Cities & Health

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rcah20

Keeping it cool: a multi-case study of temperature, vegetation, and solar radiation in Ecuadorian schools

Matea Cañizares & Daniel Romero-Alvarez

To cite this article: Matea Cañizares & Daniel Romero-Alvarez (10 Mar 2025): Keeping it cool: a multi-case study of temperature, vegetation, and solar radiation in Ecuadorian schools, Cities & Health, DOI: 10.1080/23748834.2025.2468019

To link to this article: https://doi.org/10.1080/23748834.2025.2468019

CITIES & HEALTH
https://doi.org/10.1080/23748834.2025.2468019

Routledge
Taylor & Francis Group

ORIGINAL SCHOLARSHIP

Check for updates

Keeping it cool: a multi-case study of temperature, vegetation, and solar radiation in Ecuadorian schools

Matea Cañizares [a] and Daniel Romero-Alvarez [b]

[a]Colegio Johannes Kepler, Quito, Ecuador; [b]Emerging and Neglected Diseases, Ecoepidemiology and Biodiversity Research Group, Undergraduate Program in Biomedical Sciences, Faculty of Health Sciences, Universidad Internacional SEK, Quito, Ecuador

ABSTRACT
Temperature and solar radiation in schools are relevant to children's health and well-being. Heat exposure has a negative effect on learning, while vegetation cover appears to have a positive impact on academic outcomes. Ecuador lacks standards for temperature control, protection of students from solar radiation, or green cover on school grounds. Using satellite images, this multi-case study analyzed land surface temperature, vegetation index values, and solar radiation levels in nine schools located across Ecuador throughout 2022. Findings show heterogeneity in environmental values in schools among and within ecoregions. Only one school has an average temperature below heat stress conditions (i.e. <26 ºC). Schools on the Coast reached high mean temperatures of 37°C with maximum records of 41°C, representing very strong heat stress. Schools on the Coast have the lowest vegetation values, while schools in the Andes have the highest solar radiation levels. Increasing vegetation could help reduce temperature levels and protect students from radiation through shade. Knowledge of environmental conditions in schools should inform educational standards in Ecuador to develop focused policies addressing high temperature and radiation levels together with the vegetation indexes across ecoregions, considering the characteristics of each school.

ARTICLE HISTORY
Received 4 August 2024
Accepted 12 February 2025

KEYWORDS
Children; health; physical environment; open data; heat stress; satellite images

Introduction

Students spend approximately 200 days per year in school, making it an important setting for health promotion. According to the Universal Thermal Climate Index (UTCI), heat stress in humans can be categorized into five classes, from no thermal stress below 26°C to strong heat stress >32°C and very strong >38°C (Park *et al.* 2014). In addition to influencing comfort levels, heat stress has repercussions on human health, well-being, and related outcomes (Ebi *et al.* 2021). Furthermore, students' concentration is inhibited by heat exposure, which directly impacts learning outcomes (Park *et al.* 2020, 2021).

In 2023, the mean temperature in Latin America was the highest on record, exceeding the 1991–2020 average by 0.82°C (WMO 2024). Ecuador followed a similar trend with an average summer temperature increase of 1°C in the period 2017–2021 (Torres *et al.* 2022). Increasing temperatures and heatwave occurrences in the region require modifying environmental factors to counteract the effects on health. However, national adaptation plans seldom include child health-related domains and, when they do, the focus is predominantly on education and raising awareness (Zangerl *et al.* 2024). In contrast, global standards emphasize the importance of the physical environment of schools, including adequate temperature control and green spaces, to address the well-being and learning capacity of children (WHO-UNESCO 2021).

Greenness may contribute to limiting the health impacts of increased heat (Pascal *et al.* 2021), and the presence of vegetation has been related to reduced land surface temperatures (Alshaikh 2015). Green spaces have been shown to improve mental and physical health (Nieuwenhuijsen *et al.* 2017) and school greenness has been associated with improved academic outcomes (Jimenez *et al.* 2023). Furthermore, shade from vegetations such as trees reduce solar radiation (Konarska *et al.* 2014).

