COVID-19 mortality and environmental factors during wet and dry seasons in West and Southern AFrica

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Abstract

SubSahara Africa has been the last continent to experience a significant number of cases in the novel Coronavirus (COVID-19). Several studies have suggested that air pollution is related to COVID-19 mortality; poor air quality has been linked to cardiovascular, cerebrovascular, and respiratory disease, which are considered co-morbidities linked to COVID-19 death. We examine potential connections between country-wide COVID-19 mortality and environmental conditions in Senegal, Cabo Verde, Nigeria, Cote D'Ivoire, and Angola. We analyze PM2.5 concentrations from cost-effective in situ measurements, aerosol optical depth (AOD), and fire count from space-borne platforms during the dry season when dust and biomass burning aerosols are present in Southern Africa. In addition, we examine the COVID-19 mortality during the wet season using space-borne rain measurements to determine potential linkages which might occur as a result of time spent indoors and concurrent cases of flu, waterborne and vector-borne diseases in West Africa. Results are presented from March through December of 2020.

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Abstract

Sub-Saharan Africa has been the last continent to experience a significant number of cases in the novel Coronavirus (COVID-19). Several studies have suggested that air pollution is related to COVID-19 mortality; poor air quality has been linked to cardiovascular, cerebrovascular, and respiratory disease, which are considered co-morbidities linked to COVID-19 deaths. We examine potential connections between country-wide COVID-19 mortality and environmental conditions in Senegal, Cabo Verde, Nigeria, Cote D'Ivoire, and Angola. We analyze $PM_{2.5}$ concentrations from cost-effective in situ measurements, aerosol optical depth (AOD), and fire count from space-borne platforms during the dry season when biomass burning aerosols are present in Southern Africa. In addition, we examine the COVID-19 mortality during the wet season using space-borne rain measurements to determine potential linkages which might occur as a result of time spent indoors and concurrent cases of flu, waterborne and vector-borne diseases in West Africa. Results are presented from March through November of 2020. The current dry season has the potential to increase the severity of COVID-19 cases because of expected poor air quality.

Keywords: COVID-19, environmental factors, West Africa, Southern Africa

1. Introduction

The novel coronavirus COVID-19, first detected in Wuhan, China, in December 2019, has become a global pandemic, with more than 60 million known cases and 1.5 million deaths worldwide as of December 1, 2020. COVID-19 deaths have been highly linked to co-morbidities such as heart disease, diabetes, obesity, and respiratory disease, as well as exposure to higher concentrations of air pollution [Jordan et al. 2020; Clerkin et al. 2020; Wu et al. 2020]. In the United States, racial differences in COVID-19 mortality have been found in African Americans and other minority groups [Yancy 2020; Tai et al. 2020]. These higher mortality rates among African Americans may be caused by higher rates of these co-morbidities than other racial groups. Coincidentally, African Americans are subject to the highest-burden of emissions from air pollution sources, and older African Americans have the highest mortality rates due to pollution in the United States [Mikati et al. 2018; Di et al. 2017]. Older patients who have contracted

COVID-19 also have a higher chance of dying in nursing home facilities [O'Driscol et al. 2020]. The largest number of cases have occurred in North America, Europe, and Asia in countries such as the United States, Spain, Italy, India, and Brazil.

Surprisingly, Sub Sahara Africa has been the last to see a surge in COVID-19 cases, with South Africa having nearly 750,000 cases as of December 1, 2020, followed by Ethiopia [Mbow et al. 2020]. Given the propensity of COVID-19 to lead to greater fatalities in older populations, it does not fully explain why so few have contracted the virus in Africa. Mbow et al. [2020] suggest that the age differences should lead to four times less the number of COVID-19 cases instead of 40 times and suggest that other factors related to the immune system may be at work. In addition, there is also less test available which might explain some of the lower numbers of COVID-19 cases.

The environment may also play a direct or indirect factor in the spread or seriousness of COVID19 cases. Atmospheric pollutants such as NO_2 and $PM_{2.5}$ aerosols caused by urbanization, traffic, and industrial sources are associated with higher incidence and mortality rates of respiratory diseases Landrigan et al. 2018]. COVID-19 is a viral respiratory disease that is considered to be highly contagious, with a probable aerosol spread for human transmission. Studies have linked atmospheric pollutants such as NO_2 and $PM_{2.5}$ to COVID-19 cases and mortality in the United States, Europe, and China [Wu et al. 2020; Liang et al. 2020; Ogen 2020; Yongjian et al. 2020]. The linkage between temperature and COVID cases remains unclear, with cold temperatures being expected to increase COVID-19 cases and warmer temperatures potentially reducing COVID-19, but early results show regional variations [Prata et al. 2020; Chien and Chen 2020; Sarkodie et al. 2020];

Even though COVID-19 cases in Africa are less than those in high and middle-income countries, there are reasons for concern, including the lack of critical health facilities and equipment such as intensive care units, ventilators, and health care staff Wadvalla [2020]. In addition, atmospheric pollutants vary spatially and temporally due to numerous emission sources from urban pollution to the Sahara Desert, which is the largest source of dust emission globally [Engelstaedter et al. 2006; Petkova et al. 2013]. These pollutants are poorly observed, but limited observations in West Africa show that hazardous particulate matter concentrations are observed in the densely populated city of Dakar, Senegal [Diokhane et al. 2016]. This work aims to examine trends in COVID-19 cases, mortality, and environmental variables in countries of West Africa and Southern Africa (Figure 1): Guinea Region (Nigeria, Cote D'Ivoire --Ivory Coast), Western Sahel (Senegal), Island Nation of West Africa (Cabo Verde), Southern Africa (Angola).

2. Methodology and Data Sources

We used different data sources to examine COVID-19 new cases and deaths with data from the World Health Organization (WHO) daily country data for new cases and fatalities in Angola, Cabo Verde, Ivory Coast, Nigeria, and Senegal (www.covid19.who.int). Data are averaged over a one-week period to take into account countries that do not report each day.

For environmental data, we examine rainfall, aerosol optical depth (AOD), fire counts, and used the low-cost Purple Air (PA) sensors to examine $PM_{2.5}$ concentrations and temperatures. We used satellite-based data for AOD, fire counts, and daily rainfall.

We use daily 1º x 1º gridded satellite-based AOD measurements based on the shapefile of each country from the Moderate Resolution Imaging Spectrometer (MODIS) instrument aboard the TERRA/AQUA using land and ocean point for Cabo Verde and the Deep Blue product for Angola, Ivory Coast, Nigeria and Senegal [Hsu et al. 2013]. The data is also averaged for one-week for direct comparison to WHO COVID-19 data in each country. The AOD data would capture atmospheric aerosol loading from biomass burning, urban pollution, and mineral dust aerosols from Africa's deserts.

We use thermal anomalies from the VIIRS daily overpasses to identify fire locations in each for Angola, Ivory Coast, Nigeria, and Senegal [Schroeder et al. 2014]. Cabo Verde does not have a fire season and so it is not considered. Daily fire counts are averaged over one week for direct comparison to WHO COVID-19 data in each country. We use 1° x 1° gridded daily satellite-based precipitation, which provides rainfall estimates from microwave, infrared, and the Global Precipitation Measurement (GPM) radar based on the shapefile of each country to estimate daily rainfall [Liu 2016]. Only daily rainfall amounts are used to examine its relationship to weekly COVID-19 data and determine the start, middle, and end of the rainy periods.

PA devices are low-cost devices that provide high temporal resolution data (www2.purpleair.com). Two low-cost optical devices are used for determining particulate matter (PM_1, $PM_{2.5}$, and PM_{10}), relative humidity and temperature sensors are also included. We used daily and weekly averaged $PM_{2.5}$ concentrations and temperature data comparing to country-wide COVID-19 new cases and deaths. We use the following stations for comparisons to COVID-19 data: Luanda, Angola (-8.929027° S 13.184946° E); Lobito, Angola (12.355968° S, 13.533997° E); Praia, Cabo Verde (14.911585° N, 23.526135° W); Ibadan, Nigeria (7.4430° N, 3.9036° E); Dakar, Senegal (14.681593° N -17.467438° W).

3.Results

3.1 COVID-19 Statistics

These WHO COVID-19 data show that for the five countries: (1) Nigeria has the highest number of COVID-19 cases and deaths but has the smallest number of tests per million persons; (2) Cabo Verde has the smallest number of deaths but has the highest number of tests per million; (3) the total number of COVID-19 test has not exceeded 1 million in any of the five countries (Table 1). The low total number of tests could be due to cost constraints for individuals who want to test, along with the available test kits within a country due to global availability. The data also shows that the median age is very young, with the median age being less than 20 years of age in four out of five countries.

3.2 Environmental and COVID-19 Results for Angola

Angola is subject to biomass burning as part of agricultural practices from May through November. Figure 2a shows the average number of weekly thermal anomalies and COVID-19 cases in Angola. The number of new COVID-19 weekly cases increases throughout the biomass burning period reaching a maximum value when fires decrease in November. The increase in AOD corresponds to the increasing fire count in November before falling (Figure 2b). The same pattern is repeated in new weekly deaths; however, we find the first peak in COVID-19 deaths occurring in August during the fire season, followed by a larger peak in new deaths during late October (Figure 2c). The maximum number of COVID-19 deaths also follows increasing AOD in August and during late September of 2020.

Daily precipitation amounts and their relationship to COVID-19 new cases and deaths are shown in Figure 3. The year starts with the wet period followed by diminishing rains in May and the start of a new wet season in September. Because the rainy season began before the pandemic, no relationship exists. The new rainy season occurred as the number of weekly COVID-19 cases and deaths were occurring. Because of the rainy period's earliness, it is difficult to establish a true connection between daily rainfall and weekly COVID cases and deaths.

