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Refining Drought Assessment: A Multi-Dimensional Analysis of Condition Monitoring Observer Reports in Missouri (2018–2024)

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Abstract: In this study, we propose an enhanced methodology for assessing drought conditions through the systematic categorization of Condition Monitoring Observer Reports (CMORs) from Missouri between 2018 and 2024. Our approach introduces a novel classification framework to categorize drought impacts—meteorological, agricultural, hydrological, and socioeconomic—and aligns the analysis with established United States Drought Monitor (USDM) severity classifications. To complement this framework, we incorporate the New Drought Index (NDI), a recently developed quantitative metric that integrates atmospheric anomalies. Brief consideration is also given to atmospheric blocking patterns, which influence drought development. Advanced text processing techniques are employed to bridge qualitative and quantitative insights. The findings underscore the importance of integrating observer insights, atmospheric processes, and advanced indices to refine drought monitoring, inform climate adaptation strategies, and support proactive resource management.

Keywords: drought; blocking; teleconnections; new drought index; condition monitoring observer reports; categorizing; drought severity; drought duration

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1. Introduction

Droughts are among the most impactful natural hazards, with the potential to affect vast geographic areas and populations. Characterized by a prolonged period of deficient precipitation resulting in water shortages, droughts can lead to significant agricultural, hydrological, and socioeconomic impacts. Droughts are typically classified into five main categories—meteorological, hydrological, agricultural, economic, and socioeconomic—based on their effects on the atmosphere, water systems, food production, livelihoods, and communities. In this study, we focus on four of these types: meteorological, hydrological, agricultural, and socioeconomic, as they were the most prevalent in observer-submitted reports. While the classifications in our study are based on keywords found within these reports, the keyword definitions themselves were guided by standard definitions from the World Meteorological Organization (WMO), the U.S. Drought Monitor (USDM), and the related literature. This approach ensures both scientific alignment and relevance to the lived experiences of those affected by droughts (e.g., [1]). The insidious nature of droughts, along with their complex interplay with environmental and human systems, makes them particularly challenging to assess and manage. In the study by Weaver et al. (2023) [2], we found that drought conditions occurred nearly every year within the study area; however, the key challenges lay in determining the exact severity and pinpointing the specific locations impacted. These findings underscore the complexity of drought characterization and the limitations of current methods in capturing spatial and temporal nuances. Recent climatic trends, amplified by short- and long-term variations in weather and climate, have heightened the frequency and intensity of drought events, prompting an urgent need for advanced assessment techniques that enable timely and effective responses.

Traditional drought assessment methods often rely on quantitative measures such as the Palmer Drought Severity Index (PDSI) or the Standardized Precipitation Index (SPI). While these indices are invaluable for understanding the physical dimensions of droughts, they may not fully capture the multifaceted nature of drought impacts on ecosystems and communities. Recent developments, such as the New Drought Index (NDI) [3], have aimed to address some of these limitations by incorporating diverse parameters, including vegetation health and soil moisture, via normalized monthly and seasonal precipitation and temperature anomalies to provide a more holistic evaluation of drought conditions. However, even advanced indices like the NDI may benefit from supplementary qualitative insights that reflect localized impacts.

Blocking patterns, as demonstrated by Weaver et al. (2023) [2], have been shown to significantly influence the likelihood of drought occurrence, particularly over the central regions of North America. Region blocking disrupts typical atmospheric circulation, creating stagnant conditions that prevent moisture transport into the blocked areas. This atmospheric phenomenon often exacerbates drought intensity and duration by fostering prolonged dry periods. As blocking has been proven to be a factor in whether a drought occurs [2,4], it is imperative to incorporate its role into the broader analysis of drought conditions. Understanding blocking provides critical context for evaluating the meteorological precursors to drought and complements both traditional and innovative assessment indices like the NDI. Condition Monitoring Observer Reports (CMORs) (e.g., [5,6]) offer rich qualitative insights into the local-level implications of drought conditions, which can complement the quantitative data derived from indices such as the NDI. Observer reports encapsulate a wealth of experiential knowledge, capturing nuances related to agricultural yield, water body conditions, and community impacts that numeric scores alone may not reveal. However, harnessing these qualitative data necessitates a systematic approach to parsing and analyzing the textual information contained within CMORs. Within this framework, we categorized drought types based on specific classification terms associated with meteorological, agricultural, hydrological, and socioeconomic droughts. Additionally, drought severity was categorized by extracting and analyzing terms from CMOR data that corresponded to predefined severity categories, which were then aligned with classifications of mild, moderate, or severe drought. This dual categorization framework enhances the interpretative power of CMORs, enabling a more granular and actionable understanding of drought impacts.

Our research contributions and approach employ advanced data processing techniques in R [7] to ensure rigorous categorization, laying the groundwork for the identification of emergent drought trends and their implications over a multi-year span from 2018 to 2024. By integrating qualitative descriptions from observer reports with advanced indices like the NDI, we aim to offer a comprehensive and refined perspective on drought conditions.

Through this methodology, we anticipate contributing to the advancement of drought resilience and management practices. The implications of this research are significant, with the potential to enhance the development of sophisticated drought monitoring tools [8], support policymakers in making informed decisions, and provide stakeholders with the insights necessary for implementing proactive drought mitigation strategies [9].