Around the world, government standards for school infrastructure and grounds rarely consider temperature levels, solar radiation, or vegetation in the design and planning of schools. When they do, they rarely acknowledge ecoregion-specific needs, since standards commonly apply to schools nationwide. The location on the planet has an influence; countries located on the equator or at higher altitudes receive more solar radiation (Blumthaler *et al.* 1997, Petkov 2024). However, in Ecuador, a South American country located on the equator, government standards for school infrastructure neither regulate the control of temperature levels and protection against solar

CONTACT Matea Cañizares matea.canizares@gmail.com Colegio Johannes Kepler, Av. Simón Bolívar S/N vía a Nayón, Quito, Ecuador; Daniel Romero-Alvarez daromero88@gmail.com Emerging and Neglected Diseases, Ecoepidemiology and Biodiversity Research Group, Undergraduate Program in Biomedical Sciences, Faculty of Health Sciences, Universidad Internacional SEK, calle Albert Einstein y 5ta Transversal, Carcelen, Quito, Ecuador
Supplemental data for this article can be accessed online at https://doi.org/10.1080/23748834.2025.2468019

radiation nor require a specific amount of vegetation on school grounds.

To the best of our knowledge, there is a lack of studies on the environmental characteristics of schools as a condition for student health and well-being in Ecuador. Examining environmental conditions through satellite images is useful for adopting cooling measures in urban infrastructure (Park *et al.* 2014). With the aim of understanding environmental conditions in Ecuadorian schools located in different geographic regions, we conducted a multi-case study to identify land surface temperatures, vegetation index values, and solar radiation levels of nine schools located at different altitudes and ecoregions, using satellite images. Our analysis focused on the interrelations between environmental factors that might be relevant to improving Ecuador's lack of standards for school infrastructure and grounds with consideration for their impact on children's health.

Methods

Nine schools were selected across Ecuador to characterize three environmental variables: temperature, vegetation, and solar radiation. Schools were selected applying the following criteria: (i) they were equally distributed across the three continental ecoregions (i.e. Coast, Andes, Amazon; Supplementary Appendix 1), and (ii) their limits could be observed through an examination using Google Maps and Google Earth Pro. After selection, schools were delineated and represented as polygons to calculate their area in hectares and estimate their average altitude using satellite images from the NASA Shuttle Radar Topography Mission (NASA 2024).

Environmental information for each school was obtained using satellite tools that measure Earth's electromagnetic radiation, specifically the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Terra and Aqua satellites (Horning *et al.* 2010). MODIS-derived images approximate environmental data by interpreting different sections of the electromagnetic spectrum. Three MODIS products were used: land surface temperature (LST) as a proxy for temperature, enhanced vegetation index (EVI) as a proxy for vegetation, and downward shortwave radiation (DSR) as a proxy for solar radiation (Table 1; Wang 2017, GOES-R 2020, Li *et al.* 2021).

For DSR – hereafter solar radiation – we used the band representing total DSR at Greenwich Mean Time (GMT) 12:00 and expressed it as watts per square meter (watts/m^2). The LST satellite product uses multiple satellite images to interpret temperature and expresses it in degree Celsius (°C; Wan *et al.* 2021). Vegetation indexes such as EVI show values without magnitude, directly related to low (minimum = −2,000) or high (maximum = 10,000) on-the-ground vegetation levels (Didan 2021). We used school polygons to clip satellite images and obtained a value per time unit by averaging pixel values from the rasters. Data for each variable were collected throughout 2022 considering the availability of reliable satellite data and are presented using time series plots (Figure 1) and descriptive statistics (Figure 2; mean and standard deviation).

School delimitation, satellite product visualization, clipping, and data collection were performed using Google Earth Engine (Gorelick *et al.* 2017, Vijayakumar *et al.* 2024). Further data processing was performed on R (R Core Team 2023).

Results

The temporal resolution of satellite images varied from daily for solar radiation, every 8 days for temperature and every 16 days for the vegetation index (Table 1). The paucity of satellite data is a consequence of cloud cover or rain-bearing clouds (Ismaila *et al.* 2023). In this study, the paucity of images was most significant for temperature data. In some instances, only 9 out of 44 (20.45%) images provided data (Supplementary Table S1); thus, interpolation was used to estimate overall patterns for each variable throughout 2022 (Supplementary Table S1, Figure 1).

Environmental values were heterogeneous within and between Ecuadorian ecoregions for the three types of satellite images explored (Figure 2). Schools on the Coast had the highest temperature values, reaching mean values of up to 37°C and maximum records of 41°C (Table 2 and Figure 2). Temperature mean values in schools in the Amazon and Andes regions were similar (Figure 2) except for Colegio Johannes Kepler, which showed the lowest temperatures across the year (Figures 1 and 2, Table 2).

Table 1. Characteristics of the satellite products used in this study.

