Deciphering Weather Dynamics and Climate Shifts in Seattle for Informed Risk Management

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Abstract

This research presents a comprehensive analysis of the weather characteristics in the city of Seattle over the past few years. Through a detailed understanding of the distribution of maximum and minimum temperatures, the findings indicate significant fluctuations between summer and winter seasons. The increasing temperature trend from year to year provides insights into the potential climate changes in the region. Additionally, rainfall data reveals consistent increases over time, particularly during the winter, with significant impacts on the environment and daily life. Wind speed stability throughout the year provides insights into wind dynamics, influencing the transportation and maritime sectors. Annual averages of rainfall, sunshine hours, snowfall, and foggy days provide foundational information for long-term planning and risk management in Seattle. The percentage of rainy and clear weather throughout the year gives a comprehensive overview of the seasons, facilitating daily activity planning. Through these findings, the research aims to make a significant contribution to the understanding of the general public, natural resource managers, and economic sectors regarding the potential impacts and opportunities arising from future weather changes. It is hoped that this research can serve as a solid foundation in efforts to mitigate and adapt to the continually changing weather dynamics in the city of Seattle.

Keywords: Rainfall Patterns, Seattle Climate Change, Temperature Trends, Weather Risk Management, Wind Speed Dynamics

1. Introduction

In facing the era of increasing uncertainty in global climate change, a profound understanding of the weather characteristics in a region becomes a crucial aspect. This is necessary to anticipate more effectively the potential impacts on the environment and daily life. This research plays a crucial role in unveiling the complexity of weather dynamics surrounding the city of Seattle. Through a meticulous analysis of maximum and minimum temperature data, rainfall, wind speed, and overall weather conditions throughout the year [1], deeper and more detailed information can be accessed. Thus, a more comprehensive understanding of weather variability becomes a crucial foundation for smarter and more efficient decision-making in addressing challenges arising from climate change.

The importance of this research lies in the in-depth understanding of significant temperature trends, involving data distribution over several years. The identified temperature increase from year to year reflects potential climate changes occurring in the region [2]. Additionally, the research contributes significantly to detailing factors that can influence temperature fluctuations in the area. By detailing these factors, a better understanding of local climate dynamics can be achieved, identifying potential impacts on the environment and the local community. The presented rainfall data provides a detailed overview of seasonal and yearly changes, essential for helping communities and economic sectors plan and manage risks resulting from changing weather conditions [3].

This information plays a key role in responding to challenges that may arise with weather fluctuations. With a deeper understanding of rainfall patterns, communities and economic stakeholders can adopt more effective strategies in facing climate change, enhancing their resilience and adaptability.

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Year-long wind speed analysis provides a detailed insight into wind stability, with significant impacts, especially in the transportation and maritime sectors. Meanwhile, annual averages of rainfall, sunlight hours, snowfall, and foggy days offer a comprehensive picture of overall weather conditions [4]. These factors not only affect transportation but also have a significant impact on various other sectors. In-depth knowledge of wind speed can assist in flight route planning, maritime navigation, and renewable energy resource management. Conversely, understanding annual weather variability, such as rainfall and sunlight, can support agricultural planning and the selection of crops suitable for local climate conditions. This research is expected to make a significant contribution to the general public, natural resource managers, and the economic sector in facing challenges and opportunities that may arise from the changing weather dynamics in the city of Seattle. With a strong foundation of information, it is hoped that this research can aid in directing future mitigation and adaptation efforts.

2. Literature Review

2.1. Climate Change and Temperature Dynamics

The study of current global climate change has become a primary focus in atmospheric science. Scientists and researchers are increasingly attentive to the consistent rise in global temperatures. Analysis of maximum and minimum temperature data in Seattle has contributed significantly to the scientific literature on climate change. Further understanding of these temperature trends provides profound insights into the local climate change impacts in that region [5].

In this context, research focusing on temperature analysis in Seattle has opened new windows of knowledge. The collected data offers valuable information for understanding climate change patterns and how they affect the local environment. Discoveries about temperature increase trends not only reflect global changes but also provide more specific insights into the regional impacts of climate change [6].

The results of this research contribute significantly to scientific literature and support climate change mitigation efforts. Increased understanding of local climate change can assist both the government and local communities in developing more effective adaptation strategies. Thus, this research not only has academic impacts but is also relevant to environmental protection efforts at both local and global levels [7].

2.2. Rainfall Impact on the Environment and Daily Life

Literature related to rainfall and its impacts on the environment and human life proves its relevance in this research context. Previous studies have revealed valuable information about rainfall patterns, and data analysis from these studies can offer deep insights into seasonal and yearly fluctuations. This knowledge has the potential to provide a better understanding of rainfall implications for ecosystem sustainability and its influence on the daily activities of Seattle's residents [8].

Furthermore, incorporating rainfall data into this research is crucial, allowing the identification of long-term trends that can affect the daily lives of the population. This research emphasizes the importance of examining the long-term impacts of rainfall fluctuations, especially in the context of global climate change. Thus, a deeper understanding of rainfall patterns can positively contribute to environmental and social policy planning in Seattle [9].