2. Materials and Methods

2.1. Data

The data for this study were sourced from CMOR reports for the years 2018 to 2024. The year 2019 did not have any CMOR reports, as this was a year that did not result in a drought for the state of Missouri [2,10]. Reports were categorized using predefined keywords associated with different drought types, including meteorological, agricultural, hydrological, and socioeconomic keywords. These keywords were determined by knowing the definition of each drought type [11]. We intentionally continued the research without including economical drought because there were zero reports that were ecologically categorized [12]. The categorization process also involved cleaning the text data and ensuring the accuracy of the categorization. Geospatial analysis was performed using the sf package in R [13], overlaying the drought severity data on the Missouri state map [14] to visualize the spatial distribution of drought reports.

The primary data source for this study was the Condition Monitoring Observer Reports (CMORs), accessible through the National Drought Mitigation Center, through the University of Nebraska. These reports provide comprehensive observer-based accounts of drought impacts across various sectors, including meteorological, agricultural, hydrological, and socioeconomic aspects. Data for the years 2018 through 2024 were meticulously downloaded and compiled, with the notable exception of 2019, during which Missouri did not experience significant drought conditions according to the available reports. This temporal span allowed for an in-depth analysis of recent drought patterns and their implications within the state, facilitating a longitudinal assessment of drought impacts over a six-year period. Additionally, data from the NDI were integrated to cross-validate drought severity and type classifications, offering a quantitative perspective to complement the observer-based qualitative data.

2.2. Study Region

The study region, Missouri (Figure 1), is situated in the Midwestern United States, characterized by its diverse geographical and climatic conditions [15].

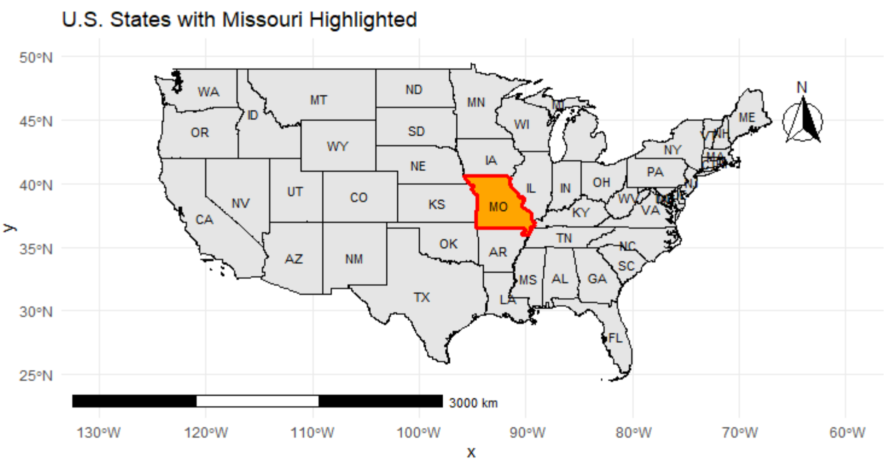

Figure 1. The study region, Missouri, highlighted within the United States, as defined by [14].

The state spans two major climatic interfaces: the humid continental climate in the north and the humid subtropical climate in the south [16]. This climatic diversity contributes to a wide range of weather patterns, significantly affecting the state's water resources, agricultural productivity [17], and ecosystem health [18]. Missouri's topography varies from the northern plains that are part of the Interior Plains to the Ozark Highlands in the southern part of the state, alongside the Mississippi River, which forms its eastern border [19]. This geographical diversity supports a variety of land uses, including extensive agricultural operations, forested areas, and urban centers. Agriculture is a cornerstone of Missouri's economy, with significant production of soybeans, corn, and livestock. The state's agricultural output heavily depends on weather conditions, making it particularly vulnerable to drought (e.g., [20]).

Water resources in Missouri are abundant but unevenly distributed, with major rivers and aquifer systems providing critical supplies for agriculture, industry, and municipal uses [21]. The variability in water availability and the increasing demand poses challenges for water management, especially during drought periods. Historically, Missouri has experienced several significant droughts, which have had profound impacts on the state's water availability, agricultural production, and economy. These events have underscored the importance of effective drought monitoring and management strategies to mitigate adverse effects on the state's resources and communities [22,23].

Given the economic reliance on agriculture and the historical precedent of drought vulnerability, understanding the nuances of drought impacts across Missouri is crucial [24]. This research aims to dissect the multifaceted nature of drought impacts, offering insights that could inform policy decisions and resilience strategies against future drought events. The analysis of CMORs from 2018 to 2024 provides a unique lens through which to view the contemporary drought dynamics within the state, offering a valuable contribution to the body of knowledge on drought assessment and management in Missouri [25]. By examining drought impacts through the lens of Missouri's unique geographical, climatic, and economic context, this study not only contributes to the regional understanding of drought but also provides a model that could be applied to similar regions facing drought vulnerabilities.

2.3. Methodology

2.3.1. Data Preprocessing

Upon acquisition, the datasets underwent a series of preprocessing steps to ensure uniformity and relevance for analysis. This included standardizing the format of dates, locations, and the categorization of drought types as reported by observers. Special attention was given to textual data cleaning, including the normalization of text to facilitate keyword-based categorization. These initial measures laid the groundwork for the comprehensive preprocessing activities detailed below, which were essential for refining the data into a format amenable to rigorous analysis:

a. Data Cleaning: The preliminary stage focused on data sanitization. Our preprocessing commenced with a meticulous data cleaning phase, essential for ensuring data quality and reliability. The process involved the elimination of duplicate entries, standardization of reporting formats, and remediation of missing values. For instance, missing values were handled using multiple imputations, leveraging patterns within the data to infer plausible values, which enhanced the robustness of subsequent analyses. We established stringent criteria for identifying duplicates, such as identical timestamps and observer reports, which were then purged from the dataset to maintain data integrity.
b. Data Transformation: To facilitate seamless analysis, raw data were transformed using a series of procedures. This included scaling normalization to unify measurement units, data type conversions for compatibility with analysis tools, and restructuring

datasets to optimize computational efficiency. For example, narrative text in CMORs was encoded into numerical scales to quantify drought severity levels, enabling statistical analysis.

