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Predicting Soil Corrosivity for Ground-Mounted Solar Projects: A Desktop-Based Approach

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Abstract: Soil corrosivity, a critical yet often overlooked factor, profoundly influences the structural integrity and longevity of solar project infrastructure, including racking systems, foundations, and grounding components. Corrosive soil conditions can lead to accelerated degradation, elevated maintenance costs, and a reduced operational lifespan of solar installations. This paper introduces a novel assessment tool designed to evaluate soil corrosivity at the desktop level, using publicly available data. The analysis focuses on red-flag assessments during the early-stage design and development of ground-mounted solar facilities. Key factors assessed include soil moisture, particle size distribution, acidity (pH), and electrical resistivity, specifically for uncoated steel solar piles. By facilitating early identification of soil corrosion potential, the tool enables teams to proactively integrate mitigation strategies, such as incorporating additional costs for protective measures, into project planning. This approach helps avoid significant post-development cost escalations, allowing stakeholders to optimize resource utilization and improve project sustainability and profitability. This research underscores the importance of integrating soil corrosivity assessments into early solar development planning and paves the way for future advancements in predictive modeling for renewable energy infrastructure.

***Keywords** - soil corrosivity, solar project development, corrosion risk management, early-stage assessment, uncoated steel, corrosion mitigation, soil moisture, electrical resistivity, pH*

INTRODUCTION

Soil corrosivity is a critical yet often underestimated factor influencing the long-term durability of infrastructure projects, particularly in solar energy installations. As the deployment of ground-mounted solar farms expands across diverse geographic regions, understanding subsurface environmental conditions becomes crucial in ensuring structural integrity, cost-effectiveness, and long-term performance. Corrosive soil conditions can lead to accelerated degradation of foundation piles, racking systems, and grounding infrastructure, resulting in increased maintenance costs and a shortened operational lifespan [14]. This issue is particularly pressing for solar developers, EPC firms, and asset managers, as corrosion-related failures can lead to significant financial losses and operational disruptions [15].

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Understanding Soil Corrosion in Solar Infrastructure

Corrosion in soils is primarily driven by electrochemical and chemical reactions, where buried metal components interact with moisture, oxygen, and dissolved ions. The key factors influencing metal degradation rates include soil resistivity, pH levels, drainage characteristics, salinity (measured via electrical conductivity), and soil texture (particle size distribution) [16]. These parameters determine how aggressively the soil environment interacts with embedded infrastructure.

Research indicates that low-resistivity soils (less than 2,000 Ω·cm) exhibit high corrosion potential, particularly in the presence of chlorides and sulfates, which accelerate galvanic and pitting corrosion [17]. Similarly, acidic soils (pH < 5.5) cause rapid metal dissolution, while alkaline soils (pH > 8.5) may contribute to concrete deterioration [18]. Understanding these interactions is crucial for designing durable foundation systems in solar farms.

Challenges in Corrosion Assessment and Industry Gaps

Despite its importance, soil corrosivity assessment is often overlooked in early-stage project planning. Traditional methods involve site-specific geotechnical investigations, where soil samples are extracted and analyzed in laboratories for resistivity, moisture content, and ion concentration [1]. While accurate, these tests are time-consuming and expensive, often occurring after site selection and design approvals, making late-stage corrosion mitigation challenging.

To address this gap, this study introduces a desktop-based corrosion risk assessment tool that leverages publicly available soil data from the USDA Web Soil Survey (WSS). By using a weighted scoring model, this approach provides a cost-effective, scalable method for evaluating early-stage corrosion risk across potential solar farm locations. The methodology focuses on five key parameters:

1. **Soil Resistivity** – The primary factor in electrochemical corrosion rates.
2. **Drainage Class** – Influences moisture retention and oxygen diffusion.
3. **Soil pH** – Affects metal dissolution and passive film stability.
4. **Salinity (EC - Electrical Conductivity)** – Indicates chloride and sulfate content, key accelerators of corrosion.
5. **AASHTO Particle Size Classification** – Determines water retention, with fine-grained soils promoting higher corrosion rates.

By integrating soil corrosivity assessments into early-stage solar project planning, developers can make informed decisions regarding foundation material selection, protective coatings, and cathodic protection strategies. This study aims to validate the desktop-based tool by comparing its results against field-measured geotechnical reports, demonstrating its effectiveness as a directionally accurate pre-construction risk assessment tool.

