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Developing a Mathematical Model to Estimate AOD using Selected Meteorological Parameters and Exploring their Impact on Air Quality Using Data from Multi-Spectral Sensors in the Period Of 2009-2020 Over Dire Dawa, Ethiopia

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Abstract

Understanding the influence of meteorological parameters that contribute to the Aerosol Optical Depth (AOD) is an important aspect towards analyzing climate change and regional air quality. In this study, the meteorological data from 2009 to 2020 are applied to analyze the contributions of rainfall, wind speed, relative humidity and temperature as well as their combined effects on AOD over Dire Dawa in the study period. The correlation results show that for MODIS-Aqua, rainfall depicted a good correlation with AOD in autumn season. An improvement for estimation of AOD using rainfall was obtained when it is fitted non-linearly, i.e., quadratically which resulted a significant correlation of R2 (0.872.) though it makes estimation of AOD from rainfall slightly difficult. MODIS-Terra revealed a satisfactory correlation with wind speed R2(0.38) in summer season, R2 (0.337) in winter season, and R2(0.445) in spring season but all with poor slopes. MODIS-Terra AOD demonstrated poor slopes in all seasons. The result show that only rainfall showed slight positive correlations with MODIS-T AOD during the wet months and with MODIS-A AOD during the dry months. The result suggest that climatic variations strongly affect the AOD, with a strong dependence in autumn and summer seasons over Dire Dawa. The study provides useful information to investigate the impacts of meteorological parameters have on aerosol dispersion, concentration and air quality in a region.

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1. INTRODUCTION

Estimation of the sensitivity of air pollutants to individual weather parameters has proven particularly challenging for several reasons. For example, meteorological parameters are inherently linked, resulting in strong interdependencies. Similarly, meteorological parameters can affect pollutants through direct physical mechanisms, such as the relationship with radiation and ozone or indirectly through influences on other meteorological parameters, such as the association between high temperatures and low wind speed (Jacob and Winner, 2009).

Aerosol Optical Depth (AOD) measures the number of aerosols in the atmosphere that can be used to indicate the level of atmospheric pollutants in a certain region. AOD measures the aerosol load in the atmosphere and represents the degree to which aerosols prevent light transmission in the atmosphere. AOD calculates how much of a light beam is absorbed as it travels through the atmosphere. For instance, an AOD of less than 0.1 indicates a clear sky with maximum visibility, whereas a value of 4 indicates a very dense aerosol load obstructing vision (Yasin *et al.*, 2021). As AOD rises, the rate of light extinction rises as well. It is a remotely sensed retrieval product, typically reported as a vertical column integral of extinction above the observed surface footprint.

More frequent and intense air pollution episodes have been observed in different areas in Dire Dawa city, Ethiopia, as Oluwasinaayomi et al. (2018) reported. Despite the magnitude of the impact of air pollution on the environment and human health, there exists limited evidence analyzing urban air pollution and the potential contributions of different meteorological parameters affecting pollutants concentration and distribution in Dire Dawa. As a result, a concerted effort is required to address air pollution threats to the environment, climate change, and human health.

Meteorological variables like temperature, relative humidity, rainfall, and wind speed affect the optical properties of aerosols as well as particulate concentration. A clear knowledge of the influence of these meteorological parameters on the variability of AOD is crucial to monitoring the magnitude, severity and dispersion of atmospheric pollutants in a Dire Dawa. Therefore, this paper intends to explore some meteorological parameters' impacts on aerosol and assess the correlation of each and combined meteorological parameter on AOD over Dire Dawa, Ethiopia. To this effect, this paper explores the seasonal and annual correlations of AOD retrieved using MODIS-Aqua, and MODIS-Terra sensors with selected meteorological parameters, namely rainfall, temperature, relative humidity, and wind speed over Dire Dawa from 2009 to 2020. It also tries to develop a mathematical relation, which is used to determine AOD retrieved using a combined meteorological parameter for each airborne sensor, MODIS-Aqua, and MODIS-Terra, after which it tried to examine the seasonal correlation of calculated and measured AOD.

2. MATERIALS AND METHODS

2.1. Study area

In this study, Dire-Dawa city was selected to explore the influence of meteorological parameters on the loading and dispersion of pollutants. The city is located in the eastern part of the country at the foot of Dengego mountain between 9°27' and 9°49'N latitude and 41°38' and 42°19'E longitude. Within the city's boundary, altitude ranges from 960 m a.s.l. in the northeast to 2450 m a.s.l. in the southwestern part, although the greater part of the city is around 1200 m a.s.l (Oluwasinaayomi *et al.,*2018).

Dire Dawa is 313 kilometers from the Port of Djibouti, 55 kilometers from Harar, and approximately 515 km east of Addis Ababa, the capital of Ethiopia. The city is located within the East African rift valley, with average temperature and rainfall of 34.6 °C and 637 mm, respectively (Dire Dawa Environmental Protection Authority, 2013). According to Ethiopian National Meteorological Agency (NMA) (2007), the mean minimum temperature has increased throughout the country, particularly during the cool months, by 0.37 °C per decade in the last 60 yr. From available data, annual maximum temperatures over the last 30 yr showed an upward trend at the meteorological stations in Dire Dawa Administration. According to NMA, the maximum temperature has increased by about 0.67 °C every 10 years. Records for relative humidity show 49.13 ± 6.25% to 54.7 ± 6.90%, and the city has an average wind speed of 2.67 m/s**.** The city spans *about 133,262 hectares* of land. Dire Dawa is a vulnerable city since it experiences extreme climate events like droughts and flash floods on top of its high temperature (Gezahegn *et al*., 2021). The location of the study area concerning Ethiopia is shown in Fig. 1.