c. Feature Selection and Engineering: Relevant features were curated based on their significance to drought characteristics and potential for insight. Selection was informed by both statistical measures, like variance inflation factors to detect multicollinearity, and domain expertise to ensure ecological validity. Additionally, new features were engineered, such as drought duration and onset metrics, to capture the temporal aspects of drought phenomena more.

d. Geospatial Data Handling: Integrating geospatial data was pivotal for spatial analysis. We aligned various spatial data sources concerning Missouri's climate divisions and county boundaries, accounting for discrepancies in projections and coordinate systems. The 'sf' package in R was instrumental for this task, enabling the manipulation and transformation of spatial data for congruent overlay onto base maps.

e. Temporal Alignment: Temporal alignment was vital, given the time-series nature of the datasets. We reconciled differing temporal granularities, such as aggregating daily meteorological data into monthly intervals to align with the periodicity of CMORs. This allowed for a harmonized temporal framework, facilitating longitudinal analysis.

f. Quality Assurance Checks: Post-processing, we instituted a regimen of quality assurance checks. These procedures, which included validations against external climatological datasets and spot-checks of processed data, served to confirm the fidelity of the preprocessing steps. Additionally, we employed anomaly detection algorithms to flag and review any irregular data points.

g. Data Integration: The culmination of preprocessing was the integration of disparate datasets into a unified analytical framework. This process entailed merging datasets on common identifiers such as geographic location and time stamps, ensuring a coherent and comprehensive data matrix. Rigorous testing was conducted post-integration to ensure that the merging process did not introduce any distortions or errors.

h. New Integration (Preprocessing and NDI-Blocking Context): A series of preprocessing steps were also undertaken to align CMOR-derived drought types with the NDI-derived severity metrics. The NDI provided essential insights by identifying temporal and spatial anomalies, enriching the overall assessment of drought impacts. Blocking events, known atmospheric precursors to drought, were analyzed by overlaying atmospheric circulation data with NDI-derived drought trends. This integration revealed temporal and spatial correlations between blocking patterns and observed drought severity, providing a critical context for understanding drought formation. These patterns were subsequently incorporated into the categorization framework, adding an atmospheric dimension to the analysis.

2.3.2. Categorization of Drought Types and Severity

A novel classification framework was developed to categorize the CMORs according to the type of drought—meteorological, agricultural, hydrological, and socioeconomic—based on a predefined list of keywords. This categorization aimed to dissect the nuanced impacts of drought across different sectors. The keywords were selected based on their relevance to the respective drought types and were validated by reviewing the datasets to ensure their appropriateness and coverage. These keywords were adapted from widely accepted drought definitions published by organizations such as the World Meteorological Organization (WMO), the U.S. Drought Monitor (USDM), and previous peer-reviewed studies including Wilhite's foundational work on drought typology and impact-based definition [26], ensuring that our observer-based approach remained consistent with established scientific frameworks. The absence of reports related to economic drought impacts underscored the specificity and targeted nature of the chosen keywords.

a. Categorization of Drought Type

This research introduces a dual-pronged methodology to enhance the assessment of drought conditions through systematic categorization and analysis of CMORs. Our classification framework distinguishes between four primary types of drought—meteorological, agricultural, hydrological, and socioeconomic—by identifying specific keywords within observer reports that align with recognized definitions. The keywords used for classification were not arbitrarily chosen but were carefully adapted from definitions provided by leading agencies such as the World Meteorological Organization (WMO), the U.S. Drought Monitor (USDM), and relevant peer-reviewed literature. These sources offer well-established criteria for identifying the impacts and drivers of each drought type. Our decision to use observer reports as the basis for categorization allowed us to apply these formal definitions in a localized, real-world context. By bridging scientifically recognized drought typologies with direct observational language, our framework supports both methodological rigor and practical relevance. The keywords used for categorization included the following:

- Meteorological Drought: low rainfall, dry weather, prolonged dry spells, high temperatures, record low rainfall, drought indices, weather pattern;
- Hydrological Drought: low river, pond, stream, low reservoir levels, decreased water table, dry creek beds, reduced lake capacity, streamflow reduction;
- Agricultural Drought: crop failure, irrigation needed, hay, grass, reduced crop yields, stunted growth, pasture degradation, plant stress, poor soil moisture;
- Economical Drought: economic loss, financial strain, loss of agricultural revenue, higher water costs, business closures, decreased farm profitability, economic downturn;
- Socioeconomical Drought: water restrictions, rationing, community impact, impact on livelihoods, reduced recreational activities, public health concerns, resource rationing.

This nuanced categorization reflects the complex reality of drought impacts, allowing for a holistic view that informs more targeted and efficient response strategies.

b. Categorization of Drought Severity: This study further endeavored to contextualize the severity of drought events within frameworks like the NDI and the United States Drought Monitor (USDM) [8]. Observer-provided descriptions were parsed for specific indicators that aligned with predefined criteria for mild, moderate, and severe drought conditions:

- Mild Drought: dust, plants suffer, outdoor livelihood changes, ecosystem changes, animal migration, early leaf drop, wilting annual crops, slight soil cracking, reduced recreational water use, decreased pollinator activity;
- Moderate Drought: less water, water quality change, vegetation change, habitat change, wildlife near people, reduced stream flow, declining pasture quality, increased invasive plants, heat stress livestock, disruption of fish spawning, increased algae growth;
- Severe Drought: loss of wetlands, fish kills, tree mortality, wildlife mortality, complete dry-up ponds, massive tree mortality, livestock deaths, severe erosion, economic crisis farming, local extinction aquatic species.

