Journal of Environmental studies [JES]
An International Journal

https://jesj.journals.ekb.eg/
doi: ***10.21608/JESJ.2024.256265.1062***

Prospecting for Air Pollution Hot Spots in the Atmosphere using Lapse Rate

Abraham Amankwah[1*], Michael Gyan[2], Jonathan Mensah – Bonsu[1] Nana Ama Brown-Klutse[1]

1Department of Physics, University of Ghana, Legon, Ghana.
2Department of Physics Education, University of Education, Winneba, Ghana.

Citation: *Amankwah, A.;. Gyan, M.; Bonsu, J. M.; Klutse, N. A. B. (2024). Prospecting for Air Pollution Hot Spots in the Atmosphere using Lapse Rate. Journal of Environmental Studies, Vol. 35(1): 23-31.*

Article Information
Received 18 Des. 2023,
Revised 11 July 2024,
Accepted 20 oct. 2024,
Published online.23 oct. 2024.

Abstract: Air contamination on highways and in urban communities poses a significant environmental concern for the country. The poor condition of many vehicles on our roads has greatly contributed to air pollution in these areas. Understanding the lapse rates at different heights can provide valuable information about the potential impact of contaminants released into the atmosphere. This study aims to investigate lapse rates at various height ranges, specifically at one-meter intervals from the ground surface to a four-meter height, to identify probable hotspots of pollutants produced by automobiles on the road. An Arduino Mega 2560 equipped with DHT22 (Digital Humidity-Temperature sensor) temperature sensors was employed to automate the measurement of daily temperatures at different heights. The data collection occurred from January 31, 2020, to March 27, 2020, at the electronic entryway on Legon-Gimpa Street, with a GPS location of 71.0 m above sea level, longitude 0.1983° W, and latitude 5.6418° N at the University of Ghana, Legon Campus, Ghana. The ground (0 m) to 1 m height range exhibited a positive lapse rate throughout the day, with a mean of 2.7770 °C/m. The mean lapse rate for the diurnal cycle (daytime) for the 0 m to 1 m height range was 4.5332 °C/m, while for the nocturnal cycle (nighttime) it was 1.0208 °C/m. Height ranges 0 m to 1 m, 1 m to 2 m, and 3 m to 4 m typically had positive lapse rate values, whereas the 2 m to 3 m height range predominantly showed negative lapse rate values. The mean lapse rates from the ground to the 5 m height for periods before, during, and after the sun were 0.2484 °C/m, 1.6297 °C/m, 1.4410 °C/m, and 0.3172 °C/m, respectively. The overall mean lapse rate for the diurnal cycle across the entire height range was 1.5353 °C/m, while for the nocturnal cycle it was 0.2828 °C/m. These findings indicate significant variability in lapse rates at different heights and times of day, which can influence the dispersion and concentration of pollutants. It is recommended to further investigate these variations and their implications for air quality management and vehicle emissions regulations in urban environments.This work gives guidelines for evaluating air contamination using the lapse rate.

Keywords: Atmosphere, air pollution, lapse rates, temperature inversion, contaminants.

Introduction

Pollution comes from the Latin pollutus, which means made unclean, dirty or foul (Numbere *et al.*, 2023; Cunningham, 2007). Thus, emission of any form of materials foreign into the atmosphere can be described as atmospheric pollution. Polluting substances can exist in the form of solid particles, liquid droplets, or gases. Nature and humans inevitably emit all kinds of foreign materials in the form of solid particles, liquids, and gases into the atmosphere (Breton *et al.*, 2021). These foreign materials especially the amounts that come from natural sources allow the regulation of temperature to a suitable value for the existence of living things on the surface of the earth. “With very few exceptions, these natural releases are either isolated and

* Corresponding author E-mail: aamankwah@ug.edu.gh

temporary (forest fires, dust storms) or produce undesirable substances slowly from widely dispersed sources (hydrocarbons from decomposing vegetation) and are therefore absorbed by the atmosphere without the more obviously adverse effects associated with excessively high man-made effluent concentrations (FN & MF, 2017; Xu *et al*., 2022). These natural emissions offer natural dilution and self-purifying processes in the atmosphere, and these are necessary to keep the global temperature at approximately 15°C that is essential for the maintenance of life on the earth. The excesses enhance the atmospheric greenhouse effect that are mostly attributed to anthropogenic activities are the disturbing component that needs to be addressed (Yoro & Daramola, 2020). Air pollution is a complex concept, and it is difficult to obtain a clear definition (Chaudhry & Malik, 2017).

