Association between malaria incidence and air quality: an ecological study.

Associação entre incidência de malária e qualidade do ar: um estudo ecológico

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ABSTRACT

The study aimed to identify an association between the incidence of malaria and indicators of air pollution. A negative binomial regression model was adjusted for analysis of the study object. As a result, the matrix indicated a strong linear correlation between the predictors, that is, multicollinearity, which was measured using the Variance Inflation Factor (VIF). In the end, the variables that were suggested for the model were organic carbon (OC) and sulfur dioxide SO2, both with VIF's =5.88. It was verified that the incidence of malaria is associated with the indicator of environmental pollution SO2 and the Human Development Index (HDI). It is concluded that with the increase in SO2 emissions, the registration of new cases of malaria decreases and that the lower the HDI, the more precarious the health care and interventions against malaria, increasing the country's vulnerability and the rates of neglected tropical diseases. While it is widely known that the water's quality affects the proliferation of mosquitoes that transmit Malaria, the effect of air quality on it is still poorly studied.

Key-words: Environmental Indicators; Malaria; Air Pollutants.

RESUMO

Foi ajustado um modelo de regressão binomial negativa para análise do objeto de estudo. Como resultado, a matriz indicou uma correlação linear forte entre os preditores, ou seja, multicolinearidade, que foi medida através do Fator de Inflação da Variância (VIF). Ao final, as variáveis que foram sugeridas para o modelo foram carbono orgânico (OC) e dióxido de enxofre SO2, ambas com VIF’s =5,88. Verificou-se que a incidência de malária está associada ao indicador de poluição ambiental SO2 e ao Índice de Desenvolvimento Humano (IDH). Conclui-se que com o aumento da emissão de SO2, o registro de novos casos de malária diminui e que quanto mais baixo o IDH, mais precário são os cuidados de saúde e intervenções contra a malária, aumentando a vulnerabilidade do país e as taxas de doenças tropicais negligenciadas. Embora seja amplamente conhecido que a qualidade da água afeta a proliferação de mosquitos transmissores da malária, o efeito da qualidade do ar sobre ela ainda é pouco estudado.

Palavras-Chave: Indicadores Ambientais; Malária; Poluentes do Ar.

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INTRODUÇÃO

Malaria is a potentially fatal disease and of great importance for global public health (Bartoloni; Zammarchi, 2012). According to the World Health Organization’s report - WHO, World Malaria Report 2017, 216 million cases of malaria were estimated in 91 countries for 2016, five million more than in 2015. Moreover, it is estimated that 3.2 billion people are still at risk of being infected by this disease (WHO, 2017; WHO, 2020).

Due to its importance, the United Nations (UN) has placed Malaria, in its Sustainable Development Goals (SDGs), as a disease to be controlled. More specifically, goal 3.3 states: “by 2030, end with the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases, and combat hepatitis, water-borne diseases, and other communicable diseases” and has as one of its indicators the incidence of malaria for every 1000 inhabitants (ONU, 2021).

Some studies evaluated the synergies and trade-offs between SDGs through their indicators (Pradhan et al., 2017; Moyer; Bohl, 2019). Due to the holistic nature of the SDGs, there are synergies and trade-offs within each SDG and between them but the specific mechanisms of each pair of associations has yet to be described.

The mosquito that transmits malaria, *Anopheles sp. genus*, reproduces in water. It is known that changes in the physicochemical properties of water, such as pH, turbidity and the presence of heavy metals, affect the mosquito’s reproductive capacity (Hogarh et al., 2018; Wang et al., 2021; Achcar et al., 2011). However, there are no studies regarding the effects of urban air pollution on malaria cases.

Given the international statistical relevance, a study is needed to verify the association between malaria incidence and air pollution indicators. This will certainly contribute to more specific knowledge about the dynamics of the disease, providing relevant information for the implementation of prevention and control strategies based on different patterns of malaria.

METHODS

The work here presented is an ecological, cross-sectional study that used WHO's national-level malaria incidence databases.

The final database contained complete observations from 99 countries with reported malaria cases for the following indicators: number of new malaria cases, black carbon, methane, carbon monoxide, ammonia, non-methane volatile organic compounds, nitrogen oxides, organic carbon, sulfur dioxide, particulate material up to 2.5 micrometers, particulate material up to 10 micrometers, population size in 2015 (POP) and HDI in 2015. For the air quality variables, Giga-grams (Gg) was the unit of measurement (Table 1.).

### Table 1. Descriptive statistics of number of new cases of malaria, air quality variables, Human Development Index and population size per country in 2015

