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Fine particulate matter ($PM_{2.5}$) concentration in air pollution and its correlation with related factors - A case study in Hanoi city, Vietnam

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Abstract. Air pollution is becoming increasingly serious, adversely affecting human health in many countries, including Vietnam. Among the factors causing air pollution, $PM_{2.5}$ is the main cause of disease and premature mortality. This study presents the current status of $PM_{2.5}$ in the air of Hanoi city in 6 months (from 02 June 2023 to 30 November 2023) from automatic monitoring data of 7 monitoring stations. The Kriging spatial interpolation method was used to establish the pollution distribution map and the Multivariate Linear Regression (MLR) model was used to establish the relationship between $PM_{2.5}$ concentration and related factors. The results show that $PM_{2.5}$ concentration in the air in Hanoi is very high, 94% of the monitored values exceed the safety limit of the World Health Organization (WHO). Compared to summer months, the winter months have higher $PM_{2.5}$ concentrations in the air. From the correlation equations, the study also shows that $PM_{2.5}$ concentration is positively correlated with CO and NO_2 emissions and negatively correlated with temperature.

1. Introduction

Currently, air pollution is a serious problem in low- and middle-income countries, causing adverse effects on human health [1]. According to the WHO report in 2018, air pollution is the cause of approximately 6.5 million premature deaths annually, of which about 4.2 million are due to ambient (outdoor) air pollution [2] and more than 90% of air pollution-related deaths occur in low- and middle-income countries [3]. Cities with poor air quality are concentrated mainly in East Asia, South Asia, and Southeast Asia [4].

Among the factors causing air pollution, fine particulate matter ($PM_{2.5}$) is the main component that has adverse health effects [5]. $PM_{2.5}$ dust particles have an aerodynamic diameter of about 2.5 μm or smaller, can survive in the air for a long time and spread far. Depending on the source, $PM_{2.5}$ is formed from many components, including some basic components such as carbon, nitrates, organic compounds, inorganic ions, and minerals [6]. Sources of $PM_{2.5}$ can be natural or anthropogenic, such as forest fires, volcanic eruptions, soil and road dust, industrial activities, traffic activities, animal husbandry and agricultural activities, etc.

Because of its very small size, $PM_{2.5}$ is very dangerous, capable of penetrating deep into the alveoli in the lungs and red blood cells, causing adverse effects on human health. There have been many studies conducted to determine the effects of $PM_{2.5}$ on humans as well as society. These studies show that $PM_{2.5}$ is the cause of some diseases such as airways and lungs diseases [7, 8]; cancer [9, 10], kidney disease [11], blood pressure diseases [12, 13], neurological diseases [14], and reproductive diseases [15].

In high-income countries, the $PM_{2.5}$ concentration in the air environment has tended to decrease in recent years because it is controlled by modern technical solutions [16]. However, $PM_{2.5}$ pollution in lower/middle-income remains a serious problem facing these countries, including Vietnam. According to statistics from the WHO, air pollution is responsible for about 60,000 premature deaths each year in Vietnam [17]. According to the 2019 World Air Quality Report, Vietnam's average $PM_{2.5}$ concentration in 2019 was 34.1 μg/m^3, the 21st highest out of 106 countries surveyed [18]. Hanoi is the capital of Vietnam, a city with rapid economic and population growth in recent years, accompanied by challenges in environmental protection, especially air quality. Many studies on $PM_{2.5}$ in Hanoi have been conducted to assess the pollution situation and provide forecasts and solutions to improve the air environment of this city [19, 20, 21, 22, 23, 24]. The research results of Vuong and colleagues showed that in 2021, Hanoi's average $PM_{2.5}$ value in 2021 is (78.09 ± 51.71) μg/m^3, the highest daily average $PM_{2.5}$ value is 271.39 μg/m^3 (3 times higher than the WHO recommended safety limit in 2020 is 25 μg/m^3) [18]. There are three main sources of $PM_{2.5}$ in Hanoi: industrial production, traffic, agricultural waste treatment [23, 24]. However, these studies have limitations such as the number of monitoring stations being less, short or intermittent monitoring periods, and have not shown the correlation between $PM_{2.5}$ with weather factors as well as with emissions. Furthermore, in 2021, the WHO issued a new safety limit for $PM_{2.5}$, so most previous studies are referring to the old standard, and there are not many studies referring to the new standard.