Carbon dioxide resulting from the combustion of fossil fuel for example has global significance and is implicated as possible causal factor leading to global fluctuation of climate (Molina & Shaddix, 2007; Molina & Shaddix, 2005). Even though air pollution is mainly associated with built up areas, the general significance that includes the nature, distribution, and intensity is not limited to only local implications but most often global consequences. According to the World Health Organization, one of every six people on the earth (more than 1.1 billion people) lives in an urban area where outdoor air is unhealthy to breath, and most of these people live in densely populated cities in developing countries where air pollution control laws do not exist or poorly enforced (Quinn *et al*., 2023; Xiao *et al*., 2023; Yan *et al*., 2022). Aside carbon dioxide and windblown soil, the total worldwide emission of air pollutants are around two billion metric tons per year (Cunningham, 2007). Polluted air has negative consequences in many fields that include health, agriculture, tourism, estate developers, transportation, and the economy in general (Miller & Spoolman, 2007). Air quality in developed countries like Western Europe, North America, and Japan has improved, but air quality in the developing world, especially in the burgeoning megacities of rapidly industrialized countries like Lima, Sao Paulo, Buenos Aires, Rio de Janerio all in South America; Accra, Lagos, Egypt, Abidjan- all in Africa; and Delhi, Mumbai, Karanchi, Madrasi, Jakarta-all in Asia are degrading, and air pollution often exceeds World Health Organization standards (Sinha *et al*., 2020; Khan *et al*., 2021). Studies shown that the number of vehicles that are imported into Ghana, and for that matter the number of vehicles plying on our roads has increased astronomically (Armah, 2020; Yahans Amuah *et al*., 2022). According to (Ayetor *et al*., 2021) 72 million vehicles are in use as of 2018 in Africa. These vehicles emit mainly CO_2, CO, and SO_2 as fossil fuels are burnt. These gases emitted from the exhausts of the vehicles eventually find their way into the atmosphere. Ayetor et al., indicated that greenhouse gas emissions from transportation in Africa is growing at a rate of 7% annually. Huo *et al*. 2023 reported that transportation is responsible for 24% of direct CO_2 emissions from fuel combustion.

Existing studies have mostly focused on climatological variabilities of lapse rates (Zhong *et al*., 2023; Joshi *et al*., 2023), altitudinal temperature variations (Rolland, 2003; He & Tang, 2023; Gierens *et al*., 2022), the influence of building materials on air quality (Maung *et al*., 2022; Arar *et al*., 2022; Arar *et al*., 2022), and precipitation gradients (Bell *et al*., 2022; Kumar *et al*., 2022; Anders & Nesbitt, 2015). These studies utilized methods such as radiosonde data analysis, temperature measurements from meteorological stations, air quality monitoring, and observational data from mountainous regions to understand lapse rates. However, while these studies have addressed lapse rates in various contexts, none have specifically used lapse rate measurements to identify and prospect air pollution hotspots. This study aims to fill that gap by leveraging lapse rate measurements at various heights to pinpoint potential hotspots of pollutants produced by automobiles on the road. Using Arduino Mega 2560 with DHT22 temperature sensors, we automated the measurement of daily temperatures at one-meter intervals up to four meters, providing detailed insights into the vertical distribution of temperature and its relation to air pollution near roadways.

Methods and procedures

Study area

The University of Ghana, legon is located in Accra, Ghana. Accra, the capital city of Ghana, is bordered by several key areas and geographical features: To the south the Gulf of Guinea, which is part of the Atlantic Ocean.To the north the Ga East Municipal District and the La Nkwantanang Madina Municipal District. To the east the Ledzokuku-Krowor Municipal District and the Tema Metropolitan District.To the west the Ga West Municipal District and the Ga South Municipal District. Accra is a bustling urban center with significant cultural, economic, and political importance in Ghana. The city's coastal location also makes it an important hub for trade and tourism. The GPS location of height is 71.0 m above sea level, at longitude 0.1983 ^{o} W, and latitude 5.6418 ^{o} N.

Governing Equations

Processes that may cause vertical changes in temperature in the atmosphere include convection, submerge due to high pressure, solar radiation, and build up air pollutants particularly greenhouse gases. In convection and submerge due to high pressure aloft, temperature decreases with increasing height thereby given a positive lapse rate. For positive lapse rate, there is continues dilution of pollution by fresh air sinking from the airmass above. For solar radiation, and build up air pollutants particularly greenhouse gases, temperature increases with increasing height, and the lapse rate is negative. The stratosphere is a classic example of negative lapse rate due to build up air pollutants particularly greenhouse gases like ozone (Asadi *et al*., 2018). Lapse rate has a variety of applications including rainfall pattern studies, dispersion of pollutants, and aviation applications. Lapse rate can help us determine the stability of air parcel at various heights during different times of the day at a given location, thus helping in pollutant dispersion studies. Lapse rate (Γ) is the negative rate of change of temperature with respect to height. This can be expressed mathematically by(Ahrens & Henson, 2016)

$$\Gamma = -\frac{dT}{dz} \qquad (1)$$

where T is the temperature and z is height into the atmosphere.

Measurement set-up

Temperature measurements were taken at the University of Ghana, Legon campus, near the electronic gate along the Legon-GIMPA road. The measurement setup is shown in Figure 1. The temperature sensors were placed at one-meter intervals, starting from the ground up to a height of four meters. Due to the automated system, temperature readings were taken at 30-second intervals daily. The measurements were taken between January 31, 2020, and March 27, 2020. MATLAB was utilized to process the data and determine the lapse rate.

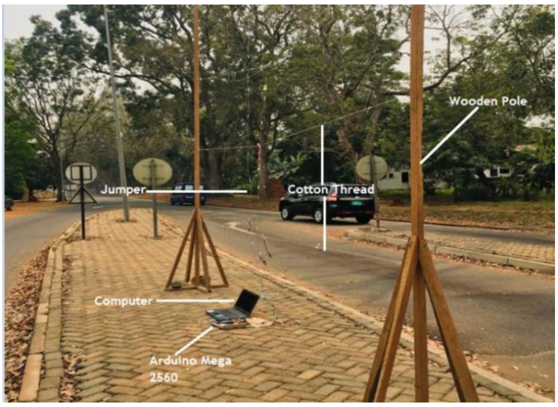

Figure 1. The experiment at Legon-GIMPA electronic gate, University of Ghana. Setup is on the concrete pavement located just before the electronic gate at the immediate left for vehicles leaving university of Ghana, Legon campus.