Environment explored	Satellite information	Satellite product	Version	Frequency	Resolution	Overall number of images (mean, range)	Url access
Temperature	Land surface temperature (LST)	MOD11A2	061	8–day	1 km	24.44 (9-41)	https://lpdaac.usgs.gov/products/mod11a2v061/
Vegetation	Enhanced vegetation index (EVI)	MOD13Q1	061	16–day	250 m	21.44 (17-22)	https://lpdaac.usgs.gov/products/mod13q1v061/
Solar radiation	Downward shortwave radiation (DSR)	MCD18A1*	061	Daily	1 km	335.44 (275-347)	https://lpdaac.usgs.gov/products/mcd18a1v061/

Satellite products from the MODIS sensors were collected systematically with Google Earth Engine for nine Ecuadorian schools in 2022. Each product has a different frequency of collection. *MCD18A1 is derived from information obtained from Terra and Aqua satellites.

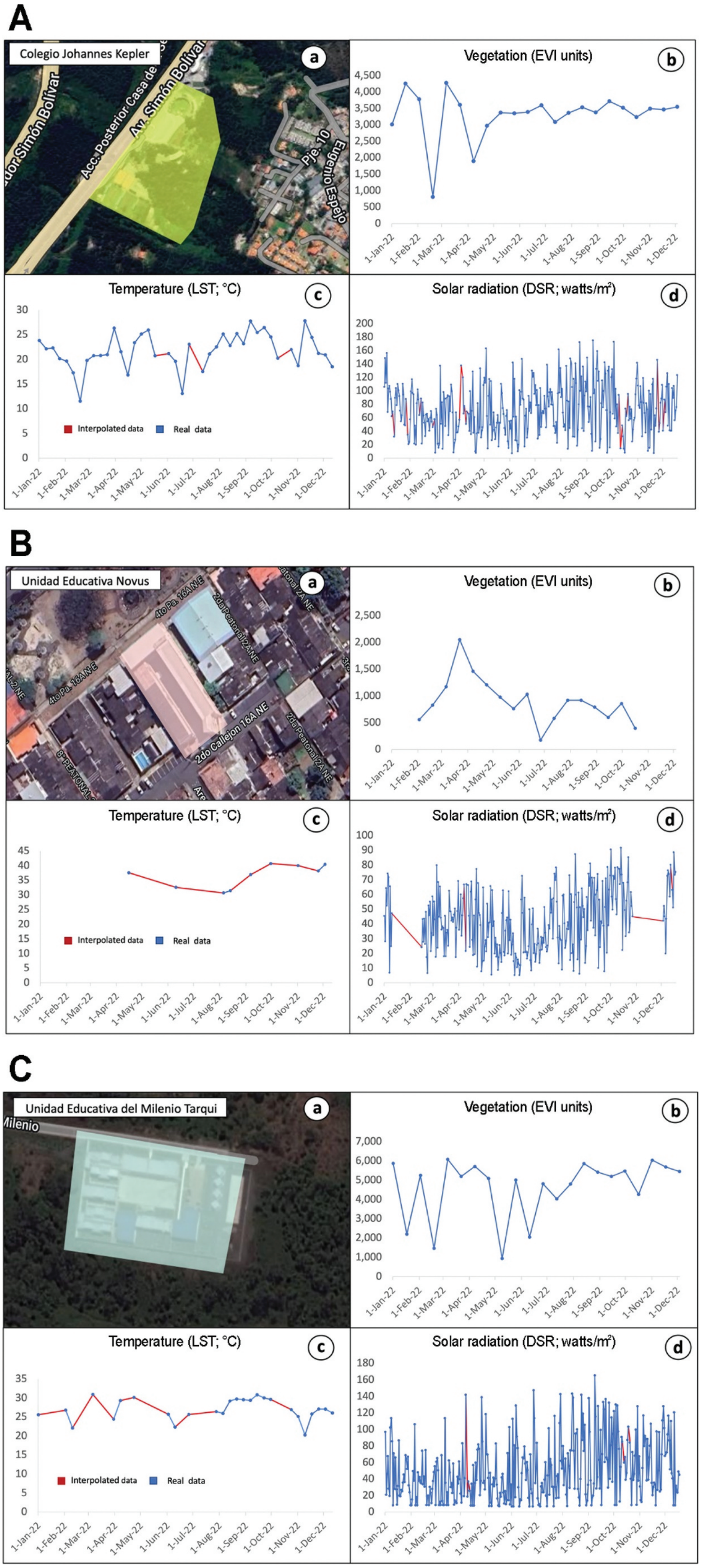

Figure 1. Representative schools from the Andean, Coast, and Amazon regions of Ecuador. We studied nine schools (a) in continental Ecuador using satellite images to characterize vegetation (EVI; b), temperature (LST; c), and solar radiation (DSR; d; see methods and Supplementary Table S1). Each panel represents a school from the Andean (A), Coast (B), and Amazon (C) regions of the country. Collected environmental data are represented in blue and linear interpolations in red.