We used the PA data at Luanda, Angola, to examine connections to local conditions at the Angolan capital. The rise in PM2.5 concentrations occurs in May and rises through September at Luanda (Figure 4a). Decreasing PM2.5 occurs several months prior to the peak in COVID-19 cases. As shown in Figure 2c, the first peak in COVID-19 deaths occurs in August when the peak of PM2.5 concentrations are found every week. We also find a decrease in PA weekly average temperatures as COVID-19 cases increase during July and August (Figure 4b). Examination of daily PA temperatures at Luanda and Lobito both show decreasing temperature trends as COVID-19 cases increase during the period with the first peak in COVID-19 deaths (Figures 4c, d).

3.3 Environmental and COVID-19 Results for Cabo Verde

Figures 5 a-b shows the weekly AOD along with COVID-19 weekly new cases and deaths. During its dry season at the beginning of the year, we find higher AOD values, but COVID-19 had not reached Cabo Verde. COVID-19 new cases and deaths began to increase during May through late October before decreasing. During late June, the peak in AOD was associated with a large dust event, which was elevated reaching the United States in the last week in June. Because the large AOD is linked to dust located 1.5 km or higher above the ground, its impact on air quality is limited.

Rainfall amounts are also very low in Cabo Verde, but flooding did occur during the second week in Praia, and several tropical disturbances passed near and over the country from late August through September. However, COVID-19 cases and mortality increased prior to and during the rain period (Figures 5 c, d). The weekly $PM_{2.5}$ concentrations and temperatures suggest a weak connection to COVID-19 cases. The PA data from Praia shows higher PM2.5 concentrations early in the year, but these values occurred before the first COVID-19 cases (Figure 6a).

Values of $PM_{2.5}$ concentrations remain low, and air quality is considered good through the period after March 2020. The ocean also controls the temperatures to a large extent, and although temperatures are rising while COVID-19 cases are rising, the physical connection to COVID-19 remains weak and unclear (Figure 6b). The COVID-19 and environmental data in Cabo Verde suggest that community spread was more important than environmental conditions.

3.4 *Environmental and COVID-19 Results for Ivory Coast*

Ivory Coast experiences poor air quality from biomass burning during its dry season (November-February). Figures 7 a, b show that the largest number of weekly average fire locations occurred in February and decreased to low values just before when the number of COVID-19 cases began to increase (Figure 7a). The AOD remains relatively high until May, with a secondary peak occurring in late May. The number of weekly fires remains uncoupled from the weekly new COVID-19 deaths (Figure 7c), while the secondary peak in AOD during May occurs a week before the highest number of recorded COVID-19 deaths (Figure 7d). The start of the rainy season begins in earnest by early April and continues until November. We find increases in COVID-19 cases and deaths from April through July, followed by a decline in COVID-19 cases during the wet season (Figures 8 a, b). The peak in COVID-19 cases and deaths occur as the ITCZ moves north of the Ivory Coast into the Sahel region during July and August. The PA sensor were not functioning during part of the spring and summer and hence there was insufficient PM2.5 concentration and temperature data for comparison to weekly COVID-19 cases.

3.5 *Environmental and COVID-19 Results for Nigeria*

Nigeria follows a similar pattern for biomass burning during the dry season compared to the Ivory Coast (Figures 9a); the number of weekly fire counts reaches a maximum value during February before falling off rapidly in April. The AOD follows a similar pattern to fire counts, with the highest values occurring in February and decreasing throughout the year (Figure 9b). The peaks in COVID-19 new cases and deaths occur during July and August when fire counts and AOD have fallen to relatively low values (Figures 9c, d).

Daily rainfall rates increase in April and May when COVID-19 cases and deaths also increasing (Figures 10a, b). The highest numbers of new COVID-19 cases and deaths occur just after the first part of the rainy season and level out as the ITCZ moves northward into the Sahel. This pattern is similar to what the patterns of rainfall and COVID-19 cases/deaths in Ivory Coast. Figure 11a shows weekly PA $PM_{2.5}$ concentrations and temperatures at Ibadan, Nigeria, for new COVID-19 cases. The $PM_{2.5}$ concentrations show very high values during February prior to COVID-19 being present in Nigeria, and values remain fairly low until November.

Figure 10b shows decreasing temperatures during the period when COVID-19 cases were increasing in response to the wet season and the likelihood of greater cloud coverage. The lowest temperatures occur in July and begin to increase while COVID-19 cases decrease. Daily temperatures from the PA sensor shows decreasing daily temperatures during April while COVID-19 cases were increasing and a second period during June just prior to the peak in COVID-19 cases (Figure 11c).

3.6 *Environmental and COVID-19 Results for Senegal*

The spatial coverage of biomass burning during the dry season is smaller in Senegal than Angola, Ivory Coast, and Nigeria because of the transition to semi-arid and arid conditions in the north, where there is less vegetation. Consequently, a lower fire count is found in February and October/November than Ivory Coast and Nigeria (Figure 12a). Senegal is also subject to dust events during the winter/spring seasons and during the summer is above the monsoon layer. A large dust event above the monsoon layer occurred in June, as is evident when examining the AOD (Figure 12b), but as shown below, the PM levels were high for only a day or two. Any influence from poor air quality would have occurred more recently as the virus was not present in Senegal during the last dry season. The peak in COVID-19 deaths and mortality occurred during late summer when aerosols levels would have been limited.

Like Nigeria and Ivory Coast, we find the highest number of new COVID-19 cases and deaths occurring during the wet season but lagging those in Nigeria and Ivory coast by 1-2 months (Figure 13a, b). The peaks in new weekly COVID-19 deaths proceeded those of new COVID-19 cases in the summer of 2020. PA data from Dakar, Senegal, shows a reduction in PM2.5 to healthy levels from March through October, which is expected during the rainy season. High $PM_{2.5}$ concentrations occurred in Jan-April prior to COVID-19 cases becoming significant (Figure 14a).

Cooler weekly and daily temperatures during April and May recorded by the PA sensor are found when COVID 19 cases began to increase relative to the warmer temperatures in March and June (Figures 14 b, c). These changes in PA temperatures need to be verified against data from the weather service of Senegal.

4. Discussion and Conclusion

In this preliminary work, we have examined the linkages between COVID-19 cases and deaths with AOD, fire locations, satellite estimated precipitation, and PA $PM_{2.5}$ concentrations and temperature data for Angola, Cabo Verde, Ivory Coast, Nigeria, and Senegal for 1 January-15 November 2020. While COVID-19 cases are relatively low in the five countries that were examined, caution and careful environmental monitoring over the next six months are required for all of the countries.

In West Africa, the dry season is expected to: (1) produce poor air quality, low relative humidity, and colder temperatures, which may become potential environmental drivers of COVID-19 cases and deaths with desert dust and biomass burning expected to increase over the next three months. (2) Decreasing temperatures in January and February are expected to increase indoor activity and transmission. (3) The impact of poor air quality for patients who contract COVID-19 could be severe for millions of people in West Africa. It is especially true for countries like Senegal, where we have identified significant numbers of adults with asthma and children with acute respiratory infections [Toure et al, 2019]. Further, possible pathogens have been identified on dust aerosol surfaces and could impact respiratory health [Marone et al. 2020]. (4) This combination of poor air quality and cooler temperatures is expected to increase indoor activity, possibly increasing COVID-19 cases and exposure to indoor pollution from cooking. In Southern Africa, (1) the wet season over the next four months may increase indoor activity in some regions and potential transmission of COVID-19. (2) The increase in precipitation may increase flu, vector, and water-borne diseases, but the interactions with COVID-19 remains unknown.

As part of this work, we have developed a low-cost air quality network in West Africa and Angola, but the network is still very sparse. Additional limited air quality data at US embassies in Africa and other developing networks can assist with real-time measurements and post-COVID-19 research with epidemiologists in these countries. Collaboration and cooperation across sectors and disciplines are required to inform decision-makers and the public about environmental conditions. The use of masks will benefit citizens and reduce COVID-19 transmission and limit some larger-sized particulate matter when outdoors. The mask can also reduce the transmission of COVID-19 and influenza indoors.

5. References

Chang, S., Pierson, E., Koh, P. W., Gerardin, J., Redbird, B., Grusky, D., & Leskovec, J. (2020). Mobility network models of COVID-19 explain inequities and inform reopening. Nature, 1-8.

Chien, L. C., & Chen, L. W. (2020). Meteorological impacts on the incidence of COVID-19 in the US. Stochastic Environmental Research and Risk Assessment, 34(10), 1675-1680.

Di, Q., Dai, L., Wang, Y., Zanobetti, A., Choirat, C., Schwartz, J. D., & Dominici, F. (2017). Association of short-term exposure to air pollution with mortality in older adults. Jama, 318(24), 2446-2456.

Diokhane, A. M., Jenkins, G. S., Manga, N., Drame, M. S., & Mbodji, B. (2016). Linkages between observed, modeled Saharan dust loading and meningitis in Senegal during 2012 and 2013. International journal of biometeorology, 60(4), 557-575.

Engelstaedter, S., Tegen, I., & Washington, R. (2006). North African dust emissions and transport. Earth-Science Reviews, 79(1-2), 73-100.

Hsu, N. C., Jeong, M. J., Bettenhausen, C., Sayer, A. M., Hansell, R., Seftor, C. S., ... & Tsay, S. C. (2013). Enhanced Deep Blue aerosol retrieval algorithm: The second generation. Journal of Geophysical Research: Atmospheres, 118(16), 9296-9315.

Jordan, R. E., Adab, P., & Cheng, K. K. (2020). Covid-19: risk factors for severe disease and death.