Results

The sensors were kept in four different positions in order to measure the temperature. Thus, there were four height ranges labelled as H_10 〖,H〗 _21 ,H_32 and H_43 for the ground/ concrete surface (0 m) to 1 m, 1 m to 2 m, 2 m to 3 m, and 3 m to 4 m respectively. In terms of periods of the day, four divisions were considered based on the observed trend of the data. The four divisions are the time between about 12 midnight (11:54 p.m.) and about 8:30 a.m.; the time between about 8:30 a.m. and about 12:25 p.m.; the time between about 12:25 p.m. and about 6:45 p.m.; and the time between about 6:45 p.m. and about 11:54 p.m. The period between 6:45 p.m. and about 8:30 a.m. was taken as the nocturnal cycle. In this cycle, the sun was generally not active and there was no solar radiation incident on the surface of the earth. The period between about 8:30 a.m. and about 6:45 p.m. was taken as the diurnal cycle. The sun is active during this cycle, and solar radiation incidents on the surface of the earth. Also, zero line is introduced to serve as a baseline for easy identification of lapse rates below and above zero.

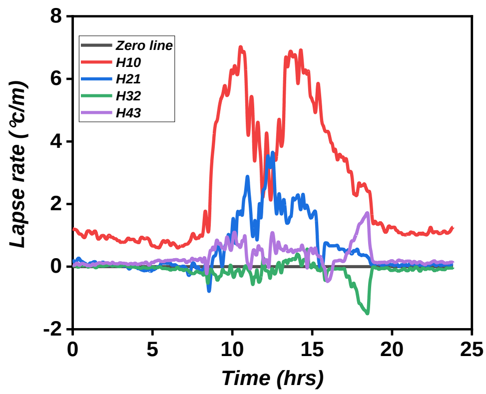

Figure 2: Comparing daily lapse rates for different height ranges

The calculated daily lapse rates for different heights were plotted together as shown in Figure 2. The lapse rates were calculated for one-meter intervals starting from the ground. Solar radiation incident on the surface of the earth (irradiation) is a major factor that influence lapse rate values, particularly, between the surface (0 m) and the 1 m height. This is shown on Figure 2 with higher lapse rate values between about 8:33 am and 6:45 pm. Within this period of the day, the sun is active, and the atmosphere is heated through the solar radiation incident on the earth surface. This observation is further confirmed with lower lapse rate values between about 6:45 pm and 8:33 am, the period over which the sun is not active at the measurement site.

The dip observed between 10:47 am with $6.93\,°C.m^{-1}$ lapse rate, and 1:27 pm with

$6.10°C.m^{-1}$ lapse rate and has a minimum lapse rate of $2.03\ °C.m^{-1}$ occurring at 12:22 pm for the 0 m to 1 m height range could be attributed to obscure of the solar radiation by either cloud cover, or obstacles such as trees and tall structures. The obscure by trees and tall structures happens as the angle of inclination of the sun changes. However, this cannot be the possible explanation because the sun is almost vertical around 12 noon in the tropics (Ahmad *et al.*, 2013). Furthermore, the obscure by tall trees and tall structures will cause the reduction of the lapse rate values for the rest of the day, not just about three hours. Thus, the observed dip is more likely to be caused by cloud cover (Wang *et al*., 2013). The lapse rate values of the 0 m and 1 m range above the zero line establish two facts namely convection, and concrete slab surface being a better conductor of heat than air. During the day when solar radiation is available, the concrete surface being a better heat conductor than the air gets heated faster thus heating the air at the immediate boundary between air and the concrete surface.

Lapse rate values between about 6:45 p.m. and about 8:33 a.m. are comparatively lower than the lapse rate values between about 8:33 a.m. and about 6:45 p.m. for the 0 m to 1 m height range. Between 6:45 p.m. and 8:33 a.m. is the period where there is no solar radiation at the site. Thus, the system constitutes the concrete surface and air in the atmosphere. Here there is natural loss of heat from the much-heated concrete surface which is at a higher temperature to the air at the immediate boundary between the earth's surface and the atmosphere. The temperature gradient in this case decreases. Between 8:33 a.m. and 6:45 p.m., the solar radiation is available thus the system of earth's surface and the atmosphere is influenced by an external agent which is the Sun. As a result, the system undergoes forced heating by the solar radiation which eventually increases the temperature gradient and consequently increases the lapse rate values. On the average, there is positive lapse rate values for 0 m and 1 m, 1 m and 2 m, and 3 m and 4 m height ranges throughout the day. However, on the average, the 2 m to 3 m height range shows a negative lapse rate.

