SHORT-TERM IMPACT OF NOISE, OTHER AIR POLLUTANTS AND METEOROLOGICAL FACTORS ON EMERGENCY HOSPITAL MENTAL HEALTH ADMISSIONS IN THE MADRID REGION

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ABSTRACT

Background: A number of environmental factors, such as air pollution, noise in urbanised settings and meteorological-type variables, may give rise to important effects on human health. In recent years, many studies have confirmed the **relation** between various mental disorders and these factors, with a possible impact on the increase in emergency hospital admissions due to these causes. The aim of this study was to analyse the impact of a range of environmental factors on daily emergency hospital admissions due to mental disorders in the Madrid Autonomous Region (MAR), across the period 2013-2018.

Methodology: Longitudinal ecological time series study analysed by Generalised Linear Models with Poisson regression, with the dependent variable being daily **Emergency Hospital Mental Health Admissions (EHMHA)** in the MAR, and the independent variable being mean daily concentrations of chemical pollutants, noise levels and meteorological variables.

Results: EHMHA were related statistically significantly in the short term with diurnal noise levels. Relative risks (RRs) for total admissions due to mental disorders and self-inflicted injuries, in the case of diurnal noise was RR: 1.008 95%CI (1.003 1.013). Admissions attributable to diurnal noise account for 5.5% of total admissions across the study period. There was no association between hospital admissions and chemical air pollution.

Conclusion: Noise is a variable that shows a statistically significant short-term association with **EHMHA** across all age groups in the MAR region. The results of this study may serve as a basis for drawing up public health guidelines and plans, which regard these variables as risk factors for mental disorders, especially in the case of noise, since this fundamentally depends on anthropogenic activities in highly urbanised areas with high levels of traffic density.

Keywords: Noise, mental health, hospital admissions, meteorological variables, pollution.

1. INTRODUCTION

Human health and the environment that surrounds us are closely related. The World Health Organisation (WHO) identifies different risk factors through which the environment can influence our health. These include air pollution, water, deficient sanitation and hygiene, chemical and biological agents, ultraviolet and ionizing radiation, environmental noise, occupational risks, urbanised settings, farming practices, and specific conditions arising as a consequence of climate change (1).

All these factors can cause important effects on human health and have an impact on the appearance, development or exacerbation of different diseases or human processes, such as respiratory **(2,3**) and cardiovascular diseases **(4)**, neurodevelopmental disorders **(5)**, cancer **(6–9),** mental disorders, and can even have an impact on mortality **(9,10).**

It has been widely documented that mental health and the wellbeing of persons are influenced by a complex interaction among genetic, psychological, social and lifestyle factors, as well as environmental exposures (11–13). A number of environmental factors can be identified as elements favouring psychiatric disease, along with morbidity and mortality. In urban settings a series of these factors come together (air pollution, noise level, inappropriate urban design, etc.), and some, such as extreme temperatures closely linked to climate change, should be at the centre of attention in matters of public health.

Currently, around 55% of the world population lives in cities, and it is expected that by 2050 cities will be housing 75% of the world population (14). In Spain, 81% of the population lives in cities (15), so that the impact on population health levels may be high.

In recent years, many studies have confirmed the **relation** between various mental disorders, such as anxiety, depression, suicide, psychotic or neuropsychiatric disorders, and environmental factors such as chemical air pollution (16–18), acoustic pollution (19–21) and meteorological variables (22), including high (23,24) or low temperatures (25), hours of sunlight (26), wind (27,28), humidity (16,20) and air pressure (29,30). **Furthermore, this association increases emergency hospital admissions** (31–33)

Most countries around the world have legislation, rules and regulations, and plans for the control of some of these factors, such as chemical pollution, noise or extreme temperatures. The WHO issues pollution guidelines, both chemical and acoustic, which tend to be more restrictive than domestic legislation, which usually tends to lag behind the latest scientific evidence. In addition, there are no plans or guidelines addressing the influence on health of other environmental and meteorological factors and, in the case of those mentioned above, no provision is made for the impact that these have specifically on mental health.

The prevalence and incidence of mental disorders are not only rising worldwide, but have also been ranked as a world public health priority due to their impact on health, social and economic matters. It is calculated that in 2019, close **to** one billion people suffered some type of mental disorder, a figure that amounts to around 13% of the world population (34).

In Spain more than one out of ten persons aged 15 years or over reported having been diagnosed with some mental health problem (10.8%)(35). **Women report these issues more frequently than men, with a 10.7% prevalence among women and 5.4% prevalence among men in Madrid (26). Additionally, prevalence increases with age (35)**.
In addition, for several European countries, including Spain, it is considered that 25% of the population will suffer some type of mental disorder at some point in their lives(36).

With regard to hospital admissions, in 2019 in Spain, the diagnostic groups that caused most hospital stays were mental disorders (15.1% of the total), and these diseases in turn also accounted for longer hospitalisations. In Madrid that same year, 14.7% of total hospital stays were due to these causes (37).

This study arises from the need to acquire greater knowledge on the impact of environmental factors on mental health and their effect on health systems. Our study's main aim was to analyse the impact of a number of environmental factors on daily **EHMHA** in the Madrid Autonomous Region (MAR), across the period 2013-2018.

There are no previous studies that analyse the combined impact of environmental variables of chemical, acoustic and meteorological pollution on **EHMHA** and self-inflicted injuries globally.

2. MATERIAL AND METHODS

2.1 Study design

We conducted a retrospective, longitudinal, ecological time series study, and analysed the **relation** between **emergency hospital mental health admissions (EHMHA)** and self-inflicted injuries in hospitals in the MAR and chemical and acoustic pollution, meteorological variables, and control variables of seasonality, trend and autoregressive nature of the series.

The dependent variable was daily **EHMHA** recorded in the MAR from 1 January 2013 to 31 December 2018, as per the International Classification of Diseases, 9th and 10th editions (ICD9-CM and ICD10-ES). For analysis purposes, we considered admissions due to "mental, behavioral and developmental neurological disorders" (ICD9-CM: 290-319 and E950-959; ICD10-ES: F00-F99 and X71-X83 and T14.91). These data were obtained under a National Statistics Institute

(*Instituto Nacional de Estadística/INE*) confidentiality protocol. The causes mentioned in the above paragraph were broken down by sex (men–women).

The independent variables selected were as follows:

- mean daily concentrations of chemical air pollution, measured in µg/m^3: particulate matter having a diameter of less than 10 micras (PM_{10}) and less than 2.5 micras ($PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3), and 8-hour ozone ($_{eight\text{-}hour}\ O_3$) (maximum value registered between 8 and 16 hours). These data were obtained from the Air Pollution Monitoring Network and supplied by the Ministry for Ecological Transition and Demographic Challenge (*Ministerio para la Transición Ecológica y Reto Demográfico*).

- Noise level measured in A-weighted decibels (dB(A)). We obtained the equivalent means in the period between 7AM and 11PM ($L_{Aeq7\text{-}23}$), between 11PM and 7AM ($L_{Aeq23\text{-}7}$) and daily noise levels, which includes both periods (LAeq24h). These data were provided by the noise monitoring networks of Madrid City Council and Madrid Airport. Noise data is only available for the period 2014-2018.

- Among the meteorological variables, we included the daily values of maximum and minimum temperature (°C), air pressure (hPa), number of hours of sunlight per day (hours), mean daily wind speed (km/h), and relative humidity (daily mean in %). These data were furnished by the State Meteorological Agency (*Agencia Estatal de Meteorología/AEMET*) for the above period.

- the following control variables were also included: annual (365 days), six-monthly (180 days), four-monthly (120 days) and quarterly (90 days) seasonality using the sine and cosine functions. The trend of the series was taken into account using a counter n1, which assigns a number to each day of the series, such that n1 equals 1 for 01/01/2013, n1 equals 2 for 02/01/2013, and so on successively. We created dummy variables for the days of the week and controlled for the autoregressive nature of the dependent variable. Similarly, we also controlled for Public Holidays across the study period.

As for the quality of the data, firstly it was ensured by the institution responsible for sourcing and validating. Secondly, we scanned data for abnormalities, outliers and missing values, which were replaced by linear interpolation.

The geographical distribution of the different monitoring stations which collected data can be seen in figure 1.

2.2. Statistical analysis

Initially, we performed a descriptive analysis of all the study variables. To ascertain the temporal distribution of the variables and the possible existence of outliers, sequence charts were plotted. According to previous studies (38–42), the functional relationships between **EHMHA** and environmental variables are deemed to display a linear distribution without threshold in all cases, except for temperature and ozone, which are quadratic in nature. **Moreover, we explored the short and middle-term effects of variables on EHMHA through the use of Cross-Correlation Function (CCF). In case of the dependent variable, we previously eliminated seasonal behaviour using ARIMA models. The lag order for each variable was therefore selected based on literature, significant CCF association and biological sense (See supplementary material).**

Taking this into account, threshold variables were created for these last two variables.