Each observer narrative was matched against these criteria, prioritizing the highest severity mentioned when multiple levels were described. This structured approach ensured consistent categorization, bridging qualitative observations with quantitative assessment methodologies. The classification also included a severity assessment, inspired by the US Drought Monitor (USDM) index, to categorize the reported drought conditions on a scale ranging from D0 (abnormally dry) to D4 (exceptional drought). While the direct linkage to the USDM index was not implemented in the provided code, the conceptual framework guided the severity classification, laying the groundwork for future methodological integration and enhancement.

2.3.3. Data Analysis

The R programming language [27] was utilized for all data processing and analysis tasks due to its robust capabilities in handling and analyzing large datasets. This included text processing for the categorization of reports, statistical analysis to identify trends and patterns, and geospatial analysis to map the distribution and severity of drought impacts across Missouri.

1. Text Processing: Utilization of R for the advanced text processing required for categorizing observer reports based on predefined keywords. This step was crucial for sorting the vast amounts of textual data into coherent categories of drought types and severity.
2. Statistical Analysis: Application of R's statistical tools to identify trends and patterns within the data, providing insights into the temporal dynamics of drought conditions across Missouri. The analysis aimed to uncover patterns in drought reports over the years 2018 to 2024, facilitating an understanding of how drought impacts have evolved over time.
3. Geospatial Analysis: Employing R's geospatial capabilities, specifically the sf package [28], to map and analyze the spatial distribution of drought impacts. This allowed for the examination of drought severity across Missouri's diverse landscape. By overlaying NDI-derived metrics onto Missouri's climate divisions, this analysis captured both quantitative drought metrics and observer-reported impacts.

The ggplot2, sf, and other relevant R packages were employed for data visualization, enabling the graphical representation of drought categories, severity, and their spatial distribution within the study region. The combined datasets were analyzed to uncover temporal trends in drought reports and to assess the distribution of drought severity over the years 2018 to 2024. This longitudinal analysis provided insights into the changing dynamics of drought in Missouri, contributing to a deeper understanding of its impacts.

2.3.4. Geospatial Analysis and Climate Divisions

In addition to the textual analysis of CMORs and severity categorization, this study employed geospatial analysis to contextualize drought events within Missouri's specific climate divisions [29]. Missouri is divided into several climate divisions, as defined by the National Oceanic and Atmospheric Administration (NOAA) [30], which reflect distinct climatic regions within the state. These divisions are critical for understanding the geographic variability of climate impacts, including drought, and for tailoring response strategies to localized conditions. Integrating Missouri's climate divisions into our analysis provided several advantages.

Firstly, it allowed for a nuanced examination of drought impacts that account for the state's climatic diversity. By analyzing drought severity and distribution within these divisions, we were able to identify region-specific trends and vulnerabilities that may not be apparent from a statewide analysis. This approach acknowledges that the impacts of drought can vary significantly across different parts of Missouri, influenced by local environmental, agricultural, and hydrological conditions.

Secondly, the use of climate divisions supports more effective drought management and mitigation efforts. By pinpointing areas most susceptible to drought within specific climatic regions, policymakers and stakeholders can devise targeted interventions, allocate resources more efficiently, and enhance the state's overall resilience to drought. To achieve this integration, this study leveraged geospatial data processing tools within R, utilizing the sf package to overlay drought severity data onto maps of Missouri's climate divisions. This spatial analysis facilitated the visual representation of drought patterns across the state, enhancing our understanding of how drought dynamics interact with Missouri's varied climate regions. The incorporation of climate divisions into our drought assessment methodology represents a significant step forward in achieving a comprehensive understanding of drought impacts. It illustrates the importance of considering both spatial and temporal dimensions in drought research and underscores the value of geospatial analysis in environmental studies.

2.3.5. New Drought Index Calculation

The New Drought Index (NDI) calculation used in this study follows the methodology established in our previous research [2,3]. This index was developed to provide a comprehensive assessment of drought severity by incorporating multiple environmental factors that influence drought conditions.

The NDI is a composite index that integrates precipitation, soil moisture, and vegetation health, offering a more holistic view of drought compared to traditional indices. It is calculated using the following formula in the paper that we reference:

$$\mathrm{NDI} = \frac{\mathrm{SPI} + \mathrm{SSI} + \mathrm{VHI}}{3} \tag{1}$$

We calculated the NDI by using the seasonal and monthly NDI by using the following formula in [3]:

$$\mathrm{NDI} = \frac{\left(\mathrm{P} - \overline{\mathrm{P}}\right)}{\mathrm{P}_{\sigma}} - \frac{\left(\mathrm{T} - \overline{\mathrm{T}}\right)}{\mathrm{T}_{\sigma}}, \tag{2}$$

where P represents the total monthly precipitation (in millimeters), and T is the average monthly temperature (in degrees Celsius). The terms $\overline{\mathrm{P}}$ and $\overline{\mathrm{T}}$ refer to the long-term climatological means of monthly precipitation and temperature, respectively, while P_{σ} and T_{σ} are their respective standard deviations. These normalized anomalies were then used to compute the NDI, which provides a standardized assessment of drought conditions based on deviations from the mean.