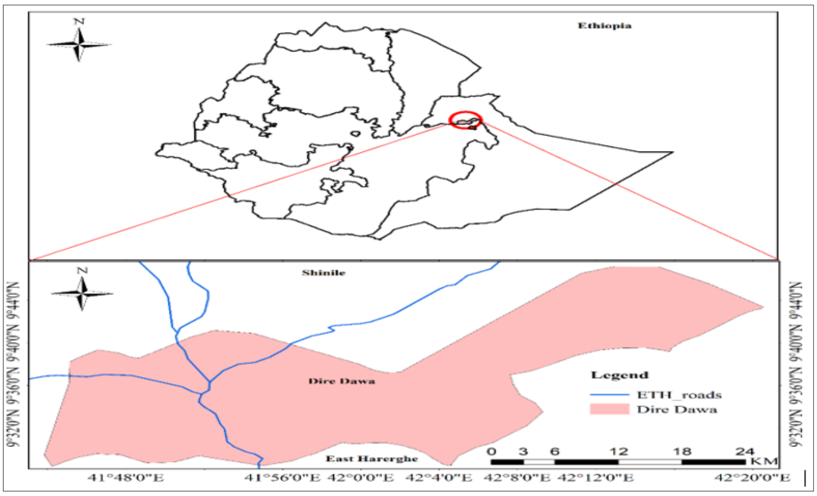

Fig 1. Map of the study area

Ecologically, the city lies within a semi-desert scrub ecosystem with various topographic features. The study of Gezahegn *et al.* (2021) evaluates extreme weather events by focusing on the analysis of daily precipitation and minimum and maximum temperatures. Oluwasinaayomi *et al.* (2018) report states the increase in maximum temperature at a rate of roughly 0.67°C per decade. The increase in land surface temperature appears to be partly attributed to global warming and the rest to urban heat islands caused by a shift in land use and land cover due to urbanization, settlement development, and building additional homes in the city.

2.2. Data Sources

2.2.1. MODIS-Aqua and MODIS-Terra

In this study, we used the MODIS (Aqua and Terra) Collection 6.1 aerosol products datasets, which were obtained at Level 3 from the Atmosphere Archive and Distribution System (LAADS) and Distributed Active Archive Center (DAAC) that has been recently validated (Wei *et al*., 2019; Hsu *et al*., 2013). We used product

MOD08_D3, which is a daily 1° product. MODIS provides almost daily global coverage with a 2330 km viewing swath width. We used the MODIS Deep Blue (DB) aerosol product (Deep_Blue_Aerosol_Optical_Depth_550_Land_Mean), which is the DB algorithm preferable for bright-reflecting land surfaces, such as semiarid and urban/industrial regions (Hsu *et al.*, 2013). The official Level 3 monthly mean AOD product at 1° x 1° resolution was used for this study. The data was accessed from a website http://disc.sci.gsfc.nasa.gov/giovanni.

2.2.2. Meteorological data

Meteorological data was obtained from National meteorological agency from 2009 to 2020.

2.3. Statistical and Performance Test Tools

In order to compare the estimated or calculated AOD using combined meteorological data such as rainfall, temperature, relative humidity, and wind speed, significant statistical parameters' test tools such as R^2 (determination coefficient), intercept, slope, and other statistical parameters such as MBE (mean bias), MAE (mean percentage error), and RMSE (root-mean-square) were used. Slope and intercept are the numbers obtained when the relationship between the predictor (x) and the predicted (y) is tested using linear curve fitting.

3. RESULTS AND DISCUSSION

3.1. Seasonal correlation of MODIS-Aqua AOD with meteorological parameters

In this study, the data points were normalized first by summing the monthly values to find the annual value. Similarly, the values of each season were also obtained by summing the values of the three corresponding months of the season. Then the seasonal value is normalized (say for rainfall, RF_{norm}) as

$$RF_{norm} = \frac{\sum_{i=1}^{3} RF_{month}}{\sum_{i=1}^{12} RF_{month}}. \quad (1)$$

The normalized rainfall is now a dimensionless number (with a value between 0 and 1) that can be treated as a plain number with other dimensionless numbers. Similar procedures were followed to make the other three meteorological parameters dimensionless.

