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Spatial diffusion of COVID-19 in Algeria during the third wave

Carlos M. Leveau · Hani Amir Aouissi · Feriel Kheira Kebaili

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Abstract The differential geographic impact of the third wave of COVID-19 is unknown in Algeria. We thus analyze the spatiotemporal variations of cases and deaths of COVID-19 in Algeria, between January and mid-August 2021. Cases and deaths due to COVID-19 were aggregated at the *wilaya* (province) level. The space–time permutation scan statistic was applied retrospectively to identify spatial–temporal clusters of COVID-19 cases and deaths. We detected 14 spatio-temporal clusters of COVID-19 cases, with only one high risk cluster. Among the 13 low risk clusters, 7 clusters emerged before the start of the third wave and were mostly located in *wilayas* with lower population density compared to the clusters that emerged during the third wave. For deaths, the largest geographic low-risk cluster emerged in southern Algeria, between April and early July 2021. Northern and coastal *wilayas* should be prioritized when allocating resources and implementing various quarantine and isolation measures to slow viral transmission.

Keywords Coronavirus Infections · Spatio-Temporal Analysis · Mortality · Population Density · Algeria

Introduction

Between February and March 2020, the countries of North Africa –Algeria, Egypt, Libya, Morocco, and Tunisia– detected their first cases of COVID-19, mostly from European countries (Daw, 2020). Since then, the virus has spread within these countries, with 3,138,333 confirmed cases and 76,810 deaths as of January 31, 2021 (WHO, 2022). This general picture does not reflect the heterogeneous impact of the COVID-19 pandemic on the countries of the region, with rates of reported cases per 100,000 inhabitants ranging from 7766 in Tunisia to 418 in Egypt. Regarding mortality due to COVID-19, rates per 100,000 inhabitants range from 223 in Tunisia to 15 in Algeria (WHO, 2022).

Despite this heterogeneity, there appears to be a common pattern of virus spread in the region. During the first wave, COVID-19 first spread to the most

C. M. Leveau (✉)
Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina
e-mail: cmleveau@hotmail.com

C. M. Leveau
Instituto de Producción, Economía y Trabajo (IPET), Universidad Nacional de Lanús, Remedios de Escalada, Argentina

H. A. Aouissi
Scientific and Technical Research Center on Arid Regions (CRSTRA), 07000 Biskra, Algeria
e-mail: aouissi.amir@gmail.com

F. K. Kebaili
Laboratoire de Recherche et d'étude en Aménagement et Urbanisme (LREAU), USTHB, 16000 Algiers, Algeria
e-mail: kebailifer.94@gmail.com

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populous cities and other coastal cities in North African countries (Daw et al., 2020). The virus then moved into the less populated southern regions of these countries. This space–time pattern is consistent with the qualitative model of the spread of mortality from a communicable disease within a system of cities (Cliff et al., 1998). First, in the context of a pandemic, large cities experience the first spikes in mortality and act as reservoirs of infection. Second, a hierarchical transmission begins, from large cities to smaller cities. Third, due to the small size of the susceptible populations in the smaller cities, the recurrence of their mortality peaks is caused primarily through hierarchical transmission.

Algeria is one of the most populous North African countries and with the largest territorial extension in Africa. Facing southern Europe, Algeria is considered vulnerable to the spread of new variants of concern of SARS-CoV-2 (Aouissi, 2021; Sun et al., 2020). During February and March 2020, Algeria likely received the highest number of imported COVID-19 cases from Europe, compared to any other African country (Sun et al., 2020). The COVID-19 pandemic emerged in Algeria through imported cases from Italy, France and Spain (Daw et al., 2020), with the first case detected on February 25, 2020 (Ababsa & Aouissi, 2020; Aouissi et al., 2021). Since then, Algeria has been hit by three waves of COVID-19 (World Health Organization, 2021). Introducing the spatial dimension in the analysis of COVID-19 waves is critical to predicting local outbreaks and developing differential public health policies according to each wave. To our knowledge, only two studies analyzed the spatial distribution of COVID-19 in Algeria: covering the first month of the pandemic (Daw et al., 2020), or analyzing until the second wave of transmission in 2020 (Kalla et al., 2021). During the first months of the pandemic, the virus appeared to follow a hierarchical pattern of spatial diffusion, initially affecting the main cities in the north of Algeria (Kadi & Khelfaoui, 2020) and then spreading to the less densely populated *wilayas* (provinces) in the south of the country. The third wave that began in July 2021 (Fig. 1) was marked by two opposing phenomena: the introduction and rapid transmission of the Delta variant in the country – responsible for 71% of the cases (Institut Pasteur d'Algérie, 2021e)–, and the start of vaccination against COVID-19. In this context, we expect that during the third wave, the *wilayas* in the north of Algeria, where the most populated cities are located, will register the highest proportion of cases and deaths compared to the pre-wave phase and the *wilayas* in the south of the country. The aim of this paper is to analyze the spatiotemporal variations of cases and deaths of COVID-19 in Algeria, between January and mid-August 2021.

