

Original article

UDC 351.811

doi: 10.46684/2026.1.1

EDN: TMGXHA

Studying the influence of humidification of atmospheric aerosol on visibility on roads

Elshan R. Ragimov¹, Elchin B. Iskenderzade², Jeyhun R. Ragimov³, Khumar S. Aliyeva^{4✉}

¹ Baku Higher Oil School; Baku, Azerbaijan

^{2,4} National Aerospace Agency; Baku, Azerbaijan

³ Azerbaijan Technical University; Baku, Azerbaijan

¹⁻⁴ a.khumar.1962@gmail.com✉

ABSTRACT Introduction: The subject of the study is the effect of humidification of aerosol on visibility on roads. When hygroscopic aerosol becomes humidified, the size of aerosol particles increases several times, which significantly impairs visibility on roads. The aim of the study is to study the effect of humidification of hygroscopic aerosol on visibility on highways. Materials and methods: A model is proposed for calculating integral visibility on a long highway, taking into account the hygroscopicity of the aerosol, i.e. the effect of humidification of the aerosol in these zones. The variational optimization method was used to perform a model-based study of total visibility along a long highway passing through geometric zones characterized by varying degrees of aerosol air pollution and relative humidity in these zones. A logarithmic measure of aerosol air pollution has been introduced for consideration, as well as an integral logarithmic measure of such pollution in both discrete and continuous representations. Findings: It is shown that the integral logarithmic measure of aerosol pollution taking into account the effect of humidification of aerosol reaches a maximum with a certain type of introduced relationship function, and at the same time, visibility on a highway reaches a minimum in the integral sense. Conclusions: It is determined that when a certain restrictive condition imposed on the integral of the introduced relationship function is satisfied, the integral logarithmic measure of aerosol pollution reaches a maximum with a certain type of the introduced relationship function, and visibility on the highway reaches a minimum, in the integral sense.

KEYWORDS: visibility; road; optimization; aerosol; humidification

For citation: Ragimov E.R., Iskenderzade E.B., Ragimov J.R., Aliyeva K.S. Study of the influence of atmospheric aerosol humidification on visibility on roads. *BRICS Transport*. 2026;5(1):1. <https://doi.org/10.46684/2026.1.1>. EDN: TMGXHA.

Научная статья

Исследование влияния увлажнения атмосферного аэрозоля на видимость на автодорогах

Э.Р. Рагимов¹, Э.Б. Искендерзаде², Дж.Р. Рагимов³, Х.С. Алиева^{4✉}

¹ Бакинская высшая школа нефти; г.Баку, Азербайджан,

^{2,4} Национальное аэрокосмическое агентство; г. Баку, Азербайджан

³ Азербайджанский технический университет; г. Баку, Азербайджан

¹⁻⁴ a.khumar.1962@gmail.com✉

АННОТАЦИЯ Предмет исследования — влияние увлажнения аэрозоля на видимость на автодорогах. При увлажнении гигроскопичного аэрозоля размеры аэрозольных частиц увеличиваются в несколько раз, что значительно ухудшает видимость на дорогах. Цель исследования — изучение влияния увлажнения гигроскопичного аэрозоля на видимость на автодорогах. Предложена модель для вычисления интегральной видимости на продолжительной

автотрассе с учетом гигроскопичности аэрозоля, т.е. эффекта увлажнения аэрозоля в этих зонах. С использованием вариационного метода оптимизации проведено модельное исследование суммарной видимости по продолжительной автотрассе, проходящей через геометрические зоны, отличающиеся различной степенью аэрозольного загрязнения воздуха и величиной относительной влажности воздуха в них. Предложен логарифмический индекс загрязненности воздуха аэрозольными частицами, а также разработан показатель суммарной логарифмической оценки этого загрязнения — как в дискретной, так и в непрерывной постановке. Результаты: Показано, что интегральная логарифмическая оценка аэрозольного загрязнения с учетом эффекта увлажнения аэрозоля достигает максимума при некотором виде введенной функции связи, и при этом видимость на автотрассе в интегральном смысле достигает минимума. Выводы: Определено, что при выполнении некоторого ограничительного условия, налагаемого на интеграл введенной функции связи, интегральная логарифмическая оценка аэрозольного загрязнения достигает максимума при некотором виде введенной функции связи, а видимость на автотрассе в интегральном смысле достигает минимума.