In order to create the above threshold variables, the threshold levels that parametrise the functional **relation** between variables had to be ascertained. To this end, a second-order polynomial was adjusted to the curve described between daily ozone and the response variable, and the minimum of the function was determined by numerical calculation. This minimum value was 74 ug/m3. Once this value had been calculated, a new variable (“O3high”) was created to identify values that exceeded the threshold calculated:

$O3high = 0,\ if [O3\ ] < 74\ \mu g/m3$

$O3high = O3 - 74\ \mu g/m3,\ if [O3\ ] > 74\ \mu g/m3$

In the case of temperature, a similar procedure was performed. According to previous studies (43), the threshold from which daily mortality is estimated to increase is a maximum daily temperature of 34°C for the definition of heat wave, and a minimum daily temperature of -2°C for the definition of cold wave. To this end, we created two new variables, defined as:

$Theat = 0$, $if\ Tmaxº C < 34ºC$

$Theat = TmaxºC - 34°C$, $if Tmax ºC > 34ºC$

$Tcold = 0$, $if Tmin ºC > -2ºC$

$Tcold = -2°C - Tmin ºC$, $if Tmin ºC < -2ºC$

With regard to air pressure, a new variable (pressure trend) was created, namely, the daily air pressure value on the day minus the previous day's pressure. This variable was created to highlight daily variations in pressure in the model because previous studies show that sudden changes in air pressure are those that can have an influence on health (44).

Lags were introduced for independent variables because the health effect of the independent variables on the dependent variables may be delayed in time. For the pollution variables, PM_{10}, $PM_{2.5}$, NO_2 and noise, the effect may be lagged by up to 5 days (38,45), and for ozone by up to 9 days (38). The effect of changes in pressure can be detected up to 8 days afterwards, and the effect of relative humidity may be delayed by 14 days (38). In the case of temperature, the effect of high temperatures may be lagged by up to 5 days (39), and in the case of low temperatures by up to 14 days (46). **In addition, the CCFs shown in the supplementary material have been taken into account.**

To ascertain the impact of environmental variables on daily hospital admissions due to the causes cited, we fitted generalised linear models (GLMs) with a Poisson regression link and controlled for overdispersion. These variables were gradually eliminated, taking statistical significance as reference until all the variables had a significance of p<0.05 (backward stepwise method). Once the values of the significant estimators had been obtained, we calculated relative risks (RRs), attributable risks of **EHMHA** (ARs), and the number of daily admissions attributable to the variables which proved to be significant, considering the level or concentration of the pertinent environmental risk factor per day.

All statistical analyses were performed using the STATA v15 computer software package (StataCorp LP, College Station, Texas 77845 USA).

3. RESULTS

2191 observations were made across the study period, with a total of 67225 admissions due to **EHMHA** and self-inflicted injuries.

Table I shows the descriptive statistics of the dependent variable. The sequence charts of daily **EHMHA** and self-inflicted injuries in the MAR are shown in **Figure 2**. There was no evidence of variation in trend or clear seasonality.

Table II shows the descriptive statistics of the independent variables. For the variables of chemical and acoustic pollution in general, the sequence chart shows variations in trend, and in terms of seasonality all the variables had a "cyclical" component, varying in winter and in summer (Figure 3 and 4).

While the meteorological variables did not present a changing trend across the study period, in this case seasonality is intrinsic to these variables since climatological conditions are different in winter and in summer.

As for noise, we will take as reference values 50 dB(A) for the daily level (LAeq7-23) and 45 dB(A) for the night level (LAeq23-7), which corresponds to the WHO recommendations of Ln 45 dB(A) and Lden 53dB(A)(47). These values were exceeded 99% of the days during the day and 98% at night. The daily level (LAeq24h) corresponding to this reference (48.9 dBA) is exceeded during 99% of the days.

As a result of the modelling process, this study observed that hospital admissions due to mental disorders and self-inflicted injuries were significantly related with diurnal noise levels without lags and hours of sunlight at lag 5. For hours of sunlight this **relation** was negative, i.e., the fewer the hours of sunlight, the higher the admissions. Seasonality presented in six- and three-monthly cycles.

Analysis by sex (women and men) was also performed. Admissions due to mental disorders and self-inflicted injuries in women were significantly related with air pressure at lag 12, sunstroke at lags 5, and diurnal noise without lags. As in the previous case, hours of sunlight and humidity displayed a negative relationship.

Admissions due to mental disorders in men were related with sunstroke at lag 4, wind speed at lag 13. As before, hours of sunlight had a negative relationship, and were interpreted as the fewer the hours of sunlight, the higher the admissions.

Table III shows the relative and attributable risks with their respective confidence intervals of each significant variable.

In general, it can be seen that the lags which most frequently present a significant result are: at lag 0 for diurnal noise, i.e., the increase in emergency admissions takes on same day as increase in noise levels; at lag 5 for hours of sunlight, i.e., there is an increase in admissions on the 5th day of the dark days.

We also calculated the number of **EHMHA** per year attributable to anthropogenic activities based on attributable risks. The results are shown in Table IV.

In our case, no significant relation was found between **EHMHA** and environmental chemical pollutants or other meteorological variables, such as temperature in heat and cold waves.

4. DISCUSSION

In Spain, few studies have been conducted that link different environmental factors to emergency all-cause admissions. In the specific case of mental health, no study has been undertaken to assess this **relation** with total admissions due to mental disorders and analyse them by sex.

The results of our study show a statistically significant association between noise levels, hours of sunlight and **EHMHA** and self-inflicted injuries, with this association varying slightly between men and women. Among women the trend in air pressure also shows an association, and in the case of men diurnal noise does not prove significant.

Other similar studies support these results. In a recent study undertaken in Madrid which analysed the effects of road traffic noise and other environmental factors with emergency hospital admissions due to suicide, depression and anxiety, we found a **relation** between emergency admissions due to these disorders and noise, but did not however find an association with environmental chemical pollutants (48).

In other studies that analysed the effects of different environmental factors on **admissions in Madrid** due to diseases such as Parkinson's (32), Dementia (42) or Multiple Sclerosis (49), we also found a **relation** with acoustic pollution. In the case of Parkinson's and multiple sclerosis there was no **relation** with chemical air pollution. There are studies which support the fact that noise has a greater impact on health than does air pollution **(32,42,45,46,48,50)**. A recently published systematic review also supports these results, with a **relation** being found between noise and disorders such as depression and anxiety (51).

In the analysis, the diurnal noise levels were related to the dependent variable analysed. This finding should lead one to reflect on the need to update national and regional regulations in line with WHO guidelines and ensure their compliance, since it has been widely shown that exceedance of noise levels has an impact on health, and the findings of our study support this claim. Broken down by sex, noise levels were related with the dependent variable in the case of women, but not in the case of men. There are studies **in german populations** that suggest a greater sensitivity to noise among women (21,52). These differences should lead one to take gender into consideration when it comes to the drawing up of noise-related public health policies.

In relation to the biological mechanism whereby noise affects mental health, there are diverse theories. Noise could give rise to anomalies in response to stress in the hypothalamic-pituitary-adrenal (HPA) axis and serotonin neurotransmission (18), and would activate inflammatory and oxidative stress pathways (53).

As for sunstroke, greater exposure to sunlight is related to a lower number of days with mental disorders (54), and variations in sunlight have correlated with the prescription of antidepressants (55). Among its diagnoses, the DSM-V includes the seasonal affective disorder (56), which is defined as the presence of recurrent depressive episodes in a season of the year (usually autumn and winter) (57). Among the mechanisms implicated in their physiopathology are alterations in circadian rhythm (58), retinal sensitivity to light (59), melatonin metabolism abnormality (60), and a decrease in the secretion of neurotransmitters such as serotonin (61).

The pattern of prevalence in a specific area may not only depend on the quantity of irradiated light but also on such things as pollution, the presence of clouds, or architectural design. In the province of Madrid, there are areas that frequently meet these criteria, particularly high pollution and heavily built-up areas that allow little light to pass between buildings. There are no previous studies that have examined the hours of sunlight and their lags as a risk factor for an increase in **EHMHA**. This variable has proved to be significant for total admissions due to mental disorders in men and women alike. The effect of lack of light is produced especially in the short term, at 4-5 days after the day with little sunstroke, particularly in women, and here there is also an effect on the same day, which is an especially relevant result of this study.

There are studies that link air pollution to mental health **in London** (62) and hospital admissions caused by these disorders **in China** (16,63), but in our study there was no association with these factors. In another study conducted in the same region, which linked environmental factors to suicides, anxiety and depression, no association was found with chemical pollutants (48). Other studies that controlled for many seasonal factors have also found similar results in terms of association between urban air pollution and suicides **in Mexico City and Colombia** (64,65).

