Low-income neighbourhood was a key determinant of severe COVID-19 incidence during the first wave of the epidemic in Paris

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ABSTRACT
Background Previous studies have demonstrated that socioeconomic factors are associated with COVID-19 incidence. In this study, we analysed a broad range of socioeconomic indicators in relation to hospitalised cases in the Paris area.

Methods We extracted 303 socioeconomic indicators from French census data for 855 residential units in Paris and assessed their association with COVID-19 hospitalisation risk.

Findings The indicators most associated with hospitalisation risk were the third decile of population income (OR=9.10, 95% CI 4.98 to 18.39), followed by the primary residence rate (OR=5.87, 95% CI 3.46 to 10.61), rate of active workers in unskilled occupations (OR=5.04, 95% CI 3.03 to 8.85) and rate of women over 15 years old with no diploma (OR=5.04, 95% CI 3.03 to 8.85). Of note, population demographics were considerably less associated with hospitalisation risk. Among these indicators, the rate of women aged between 45 and 59 years (OR=2.17, 95% CI 1.40 to 3.44) exhibited the greatest level of association, whereas population density was not associated. Overall, 86% of COVID-19 hospitalised cases occurred within the 45% most deprived areas.

Interpretation Studying a broad range of socioeconomic indicators using census data and hospitalisation data as a readily available and large resource can provide real-time indirect information on populations with a high incidence of COVID-19.

INTRODUCTION
The COVID-19 outbreak has been raging worldwide since late 2019, killing thousands and disrupting health systems with hundreds of hospitalised patients. During the first wave in France, 30 000 deaths occurred and more than 30 000 patients were hospitalised at its peak.

Some neighbourhoods had a higher incidence than others. From a public health perspective, highlighting neighbourhoods at high risk for severe COVID-19 infections is particularly useful to improve resource allocation. These neighbourhoods could be identified through census data linked to patient localisation, considering that individual outcomes, such as COVID-19 infection, are ultimately a product of context. Indeed, varying trends within countries in many of the core determinants of health, such as socioeconomic position, suggest a rich field for examining both the impact of social determinants on COVID-19 and the extent to which they depend on context. Numerous ecological studies have already been performed on COVID-19 and wide inequities have been shown.

These inequities are multifactorial, involving geographical, ethnical and socioeconomic factors, and no specific socioeconomic factors have been highlighted as particularly important regarding COVID-19 burden. Studying a very broad range of socioeconomic indicators by using all available census indicators with no a priori selection provides a global picture of neighbourhoods at risk and would allow us to highlight unexpected associations between COVID-19 incidence and some socioeconomic factors. This data-mining strategy has become common since the first genome-wide association studies and has been adapted to many kinds of data, such as phenotypes and medications. This type of study would facilitate the identification of specific environmental characteristics strongly associated with risk of COVID-19 with no a priori hypotheses regarding the type of associated indicator.

In this paper, our objective is to analyse to what extent a broad range of census indicators were associated with the incidence of hospitalisation for COVID-19 in the Paris area during the first wave of the epidemic.

MATERIALS AND METHODS
Our analysis follows the recommendations provided by RECORD (REporting of studies Conducted using Observational Routinely collected health Data) (online supplemental table S2).

Data extraction
New patients who tested positive by PCR from 1 February until 4 June, hospitalised in one of the hospitals of Assistance Publique - Hôpitaux de Paris (AP-HP) and living in Paris were aggregated at the Ilots Regroupés pour l’Information Statistique (IRIS) Paris division level, which is the smallest geographical division in France with 2000 inhabitants, on average, to generate the data set for this study. Patient addresses reported by patients when hospitalised were localised through an open application programming interface available from...
the French government website. Given the centralised healthcare organisation during the COVID-19 epidemic, COVID-19-infected patients were mostly hospitalised at AP-HP hospitals, and private clinics did not treat patients with COVID-19.

For each IRIS unit, we retrieved all information available as open data at this IRIS scale from 2016 census data, including 71 indicators on population demographics and distribution, 51 on housing, 86 on professional activity, 55 on family types, 19 on education and 21 on income, for a total of 303 indicators.

Methods
High-risk and low-risk IRIS units were defined using the first decile of this proportion. We then assessed the association of a given socioeconomic indicator above the median value with having a high risk of COVID-19 for each of the 303 socioeconomic indicators using $\chi^2$ test. P values for the different tests performed were represented through a Manhattan plot using the type of indicator as the variable group.

RESULTS
As of 3 June 2020 (the end of the first wave of the epidemic), 3400 patients have been hospitalised in one of the 855 residential areas (online supplemental figure S1), with a median number of hospitalised cases per residential area of 3 (IQR: 1–5). According to 2016 census data, these 855 Paris residential areas had a population of 2,145,817 individuals for a total area of 71.5 km$^2$, that is, 30,011 inhabitants/km$^2$. These 3400 patients had a median age of 71 years (IQR: 57–83) and 55% were men. The median number of days of hospitalisation was 12 (IQR: 5–34). In total, 20% were hospitalised in the intensive care unit and 7% died 30 days after admission. The first decile of the COVID-19 hospitalisation rate among Paris residential areas was equal to 3 per 1000 inhabitants.