Landrigan, P. J., Fuller, R., Acosta, N. J., Adeyi, O., Arnold, R., Baldé, A. B., ... & Chiles, T. (2018). The lancet commission on pollution and health.391(10119), 462. doi:10.1016/S0140-6736(17)32345-0

Liang, D., Shi, L., Zhao, J., Liu, P., Schwartz, J., Gao, S., ... & Chang, H. H. (2020). Urban Air Pollution May Enhance COVID-19 Case-Fatality and Mortality Rates in the United States. medRxiv.

Liu, Z. (2016). Comparison of integrated multisatellite retrievals for GPM (IMERG) and TRMM multisatellite precipitation analysis (TMPA) monthly precipitation products: initial results. Journal of Hydrometeorology, 17(3), 777-790.

Mbow, M., Lell, B., Jochems, S. P., Cisse, B., Mboup, S., Dewals, B. G., ... & Yazdanbakhsh, M. (2020). COVID-19 in Africa: Dampening the storm?. Science, 369(6504), 624-626.

Mikati, I., Benson, A. F., Luben, T. J., Sacks, J. D., & Richmond-Bryant, J. (2018). Disparities in distribution of particulate matter emission sources by race and poverty status. American journal of public health, 108(4), 480-485.

Marone, A., Kane, C. T., Mbengue, M., Jenkins, G. S., Niang, D. N., Dramé, M. S., & Gernand, J. M. (2020). Characterization of Bacteria on aerosols from dust events in Dakar, Senegal, West Africa. GeoHealth, e2019GH000216.

O'Driscoll, M., Dos Santos, G. R., Wang, L., Cummings, D. A., Azman, A. S., Paireau, J., ... & Salje, H. (2020). Age-specific mortality and immunity patterns of SARS-CoV-2 infection in 45 countries. medRxiv.

Ogen, Y. (2020). Assessing nitrogen dioxide (NO2) levels as a contributing factor to the coronavirus (COVID-19) fatality rate. Science of The Total Environment, 138605.

Petkova, E. P., Jack, D. W., Volavka-Close, N. H., & Kinney, P. L. (2013). Particulate matter pollution in African cities. Air Quality, Atmosphere & Health, 6(3), 603-614.

Prata, D. N., Rodrigues, W., & Bermejo, P. H. (2020). Temperature significantly changes COVID-19 transmission in (sub) tropical cities of Brazil. Science of the Total Environment, 138862.

Sarkodie, S. A., & Owusu, P. A. (2020). Impact of meteorological factors on COVID-19 pandemic: Evidence from top 20 countries with confirmed cases. Environmental Research, 191, 110101.

Schroeder, W., Oliva, P., Giglio, L., & Csiszar, I. A. (2014). The New VIIRS 375 m active fire detection data product: Algorithm description and initial assessment. Remote Sensing of Environment, 143, 85-96.

Tai, D. B. G., Shah, A., Doubeni, C. A., Sia, I. G., & Wieland, M. L. (2020). The disproportionate impact of COVID-19 on racial and ethnic minorities in the United States. Clinical Infectious Diseases.

Toure, N. O., Gueye, N. R. D., Mbow-Diokhane, A., Jenkins, G. S., Li, M., Drame, M. S., ... & Thiam, K. (2019). Observed and modeled seasonal air quality and respiratory health in Senegal during 2015 and 2016. GeoHealth, 3(12), 423-442.

Wadvalla, B. A. (2020). How Africa has tackled covid-19. bmj, 370.

Wu, X., Nethery, R. C., Sabath, B. M., Braun, D., & Dominici, F. (2020). Exposure to air pollution and COVID-19 mortality in the United States. medRxiv.

Yancy, C. W. (2020). COVID-19 and African Americans. Jama

Yongjian, Z., Jingu, X., Fengming, H., & Liqing, C. (2020). Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. Science of the total environment, 138704.

COUNTRY	ANGOLA	CABO VERDE	IVORY COAST	NIGERIA	SENEGAL
POSITIVE CASES	15,251	10,816	21,334	67,838	16,107
FATALITIES	350	106	132	1,176	333
TOTAL TEST	171,247	104,510	218,660	779,708	231,541
POSITIVE CASES/MILLION	458	19,366	801	326	952
FATALITIES/MILLION	11	190	5	6	20
TEST/MILLION	5,145	187,123	8,206	3,744	13,680
POPULATION	33,285,657	558,510	26,647,390	208,244,503	16,925,413
MEDIAN AGE	16.7	27.6	18.9	18.1	18.4

Table 1: COVID-19 and statistics data for the five countries based on 1 December 2020 values.

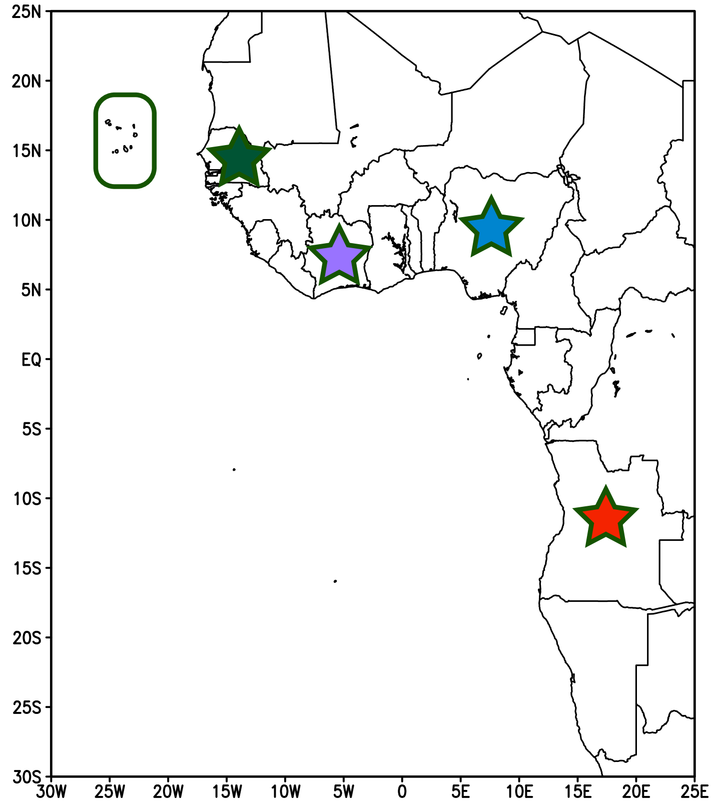


Figure 1. Countries locations used in this work.

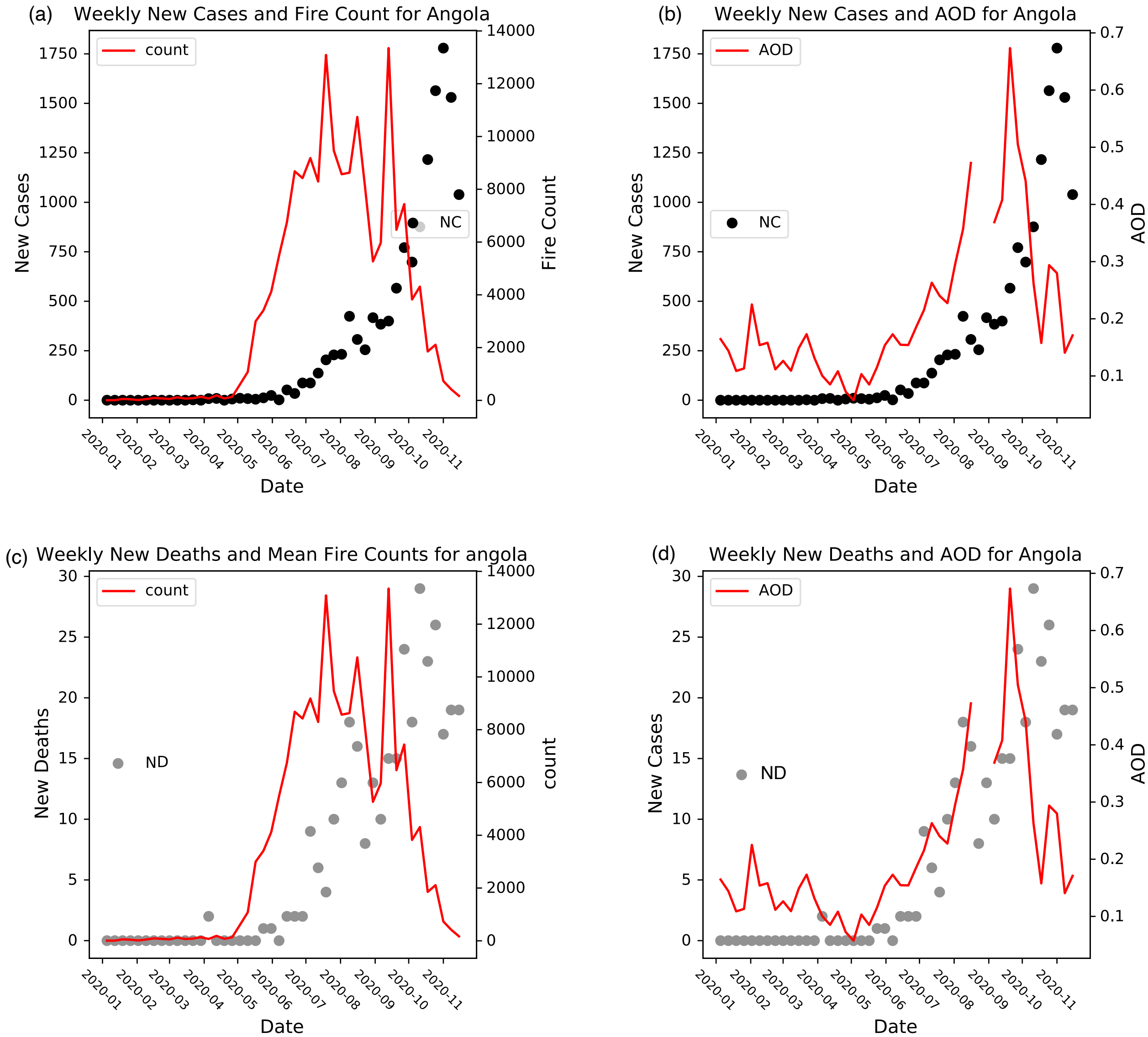
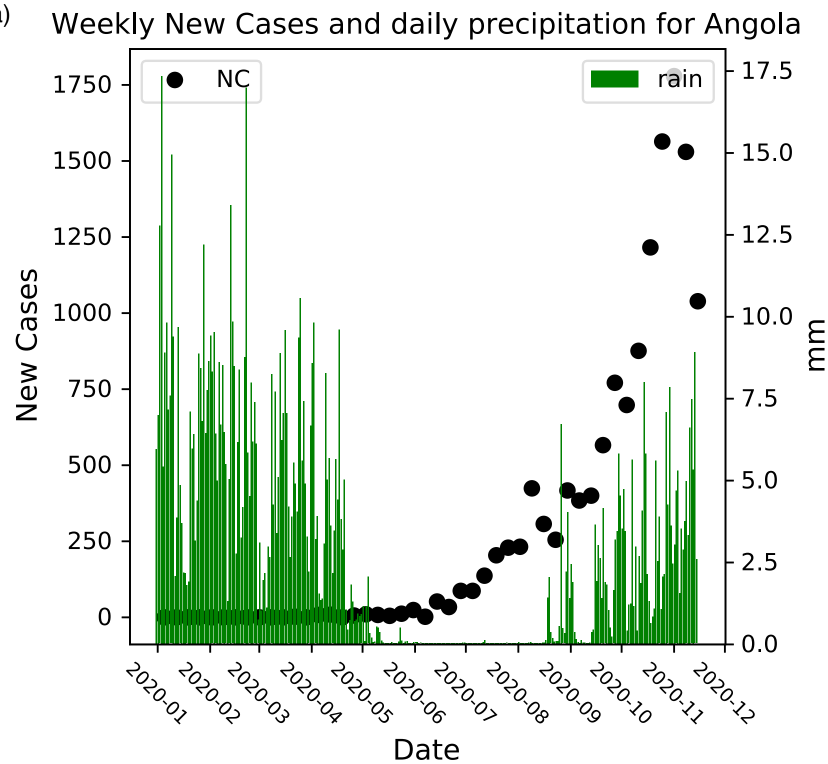