From our point of view, there are several factors that could account for this lack of association. In the MAR, the prevalence of some mental disease is below the Spanish mean (35). This contrasts with the higher prevalence of mental disorders in other countries where studies have been conducted which found an association with air pollution.

Our study, moreover, did not permit a breakdown by age group and this may have had an influence on the results, since prevalence of mental disorders varies with age.

Another reason is that the pollution levels included in the study correspond to the mean of measures from stations across the region, which smooths the maximum peaks of pollution at some stations, reducing their potential impact. That said, however, including meteorological variables such as pressure trend could be an indirect indicator of pollution. A positive pressure trend indicates an anticyclonic pattern, and this maintained over a long time may be indirectly indicating an increase in air pollution.

Other meteorological variables, such as wind (men) and pressure trend (women), also showed an association with EHMHA.

There are studies which correlate the direction of the wind with recurrent anxiety disorder (27). **In Kentucky** (USA) (30), wind speed was associated with an increase in violent acts. There are also studies that correlate the wind with the thermal feeling of cold, the so-called wind-chill factor (66), and cold has been associated **in China and Taiwan** with a worsening of mental disorders and an increase in admissions due to schizophrenia (67,68) or anxiety (69).

It is of note that no association was detected with **EHMHA** and high temperatures in heat waves, when there is literature in this respect that indicates that persons with mental diseases are a special risk group vis-à-vis heat waves (70–72). **One possible explanation for the lack of association is that the days on which there is a temperature considered a "heat wave" are few in relation to the rest of the year (199 days of the 2191 in the period), and it is possible that an association would be found if the analysis were performed focusing solely on the summer season.**

This finding, along with the effect of a few hours of sunlight, is concordant, since both variables can act as indicators of ambient cold.

Homeostasis, the process whereby the body is maintained in a stable state when the external surroundings are modified, may be implicated in this effect. The principal integrative centre of human thermoregulation is found in the preoptic region and anterior hypothalamus. The epigenetic changes and pre- and postnatal factors proposed for schizophrenia may be altered by thermoregulatory dysfunction (73). Ambient temperature has an influence on the neurotoxicity of dopamine and serotonin induced by drugs in mice (74). Given that it has been shown that dopaminergic transmission in schizophrenia is altered in animal models, schizophrenic patients could be prone to develop a thermoregulatory dysfunction. Furthermore, the sensitivity of patients with schizoaffective disorder to temperature may be partially explained by the anomalies of serotonin and norepinephrine in bipolar disorder (75). **In contrast to our case, Almendra et al (76) assessed the effect of all temperature range temperature on mental health and population analysed by Almendra is situated in a coastal city. Both are important differences.**

In coastal environments temperature tend to combine with higher relative humidity levels. In fact, this could be checked contrasting Lisbon's relative humidity (HR) values with Madrid's ones. Although Almendra did not report means values among their descriptive statistics, one could use their 50th percentile for RH (72.1%) as a proxy of the mean value assuming normal distribution for this variable. By doing so, one notice higher HR level in Lisbon than in Madrid (59,7%).

Higher HR interferes the evapotranspiration ability of the human body and ambient temperature perception, potentially increasing stress levels. This partially might explain the different results between the two studies.

Nevertheless, the temperature variables analysed in both studies are different, so that there is no suitable comparison. Firstly, Almendra assessed all-range-temperature and we have assessed temperature over regional heat-health-risk plan activation. Secondly, extreme-heat Relative Risks calculated by Almendra compares admissions at 99th vs 50th temperature percentiles while ours compare the temperatures over regional heat-health-risk plan activation vs temperature bellow this point.

Lastly, the air pressure trend proved significant, and acted, according to the analysis, as a risk factor in the case of women. Anticyclonic meteorological conditions with warm weather and low relative humidity have been linked to an increase in the frequency of suicides **in Budapest (Hungary)** (77). Even so, there is literature that suggests that low air pressures are related with an increase in impulsive behaviours and hospital emergency visits (30). It is possible that this variable may also act as a confounding variable, exerting an influence on the effect of the rest, and it is probable that the association found may be random.

During the study period there were a total of 67225 admissions, a mean of 11204 admissions per year of study. For the environmental factors for which an association with mental disease admissions was found, the number of admissions due to mental disorders attributable to these factors was calculated (Table IV).

The number of **EHMHA** attributable to diurnal noise was calculated by considering the threshold value as the lowest noise level registered across the study period (48.1 dB (A)), since there was no real zero-noise scenario. Departing from this point, the number of attributable **EHMHA** was 745, accounting for 5.5% of total admissions per year. It is necessary to underscore the wide confidence interval within which these probable admissions attributable to this variable tend to move.

The findings of our study show that the noise levels are associated with **EHMHA** in the MAR, with the main source being of the same anthropogenic nature. Other natural environmental factors also show that they have an influence on admissions due to these causes. The mental health of populations is influenced by complex interactions between genetic, social, lifestyle and environmental factors. Mental disorders are currently a growing problem worldwide, and ensuing crises, such as COVID-19, exacerbate the situation.

In Spain, there is no specific surveillance system integrated into public health, which would monitor the mental health of the population, as if it existed alongside other non-communicable diseases. Similarly, at a European level there **is** no integrated system that collects data from the different countries. This poses a difficulty, both for the undertaking of studies and surveillance, and the implementation of response measures.

More research is called for in this respect, as is the implementation of political, social and health measures that safeguard the mental health of the population.

5. LIMITATIONS AND STRENGTHS

5.2. Limitations

The values of the pollutants and the meteorological variables are the result of the mean of the measurements from different measuring stations located in different areas, which could smooth the impact, since it does not take into account the maximum peaks that take place in some areas of the region.

These biases are minimised by the inclusion of control variables in the models, such as trend, seasonality and the autoregressive nature of the series. On the other hand, as occurs in studies that analyse the effect of air pollution on health variables, there is a problem of adjustment (78). It should not be forgotten that the physical and socio-economic characteristics of the neighbourhood are related with behavioural disorders (79), and that these variables were not considered in this study.
One meteorological observatory collected all weather variables, which is called “MADRID-RETIRO” and is located in Retiro Park, in the centre of the city. Madrid Region has a few

meteorological observatories covering different weather forecast zones and the selected observatory has high correlation with approximately two-thirds of this area.

Noise measurements concern a total of 47 locations located in mostly urban areas of Madrid City and some other neighboring cities and towns (80,81). No source identification methods have been applied; therefore, overall noise has been assessed at each location. Nevertheless, given the distribution of the main road network in the region, road traffic is the main source of noise in most of the monitoring locations (even for the airports network). The small number of locations closest to the airport may have been influenced by aircraft noise too, depending on the airport runways configuration (82).

The daily means values used for the analysis reflect a linear average of the 47 overall noise level observations (data during maintenance operations were excluded) for each of the indicators ($L_{7\text{-}23h}$, $Ln_{23\text{-}7h}$, and L_{24h}).

The existence of comorbidities that might alter the admission diagnosis were not considered (82).

The admission data include the principal cause of admission and no secondary diagnoses or contacts with emergencies without hospitalisation. This may entail not considering some diagnoses of mental health concomitant with the underlying cause of admission.

On dealing with a study with aggregate data and considering the previous limitations, the results cannot be extrapolated at an individual level.

5.3. Strengths

Our study is based on a widely used and accepted methodology for the conduct of this type of approach, since it has been previously used in similar studies (40,42,48). In the model we controlled for many environmental variables, which adds value to the study because we considered possible confounding environmental variables not considered in other studies. In addition, the data used were sourced from reliable official sources and the measuring stations from which the data on the environmental variables were obtained are representative of the region where the study was developed, including both urban and rural areas.

6. CONCLUSIONS

Noise is a variable related with **emergency hospital mental health admissions** in general for all age groups and for women independently in the MAR. The percentage of admissions per year attributable to this variable accounts for 5.5% of the total.

The few hours of sunlight and wind speed have proved equally significant, with this finding being interpreted as an indicator of the effect of the thermal feeling of cold. Previously this had not been analysed in similar studies.

The results of this study may may be useful for drawing up health guidelines and plans which consider these variables as risk factors for mental health, particularly in the case of noise, since acoustic pollution depends fundamentally on anthropogenic activities in highly urbanised areas and on high traffic density, and may thus be potentially modifiable by the implementation of regulations and policies based on scientific evidence. Although there are variables on which one can´t intervene, such as the hours of sunlight or wind speed, research in the field of mental health should additionally consider environmental factors, both pollution or meteorological variables.

Conflicts of interest

The authors declare that there are no conflicts of interest.