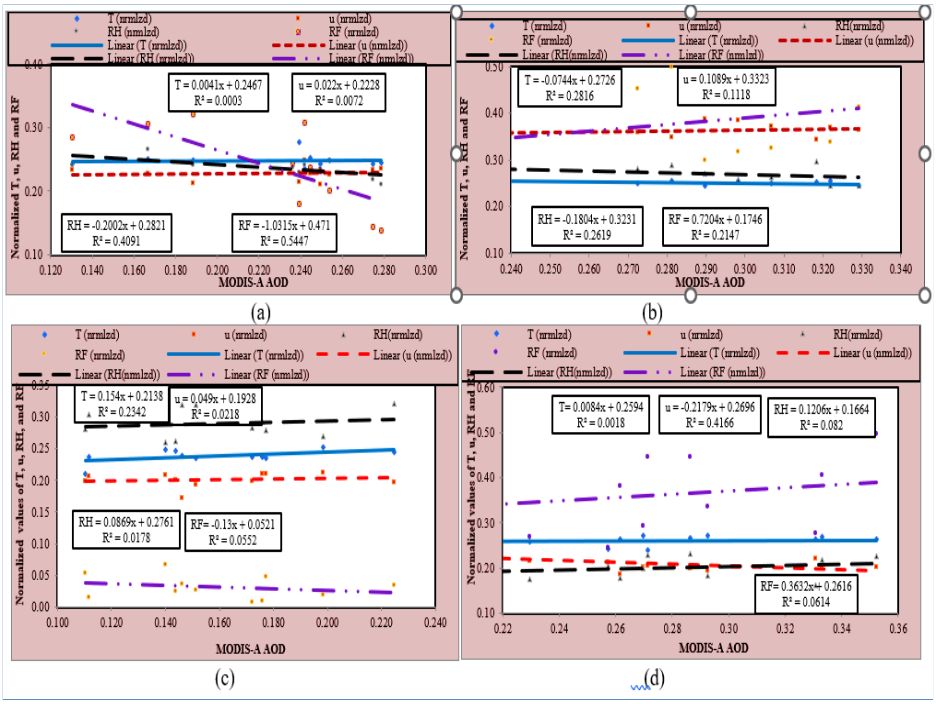

Fig. 2. Seasonal normalized meteorological parameters plotted against MODIS-Aqua AOD for (a) autumn, (b) summer, (c) winter and (d) spring seasons

As can be seen in Fig 2, rainfall shows a better correlation, followed by relative humidity in autumn. In the summer and winter seasons, temperature reveals a better correlation next to relative humidity, while wind speed demonstrated a better correlation among the rest of the meteorological parameters in the spring.

Fig 2 shows a correlation between rainfall and MODIS-A AOD (slope = -1.03 and R^2 = 0.54) during autumn. In this case, the correlation can be considered good regarding R^2 and the slope. The correlation between relative humidity is considered unsatisfactory (even though the R^2 = 0.40 is considered satisfactory) because the slope is very far from -1. For this season, only the rainfall can be correlated to MODIS-A AOD. The negative correlation between rainfall and AOD in this can be given as:

$$RF_{norm} =- 1.032\ (AOD) + 0.471$$

$$\frac{RF_{norm} - 0.471}{-1.032} = AOD \qquad (2a)$$

The rainfall value utilized is the normalized value for a given year.

$$\frac{\sum_{i=1}^{3} RF_{monthly}}{\sum_{i=1}^{12} RF_{monthly}} = RF_{norm}. \qquad (2b)$$

The seasonal sum can be expressed as three times the seasonal average or

$$RF_{autumn} = \sum_{i=1}^{3} RF_{monthly} = 3\overline{(RF_{autumn})}$$

The value under the bar is the autumn season monthly average rainfall. Similarly, the annual value can be expressed as:

$$\sum_{i=1}^{12} RF_{monthly} = 12\overline{(RF_{annual})}.$$

In this case, the value under the bar is the annual average of monthly rainfall. Therefore

$$\frac{\sum_{i=1}^{3} RF_{monthly}}{\sum_{i=1}^{12} RF_{monthly}} = RF_{norm} = \frac{3\overline{(RF_{autumn})}}{12\overline{(RF_{annual})}} = 0.25\frac{\overline{(RF_{autumn})}}{\overline{(RF_{annual})}} \qquad (2c)$$

Now Eq. (10a) can be expressed in terms of seasonal and annual monthly mean rainfalls.

$$AOD = \frac{0.25\frac{\overline{(RF_{autumn})}}{\overline{(RF_{annual})}} - 0.471}{-1.032} = -0.242\frac{\overline{(RF_{autumn})}}{\overline{(RF_{annual})}} + 0.456$$

$$AOD = 0.456 - 0.242\frac{\overline{(RF_{autumn})}}{\overline{(RF_{annual})}}. \qquad (3)$$

All that is required to use Eq. (3) is to determine the annual and the seasonal monthly rainfall averages for the particular year. Even if slight correlations are observed between relative humidity and AOD (R^2 = 0.41) in autumn and between wind speed and AOD (R^2 = 0.417) in the spring, their slopes are not satisfactory enough to warrant such calculation as the one done for rainfall of the autumn season. The next step is to plot the calculated value of AOD estimated from rainfall (Eq. 3) with the MODIS–A AOD of the same season. The plot is shown in Fig. 3.