Figure 3 shows graphs of lapse rates at different height ranges for the period between about 12 midnight and about 8:33 am. Within the period between about 12 midnight and about 4:00 am, the sun is not active over the location where measurements were taken. For the range between the ground and 1 m height, the lapse rate values are above zero. This indicates that the atmosphere within this range is unstable, there is turbulence, and the atmospheric constituent within this range is well mixed. The lapse rate within this range has an average of 2.777 °C/m with the highest value of 7.100 °C/m and the lowest values of 0.5800 °C/m occurring at about 2:17 p.m. and 6:33 a.m. respectively. The abrupt shooting of the lapse rate or highest lapse rate of 7.060 °C/m and 7.100 °C/m at 10:32 a.m. and 2:17 p.m. respectively may be attributed partly to instant release of hot exhaust fumes from vehicles and partly to solar radiation heating the ground thus causing the air closer to the ground to increase in temperature, expand and becomes less dense than the air above it. The relative higher values within this height range as compared to the other height ranges in this study indicate that there is relatively higher turbulence and effective mixing of atmospheric constituents within this height range.

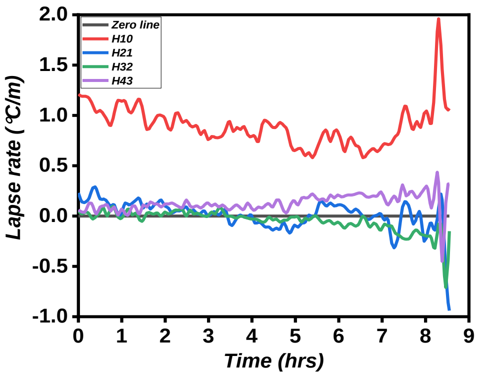

Figure 3: Lapse rate for different height range but the same period between 12 midnight and about 8:33 am.

Thus, air pollutants released from the ground could easily spread within this height range. Between 12 midnight (12 am) and about 3:30 am, all the height ranges namely 1 m and 0, 2 m and 1 m, 3 m and 2 m, and 4 m and 3 m in this study have lapse rates above zero. This means that pollution levels can be much reduced within this period because pollutant released at any given height is heavily diluted with fresh unpolluted air within the entire region. However, the intensity of mixing is greatest within the 1 m and 0 m height range. This is because the ground being a better heat conductor than air quickly releases much of its heat thus warming the air closer, reduces its density and consequently causing the cooler denser air above to sink down in the mixing process.

Figure 4 shows graphs of lapse rates at different height ranges for the period between about 8:33 am and about 12:25 pm. The sun is active, and the surface of the earth is actively warming up. Furthermore, there is much traffic on the road between about 8:33 am and about 9:25 am. Vehicles trying to get access at the gate are much closer to one another and much pollution is released from the exhaust pipes of the vehicles.

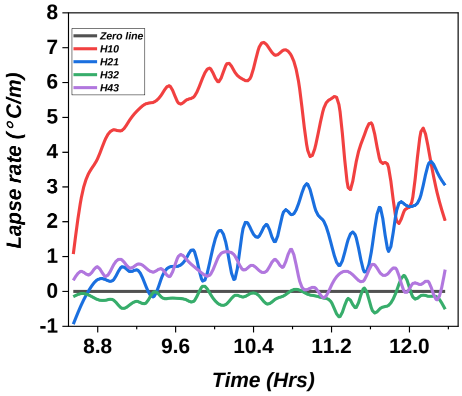

Figure 4: Lapse rate for different height range but the same period between 8:33 am and 12:25 pm.

The dominance of the H_{10m} range is a confirmation of the concrete surface being a better conductor of heat than air. The H_{10m} has a mean, maximum, minimum, and standard deviation of 4.804 °C/m, 7.060 °C/m, 1.070 °C/m, and 1.4977 respectively. The lapse rate values for the H_{10m} range is completely far above the lapse rate values for the other height ranges. This observation indicates a convective activity particularly between the boundaries between surfaces with different specific heat capacities. The temperature sharply drops as heat is transferred from the relatively good conductor, in this case the concrete surface, to the air which is a poor conductor of heat. The general trend of the H_{10m} increasing from about 8:33 a.m. to about 10:33 a.m. shows that temperature was dropping faster for the convective activities during that period.

In general, the curves for the H_{10m} , H_{21m}, and H_{43m} ranges showing positive lapse rates clearly indicate that as the hotter less dense air are displaced upwards, it becomes denser as the temperature drops. However, the lapse rate values of the H_{32m} range are negative with a mean of about -0.2004 °C/m. This means that the temperature increases with increasing height. This observation is not a characteristic of a convective activity.

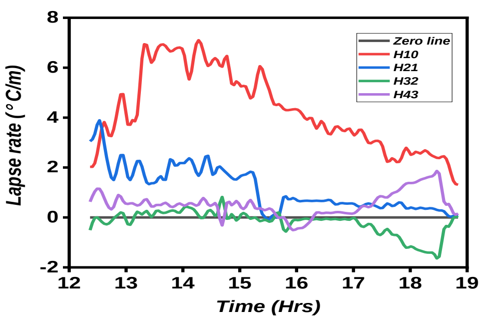

Figure 5: Lapse rate for different height range but the same period between about 12:25 pm and about 6:45 pm.

Like the other periods of the day, the lapse rate for the 0 m to 1 m height range generally dominate over the lapse rates for the other height ranges as shown in Figure 5. It shows total dominance from about 12:37 pm to about 6:45 pm. It generally increases from about 12:25 pm to about 3:25 pm. Within the period between 12:25 pm and 3:25 pm, the H_{10} has an average of 4.2624 °C/m as compared to the overall average of 1.4410 °C/m within the entire period of 12:25 pm to 6:45 pm. The increase in the mean of H_{10} gives at least two confirmations. Firstly, it confirms that the concrete surface is far better conductor than air such that response rate of the concrete surface is faster than that of the air. This gives a greater temperature gradient. There is much turbulence at that period because much denser cold air will be above much less dense warmer air. Secondary, it is a confirmation that at that period the concrete surface receives much solar radiation.