Disclaimer The researchers declare that they have no conflicts of interest that would compromise the independence of this research work. The views expressed by the authors are not necessarily those of the institutions with which they are affiliated.

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SHORT-TERM IMPACT OF NOISE, OTHER AIR POLLUTANTS AND METEOROLOGICAL FACTORS ON EMERGENCY HOSPITAL MENTAL HEALTH ADMISSIONS IN THE MADRID REGION

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ABSTRACT

Background: A number of environmental factors, such as air pollution, noise in urbanised settings and meteorological-type variables, may give rise to important effects on human health. In recent years, many studies have confirmed the **relation** between various mental disorders and these factors, with a possible impact on the increase in emergency hospital admissions due to these causes. The aim of this study was to analyse the impact of a range of environmental factors on daily emergency hospital admissions due to mental disorders in the Madrid Autonomous Region (MAR), across the period 2013-2018.

Methodology: Longitudinal ecological time series study analysed by Generalised Linear Models with Poisson regression, with the dependent variable being daily **Emergency Hospital Mental Health Admissions (EHMHA)** in the MAR, and the independent variable being mean daily concentrations of chemical pollutants, noise levels and meteorological variables.

Results: EHMHA were related statistically significantly in the short term with diurnal noise levels. Relative risks (RRs) for total admissions due to mental disorders and self-inflicted injuries, in the case of diurnal noise was RR: 1.008 95%CI (1.003 1.013). Admissions attributable to diurnal noise account for 5.5% of total admissions across the study period. There was no association between hospital admissions and chemical air pollution.

Conclusion: Noise is a variable that shows a statistically significant short-term association with **EHMHA** across all age groups in the MAR region. The results of this study may serve as a basis for drawing up public health guidelines and plans, which regard these variables as risk factors for mental disorders, especially in the case of noise, since this fundamentally depends on anthropogenic activities in highly urbanised areas with high levels of traffic density.

Keywords**:** Noise, mental health, hospital admissions, meteorological variables, pollution.

1. INTRODUCTION

Human health and the environment that surrounds us are closely related. The World Health Organisation (WHO) identifies different risk factors through which the environment can influence our health. These include air pollution, water, deficient sanitation and hygiene, chemical and biological agents, ultraviolet and ionizing radiation, environmental noise, occupational risks, urbanised settings, farming practices, and specific conditions arising as a consequence of climate change (1).

All these factors can cause important effects on human health and have an impact on the appearance, development or exacerbation of different diseases or human processes, such as respiratory **(2,3**) and cardiovascular diseases **(4)**, neurodevelopmental disorders **(5)**, cancer **(6–9),** mental disorders, and can even have an impact on mortality **(9,10).**

It has been widely documented that mental health and the wellbeing of persons are influenced by a complex interaction among genetic, psychological, social and lifestyle factors, as well as environmental exposures (11–13). A number of environmental factors can be identified as elements favouring psychiatric disease, along with morbidity and mortality. In urban settings a series of these factors come together (air pollution, noise level, inappropriate urban design, etc.), and some, such as extreme temperatures closely linked to climate change, should be at the centre of attention in matters of public health.

Currently, around 55% of the world population lives in cities, and it is expected that by 2050 cities will be housing 75% of the world population (14). In Spain, 81% of the population lives in cities (15), so that the impact on population health levels may be high.

In recent years, many studies have confirmed the **relation** between various mental disorders, such as anxiety, depression, suicide, psychotic or neuropsychiatric disorders, and environmental factors such as chemical air pollution (16–18), acoustic pollution (19–21) and meteorological variables (22), including high (23,24) or low temperatures (25), hours of sunlight (26), wind (27,28), humidity (16,20) and air pressure (29,30). **Furthermore, this association increases emergency hospital admissions** (31–33)

Most countries around the world have legislation, rules and regulations, and plans for the control of some of these factors, such as chemical pollution, noise or extreme temperatures. The WHO issues pollution guidelines, both chemical and acoustic, which tend to be more restrictive than domestic legislation, which usually tends to lag behind the latest scientific evidence. In addition, there are no plans or guidelines addressing the influence on health of other environmental and meteorological factors and, in the case of those mentioned above, no provision is made for the impact that these have specifically on mental health.

The prevalence and incidence of mental disorders are not only rising worldwide, but have also been ranked as a world public health priority due to their impact on health, social and economic matters. It is calculated that in 2019, close **to** one billion people suffered some type of mental disorder, a figure that amounts to around 13% of the world population (34).

In Spain more than one out of ten persons aged 15 years or over reported having been diagnosed with some mental health problem (10.8%)(35). **Women report these issues more frequently than men, with a 10.7% prevalence among women and 5.4% prevalence among men in Madrid (26). Additionally, prevalence increases with age (35)**.
In addition, for several European countries, including Spain, it is considered that 25% of the population will suffer some type of mental disorder at some point in their lives(36).

With regard to hospital admissions, in 2019 in Spain, the diagnostic groups that caused most hospital stays were mental disorders (15.1% of the total), and these diseases in turn also accounted for longer hospitalisations. In Madrid that same year, 14.7% of total hospital stays were due to these causes (37).

This study arises from the need to acquire greater knowledge on the impact of environmental factors on mental health and their effect on health systems. Our study's main aim was to analyse the impact of a number of environmental factors on daily **EHMHA** in the Madrid Autonomous Region (MAR), across the period 2013-2018.

There are no previous studies that analyse the combined impact of environmental variables of chemical, acoustic and meteorological pollution on **EHMHA** and self-inflicted injuries globally.

2. MATERIAL AND METHODS

2.1 Study design

We conducted a retrospective, longitudinal, ecological time series study, and analysed the **relation** between **emergency hospital mental health admissions (EHMHA)** and self-inflicted injuries in hospitals in the MAR and chemical and acoustic pollution, meteorological variables, and control variables of seasonality, trend and autoregressive nature of the series.

The dependent variable was daily **EHMHA** recorded in the MAR from 1 January 2013 to 31 December 2018, as per the International Classification of Diseases, 9^{th} and 10^{th} editions (ICD9-CM and ICD10-ES). For analysis purposes, we considered admissions due to "mental, behavioral and developmental neurological disorders" (ICD9-CM: 290-319 and E950-959; ICD10-ES: F00-F99 and X71-X83 and T14.91). These data were obtained under a National Statistics Institute

(*Instituto Nacional de Estadística/INE*) confidentiality protocol. The causes mentioned in the above paragraph were broken down by sex (men–women).

The independent variables selected were as follows:

- mean daily concentrations of chemical air pollution, measured in μg/m^3: particulate matter having a diameter of less than 10 micras (PM_{10}) and less than 2.5 micras ($PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3), and 8-hour ozone ($_{\text{eight-hour}}O_3$) (maximum value registered between 8 and 16 hours). These data were obtained from the Air Pollution Monitoring Network and supplied by the Ministry for Ecological Transition and Demographic Challenge (*Ministerio para la Transición Ecológica y Reto Demográfico*).

- Noise level measured in A-weighted decibels (dB(A)). We obtained the equivalent means in the period between 7AM and 11PM ($L_{Aeq7-23}$), between 11PM and 7AM ($L_{Aeq23-7}$) and daily noise levels, which includes both periods (LAeq24h). These data were provided by the noise monitoring networks of Madrid City Council and Madrid Airport. Noise data is only available for the period 2014-2018.

- Among the meteorological variables, we included the daily values of maximum and minimum temperature (°C), air pressure (hPa), number of hours of sunlight per day (hours), mean daily wind speed (km/h), and relative humidity (daily mean in %). These data were furnished by the State Meteorological Agency (*Agencia Estatal de Meteorología/AEMET*) for the above period.

- the following control variables were also included: annual (365 days), six-monthly (180 days), four-monthly (120 days) and quarterly (90 days) seasonality using the sine and cosine functions. The trend of the series was taken into account using a counter n1, which assigns a number to each day of the series, such that n1 equals 1 for 01/01/2013, n1 equals 2 for 02/01/2013, and so on successively. We created dummy variables for the days of the week and controlled for the autoregressive nature of the dependent variable. Similarly, we also controlled for Public Holidays across the study period.

As for the quality of the data, firstly it was ensured by the institution responsible for sourcing and validating. Secondly, we scanned data for abnormalities, outliers and missing values, which were replaced by linear interpolation.

The geographical distribution of the different monitoring stations which collected data can be seen in figure 1.

2.2. Statistical analysis

Initially, we performed a descriptive analysis of all the study variables. To ascertain the temporal distribution of the variables and the possible existence of outliers, sequence charts were plotted. According to previous studies (38–42), the functional relationships between **EHMHA** and environmental variables are deemed to display a linear distribution without threshold in all cases, except for temperature and ozone, which are quadratic in nature. **Moreover, we explored the short and middle-term effects of variables on EHMHA through the use of Cross-Correlation Function (CCF). In case of the dependent variable, we previously eliminated seasonal behaviour using ARIMA models. The lag order for each variable was therefore selected based on literature, significant CCF association and biological sense (See supplementary material).**

Taking this into account, threshold variables were created for these last two variables.