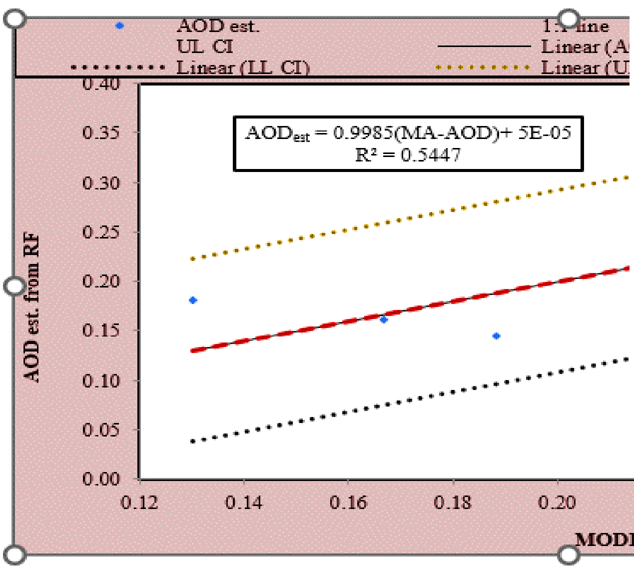

Fig.3. Plot of autumn season AOD estimated from rainfall versus AOD obtained from MODIS Aqua (MA-AOD) sensor. LL = Lower level and UL = upper level 95% confidence intervals, respectively.

The calculated value can be estimated to 54% of AOD from rainfall during autumn. The estimated value also underestimates the MODIS-A AOD by 0.0015, which is considered very small. The intercept is very small, and the fitted line is almost overlapping with the 1:1 line, which is a measure of a perfect fit line. The remaining 46% can be attributed to other meteorological parameters such as relative humidity and other non-meteorological factors like the increased number of pollens in the atmosphere during this season.

Relative humidity shows slight dependence on AOD in the autumn (R^2 = 0.409) even if the slope is low. The next logical step is to assess how much the relative humidity is correlated with AOD by considering it along with rainfall. In this next attempt, we plot AOD against relative humidity and rainfall, but this time instead of assuming a linear correlation, we consider a nonlinear correlation. The such plot is shown in Fig. 4.

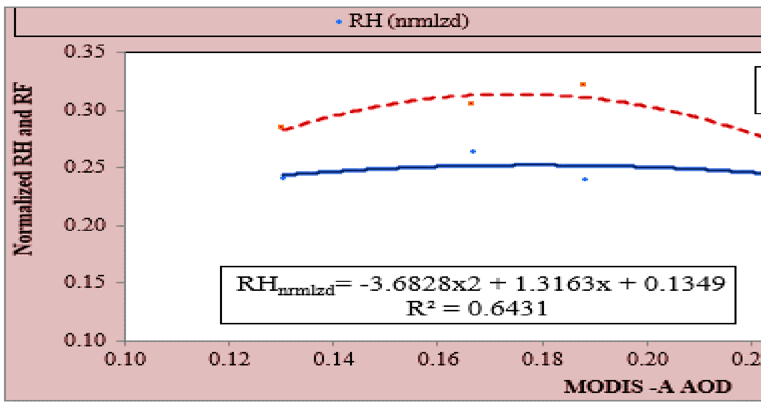

Fig.4. Plot of autumn season AOD estimated from rainfall (RF) and relative humidity (RH) versus AOD obtained from MODIS Aqua (MA-AOD) sensor.

As observed in Fig. 4, better fits were observed when AOD is nonlinearly correlated with RH (R^2= 0.643) and RF (R^2= 0.775). The curve fits were quadratic since the data points indicated downward curvature. Now let us try to combine the two. In order to estimate the contribution of each term, we first add the two R^2 values together and find the ratio of each R^2 concerning the summed R^2. In this case, the sum is 1.418, and the ratios are 0.4534 and 0.5466 for RH and RF, respectively. This makes the assumption that the two are the sole meteorological parameters correlated to AOD. Next, we multiply the normalized relative humidity and rainfall calculated data values with the corresponding ratios (i.e., 0.4534 (RH_{nrmlzd}) and 0.5466(RF_{nrmlzd})). The two are summed together; this sum is plotted against sensor-measured AOD. The plot is a curve fitted with a function that gives a better R^2 value. The plot and the curve-fitted equation are shown in Fig. 5.