3. Results

The multi-year analysis utilizing Condition Monitoring Observer Reports (CMOR) in Missouri yielded a comprehensive portrayal of drought incidence and severity across varying climatological and geographical landscapes. This investigation covered an extensive period from 2018 to 2024, deliberately excluding 2019 where drought conditions were not reported, hence providing a detailed chronology of drought dynamics within the state.

3.1. Drought 2022 in Context: United States Statewide Ranks

Our categorization efforts distilled the CMORs into discrete drought categories—agricultural, hydrological, meteorological, and socioeconomic—providing a multi-dimensional perspective on drought impacts. Annual "Distribution of Drought Categories" visualizations revealed striking patterns and anomalies, as seen in Figure 2, such as the dominant prevalence of hydrological drought reports, especially in 2018 and 2022–2024, possibly indicative of specific environmental triggers unique to that period. The third-largest number of reports came from the agricultural drought category, especially over the same years.

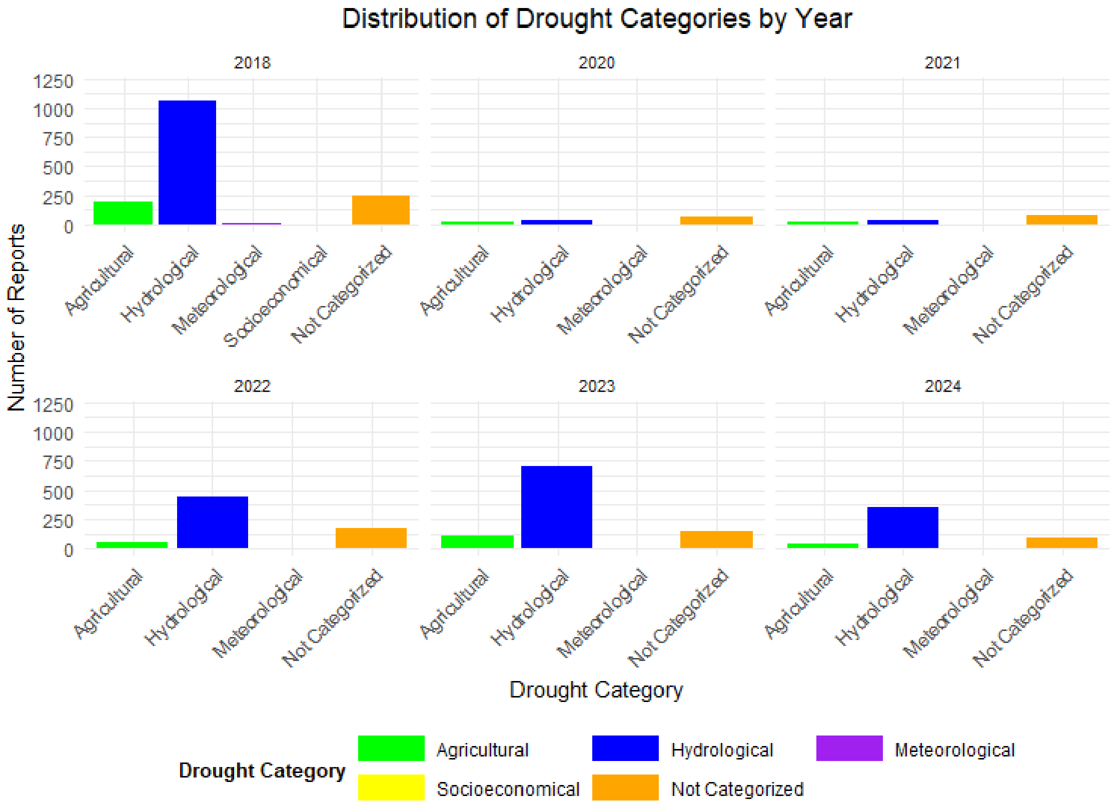

Figure 2. Distribution of drought reports for the entire years for 2018, 2020, 2021, 2022, 2023, and 2024 in Missouri, as categorized by the type, via agricultural (green), hydrological (blue), meteorological (purple), socioeconomical (yellow), and reports that were not categorized (orange).

The visual narrative across the years unfolded a complex interplay of drought types, with variances in frequency and severity, offering insights into the temporal behavior of drought occurrences within the state of Missouri. By examining the distribution of agricultural, hydrological, meteorological, and socioeconomic droughts, as depicted in the annual data, we can observe the shifting patterns and intensities of these conditions over the years. This analysis permits the identification of the most prevalent drought types and any emerging trends, suggesting changes in environmental conditions, resource management, or socioeconomic factors. For instance, a trend of increasing agricultural drought frequencies may signal changes in regional farming practices or climate patterns affecting crop production. Similarly, a rise in hydrological drought instances might reflect long-term alterations in precipitation patterns or heightened water consumption. Through this lens, the temporal dynamics of drought events are clarified, enabling the development of nuanced mitigation strategies, and informing statewide resource management and community resilience initiatives.

As shown in Figure 2, meteorological and socioeconomical drought reports were few and far between, and it is noteworthy that the second-largest categorization was not categorized. It is possible that many who report drought are unsure of how to categorize drought and what constitutes a meteorological or socioeconomical drought. A survey of drought reporters would be warranted based on this assessment.

3.2. Severity Analysis Through a Temporal Lens

The analysis of drought severity, as depicted in Figures 3 and 4, offered a quantified visualization of the prevalence and frequency of drought conditions across the timeline studied. The years 2018, 2020, 2021, 2022, and 2023 revealed significant interannual variability in the frequency and type of drought, as per the CMOR reports. In 2018, the dominance of hydrological droughts was pronounced, indicating a particular stress on water bodies, which could be attributed to factors such as reduced precipitation and high demand for agricultural irrigation during this period. Subsequent years exhibited a shift in the prevalence of drought types, with meteorological droughts gaining prominence, possibly reflective of changing climatic conditions affecting precipitation patterns in Missouri.

