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Review Article

Assessing the Influence of Forest Fires on the Well-Being of Watersheds through SAR Technology

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ABSTRACT

Watersheds are interconnected systems in charge of gathering, storing, and transferring water. Forests constitute a key part of these systems. A healthy forest functions like a natural sponge, soaking up rain and snowmelt and then slowly releasing it to control the flow and prevent floods. Additionally, by filtering pollutants and sediments before they enter streams and rivers, trees contribute to the maintenance of water quality. Thus, there is a close relationship between the health of watersheds and the sustainability of forest ecosystems. Understanding forest fires' effects on watershed health is important since they continue to pose a serious danger to our ecosystems and water supplies. Synthetic Aperture Radar (SAR) technology provides a thorough and effective way to examine the damage left behind by these fires, supplying vital information to direct efficient conservation and restoration activities. We can improve our comprehension of forest fire dynamics and their effects on watersheds by additional study and implementation of SAR technology, ultimately resulting in more sustainable management practices and the preservation of our precious water supplies for future generations. This chapter will be focusing on the effects of forest fires on the health of the watershed ecosystem and methods that could be used to mitigate the same.

Keywords: Watersheds; Forest; Ecosystems; Dynamics; Sustainability

INTRODUCTION

Watershed

A watershed is a region of land where all streams and rainfall run to a single place, such as the bay's mouth, a reservoir's outflow, or any location along a stream's course. Sometimes, the terms "watershed" and "catchment" are used synonymously. Drainage divides are ridges and hills that divide two watersheds. The watershed is made up of all the subsurface groundwater as well as surface water, such as lakes, streams, reservoirs, and wetlands. Many micro watersheds can be found within larger watersheds. Everything is dependent on the outflow point the watershed for that outflow site includes all the land that drains water to the outflow point. Watersheds are important because events occurring in the land region "above" the river's outflow point have an impact on a river's streamflow and water quality, whether or not they are caused by human activity.

The amount of rainfall that falls in the watershed as rain or snow is by far the biggest factor affecting streamflow. However, not all of the precipitation that accumulates in a watershed evaporates, and a stream will frequently keep running even in areas where there hasn't been any recent runoff.

Some of the water from rain that falls on bare ground soaks into or penetrates the soil. A portion of the water that infiltrates will stay in the thin soil layer, where it will slowly percolate through the soil and eventually soak into the stream bank. Some of the water may seep far deeper an replenish aquifers of groundwater. Before rising to the surface, water may travel a great distance or stay in storage for a very long time.

The amount of water that will gradually seep in is influenced by a number of the watershed's features, including:

Soil properties: Northern clayey and rocky soils absorb water more slowly than sandy soils, but less quickly overall. Less water absorbed by the soils causes more runoff into streams over land.

Soil saturation: Much like a wet sponge, soil that has already absorbed previous rainfall is unable to absorb much more, resulting in surface runoff from additional precipitation.

Land cover: Some land covers significantly affect infiltration and runoff from rainfall. Rainfall travels in a "fast lane" through

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impervious surfaces like parking lots, streets, and housing developments immediately into storm drains that empty into streams. The likelihood of flooding rises as the area covered by impervious surfaces does.

Ground slope: Water that falls on steeply sloping ground drains more quickly than water that falls on flat land.

Evaporation accounts for the vast majority of rainfall water returning to the atmosphere. Temperature, solar radiation, wind, atmospheric pressure, and other variables all affect how much water evaporates.

Different amounts of water are absorbed by plant roots from the surrounding soil. The majority of this water permeates the plant and evaporates through the leaves, entering the atmosphere. The qualities and density of the plant, as well as the same variables that affect evaporation, govern transpiration. Runoff is slowed by vegetation, which also allows water to sink into the earth. Water is stored in reservoirs, which also increase the quantity of evaporation and infiltration. The patterns of streamflow in the river below the dam can be significantly impacted by the storage and release of water in reservoirs.

Watersheds are diverse ecosystems that support a wide range of plant and animal species. The health and integrity of a watershed are vital for maintaining biodiversity. Pollution or environmental degradation within a watershed can have adverse effects on the flora and fauna that rely on its resources.