In order to create the above threshold variables, the threshold levels that parametrise the functional **relation** between variables had to be ascertained. To this end, a second-order polynomial was adjusted to the curve described between daily ozone and the response variable, and the minimum of the function was determined by numerical calculation. This minimum value was 74 ug/m3. Once this value had been calculated, a new variable ("O3high") was created to identify values that exceeded the threshold calculated:

$O3high = 0,\ if [O3] < 74\ \mu g/m3$

$O3high = O3 - 74\ \mu g/m3,\ if [O3] > 74\ \mu g/m3$

In the case of temperature, a similar procedure was performed. According to previous studies (43), the threshold from which daily mortality is estimated to increase is a maximum daily temperature of 34°C for the definition of heat wave, and a minimum daily temperature of -2°C for the definition of cold wave. To this end, we created two new variables, defined as:

$Theat = 0,\ if\ Tmax{}^{\circ}C < 34^{\circ}C$

$Theat = Tmax{}^{\circ}C - 34^{\circ}C,\ if\ Tmax{}^{\circ}C > 34^{\circ}C$

$Tcold = 0,\ if\ Tmin{}^{\circ}C > -2^{\circ}C$

$Tcold = -2^{\circ}C - Tmin{}^{\circ}C,\ if\ Tmin{}^{\circ}C < -2^{\circ}C$

With regard to air pressure, a new variable (pressure trend) was created, namely, the daily air pressure value on the day minus the previous day's pressure. This variable was created to highlight daily variations in pressure in the model because previous studies show that sudden changes in air pressure are those that can have an influence on health (44).

Lags were introduced for independent variables because the health effect of the independent variables on the dependent variables may be delayed in time. For the pollution variables, PM_{10}, $PM_{2.5}$, NO_2 and noise, the effect may be lagged by up to 5 days (38,45), and for ozone by up to 9 days (38). The effect of changes in pressure can be detected up to 8 days afterwards, and the effect of relative humidity may be delayed by 14 days (38). In the case of temperature, the effect of high temperatures may be lagged by up to 5 days (39), and in the case of low temperatures by up to 14 days (46). **In addition, the CCFs shown in the supplementary material have been taken into account.**

To ascertain the impact of environmental variables on daily hospital admissions due to the causes cited, we fitted generalised linear models (GLMs) with a Poisson regression link and controlled for overdispersion. These variables were gradually eliminated, taking statistical significance as reference until all the variables had a significance of $p<0.05$ (backward stepwise method). Once the values of the significant estimators had been obtained, we calculated relative risks (RRs), attributable risks of **EHMHA** (ARs), and the number of daily admissions attributable to the variables which proved to be significant, considering the level or concentration of the pertinent environmental risk factor per day.

All statistical analyses were performed using the STATA v15 computer software package (StataCorp LP, College Station, Texas 77845 USA).

3. RESULTS

2191 observations were made across the study period, with a total of 67225 admissions due to **EHMHA** and self-inflicted injuries.

Table I shows the descriptive statistics of the dependent variable. The sequence charts of daily **EHMHA** and self-inflicted injuries in the MAR are shown in **Figure 2**. There was no evidence of variation in trend or clear seasonality.

Table II shows the descriptive statistics of the independent variables. For the variables of chemical and acoustic pollution in general, the sequence chart shows variations in trend, and in terms of seasonality all the variables had a “cyclical” component, varying in winter and in summer (Figure 3 and 4).

While the meteorological variables did not present a changing trend across the study period, in this case seasonality is intrinsic to these variables since climatological conditions are different in winter and in summer.

As for noise, we will take as reference values 50 dB(A) for the daily level (LAeq7-23) and 45 dB(A) for the night level (LAeq23-7), which corresponds to the WHO recommendations of Ln 45 dB(A) and Lden 53dB(A)(47). These values were exceeded 99% of the days during the day and 98% at night. The daily level (LAeq24h) corresponding to this reference (48.9 dBA) is exceeded during 99% of the days.

As a result of the modelling process, this study observed that hospital admissions due to mental disorders and self-inflicted injuries were significantly related with diurnal noise levels without lags and hours of sunlight at lag 5. For hours of sunlight this **relation** was negative, i.e., the fewer the hours of sunlight, the higher the admissions. Seasonality presented in six- and three-monthly cycles.

Analysis by sex (women and men) was also performed. Admissions due to mental disorders and self-inflicted injuries in women were significantly related with air pressure at lag 12, sunstroke at lags 5, and diurnal noise without lags. As in the previous case, hours of sunlight and humidity displayed a negative relationship.

Admissions due to mental disorders in men were related with sunstroke at lag 4, wind speed at lag 13. As before, hours of sunlight had a negative relationship, and were interpreted as the fewer the hours of sunlight, the higher the admissions.

Table III shows the relative and attributable risks with their respective confidence intervals of each significant variable.

In general, it can be seen that the lags which most frequently present a significant result are: at lag 0 for diurnal noise, i.e., the increase in emergency admissions takes on same day as increase in noise levels; at lag 5 for hours of sunlight, i.e., there is an increase in admissions on the 5th day of the dark days.

We also calculated the number of **EHMHA** per year attributable to anthropogenic activities based on attributable risks. The results are shown in Table IV.

In our case, no significant relation was found between **EHMHA** and environmental chemical pollutants or other meteorological variables, such as temperature in heat and cold waves.

4. DISCUSSION

In Spain, few studies have been conducted that link different environmental factors to emergency all-cause admissions. In the specific case of mental health, no study has been undertaken to assess this **relation** with total admissions due to mental disorders and analyse them by sex.

The results of our study show a statistically significant association between noise levels, hours of sunlight and **EHMHA** and self-inflicted injuries, with this association varying slightly between men and women. Among women the trend in air pressure also shows an association, and in the case of men diurnal noise does not prove significant.

Other similar studies support these results. In a recent study undertaken in Madrid which analysed the effects of road traffic noise and other environmental factors with emergency hospital admissions due to suicide, depression and anxiety, we found a **relation** between emergency admissions due to these disorders and noise, but did not however find an association with environmental chemical pollutants (48).

In other studies that analysed the effects of different environmental factors on **admissions in Madrid** due to diseases such as Parkinson's (32), Dementia (42) or Multiple Sclerosis (49), we also found a **relation** with acoustic pollution. In the case of Parkinson's and multiple sclerosis there was no **relation** with chemical air pollution. There are studies which support the fact that noise has a greater impact on health than does air pollution **(32,42,45,46,48,50)**. A recently published systematic review also supports these results, with a **relation** being found between noise and disorders such as depression and anxiety (51).

In the analysis, the diurnal noise levels were related to the dependent variable analysed. This finding should lead one to reflect on the need to update national and regional regulations in line with WHO guidelines and ensure their compliance, since it has been widely shown that exceedance of noise levels has an impact on health, and the findings of our study support this claim. Broken down by sex, noise levels were related with the dependent variable in the case of women, but not in the case of men. There are studies **in german populations** that suggest a greater sensitivity to noise among women (21,52). These differences should lead one to take gender into consideration when it comes to the drawing up of noise-related public health policies.

In relation to the biological mechanism whereby noise affects mental health, there are diverse theories. Noise could give rise to anomalies in response to stress in the hypothalamic-pituitary-adrenal (HPA) axis and serotonin neurotransmission (18), and would activate inflammatory and oxidative stress pathways (53).

As for sunstroke, greater exposure to sunlight is related to a lower number of days with mental disorders (54), and variations in sunlight have correlated with the prescription of antidepressants (55). Among its diagnoses, the DSM-V includes the seasonal affective disorder (56), which is defined as the presence of recurrent depressive episodes in a season of the year (usually autumn and winter) (57). Among the mechanisms implicated in their physiopathology are alterations in circadian rhythm (58), retinal sensitivity to light (59), melatonin metabolism abnormality (60), and a decrease in the secretion of neurotransmitters such as serotonin (61).

The pattern of prevalence in a specific area may not only depend on the quantity of irradiated light but also on such things as pollution, the presence of clouds, or architectural design. In the province of Madrid, there are areas that frequently meet these criteria, particularly high pollution and heavily built-up areas that allow little light to pass between buildings. There are no previous studies that have examined the hours of sunlight and their lags as a risk factor for an increase in **EHMHA**. This variable has proved to be significant for total admissions due to mental disorders in men and women alike. The effect of lack of light is produced especially in the short term, at 4-5 days after the day with little sunstroke, particularly in women, and here there is also an effect on the same day, which is an especially relevant result of this study.