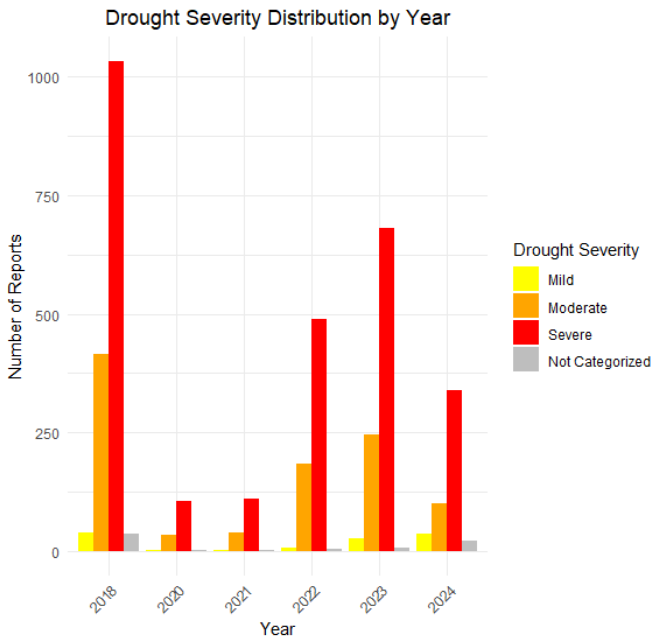

Figure 3. Drought reports for the years 2018, 2020, 2021, 2022, and 2023 categorized by severity based on year and frequency, categorized as mild (yellow), moderate (orange), severe (red), or not categorized (gray).

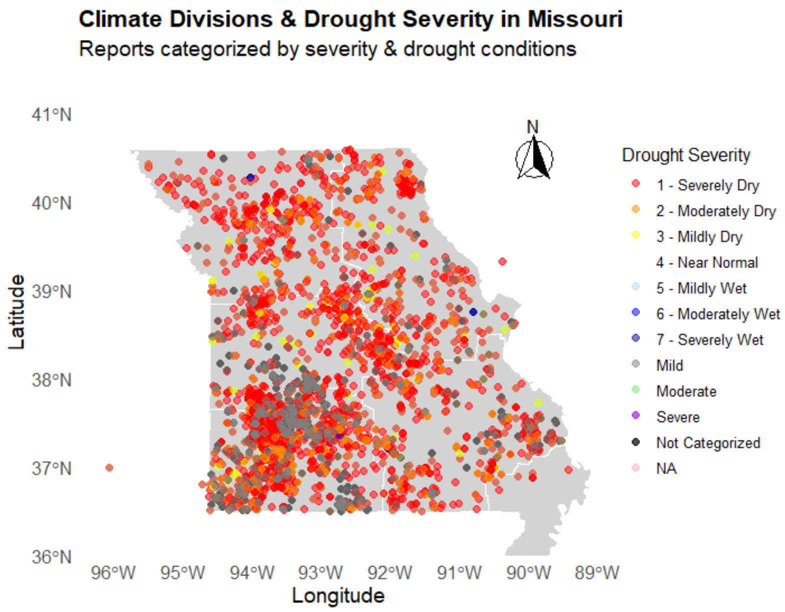

Figure 4. Drought severity via CMOR reports shown across Missouri and overlay into the appropriate climate divisions of the state; reports were categorized by severity and drought conditions for 2018 through 2024.

Figure 3 illustrates the distribution and frequency of drought severity levels by year and presents a compelling narrative of the ebbs and flows of drought conditions over the studied timeframe. For instance, the stark contrast in the severity of drought conditions between years, as shown by the varied heights of bars representing 'severe' drought, underscores the episodic nature of extreme drought events. These peaks in drought severity, especially the substantial increase in severe drought conditions reported in 2023, highlight periods of heightened vulnerability and potential environmental and economic stress. Moreover, the comparative analysis across years illustrates the cyclical patterns of milder drought conditions, indicating underlying persistent dryness that could be exacerbating the severity of subsequent drought occurrences.

These visualizations serve as a testament to the CMOR's effectiveness as a monitoring tool that not only captures the occurrence and intensity of drought but also aids in understanding the progression and regression of drought severity over time. The results emphasize the critical need for continuous monitoring and proactive management strategies to mitigate the impacts of severe drought conditions when they do occur.

3.3. Spatial Representation of Drought Impact with Geographical Significance

As shown in Figure 4, we effectively overlaid the CMOR-derived data onto the state's climate divisions, affording a granular visualization of drought severity distribution. By taking the CMOR data and dissecting them, we were able to categorize the reports into the climate divisions for Missouri. This approach uncovered the varied impact of drought across different regions, which can be crucial for directing drought relief and developing region-specific policies. It showed that a one-size-fits-all strategy might not be effective and that resources should be allocated based on the unique climatic needs of each division. This spatial representation, with varying hues from intense reds to milder blues, transformed the qualitative aspects of drought reports into a vivid topographical narrative. The map's color-coded scheme revealed the severity gradations, from "Severely Dry" to "Severely Wet", effectively correlating drought severity with specific geographic locations and thereby presenting a powerful tool for localized drought analysis and response planning.