In the local context, such as Seattle, the analysis of rainfall data can provide specific information to enhance the city's resilience to climate change. Implications for water sustainability, flood management, and urban planning can be further developed based on these findings. Therefore, this research establishes a strong foundation for understanding the role of rainfall in both local and global contexts, serving as a basis for better decision-making in facing future environmental challenges.

2.3. Wind Speed and Its Influence on Transportation and Maritime Activities

Analyzing wind speed is a crucial aspect of meteorological studies and atmospheric dynamics. Through the literature framework, a profound understanding of wind stability throughout the year can be obtained. Various studies not only provide a general overview of wind speed but also discuss its impacts on air and maritime transportation sectors [10].

In the meteorological literature context, research on wind speed serves as a primary foundation for understanding atmospheric stability. These literatures offer insights into variations in wind speed throughout the year and the factors influencing these changes. Moreover, knowledge gained from this literature also presents how wind speed can affect travel and navigation in air and maritime transportation [11].

By detailing information through meteorological literature, a deeper understanding of the crucial role of wind speed in atmospheric stability is achieved. This literature helps present detailed information on how variations in wind speed can affect weather conditions throughout the year. Additionally, this understanding provides a foundation for describing the concrete impact of wind speed on the operational aspects of air and maritime transportation, closely linked with meteorological factors [12].

2.4. Weather Conditions as the Basis for Planning and Risk Management

Based on relevant literature, much has been discussed regarding the theoretical basis of planning and risk management related to weather conditions. Parameters such as annual average rainfall, sunshine hours, snowfall amounts, and foggy days in Seattle serve as a solid foundation for understanding risks and opportunities. This understanding forms a crucial basis for managing climate risks [13].

In this context, this research aims to strengthen this literature foundation and contribute to thinking related to climate risk management. By further analyzing these weather factors, this research is expected to provide new insights and more effective strategies in dealing with climate risks in Seattle [14].

Over time, a deep understanding of these weather parameters proves beneficial not only for identifying risks but also for establishing a solid foundation for formulating more adaptive and responsive climate management strategies in the face of potential future changes. Thus, this research is expected to make a meaningful contribution to the development of better climate risk management practices [15].

3. Methodology

Figure 1 illustrates the research flow used in this study.

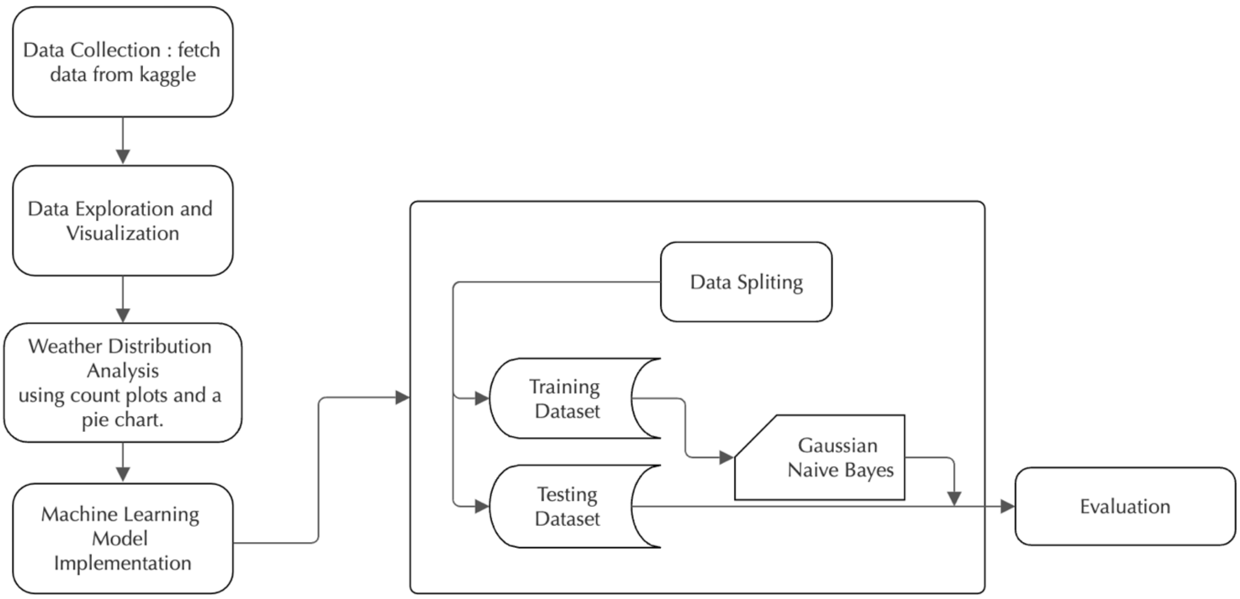

Figure 1. Research Workflow

3.1. Data Collection and Preprocessing

In the crucial phase of data collection and preprocessing, the Seattle weather dataset was obtained from Kaggle [16]. This step ensures the completeness of the required data for accurate analysis. Using the Pandas library, the data is carefully cleaned, missing values are addressed, and duplicates are identified and removed. This process not only enhances the integrity of the data but also improves the accuracy of the dataset used.