Methods

COVID-19 data were obtained from the Algerian Ministry of Health, Population and Hospital Reform. We used daily confirmed cases and deaths due to COVID-19 from January 1, 2021 to August 15, 2021. Cases and deaths were aggregated at the *wilaya* level (n = 48). The space–time permutation scan statistic (Kulldorff, 2013) was applied retrospectively to identify spatial–temporal clusters of COVID-19 cases and deaths, georeferenced to the centroid of each province. This space–time model uses only case data and detects a space–time cluster if an area, during a specific period of time, has a higher proportion of cases than the rest of the areas during that same period of time (Kulldorff, 2013). For cases, the time was considered as the day of confirmation of a positive COVID-19 case using PCR methods. For deaths, time was considered as the date of death. The spatial dimension was the *wilaya* of residence for both the cases and the deaths. The space–time scan statistic investigated the concentration of cases and deaths within a variable time window in different geographic areas to compare the expected number of cases and deaths and the actual number of cases and deaths within and outside the window (Kulldorff, 2013). The variable scan window was set at a maximum limit of 10% of deaths, to detect small clusters, and 50% of the study period. The result is a set of cylinders where the base represents the area and the height represents the period of time in which the cases and deaths are concentrated. Maximum likelihoods were calculated to determine the clusters with the lowest probability of being explained by chance, whose *P* value is assigned by the Monte Carlo hypothesis test, performing 9,999 replications.