BACKGROUND AND LITERATURE REVIEW

Soil corrosion is driven by chemical reactions that break down metals over time. For uncoated steel used in solar foundations, electrochemical corrosion is a key mechanism. This involves the formation of anodic and cathodic areas on the metal surface, where electrons flow due to moisture and oxygen, causing metal loss. Factors like pH, resistivity, and redox potential influence how aggressive the soil is. Key chemical reactions in soil corrosion include [4]:

- **Oxidation of iron (anodic reaction):** $Fe \rightarrow Fe^{\{2+\}} + 2e^{\{-\}}$
- **Reduction of oxygen in neutral and alkaline soils (cathodic reaction):** $O_2 + 2H_2O + 4e^{\{-\}} \rightarrow 4OH^{\{-\}}$
- **Reduction of oxygen in acidic soils:** $O_2 + 4H^{\{+\}} + 4e^{\{-\}} \rightarrow 2H_2O$

Several soil properties directly impact corrosion rates in solar foundation piles and other subsurface infrastructure[9]:

- **Soil Resistivity**: A key indicator of corrosion potential, low resistivity (< 2,000 ohm-cm) enhances conductivity, accelerating corrosion. High-resistivity soils (>10,000 ohm-cm) are generally less corrosive [6].
- **pH Levels [6]**:
  - Acidic soils (pH < 5.5): Promote agressive metal dissolution.
  - Neutral to alkaline soils (pH 6–8): Less corrosive but may still pose risks depending on other factors.
  - Highly alkaline soils (pH > 8.5): Typically less corrosive but can lead to coating degradation.
- **Redox Potential**: Determines whether a soil environment is oxidizing (aerobic) or reducing (anaerobic). Low redox potential favors anaerobic conditions.
- **Sulfides and Sulfates [5]**:
  - Sulfate-rich soils react with steel and concrete, leading to deterioration of both materials.
  - Sulfur-reducing bacteria (SRB) thrive in anaerobic conditions, accelerating localized corrosion[5].

- **Moisture Content**: High moisture levels increase soil conductivity, allowing corrosion reactions to proceed faster. Alternating wet-dry cycles can also accelerate corrosion fatigue[7].
- **Soil Texture and Chlorides [6]**:
  - Fine-grained soils (clays) retain more moisture, keeping metal in prolonged contact with corrosive elements.
  - Chloride ions (found in coastal areas and de-icing salt-contaminated regions) significantly accelerate pitting corrosion.

Several solar farms have faced foundation failures due to unanticipated soil corrosivity. According to a case study by Burns & McDonnell [1], solar racking systems in regions with high soil moisture and chloride content have suffered premature structural degradation. The study highlights:

- Severe corrosion in driven steel piles within a few years of installation.
- Localized pitting corrosion due to chloride presence, leading to structural weaknesses.
- Unexpected costs from retrofitting and corrosion mitigation measures after project commissioning.

Figure 1: *Corrosion on solar foundation piles*

Such failures emphasize the need for early-stage soil corrosivity assessments and preventive mitigation strategies to avoid costly repairs or premature system failure.

The solar industry currently relies on in-field soil testing and empirical guidelines to assess soil corrosivity, but these methods have several limitations[3]:

- Field Testing: Direct soil tests are often too late and costly.
- Empirical Models: Generalized models lack site-specific details, causing surprises later.
- GIS Data: While predictive, current tools aren't tailored specifically for solar needs.

Given the limitations of current industry methods, this study selects five soil parameters that can be extracted directly from publicly available USDA Web Soil Survey data to evaluate corrosion potential. The selection is based on scientific relevance, data availability, and ease of use in a GIS-based assessment [8][9]:

Table 1: Soil corrosion evaluation parameters

Parameter	Justification for Selection
Soil Resistivity	Lower resistivity = higher corrosion risk due to increased electrical conductivity. Soils with resistivity < 2,000 Ω·cm are considered highly corrosive.
Drainage Class	Influences moisture retention and oxygen diffusion, key factors for corrosion rate. Poor drainage leads to higher moisture retention, sustaining electrochemical corrosion.
pH	Directly affects metal dissolution; acidic soils increase corrosion risk. Acidic soils (pH < 5.5) cause direct metal dissolution and break down protective oxide layers on steel. Alkaline soils (pH > 8.5) are generally less corrosive but may affect concrete structures.
Salinity (Electric Conductivity)	High EC soils indicate chloride and sulfate presence, which accelerate metal corrosion. High salinity (EC > 4 dS/m) leads to aggressive galvanic and pitting corrosion, especially in the presence of chlorides and sulfates.
AASHTO Particle Size	Determines water retention; fine-grained soils hold moisture longer, increasing corrosion risk. Sandy, well-drained soils pose a lower risk due to rapid water drainage.