Figure 2. January 1-Nov 15, 2020 weekly data for Angola: (a) weekly COVID-19 cases and Fire counts; (b) weekly COVID-19 cases and AOD; (c) weekly COVID-19 mortality and Fire counts; (d) weekly COVID-19 mortality and AOD.

(a)



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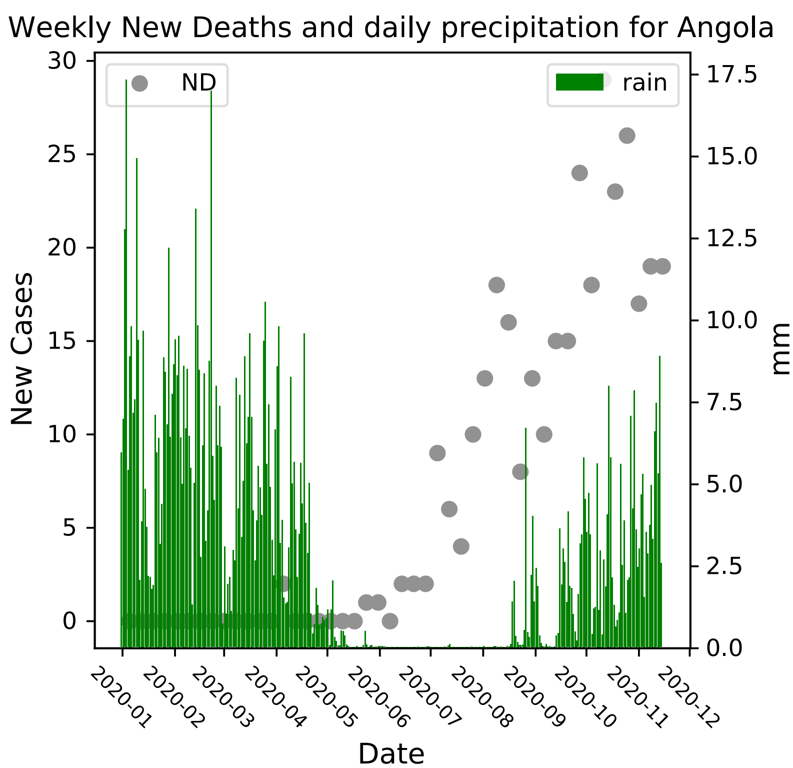


Figure 3. January 1-Nov 15, 2020 weekly data for Angola: (a) new cases and precipitation; (b) weekly new deaths and daily precipitation.

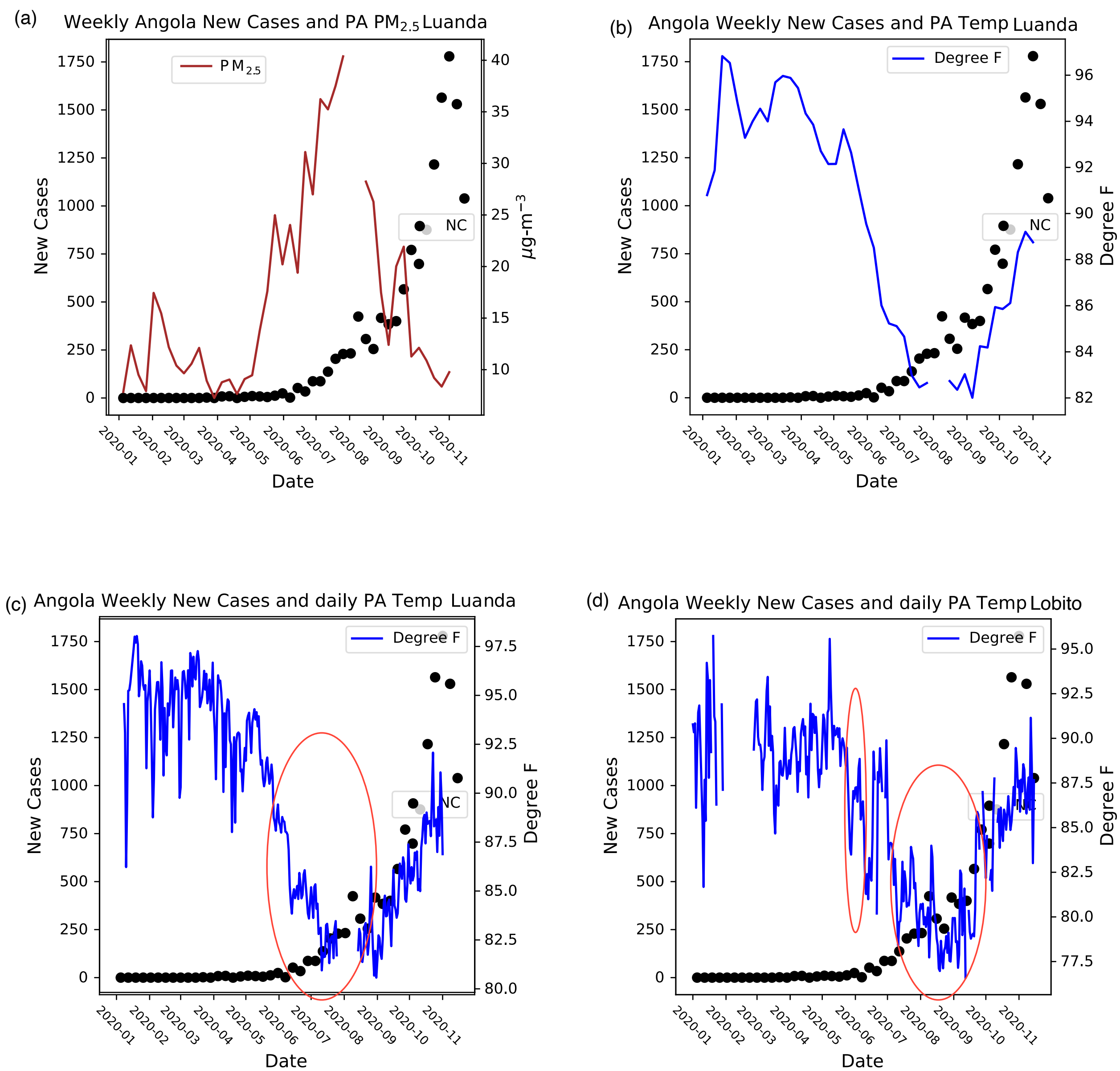


Figure 4. January 1-Nov 15, 2020 weekly data for Angola: (a weekly new cases and PA $PM_{2.5}$ concentrations ; (b) weekly new cases and PA Temp; (c) weekly new cases and daily PA Temp for Luanda;(d) weekly new deaths and daily PA Temp for Lobito.

