Earth Similarity Assessment of Confirmed Exoplanets Using NASA PSCompPars Data

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Code Repository: `https://github.com/chetandhawan08/earth-similarity-index-exoplanets`

Abstract

How can we identify potentially Earth-like planets among the thousands of confirmed exoplanets discovered so far? With the rapid growth of detections, public datasets such as the NASA Exoplanet Archive now allow systematic evaluation of Earth analog candidates. In this study, confirmed exoplanets from the PSCompPars (2026) catalog are analyzed using the Earth Similarity Index (ESI), a quantitative metric based on measurable bulk properties including radius, mass, density, escape velocity, and equilibrium temperature. Sequential constraints on planetary size, mass, orbital stability, and stellar energy within the habitable zone are applied to exclude gas-rich planets and retain likely rocky worlds. The analysis produces a refined ranking of physically plausible Earth-like candidates. Although similarity metrics cannot confirm true habitability, this framework provides a reproducible, data-driven approach for identifying promising Earth analogs for future investigation.

1 Introduction

To analyze thousands of confirmed exoplanets and identify potentially Earth-like candidates using basic physical and astronomical criteria, we use the publicly available dataset from the NASA Exoplanet Archive, PSCompPars 2026 (Composite Planet Parameters).

In this study, classification is performed primarily using the Earth Similarity Index (ESI). The ESI is based on planetary parameters such as mass, radius, density, escape velocity, and surface temperature, with Earth serving as the reference point, as it is currently the only known world that supports life.

Although broader habitability metrics have been proposed to evaluate general conditions for life, their computation requires detailed planet-specific information such as atmospheric composition, substrate properties, internal energy sources, and solvent availability. These parameters are not uniformly available across large exoplanet datasets and often depend on indirect modeling assumptions. Consequently, such indices cannot be consistently applied as automated filters across thousands of planets.

In contrast, ESI relies solely on well-measured bulk physical parameters that are widely available in standardized exoplanet catalogs. This makes it particularly suitable for large-scale statistical screening and reproducible analysis. Therefore, this study adopts an ESI-focused framework to ensure methodological consistency and computational feasibility when analyzing the full PSCompPars dataset.

2 Earth Similarity Index (ESI)

To quantify similarity to Earth, we define the Earth Similarity Index (ESI), which measures how closely an exoplanet resembles Earth based on selected physical parameters.

$$ESI_x = \left(1 - \left|\frac{x - x_0}{x + x_0}\right|\right)^w \tag{1}$$

The global index is computed using the geometric mean:

$$ESI = \left(\prod_{i=1}^{n} ESI_i\right)^{1/n} \quad (2)$$

Interior similarity:

$$ESI_I = (ESI_r \cdot ESI_\rho)^{1/2} \quad (3)$$

Surface similarity:

$$ESI_S = (ESI_{ve} \cdot ESI_T)^{1/2} \quad (4)$$

Global ESI:

$$ESI = (ESI_I \cdot ESI_S)^{1/2} \quad (5)$$

3 Discussion

The filtering criteria applied in this study are designed to isolate planets that are most comparable to Earth in terms of bulk physical properties and orbital environment, while remaining consistent with the limitations of large exoplanet datasets.

The radius and mass constraints are motivated by the observed "radius valley" in exoplanet populations, which separates rocky terrestrial planets from gas-rich sub-Neptunes. By restricting the radius range to 0.8–1.2 Earth radii and applying corresponding mass limits, the analysis reduces contamination from volatile-dominated planets and retains candidates most likely to possess solid surfaces.

The stellar flux constraint ensures that selected planets receive energy levels comparable to Earth's, which is necessary for maintaining moderate equilibrium temperatures under simplified assumptions. This step provides a consistent method for identifying planets located within conservative habitable zone limits using only observable parameters.

The orbital eccentricity criterion serves to exclude planets experiencing extreme variations in stellar energy input over their orbital cycles. By limiting eccentricity to low values, the analysis focuses on systems where long-term climatic stability is more likely under simplified thermal assumptions.