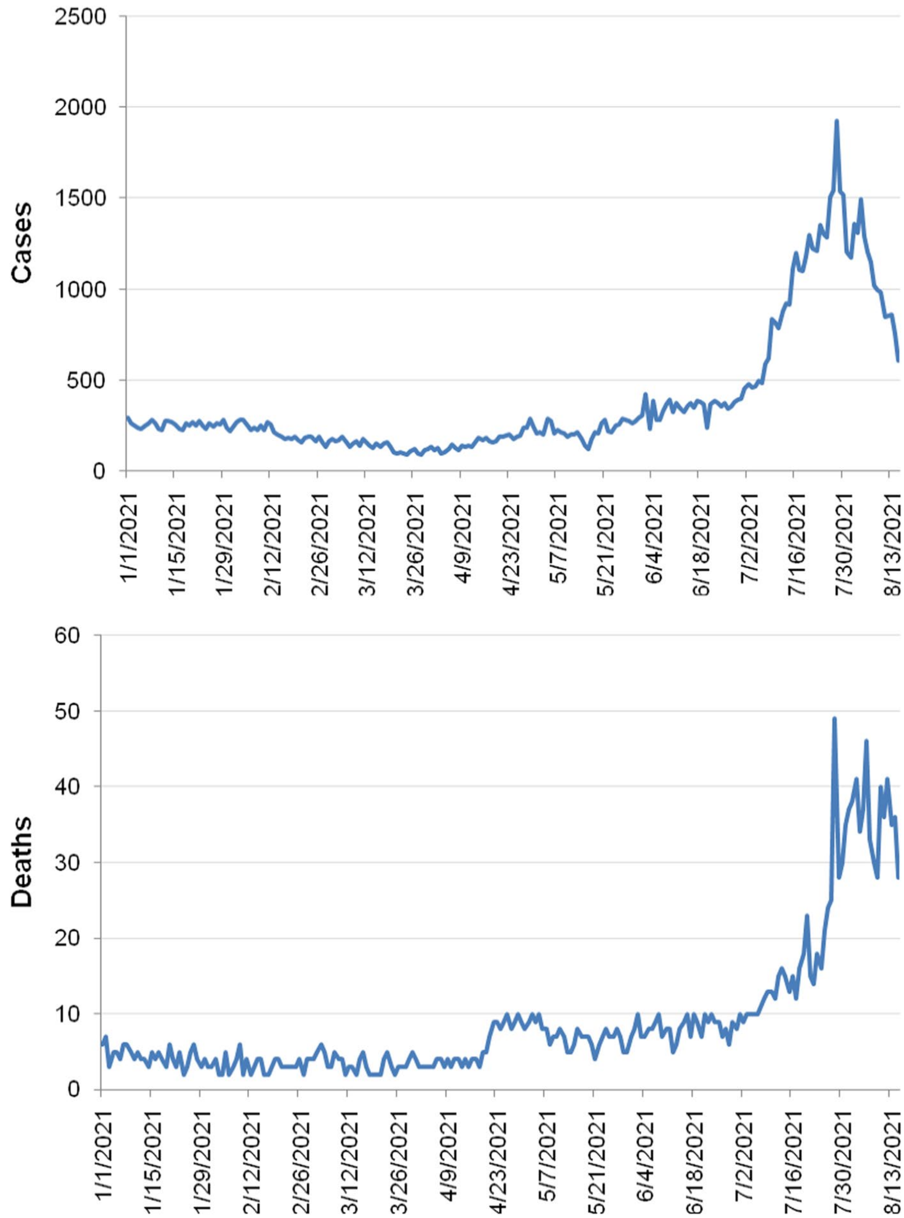

Fig. 1 Daily cases and deaths from COVID-19. Algeria, January 1, 2021–August 15, 2021

Results

Between January and June 2021, positive cases of COVID-19 ranged between 181 and 422 cases per day (Fig. 1). Then, an accelerated growth of cases began to be observed from July 9, reaching a peak of 1927 cases on July 27. Deaths from COVID-19 showed a similar temporal variation to cases, without exceeding 10 daily deaths between January and June (Fig. 1). Then, between July and mid-August, there were two peaks of 49 and 46 deaths on July 28 and August 6, respectively.

We detected 14 spatio-temporal clusters of COVID-19 cases, with only one high risk cluster (more cases than expected). Clusters that emerged as of January 1, 2021 and ended before July 9, 2021 (Fig. 2: clusters 3, 5, 8, 9, 11, 13, and 14) were considered pre-third wave clusters (Fig. 1). Among the 13 low risk clusters, 7 clusters emerged before the start of the third wave and were mostly located in *wilayas*