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of new cases</td>
<td>99</td>
<td>2,230,138,000</td>
<td>6,234,764,000</td>
<td>0</td>
<td>53,631,429</td>
</tr>
<tr>
<td>Black carbon</td>
<td>99</td>
<td>41.482</td>
<td>156.449</td>
<td>0.054</td>
<td>1,313.796</td>
</tr>
<tr>
<td>Methane</td>
<td>99</td>
<td>2,604.353</td>
<td>7,422.597</td>
<td>3.190</td>
<td>62,330.510</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>99</td>
<td>4,828.260</td>
<td>15,476.880</td>
<td>5.075</td>
<td>129,684.100</td>
</tr>
<tr>
<td>Ammonia</td>
<td>99</td>
<td>346.162</td>
<td>1,093.808</td>
<td>0.615</td>
<td>8,733.159</td>
</tr>
<tr>
<td>Non-methane volatile organic compounds</td>
<td>99</td>
<td>1,100.417</td>
<td>3,456.632</td>
<td>1.791</td>
<td>30,867.940</td>
</tr>
<tr>
<td>nitrogen oxides</td>
<td>99</td>
<td>698.529</td>
<td>2,871.787</td>
<td>0.815</td>
<td>26,365.370</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>99</td>
<td>103.453</td>
<td>336.346</td>
<td>0.139</td>
<td>2,618.724</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>99</td>
<td>685.713</td>
<td>3,321.358</td>
<td>0.500</td>
<td>30,900.830</td>
</tr>
<tr>
<td>Particulate Matter 2.5</td>
<td>99</td>
<td>319.016</td>
<td>1,282.479</td>
<td>0.383</td>
<td>11,055.190</td>
</tr>
<tr>
<td>Particulate Matter 10</td>
<td>99</td>
<td>526.714</td>
<td>1,912.401</td>
<td>0.501</td>
<td>16,022.090</td>
</tr>
</tbody>
</table>
The NCM variable for each country was calculated using the mathematical formula that defines the concept of incidence rate considering the incidence rate per 1000 inhabitants and the population size, both for the year 2015. The variable Population was used for this calculation because this was the variable used by WHO to calculate the incidence rate. This same variable was later used as an offset in the negative binomial regression to estimate the association between malaria incidence and air quality indicators.

The HDI variable was considered in the study because it is a confounding variable. So we included it in the model to adjust for socioeconomic issues that could influence the estimates.

The association between the variable response “number of new malaria cases” and the predictive variables of air quality was estimated using negative binomial regression adjusted for HDI and using POP as an offset variable. Negative binomial regression was chosen because the response variable is of the count type with negative binomial distribution and arithmetic mean different from the variance.

An exploratory analysis using Pearson’s linear correlation showed multicollinearity between the predictor variables. To correct the problem Variance Inflation Factors (VIF) were estimated for the complete model and backward elimination was used to select the variables presenting VIF lower than 10. The final model considered only Organic Carbon (OC) and Sulfur Dioxide (SO2) as predictors. All analyzes were performed using the Software R v.3.6.2. (Team, 2019).

**RESULTS AND DISCUSSION**

The results let us to suggest that an association between the incidence of malaria and SO2 exists (p < 0.01). The estimated coefficient of -0.0002 shows a negative association. Therefore, the greater the amount of SO2 present in the air, the lower the incidence of malaria. The logarithms of the coefficients give us the incidence rate ratios (IRR) which is a measure of effect size (Table 2).
Table 2. Regression analysis results

<table>
<thead>
<tr>
<th>Variable</th>
<th>IRR*</th>
<th>Confidence interval 95%</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>242.0771608</td>
<td>12.8878477-5957.1051464</td>
<td>0.0000055</td>
</tr>
<tr>
<td>OC</td>
<td>1.0025889</td>
<td>0.9991258-1.0073189</td>
<td>0.1312073</td>
</tr>
<tr>
<td>SO2</td>
<td>0.9994174</td>
<td>0.9989888-0.9999409</td>
<td>0.0008881</td>
</tr>
<tr>
<td>HDI</td>
<td>0.0000005</td>
<td>0.0000000-0.0000645</td>
<td>0.0000000</td>
</tr>
</tbody>
</table>

*IRR: Incidence Rate ratio (log of the regression coefficient estimates).

Associations between all air pollution variables showed Pearson values close to +1 and statistical significance with p value <0.001. For example, in the correlation between black carbon (BC) and methane (CH4) we rejected H0, we found a positive and strong association, Pearson's r 0.98 and p<0.001, being highly significant.

The association between the number of new cases and the HDI covariate is also considered relevant, as the latter showed a moderate negative association, r Pearson's -0.32 and p=0.001, being highly significant. Thus, as the HDI increases, the number of new cases of malaria decreases, which is an inversely proportional correlation (Figure 1).

Figure 1: Pearson Linear Correlation between study variables.
The IRR of SO2 is equal to 0.9994174. That means that an increase of one unit of SO2 causes the malaria incidence rate to decrease by 0.99994174% when compared to the previous incidence rate. Although the effect size seems small, in absolute terms the global number of clinical cases in 2015 (218839) would have decreased by about 2188 cases with the decrease of just one Gg SO2 present in the air.

A possible explanation for this reduction in the incidence rate of malaria would be the reduction of mosquitoes’ number due to rainwater bodies acidification. In this case, the SO2 in the air reacts with oxygen to form sulfur trioxide (SO2 + O2 → SO3). Then, the SO3 reacts with water vapor to form sulfuric acid (SO3 + H2O → H2SO4). This acid rain would lower the water body’s pH, making it difficult for mosquitoes to proliferate, as seen in the literature (Hogarh et al., 2018; Wang et al., 2021; Achcar et al., 2011).

The negative association between the incidence rate of malaria and the SO2 present in the air implies that worse air quality can improve malaria indicators, which contradicts with the SDGs that aim to improve both dimensions simultaneously. Thus, depending on the method used, it is possible that the improvement of one indicator cannot happen without worsening the other within those proposed by the UN for the SDGs.

**CONCLUSION**

In view of the results of the present study and other studies reported in the literature, it is possible to conclude that the emission of air pollutants, specifically sulfur dioxide (SO2), together with the water molecule, forming sulfuric acid, consequently acid rain, causing acidification of the water, preventing larvae, small algae and insects from developing, thus favoring a reduction in the number of new cases of malaria.

Human development, income, schooling, population growth and ecological changes are associated with increased risk of malaria. The pace of progress countries will make will depend on the strength of their national health system, the level of investment in malaria control, and a range of other factors, including: biological determinants, environment, and social, demographic, political, and economic realities from each country.
REFERÊNCIAS