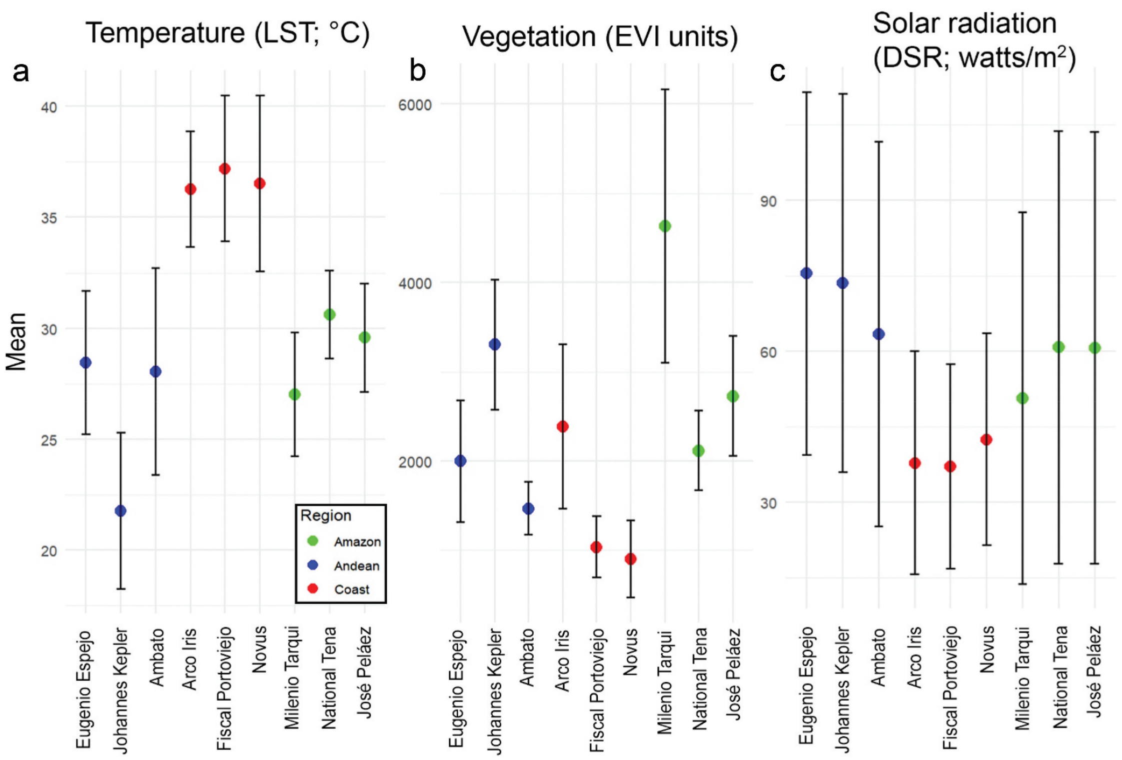

Figure 2. Distribution of the studied schools by region and type of satellite image processed. Nine schools, three for each Ecuadorian land ecoregion (Andean = blue, Coast = red, Amazon = green), are compared using the mean and ±one standard deviation values obtained from different satellite products: (A) Temperature (LST, ºC), (B) vegetation index (EVI units), and (C) solar radiation; (DSR, watts/m^2). Note: The figure aims to show differences in environmental values within and not across ecoregions. The y-axis for each environmental variable is readable; if cross-comparison is needed, data can be interpreted accordingly across schools.

The Unidad Educativa Milenio Tarqui in the Amazon region had the highest vegetation index values among the schools studied, exceeding the averages of vegetation of schools in the Andes and Coast regions (Figures 1 and 2). Conversely, Unidad Educativa Fiscal Portoviejo and Unidad Educativa Novus on the Coast presented the lowest vegetation values (Figures 1 and 2, Table 2).

Schools in the Andes region showed the highest levels of solar radiation across all studied schools (Figure 2); among them, Unidad Educativa Ambato had the lowest levels of radiation across Andean schools (Figure 2). Despite having the highest temperature levels, schools in the Coast region showed the lowest values of solar radiation (Figure 2), followed by schools in the Amazon region. Radiation was the variable with the largest heterogeneity (Figure 2). Supplementary Appendix 1 depicts environmental values as time series plots of the other six schools included in the study.