Effect of forest fires on the health of watershed

Severe forest fires expose soils to short-term sediment, nitrogen, metal, and organic matter losses due to combustion, loss of forest vegetation, and organic soil cover. This has a profound impact on the biochemical processes that regulate water quality.

Large amounts of ambiguity surround the post-fire effects on surface water composition and drinking water treatment due to the extremely varied behavior of forest fires and spatially complex patterns in vegetation, topography, hydrology, and other elements.

Extreme post-fire erosion can cause infrastructure damage, build up in reservoirs, and provide difficulties for solids handling, coagulation, and filtering. Metal content increases during fires have been seen and may increase toxicity.

An increasing body of research shows that high severity fires can have long-lasting effects on water quality because of the slow vegetation regrowth and higher levels of nitrogen and DOC (Dissolved Organic Carbon) that have persisted for fifteen years.

The management of forest resources for a more effective response by local authorities depends on the forest fire risk map. The creation of a database on forest dangers appears to be of high priority for this reason.

SWAT: Soil and Water Assessment Tool

To identify physically-based model components necessary to run a SWAT model to predict the impact of management on water and sediment in a watershed.

The Soil and Water Assessment Tool (SWAT) is a comprehensive modelling tool developed to assess the impact of land management practices and land use changes on water resources, soil erosion, and water quality in watersheds or river basins. It was developed by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) and is widely used by researchers, environmental agencies, and land managers to support watershed management and decision-making. Key features and components of SWAT include:

Hydrological modelling: SWAT is primarily a hydrological model that simulates the movement of water through a watershed. It accounts for processes such as precipitation, runoff, evapotranspiration, infiltration, and groundwater flow.

Land use and land management: The tool incorporates information about land use, land cover, and various land management practices such as crop rotation, tillage, and conservation measures. These data are essential for simulating the impact of agricultural and land use changes on water resources.

Soil properties: SWAT considers soil properties, including soil type, texture, and hydrological characteristics, which influence the movement of water and nutrients within the watershed.

Weather data: Historical weather data, including rainfall, temperature, and solar radiation, are used to drive the hydrological and crop growth simulations within SWAT.

Sub-basin approach: Watersheds are divided into smaller sub-basins or Hydrologic Response Units (HRUs) based on geographical and land use characteristics. SWAT models each HRU individually, allowing for a more detailed assessment of spatial variability.

Water quality modelling: In addition to its hydrological components, SWAT also simulates the transport of sediment, nutrients (e.g., nitrogen and phosphorus), and other pollutants. This enables the assessment of water quality and the impact of land management practices on pollutant loading in rivers and streams.

Scenario analysis: SWAT allows for scenario testing, which is useful for evaluating the potential outcomes of different land use or management strategies, such as the implementation of Best Management Practices (BMPs) or changes in land cover.

Calibration and validation: To ensure the model's accuracy, SWAT typically requires calibration and validation using observed data from the study area. This fine-tunes the model's parameters to match real-world conditions.

Geographic Information System (GIS) integration: SWAT often integrates with GIS software, making it easier to set up and visualize model inputs and outputs on a spatial scale.

SWAT has been applied in various environmental studies, including watershed management, water resource planning, conservation planning, and assessments of the impacts of climate change and land use change on water quality and quantity. Its flexibility and ability to simulate a wide range of environmental processes make it a valuable tool for sustainable land and water resource management.

SWAT can be used to assess the effects of forest fires on watersheds and their impact on water resources and water quality. While SWAT is primarily developed for agricultural and land use applications, it can be adapted to study the consequences of forest fires. Here's how SWAT can be applied in this context.

Land use changes: Forest fires lead to significant changes in land cover and land use. SWAT can be modified to account for these changes by updating land use and land cover data in the model. This includes replacing forested areas with burnt or regrowing vegetation types. Changes in land use will affect the hydrology and nutrient dynamics within the watershed.

Hydrological impact: Forest fires can increase the likelihood of surface runoff and erosion due to the loss of the protective canopy and forest floor vegetation. SWAT can be configured to simulate the increased runoff and erosion caused by the fire, taking into account the modified land cover, slope, and soil conditions. This allows for the assessment of changes in streamflow and sediment yield in the post-fire period.

Water quality effects: Forest fires can also have significant effects on water quality. Ash and debris from the fire can be carried into water bodies, potentially leading to increased sedimentation and changes in nutrient and pollutant loads. SWAT can simulate these changes in water quality parameters by adjusting sediment and nutrient inputs based on the fire's impact.