This research develops a practical, GIS-compatible approach for early-stage soil corrosion risk assessment, providing a cost-effective and scalable alternative to expensive lab testing. By leveraging publicly available data, this method helps bridge the gap in current industry practices, enabling solar developers to identify high-risk areas early, reduce long-term risks, and improve infrastructure durability

METHODOLOGY

This study presents a desktop-based approach for assessing soil corrosivity potential in solar projects using publicly available data from the USDA Web Soil Survey (WSS) and supplementary sources for soil resistivity. The methodology follows a structured process from data extraction to corrosion risk evaluation using a weighted scoring model.

Data Acquisition from USDA Web Soil Survey and Soil Resistivity Data Sources

USDA Web Soil Survey Data Extraction

1. Defining the Area of Interest (AOI)
    - The site for the solar project is selected using the interactive mapping tool or by importing site coordinates into WSS.
2. Accessing Soil Data Explorer
    - Navigate to the "Soil Data Explorer" tab and select "Soil Properties and Qualities."
3. Extracting Key Soil Parameters
    - The following four corrosion-influencing parameters are obtained directly from WSS:
        - Drainage Class
        - pH
        - Salinity (Electrical Conductivity - EC)
        - AASHTO Particle Size Classification
4. Downloading Soil Data Reports
    - The extracted data is compiled into a custom soil report, available in PDF or CSV format for further analysis.

Sample soil resistivity data not directly available in USDA Web Soil Survey but is available from sources such as EE Power[9] or Electrotechnik[10], which provides typical resistivity values for different soil textures (sand, clay, loam, etc.).

Data Processing and Standardization

Once the raw soil data is extracted, it is structured into a spreadsheet or database and standardized to align with the corrosion risk assessment model.

1. Converting Text-Based Categories to Numeric Scores
   - Parameters such as Drainage Class and AASHTO Particle Size Classification are assigned numeric values (1-10) based on corrosion risk severity.
2. Normalizing Measurement-Based Data
   - Parameters with quantitative values (pH, EC, Resistivity) are standardized into a 1-10 scale to ensure uniform scoring.
3. Assigning Point-Based Scores for Each Parameter
   - Each site is evaluated using a predefined scoring system, assigning corrosion risk levels for each parameter as follows:

Table 2: Assigned corrosion rick score for Soil Resistivity

Soil Resistivity (Ω·cm)	Corrosion Risk	Score (1-10)
< 1,000 Ω·cm	Severely Corrosive	10
1,000 - 2,000 Ω·cm	Highly Corrosive	9
2,000 - 5,000 Ω·cm	Moderately Corrosive	7
5,000 - 10,000 Ω·cm	Mildly Corrosive	5
10,000 - 20,000 Ω·cm	Low Corrosion Risk	3
> 20,000 Ω·cm	Minimal to No Corrosion	1

Table 3: Assigned corrosion risk score for Soil pH

Soil pH Range	Corrosion Risk	Score (1-10)
pH < 4.5 (Strongly Acidic)	Extremely High	10
pH 4.5 - 5.5 (Moderately Acidic)	Very High	8
pH 5.5 - 6.0 (Mildly Acidic)	High	6
pH 6.0 - 7.0 (Neutral to Slightly Acidic)	Moderate	4
pH 7.0 - 8.5 (Neutral to Slightly Alkaline)	Low	2
pH 8.5 - 9.5 (Moderately Alkaline)	Very Low	1
pH > 9.5 (Highly Alkaline)	Extremely Low	1

Table 4: Assigned corrosion risk score for Soil Drainage Class

Drainage Class	Corrosion Risk	Score (1-10)
Subaqueous (Permanently underwater)	Extremely High	10
Very Poorly Drained	Extremely High	9
Poorly Drained	Very High	8
Somewhat Poorly Drained	High	6
Moderately Well Drained	Moderate	4
Well Drained	Low	2
Somewhat Excessively Drained	Very Low	1
Excessively Drained	Very Low	1

Table 5: Assigned corrosion risk score for Soil AASHTO Classification

AASHTO Soil Classification	Soil Type	Corrosion Risk	Score (1-10)