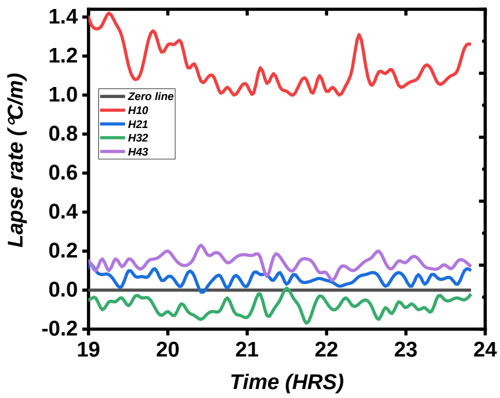

Figure 6: Lapse rate for different height range but the same period between 6:45 pm and 11:54 pm.

In Figure 6, apart from height range between 2 m and 3 m that have negative lapse rate values, all the other three height ranges namely 0 and 1 m, 1 m and 2 m, and 3 m and 4m have positive lapse rates between about 6:45 pm and 11:48 pm. There is temperature inversion between 2 m and 3 m indicating that the atmosphere is stable within this height range and no mixing occurs. There is average and standard deviation of -0.0775 °C/m and 0.0400 respectively within the 2 m and 3 m height range. The negative lapse rate within the 2 m and 3 m height range persisted over nearly 5 hours between about 6:48 pm and 11:48 pm. With this temperature inversion condition, pollution below this height range is much enhanced. Among the three height ranges that have positive lapse rates, 0 to 1 m range has the highest lapse rate, followed by the height range 3 m and 4 m, and the height range 1 m to 2 m has the least value. The highest mixing region (0 to 1 m) has an average lapse rate of 1.1441 °C/m, standard deviation of 0.1218, maximum lapse rate 1.490 °C/m occurring at 6:55 pm and minimum lapse rate of 1.000 °C/m occurring at three different times as 9:35 pm, 10:10 pm, and 10:50 pm. The height range between 3 m and 4 m has an average lapse rate of 0.1425 °C/m and a standard deviation of 0.0341. The lower standard deviation indicates that there is not much spread of the lapse rate values around the mean values. The lowest positive lapse rate over the period occurred between 1 m and 2 m heights, with the mean lapse rate of 0.0597 °C/m and a standard deviation of 0.0282. The lowest positive lapse rate values of 1 m and 2 m range below the negative lapse rate region of 2 m and 3 m range sustains the temperature inversion over the 2 m and 3 m range. The positive lapse rate values in the various height ranges over the period characterizes heavy mixing from the ground, mixing reduces abruptly along the 1 m and 2 m range until there is no mixing within the 2 m and 3 m height range. Height range 3 m to 4 m above the 2 m and 3 m temperature inversion range is characterized with moderate mixing.

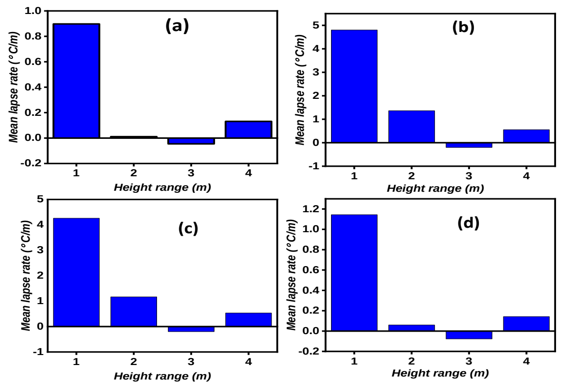

Figure 7: Shows the mean of the lapse rates for the periods (a) 11:54 pm and 8:45 am, (b) 8:45 am and 12:25 pm, (c) 12:25 pm and 6:45 pm, and (d) 6:45 pm and 11:54 pm.

The mean of the lapse rate for different height ranges but the same period is analyzed as shown in Figure 7. It is observed that the height ranges 0 to 1 m, 1 m to 2 m, and 3 m to 4 m have positive mean lapse rates except 2 m to 3 m height range that has negative lapse rate. The daily mean lapse rate for the 0 m to 1 m height range is 2.7770 °C/m and it is the highest compared to the other height ranges. There is an overall average of 4.5332 °C/m at the periods when the sun is active [(b) and (c)], and an overall mean of 1.0208 °C/m when sun is not active [(a) and (d)]. This indicates that there are high differential heating of the ground and the atmosphere when the sun is active. Furthermore, there is poor conduction of heat through the atmosphere. The observation further confirms that the atmosphere is heated mainly from the surface of the earth when the sun is active. The lower mean lapse rates during the period when the sun is not active is an indication that there is much lower heat available to be transferred, and there is fairly spread of heat within the range. The mean lapse for the 1 m to 2 m height range is much pronounced during the day when there is much radiation from the sun. The overall mean lapse rate when the sun is active is 1.2647 °C/m as compared to the overall mean lapse rate of 0.0353 °C/m when the sun is not active.