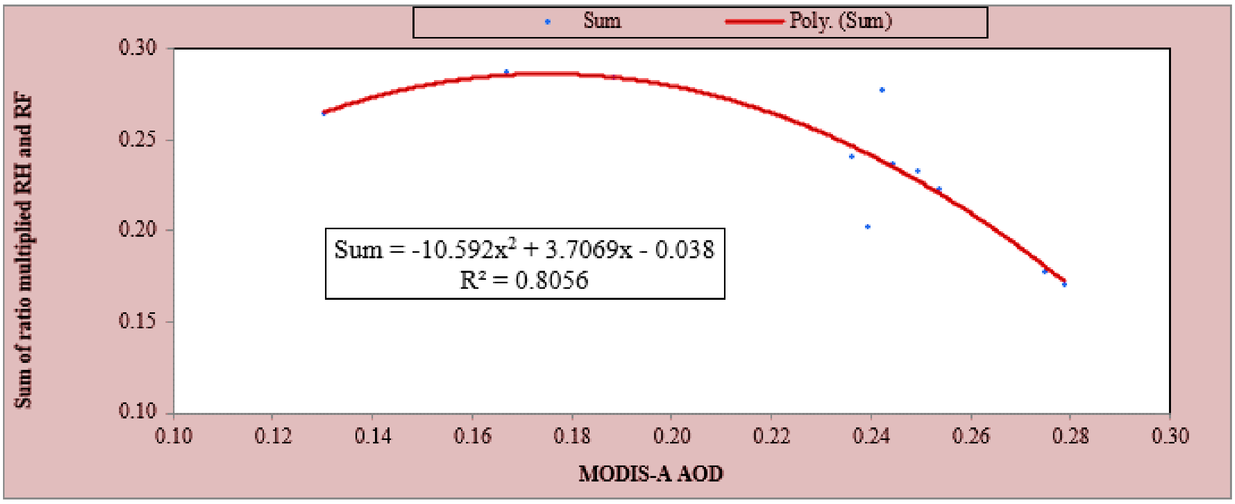

Fig.5. Plot of the sum of ratio multiplied by normalized rainfall and relative humidity against AOD obtained from MODIS Aqua (MA-AOD) sensor (autumn season).

The equation in the plot can be expressed as a quadratic equation, where the sum is considered a constant term (say S).

$$-10.592x^2 + 3.7069x - (0.038 + S) = 0$$

In equation x represents the AOD, and the quantity in the bracket represents a constant term. Solving for x gives

$$x = \frac{-3.7069 \pm \sqrt{(3.7069)^2 - 4 \times (-10.592) \times [-(0.038 + S)]}}{2 \times (-10.592)}$$

$$= 0.175 \pm \frac{\sqrt{13.779 - (-42.368) \times [-(0.038 + S)]}}{-21.182}$$

$$= 0.175 \pm \frac{\sqrt{13.779 - 1.61 - 42.368S}}{-21.182}$$

$$x = 0.175 \pm \frac{\sqrt{12.169 - 42.368S}}{-21.182}. \qquad (4)$$

The next step is finding alternative expression for S, which is given as

$$S = Sum = RH_{nrmlzd} + RF_{nrmlzd} \qquad (5a)$$

Based on Eq. 10c, the normalized values can be expressed in terms of the actual measured values, i.e.

$$\left.\begin{aligned} RH_{nrmlzd} &= 0.25\,\overline{\frac{(RH_{autumn})}{(RH_{annual})}} \\ RF_{nrmlzd} &= 0.25\,\overline{\frac{(RF_{autumn})}{(RF_{annual})}} \end{aligned}\right\}. \qquad (5b)$$

The bars indicate the averages. Substituting the expressions in Eq. 13 into Eq. 12 gives

$$x = 0.175 \pm \sqrt{\frac{12.169 - 42.368\left[\left(0.25\,\overline{\frac{(RH_{autumn})}{(RH_{annual})}}\right) + \left(0.25\,\overline{\frac{(RF_{autumn})}{(RF_{annual})}}\right)\right]}{-21.182}}.$$

$$AOD_{est} = 0.175 \pm \sqrt{\frac{12.169 - 10.592\left[\left(\overline{\frac{(RH_{autumn})}{(RH_{annual})}}\right) + \left(\overline{\frac{(RF_{autumn})}{(RF_{annual})}}\right)\right]}{-21.182}}. \qquad (6)$$

The expressions in the square bracket have positive fractional values, which means the quantity under radical has a real value solution only if:

$$12.169 \geq 10.592\left[\left(\overline{\frac{(RH_{autumn})}{(RH_{annual})}}\right) + \left(\overline{\frac{(RF_{autumn})}{(RF_{annual})}}\right)\right]. \qquad (7)$$

Except for September, with some rainfall, autumn is considered more of a dry season than wet. Therefore, the RF ratio can be small. However, the difference between the seasonal and annual RH may not be that much, and as a result, the right-hand side of the above inequality can exceed one, and the radical becomes a complex value. But if the relative humidity term is not considered, the expression will have a real acceptable result. This is one reason to exclude the RH term in Eq. 6). The other reason is its insignificant contribution to the sum. The inclusion of the RH term improved the R^2 value of RF, which is 0.775, as seen in Fig. 4 to 0.801 for the combined system (Fig. 5). This improvement is so small to warrant the inclusion of the RH term into Eq. (6). Therefore Eq. 6 can be simplified to the form

$$AOD_{est} = 0.175 \pm \sqrt{\frac{12.169 - 10.592\left(\overline{\frac{(RF_{autumn})}{(RF_{annual})}}\right)}{-21.182}} \qquad (8)$$

Assuming the inequality holds, the contribution of the term after ± in Eq. (8) remains very small because of the value of the denominator under the radical. Only the negative sign of the ± is retained since we want a positive correlation between the AOD estimated and the one measured by the satellite sensor. The plot of the two AODs and the non-linear curve fit is shown in Fig. 6.