КЛЮЧЕВЫЕ СЛОВА: видимость; автодорога; оптимизация; аэрозоль; увлажнение

Для цитирования: Рагимов Э.Р., Искендерзаде Э.Б., Рагимов Дж.Р., Алиева Х.С. Исследование влияния увлажнения атмосферного аэрозоля на видимость на автодорогах // Транспорт БРИКС. 2026. Т. 5. Вып. 1. Ст. 1. <https://doi.org/10.46684/2026.1.1>. EDN: TMGXHA.

INTRODUCTION

The World Meteorological Organization defines visibility as a distance at which an observed object is seen against its background with a contrast equal to the contrast threshold for the observer [1]. The importance of visibility on roads is hard to overestimate [2–5]. High levels of air pollution usually impair visibility on roads. In particular, high aerosol concentrations in the air cause high light scattering, thus significantly reducing visibility on roads. Thus, according to [6], in London, smog reduces visibility to just few meters. A similar situation has been also observed in large cities in China [7] and India [8]. At the same time, in clear air, meteorological factors, such as temperature, relative humidity, wind velocity, and wind direction, have no impact on visibility. However, the situation is different when aerosol pollution is high. In particular, the hygroscopicity of the bulk of atmospheric aerosol causes humidification of aerosol particles, which, in turn, makes them grow in size, volume, and weight. As a result, the refractive index of aerosol particles changes causing the dependence of visibility on relative air humidity [9–10]. To carry out a model-based study of the problem, let us briefly overview the existing model relations found in [11].

The basic measure of light attenuation by an aerosol particle is the extinction coefficient determined as follows:

$$\beta_{ext} = \beta_{sca} + \beta_{abs}, \quad (1)$$

where β_{ext} is the extinction (attenuation) coefficient; β_{sca} is the scattering coefficient; and β_{abs} is the absorption coefficient.

According to Koschmieder's definition, horizontal visibility (γ) is determined as

$$\gamma = \frac{k}{\beta_{ext}}, \quad (2)$$

where k is the experimentally determined coefficient that takes into account the sensitivity threshold of the observer's eyes.

According to [11], when aerosol pollution is high:

$$\beta_{sca} \gg \beta_{abs}. \quad (3)$$

The scattering coefficient is determined according to the Mie theory as follows:

$$\beta_{sca} = \int_0^{\infty} n \left(\frac{D}{2} \right)^2 Q_{sca}(\alpha, \lambda, n) N \cdot f(D) dD, \quad (4)$$

where D is the particle diameter; and α is the size parameter which is determined as follows:

$$\alpha = \frac{\pi D}{\lambda}, \quad (5)$$

where λ is the wavelength; N is the quantitative concentration of particles; n is the refractive index; and $f(D)$ is the particle size distribution law.

According to [12], when aerosol is humidified, all values in equation (4) change. For example, the scattering coefficient is determined as follows:

$$\frac{\beta_{sca}(RH)}{\beta_{sca}(dry)} = \left(1 - \frac{RH}{100} \right)^{-\gamma}, \quad (6)$$

where $\beta_{sca}(RH)$ is the value of the scattering coefficient at relative humidity RH ; $\beta_{sca}(dry)$ is the value of the

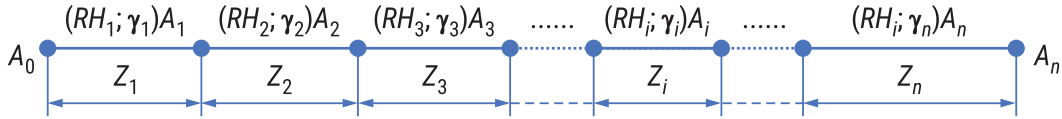


Fig. 1. Geometric interpretation of the proposed model of a highway running through zones (Z); $i = \overline{1, n}$

scattering coefficient in dry weather; and γ is the aerosol hygroscopicity.