The 3 m to 4 m height range shows low positive mean lapse rates throughout the day. The overall mean lapse rate is 0.3399 °C/m. This can be interpreted as fairly spread of heat, and relatively very low mixing within the range. The lower lapse rates in the 1 m to 2 m range, and the 3 m to 4 m range indicates that there is heat transfer of heat within the same medium that is a poor conductor. Here there is a kind of pseudo equilibrium created and there is not appreciate change in temperature between any two given layers. The 2 m to 3 m height range shows negative mean lapse rates throughout the day with an overall mean lapse rate of -0.1306 °C/m. This is temperature inversion, a condition where temperature increases with increasing height. The observed temperature inversion within the 2 m to 3 m height range could have negative consequence on air quality, rainfall, and heat island especially when it occurs over large area, and it prevails over long period- months. The condition acts like a ceiling to prevent vertical movement of air parcel above it. Air pollutants, moist air from surface evaporation, and heat transferred from the earth's surface are all trapped below the height range of the inversion layer. In terms of air quality, there is accumulation of air pollution thus leading to poor air quality. In terms of rainfall, contribution of moist air from the earth's surface for the development of rain is prevented by the inversion layer. In this case if the moist air from transpiration of trees with heights above the inversion layer is not sufficient for local rain formation, then that location will lack regular rainfall and may be dry. In terms of heat island, the intensities of heat below the height of temperature inversion will be intensified.

Discussion

The ground (0 m) to 1 m height range showed a positive lapse rate throughout the day, with a mean of 2.7770 °C/m. This positive lapse rate indicates that the temperature decreases with height, which is typical for surface heating effects and could suggest significant pollutant concentration near the ground level, where vehicle emissions are most intense. The mean lapse rate for the diurnal cycle (daytime) for the 0 m to 1 m height range is 4.5332 °C/m. This high positive lapse rate during the day suggests strong heating near the ground, which could enhance the vertical mixing of pollutants. The mean lapse rate for the nocturnal cycle (nighttime) for the 0 m to 1 m height range is 1.0208 °C/m. The lower lapse rate at night implies reduced vertical mixing, potentially leading to higher pollutant concentrations near the ground as emissions accumulate. For the height ranges of 0 m to 1 m, 1 m to 2 m, and 3 m to 4 m, typically positive lapse rate values were observed. However, the 2 m to 3 m height range had mainly negative lapse rate values, indicating a temperature inversion. This inversion can trap pollutants near the surface, exacerbating air quality issues.

The mean lapse rate before sunrise, during daytime and after sunset are 0.2484 °C/m, 1.6297 °C/m and is 0.3172 °C/m respectively. These mean lapse rates indicate that the vertical temperature gradient is strongest during the daytime, promoting the dispersion of pollutants, while weaker gradients before sunrise and after sunset suggest limited dispersion and potential accumulation of pollutants near the ground. The temperature decreases as the pollutant (air mass) rises; this is a result of turbulence. Also, convective activities related to solar radiation cause heavier air masses to sink and lighter air masses closer to the surface to rise. This leads to the cooling of the air masses as they rise in the atmosphere. This study shows that at an observed height (2-3 m), there is a temperature inversion, which means that the temperature increases with height, contrary to what convective activities typically cause. Therefore, the observed result cannot be attributed to solar radiation but rather to pollution from automobile emissions. The influx from the surface of earth as a result of radiative heating of the sun leads to covective activities that is associated with the rise of gases including greenhouse gases into the atmosphere. Generally, this process is characterized by cooling as the air mass rises into the atmosphere.

The findings suggest that pollutant concentrations are likely to be higher near the ground level, especially during nighttime and early morning when temperature inversions are common. This has significant implications for air quality management and public health, particularly in urban areas with heavy traffic. Strategies to mitigate air pollution should consider these temporal and vertical variations in temperature and pollutant dispersion.

Conclusion

In this work, temperature profile from the surface of the earth to a 4 m height into the atmosphere obtained from automated measurement using Arduino sensor system was used. The work reveals that the lapse rates for the 0 m to 1 m height range were all positive with an overall average lapse rate of 2.7770 ^{o}C/m, diurnal average lapse rate of 4.5332 ^{o}C/m and nocturnal average lapse rate of 1.0208 ^{o}C/m. The mean lapse rate for the diurnal and nocturnal cycles for the 1 m to 2 m height range are 1.2647 ^{o}C/m and 0.0353 ^{o}C/m respectively. The mean lapse rate for the diurnal and nocturnal cycles for the 3 m to 4 m height range are 0.5431 ^{o}C/m and 0.1368 ^{o}C/m respectively. The positive lapse rates indicate that the atmosphere is not stable in these regions, and it is characterized by mixing. The mean lapse rate for the diurnal and nocturnal cycles for the 2 m to 3 m height range are -0.1996 ^{o}C/m and -0.0616 ^{o}C/m respectively. The negative lapse rates indicate that the atmosphere is stable in this region, and there is no mixing. Thus, the temperature inversion at the 2 m to 3 m height range is prevalent throughout the period and has high potential to affect air quality in the regions below the 2 m height. The study period from January 31, 2020, to March 27, 2020, provides a snapshot of temperature conditions during that time but may not capture long-term seasonal variations. Further research is needed to study the long-term trends and impacts of climate change on urban temperature patterns in Accra as well as combine ground-based measurements with satellite data to enhance spatial coverage and accuracy of temperature monitoring.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability Statements

The authors confirm that the data supporting the findings of this study are available within the article.