Model calibration and validation: To use SWAT effectively in the context of forest fires, it's important to calibrate and validate the model against observed data in post-fire conditions. This includes monitoring data on streamflow, sediment, and water quality parameters. Calibration helps ensure that the model accurately represents the post-fire conditions in the watershed [1].

Scenario analysis: SWAT allows for scenario testing, which can be useful for assessing different management strategies to mitigate the effects of forest fires. For instance, it can simulate the impacts of post-fire reforestation or the implementation of erosion control measures (e.g., check dams or vegetative cover) on water resources and water quality.

Climate change considerations: In some cases, forest fires may be influenced by climate change factors, such as prolonged droughts or changing precipitation patterns. SWAT can incorporate climate change scenarios to assess the combined impacts of climate change and forest fires on watershed conditions.

SAR application in forest fires and watershed

Synthetic Aperture Radar (SAR) is a powerful remote sensing technology that has various applications in environmental monitoring, including the assessment of watershed health. Watersheds are essential components of the hydrological cycle, and their health is critical for the sustainable management of water resources and the protection of ecosystems. SAR applications in watershed health monitoring involve the use of radar data to assess and manage various aspects of these vital areas. Here's how SAR is applied in watershed health monitoring.

Flood monitoring: SAR can provide near-real-time monitoring of flood events within a watershed. By capturing radar data before and after heavy rainfall or snowmelt, SAR can help track the extent and severity of flooding. This information is invaluable for disaster management and early warning systems to mitigate flood-related damages.

Land cover and land use classification: SAR can be used to classify different land cover and land use types in a watershed. This information is important for understanding the impact of human activities on the watershed, such as urban development, deforestation, or agriculture.

Wetland and vegetation mapping: SAR can penetrate through clouds and vegetation, allowing for the monitoring of wetlands, vegetation, and changes in vegetation health. This information is vital for assessing the ecological health of the watershed, as it helps in tracking the condition of important habitats and potential disturbances.

Soil moisture monitoring: SAR can estimate soil moisture content, which is essential for understanding water availability and the overall health of the watershed. Changes in soil moisture can indicate drought conditions, increased risk of erosion, or groundwater recharge rates.

Topographic mapping: SAR can provide high-resolution Digital Elevation Models (DEMs) and terrain information. This data is essential for watershed management and understanding how water flows within the watershed, aiding in flood modelling and erosion control strategies [2].

Change detection: SAR time-series data can be used to detect changes in the landscape over time, such as land subsidence, erosion, or landslides. These changes can be indicative of the overall health and stability of the watershed.

Water quality monitoring: SAR can be used in combination with other remote sensing data to estimate water quality parameters. Changes in water quality can reflect the health of the watershed and potential pollution sources [1].

Hydrological modelling: SAR data can contribute to the development of hydrological models, which are essential for predicting water availability and flow patterns in the watershed. This helps in managing water resources and ensuring the sustainability of the ecosystem [3].

Vegetation stress and disease detection: SAR can detect changes in vegetation health, including stress and diseases. Monitoring such changes can be instrumental in understanding the ecological impacts on the watershed.

Deforestation and land degradation assessment: SAR data can help identify areas experiencing deforestation, land degradation, or illegal logging activities, which can have detrimental effects on watershed health.

SAR technology plays an important role in watershed health monitoring by providing valuable information about various environmental parameters. This information aids in making informed decisions for watershed management, environmental conservation, and disaster mitigation, ultimately contributing to the sustainable and healthy functioning of watersheds.

SAR data at higher incidence angles has potential applications in characterizing forest vegetation parameters such as tree height, basal area and total tree biomass. Multipolarization SAR data is useful in delineating water inundated wetland vegetation. Use of SAR has the potential to detect fire, smoke and infiltrate clouds, on the other hand providing data on the level of burnt intensity [4]. SAR has been widely used for biomass estimation, vegetation mapping and ecological monitoring and development. Retrieving biophysical parameters of considerable effect from local topography is a big challenge when using SAR images to monitor fire burn scars.