Next, we will conduct a comprehensive model-based study of visibility on highways running through geographic areas with varying degrees of aerosol air pollution.

MATERIALS AND METHODS

We will consider the proposed meteorological model of a substantially long highway passing through areas with different degrees of aerosol pollution (Fig. 1).

According to the model shown in Fig. 1, a highway with length A_0A_n runs through n zones with varying weather conditions. Specifically, for zone Z_i , relative humidity is defined as RH_i and aerosol hygroscopicity as γ_i . Hence, we can speak of the two sets $Z \gamma$.

$$RH = \{RH_i\}. \tag{7}$$

$$\gamma = \{\gamma_i\}. \tag{8}$$

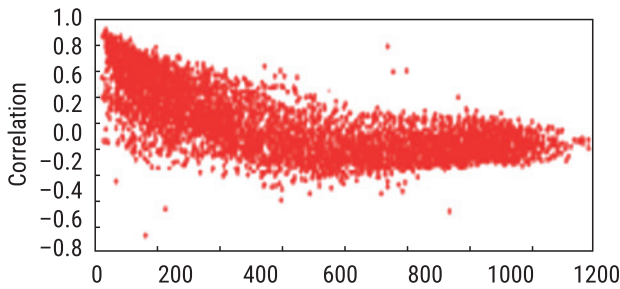


Fig. 2. Scattergram of dependence of the correlation coefficient in values of relative humidity on the distance [13] between correlated points

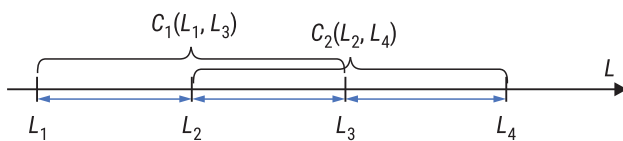


Fig. 3. Explaining the introduction of condition (9)

Next, we assume that in the proposed model of a weather-dependent highway, (7) and (8) are ordered sets, i.e. the following conditions are satisfied:

$$RH_i = RH_{i-1} + \Delta RH; \quad i = \overline{1, n}, \tag{9}$$

where $\Delta RH = \text{const}; RH_0 = 0$.

$$\gamma_i = \gamma_{i-1} + \Delta \gamma, \tag{10}$$

where $\Delta \gamma = \text{const}; \gamma_0 = 0$.

Condition (9) can be substantiated as follows: As is known [13], relative humidity exhibits a fairly strong spatial correlation (Fig. 2).

Let us plot discrete points L_i on axis L , where $i = \overline{1, 4}$ (Fig. 3).

L is the spatial distance, where $L_3 - L_1 = L_4 - L_2 = \Delta L$.

For points L_1 and L_3 , we will write the following:

$$RH(L_1) = C(L_1, L_3) \cdot RH(L_3), \tag{11}$$

where $C(L_1, L_3)$ is the RH correlation coefficient at points L_1 and L_3 .

$$RH(L_2) = C(L_2, L_4) \cdot RH(L_4), \tag{12}$$

where $C(L_2, L_4)$ is the RH correlation coefficient at points L_2 and L_4 .

Taking into account that $C(L_1, L_3) = C(L_2, L_4)$, from (11) and (12), we obtain:

$$\Delta RH = RH(L_1) - RH(L_2) = RH(L_3) - RH(L_4). \tag{13}$$

Equation (13) shows that increment ΔRH is constant along the entire axis L (see Fig. 3).

