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Solar Energy Assessment in Rural Areas of the Colombian Caribbean Using Sunshine-Based Empirical Models for Water Treatment Applications

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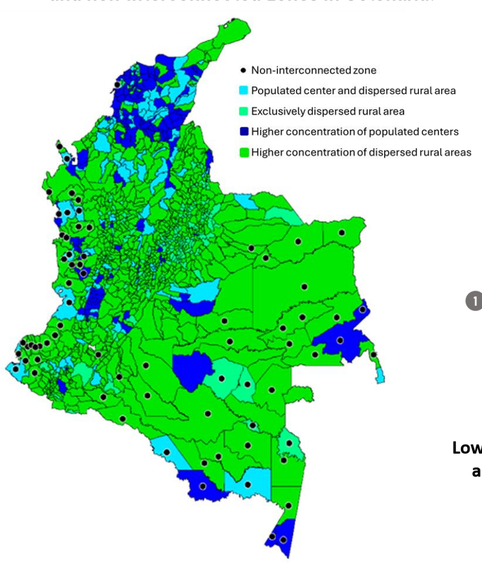
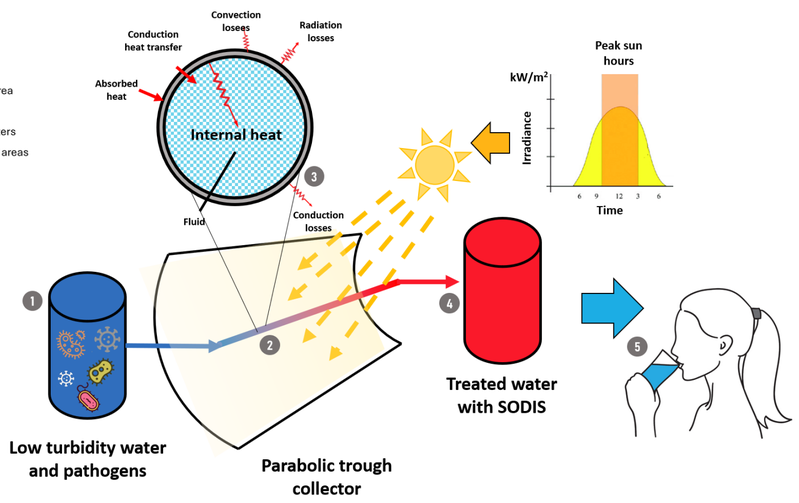
INTRODUCTION & AIM

Solar radiation is a key resource for the development of renewable energy and solar-based water treatment technologies. However, direct irradiance measurements remain scarce in rural and non-interconnected regions of developing countries, limiting the technical assessment of decentralized solar applications. In the Colombian Caribbean region, empirical radiation models provide a practical alternative for estimating solar energy availability and evaluating the feasibility of solar water disinfection systems under data-scarce conditions. This study aimed to estimate the solar energy potential in non-interconnected zones of the Colombian Caribbean region using empirical sunshine-based radiation models and evaluate its applicability for solar water disinfection applications.

Distribution of rural areas, populated centers, and non-interconnected zones in Colombia.





METHOD

Monthly average sunshine duration and meteorological data from IDEAM stations were used to estimate global solar radiation in non-interconnected zones of the Colombian Caribbean region. Five empirical sunshine-based models (Angstrom–Prescott, Page, Bahel, Glover & McCulloch, and Dogniaux & Lemoine) were applied together with standard astronomical calculations for extraterrestrial radiation and day length. Estimated irradiance values were subsequently analyzed to assess their suitability for solar water disinfection through a wavelength-equivalent microbial inactivation approach considering solar irradiance and thermal effects.

Model	Equation
Angstrom – Prescott	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$ (1)
Glover y McCulloch	$\frac{H}{H_0} = a\cos\varphi + b\left(\frac{S}{S_0}\right)$ (2)
Dogniaux y Lemoine	$\frac{H}{H_0} = 0{,}37022 + \left[0{,}00506\left(\frac{S}{S_0}\right) - 0{,}00313\right]\varphi + 0{,}32029\left(\frac{S}{S_0}\right)$ (3)
Page	$\frac{H}{H_0} = 0{,}23 + 0{,}48\left(\frac{S}{S_0}\right)$ (4)
Bahel	$\frac{H}{H_0} = 0{,}16 + 0{,}87\left(\frac{S}{S_0}\right) - 0{,}61\left(\frac{S}{S_0}\right)^2 + 0{,}34\left(\frac{S}{S_0}\right)^3$ (5)

RESULTS & DISCUSSION

The estimated annual solar energy potential in rural areas of the Colombian Caribbean ranged from approximately 4.8 to 6.2 kW m^{-2} across 92 municipalities located in the departments of Atlántico, Bolívar, Cesar, Magdalena, Córdoba, Sucre, and La Guajira. All empirical sunshine-based models showed similar monthly and annual radiation patterns, indicating relatively stable solar availability throughout the year. Satellite-derived radiation data obtained from the NASA POWER platform showed acceptable agreement with the empirical estimations.

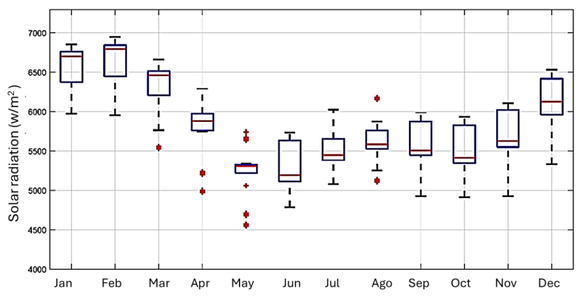


Figure 1. Monthly average estimated global solar radiation values obtained from each empirical model for the evaluated locations.

