature of our study design, we could not assess usage of green space by the Lyon area population. Another limitation of our study concerns the construction of the greenness index. The information on topography or on land cover used to construct the index does not distinguish different types of vegetation; now they may have variable influences on the pathways we propose for the effects of noise or ambient air pollution. Unlike the Normalized Difference Vegetation Index
(NDVI) which measures small-scale green spaces in a standardized way, and other more specific synthetic measures of greenness, our index only measures the degree of greenness in each census block. Finally, because the outcome of interest is rare, this study faces statistical power limitations. Despite of these limitations, our findings are consistent with those derived from usage of the more elaborated NDVI index [38].

6. Conclusion

These results add some evidence to the link between access to green space and pregnancy outcomes. Policies that ensure an equitable distribution of green areas within metropolitan areas may contribute to the promotion of fair access to healthy environments. We recommend further studies on the impact of green space on pregnancy outcome to document its mechanisms of action.
Abbreviations

RR Relative Risks

LLr Log Likelihood ratio

PM 2,5: particulate matter < 2,5µm

A competing financial interest’s declaration:

The authors declare they have no competing financial interests.

Author’s contributions

Wahida Kihal has performed the spatial analysis, produced the map, conceptual model, drafted the article, and conducted the literature review. Cindy Padilla has collected health data, geocoded the cases to the IRIS level, has contributed to interpretation of results and to the drafting of article and to its finalization. Benoit Lalloué has implemented statistical model sand contributed to drafting of the article and its finalization. Marcello Gelormini has conducted the literature review and has contributed to the drafting of article and to its finalization. Denis Zmirou-Navier, Head of the environmental and occupational health department at the EHESP and co-PI of the Equit'Area Project, guarantees quality assurance and rigor in the data analysis, has reviewed the drafts of the article and contributed to its finalization. Séverine Deguen, PI of the Equit'Area Project examining the role of environmental exposures on health inequalities, has followed up the general labor, contributed to the analysis, interpretation of results, writing the paper and its finalization.

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References


Table 1. Description of the deprivation categories

<table>
<thead>
<tr>
<th>Classes of deprivation</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1: low deprivation</td>
<td></td>
<td>Census block with high median income, low proportion of households without a car, low proportion with non-owner-occupied primary residences</td>
</tr>
<tr>
<td>Group 2: moderate deprivation</td>
<td></td>
<td>Census block with median income average, medium proportion of households without a car, medium proportion with non-owner-occupied primary residences</td>
</tr>
<tr>
<td>Group 3: high deprivation</td>
<td></td>
<td>Census block with low median income, high proportion of households without a car, high proportion with non-owner-occupied primary residences</td>
</tr>
</tbody>
</table>
Table 2. The most likely clusters resulting from the unadjusted analysis (stage 1) and adjusted analysis (stages 2 and 3)

<table>
<thead>
<tr>
<th>Most likely cluster</th>
<th>Confounders</th>
<th>Radius (meter)</th>
<th>Census block included</th>
<th>Expected cases</th>
<th>Observed cases</th>
<th>RR(^a)</th>
<th>LLr(^b)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unadjusted analysis(^c)- Stage 1-</strong></td>
<td>None</td>
<td>5117.81</td>
<td>53</td>
<td>73.30</td>
<td>116</td>
<td>1.70</td>
<td>12.00</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Adjusted analysis(^d)- Stage 2-</strong></td>
<td>Green space</td>
<td>5117.81</td>
<td>53</td>
<td>76.46</td>
<td>116</td>
<td>1.52</td>
<td>10.06</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>SES level</td>
<td>9258.9</td>
<td>66</td>
<td>85.68</td>
<td>124</td>
<td>1.54</td>
<td>8.74</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>Adjusted analysis(^e)- Stage 3-</strong></td>
<td>SES level and greenness level</td>
<td>9258.9</td>
<td>66</td>
<td>85.95</td>
<td>124</td>
<td>1.50</td>
<td>7.60</td>
<td>0.12</td>
</tr>
</tbody>
</table>

\(^a\)RR: Relative Risks  
\(^b\)LLr: Log Likelihood ratio  
\(^c\)Unadjusted analysis, to identify and localize the most likely cluster/s of high risk of mortality, (first step of analysis)  
\(^d\)Adjusted analysis for greenness level or socio-economic neighbourhood (deprivation index), (second step of analysis)  
\(^e\)Adjusted analysis for greenness level and deprivation index at the neighbourhood level including the interaction between the two variables, (third step of analysis)
Figure legends

Figure 1. (A) Spatial distribution of the neighborhood socioeconomic index; (B) spatial distribution of greenness levels modeled across the Lyon metropolitan area.

Figure 2. Mapping of the most likely cluster of infant mortality (A), spatial shift of the most likely cluster of infant mortality after adjustment (B)

Figure 3. A conceptual model of mediating variables and their hypothesized association with pregnancy outcomes
Figure 1

Deprivation index
- High deprivation
- Moderate deprivation
- Low deprivation

Greenness index
- Low greenness index
- Moderate greenness index
- High greenness index

(A) Deprivation index map
(B) Greenness index map
Figure 2
Additional files provided with this submission:

Additional file 1: Appendix_0403.docx, 18K
http://www.biomedcentral.com/imedia/2927336069533628/supp1.docx