LITERATURE REVIEW

Study area

South Goa is a region located in the southwestern part of the Indian state of Goa. Known for its serene and unspoiled beauty, South Goa offers a distinct contrast to the more bustling and touristy North Goa. This area boasts a unique blend of natural landscapes, cultural heritage, and a relaxed atmosphere that makes it a popular destination for travelers seeking a tranquil and authentic Goan experience [3].

Geographically, South Goa is characterized by its lush green countryside, rolling hills, and pristine beaches that stretch along the Arabian Sea. The region is blessed with a tropical climate, making it an ideal destination for beach lovers and sunseekers throughout the year. Some of the well-known beaches in South Goa include Palolem, Agonda, Benaulim, Colva, and Majorda, each offering its own charm and character [5].

Ecology and biodiversity: South Goa's natural environment is incredibly diverse, with lush forests, estuaries, and rich marine life. Researchers can study the local flora and fauna, including various species of birds, mammals, and reptiles, in an effort to better understand and conserve the region's biodiversity.

Cultural heritage: South Goa is rich in cultural heritage, with its colonial-era churches, temples, and traditional Goan architecture. Researchers can delve into the history and cultural practices of the local communities, including their festivals, music, and art forms.

Agriculture and farming: Agriculture plays a significant role in South Goa's economy. Researchers can explore the agricultural practices, land use patterns, and sustainability initiatives in the region, including the cultivation of rice, coconuts, and cashew nuts.

Environmental sustainability: Given the increasing concern for environmental conservation, researchers can study various sustainability projects and initiatives, such as eco-friendly tourism practices, waste management, and efforts to protect the coastal ecosystems.

Healthcare and wellness: The region also offers opportunities for healthcare and wellness research. Researchers can investigate traditional healing practices, healthcare infrastructure, and the well-being of the local population [6].

Infrastructure and connectivity: The development of transportation, roads, and connectivity is important for the region's growth. Researchers can examine the state of infrastructure and its role in facilitating economic and social development as shown in Figure 1.

Figure 1: Image of South goa from PhenoCam. **Note:** ( ): PhenoCam location.

Methodology

The methodology to developments a database for forest fire regime is primary to know the effects on watershed health.

Data collection: Gather relevant data sources, including remote sensing data, geographic information, historical fire records, and climate data. Remote sensing data sources can include satellite imagery (e.g., MODIS, Landsat), aerial photography, or lidar data. Historical fire records can be obtained from agencies responsible for fire management and conservation.

Data pre-processing: Clean and preprocess the data to ensure compatibility and consistency. This may involve georeferencing, mosaicking, and rectification of remote sensing imagery. Convert data to a common coordinate system and projection if necessary.

Land cover classification: Use remote sensing data to classify land cover types within the study area. Supervised or unsupervised classification techniques can be employed. Include classes relevant to your fire regime analysis, such as forest types, grasslands, and urban areas.

Fire detection and mapping: Utilize remote sensing data to detect and map historical fire occurrences. This can be achieved using techniques like change detection, burn scar mapping, or thermal anomaly detection. Incorporate fire perimeter data and attribute information [7].

Fire regime analysis: Calculate fire regime parameters, such as fire frequency, fire return intervals, fire severity, and ignition sources. This often involves spatial analysis in a GIS environment. Use statistical methods to analyze the data and identify trends in fire regimes.

Database design: Create a database schema to store the collected and derived data. Popular database management systems like PostgreSQL or MySQL can be used. Define tables and relationships for storing attributes, spatial data, and metadata.

Data integration: Populate the database with the processed and analyzed data, ensuring proper organization and structure. Link the spatial data to attribute data through unique identifiers or spatial joins.

Metadata documentation: Document all data sources, processing steps, and methods used in the creation of the database. This metadata is essential for data sharing and transparency.

Quality control and validation: Verify the accuracy of the data by cross-referencing it with ground-truth information and other reliable sources. Perform validation and accuracy assessments for the land cover classification and fire mapping results.

Visualization and reporting: Use GIS software to visualize the database's content, create maps, and generate reports to communicate findings and insights. Make the database as shown in Figure 2. Now, methodology for the development of watershed and monitoring the anomalies.