There are studies that link air pollution to mental health **in London** (62) and hospital admissions caused by these disorders **in China** (16,63), but in our study there was no association with these factors. In another study conducted in the same region, which linked environmental factors to suicides, anxiety and depression, no association was found with chemical pollutants (48). Other studies that controlled for many seasonal factors have also found similar results in terms of association between urban air pollution and suicides **in Mexico City and Colombia** (64,65).

From our point of view, there are several factors that could account for this lack of association. In the MAR, the prevalence of some mental disease is below the Spanish mean (35). This contrasts with the higher prevalence of mental disorders in other countries where studies have been conducted which found an association with air pollution.

Our study, moreover, did not permit a breakdown by age group and this may have had an influence on the results, since prevalence of mental disorders varies with age.

Another reason is that the pollution levels included in the study correspond to the mean of measures from stations across the region, which smooths the maximum peaks of pollution at some stations, reducing their potential impact. That said, however, including meteorological variables such as pressure trend could be an indirect indicator of pollution. A positive pressure trend indicates an anticyclonic pattern, and this maintained over a long time may be indirectly indicating an increase in air pollution.

Other meteorological variables, such as wind (men) and pressure trend (women), also showed an association with EHMHA.

There are studies which correlate the direction of the wind with recurrent anxiety disorder (27). **In Kentucky** (USA) (30), wind speed was associated with an increase in violent acts. There are also studies that correlate the wind with the thermal feeling of cold, the so-called wind-chill factor (66), and cold has been associated **in China and Taiwan** with a worsening of mental disorders and an increase in admissions due to schizophrenia (67,68) or anxiety (69).

It is of note that no association was detected with **EHMHA** and high temperatures in heat waves, when there is literature in this respect that indicates that persons with mental diseases are a special risk group vis-à-vis heat waves (70–72). **One possible explanation for the lack of association is that the days on which there is a temperature considered a "heat wave" are few in relation to the rest of the year (199 days of the 2191 in the period), and it is possible that an association would be found if the analysis were performed focusing solely on the summer season.**

This finding, along with the effect of a few hours of sunlight, is concordant, since both variables can act as indicators of ambient cold.

Homeostasis, the process whereby the body is maintained in a stable state when the external surroundings are modified, may be implicated in this effect. The principal integrative centre of human thermoregulation is found in the preoptic region and anterior hypothalamus. The epigenetic changes and pre- and postnatal factors proposed for schizophrenia may be altered by thermoregulatory dysfunction (73). Ambient temperature has an influence on the neurotoxicity of dopamine and serotonin induced by drugs in mice (74). Given that it has been shown that dopaminergic transmission in schizophrenia is altered in animal models, schizophrenic patients could be prone to develop a thermoregulatory dysfunction. Furthermore, the sensitivity of patients with schizoaffective disorder to temperature may be partially explained by the anomalies of serotonin and norepinephrine in bipolar disorder (75). **In contrast to our case, Almendra et al (76) assessed the effect of all temperature range temperature on mental health and population analysed by Almendra is situated in a coastal city. Both are important differences.**

In coastal environments temperature tend to combine with higher relative humidity levels. In fact, this could be checked contrasting Lisbon's relative humidity (HR) values with Madrid's ones. Although Almendra did not report means values among their descriptive statistics, one could use their 50th percentile for RH (72.1%) as a proxy of the mean value assuming normal distribution for this variable. By doing so, one notice higher HR level in Lisbon than in Madrid (59,7%).

Higher HR interferes the evapotranspiration ability of the human body and ambient temperature perception, potentially increasing stress levels. This partially might explain the different results between the two studies.

Nevertheless, the temperature variables analysed in both studies are different, so that there is no suitable comparison. Firstly, Almendra assessed all-range-temperature and we have assessed temperature over regional heat-health-risk plan activation. Secondly, extreme-heat Relative Risks calculated by Almendra compares admissions at 99th vs 50th temperature percentiles while ours compare the temperatures over regional heat-health-risk plan activation vs temperature bellow this point.

Lastly, the air pressure trend proved significant, and acted, according to the analysis, as a risk factor in the case of women. Anticyclonic meteorological conditions with warm weather and low relative humidity have been linked to an increase in the frequency of suicides **in Budapest (Hungary)** (77). Even so, there is literature that suggests that low air pressures are related with an increase in impulsive behaviours and hospital emergency visits (30). It is possible that this variable may also act as a confounding variable, exerting an influence on the effect of the rest, and it is probable that the association found may be random.

During the study period there were a total of 67225 admissions, a mean of 11204 admissions per year of study. For the environmental factors for which an association with mental disease admissions was found, the number of admissions due to mental disorders attributable to these factors was calculated (Table IV).

The number of **EHMHA** attributable to diurnal noise was calculated by considering the threshold value as the lowest noise level registered across the study period (48.1 dB (A)), since there was no real zero-noise scenario. Departing from this point, the number of attributable **EHMHA** was 745, accounting for 5.5% of total admissions per year. It is necessary to underscore the wide confidence interval within which these probable admissions attributable to this variable tend to move.

The findings of our study show that the noise levels are associated with **EHMHA** in the MAR, with the main source being of the same anthropogenic nature. Other natural environmental factors also show that they have an influence on admissions due to these causes. The mental health of populations is influenced by complex interactions between genetic, social, lifestyle and environmental factors. Mental disorders are currently a growing problem worldwide, and ensuing crises, such as COVID-19, exacerbate the situation.

In Spain, there is no specific surveillance system integrated into public health, which would monitor the mental health of the population, as if it existed alongside other non-communicable diseases. Similarly, at a European level there **is** no integrated system that collects data from the different countries. This poses a difficulty, both for the undertaking of studies and surveillance, and the implementation of response measures.

More research is called for in this respect, as is the implementation of political, social and health measures that safeguard the mental health of the population.

5. LIMITATIONS AND STRENGTHS

5.2. Limitations

The values of the pollutants and the meteorological variables are the result of the mean of the measurements from different measuring stations located in different areas, which could smooth the impact, since it does not take into account the maximum peaks that take place in some areas of the region.

These biases are minimised by the inclusion of control variables in the models, such as trend, seasonality and the autoregressive nature of the series. On the other hand, as occurs in studies that analyse the effect of air pollution on health variables, there is a problem of adjustment (78). It should not be forgotten that the physical and socio-economic characteristics of the neighbourhood are related with behavioural disorders (79), and that these variables were not considered in this study.

One meteorological observatory collected all weather variables, which is called "MADRID-RETIRO" and is located in Retiro Park, in the centre of the city. Madrid Region has a few

meteorological observatories covering different weather forecast zones and the selected observatory has high correlation with approximately two-thirds of this area.

Noise measurements concern a total of 47 locations located in mostly urban areas of Madrid City and some other neighboring cities and towns (80,81). No source identification methods have been applied; therefore, overall noise has been assessed at each location. Nevertheless, given the distribution of the main road network in the region, road traffic is the main source of noise in most of the monitoring locations (even for the airports network). The small number of locations closest to the airport may have been influenced by aircraft noise too, depending on the airport runways configuration (82).

The daily means values used for the analysis reflect a linear average of the 47 overall noise level observations (data during maintenance operations were excluded) for each of the indicators ($L_{7\text{-}23h}$, $Ln_{23\text{-}7h,}$ and L_{24h}).

The existence of comorbidities that might alter the admission diagnosis were not considered (82).

The admission data include the principal cause of admission and no secondary diagnoses or contacts with emergencies without hospitalisation. This may entail not considering some diagnoses of mental health concomitant with the underlying cause of admission.

On dealing with a study with aggregate data and considering the previous limitations, the results cannot be extrapolated at an individual level.

5.3. Strengths

Our study is based on a widely used and accepted methodology for the conduct of this type of approach, since it has been previously used in similar studies (40,42,48). In the model we controlled for many environmental variables, which adds value to the study because we considered possible confounding environmental variables not considered in other studies. In addition, the data used were sourced from reliable official sources and the measuring stations from which the data on the environmental variables were obtained are representative of the region where the study was developed, including both urban and rural areas.

6. CONCLUSIONS

Noise is a variable related with **emergency hospital mental health admissions** in general for all age groups and for women independently in the MAR. The percentage of admissions per year attributable to this variable accounts for 5.5% of the total.

The few hours of sunlight and wind speed have proved equally significant, with this finding being interpreted as an indicator of the effect of the thermal feeling of cold. Previously this had not been analysed in similar studies.

The results of this study may may be useful for drawing up health guidelines and plans which consider these variables as risk factors for mental health, particularly in the case of noise, since acoustic pollution depends fundamentally on anthropogenic activities in highly urbanised areas and on high traffic density, and may thus be potentially modifiable by the implementation of regulations and policies based on scientific evidence. Although there are variables on which one can´t intervene, such as the hours of sunlight or wind speed, research in the field of mental health should additionally consider environmental factors, both pollution or meteorological variables.