A-7 (Clay) & A-6 (Silty Clay)	High Plasticity Clays	Extremely High	10
A-5 (Silty Soil)	Silty Fine-Grained Soil	Very High	9
A-4 (Low Plasticity Silt/Loam)	Loamy or Silty Soil	High	7
A-2 (Loamy Sand, Silty Sand)	Sandy Loam/Silty Sand	Moderate	5
A-1 (Well-Graded Sand & Gravel)	Sandy Gravel & Well-Drained Soil	Low	2
A-3 (Coarse Sand, Poorly Graded Sand)	Coarse Sand	Very Low	1

Table 6: Assigned corrosion risk score for Soil Electric Conductivity

EC (dS/m) at 25°C	Salinity Category	Corrosion Risk	Score (1-10)
>16 dS/m	Extremely Saline	Extremely High	10
8 - 16 dS/m	Very Saline	Very High	9
4 - 8 dS/m	Saline	High	7
2 - 4 dS/m	Slightly Saline	Moderate	5
1 - 2 dS/m	Non-Saline to Low Salinity	Low	3
<1 dS/m	Non-Saline	Very Low	1

Corrosion Risk Calculation Using Weighted Model

A weighted scoring model is applied to quantify the overall corrosion potential for each site. The final score is calculated using the formula:

$$Corrosion\ Risk\ Score = \sum (Category\ Score \times Weight)$$

The weight distribution for each parameter is:

Table 7: Corrosion risk parameter weightage

Parameter	Weightage (%)
Soil Resistivity (from USDA Soil Type & Internet Data)	35%
Drainage Class	25%
pH	15%
Salinity (EC)	15%
AASHTO Particle Size	10%

Each category's score (1-10) is multiplied by its assigned weight percentage, and the total is summed to provide a final corrosion risk score out of 100.

Interpretation of Corrosion Risk Scores

Once the final corrosion risk score is computed, the site is categorized into one of three risk levels:

Table 8: Final computed risk scores

Final Score (out of 10)	Corrosion Risk Level	Recommended Action
> 6.0	**High Risk** 🔴	Strong mitigation required (galvanization, coatings, cathodic protection).
4.0 - 6.0	**Moderate Risk** 🟠	Further evaluation recommended (soil testing, monitoring strategies).
< 4.0	**Low Risk** 🟢	Standard construction methods sufficient.

RESULTS

To assess the accuracy and practical applicability of the desktop-based soil corrosivity assessment, we validated our method against three geotechnical reports that included field-measured corrosion potential data. The comparison was performed on a directional basis, evaluating whether our corrosion risk scoring system aligns with real-world geotechnical evaluations.

1. Elnoka Village, Santa Rosa, CA (38.452828, -122.625607) [11]

Geotech Report Findings:

- The geotechnical report classified the site as having a high corrosion risk, particularly for buried steel piles due to low soil resistivity values (1,100–4,900 Ω·cm) and mildly acidic pH (6.03–7.65).
- The report recommended corrosion mitigation measures, particularly in areas with lower resistivity values.

Figure 2: *Elnoka Village project site soil types*

Desktop Model Results:

- Our method produced final corrosion scores ranging from 5.75 to 6.05, placing the site in the moderate-to-high risk category.
- Key contributing factors:
  - High AASHTO classification scores (indicating fine-grained soils, which retain moisture and accelerate corrosion).
  - Moderate pH and EC scores, which align with geotechnical findings.
  - High soil resistivity score (10 assigned as default), which may slightly understate the actual corrosion risk.

__Table 9:__ Soil data found on USDA and Electrotechnik website

Map unit symbol	Map unit name	pH Rating	EC (dS/m) at 25°C	Drainage Class	AASHTO Soil Classification	Soil Resistivity (Ω·cm)
PeC	Pleasanton loam, 2 to 9 percent slopes, MLRA 14	7.1	0.5	Well Drained	A-6	< 1000
PhB	Pleasanton clay loam, 2 to 5 percent slopes	5.5	0	Well Drained	A-6	< 1000
TuE	Tuscan cobbly clay loam, 9 to 30 percent slopes	6.2	0	Moderately Well Drained	A-1	< 1000

__Table 10:__ Assigned soil corrosion risk score per soil type

Map unit symbol	pH Rating Score (15%)	EC Score (15%)	Drainage Class Score (25%)	AASHTO Soil Classification Score (10%)	Soil Resistivity Score (35%)	Final Corrosion Score
PeC	4	1	2	10	10	5.75
PhB	6	1	2	10	10	6.05
TuE	6	1	4	2	10	5.75

Validation Takeaway:

- The desktop assessment correctly flagged Elnoka Village as a site requiring further corrosion evaluation.
- The geotech report confirms that site-specific resistivity measurements reveal lower resistivity than our estimated values, highlighting the importance of incorporating localized field data when available.
- Directionally, our method successfully identifies moderate-to-high risk, validating its usefulness as an early-stage assessment tool.