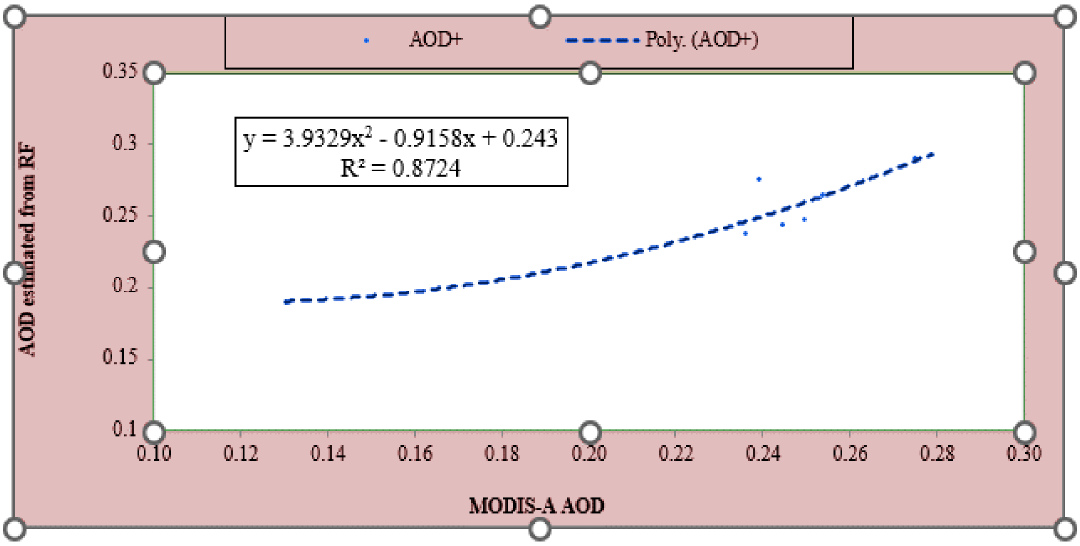

Fig. 6. Plot of the seasonal- to annual-averaged rainfall ratio versus AOD obtained from MODIS Aqua (MA-AOD) sensor (autumn season).

Looking at figures 3 and 6, and Eq. 6, we can make two conclusions. The first is the nonlinear relationship between the AOD obtained from MODIS-A satellite sensor and the one estimated from rainfall (comparisons of Fig. 3 with Fig. 6). The improvement of using quadratic fit over linear fit brought a difference of 0.3277 in R^2 (= 0.8724 – 0.5447), which is a great improvement. Such nonlinear relation, despite its benefit, makes estimation of AOD from rainfall slightly difficult. The second one is the challenge observed using the value of R^2 alone when evaluating the correlation between two quantities. Relative humidity showed satisfactory and good correlations with satellite-sensed AOD when fitted linearly and quadratically, respectively (Fig. 2a and Fig. 4). However, the slope of the linear fit is very small (-0.2002), as seen in Fig. 2a. Thus, the attempt that we made to combine it with RF did not show much improvement over that of RF (Fig. 4) as seen in the curve-fitted equation of Fig. 5. This result indicates the importance of considering the slope with R^2 instead of relying on R^2 alone.

According to a study by Li *et al.* (2021), temperature, wind speed, rainfall and relative humidity were the four factors that most affected the shift in AOD during the autumn season. However, in our case, as far as the data of MODIS- A AOD is concerned, only rainfall seems to be the factor that affects AOD during autumn. In Dire Dawa, the dry season's rainfall is less than the wet season since rain is observed only during the first one or two weeks of September. It is unclear why the very few days of rainfall during autumn showed such a negative influence on AOD. The high rain rates decrease the airborne particles by washing them out, reducing the AODs to their minimum. Conversely, the higher AOD results from fewer particles washout by lower rainfall. During summer, though there is a washout of some aerosol particles, a significant fraction remains in the atmosphere trapped with water vapor and clouds. As observed in Fig. 2d, the wind showed a slight negative correlation with AOD. However, the slope remained very small despite the R^2 value of 0.42 (-0.218). According to Rahul *et al.* (2008), higher surface wind speed values are associated with removing aerosols and lower surface wind speed with adding aerosols. The causes of AOD correlation with surface meteorological parameters, results showing that they are closely connected to pollutant concentrations, water vapor, cloud and climate change.

3.2. Seasonal correlation of MODIS-Terra AOD with meteorological parameters

The correlations of MODIS-Terra AOD with temperature, wind speed, relative humidity and rainfall during the four seasons are shown in Fig 7.