To determine the distribution of $PM_{2.5}$ concentration in Hanoi and examine the dependence of PM2.5 concentration on related factors, we collected 6-month monitoring data (from 02 June 2023 to 30 November 2023) from 07 automatic monitoring stations in the inner city of Hanoi. Surfer software with the Kriging spatial interpolation method was used to build $PM_{2.5}$ pollution distribution maps. Based on the monitored data, the dependence of $PM_{2.5}$ value on temperature, pressure, humidity, CO, and NO_2 factors is built to propose suitable solutions to control $PM_{2.5}$ concentration.

2. Materials and methods

2.1. Study area

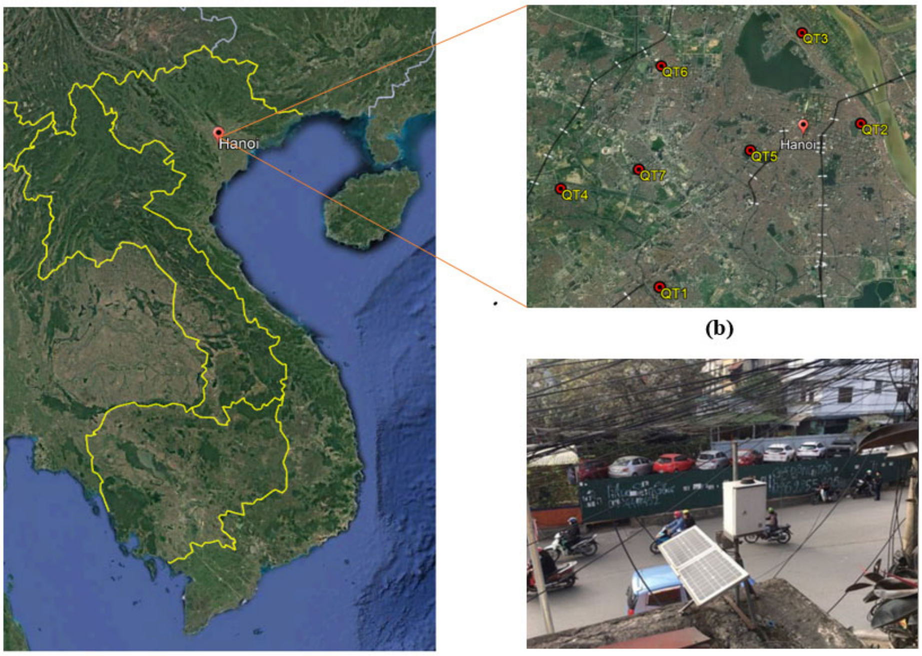
The Hanoi capital is located in the northern region of Vietnam, in the central region of the Red River Delta (Fig. 1a). Hanoi is an important economic, political, cultural, and educational center of Vietnam, with a population of 8.6 million in 2023, an average population density of 2,556 people/km^2 [25]. Hanoi's climate is a tropical monsoon climate, with two distinct seasons: summer (from May to September) and winter (from November to March). However, due to the strong influence of the monsoon, the start and end times of each season are often not the same between years, so the division of months is only relative. During the winter months, dry air combined with calm wind conditions causes the accumulation of ambient air pollution in Hanoi to increase sharply [24].

The study area is located from 20.972337^{0}N to 21.064172^{0}N and 105.749607^{0}E to 105.85498^{0}E, located in the inner city of Hanoi capital, affected by $PM_{2.5}$ sources such as traffic activities, industrial activities, construction activities, and civil activities. In addition, this area is also polluted by the burning of agricultural waste (rice straw) by neighboring districts after each harvest season.

2.2. Monitor data

The research data is provided by the Hanoi Center for Natural Resources and Environment Engineering, under the Hanoi Department of Natural Resources and Environment, which is data collected from automatic monitoring stations of the Hanoi Department of Natural Resources and Environment. The study uses monitoring data for 6 months (from 02 June 2023 to 30 November 2023) of 7 monitoring stations. These monitoring stations are evenly distributed in the study area (Fig. 1b), their information is shown in Table 1.