Next, taking into account formula (6), we introduce the logarithmic measure for the i -th aerosol-polluted zone as follows:

$$\eta_i = \ln \frac{\beta_{sca}(RH_i)}{\beta_{sca}(dry)} = -\gamma \ln \left(1 - \frac{RH_i}{100} \right). \tag{14}$$

By summing up (11) for all i 's, we obtain the following:

$$\alpha = \sum_{i=1}^n \eta_i = -\sum \gamma_i \ln \left(1 - \frac{RH_i}{100} \right). \tag{15}$$

For the relationship between γ_i and RH_i , let us introduce a discrete function as follows:

$$RH_i = \Psi(\gamma_i). \tag{16}$$

In the physical sense, the introduced function (15) means that air humidity decreases as aerosol hygroscopicity increases, because aerosol kind of “ingests” some of the moisture present in the air.

Let us impose a restrictive condition on function (13) as follows:

$$\sum_{i=1}^n \Psi(\gamma_i) = C_1; \quad C_1 = \text{const.} \tag{17}$$

In meteorological terms, restriction (14) means that the sum of all highway zones $\sum_{i=1}^n RH_i$ may remain constant.

The meaning of condition (17) for the subject model is easily seen from expression (13).

Obviously, if condition (13) is satisfied, i.e. when ΔL is constant, ΔRH is constant too, i.e. with the fixed value of

$$n = \frac{L_{\max}}{\Delta L}, \tag{18}$$

where L_{\max} is the maximum route length, We obtain:

$$C_1 = n \cdot \Delta RH. \tag{19}$$

Next, let us switch to continuous analogues of discrete models (9)–(17). Model (14) is presented as follows:

$$\eta = -\int_0^{\gamma_{\max}} \gamma \cdot \ln\left(1 - \frac{\Psi(\gamma)}{100}\right) dx, \tag{20}$$

and model (17) is presented as follows:

$$\int_0^{\gamma_{\max}} \Psi(\gamma) d\gamma = C_2; \quad C_2 = \text{const.} \tag{21}$$

Next, we will seek for a form of function $\Psi(\gamma)$ with which η reaches an extreme value.

Taking into account expressions (20) and (21), we compose the objective functional F of variational optimization as follows:

$$\int_0^{\gamma_{\max}} \gamma \cdot \ln\left(1 - \frac{\Psi(\gamma)}{100}\right) + \lambda \left[\int_0^{\gamma_{\max}} \Psi(\gamma) d\gamma - C_2 \right], \tag{22}$$

where λ is the Lagrange multiplier.

According to the Euler’s method, the solution to optimization problem (22) satisfies the following condition:

$$\frac{d\left\{-\gamma \ln\left(1 - \frac{\Psi(\gamma)}{100}\right) + \lambda \Psi(\gamma)\right\}}{d\Psi(\gamma)} = 0. \tag{23}$$

From condition (18), we obtain:

$$\frac{-\gamma\left(1 - \frac{1}{100}\right)}{1 - \frac{\Psi(\gamma)}{100}} + \lambda = 0 \tag{24}$$

or

$$\gamma - \frac{\gamma}{100} = \lambda - \frac{\lambda \cdot \Psi(\gamma)}{100}.$$

From this, we obtain:

$$\lambda \frac{\Psi(\gamma)}{100} = \lambda - \gamma + \frac{\gamma}{100}$$

or

$$\frac{\Psi(\gamma)}{100} = 1 - \frac{\gamma}{\lambda} + \frac{\gamma}{\lambda \cdot 100}$$

or

$$\Psi(\gamma) = 100 - \frac{99\gamma}{\lambda}. \tag{25}$$

It can be shown that with solution (25), the objective functional (22) reaches its maximum. To this end, according to Lagrange, it is sufficient to examine the sign of the derivative of expression (24) for the required function $\Psi(\gamma)$. The result will have a negative sign and therefore functional (22) reaches its maximum. And taking into account (2), in the integral terms, visibility on the highway decreases to its minimum.