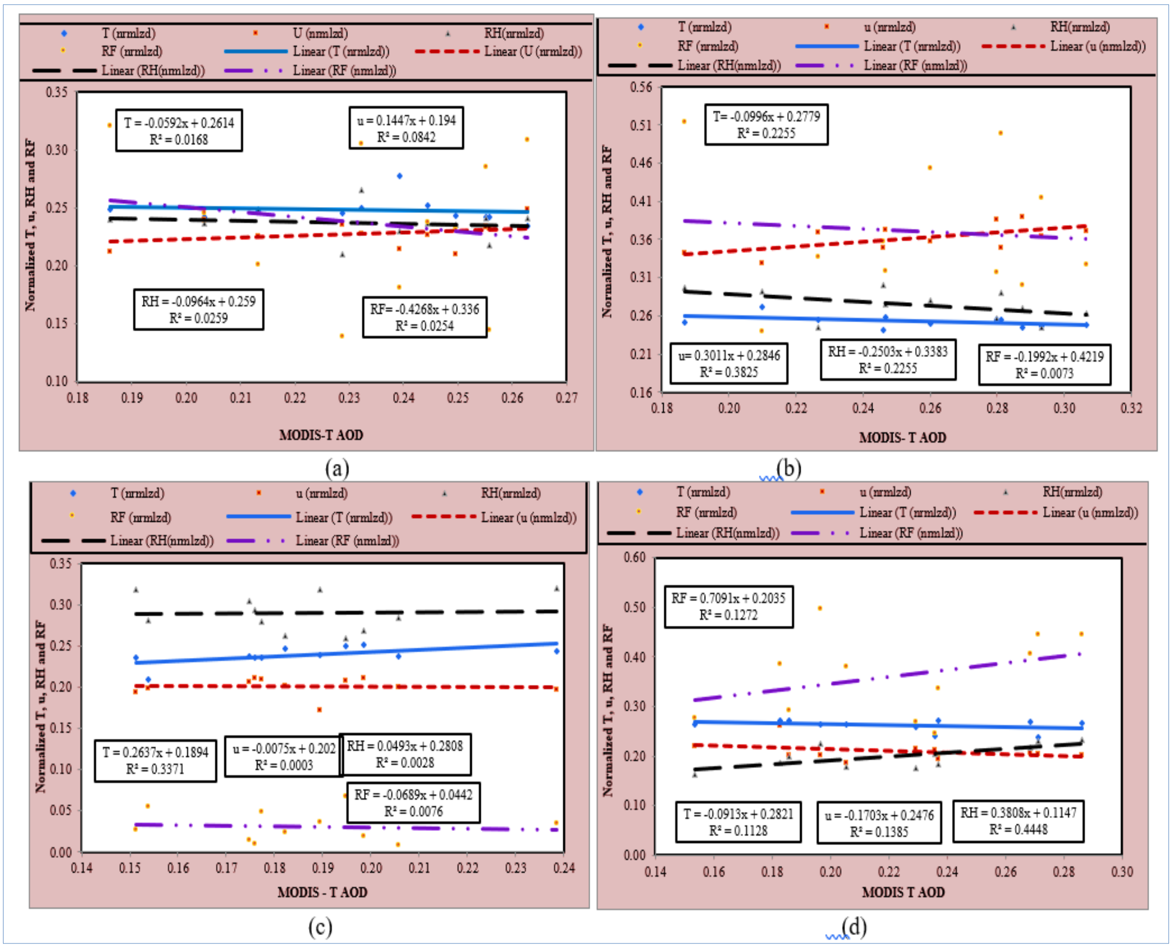

Fig 7. Seasonal normalized meteorological parameters plotted against MODIS-Terra AOD for (a) autumn, (b) summer, (c) winter and (d) spring seasons

The seasonal correlation of MODIS-Terra AOD with temperature, wind speed, relative humidity and rainfall shows an insignificant correlation in all seasons. However, in the summer season, wind speed showed a slightly better correlation ($R^2 = 0.38$) than the other three meteorological parameters, even though the slope is poor (0.30), as seen in Fig 7b.

During winter, temperature showed a slight positive correlation with AOD ($R^2 = 0.337$) with a weak slope of 0.26 (Fig 7c). In both cases, considering the two parameters is not worth considering because of their low slopes for a new mathematical model development. In the spring, RH showed a positive correlation ($R^2 = 0.445$) with AOD but with a poor slope of 0.38 (Fig. 7d). On the other hand, rainfall did not show any correlation ($R^2= 0.127$) even if the slope (0.709) showed a good positive correlation with AOD. All in all, data from MODIS-T AOD failed to show a substantial correlation with any of the meteorological parameters, and in this respect, the result is different from what was obtained from MODIS-A AOD.

The study of Kazuhisa *et al*. (2022) revealed that the localized uncertainties, particularly surrounding a humid coastal city, are exacerbated by heterogeneous surface reflectance, mixed aerosol optical characteristics, and strong meteorological variability.

4. **Conclusions**

Meteorological and environmental conditions are critical indicators of air-pollution episodes and highly-related with aerosol transport and formation mechanisms. This study assessed meteorological parameters' influence on aerosols' concentration and dispersion over Dire Daw from 2009 to 2020. The result confirmed that rainfall shows a better correlation followed by relative humidity in autumn, and a new mathematical model was developed using rainfall which was used to estimate MODIS-Aqua AOD. The method developed was acceptable and worked well as validated using R^2 and slope values. Besides, an improvement in the estimation of AOD using rainfall was obtained when it is fitted non-linearly, i.e., quadratically, which resulted in a significant correlation.

On the other hand, MODIS-Terra revealed a good correlation between wind speed in the summer season, winter season with temperature, and humidity in the spring season. Both wind speed and temperature showed negative correlations with AOD, which means that as both parameters increased, AOD showed a reduction. Since MODIS-Terra AOD demonstrated a poor slope in all seasons though the correlation coefficient was satisfactory, estimation of AOD in these seasons was not performed. Therefore, based on the linear curve fit, rainfall during the summer with and without intercept curve fits demonstrated good performance. It should be noted that different data sets may have a certain effect on global and regional trend assessment of AOD due to their uncertainties or algorithm efficiency of satellite sensors, mixed aerosol characteristics, surface reflectance and strong meteorological variability which might affect the correlation of AOD has in seasonal period over Dire Dawa. The study provides useful information to investigate the impact of meteorological parameters on aerosol dispersion and concentration, a new approach used to estimate AOD using a statistical model developed based on meteorological parameters and to monitor air quality in a certain region. Further study using combination(s) of several meteorological parameters such as PBL, wind direction, solar radiation, normalized vegetation index, carbon, nitrogen, sulfur pollutants etc. are useful to obtain a comprehensive understanding and to develop a stable mathematical model which is used to estimate AOD in daily, monthly, annual and seasonal period in a given region.