All of these stations are automatic monitoring stations using sensors. Of the 7 stations, 3 are traffic monitoring stations, 2 are urban stations and 2 are near-urban monitoring stations. The pollution index analyzer is an automatic machine from ENVEA, France (Fig. 1c). At each monitoring point, the data collected includes the following indicators: $PM_{2.5}$, CO, NO_2, temperature, humidity, and pressure.



(a) (c)

Figure 1. (a) Location of the capital Hanoi on Vietnam's map; (b) location of monitoring stations; (c) illustration of the monitoring station in operation

Table 1. Information of monitoring stations

Stations	Type of monitoring	Longitude $(^0)$	Latitude $(^0)$
QT1	Near-urban	105.786271	20.972337
QT2	Traffic	105.854998	21.029462
QT3	Urban	105.833787	21.064172
QT4	Near-urban	105.749607	21.005870
QT5	Traffic	105.815562	21.019775
QT6	Traffic	105.782220	21.051140
QT7	Urban	105.776627	21.012832

(Source: Hanoi Center for Natural Resources and Environment Technology)

The data will be automatically analyzed, calculated and given results by the receiver with a frequency of 1 hour/value. The research team has compiled the data and calculated the average $PM_{2.5}$ value of the stations by month as shown in Table 2.

Table 2. Monthly average $PM_{2.5}$ concentration value

Station	Average $PM_{2.5}$ value ($\mu g/m^3$)					
	June	July	August	September	October	November
QT1	16.7	14.1	24.1	27.1	35.1	47.1
QT2	25.7	21.7	42.1	50.7	59.5	77.5
QT3	27.1	23.1	28.6	27.9	33.8	48.4
QT4	27.7	23.9	29.9	27.1	33.8	40.7
QT5	32.7	31.7	41.7	45.5	56.9	76.3
QT6	36.3	33.7	46.1	47.2	60.4	76.2
QT7	23.3	21.7	30.3	28.8	38.0	43.0

2.3. Spatial interpolation using Kriging method

The Kriging algorithm is a method used to interpolate the unknown value of a location based on the known values of the the measurement points around it [26]. This value can be the pollution level of the land, the air pollution concentration, the elevation of terrain, etc. The Kriging algorithm's interpolation result depends on the spatial correlation between the interpolated point and the sample values. This is shown in the following formula [27]:

$$T^{*} - \mu = \sum_{n}^{1} \mathrm{W}_i (g_i - \mu_i) \quad (1)$$

where T^* is the value to be estimated at a coordinate in space, μ is the average value, W is weight, g is the value of other points, n is the number of surrounding data used to estimate the value of T.

The Kriging method will assign weight values (W) to sample points with known values. Depending on the relative position between the sample points and the point to be interpolated to determine weight values, closer points will have greater weight than farther points. The weight assignment process will be done by approximating a curve with known points, satisfying the condition that the variance is minimal. After modeling the data with mathematical functions, the variance is used to evaluate the interpolation accuracy of each point as well as the entire interpolation surface [28].

The Kriging method is one of the most flexible methods, can be used with most data, and is very effective. The advantage of the Kriging method is that it combines both the distance factor and the spatial distribution factor between points to provide highly accurate interpolation results and has a better spatial correlation. However, the implementation algorithm is complex, requires a lot of calculation time, modeling, and requires a lot of input data.

2.4 Multiple linear regression (MLR) model

The MLR model is used to build equations showing the correlation between $PM_{2.5}$ concentration with emission variables (CO, NO_2) and meteorological variables (pressure, humidity, temperature). The model is established according to the following equation [29]:

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \cdots + \alpha_n x_n + \varepsilon \quad (2)$$

where y is the dependent variable (in this study, it is the $PM_{2.5}$ value); x_i are the independent variables (in this study, they are the CO, NO_2 values, and meteorological values: pressure, humidity, temperature); α_0 is the intercept on the vertical axis; α_1, α_2,..., α_n are the coefficients of the correlation equation; ε is the random error.

Based on the data of average hourly monitoring values from the stations, SPSS software was used to train the model to obtain correlation equations showing the dependence of $PM_{2.5}$ concentration values on related factors.

3. Results and Discussion

3.1. Current status of $PM_{2.5}$ concentration in Hanoi city

The daily average $PM_{2.5}$ data of 7 monitoring stations over 6 months (from 02 June 2023 to 30 November 2023) are shown in Figure 2.