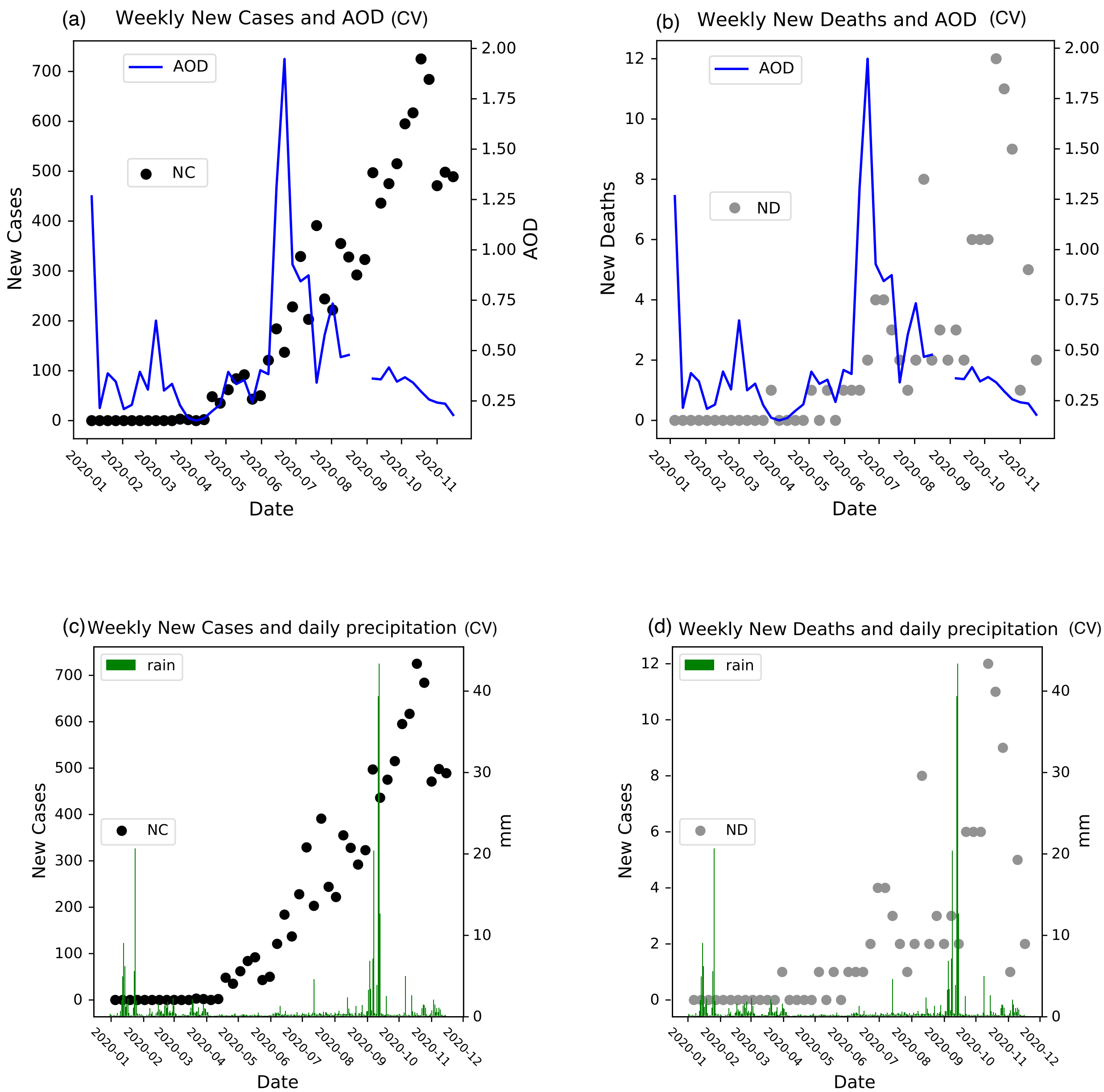


Figure 5. January 1-Nov 15, 2020 weekly data for Cabo Verde: (a) weekly new cases and AOD; (b) weekly new deaths and AOD; (c) weekly new cases and daily precipitation;(d) weekly new deaths and precipitation.

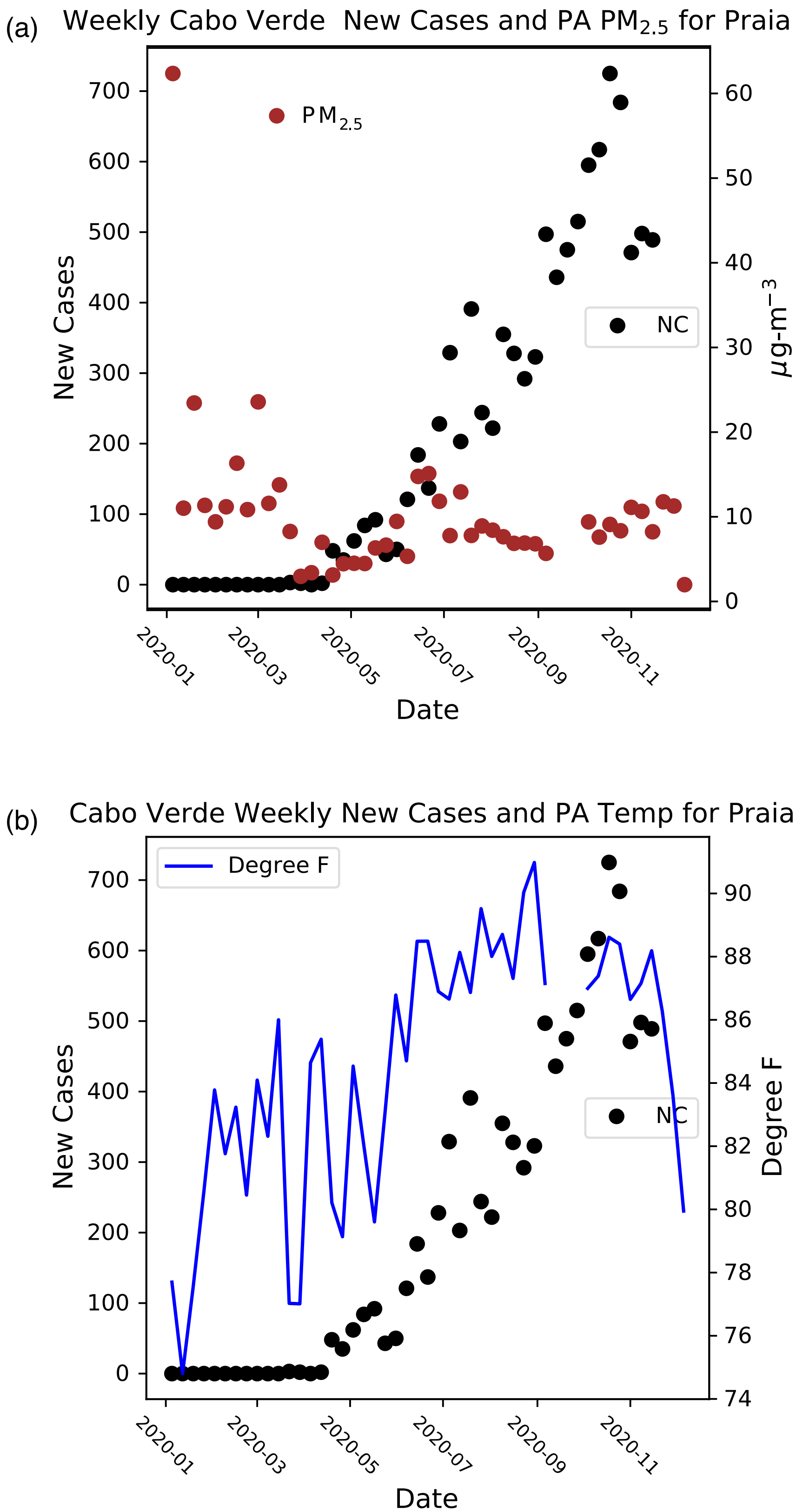


Figure 6. January 1-Nov 15, 2020 weekly data for Cabo Verde: (a) weekly new cases and PA $PM_{2.5}$ concentrations; (b) weekly new cases and PA Temp