Furthermore, feature engineering is involved in this stage to enhance the quality of the dataset [17]. Normalization techniques are applied to adjust the scale of features, while encoding is used to transform categorical data into a format that can be processed by the model. This is essential to ensure that the dataset features align with the requirements of the intended model. Thus, data collection and preprocessing are not only initial steps in data analysis but also a solid foundation for building a reliable model.

3.2. Exploratory Data Analysis (EDA) and Visualization

Exploratory Data Analysis and Visualization are critical stages in understanding the weather dataset [18]. In this phase, tools such as Matplotlib, Seaborn, and Pandas are employed to generate informative visualizations regarding temperature patterns, precipitation, and wind speed throughout a specific time period [19]. Through the generated graphs and plots, temperature fluctuations, precipitation patterns, and wind speed variability can be clearly observed. Moreover, not limited to visualization, in-depth statistical analysis is also conducted to gain further insights into the dataset. Through this analysis, hidden trends and patterns can be identified, aiding in more informed decision-making regarding weather data.

3.3. Model Development and Evaluation

In the steps of model development and evaluation, the Gaussian Naive Bayes classification from scikit-learn is carefully chosen for weather prediction due to its compatibility with the characteristics of the used dataset [20]. Firstly, the dataset is divided into two parts, namely the training set and the testing set. In this stage, the model is trained using the training set to understand the data patterns. After training, the model's performance is evaluated using various metrics, including accuracy, confusion matrix, and classification report [21]. Accuracy provides an overview of how well the model can predict the weather correctly, while the confusion matrix gives insights into how well the model can handle specific classes. The classification report provides more detailed information about the model's performance for each prediction class. With this approach, it ensures that the developed model not only fits the data used but also has reliable performance in predicting weather conditions.

4. Results and Discussion

4.1. Distribusi Data Suhu Maksimum dan Minimum di Seattle

In conducting an analysis of the maximum and minimum temperature distribution in Seattle over the past few years, the data illustrated in Figures 2 and 3 provide a detailed overview of the dynamics of temperature changes during that period. Through this visualization, it can be clearly observed that the maximum temperature tends to peak during the summer season, reaching its highest point at around 18 degrees Celsius. Meanwhile, the minimum temperature also exhibits a similar trend, with the peak of the histogram in the range of about 12 degrees Celsius. This analysis clearly depicts a consistent pattern reflecting seasonal changes, where temperatures reach their peak during the summer and decline to their lowest point in the winter. Thus, understanding this temperature distribution can provide deeper insights into the temperature fluctuations over time in the Seattle region.

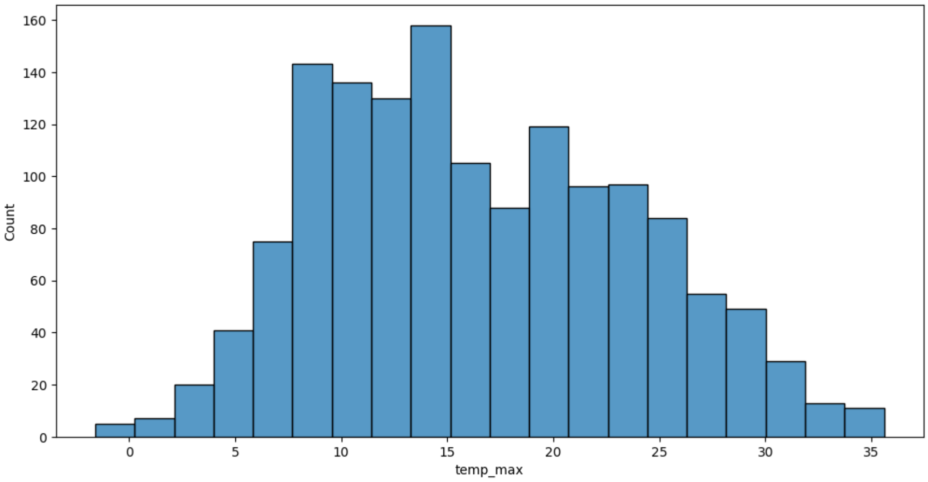

Figure 2. Distribution of Maximum Temperature Data in Seattle

Figures 2 and figure 3 provide detailed depictions of the distribution of maximum and minimum temperatures in Seattle over the past few years. From these images, it is clear that the maximum temperature in the city tends to reach its peak during the summer, reaching the histogram's peak at around 18 degrees Celsius. Conversely, the minimum temperature shows a similar trend to the maximum temperature, but with the histogram peak located around 12 degrees Celsius. These results reflect a consistent pattern with seasonal changes, where temperatures peak during the summer and reach their lowest during the winter.