In 2022, average temperatures exceeded the heat-stress threshold in all but one school in the Andes region. The Andes region registered the largest solar radiation, while the Coast region had the highest temperature levels. In the Coast region, two of the three schools showed the lowest vegetation index values (Figure 2). Considering that environmental conditions are relevant for the health, well-being, and learning of students, our findings suggest that the infrastructure and grounds at schools might be suboptimal.

Discussion

This research is the first to examine patterns of temperature, vegetation, and solar radiation in schools in Ecuador using satellite imagery. Using Google Earth Engine, we collected satellite data to study nine school sites through 2022. The results indicate that certain conditions are characteristic of specific ecoregions, although variations among schools within the same ecoregion are common.

Using the 26°C threshold for moderate heat stress (Park *et al.* 2014), only one school, located in the Andes region, had an average temperature below heat stress conditions (i.e. Colegio Johannes Kepler = 21.76°C Figures 1 and 2, Table 2). Unidad Educativa del Milenio Tarqui, in the Amazon region, had an average temperature of 27.01°C, just above the threshold of heat stress (Figures 1 and 2, Table 2). In the Coast region, the three schools registered temperatures in the strong heat stress category (above 30 ºC) and had the highest temperature extremes of all schools, within the very strong heat stress category, from 40.07°C to 41.07°C (Table 2). These conditions

Table 2. Compilation of schools and environmental variables collected for this study.

AMIE code	City, Province. Region	School name	Student population	Area (m^2)	Elevation (m; mean)	Land surface temperature (LST; °C) (mean, standard deviation) [range]	Downward solar radiation (DSR; watts/m^2) (mean, standard deviation) [range]	Enhanced vegetation index (EVI) (mean, standard deviation) [range]
17H00872	Quito, Pichincha. Andean	Unidad Educativa Municipal Eugenio Espejo	2,864	57,453	2,578.05	28.44 (3.22) [23.49-34.82]	75.46 (36.06) [7.19-176.01]	1,998.23 (682.65) [1,498.74-3,230.88]
17H01748	**Quito, Pichincha. Andean**	**Colegio Johannes Kepler**	**914**	**59,857.02**	**2,737.97**	**21.76 (3.52) [11.57-27.85]**	**73.53 (37.6) [6.97-175.01]**	**3,302 (727.54) [810-4,273]**
18H00108 2931	Ambato, Tungurahua. Andean	Unidad Educativa Ambato	2,931	25,844.61	2,540.39	28.03 (4.66) [16.65-34.06]	63.41 (38.26) [6.89-176.46]	1,466.11 (295.4) [931.85-2,131.31]
13H00301	Portoviejo, Manabí. Coastal	Unidad Educativa Arco Iris	606	22,452.92	32.79	36.26 (4.66) [31.55-40.07]	37.78 (22.17) [5.12-116.66]	2,386.30 (922.2) [379.18-4,658.05]
13H00288	Portoviejo, Manabí. Coastal	Unidad Educativa Fiscal Portoviejo	2,207	15,422.29	41.98	37.20 (3.28) [30.38-41.07]	37.12 (20.32) [5.14-103.40]	1,036 (339.9) [238-1,643]
01H02017	**Guayaquil, Guayas. Coastal**	**Unidad Educativa Novus**	**210**	**1,319.14**	**4.38**	**36.53 (3.97) [30.67-40.77]**	**42.45 (21.02) [5.13-91.53]**	**899.18 (429.82) [175-2,051]**
16H00123	**Puyo, Pastaza. Amazon**	**Unidad Educativa del Milenio Tarqui**	**570**	**24,584.99**	**929.86**	**27.01 (2.8) [20.27-30.94]**	**50.66 (36.97) [6.63-165.26]**	**4,631 (1,534.81) [945-6,081]**
15H00047	Tena, Napo. Amazon	Unidad Educativa José Peláez	1,432	5,889.00	510.21	30.61 (2) [26.69-34.47]	60.72 (43.06) [7.11-178.85]	2,117 (448.04) [977-3,017]
15H00034	Tena, Napo. Amazon	Unidad Educativa Nacional Tena	2,153	46,987.18	514.30	29.57 (2.43) [23.35-33.17]	68.58 (42.93) [7.08-178.81]	2,727.51 (667.93) [936.51-4,098.55]

A total of nine Ecuadorian schools were examined for temperature, vegetation, and solar radiation values with satellite images during 2022. AMIE: Archivo Maestro de Instituciones Educativas, in Spanish. In bold are the schools depicted in Figure 1 in the main text, the rest of the schools are depicted in the supplementary appendix.

potentially expose students on the Coast to heat-related physical health risks (Ebi *et al.* 2021) and negative impacts on their learning outcomes (Park *et al.* 2020, 2021).