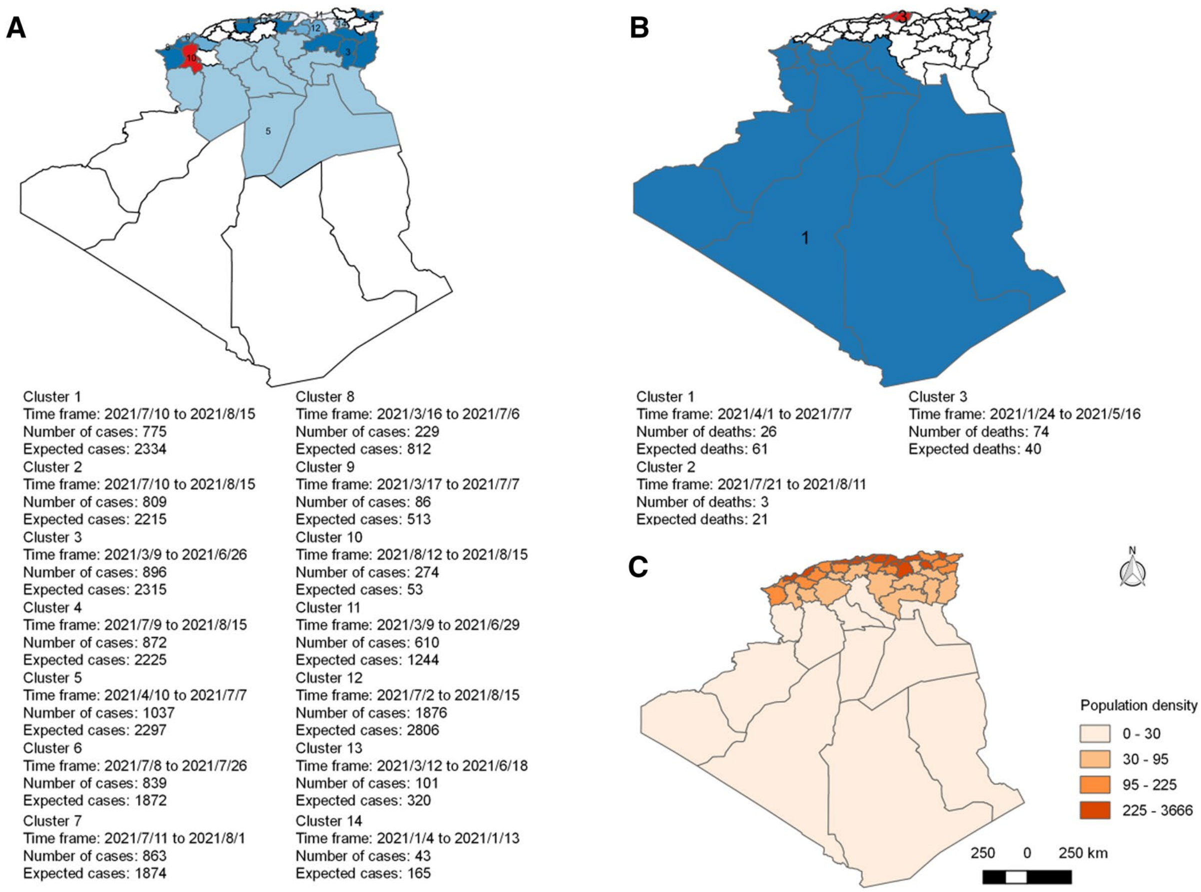

Fig. 2 Space–time clusters of COVID-19 cases (**A**) and deaths (**B**), and geographic distribution of population density (C, inhabitants per km2 based on 2008 population census)

with lower population density compared to the clusters that emerged during the third wave (Mann–Whitney test; $Z=2.9$, $P<0.01$; Fig. 2). For deaths, low risk clusters were located first in the southern part of the country, between April and early July 2021, and then in the extreme northwest of the country between late July and early August 2021 (Fig. 2). Only a high risk cluster emerged west of Algiers, between late January and mid-May 2021.

Discussion

Low transmission clusters of COVID-19 prior to the third wave tended to be located in *wilayas* of lower population density with respect to the low transmission clusters during the third wave. This wave has not appeared to disproportionately affect Algiers, the most populated city of the country. The spatio-temporal analysis did not detect clusters in this city, showing that the proportion of cases and deaths remained at the same levels before and during the third wave. Two spatio-temporal processes could explain these variations in the emergence of clusters.

First, the introduction of the Delta variant in Algeria seemed to follow hierarchical diffusion. The first cases of this variant were predominantly detected in early May in Algiers (Institut Pasteur d'Algérie, 2021c, 2021d) and other contiguous high-density *wilayas* (Institut Pasteur d'Algérie, 2021a, 2021b) in the north of the country. This could explain the emergence of low-risk clusters of cases and deaths until the beginning of July 2021 in low-density *wilayas* in southern Algeria. Second, the vaccination campaign was first launched in most populated cities in northern Algeria (Kacimi et al., 2021; Slimani, 2021). It is possible that a rapid progress of vaccination against COIVD-19 in the *wilayas* of high population density in the north of the country could be related to the emergence of clusters of low risk of transmission during the third wave.

Although to our knowledge there are no spatio-temporal analyzes of the spread of COVID-19 in other North African countries during the third wave, there are some indications of a hierarchical spread of the virus through the settlement system in these countries. It is possible that the entry of the Delta variant was in the main cities through passenger air transport, as was reported in Morocco (Babas, 2021), and then a rapid transmission of the virus within these cities (Bounouh, 2021). Furthermore, like Algeria, the other North African countries have a concentration of their main cities in the north, mainly in coastal areas, while small cities and areas with very low population density predominate in the south. This general geographic pattern of population distribution in North Africa could translate into a constant north–south spread of COVID-19 in its successive waves of transmission.

This study has some limitations. First, a sub-registry of COVID-19 cases and deaths is possible in Algeria. However, since April 2020 the government decided to severely punish the non-declaration of a case of COVID-19 (Mounia, 2020). Unfortunately, to our knowledge there is no information available to assess whether this sub-registry showed geographic differences. Second, the Modifiable Areal Unit Problem arises from the use of spatially aggregated data, meaning that the availability of data in spatial units smaller than the *wilayas* could yield different results.

In summary, during the initial phase of increase in cases of the third wave of COVID-19, the southern part of Algeria was at low risk of virus transmission, while the northern part of the country showed an expected increase in transmission. We suggest that northern and coastal *wilayas* should be prioritized when allocating resources and implementing various quarantine and isolation measures to slow viral transmission.

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Authors' contributions **Carlos M. Leveau**: Conceptualization; Methodology; Software; Writing—Original Draft Preparation; Writing—Review & Editing; Supervision; Validation. **Hani Amir Aouissi**: Conceptualization; Methodology; Investigation; Writing – Original Draft Preparation; Writing—Review & Editing; Validation; Visualization. **Feriel Kheira Kebaili**: Investigation; Resources; Data Curation.

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Availability of data and materials The data generated and/or analyzed in the current study is available from the corresponding author on reasonable request.

Declarations

Conflict of interest All authors declare no conflict of interest.

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Consent to participate Not applicable.

Consent for publication Not applicable.

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