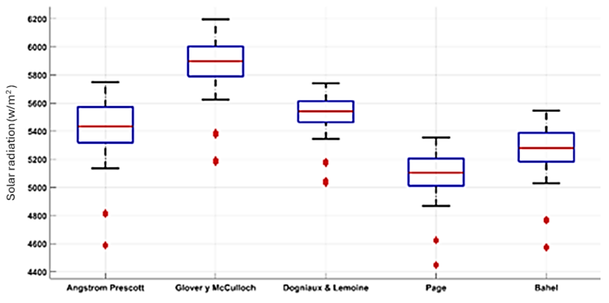


Figure 2. Monthly average estimated global solar radiation values obtained from each empirical model for the evaluated locations.

Pearson correlation. coefficients indicated moderate positive correlations between estimated and reference radiation values (r ≈ 0.46–0.48). The observed monthly variability in solar radiation was relatively low, consistent with tropical climatic conditions in the Caribbean region.

The Page model presented the best statistical performance, with the lowest RMSE (1.075) and MSE (1.155) values among the evaluated formulations.

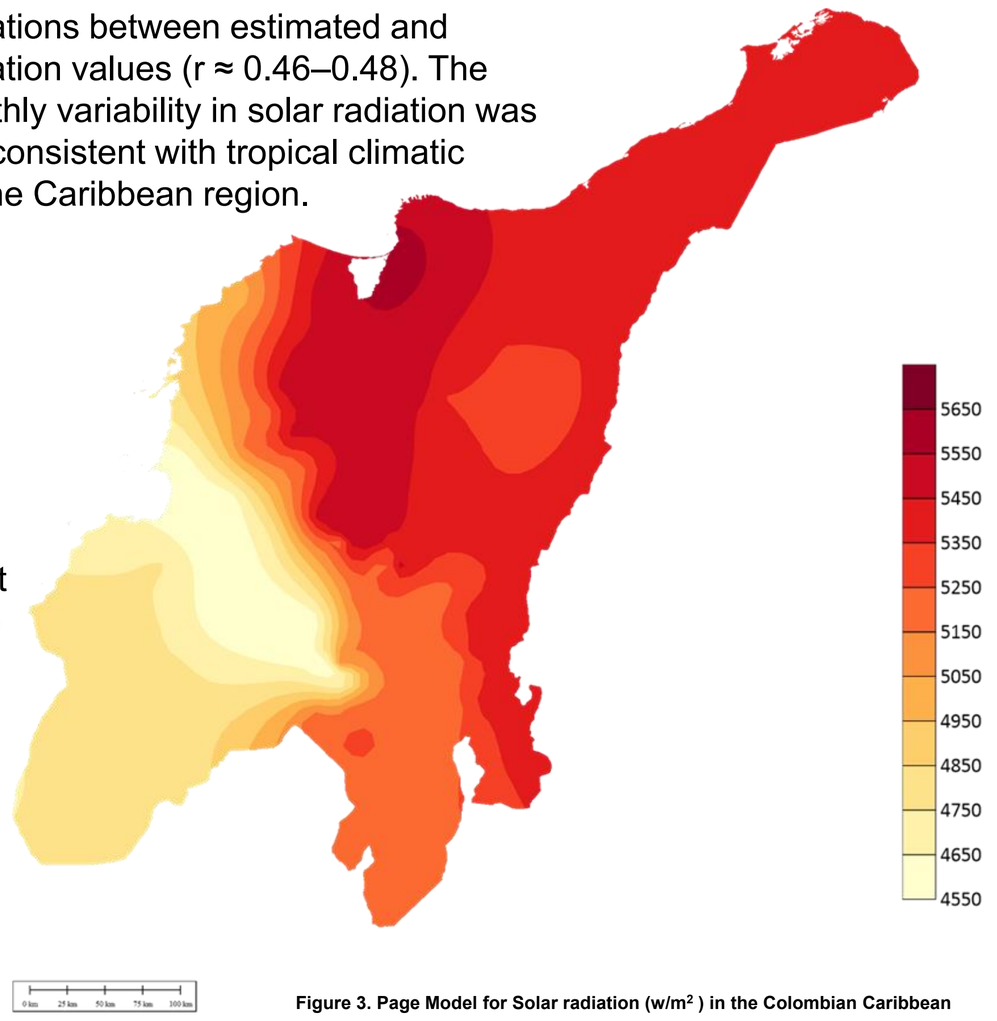


Figure 3. Page Model for Solar radiation (w/m²) in the Colombian Caribbean

Despite relatively low coefficients of determination (R^2 ≈ 0.21–0.23), the low RMSE and MBE values indicate acceptable predictive performance and limited estimation bias. The stable irradiance conditions observed across the Colombian Caribbean support the technical feasibility of solar water disinfection systems under regional environmental conditions. Differences among models were mainly associated with their empirical parameterizations and latitude-dependent corrections.

CONCLUSION

The evaluated empirical sunshine-based models provided a practical approach for estimating solar energy availability in rural and non-interconnected areas of the Colombian Caribbean region. The estimated solar radiation levels demonstrated favorable conditions for the implementation of solar water disinfection technologies, supporting the feasibility of decentralized and sustainable water treatment alternatives in data-scarce rural environments.

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