Figure 2. $PM_{2.5}$ concentration during monitoring period (from 02 June 2023 to 30 November 2023) of 7 monitoring stations. The blue wavy line are $PM_{2.5}$ values, the red lines are WHO safety limits.

In Figure 2, the red line shows the WHO 24-hour average $PM_{2.5}$ safety limit (15 μg/m^3) [17], the blue wavy line shows the $PM_{2.5}$ monitoring values of the stations. The results show that the $PM_{2.5}$ concentration in Hanoi is very high level. Out of 1,274 monitored values, only 76 values are less than 15 μg/m^3, accounting for 6%. Notably, out of 7 monitoring stations, 2 stations QT5 and QT6 do not have any $PM_{2.5}$ values within the safe limit recommended by WHO. The highest $PM_{2.5}$ value was 150.4 μg/m^3 on 22 November 2023 at station QT6, the lowest observed value was 5.9 μg/m^3 on 06 August 2023 at station QT1. The average $PM_{2.5}$ concentration during this period was 37.68 μg/m^3.

This result is about 1/2 the average value from May 2021 to March 2022 of 78.09 μg/m^3 [18] and equivalent to the average value from 2002 - 2005 of 35.84 μg/m^3 [30]

Comparing the monthly average $PM_{2.5}$ values at monitoring stations, the results showed that in the winter months, the $PM_{2.5}$ concentration in the air increased significantly (Fig. 3). The highest monthly average $PM_{2.5}$ value is in November at stations QT2 (77.5 μg/m^3), QT5 (76.3 μg/m^3), QT6 (76.2 μg/m^3), and the lowest is in July at station QT1 (14.1 μg/m^3).

Based on monthly $PM_{2.5}$ concentration monitoring data from stations as shown in Table 2, Surfer software with the Kriging interpolation method was used to create a monthly $PM_{2.5}$ status map of Hanoi city. We obtain $PM_{2.5}$ concentration distribution maps of Hanoi city as shown in Figure 4.

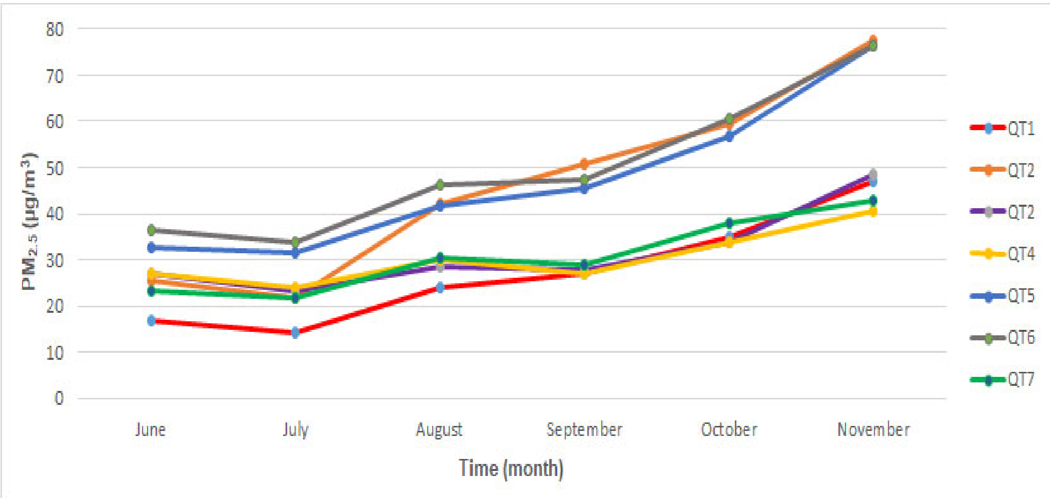


Figure 3. Monthly average $PM_{2.5}$ concentration variation

In Figure 4, there are 3 areas with high $PM_{2.5}$ concentrations: QT2, QT5, and QT6. Thus, it can be seen that the $PM_{2.5}$ concentration in Hanoi's inner city is greatly affected by traffic activities. November is the month with the highest pollution level, all monitoring values are at high levels, 3÷5 times the WHO safety limit. Similar results have also been published in previous studies [24; 31].