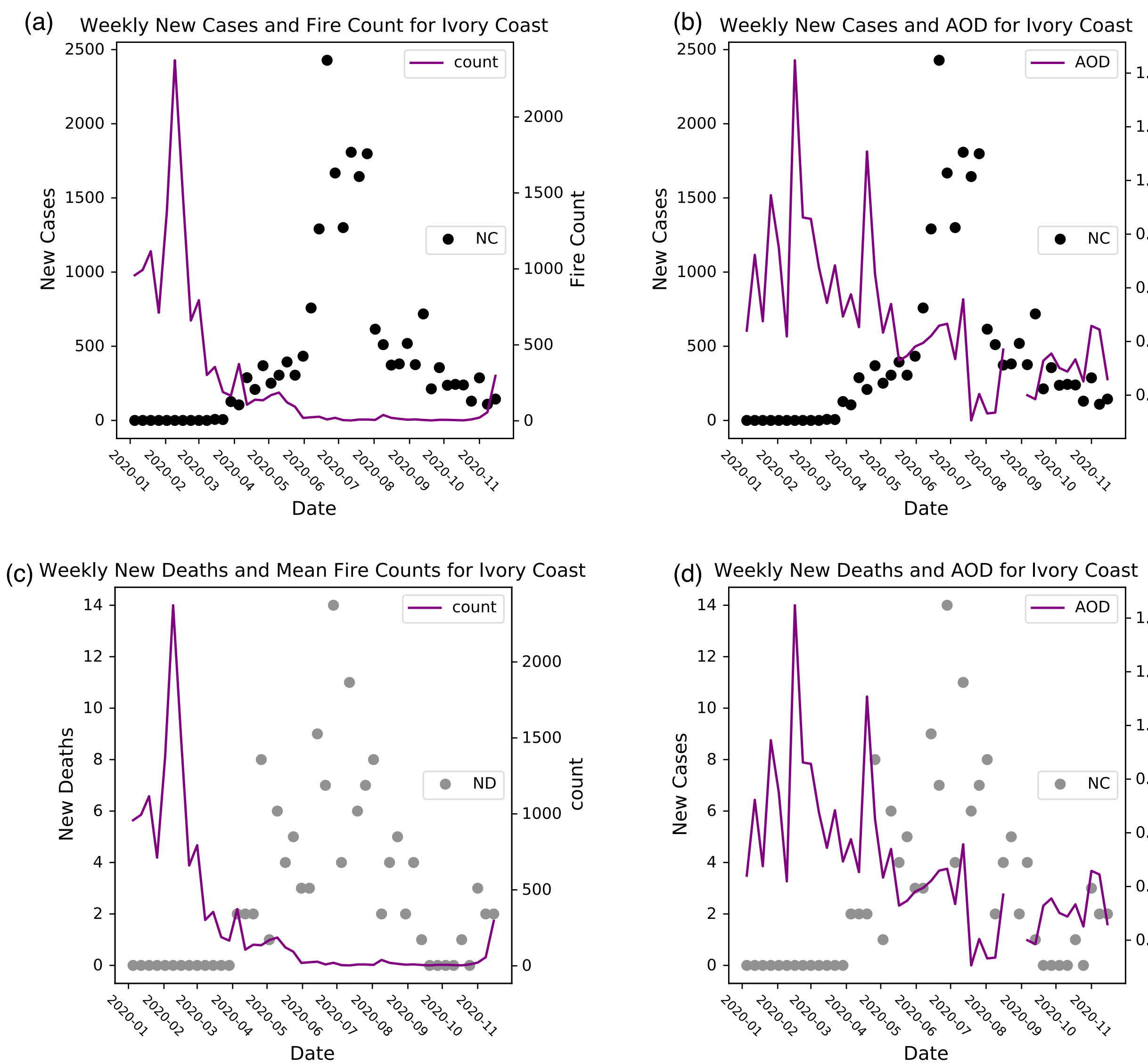
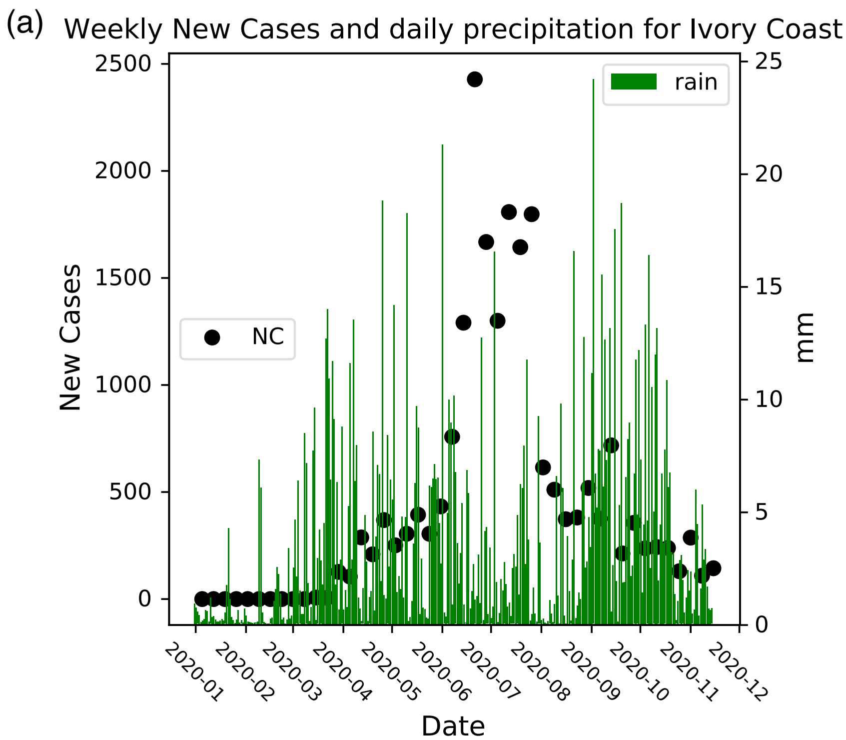


Figure 7. January 1-Nov 15, 2020 weekly data for Ivory Coast: (a) weekly COVID-19 cases and Fire counts; (b) weekly COVID-19 cases and AOD; (c) weekly COVID-19 mortality and Fire counts; (d) weekly COVID-19 mortality and AOD



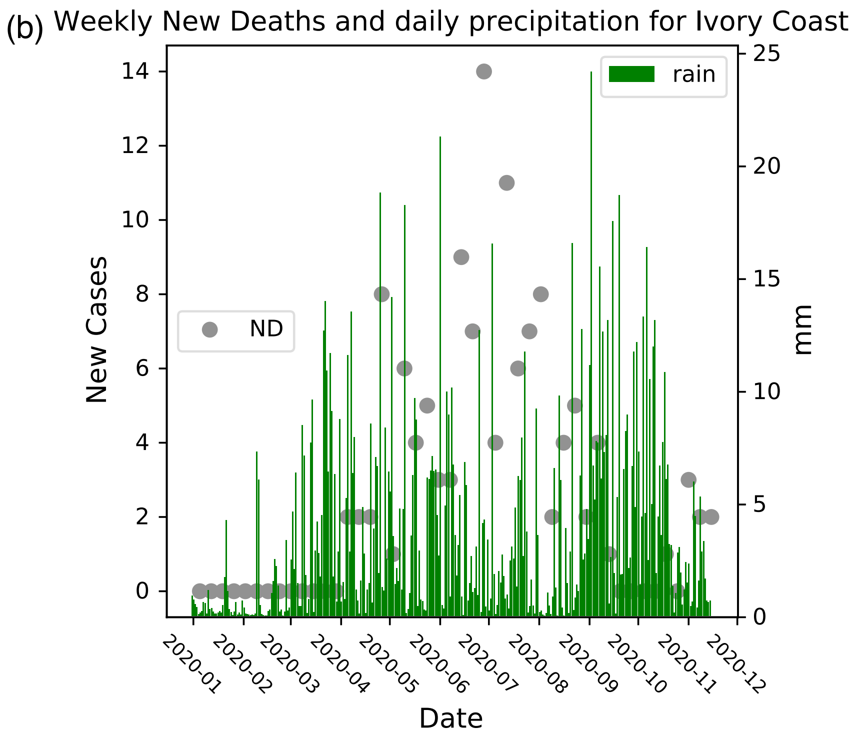


Figure 8. January 1-Nov 15, 2020 weekly data for Ivory Coast: (a) weekly new cases and precipitation; (b) weekly new deaths and daily precipitation

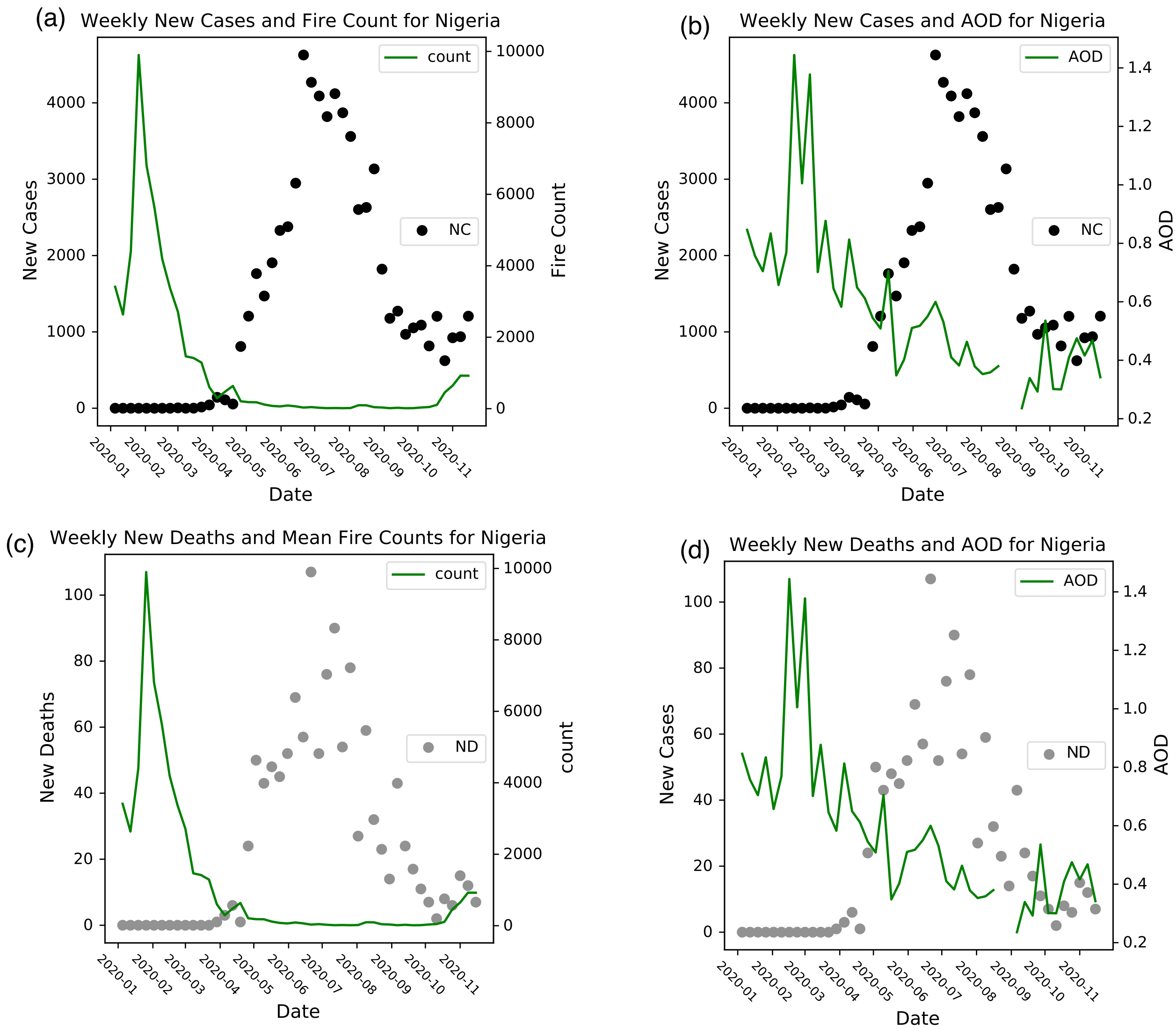


Figure 9. January 1-Nov 15, 2020 weekly data for Nigeria: (a) weekly COVID-19 cases and Fire counts; (b) weekly COVID-19 cases and AOD; (c) weekly COVID-19 mortality and Fire counts; (d) weekly COVID-19 mortality and AOD