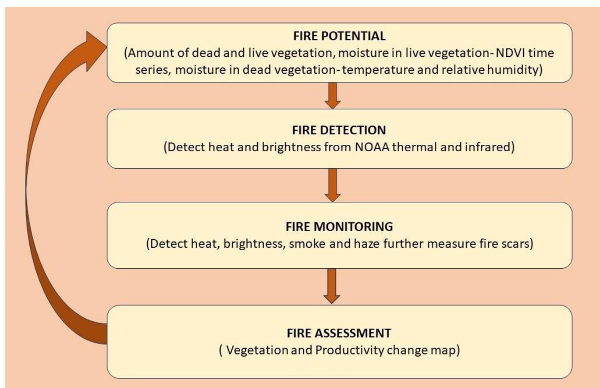

Figure 2: Database creation for forest fire.

Data acquisition: Collect relevant data sources, such as satellite imagery, topographic maps, soil data, land cover data, and hydrological information.

Data preprocessing: Clean and preprocess the data to ensure accuracy and consistency. This may involve correcting sensor errors, removing noise, and aligning data to a common coordinate system.

Watershed delineation: Use Digital Elevation Models (DEMs) to identify the boundaries of the watershed. Watershed delineation helps in understanding the flow of water within the area [5].

Land cover classification: Utilize remote sensing data (e.g., satellite imagery) to classify and map land cover types within the watershed. This information is critical for understanding land use and its impact on water resources.

Soil analysis: Analyze soil data to understand soil properties, which can influence water infiltration and runoff characteristics.

Hydrological modelling: Build hydrological models, such as the Soil and Water Assessment Tool (SWAT) or Hydrologic Engineering Centre's Hydrologic Modelling System (HEC-HMS), to simulate and predict water flow within the watershed.

Rainfall data: Incorporate historical and real-time rainfall data, as precipitation is a critical factor in watershed management and anomaly detection [5].

Remote sensing for anomaly detection: Monitor the watershed area using time-series satellite imagery and remote sensing techniques to detect anomalies. Common anomalies include changes in land cover, water quality, vegetation health, or infrastructure.

Image processing and change detection: Analyze remote sensing data over time to detect changes. This may involve techniques like image differencing, image classification, or spectral indices (e.g., NDVI for vegetation health).

GIS analysis: Combine remote sensing data with GIS data layers to create maps and visualizations that highlight anomalies. GIS allows for spatial analysis and integration of different data types [8].

Data integration: Integrate all relevant data layers, including hydrological models, land cover, soil data, and anomaly information, into a single GIS platform for a comprehensive view of the watershed.

Anomaly identification: Use established criteria and thresholds to identify anomalies in the watershed [3]. These may include rapid land cover changes, unusual water quality readings, or variations in hydrological patterns as shown in Figures 3 and 4.

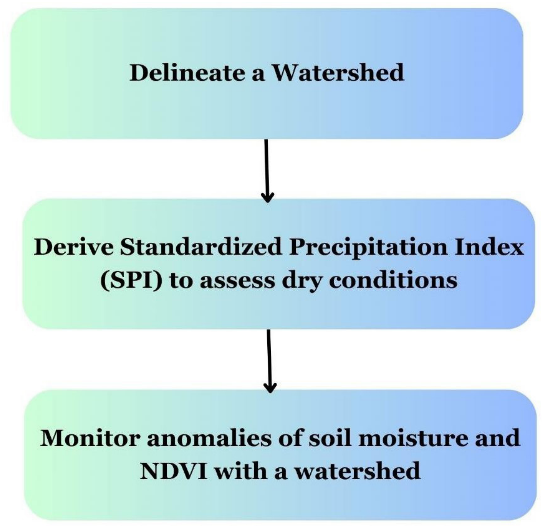

Figure 3: Processing of watershed to derive forest fire effects.

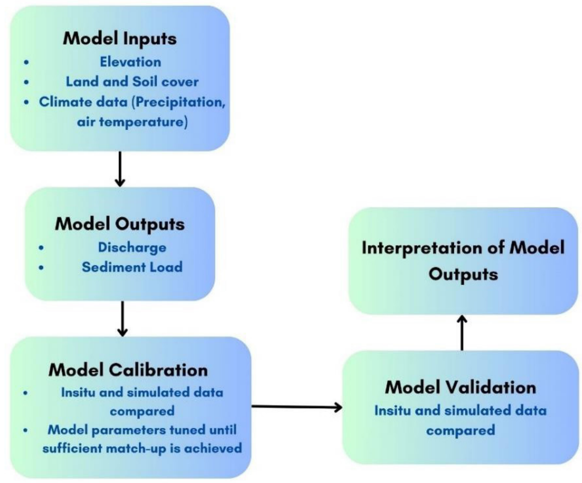

Figure 4: Flowchart of working of Soil and Water Assessment Tool (SWAT).