These methodological constraints collectively provide a reproducible and data-driven framework for large-scale screening of Earth-like exoplanet candidates, while acknowledging that many key habitability factors — including atmospheric composition, geological activity, and magnetic shielding — remain beyond the scope of current large catalog datasets.

4 Methodology

Confirmed exoplanets were obtained from the NASA Exoplanet Archive (PSCompPars 2026). Only planets with complete measurements of radius, mass, orbital distance, eccentricity, equilibrium temperature, and stellar insolation were retained.

4.1 Derived Physical Quantities

$$\rho = \frac{M}{R^3} \quad (6)$$

$$v_{esc} \propto \sqrt{\frac{M}{R}} \quad (7)$$

4.2 Rocky Planet Selection

$$0.8 \le R/R_\oplus \le 1.2 \quad (8)$$

$$0.5 \le M/M_\oplus \le 2.0 \quad (9)$$

4.3 Habitable Zone Constraint

$$0.75 \le S/S_\oplus \le 1.5 \quad (10)$$

4.4 Orbital Stability

$$e \le 0.2 \quad (11)$$

5 Results

The sequential filtering process significantly reduced the initial dataset. After applying completeness criteria, rocky planet constraints, habitable zone limits, and orbital stability conditions, a refined subset of physically plausible Earth-analog candidates was obtained.

Planets were ranked according to their global Earth Similarity Index (ESI). Higher ESI values indicate closer resemblance to Earth's bulk physical and surface properties.

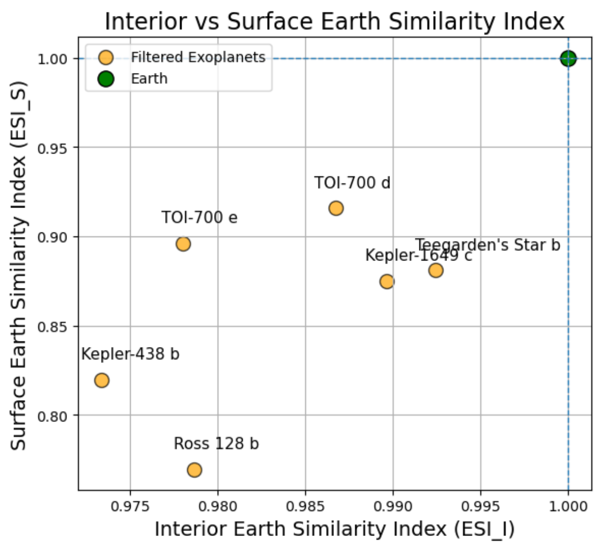

Figure 1: Interior versus Surface Earth Similarity Index (ESI) for rocky habitable-zone candidates. The Earth reference point is shown at (1,1). Planets closer to this location exhibit stronger similarity to Earth-like structural and surface properties.

Table 1 lists the highest-ranked exoplanet candidates based on their global Earth Similarity Index (ESI).

Planet Name	Host Star	ESI
TOI-700 d	TOI-700	0.951
TOI-700 e	TOI-700	0.936
Teegarden's Starb	Teegarden's Star	0.935
Kepler-1649 c	Kepler-1649	0.931
Kepler-438 b	Kepler-438	0.893
Ross 128 b	Ross 128	0.868

Table 1: Top Earth-like exoplanet candidates ranked by global Earth Similarity Index (ESI).

6 Conclusion

Using a structured filtering pipeline and the Earth Similarity Index (ESI), a refined list of physically plausible Earth-analog candidates was identified from the PSCompPars dataset. Because ESI relies exclusively on measurable bulk physical parameters, it provides a consistent and reproducible framework for large-scale statistical screening of exoplanets. Although high ESI values indicate strong resemblance to Earth's physical properties, they do not confirm biological habitability. Moreover, the index does not incorporate critical factors such as atmospheric composition, stellar activity, magnetic protection, or geological processes, which are essential for determining true habitability.

References

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