Acknowledgements

We extend our appreciation to the PDMSD, University of Ghana for giving us the permission to mount the setup at the site, and to the Legon Security for providing security of the setup.

Credit Author Statement

Abraham Amankwah: Supervision, Conceptualization, Methodology, Formal analysis, Writing- Reviewing and Editing; **Michael Gyan**: Formal analysis, Writing-Reviewing and Editing, Validating; **Jonathan Mensah-Bonsu**: Conceptualization, Methodology, Formal analysis, Writing- Original draft preparation, Validation; **Nana Ama Brown-Klutse**: Formal analysis, Reviewing and Editing.

References

Ahmad, S.; Shafie, S.; Ab Kadir, M. Z. A.; Ahmad, N.S. (2013). On the effectiveness of time and date-based sun positioning solar collector in tropical climate: A case study in Northern Peninsular Malaysia. *Renewable and Sustainable Energy Reviews*, *28*: 635 - 642. https://doi.org/https://doi.org/10.1016/j.rser.2013.07.044

Ahrens, C. D.; Henson, R. (2016). *Essentials of Meteorology: An Invitation to the Atmosphere*. Cengage Learning.

Anders, A.M.; Nesbitt, S. W. (2015). Altitudinal precipitation gradients in the tropics from tropical rainfall measuring mission (TRMM) precipitation radar. *Journal of Hydrometeorology*, *16*(1). https://doi.org/10.1175/JHM-D-14-0178.1

Arar, M.; Jung, C.; Qassimi, N. Al. (2022). Investigating the Influence of the Building Material on the Indoor Air Quality in Apartment in Dubai. *Frontiers in Built Environment*, *7*. https://doi.org/10.3389/fbuil.2021.804216

Armah, S. (2020). Nurturing sustainable prosperity in West Africa: Examples from Ghana. In *Nurturing Sustainable Prosperity in West Africa: Examples from Ghana*. https://doi.org/10.1007/978-3-030-37490-7

Asadi, I.; Shafigh, P.; Hassan, Z.F.A.; Mahyuddin, N. (2018). Thermal conductivity of concrete – A review. *Journal of Building Engineering*.

Atkinson, B.W. (1975). Principles of Applied Climatology. K. Smith. New York (McGraw-Hill) 1975. 233 pp. £5·25. *Quarterly Journal of the Royal Meteorological Society*, *101*(430): 1031. https://doi.org/https://doi.org/10.1002/qj.49710143030

Ayetor, G.K.; Mbonigaba, I.; Ampofo, J.; Sunnu, A.K. (2021). *Investigating the state of road vehicle emissions in Africa: A case study of Ghana and Rwanda*.

Bell, B.A.; Hughes, P.D.; Fletcher, W.J.; Cornelissen, H.L.; Rhoujjati, A.; Hanich, L.; Braithwaite, R. J. (2022). Climate of the Marrakech High Atlas, Morocco: Temperature lapse rates and precipitation gradient from piedmont to summits. *Arctic, Antarctic, and Alpine Research*, *54*(1). https://doi.org/10.1080/15230430.2022.2046897

Breton, R.M. C.; Breton, J. C.; Fuentes, M. de la L. E.; Kahl, J.; Guzman, A.A.E.; Martínez, R.G.; Guarnaccia, C.; Severino, R.D.C.L.; Lara, E.R.; Francavilla, A.B. (2021). Short-term associations between morbidity and air pollution in metropolitan area of Monterrey, Mexico. *Atmosphere*, *12*(10). https://doi.org/10.3390/atmos12101352

Chaudhry, F.N.; Malik, M.F. (2017). Factors Effecting Water Pollution Factors Affecting Water Pollution: A Review. *Journal of Ecosystem & Ecography*, *7*(1).

Cunningham, W.P. (2007). *Environmental science: a global concern*. New York: McGraw-Hill, 2007.

FN, C.; MF, M. (2017). Factors Affecting Water Pollution: A Review. *Journal of Ecosystem & Ecography*, *07*(01). https://doi.org/10.4172/2157-7625.1000225

Gierens, K.; Wilhelm, L.; Hofer, S.; Rohs, S. (2022). The effect of ice supersaturation and thin cirrus on lapse rates in the upper troposphere. *Atmospheric Chemistry and Physics*, 22(11). https://doi.org/10.5194/acp-22-7699-2022

He, Z.W.; Tang, B.H. (2023). Spatiotemporal change patterns and driving factors of land surface temperature in the Yunnan-Kweichow Plateau from 2000 to 2020. *Science of the Total Environment*, *896*. https://doi.org/10.1016/j.scitotenv.2023.165288

Huo, T.; Du, Q.; Xu, L.; Shi, Q.; Cong, X.; Cai, W. (2023). Timetable and roadmap for achieving carbon peak and carbon neutrality of China's building sector. *Energy*, *274*. https://doi.org/10.1016/j.energy.2023.127330

Joshi, R.; Tamang, N.D.; Sambhav, K.; Mehra, C.; Bisht, B. S.; Singh, S.P. (2023). Temperature Lapse Rate in Climatically Different Himalayan Treeline Environments: Regional Analysis of Patterns, Seasonality, and Variability. In *Ecology of Himalayan Treeline Ecotone*. https://doi.org/10.1007/978-981-19-4476-5_3