Conflicts of interest

The authors declare that there are no conflicts of interest.

Disclaimer The researchers declare that they have no conflicts of interest that would compromise the independence of this research work. The views expressed by the authors are not necessarily those of the institutions with which they are affiliated.

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Table I. Descriptive statistics for emergency hospital mental health admissions (EHMHA)

	Mean	SD	Min	Max
Total	30.68	9.45	7	61
EHMHA in women	15.99	5.84	2	34
EHMHA in men	14.69	5.14	2	36

SD: standard deviation. Min: minimum. Max: maximum.

Table II. Descriptive statistics independent variables.				
Variable	**Mean**	**SD**	**Min**	**Max**
PM10 (µg/m3)	19.3	9.7	2.9	85.7
PM2.5 (µg/m3)	10.3	4.7	3.15	33.1
NO2 (µg/m3)	30.7	14.5	5.8	90.9
Daily O3 (µg/m3)	56.4	23.0	6.1	113.7
8-hour O3 (µg/m3)	78.5	28.8	9.9	171.5
Relative humidity (%)	59.7	16.3	19.0	95.2
Air pressure (hPa)	940.7	6.0	911.8	962.6
$L_{Aeq7\text{-}23h}$ dB(A)*	56.2	2.2	48.1	62.0
$L_{Aeq23\text{-}7h}$ dB(A)*	49.7	2.1	41.5	58.1
L_{Aeq24h} dB(A)*	54.9	2.2	46.8	54.9
T max (^{o}C)	21.1	9.1	2.8	40.0
T min (^{o}C)	10.9	6.8	-3.0	25.9
Wind (km/h)	6.4	3.0	0.0	18.7
Hours of sunlight	8.1	4.3	0.0	14.4

SD: standard deviation. Min: minimum. Max: maximum. Obs: number of observations. T: temperature

*Period 2014-2018

Table III. Relative risks (RR) and attributable risks (AR) with 95% confidence intervals (CI) for each unit increment of the independent variable, in the emergency hospital mental health admissions (EHMHA) analized, overall and broken down by sex across all age groups.							
Total admissions							
	Lag	**RR**	**95% CI RR**		**AR**	**95% CI AR**	
Hours of sunlight*	5	1.004	1.001	1.007	0.40	0.09	0.70
$L_{Aeq7\text{-}23h}$ dB(A)	0	1.008	1.003	1.013	0.79	0.30	1.28
Admissions women							
	Lag	**RR**	**95% CI RR**		**AR**	**95% CI AR**	
Pressure trend	12	1.003	1.000	1.006	0.30	0.00	0.60
Hours of sunlight*	5	1.005	1.002	1.008	0.50	0.20	0.80
$L_{Aeq7\text{-}23h}$ dB(A)	0	1.009	1.003	1.012	0.89	0.30	1.19
Admissions men							
	Lag	**RR**	**95% CI RR**		**AR**	**95% CI AR**	
Hours of sunlight*	4	1.006	1.001	1.010	0.58	0.14	1.02
Wind speed	13	1.006	1.003	1.011	0.63	0.27	0.99

RR: relative risk. CI: confidence interval. AR: attributable risk * In the case hours of sunlight, the interpretation is as follows: the fewer the hours of sunlight, the more admissions.

Table IV. Number of attributable emergency hospital mental health admissions (EHMHA) per year with 95% confidence intervals due to anthropogenic activities.		
	Lag	**EHMHA (men and women)**
$L_{Aeq7-23h}$ (dBA) threshold*	0	745 (283 - 1207)
		EHMHA (women)
$L_{Aeq7-23h}$ (dBA) threshold *	0	437 (147 - 584)

*Daily noise threshold refers to the noise level subtracting the minimum noise level recorded (48.1 dB(A)), because for the purposes of the effects of admissions, no zero-noise scenario is deemed to exist.

Figure Click here to access/download;Figure;FiguresR.docx

Map of the study area

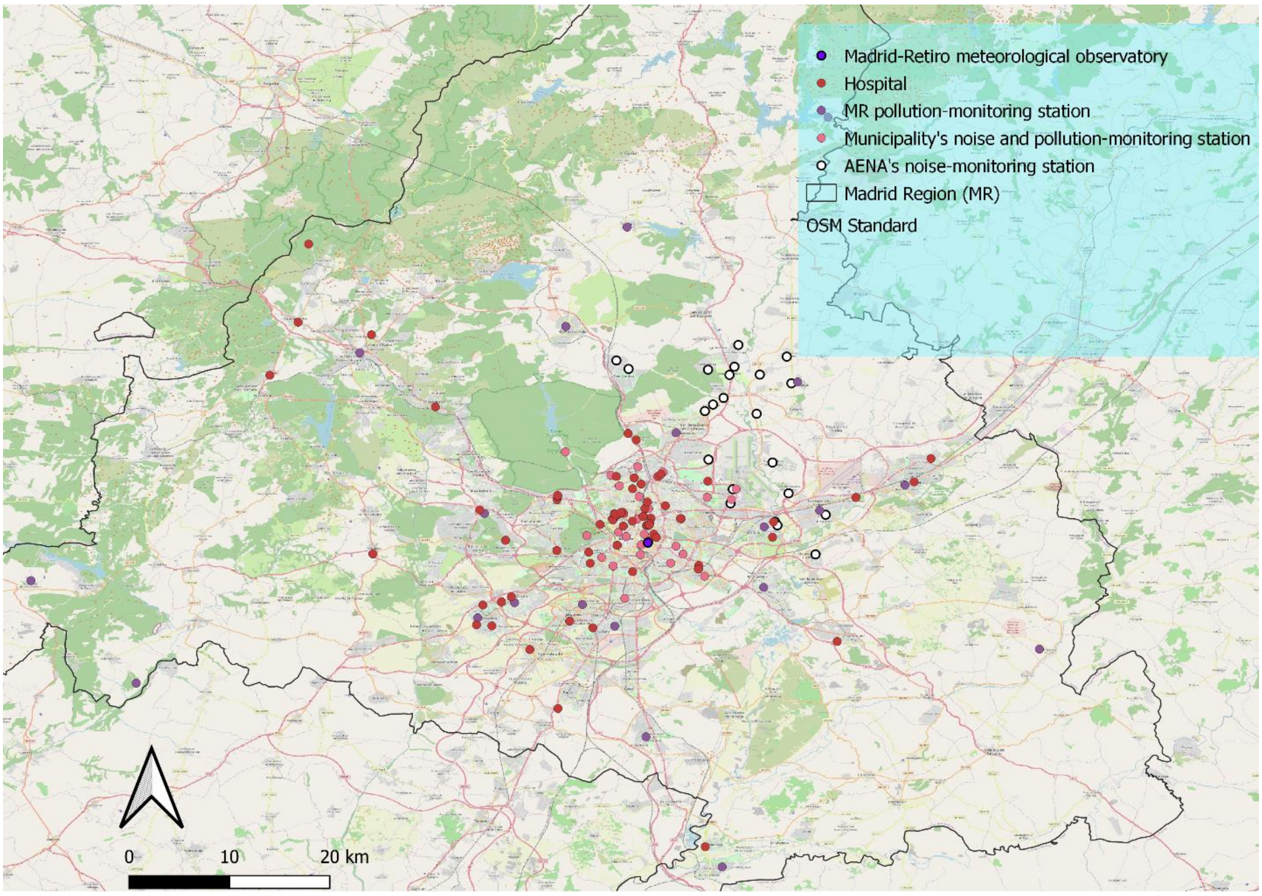


Figure 1. The map shows the geographical distribution of noise and pollution-monitoring stations, hospitals and the meteorological station used as data source.