We were able to carry out a temporal–spatial analysis. By examining drought conditions over multiple years and across different climate divisions, our study revealed patterns and trends that can help in understanding how drought evolves over time within these regions. We have provided a multi-dimensional view that not only considered the severity of drought year by year but also its location, helping to predict which areas may require more attention in the future. We were also able to contextualize anomalies. With mapping out the drought severity, our research highlighted certain climate divisions that deviated from their expected moisture conditions. These findings prompt further investigation into why certain regions defy their usual patterns, which could lead to a better understanding of the local factors driving these anomalies.

Like most weather, drought impacts water resources and agriculture. Through spatial analysis, our study offers insights into the implications of drought on local water systems and the agricultural sector within the climate divisions. It could provide a data-driven foundation for recommending resilient agricultural practices and water resource management in divisions that are prone to severe drought. By being able to integrate climate divisions with the CMOR reports of drought for the timeframe we studied, we can tailor strategies for drought mitigation that cater to the specific conditions of each climate division. This could be through advocating for water-saving irrigation systems in arid divisions or supporting the cultivation of drought-resistant crops in regions that face frequent dry spells. With our research, we have integrated existing monitoring systems by adding a layer of climate-division-specific analysis, which potentially offers more detailed insights. This granular approach can enhance the understanding of drought impacts at a more localized level, providing a valuable tool for decision-makers.

By covering and analyzing multiple years, this allows for the identification of trends that could be used to predict future drought scenarios. This predictive element is critical for early intervention and for preparing communities for potential drought conditions. The data that we uncovered and the detailed maps we have created can serve as communication tools to foster discussions on drought preparedness among local communities, stakeholders, and policymakers. Our research can help visualize the data in a way that is accessible and actionable, potentially leading to more informed decision-making and community-specific drought preparedness plans.

By integrating Missouri's climate divisions into our analysis, we established a geographical framework that contextualizes the severity of drought conditions. This integration is pivotal, as it interlinks the observed drought characteristics with the underlying regional climatology, thus enhancing the interpretative value of the data for decision-making and policy formulation. The spatial analysis also illuminated drought patterns that are intrinsically linked to the climatic idiosyncrasies of Missouri's diverse topography, from the plains to the Ozark Highlands, providing a nuanced understanding that is essential for tailoring region-specific drought mitigation strategies.

3.4. Blocking Events and NDI Analysis

An analysis of upstream (East Pacific) blocking events (e.g., [2,23,31,32] (Table 1), and their relationship to the New Drought Index (NDI) values (Table 2) during the summer months revealed notable patterns in drought development across Missouri. The NDI values were calculated from the National Weather Service (NWS) station in central MO, and [31,32] (and others) show that this reflects the summer climate of Missouri. Summer seasons with positive NDI values generally experienced more frequent blocking events and days, which contributed to moister seasons and diminished drought severity (2019). In contrast, summers with negative NDI values saw little to no blocking, coinciding with drier conditions and more severe drought-related impacts (2012, 2022).

Further, the summers of 2019, 2021, and 2024, which had NDI values of 0.41, 0.95, and 1.4, respectively, recorded moderate summer season temperatures in mid-Missouri (+0.2 C, +1.1 C, and 0.3 C) and above-average rainfall of (+45.0 mm, +153.9 mm, and +160.3). The year 2019 experienced four spring and summer season blocking events, indicating a clear link between atmospheric flow stagnation and increased precipitation over the central USA [31]. The summers of 2021 and 2024 experienced three blocking events. The summer blocks during 2019 and 2024 were stronger than the typical summer season Northern Hemisphere event [33,34]. Additionally, these summers showed fewer CMOR reports (Figure 2) across all categories in general, except for hydrological drought 2024. This may be explained by a dry spring (Table 2) and the fact that hydrological drought (river level) can be impacted by factors occurring outside of a region.

However, in contrast, years such as 2012 (+2.5 C/−182.1 mm), 2018 (+1.8 C/−128.3 mm), and 2022 (+2.1 C/−126.2 mm) had the strongest negative summer NDI values, and these summer season observed zero, two, and one blocking events, respectively, which were generally weaker and associated with drier conditions and more pronounced drought impacts. The summers of 2018, 2022, and 2023 showed the largest number of agricultural and hydrological drought reports. The summer of 2023 was preceded by a dry spring but showed a slightly positive NDI in spite of the temperature being above normal (+0.9 C). The summer temperature contribution was countered by ample precipitation when looking at the seasonal contribution (+102.6 mm). The 2023 summer demonstrates that seasonal climate variables may mask monthly anomalies, as the August 2023 precipitation was +147.6 mm. June and July 2023 were characterized by highly negative NDI values. The spring season showed a lesser correspondence to the NDI, which is consistent with the work of [32].

Table 1. Blocking events occurring during the spring (March–May)/summer (June–August) months for the years of study over the Pacific Region, from 180° to 100° W in longitude.

Year	Blocking Events	Blocking Days	Block Intensity (BI)
2012	0/0	0.0/0.0	NA/NA
2018	1/2	9.0/14.0	4.24/2.69
2019	4/4	51.0/38.0	4.08/2.70
2020	6/1	47.0/15.5	3.80/2.49
2021	4/3	34.5/24.5	2.78/2.28
2022	6/1	52.5/20.5	3.00/2.13
2023	4/1	54.0/32.5	3.08/2.23
2024	5/3	38.0/28.5	2.68/2.69

Table 2. The NDI calculations using the NWS for Columbia, MO airport in Missouri during spring and summer of 2012, 2018, 2020, 2021, 2022, 2023, and 2024.