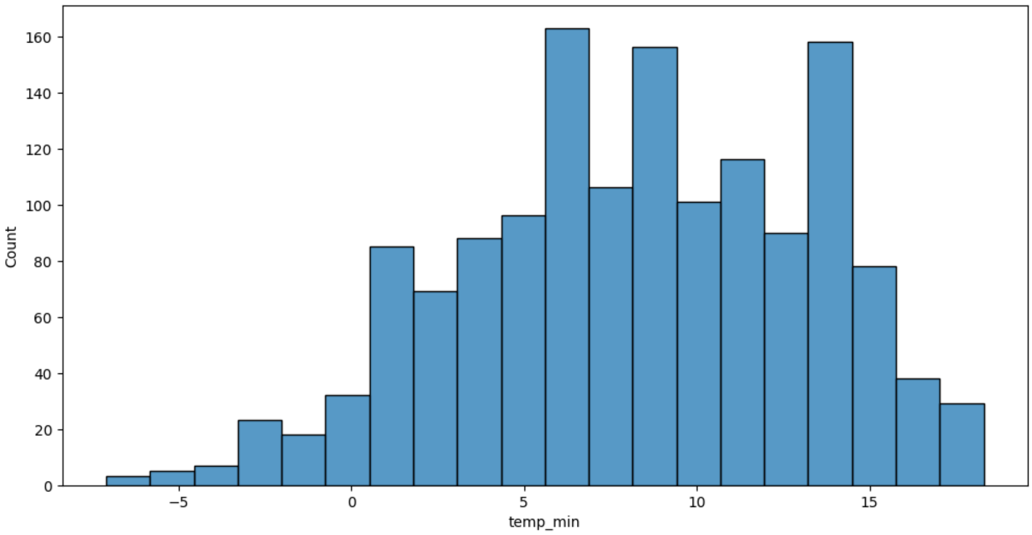

Figure 3. Distribution of Minimum Temperature Data in Seattle

Furthermore, the normal distribution of temperature data provides an overview that the weather in Seattle during the observation period tends to be relatively stable. The normal distribution indicates that the majority of temperature data is centered around the average value, with uniform fluctuations around it. This suggests a balance in temperature variation, which can serve as a basis for a deeper understanding of the climate characteristics of the city.

This analysis offers significant insights into understanding temperature fluctuations in Seattle and opens up potential for further applications, such as the development of predictive models that can provide more accurate weather information in the future. By comprehensively understanding temperature distribution, we can identify long-term trends and anticipate climate changes that may occur in the region.

4.2. Graphs of Maximum and Minimum Temperatures Each Month Each Year

In the temperature analysis of Seattle during the period from 2012 to 2015, figures 4 and figure 5 depict maximum and minimum temperatures, providing a consistent picture of the increasing temperature trends from year to year. This temperature increase not only reflects seasonal climate changes, such as the peak maximum temperature in August and minimum temperature in December but also indicates larger climate changes in the region.

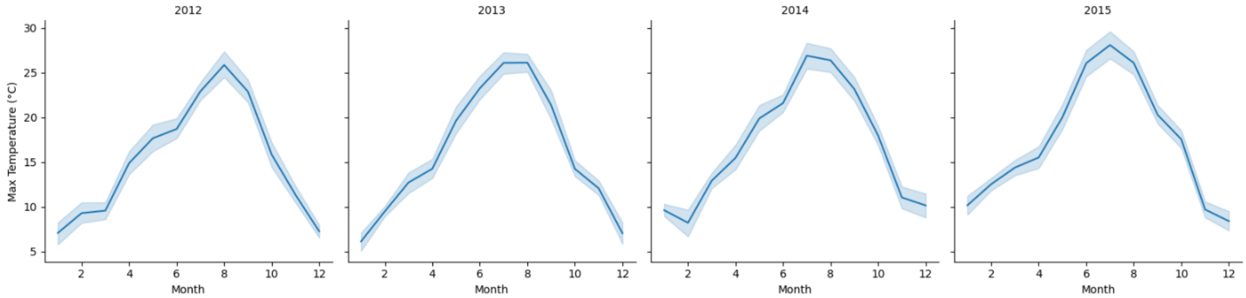

Figure 4. Maximum Temperature in Each Month for Each Year

Figures 4 and figure 5 reflect the maximum and minimum temperatures in Seattle during the period from 2012 to 2015. Both figures provide a consistent overview of the increasing temperature trends from year to year. This increase indicates significant climate change in this region. The peak of the maximum temperature occurring in August and the minimum temperature occurring in December serve as clear indicators that these changes are seasonal. However, these changes also reflect a larger pattern of climate change, highlighting broader and deeper impacts on the climatic conditions in the region.