DISCUSSION

It should be noted that we can calculate the Lagrange multiplier in expression (25) using expressions (25) and (21). Let us use expressions (20) and (25) to calculate the maximum value. Taking into account the above, we obtain:

$$\int_0^{\gamma_{\max}} \left(100 - \frac{99\gamma}{\lambda}\right) d\gamma = C_2. \tag{26}$$

From (26), we obtain:

$$100\gamma_{\max} - \frac{99\gamma_{\max}^2}{2\lambda} = C_2. \tag{27}$$

From (27), we obtain:

$$\frac{99\gamma_{\max}^2}{2\lambda} = -C_2 + 100\gamma_{\max}. \quad (28)$$

From (28), we obtain:

$$\lambda = 99\gamma_{\max}^2 : 100\gamma_{\max} - C_2. \quad (29)$$

Hence, taking into account (29), solution (25) will look as follows:

$$\begin{aligned} \Psi(\gamma) &= 100 - \frac{99\gamma(100\gamma_{\max} - C_2)}{99\gamma_{\max}^2} = 100 + C_2 - \frac{100\gamma}{\gamma_{\max}} = \\ &= C_2 + 100 \left(1 - \frac{\gamma}{\gamma_{\max}} \right) = C_3 - C_4 \cdot \gamma, \end{aligned} \quad (30)$$

where

$$C_3 = C_2 + 100; C_4 = \frac{100}{\gamma_{\max}}.$$

Taking into account (30) in expression (20), we obtain:

$$\begin{aligned} \eta_{\max} &= \int_0^{\gamma_{\max}} \gamma \ln \left(1 - \frac{C_2}{100} - \left(1 - \frac{\gamma}{\eta_{\max}} \right) \right) d\gamma = \\ &= \gamma \ln \left(\frac{C_2}{100} + \frac{\gamma}{\gamma_{\max}} \right) d\gamma. \end{aligned} \quad (31)$$

CONCLUSION

Consequently, the newly introduced value η increases with growth of γ , but decreases with growth of γ_{\max} and C_2 .

We have conducted a model-based study of total visibility along a long highway running through geometric zones with varying degrees of aerosol air pollution and relative air humidity.

The study has:

1. Proposed a model for calculating integral visibility along a long highway taking into account the hygroscopicity of the aerosol, i.e. the effect of humidification of the aerosol in these zones;

2. Introduced for consideration a logarithmic measure of air pollution by aerosols, as well as an integral logarithmic measure of pollution both in discrete and continuous representations;

3. Introduced for consideration a regression relationship function between relative humidity and aerosol hygroscopicity;

4. Shown that with a certain restrictive condition on the integral of the introduced relationship function, the integral logarithmic measure of aerosol pollution taking into account the effect of humidification of aerosol reaches a maximum with a certain type of the introduced relationship function, while visibility on a highway reaches a minimum, in the integral sense.

REFERENCES

1. World Meteorological Organization. Geneva: WMO; 1992, 2015.
2. González-Gómez K., Castro M. Analysis of sight distances at urban intersections from a vulnerable users' approach: A case study. *Transportation Research Procedia*. 2020;45:226-233. DOI: 10.1016/j.trpro.2020.03.011.
3. González-Gómez K., López-Cuervo M.S., Castro M. Assessment of intersection conflicts between riders and pedestrians using a GIS-based framework and portable LiDAR. *GIScience & Remote Sensing*. 2021;58(4):587-602. DOI: 10.1080/15481603.2021.1920199.
4. Gruden C., Otković I.I., Šraml M. An Eye-Tracking Study on the Effect of Different Signalized Intersection Typologies on Pedestrian Performance. *Sustainability*. 2022;14(4):2112. DOI: 10.3390/su14042112.
5. Hauer E. Engineering judgment and road safety. *Accident Analysis and Prevention*. 2019;129:180-189. DOI: 10.1016/j.aap.2019.04.022.
6. Brimblecombe P. *The big smoke*. London, New York: Methuen; 1987.
7. Zhang Y.H., Shao M., Cheng C.L. Quantitative relationship between visibility and mass concentration of PM2.5 in Beijing. *J Environ Sci*. 2006;18(3):475-481.
8. Singh A., Bloss W.J., Pope F.D. Remember, remember the 5th of November; gunpowder, particles and smog. *Weather*. 2015;70(11):320-324.
9. Singh A., Dey S. Influence of aerosol composition on visibility in megacity Delhi. *Atmos Environ*. 2012;62:367-373.
10. Liu X., Zhang Y., Cheng Y., Hu M., Han T. Aerosol hygroscopicity and its impact on atmospheric visibility and radiative forcing in Guangzhou during the 2006 PRIDE-PRD campaign. *Atmos Environ*. 2012;60:59-67.
11. Singh A., Bloss W.J., Pope F.D. 60 years of UK visibility measurements: impact of meteorology and atmospheric pollutants on visibility. *Atmos Chem Phys*. 2017;17(3):2085-2101. DOI: 10.5194/acp-17-2085-2017.
12. Titos G., Jefferson A., Sheridan P.J., Andrews E., Lyamani H., Alados-Arboledas L., et al. Aerosol light-scattering enhancement due to water uptake during the TCAP campaign. *Atmos Chem Phys*. 2014;14(13):7031-7043. DOI: 10.5194/acp-14-7031-2014.
13. Nguyen X.T., Nguyen B.T., Do K.P., Bui Q.H., Nguyen T.N.T., Vuong V.Q., et al. Spatial Interpolation of Meteorologic Variables in Vietnam using the Kriging Method. *Journal of Information Processing Systems*. 2015;11(1):134-147. DOI: 10.3745/JIPS.02.0016.