Considering the potential contribution of vegetation to lowering temperature values (Alshaikh 2015), we found that in the three ecoregions, the schools with the highest vegetation index had the lowest temperature values in both average and range (Figure 2 and Table 2); however, the relationship between temperature values and vegetation indexes varies by ecoregion. For example, despite having the largest vegetation on the Coast, Unidad Educativa Arco Iris still has one-year average temperature levels similar to the values registered for the two other schools from the Coast, which have the lowest vegetation values across the studied schools (Figure 2 and Table 2). This relationship might be different in the Andes and Amazon regions where schools with larger values of vegetation also have lower values of temperatures (i.e. Figures 1 and 2, and Table 2).

As expected, solar radiation in the schools in the Andes region, with average elevations between 2,540.39 and 2,737.97 m above sea level (masl), showed larger values than schools at the Coast, where the average elevation across the three schools ranged from 4.38 to 32.79 masl (Table 2 and Figure 2, Supplementary Appendix 1). In Ecuador, 10% of the population resides at moderate altitudes (1,500-2,500 masl), 27% at high altitudes (2,500-3,500 masl), and 3% at very high altitudes (3,500-5,500 masl; Ortiz-Prado *et al.* 2021). Ecuador has more than 4.3 million school students (Ecuadorian Ministry of Education 2023). The large percentage of people living at high altitudes means that a significant number of students are at risk of solar radiation exposure, with a potential impact on their health (Neale *et al.* 2023).

Green spaces in schools are important for promoting health in a school setting (WHO-UNESCO 2021). Replacing heat-intensifying surfaces with vegetation and increasing tree canopy to provide shade are important cooling strategies for schools. The European 'Cool Schools' project describes these spaces as 'nature-based climate shelters' (Grand-Meyer *et al.* 2024), while the Oasis project in Paris, France, views them as 'cool islands' serving the broader urban goal of alleviating rising temperatures (Ferrer *et al.* 2022). Furthermore, greenness may contribute to students' mental and physical health (Nieuwenhuijsen *et al.* 2017) and improved academic outcomes (Jimenez *et al.* 2023).

The results of this study highlight the relevance of studying environmental conditions in Ecuadorian schools and, consequently, the need to implement measures to alleviate heat stress and direct exposure to sunlight, potentially by increasing green spaces and shade. Given the different environmental patterns, interventions should address the context-specific needs of each ecoregion. Strategies to reduce students' exposure to solar radiation may be more important for schools in the Andes, while mitigating heat stress may be more relevant for schools in the Coast and Amazon regions. The higher vegetation indexes in the cooler schools in the Andes and Amazon regions suggest a potential model for school infrastructure reform in the Coast region.

Limitations

The present study analyzed satellite images available through 2022 to capture the state of environmental conditions at selected schools, which do not allow for generalizations and should be further assessed in time. However, as a multi-case study, our results underscore the importance of integrating remote sensing data in the assessment of school conditions. Satellite images might be unavailable due to the presence of clouds (Table 1); to address data gaps, we interpolated between data points to ensure reliable interpretations (Supplementary Table S1). Future studies should incorporate local sensor monitoring to complement these findings. Finally, we selected nine schools from the three ecoregions of the country; a larger sample size would allow to identify broader patterns.

Conclusion

Like other sites of daily life, schools are a setting that influences health, with the physical environment playing an important role in children's well-being and learning. School greenness and thermal comfort can have a positive impact on mental and physical health and learning outcomes (Nieuwenhuijsen *et al.* 2017, Park *et al.* 2020, 2021, Jimenez *et al.* 2023). In this multi-case study, we obtained environmental information through open-access tools to obtain environmental data and characterize nine Ecuadorian schools using temperature, vegetation, and solar radiation values. Our findings indicate that schools in the Coast region might experience high levels of heat stress throughout the year and schools in the Andes region are exposed to higher solar radiation compared to schools in other ecoregions. Vegetation cover appears to help regulate temperatures in the Andes and Amazon region, although the effect varies by ecoregion.

Knowledge of environmental conditions across different locales could inform the development and reform of school infrastructure standards and the implementation of changes in existing schools to address the interplay of temperature, vegetation, and solar radiation. Reforms should account for differences within and across Ecuadorian ecoregions. Leveraging satellite data may help anticipate heat stress in school students; therefore, we recommend incorporating these freely available data into planning and decision-making. Further research could replicate this method using a larger sample of schools in Ecuador and in other countries.