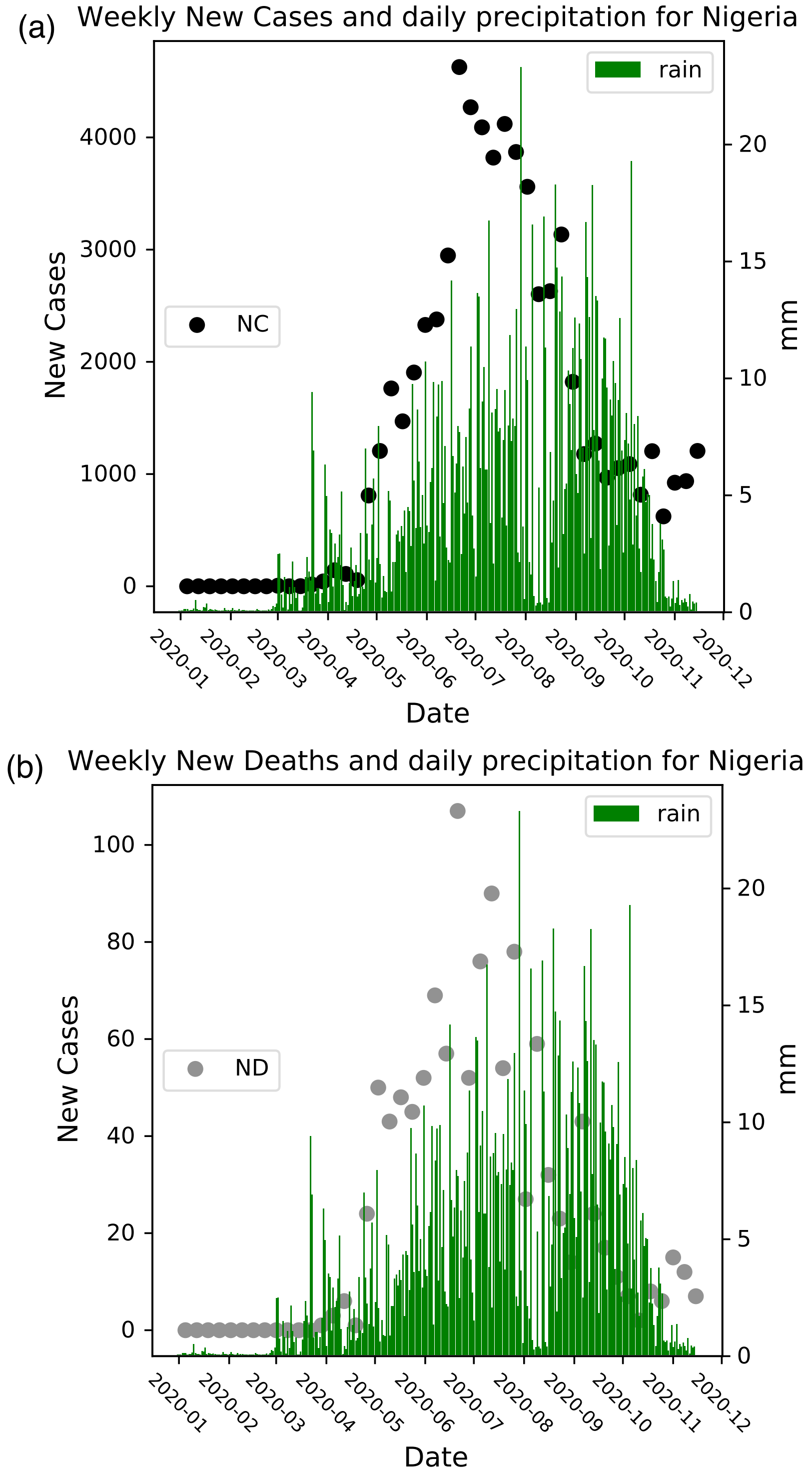


Figure 10. January 1-Nov 15, 2020 weekly data for Nigeria: (a) weekly new cases and daily precipitation; (b) weekly new deaths and daily precipitation

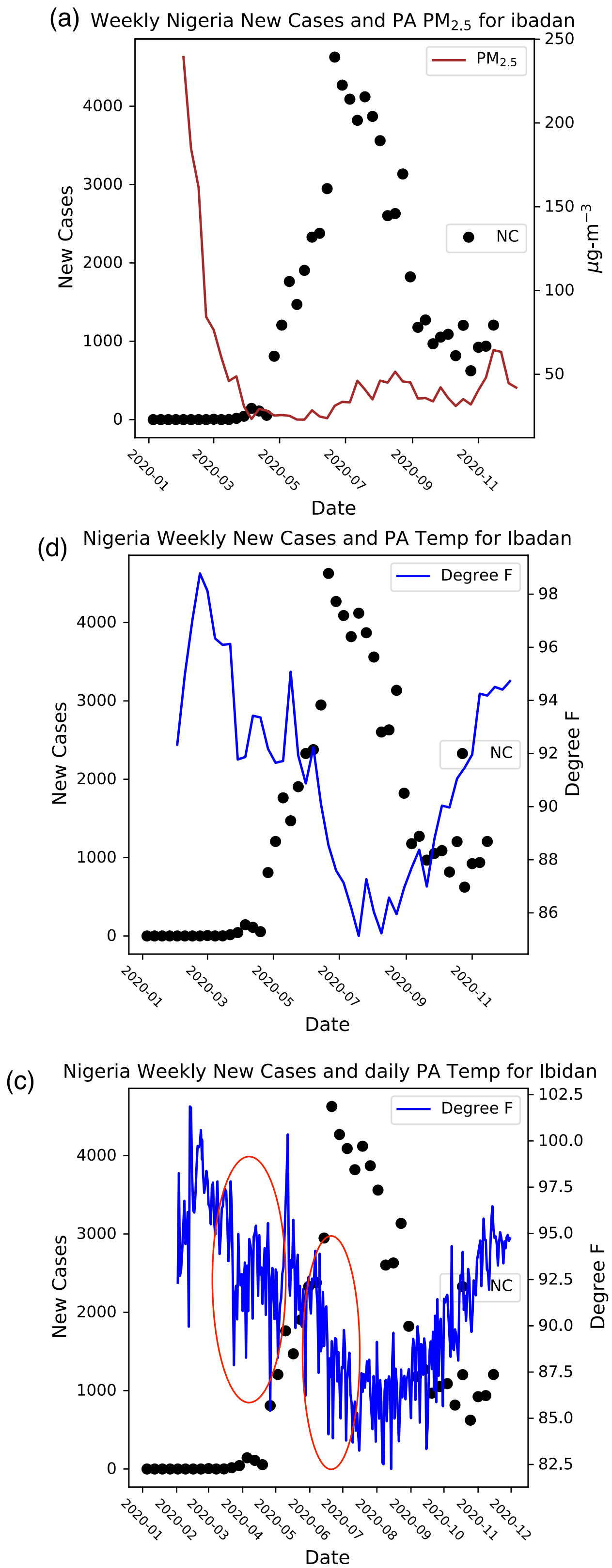


Figure 11. January 1-Nov 15, 2020 weekly data for Ibadan, Nigeria: (a) weekly new cases and PA $PM_{2.5}$ concentrations; (b) weekly new cases and daily PA temperatures.