Bionotes

Elshan R. Ragimov — Cand. Sci (Eng.), lecturer; **Baku Higher Oil School (BHOS)**; 30 H. Javid Avenue, Baku, Azerbaijan;

Elchin B. Iskenderzade — Dr. Sci (Eng.), Professor; **Scientific Research Institute of Aerospace Information (SRI AI), National Aerospace Agency**; 1 S.S. Akhundov Street, Baku, Azerbaijan;

Jeyhun R. Ragimov — **Azerbaijan Technical University**; 25 G. Javid Avenue, Baku, Azerbaijan;

Khumar S. Aliyeva — Cand. Sci (Eng.), Associate Professor, Leading Researcher, Department of Optical-Electronic Surveillance Systems; **Scientific Research Institute of Aerospace Information (SRI AI), National Aerospace Agency**; 1 S.S. Akhundov Street, Baku, Azerbaijan; a.khumar.1962@gmail.com.

Об авторах

Эльшан Расиф оглы Рагимов — кандидат технических наук, преподаватель; **Бакинская высшая школа нефти (БАНМ)**; Азербайджан, г. Баку, Пр. Ходжалы 30;

Эльчин Барат оглы Искендерзаде — доктор технических наук, профессор, директор; **Научно-исследовательский институт аэрокосмической информатики (НИИАИ), Национальное аэрокосмическое агентство**; Азербайджан, г. Баку, С.С. Ахундова 1;

Джейхун Расиф оглы Рагимов — **Азербайджанский технический университет**; Азербайджан, г. Баку, пр. Г. Джавида, 25;

Хумар Сабир кызы Алиева — кандидат технических наук, доцент, ведущий научный сотрудник, отдел «Опτικο-электронные системы наблюдения», **Научно-исследовательский институт аэрокосмической информатики (НИИАИ), Национальное аэрокосмическое агентство**; Азербайджан, г. Баку, С.С. Ахундова 1; a.khumar.1962@gmail.com.

Contribution of the authors: the authors contributed equally to this article.

The authors declare no conflicts of interests.

Заявленный вклад авторов: все авторы сделали эквивалентный вклад в подготовку публикации.

Авторы заявляют об отсутствии конфликта интересов.

Corresponding author: Khumar S. Aliyeva, a.khumar.1962@gmail.com.

Автор, ответственный за переписку: Хумар Сабир кызы Алиева, a.khumar.1962@gmail.com.

The article was submitted 24.10.2025; approved after reviewing 14.12.2025; accepted for publication 29.01.2026.

Статья поступила в редакцию 24.10.2025; одобрена после рецензирования 14.12.2025; принята к публикации 29.01.2026.