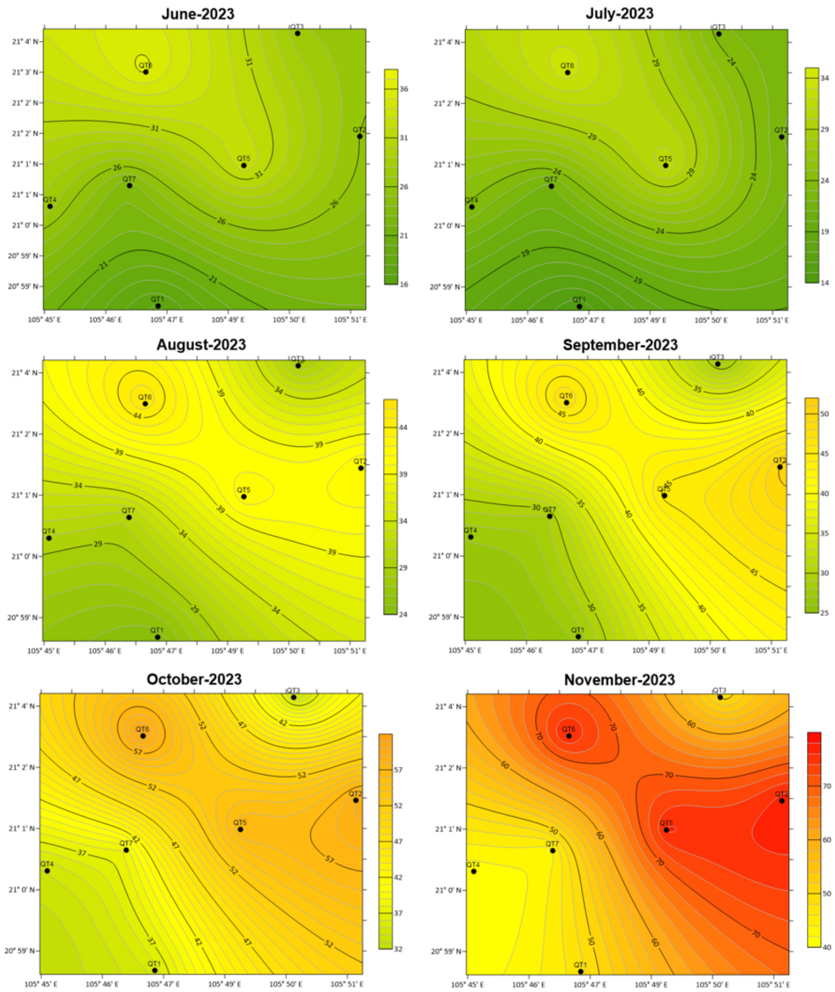


Figure 4. $PM_{2.5}$ concentration map of Hanoi city in 6 months of 2023

3.2. Correlation between $PM_{2.5}$ concentration and related factors

3.2.1. Dependence of $PM_{2.5}$ concentration on emission factors (CO, NO_2). According to Subsection 2.4, the regression equation showing the multivariate correlation between 02 types of emissions (x_1 - CO; x_2 - NO_2) for $PM_{2.5}$ concentration value (y) is shown in Table 3. The monitoring data are 1-hour average values.

Table 3. Correlation equation between $PM_{2.5}$ concentration with CO and NO_2 at monitoring stations

Station	Correlation equation	R Square
QT1	$y = 0.809 + 0.018x_1 + 0.702x_2$	0.263
QT2	$y = 4.177 - 0.002x_1 + 1.792x_2$	0.262
QT3	$y = 3.55 + 0.002x_1 + 1.648x_2$	0.347
QT4	$y = 17.679 - 0.001x_1 + 0.435x_2$	0.138
QT5	$y = 15.182 + 0.004x_1 + 0.612x_2$	0.261
QT6	$y = 26.539 + 0.003x_1 + 0.267x_2$	0.093
QT7	$y = 13.222 + 0.004x_1 + 0.296x_2$	0.223

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The correlation equations show that the $PM_{2.5}$ concentration values and CO and NO_2 emissions are mainly positively correlated. Only at the QT2 and QT4 stations, the relationship between $PM_{2.5}$ concentration and CO value is negatively correlated. This shows that to minimize $PM_{2.5}$ concentration, we must have a plan to minimize CO and NO_2 emissions, which are emissions that can increase $PM_{2.5}$ concentrations. When these substances decrease, the $PM_{2.5}$ concentration also decreases. Some activities that can cause CO and NO_2 emissions that Hanoi needs to have a control plan for are industrial activities, burning agricultural waste, transportation activities, etc. Similar relationships have also been published in several previous studies [32].