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Author statements

Statement of Contribution of CRediT Author

T.A. Endale: Original Study and Design Methodology, Data Retrieval, Software, Data Analysis and Interpretation, Writingoriginal draft, Writing-review and critical revisions. **G.A. Raba**: Design Methodology, Data analysis, interpretation, Supervision, Writing-review and critical revisions. **K.T. Beketie, and G.L. Feyisa:** Manuscript editing, and supervision. In general, all authors provide critical feedback and support until the research analysis is complete.

Availability of data and material: Additional data will be available upon request.

Competing interests: The authors declare no conflict of interest to disclose.

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REFERENCES

Chu, D.A., Kaufman, Y.J., Ichoku, C., Remer, L.A., Tanre, D. & Holben, B.N., Validation of MODIS aerosol optical 703 depth retrieval over Land. *Geophys. Res. Lett*. 2002, 29: 8007.

Dire Dawa Environmental Protection Authority. Regional state of the environmental outlook report 2013. Dire Dawa, Ethiopia: Dire Dawa Environmental Protection Authority. 2013.

Gezahegn B., Tashebo E., Fiseha M., Aklile A., Trends in Daily Temperature and Precipitation Extremes over Dire-Dawa, 1980-2018. *Journal of Environment & Earth Science.* 2021. Vol.11, No.9.

Gohar A., Yansong B., Waheed U., Qin G., Xulin L., Lin L., Yuhong L., Guangwen L., and Jun M., Spatiotemporal trends of aerosols over urban regions in Pakistan and their possible links to meteorological parameters. *Atmosphere*. 2020, 11,306; doi:10.3390/atmos11103036.

Hsu, N.C.; Jeong, M.-J.; Bettenhausen, C.; Sayer, A.M.; Hansell, R.; Seftor, C.S.; Huang, J.; Tsay, S.-C., Enhanced Deep Blue Aerosol Retrieval Algorithm: *The Second Generation. J. Geophys. Res*., 2013. 118.

Jacob, D. J., and D.A. Winner. Effect of climate change on air quality. *Atmos. Environ*. 2009, 43 (1):51–63. doi:10.1016/j. atmosenv.09.051.

Kazuhisa T., Hiroshi M., Tadahiro H., and Mayumi Y., Aerosol Optical Properties of Extreme Global Wildfires and Estimated Radiative Forcing with GCOM-C SGLI, *Egusphere,* 2022. https://doi.org/10.5194/egusphere.

Levy, R. C., Remer, L. A., Kleidman, R. G., Mattoo, S., Ichoku, C., Kahn, R., and Eck, T. F.,. Global evaluation of the Collection 5 MODIS dark-target aerosol products over land. *Atmos. Chem. Phys.,* 2010., 10, 10399–10420, https://doi.org/10.5194/acp-10-10399**.**

Li J, Ge X, He Q, Abbas A., Aerosol optical depth (AOD): spatial and temporal variations and association with meteorological covariates in Taklimakan desert, China. *PeerJ*. 2021, (9), 10-42. DOI: 10.7717/peerj.10542.

Li, W. J., Shao, L. Y., and Buseck, P. R.,. Haze types in Beijing and the influence of agricultural biomass burning. *Atmospheric Chemistry & Physics*, 2010, 10, 8119–8130, doi:10.5194/acp-10-8119-2010.

Mainul M., Islam Mamun1, Md Monirul Islam1, Ahsan Habib Rasel,. An observational study of aerosol optical properties and their relationships with meteorological parameters over Bangladesh, *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG), e-ISSN.* 2014, *2321–0990, p-ISSN: 2321–0982.Volume 2, Issue 6 Ver. I*

Mengistu and Amente, Reformulating and

testing Temesgen-’” ’Melesse’s temperature-based evapotranspiration estimation method. *Heliyon.* 2020, 6, 02954, 4-5 (ISSN: 2405-8440). https://doi.org/10.1016/j.heliyon.2019.e02954.

National Meteorological Agency. National Adaptation Programme of Action of Ethiopia (NAPA). Addis Ababa, Ethiopia: National Meteorological Agency. 2007

Oluwasinaayomi F., Muluneh W. Abshare & Samuel B., Analysis of air quality in 866 Dire Dawa, Ethiopia. *Journal of the Air & Waste Management Association*, 2018. VoL. 68, No. 8, 801–811 867 https://doi.org/10.1080/10962247.2017.1413020.

Tripathi, S., Dey S., Chandel A., Srivastava S., Singh P., Holben, B., Comparison of MODIS and AERONET derived aerosol optical depth over the Ganga Basin, India. *Ann. Geophys*. 2005, 23:1093-1101.

Wei, J.; Li, Z.; Peng, Y.; Sun, L. MODIS Collection 6.1 aerosol optical depth products over land and ocean: Validation and comparison. *Atmos. Environ*. 2019, 201, 428–440.

Wilks, D.S. Statistical Methods in the Atmospheric Sciences. (2nd Eds) *Academic Press* (pp.73-81), London. 2006.