Although preliminary, our results indicate an urgent need to implement changes in school infrastructure to reduce heat stress levels in the Coast region and exposure to solar radiation in the Andes region of Ecuador. Despite fiscal constraints (Central Bank of Ecuador 2024), focused interventions, such as increasing green cover, could be a cost-effective way to improve school environments, promoting better health and learning outcomes.

Ethical approval

According to local regulations, the study does not require ethical approval since it does not involve human participants or confidential data.

Disclosure statement

MC is a student at Colegio Johannes Kepler, one of the schools selected for this study.

Notes on contributors

Matea Cañizares is a member of the Youth Advisory Panel of The Lancet Child & Adolescent Health and conducts health-related research.

Daniel Romero-Alvarez is an MD and PhD who specializes in the ecology of infectious diseases. He is a founding member of the Observatory on the Health Information System of Ecuador. His research is available at www.romerostories.com.

ORCID

Matea Cañizares http://orcid.org/0009-0002-4986-3344
Daniel Romero-Alvarez http://orcid.org/0000-0002-6762-6046

Data availability

All data are publicly available from the sources cited here. The Google Earth Engine script to download the satellite data and all downloaded data are available at https://github.com/daromero-88/cities_and_health.

Geolocation information

The centroid-based geolocation of Ecuador is Latitude: −1.7929665 and Longitude: −78.1368875.

References

Alshaikh, A., 2015. Vegetation cover density and land surface temperature interrelationship using satellite data, case study of Wadi Bisha, South KSA. *Advances in Remote Sensing*, 4 (3), 248. doi:10.4236/ars.2015.43020.

Blumthaler, M., Ambach, W., and Ellinger, R., 1997. Increase in solar UV radiation with altitude. *Journal of photochemistry and photobiology B, Biology*, 39 (2), 130–134. doi:10.1016/S1011-1344(96)00018-8.

Central Bank of Ecuador, 2024. *El adecuado funcionamiento de la dolarización requiere de un urgente ordenamiento integral de las finanzas públicas (A proper functioning of dollarization requires an urgent and comprehensive reorganization of public finances)*. Available from: https://www.bce.fin.ec/boletines-de-prensa-archivo/el-adecuado-funcionamiento-de-la-dolarizacion-requiere-de-un-urgente-ordenamiento-integral-de-las-finanzas-publicas. [Accessed 5 February 2025].

Didan, K., 2021. *Modis/terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V061*. NASA EOSDIS Land Processes Distributed Active Archive Center. Available from: https://doi.org/10.5067/MODIS/MOD13Q1.061.

Ebi, K.L., *et al.*, 2021. Hot weather and heat extremes: health risks. *Lancet*, 398 (10301), 698–708. doi:10.1016/S0140-6736(21)01208-3.

Ecuadorian Ministry of Education, 2023. *Estadística Educativa*. Volumen 4. Noviembre 2023 (Educational Statistics. Volume 4. November 2023). Available from: https://educacion.gob.ec/wp-content/uploads/downloads/2023/11/Estadistica-Educativa_Volumen-4.pdf.

Ferrer, S., *et al.*, 2022. *Oasis schoolyards. Recommendations booklet for transforming schoolyards*. Available from: https://ltl.org.uk/wp-content/uploads/2023/09/oasis-recommendations-for-transforming-schoolyards.pdf. [Accessed 8 June 2024].

GOES-R, 2020. *Geostationary operational environmental satellites—R Series*. NOAA-NASA. Available from: https://lpdaac.usgs.gov/products/mcd18a1v006/. [Accessed 8 June 2024].

Gorelick, N., *et al.*, 2017. Google Earth engine: planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18–27. doi:10.1016/j.rse.2017.06.031.

Grand-Meyer, E., *et al.*, 2024. *The COOLSCHOOLS guidelines for schools: how to turn your schoolyard into a nature-based climate shelter*. European Schoolnet, Brussels. Available from: https://coolschools.eu/wp-content/uploads/sites/19/2024/03/COOLSCHOOLS-WP6-D6.1-Guidelines-Final.pdf. [Accessed 8 June 2024].

Horning, N., *et al.*, 2010. *Remote sensing for ecology and conservation: a handbook of techniques*. New York, US: Oxford University Press.

Ismaila, A.B., Muhammed, I., and Adamu, B., 2023. A spatial regression approach to modeling urban land surface temperature. *MethodsX*, 10, 102022. doi:10.1016/j.mex.2023.102022.

Jimenez, R.B., *et al.*, 2023. School greenness and student-level academic performance: evidence from the global south. *GeoHealth*, 7 (8), e2023GH000830. doi:10.1029/2023GH000830.