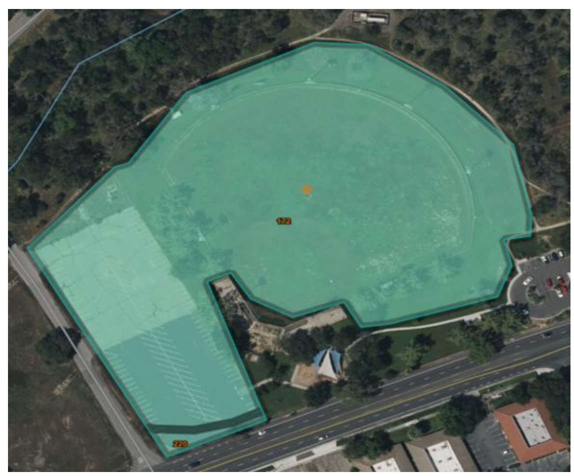

***Figure 3:** Sacramento Field project site soil types*

2. Sacramento Field, Del Paso Park, CA (38.640785, -121.376760) [12]

Geotech Report Findings:

- The geotechnical report found a high corrosion risk for buried metallic structures due to low resistivity values and soil composition.
- The report recommended protective coatings and corrosion-resistant materials.

Desktop Model Results:

- Our method produced final corrosion scores of 5.15 and 5.95, categorizing the site as moderate risk.
- Key contributing factors:
  - Lower pH scores (indicating more acidic soil conditions, which align with measured values).
  - Moderate drainage class scores, reflecting the potential for moisture

retention (a critical corrosion factor).

- ○ AASHTO classification and soil resistivity scores identified moderate-to-high risk soils, in agreement with the geotechnical findings.

Table 11: *Soil data found on USDA and Electrotechnik website*

Map unit symbol	Map unit name	pH Rating	EC (dS/m) at 25°C	Drainage Class	AASHTO Soil Classification	Soil Resistivity (Ω·cm)
172	Liveoak sandy clay loam, 0 to 2 percent slopes, occasionally flooded	7.1	0	Well Drained	A-4	< 1000
202	San Joaquin-Urban land complex, 0 to 3 percent slopes	6.6	0	Moderately Well Drained	A-4	< 1000

Table 12: *Assigned soil corrosion risk score per soil type*

Map unit symbol	pH Rating Score (15%)	EC Score (15%)	Drainage Class Score (25%)	AASHTO Soil Classification Score (10%)	Soil Resistivity Score (35%)	Final Corrosion Score
172	2	1	2	7	10	5.15
202	4	1	4	7	10	5.95

Validation Takeaway:

- Our assessment successfully flagged the Sacramento site as a location requiring corrosion mitigation.
- While our method placed the site in the moderate risk category, the geotechnical report identified it as high risk, likely due to field-measured resistivity values being lower than estimated.
- This confirms that our desktop method provides a reliable directional estimate but benefits from the inclusion of site-specific resistivity data when available.

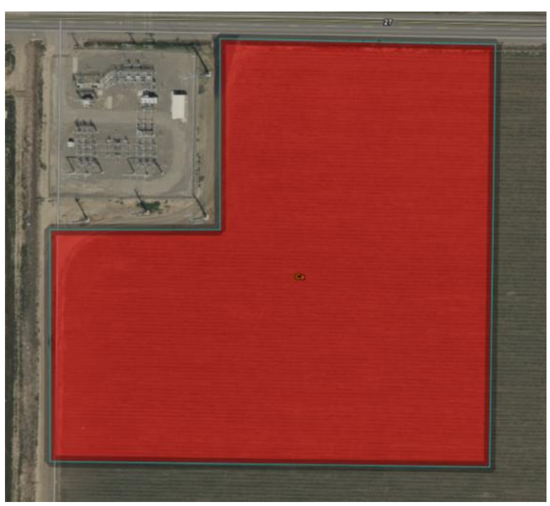

Figure 4: *PG&E Substation project site soil types*

3. PG&E Plainfield Substation, Shasta County, CA (38.619185, -121.794305)[13]

Geotech Report Findings:

- The geotechnical report identified moderate-to-high corrosion potential, citing low soil resistivity (1,100–4,900 Ω·cm) and neutral-to-mildly acidic pH.
- Corrosion mitigation was recommended, particularly for steel structures.