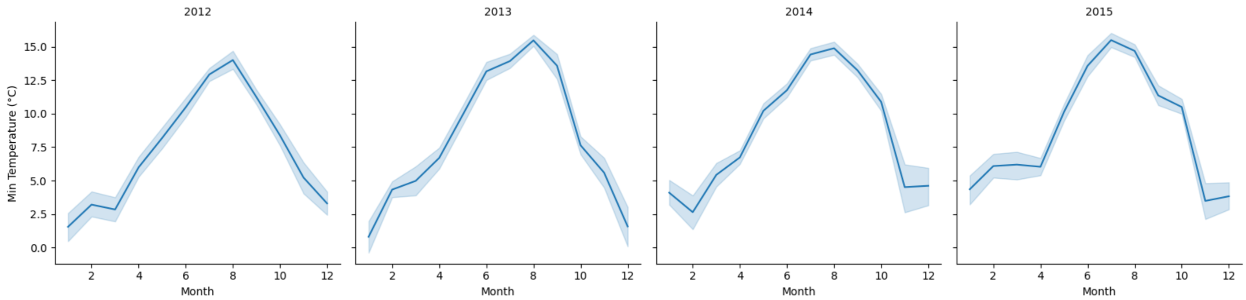

Figure 5. Minimum Temperature in Each Month in Every Year

The upward trend in temperature, as seen in these images, becomes crucial for stakeholders across various sectors, including government, businesses, and the general public. With a better understanding of these changes, appropriate mitigation measures can be taken to reduce their impact. For instance, infrastructure and energy policies can be adjusted to address potential extreme temperatures in the future. Additionally, community-based approaches, such as education on climate change adaptation, can also be implemented.

The maximum and minimum temperature data from these images provide a strong foundation for further analysis of how climate change affects ecosystems, daily life, and other sectors. Therefore, an in-depth understanding of these temperature trends is not only beneficial for stakeholders directly in Seattle but also globally relevant for comprehending and addressing the impacts of climate change.

4.3. Monthly Rainfall Each Year

The consistent increase in rainfall patterns in Seattle from 2012 to 2015, as reflected in figure 6, carries significant implications for several critical sectors. Particularly, changes in the rainy season can have substantial impacts on the agricultural sector. Plant growth and overall agricultural production are highly influenced by adequate rainfall, and the peak rainfall in December indicates that intense rainy seasons at the end of the year can play a crucial role in supporting crop productivity.

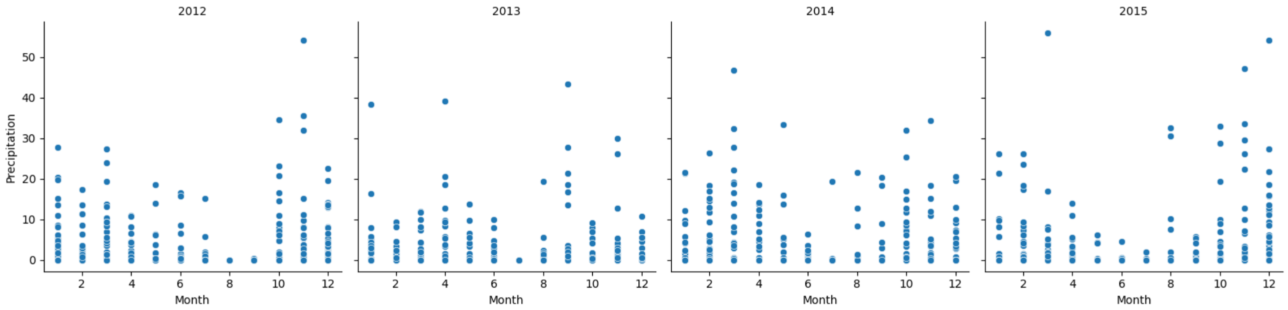

Figure 6. Monthly Rainfall for Each Year

In addition, the impact on the infrastructure sector should also be carefully considered. Increased rainfall can trigger the risk of floods, landslides, and other disturbances to transportation and settlement infrastructure. Effective planning and adaptation of infrastructure are becoming increasingly important to address the potential consequences of these changes in rainfall patterns. Therefore, a profound understanding of rainfall trends as presented in this picture can assist stakeholders in taking necessary preventive and mitigation measures to protect the community, agriculture, and city infrastructure from potential impacts. Thus, this research contributes essential insights into risk management and sustainable planning in Seattle.

4.4. Wind Speed Each Month Every Year

Figure 7 provides in-depth insights into the wind speed in Seattle over the last four years. With relatively constant wind speeds throughout the year, this picture indicates that the region has considerable stability in terms of average wind speed. Observations show that the highest wind speeds are recorded in January, indicating that the winter season, particularly early in the year, tends to experience stronger winds.