3.2.2. Dependence of $PM_{2.5}$ concentration on meteorological factors. The dependence of $PM_{2.5}$ concentration on 3 meteorological variables (pressure, humidity, and temperature) is determined by the coefficients β_i in the corresponding multiple linear regression equations associated with the meteorological variables x_1, x_2, x_3 (x_1 - pressure; x_2 - humidity; and x_3 - temperature). The correlation functions at the stations are presented in Table 4.

Table 4. Correlation equation between $PM_{2.5}$ concentration with meteorological factors

Station	Correlation equation	R Square
QT1	$y = -1157.768 + 1.191x_1 + 1.300x_2 - 0.722x_3$	0.217
QT2	$y = -1519.854 + 1.622x_1 - 0.820x_2 - 2.021x_3$	0.226
QT3	$y = -271.626 + 0.340x_1 + 0.095x_2 - 1.591x_3$	0.174
QT4	$y = 158.923 - 0.080x_1 - 0.850x_2 - 1.352x_3$	0.128
QT5	$y = -639.829 + 0.806_{x1} - 0.477x_2 - 2.891x_3$	0.22
QT6	$y = -1118.697 + 1.198x_1 + 0.155x_2 - 1.600x_3$	0.201
QT7	$y = -562.73 + 0.608x_1 + 0.062x_2 - 0.759x_3$	0.160

The correlation functions in Table 4 show that the $PM_{2.5}$ concentration and temperature values are negatively correlated. That is, in the case where the two factors of pressure and humidity remain unchanged if the temperature decreases, the $PM_{2.5}$ concentration will increase, and conversely, if the temperature increases, the $PM_{2.5}$ concentration will decrease. This is consistent with the results presented in Subsection 3.1, the $PM_{2.5}$ concentration increases in winter and decreases in summer. The two factors of pressure and humidity have a more complex correlation, different stations will have different positive/negative correlations. Pressure and $PM_{2.5}$ concentration are negatively correlated at the location of monitoring station QT4 and are positively correlated at the remaining monitoring stations. Humidity and $PM_{2.5}$ concentration are negatively correlated at QT2, QT4, and QT5 stations, and positively correlated at QT1, QT3, QT6, and QT7 stations.

4. Conclusions

The Hanoi capital is increasingly developing, so air pollution - especially $PM_{2.5}$ concentration in the air - is an issue that needs to be researched to protect human health. This study shows that Hanoi's $PM_{2.5}$ pollution level is high, especially on some days when it is 10 times higher than the WHO's safe limit. $PM_{2.5}$ concentrations in winter are higher than in summer. This is also clearly shown by the correlation equation between $PM_{2.5}$ concentrations and meteorological factors (pressure, humidity, and temperature). The correlation equation between $PM_{2.5}$ and CO and NO_2 emission factors shows that solutions are needed to reduce these emissions, helping to reduce $PM_{2.5}$ concentrations. Some possible measures are to reduce industrial production activities, prohibit burning agricultural waste, encourage the use of public transport, plant more trees, etc. However, other influencing factors such as wind speed and direction, dust from burning straw, have not been mentioned in this study.

In addition, the monitoring time in winter is not long, winter monitoring time is not long, so there is no full comparison of pollution levels between the two seasons (summer and winter). In the future, other studies are needed to supplement the above shortcomings to have more accurate conclusions about $PM_{2.5}$ concentration in Hanoi.

To better manage the air environment, Hanoi city needs to strengthen the network of $PM_{2.5}$ concentration monitoring stations, especially in urban areas and concentrated traffic areas. Add measuring stations at important locations such as near factories, schools, and densely populated areas to have accurate and immediate fine particle pollution monitoring data, as a basis for managers to take appropriate measures to ensure public health and safety.

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