The indicators most strongly associated with this first decile were related to income and occupational status (figure 1 and online supplemental table S3). The indicator most significantly associated with hospitalisation risk was income corresponding to the third decile of the population (OR=9.10, 95% CI 4.98 to 18.39) (figure 2 and online supplemental figure S2). Overall, 86% of COVID-19 hospitalised cases occurred within the 45% most deprived areas. Regarding population indicators, the most significantly associated indicators concerned population activities. Specifically, the rate of workers in blue-collar unskilled occupations was strongly associated with high-risk areas (OR=4.38, 95% CI 2.67 to 7.51), and the rate of highly qualified workers was strongly associated with low-risk areas (OR=0.19, 95% CI 0.10 to 0.31). Population demographics were much less associated with hospitalisation risk. Among these factors, the highest association was observed for the rate of women aged between 45 and 59 years (OR=2.17, 95% CI 1.40 to 3.44). Of note, population density was not associated with hospitalisation risk (OR=1.1, 95% CI 0.72 to 1.69). In addition, male sex (OR=1.27, 95% CI 0.83 to 1.95), age 80 years or older (OR=0.76, 95% CI 0.49 to 1.16) and age 65–79 years old (OR=1.05, 95% CI 0.69 to 1.61) were not associated with hospitalisation risk. The rate of immigrants (OR=3.20, 95% CI 2.01 to 5.25), rate of active workers in unskilled occupations (OR=5.04, 95% CI 3.03 to 8.85) and rate of unemployment (OR=4.69, 95% CI 2.84 to 8.14) were strongly associated with hospitalisation risk. The most strongly associated housing indicators were the primary residence rate (OR=5.87, 95% CI 3.46 to 10.61) and public low-rent housing rate (OR=4.69, 95% CI 2.84 to 8.14). The most associated education indicator was the rate of women over 15 years old with no diploma (OR=5.04, 95% CI 3.03 to 8.85). The two most associated household indicators were the rate of household heads with an unskilled occupation (OR=4.38, 95% CI 2.67 to
We show that many socioeconomic indicators are strongly associated with areas of high incidence of hospitalised patients with COVID-19 in Paris. Overall, 86% of COVID-19 hospitalised cases occurred within the 45% most deprived areas. This finding is consistent with the idea that COVID-19 occurred as a syndemic—a synergistic pandemic that interacts with and exacerbates a person’s existing non-communicable diseases and social conditions. The subgroup highlighted as over-represented in the high-risk area, that is, the population with unskilled occupations living in deprived areas, is not at high risk for severe COVID-19 because these people are still active, but are likely to have a high rate of infection. Indeed, lower-paid workers, particularly in the service sector (e.g., food, cleaning or delivery services), are much more likely to be designated as key workers and thus are required to go to work and rely on public transport to do so. All of these factors increase their exposure to the virus and virus transmission in their neighbourhood and thus indirectly contributing to an increased hospitalisation rate.

The strong association between income level and high-risk areas has to be faced with the low level of inequalities in France compared with the level worldwide. The French healthcare system is ranked among the best in terms of waiting times, results and benefits, which renders these results unexpected. Indeed, socioeconomic studies performed in other countries, including the USA and the UK, did not show such strong associations, with an OR of approximately 3 for poverty in Chicago and approximately 2 in England.

Population density in residential areas is high, but the IQR area, that is, the population with unskilled occupations living in deprived areas, is not at high risk for severe COVID-19 because these people are still active, but are likely to have a high rate of infection. Indeed, lower-paid workers, particularly in the service sector (e.g., food, cleaning or delivery services), are much more likely to be designated as key workers and thus are required to go to work and rely on public transport to do so. All of these factors increase their exposure to the virus and virus transmission in their neighbourhood and thus indirectly contributing to an increased hospitalisation rate.

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The gradient of the income third decile (left) and COVID-19 hospitalised cases >3 per 1000 inhabitants (right) in Paris residential areas. Non-residential areas are not covered by a red colour gradient.
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Contributors
A-SJ designed the study. HC, BR and AB developed the framework for GeoCancer, the pipeline that was reused to integrate the geodata of patients with COVID-19 in this study. HC and BR performed the geolocalisation of patients’ residential address and the data aggregation. A-SJ, HC and BR had full access to the aggregated data used for this study and take responsibility for the integrity of the data. A-SJ did the analyses and takes responsibility for the accuracy of the data analysis. AVS extracted the clinical data of patients with COVID-19 and participated in their analysis. A-SJ drafted the paper with the help of HC, AB and SK. Data were collected from Assistance Publique - Hôpitaux de Paris. All authors critically reviewed the manuscript for important intellectual content and gave final approval for the version to be published.

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Competing interests
None declared.

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Not required.

Ethics approval
This study was approved by the Scientific and Ethical Committee of AP-HP (Assistance Publique - Hôpitaux de Paris) (authorisation number IRB 00011591).

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