Year	NDI Calculation Spring	NDI Calculation Summer
2012	−2.92	−3.26
2018	−1.32	−2.22
2019	−0.70	0.41
2020	0.36	−0.28
2021	0.85	0.95
2022	0.36	−2.04
2023	−2.15	0.08
2024	−1.96	1.40

4. Discussion

4.1. Utility of CMOR Reports

By dissecting drought into type and severity, we reinforced the value of CMORs in offering a holistic view of drought's multifaceted impacts. The dual categorization framework used in this study—based on observer-reported keywords—demonstrated its potential to enhance the precision of drought assessment methodologies. CMORs offer localized, real-time accounts of agricultural stress, water scarcity, and socioeconomic consequences. These reports contribute to the development of advanced monitoring tools and can bolster Missouri's resilience in agriculture, water management, and community preparedness. By integrating CMORs into a broader framework, we provide a replicable model for future drought assessments that blends quantitative and qualitative data sources.

4.2. Importance of Atmospheric Blocking Events

Blocking events emerged as a pivotal atmospheric factor influencing the onset and persistence of drought across Missouri. The temporal analysis of summer-season blocking events from 2018 through 2024, alongside their correlation with NDI-derived severity metrics, revealed that prolonged blocking periods coincided with intensified drought conditions. The limited correspondence between spring and summer blocking may reflect seasonal regime differences. Studies such as refs. [2,23,35] suggest that summers over North America are often marked by a central U.S. ridge, whereas wetter, cooler summers tend to exhibit a trough over the same region and a ridge upstream. Upstream ridging increases the likelihood of block formation [34]. Years like 2018, 2022, and 2023 lacked significant summer blocking and experienced more widespread drought impacts, especially hydrological drought. This underscores the importance of including atmospheric circulation anomalies in drought forecasting and planning models.

4.3. Predictive Power of the New Drought Index (NDI)

The inclusion of the NDI allowed for a more nuanced and data-driven assessment of drought severity and spatial distribution. By incorporating anomalies in precipitation, temperature, soil moisture, and vegetation health, the NDI enhanced our categorization of CMOR-derived impacts. For instance, NDI calculations in Columbia, MO revealed notable drought conditions in 2022, corresponding with severe observer-reported impacts. Although the NDI generally aligned with blocking and CMOR trends, some years like 2023 and 2020 presented complexities. In 2023, a slightly positive NDI did not reflect the limited blocking, and CMOR reports were still high—likely due to a dry spring and strong monthly precipitation variability. Likewise, 2020 showed relatively few CMORs despite negative NDI values and low blocking, which may be explained by an unusually wet June. These findings highlight that while the NDI is a promising tool, further research using expanded datasets and longer timeframes is needed to refine its predictive accuracy.

5. Summary and Conclusions

The systematic categorization and analysis of drought conditions in Missouri from 2018 to 2024, excluding the non-drought year of 2019, has showcased the nuanced complexities of drought impacts, as captured through Condition Monitoring Observer Reports (CMOR). The incorporation of Missouri's climate divisions into our spatial analysis provided an essential geographical context, underscoring the regional specificities of drought impact and aiding in the precision of targeted mitigation strategies.

Our study highlights the multifaceted nature of drought, revealing significant inter-annual variability in drought type and severity. By employing a categorization framework encompassing meteorological, agricultural, hydrological, and socioeconomic dimensions, we have developed a nuanced understanding of drought phenomena, paving the way for a more informed and adaptive response mechanism. The insights derived from our research demonstrate the potential for CMORs to serve as a pivotal resource in drought monitoring and assessment. When aligned with climate division data, CMORs become a more powerful tool, revealing the critical interplay between environmental factors and human observations.

Moreover, the integration of atmospheric blocking event analysis and the New Drought Index (NDI) has expanded the scope of this research. Blocking events emerged as a critical determinant of drought occurrence and severity, disrupting atmospheric circulation and moisture transport. This study underscores the importance of incorporating blocking indices into predictive models to enhance early warning systems for droughts. Similarly, the adoption of the NDI within our framework bridged the gap between qualitative observations and quantitative indices. By identifying temporal anomalies and aligning with CMOR-derived impacts, the NDI demonstrated its utility as a robust tool for drought monitoring. This integration enriches the assessment of drought conditions, offering actionable insights for both policymakers and resource managers.

Analysis of blocking events and NDI trends revealed that years with a higher number of blocking scenarios were often associated with positive NDI values and fewer CMOR reports, suggesting drier but less frequently reported drought conditions. Conversely, years with little to no blocking resulted in negative NDI values and a higher frequency of CMOR reports, indicating that wetter conditions correlated with more localized drought impacts being observed. This pattern highlights the strong relationship between atmospheric circulation, drought severity, and observational reporting, reinforcing the need for further research to explore these connections in greater depth.

The findings emphasize the need for a multifaceted approach to drought management that incorporates both meteorological phenomena, like blocking, and innovative indices such as the NDI. This integrated perspective can inform targeted interventions, including region-specific water conservation practices and climate-adaptive agricultural strategies, thereby bolstering resilience against future droughts.

In conclusion, this study reinforces the essential role of comprehensive data analysis in understanding drought dynamics and stresses the importance of continued research in this field. As climate patterns evolve and the incidence of drought potentially becomes more frequent and severe, the methodologies refined and insights gained from this research will contribute to building resilience against drought impacts, benefiting communities, ecosystems, and economies alike. By synthesizing observer reports with blocking event data, advanced indices like the NDI, and spatial data, we have contributed a methodological blueprint for future studies aiming to enhance drought resilience through improved monitoring and analysis. It is our hope that the findings of this research will inform policy, support proactive planning, and inspire continued innovation in drought assessment and response strategies.

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