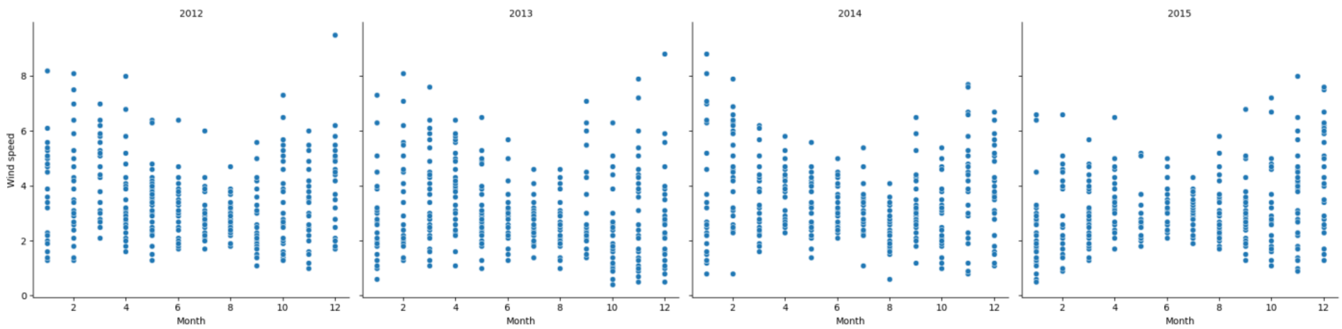

Figure 7. Wind Speed Each Month in Each Year

This wind speed data has significant implications, especially in the transportation sector, particularly air and sea transportation. High wind speeds can impact the operations of flights and shipping, considering that atmospheric dynamics can pose additional challenges for aircraft and ship control. Therefore, these results can provide valuable guidance for stakeholders in planning and managing transportation activities in Seattle, especially during the winter months that tend to be windier. The sustainability of observing wind speed can also provide further information about future changes in atmospheric dynamics, which can be utilized to enhance safety and efficiency in transportation in the region.

4.5. Bar Graph of Average Rainfall, Sunshine, Snowfall, and Fog

Figure 8 illustrates the average amount of rainfall, hours of sunshine, snowfall, and the number of foggy days each year in Seattle, opening the door to deep insights into the annual climate dynamics in the city.

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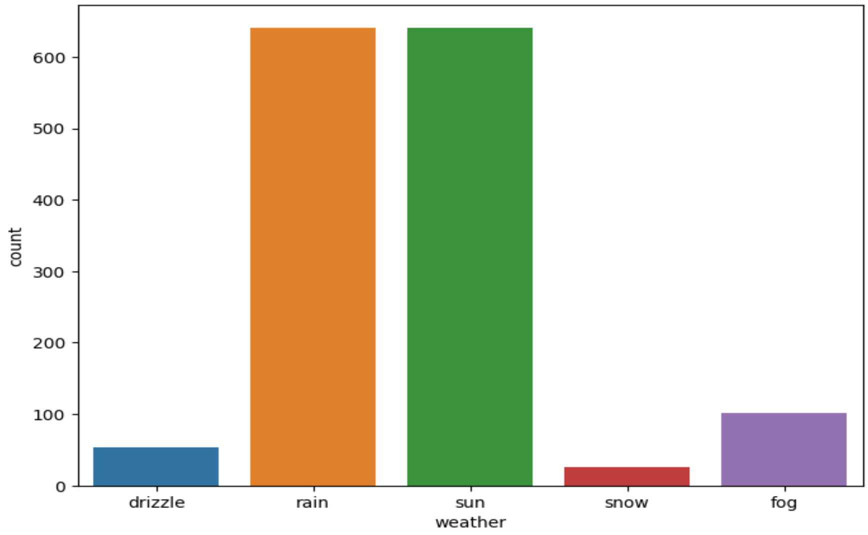

Figure 8. Average Annual Rainfall, Sunshine, Snow, and Fog in One Year

This data shows that rainy weather dominates most of the time, reaching its peak in December and contributing approximately 1,200 millimeters of rainfall per year. Conversely, sunny weather, although not always dominant, has a significant impact, especially in July with an average of 280 hours of sunshine. Both of these phenomena contribute significantly to the daily experiences of the inhabitants, as well as to sectors vulnerable to fluctuations in weather conditions. In addition, data on snow and fog provide additional insights into seasonal variations in Seattle, with the highest snowfall occurring in January, averaging 30 centimeters, and the highest number of foggy days in January with an average of 15 days. This information is not only beneficial for planning daily activities but also strengthens our understanding of climate change and weather phenomena in the Seattle region.

4.6. Percentage of Weather Types in Seattle

The results from figure 9 reveal that rainy weather and sunny weather each contribute about 43.9% of the total days in a year in Seattle. The high percentage of both types of weather reflects the dynamic climate characteristics in the region. Rainy weather, with a significant contribution of 43.9%, reflects seasonal conditions that impact the daily activities of the population, including mobility, work, and recreation.