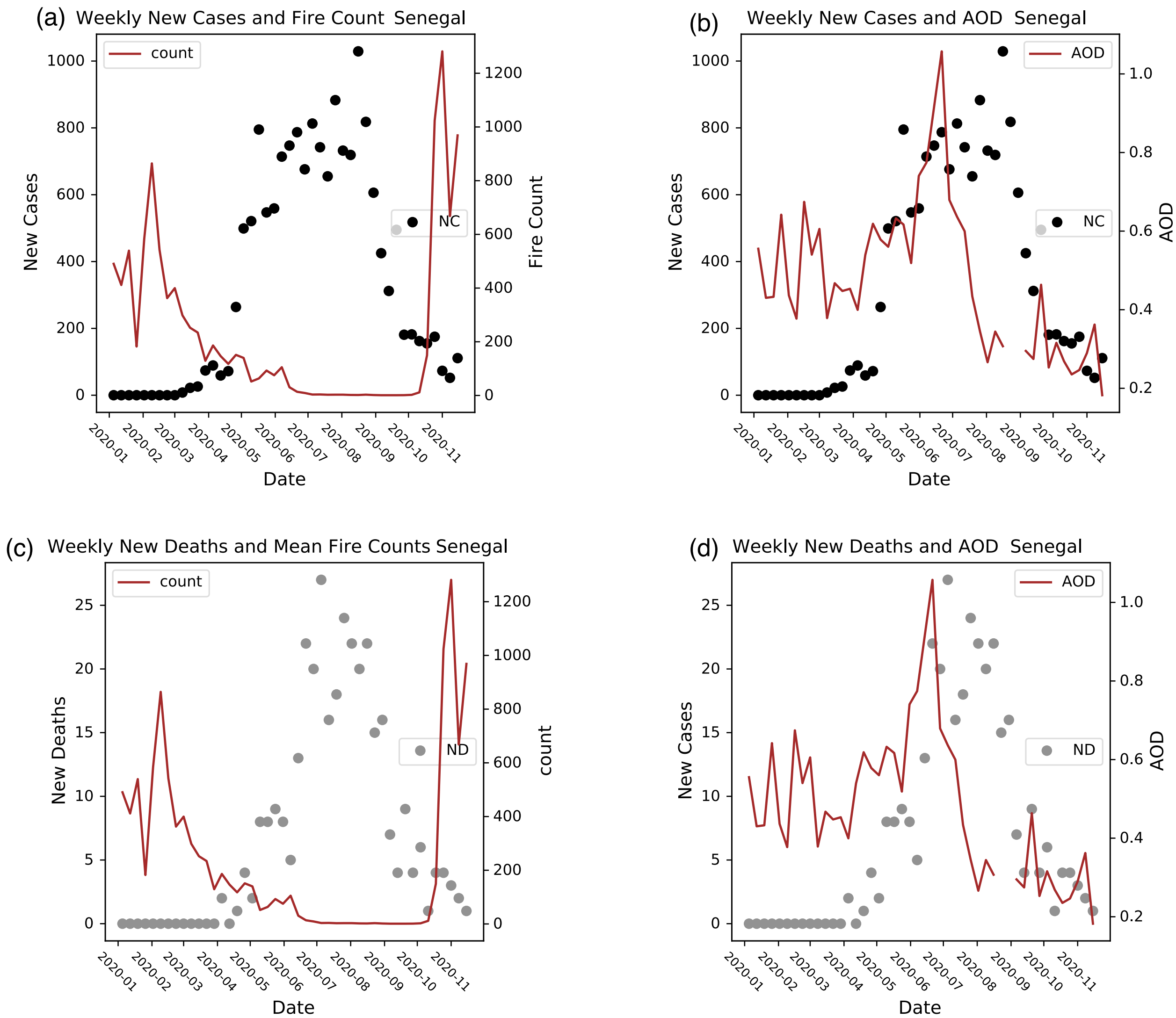


Figure 12. January 1-Nov 15, 2020 weekly data for Senegal: (a) weekly COVID-19 cases and Fire counts; (b) weekly COVID-19 cases and AOD; (c) weekly COVID-19 mortality and Fire counts; (d) weekly COVID-19 mortality and AOD

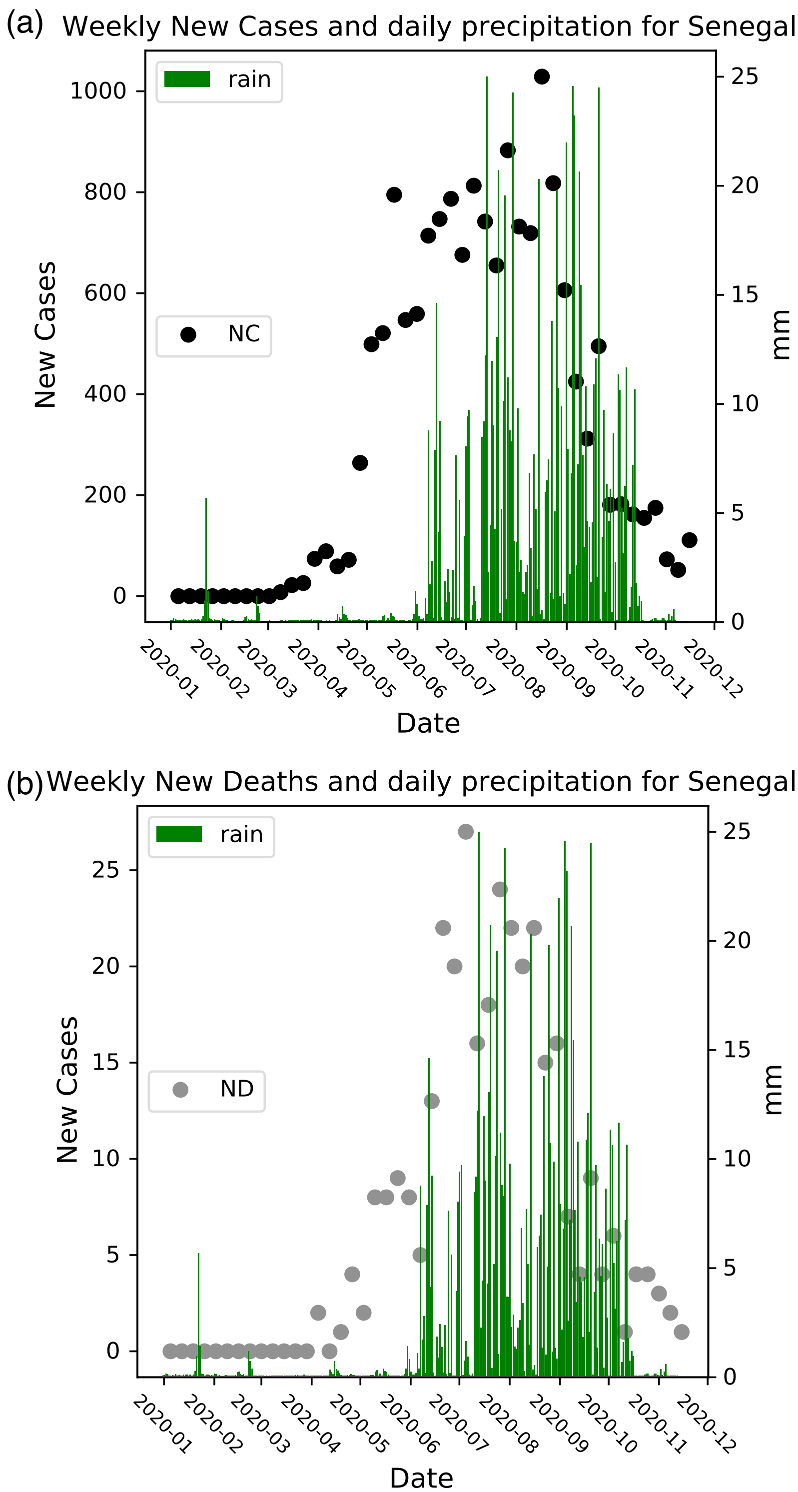


Figure 13. January 1-Nov 15, 2020 weekly data for Senegal: (a) weekly new cases and daily precipitation; (b) weekly new deaths and daily precipitation

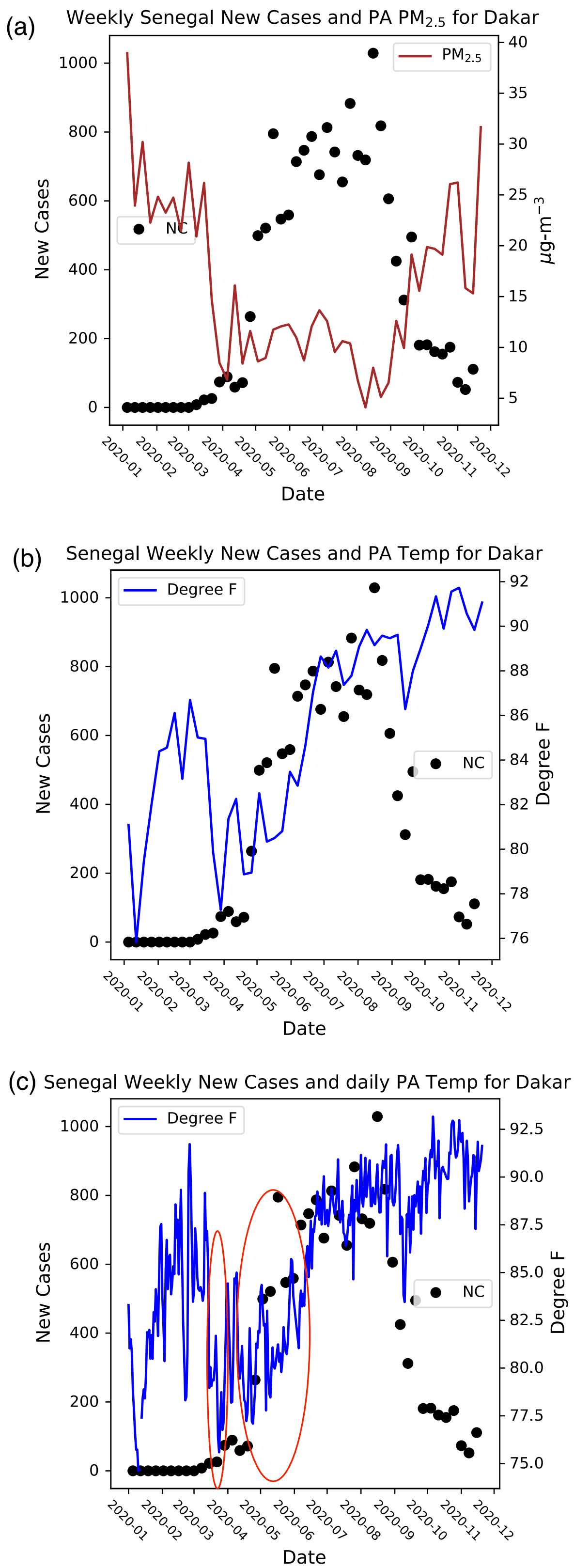


Figure 14. January 1-Nov 15, 2020 weekly data for Dakar, Senegal: (a) weekly new cases and PA $PM_{2.5}$; (b) weekly new cases and daily PA Temp