DISCUSSION

SAR is a remote sensing technology that uses microwave radar to create high-resolution images of the Earth's surface. SAR has various applications in environmental monitoring, including its use in assessing the impacts of forest fires on watersheds. Some key applications of SAR in this context include:

- **Monitoring burn scars:** SAR can be used to detect and map burn scars resulting from forest fires. This helps researchers assess the extent of fire damage in watersheds.
- **Soil moisture estimation:** SAR can estimate soil moisture content, which is valuable for understanding how water availability in watersheds is affected by fires.
- **Flood monitoring:** SAR can be used to monitor water levels and flood extent, aiding in flood risk assessment in post-fire watersheds.

SWAT's adaptability and capacity to model a wide range of environmental processes make it an indispensable tool for sustainable land and water resource management [9]. Its ability to analyze the consequences of forest fires on watersheds, water resources, and water quality underscores its versatility and relevance in addressing pressing environmental challenges.

CONCLUSION

The interplay between forest fires, watersheds, and Synthetic Aperture Radar (SAR) technology underscores the intricate relationship between environmental processes and modern monitoring techniques. Forest fires have a profound impact on watersheds, disrupting their ecological balance and affecting the quality and quantity of water resources. SAR technology plays a important role in mitigating the consequences of forest fires on watersheds.

SAR provides the means to monitor and assess the extent and severity of forest fires from space, enabling rapid response and informed decision-making for firefighting efforts. Additionally, SAR data aids in understanding post-fire watershed dynamics, including erosion, sedimentation, and water quality changes, which are critical for managing and restoring affected ecosystems.

The combination of SAR technology and watershed management strategies offers a holistic approach to addressing the ecological and hydrological consequences of forest fires. This synergy allows for early detection, efficient response, and long-term rehabilitation of impacted watersheds, ensuring the sustainability of vital water resources and the preservation of these ecosystems. It underscores the importance of integrating advanced technology with environmental stewardship to safeguard our natural landscapes in the face of increasing environmental challenges.

REFERENCES

1. Hohner AK, Rhoades CC, Wilkerson P, Rosario-Ortiz FL. Wildfires alter forest watersheds and threaten drinking water quality. Acc Chem Res. 2019;52(5):1234-1244.

2. Wu ST, Sader SA. Multipolarization SAR data for surface feature delineation and forest vegetation characterization. IEEE Trans Geosci Rem Sens. 1987;(1):67-76.

3. Engda TA, Bayabil HK, Legesse ES, Ayana EK, Tilahun SA, Collick AS, et al. Watershed hydrology of the (semi) humid Ethiopian highlands. Nile River Bas. 2011:145-162.

4. Li Z, Deng X, Wu F, Hasan SS. Scenario analysis for water resources in response to land use change in the middle and upper reaches of the Heihe river basin. Sustainabil. 2015;7(3):3086-3108.

5. Mutai S, Chang L. Post-fire hazard detection using ALOS-2 radar and landsat-8 optical imagery. ISPRS Ann Photogramm Remote Sens Spatial Inf Sc. 2020;3(6):75-82.

6. Chen M, Strobl J. Multispectral textured image segmentation using a multi-resolution fuzzy Markov random field model on variable scales in the wavelet domain. Int J Remote Sens. 2013;34(13):4550-4569.

7. Zhong P, Liu F, Wang R. Learning sparse conditional random fields to select features for land development classification. Int J Remote Sens. 2011;32(15):4203-4219.

8. Ohana-Levi N, Givati A, Alfasi N, Peeters A, Karnieli A. Predicting the effects of urbanization on runoff after frequent rainfall events. J Land Use Scie. 2018;13(1-2):81-101.

9. Janardhanan VM, Monder DS. Microkinetic modeling of CO_2 reduction on Pt in a solid oxide electrolysis cell. Electrochimic Acta. 2022;410:139742.