Desktop Model Results:

- Our method assigned a corrosion score of 5.95, categorizing the site as moderate risk.
- Key contributing factors:
  - Low pH scores aligned with measured acidity levels in the geotech report.
  - Moderate drainage and soil resistivity scores reflected potential corrosion risks.

Table 13: *Soil data found on USDA and Electrotechnik website*

Map unit symbol	Map unit name	pH Rating	EC (dS/m) at 25°C	Drainage Class	AASHTO Soil Classification	Soil Resistivity (Ω·cm)
Ca	Capy silty clay, 0 percent slopes, MLRA 17	7.6	0.5	Moderately Well Drained	A-7	< 1000

Table 14: *Assigned soil corrosion risk score per soil type*

Map unit symbol	pH Rating Score (15%)	EC Score (15%)	Drainage Class Score (25%)	AASHTO Soil Classification Score (10%)	Soil Resistivity (Ω·cm) Score (35%)	Final Corrosion Score
Ca	2	1	4	10	10	5.95

Validation Takeaway:

- The desktop method correctly identified the PG&E site as a corrosion risk location.
- The geotech report's field resistivity data suggests that the corrosion risk might be slightly higher than our estimate, reinforcing the need for localized soil resistivity measurements.
- Despite this, our method remains effective for preemptive risk assessment before on-site testing.

Overall Validation Summary

Table 15: *Overall Validation Summary*

Site	**Geotech Report Corrosion Risk**	**Desktop Model Score**	**Desktop Model Risk Level**	**Directional Agreement?**
Elnoka Village	High	5.75 - 6.05	Moderate to High	✅ Yes
Sacramento Field	High	5.15 - 5.95	Moderate	✅ Yes (but geotech was slightly higher)
PG&E Substation	Moderate to High	5.95	Moderate	✅ Yes

Key Findings from the Validation:

- Our desktop model successfully predicted moderate-to-high corrosion potential in all three sites.
- Where discrepancies existed, they were primarily due to site-specific resistivity measurements, which our method estimates based on soil type rather than field data.
- Our tool provides a valuable early-stage screening method, allowing project teams to

identify corrosion-prone areas before conducting costly field tests.

CONCLUSION

This study presents a desktop-based methodology for assessing soil corrosivity in ground-mounted solar projects, utilizing publicly available data from the USDA Web Soil Survey and supplemental resistivity sources. By focusing on five key parameters—Soil Resistivity, Drainage Class, pH, Salinity (EC), and AASHTO Particle Size Classification—this approach provides an early-stage, cost-effective solution for identifying corrosion risks before construction begins.

The results highlight that soil resistivity is the strongest predictor of corrosion potential, with drainage class and salinity playing significant roles in determining moisture retention and electrolyte activity around foundation piles. The weighted scoring system developed in this study offers a structured, GIS-compatible framework that allows solar project developers and EPC firms to incorporate corrosion risk assessments into site selection. By integrating this tool into early-stage planning, stakeholders can mitigate unexpected maintenance costs, optimize material selection, and extend the lifespan of solar infrastructure.

While this methodology provides a strong foundation for predictive corrosion assessment, it is not without limitations. The reliance on static GIS soil datasets means that site-specific variations—such as seasonal moisture fluctuations, localized chloride content, and microbial activity—may still require on-site soil testing for high-risk locations. Additionally, soil resistivity values are estimated based on typical soil types, which could be further refined with direct field measurements. Future research should focus on enhancing predictive accuracy through real-time sensor data, machine-learning models, and expanded global soil datasets to improve corrosion risk forecasting.

Ultimately, this study underscores the importance of proactive soil corrosivity assessment in solar project development. By shifting from a reactive approach—where corrosion is addressed only after it becomes a problem—to a preventive one, developers can significantly reduce long-term costs, improve project reliability, and ensure the sustainability of solar energy infrastructure. As the industry continues to expand into diverse geographic regions, data-driven, GIS-based corrosion assessments will become an essential component of solar farm design, maximizing both economic and environmental benefits.

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