Khan, I.; Hou, F.; Le, H. P. (2021). The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. *Science of the Total Environment*, *754*. https://doi.org/10.1016/j.scitotenv.2020.142222

Kumar, B.; Roy, D.; Lakshmi, V. (2022). Impact of temperature and precipitation lapse rate on hydrological modelling over Himalayan Gandak River Basin. *Journal of Mountain Science*, *19*(12). https://doi.org/10.1007/s11629-020-6602-5

Maung, T. Z.; Bishop, J. E.; Holt, E.; Turner, A. M.; Pfrang, C. (2022). Indoor Air Pollution and the Health of Vulnerable Groups: A Systematic Review Focused on Particulate Matter (PM), Volatile Organic Compounds (VOCs) and Their Effects on Children and People with Pre-Existing Lung Disease. In *International Journal of Environmental Research and Public Health*, 19 (14). https://doi.org/10.3390/ijerph19148752

Miller, G.T.; Spoolman, S. (2007). *Living in the Environment: Principles, Connections, and Solutions*. Thomson Brooks/Cole.

Molina, A.; Shaddix, C.R. (2005). Coal particle ignition and devolatilization during oxygen-enhanced and oxygen/carbon dioxide pulverized coal combustion. *Fall Technical Meeting of the Western States Section of the Combustion Institute 2005, WSS/CI 2005 Fall Meeting*, *1*.

Molina, A.; Shaddix, C.R. (2007). Ignition and devolatilization of pulverized bituminous coal particles during oxygen/carbon dioxide coal combustion. *Proceedings of the Combustion Institute, 31 II.* https://doi.org/10.1016/j.proci.2006.08.102

Numbere, A.O.; Gbarakoro, T.N.; Babatunde, B.B. (2023). *Environmental Degradation in the Niger Delta Ecosystem: The Role of Anthropogenic Pollution*. https://doi.org/10.1007/978-981-19-6974-4_15

Quinn, B.; Gallagher, R.; Kuosmanen, T. (2023). Lurking in the shadows: The impact of CO_2 emissions target setting on carbon pricing in the Kyoto agreement period. *Energy Economics, 118.* https://doi.org/10.1016/j.eneco.2022.106338

Rolland, C. (2003). Spatial and seasonal variations of air temperature lapse rates in alpine regions. *Journal of Climate*, *16*(7). https://doi.org/10.1175/1520-0442(2003)016<1032:SASVOA>2.0.CO;2

Sinha, A.; Sengupta, T.; Alvarado, R. (2020). Interplay between technological innovation and environmental quality: Formulating the SDG policies for next 11 economies. *Journal of Cleaner Production, 242.* https://doi.org/10.1016/j.jclepro.2019.118549

Wang, X.; Li, Q.; Xie, G.; Saylor, J. E.; Tseng, Z. J.; Takeuchi, G. T.; Deng, T.; Wang, Y.; Hou, S.; Liu, J.; Zhang, C.; Wang, N.; Wu, F. (2013). Mio-Pleistocene Zanda Basin biostratigraphy and geochronology, pre-Ice Age fauna, and mammalian evolution in western Himalaya. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 374: 81–95. https://doi.org/10.1016/j.palaeo.2013.01.007

Xiao, W.; Liu, T.; Tong, X. (2023). Assessing the carbon reduction potential of municipal solid waste management transition: Effects of incineration, technology and sorting in Chinese cities. *Resources, Conservation and Recycling, 188.* https://doi.org/10.1016/j.resconrec.2022.106713

Xu, X.; Yang, H.; Li, C. (2022). Theoretical Model and Actual Characteristics of Air Pollution Affecting Health Cost: A Review. In *International Journal of Environmental Research and Public Health.* 19(6). https://doi.org/10.3390/ijerph19063532

Yahans Amuah, E.E.; Boadu, J.A.; Nandomah, S. (2022). Emerging issues and approaches to protecting and sustaining surface and groundwater resources: Emphasis on Ghana. In *Groundwater for Sustainable Development*, (Vol. 16). https://doi.org/10.1016/j.gsd.2021.100705

Yan, G.; Zheng, Y.; Wang, X.; Li, B.; He, J.; Shao, Z.; Li, Y.; Wu, L.; Ding, Y.; Xu, W.; Li, X.; Cai, B.; Chen, X.; Song, X.; Wang, Q.; Lei, Y.; Wang, J. (2022). Pathway for Carbon Dioxide Peaking in China Based on Sectoral Analysis. *Research of Environmental Sciences*, *35*(2). https://doi.org/10.13198/j.issn.1001-6929.2021.11.13

Yoro, K.O.; Daramola, M.O. (2020). CO_2 emission sources, greenhouse gases, and the global warming effect. In *Advances in Carbon Capture: Methods, Technologies and Applications*. https://doi.org/10.1016/B978-0-12-819657-1.00001-3

Zhong, H.; Zhou, J.; Tang, W.; Zhou, G.; Wang, Z.; Wang, W.; Meng, Y.; Ma, J. (2023). Estimation of Near-Surface Air Temperature Lapse Rate Based on MODIS Data Over the Tibetan Plateau. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 16.* https://doi.org/10.1109/JSTARS.2023.3270560