Konarska, J., *et al.*, 2014. Transmissivity of solar radiation through crowns of single urban trees—application for outdoor thermal comfort modelling. *Theoretical and Applied Climatology*, 117 (3–4), 363–376. doi:10.1007/s00704-013-1000-3.

Li, R., Wang, D., and Liang, S., 2021. Comprehensive assessment of five global daily downward shortwave radiation satellite products. *Science of Remote Sensing*, 4, 100028. doi:10.1016/j.srs.2021.100028.

NASA, 2024. *Shuttle radar topography mission*. Earth Data. Available from: https://cmr.earthdata.nasa.gov/search/concepts/C1000000240-LPDAAC_ECS.html.

Neale, R.E., *et al.*, 2023. The effects of exposure to solar radiation on human health. *Photochemical & Photobiological Sciences*, 1–37. doi:10.1007/s43630-023-00375-8.

Nieuwenhuijsen, M.J., *et al.*, 2017. Fifty shades of green: pathway to healthy urban living. *Epidemiology*, 28 (1), 63–71. doi:10.1097/ede.0000000000000549.

Ortiz-Prado, E., *et al.*, 2021. Stroke-related mortality at different altitudes: a 17-year nationwide population-based analysis from Ecuador. *Frontiers in Physiology*, 12, 733928. doi:10.3389/fphys.2021.733928.

Park, R.J., *et al.*, 2020. Heat and Learning. *American Economic Journal: Economic Policy, American Economic Association*, 12 (2), 306–339. doi:10.1257/pol.20180612.

Park, R.J., Behrer, A.P., and Goodman, J., 2021. Learning is inhibited by heat exposure, both internationally and within the United States. *Nature Human Behaviour*, 5 (1), 19–27. doi:10.1038/s41562-020-00959-9.

Park, S., Tuller, S.E., and Jo, M., 2014. Application of Universal Thermal Climate Index (UTCI) for microclimatic analysis in urban thermal environments. *Landscape and Urban Planning*, 125, 146–155. doi:10.1016/j.landurbplan.2014.02.014.

Pascal, M., *et al.*, 2021. Greening is a promising but likely insufficient adaptation strategy to limit the health impacts of extreme heat. *Environment International*, 151, 106441. doi:10.1016/j.envint.2021.106441.

Petkov, B.H., 2024. Variations in solar irradiance entering the Earth's atmosphere caused by the planet orbital features. *Theoretical and Applied Climatology*, 155 (1), 701–713. doi:10.1007/s00704-023-04658-z.

R Core Team, 2023. *R: A language and environment for statistical computing*. Vienna, Austria: r Foundation for Statistical Computing. Available from: https://www.r-project.org/.

Torres, I., *et al.*, 2022. Policy brief for Ecuador. *The Lancet Countdown on Health and Climate Change*. Available from: https://lancetcountdown.org/wp-content/uploads/2025/02/2022-Ecuador-Lancet-Countdown-policy-brief_EN.pdf. [Accessed 5 Feb 2025].

Vijayakumar, S., *et al.*, 2024. Google Earth engine: empowering developing countries with large-scale geospatial data analysis—a comprehensive review. *Arabian Journal of Geosciences*, 17 (4), 139. doi:10.1007/s12517-024-11948-x.

Wan, Z., Hook, S., and Hulley, G., 2021. *Modis/terra land surface temperature/emissivity 8-day L3*. Global 1km SIN Grid V061. NASA EOSDIS Land Processes Distributed Active Archive Center. Available from: https://doi.org/10.5067/MODIS/MOD11A2.061. [Accessed 8 June 2024].

Wang, D., 2017. *Modis/terra+aqua Surface Radiation Daily/3-Hour L3 Global 5km SIN Grid V006*. [Data set]. NASA EOSDIS Land Processes Distributed Active Archive Center. Available from: https://doi.org/10.5067/MODIS/MCD18A1.006. [Accessed 8 June 2024].

WHO-UNESCO, 2021. *Making every school a health-promoting school: global standards and indicators.*

World Health Organization-United Nations Educational, Scientific and Cultural Organization. Available from: https://unesdoc.unesco.org/ark:/48223/pf0000377948.

WMO, 2024. *State of the climate in Latin America and the Caribbean 2023*. World Meteorological Association. Available from: https://library.wmo.int/records/item/68891-state-of-the-climate-in-latin-america-and-the-caribbean-2023.

Zangerl, K.E., *et al*., 2024. Child health prioritisation in national adaptation policies on climate change: a policy document analysis across 160 countries. *The Lancet Child & Adolescent Health*. doi:10.1016/S2352-4642(24)00084-1.