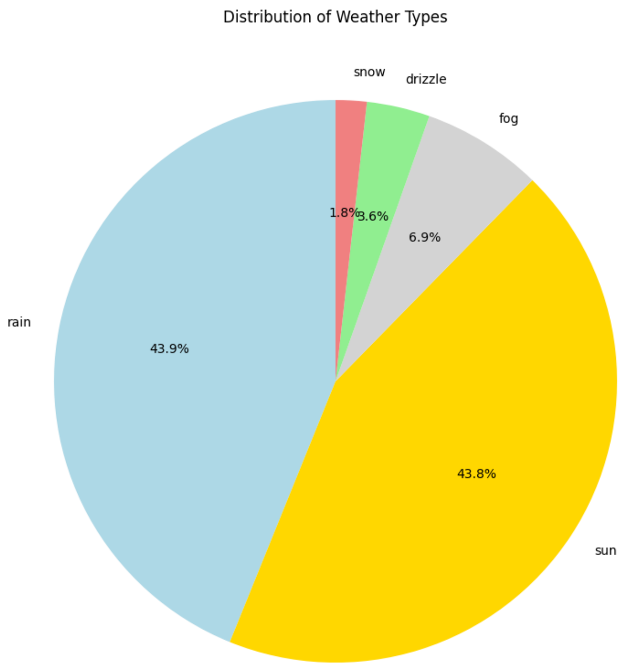

Figure 9. Distribution of Weather Types

On the other hand, clear weather, which also has a high percentage, becomes a crucial consideration for the community and sectors highly dependent on weather conditions, such as tourism and agriculture. A profound understanding of the distribution of these weather types not only provides insights into daily fluctuations but also establishes a solid foundation for long-term planning that takes into account seasonal weather variations in Seattle. This data can serve as a useful basis for relevant parties, both in managing economic activity risks and in making daily decisions related to weather factors.

5. Conclusion

Based on the analysis of weather conditions in Seattle, findings from the distribution of maximum and minimum temperatures indicate significant fluctuations between summer and winter. The increasing temperature trend over the years provides an overview of potential climate changes in the region. Rainfall data shows consistent increases over time, especially during the winter, which can have a significant impact on the environment and daily life. The relatively constant wind speed throughout the year provides an understanding of wind stability, which can affect the transportation and maritime sectors.

Annual averages of rainfall, sunshine hours, snowfall, and foggy days provide a basis for long-term planning and risk management in Seattle. The percentages of rainy and clear weather throughout the year offer a clear picture of the seasons and aid in planning daily activities. By detailing these findings, this research aims to provide deeper insights for the general public, natural resource managers, and economic sectors regarding the impacts and opportunities that may arise from future weather changes. The hope is that this research can make a significant contribution to efforts to mitigate and adapt to the ever-changing weather dynamics in the city of Seattle.

6. Declarations

6.1. Author Contributions

Conceptualization: N.C.R., A.N.; Methodology: N.C.R., A.N.; Software: N.C.R.; Validation: A.N.; Formal Analysis: N.C.R.; Investigation: N.C.R.; Resources: A.N.; Data Curation: N.C.R.; Writing – Original Draft Preparation: N.C.R.; Writing – Review and Editing: N.C.R., A.N.; Visualization: N.C.R.; All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J. Liu, R. Li, S. Li, A. Meucci, and I. R. Young, "Increasing wave power due to global climate change and intensification of Antarctic Oscillation," *Appl. Energy*, vol. 358, no. March, pp. 1–12, 2024, doi: https://doi.org/10.1016/j.apenergy.2023.122572.

[2] P. Zhu, Z. (Justin) Zhang, and B. Lin, "Understanding spatial evolution of global climate change risk: Insights from convergence analysis," *J. Clean. Prod.*, vol. 413, no. August, pp. 137423, 2023, doi: https://doi.org/10.1016/j.jclepro.2023.137423.

[3] G. Bocewicz, G. Radzki, I. Nielsen, M. Witczak, and B. Zbigniew, "UAVs fleet mission planning robust to changing weather conditions," *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 10518–10524, 2020, doi: https://doi.org/10.1016/j.ifacol.2020.12.2798.

[4] S. R. Moreno, L. O. Seman, S. F. Stefenon, L. dos S. Coelho, and V. C. Mariani, "Enhancing wind speed forecasting through synergy of machine learning, singular spectral analysis, and variational mode decomposition," *Energy*, vol. 292, no. April, pp. 130493, 2024, doi: https://doi.org/10.1016/j.energy.2024.130493.

[5] L. Gouldsbrough, R. Hossaini, E. Eastoe, and P. J. Young, "A temperature dependent extreme value analysis of UK surface ozone, 1980–2019," *Atmos. Environ.*, vol. 273, no. 1–13, pp. 118975, 2022, doi: https://doi.org/10.1016/j.atmosenv.2022.118975.

[6] B. Wilson, M. Pope, J. R. Porter, E. Kearns, E. Shu, M. Bauer, N. Freeman, M. Amodeo, D. M-Vazquez, H. Hsieh, and M. Tarasovitch, "Characterizing changes in extreme ozone levels under 2050s climate conditions: An extreme-value analysis in California," *Atmos. Environ. X*, vol. 16, no. December, pp. 1–10, 2022, doi: https://doi.org/10.1016/j.aeaoa.2022.100195.