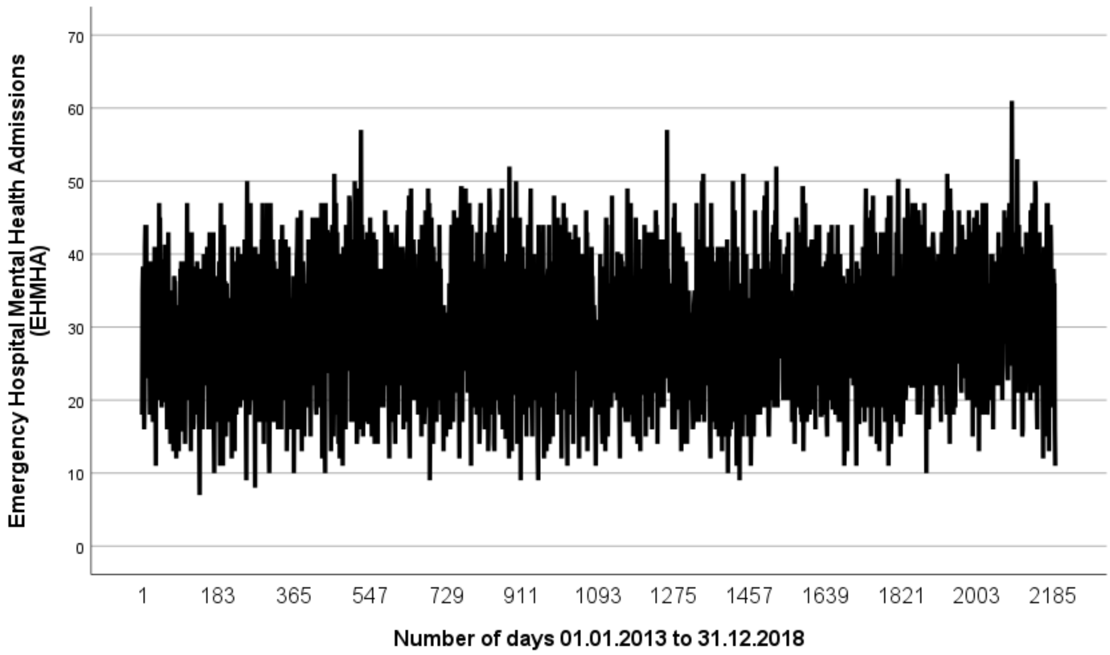


Figure 2. Sequence chart showing the number of daily **emergency hospital mental health admissions (EHMHA)** in Madrid region during the 2013-2018 period.

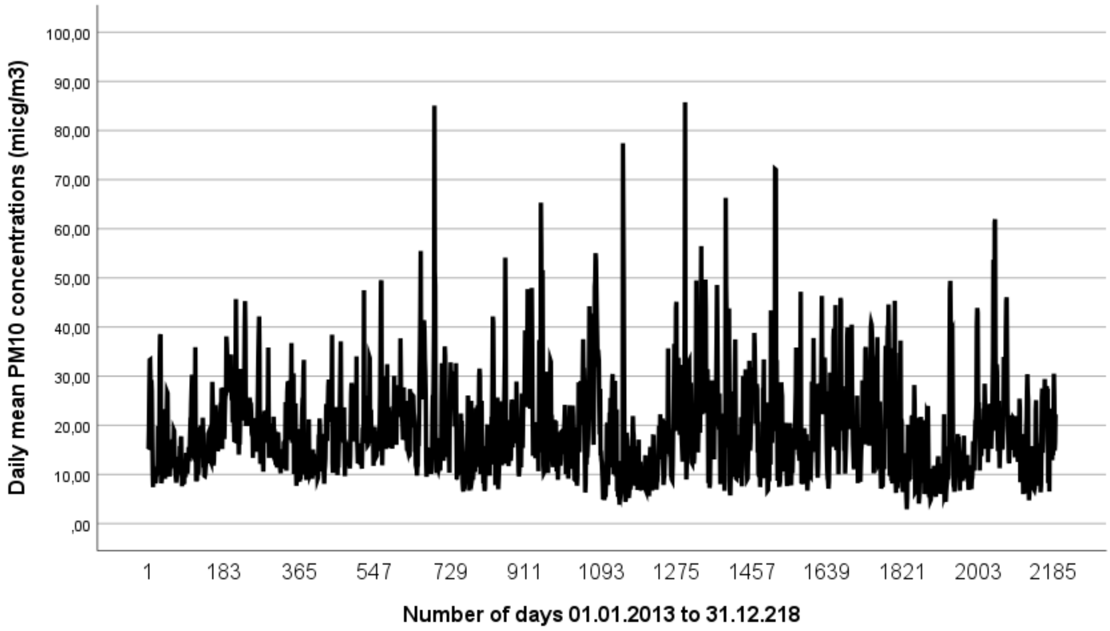
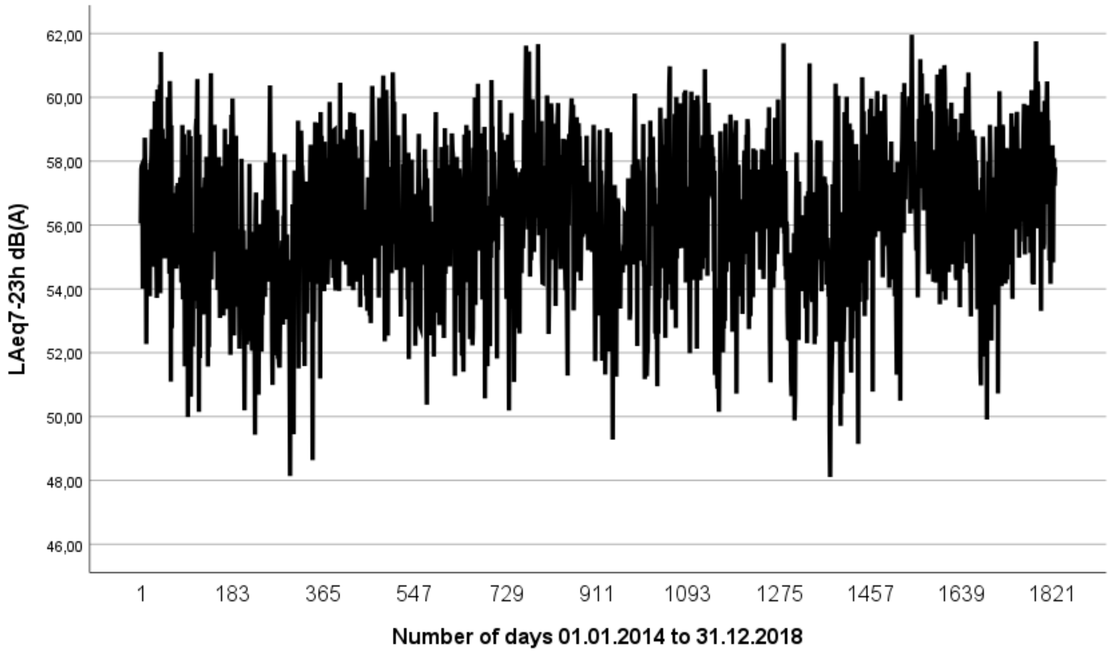


Figure 3. Sequence chart showing daily mean of PM10 concentrations (µg/m³) in the Madrid Region during the 2013-18 period.



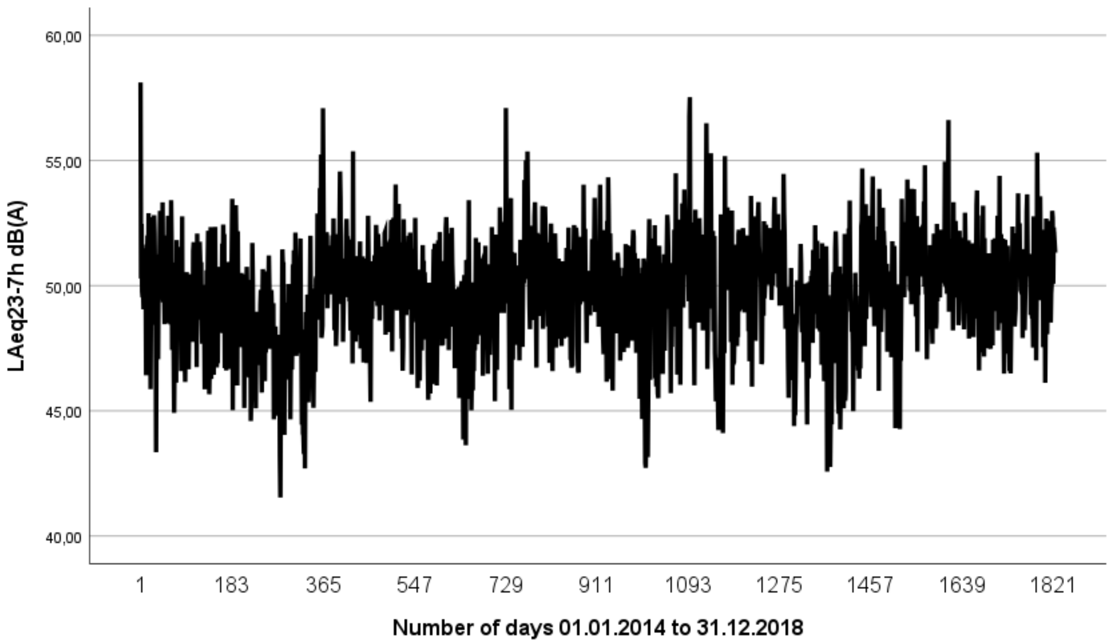


Figure 4. Sequence chart showing LAeq7-23h diurnal noise levels and LAeq237h nocturnal noise levels in the Madrid Region during the 2014-2018 period.