[7] N. Abid, F. Ahmad, J. Aftab, and A. Razzaq, "A blessing or a burden? Assessing the impact of Climate Change Mitigation efforts in Europe using Quantile Regression Models," *Energy Policy*, vol. 178, no. 1–16, pp. 113589, 2023, doi: https://doi.org/10.1016/j.enpol.2023.113589.

[8] N. N. van der Breggen and P. F. Hudson, "Influence of atmospheric rivers on extreme rainfall and high streamflow events in northwestern Europe: Rur (Roer) River basin," *J. Hydrol. Reg. Stud.*, vol. 51, no. February, pp. 1–15, 2024, doi: https://doi.org/10.1016/j.ejrh.2023.101644.

[9] R. H. Patil, M. Laegdsmand, J. E. Olesen, and J. R. Porter, "Effect of soil warming and rainfall patterns on soil N cycling in Northern Europe," *Agric. Ecosyst. Environ.*, vol. 139, no. 1, pp. 195–205, 2010, doi: https://doi.org/10.1016/j.agee.2010.08.002.

[10] J. Lian, F. Ye, P. Wang, Y. Guo, H. Wang, T. Xiao, and D. Xiong, "Integrated transportation of offshore wind turbine and bucket foundation based on a U and K shaped assembled platform," *Ocean Eng.*, vol. 275, no. May, pp. 114096, 2023, doi: https://doi.org/10.1016/j.oceaneng.2023.114096.

[11] C. Yu, G. Yan, C. Yu, X. Liu, and X. Mi, "MRIformer: A multi-resolution interactive transformer for wind speed multi-step prediction," *Inf. Sci. (Ny).*, vol. 661, no. March, pp. 120150, 2024, doi: https://doi.org/10.1016/j.ins.2024.120150.

[12] L. Xiaomeng, Z. Minbo, Z. Xiaoyan, T. Bo, and G. Saiyi, "Numerical-simulation study on the influence of wind speed and segregation effect on spontaneous combustion of coal bunker," *Case Stud. Therm. Eng.*, vol. 52, no. December, pp. 1–18, 2023, doi: https://doi.org/10.1016/j.csite.2023.103678.

[13] J. J. Porter and C. Clark, "Usable, but unused: A critical story of co-producing the UK's Climate Change Risk Assessments," *Environ. Sci. Policy*, vol. 139, no. January, pp. 83–91, 2023, doi: https://doi.org/10.1016/j.envsci.2022.10.018.

[14] A. Sakhel, "Corporate climate risk management: Are European companies prepared?," *J. Clean. Prod.*, vol. 165, no. November, pp. 103–118, 2017, doi: https://doi.org/10.1016/j.jclepro.2017.07.056.

[15] T. A. Brás, S. G. Simoes, F. Amorim, and P. Fortes, "How much extreme weather events have affected European power generation in the past three decades?," *Renew. Sustain. Energy Rev.*, vol. 183, no. September, pp. 113494, 2023, doi: https://doi.org/10.1016/j.rser.2023.113494.

[16] H. Jiang, Y. Chen, H. Jiang, Y. Ni, and H. Su, "A granular sigmoid extreme learning machine and its application in a weather forecast," *Appl. Soft Comput.*, vol. 147, no. November, pp. 110799, 2023, doi: https://doi.org/10.1016/j.asoc.2023.110799.

[17] M. Liu, C. Guo, and L. Xu, "An interpretable automated feature engineering framework for improving logistic regression," *Appl. Soft Comput.*, vol. 153, no. March, pp. 111269, 2024, doi: https://doi.org/10.1016/j.asoc.2024.111269.

[18] J. R. Gautney, "A new approach to exploratory data analysis in hominin phylogenetic reconstruction," *J. Hum. Evol.*, vol. 182, no. September, pp. 103412, 2023, doi: https://doi.org/10.1016/j.jhevol.2023.103412.

[19] J. Sánchez-Morales, E. Pardo-Igúzquiza, and F. J. Rodríguez-Tovar, "Terrain methods on spectral analysis for paleoclimate interpretations: A novel visualization technique using python," *Comput. Geosci.*, vol. 175, no. June, pp. 1–13, 2023, doi: https://doi.org/10.1016/j.cageo.2023.105342.

[20] P. Venkata and V. Pandya, "Data mining model and Gaussian Naive Bayes based fault diagnostic analysis of modern power system networks," *Mater. Today Proc.*, vol. 62, no. Part 13, pp. 7156–7161, 2022, doi: https://doi.org/10.1016/j.matpr.2022.03.035.

[21] W. Tang, F. Zhou, X. Zheng, Q. Wang, Y. Wang, L. Hu, J. J. Sheng, and X. Wang, "Evaluation of matrix energization effect of pre-fracturing method in tight reservoirs- A comparative study of CO2, N2, and water," *Geoenergy Sci. Eng.*, vol. 233, no. February, pp. 212535, 2024, doi: https://doi.org/10.1016/j.geoen.2023.212535.