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Developing an Interactive Climate Dashboard through Data-Driven Storytelling for Public Climate Awareness

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Abstract

Climate change presents a significant global challenge, highlighting the need for accessible and effective communication strategies to improve public understanding of climate-related information. Although climate datasets are increasingly available, their technical complexity may limit their accessibility to non-specialist audiences. This study aims to develop an interactive climate data dashboard that integrates data visualization and interactive storytelling to support public education and awareness of climate change. The research employed a descriptive approach comprising four stages: data collection, data cleaning and preprocessing, data analysis and implementation, and interactive dashboard development. Secondary climate data were obtained from the Indonesia Climate dataset available on Kaggle, with an intended observation period from January 2010 to January 2020, subject to the dataset's verified temporal coverage. Data processing and analysis were conducted using Python in Google Colaboratory, while Google Looker Studio was used to develop the interactive dashboard. The analytical and visualization components included geographical temperature comparisons, monthly temperature summaries, and exploratory visualizations of relationships among climate variables. The dashboard integrates geographical and temporal exploration with contextual narratives to help users interpret climate observations more systematically. The resulting design provides a structured approach to presenting climate information through interactive visualizations and explanatory content. This study contributes to the development of data-driven climate communication by demonstrating how historical climate data can be organized into an interactive educational medium. However, the effectiveness of the dashboard in improving public awareness has not yet been empirically established. Further research should evaluate its usability, information comprehension, and educational impact through user-based testing.

Keywords: climate change; interactive dashboard; interactive storytelling; climate data visualization; public awareness; climate communication

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Introduction

Climate change has become one of the most pressing global challenges due to its extensive implications for environmental sustainability, human health, economic stability, and societal well-being. It is characterized by long-term changes in temperature, precipitation, humidity, wind patterns, and other climatic variables that influence ecosystem dynamics and human activities. Climate is generally defined in terms

of the statistical characteristics of weather conditions in a particular region over an extended period, conventionally 30 years or more (Intergovernmental Panel on Climate Change [IPCC], 2021; World Meteorological Organization [WMO], 2017). Various national and international institutions regularly provide climate data to support the understanding of atmospheric dynamics, the monitoring of environmental changes, and evidence-based decision-making. Nevertheless, the availability of climate data does not automatically ensure that the information can be effectively understood and utilized by the public. The complexity of scientific datasets, the use of technical terminology, and the lack of contextualized information presentation may create barriers to public understanding of climate change and its implications for everyday life (Lorenzoni et al., 2007; Weber & Stern, 2011).

The urgency of improving public understanding of climate change has increased alongside growing evidence of changes in the global climate system, including rising global mean surface temperatures, the loss of ice mass, sea-level rise, and changes in the patterns and intensity of extreme weather events (IPCC, 2021, 2023). These changes can contribute to increasing risks of droughts, floods, forest fires, food insecurity, and threats to public health (IPCC, 2022). However, the relationships between climate change and its impacts on society are not always readily understood when information is presented exclusively through numerical data, statistical tables, or graphs that are disconnected from real-world contexts (Harold et al., 2016; Moser, 2010). Therefore, climate change communication requires an approach that emphasizes not only data accuracy and completeness but also comprehensibility, relevance, and audience engagement (Moser, 2016; Nisbet, 2009). In this context, developing information systems capable of translating scientific data into accessible and contextualized knowledge represents a strategic effort to strengthen climate literacy and encourage public awareness of the importance of climate change mitigation and adaptation (Lee et al., 2015; O'Neill & Nicholson-Cole, 2009).

With the advancement of information and communication technologies, interactive data visualization has emerged as a promising approach to bridging the gap between the complexity of scientific information and the public's need for accessible knowledge. Through dynamic graphs, interactive maps, visual indicators, and data exploration features, users can observe patterns, compare conditions across different periods, and identify climate trends in a more contextualized manner (Munzner, 2014; Shneiderman, 1996). Nevertheless, interactive visualization alone may not generate meaningful understanding if it is not accompanied by adequate explanations of the meaning, relationships, and implications of the information presented (Grainger et al., 2016; Harold et al., 2016). Data presentations that focus primarily on technical exploration may limit the ability of non-expert users to connect visual findings with environmental challenges that affect their daily lives. Consequently, an approach that integrates data visualization with effective communication strategies is needed to establish a coherent progression of understanding, connect scientific evidence with social contexts, and sustain users' attention throughout the learning process (Dahlstrom, 2014; Kosara & Mackinlay, 2013).

One approach that may address these challenges is interactive storytelling, a strategy for communicating information through narratives that allow users to interact with content, explore data, and follow explanatory sequences according to their interests and needs (Segel & Heer, 2010). In the context of climate information, this approach can integrate textual narratives, interactive graphs, dynamic maps, visual illustrations, and data exploration features to explain climatic phenomena in a more structured and accessible manner. For example, users can follow a narrative describing changes in temperature over time, examine their relationships with relevant environmental phenomena, and explore the implications of these changes for human activities and societal well-being. This approach can also facilitate the communication of climate change mitigation and adaptation strategies through contexts that are more closely connected to everyday experiences. By combining data, visualization, and narrative, interactive storytelling has the potential to help users comprehend complex information through a more coherent communication process while encouraging active participation in knowledge exploration (Hullman & Diakopoulos, 2011; Kosara & Mackinlay, 2013). However, the effectiveness of this approach in improving public understanding and awareness requires empirical evaluation using appropriate indicators.

Various climate dashboards have been developed to provide access to meteorological and climatological information. Nevertheless, the challenge addressed in this study is not merely the availability of dashboards or the completeness of their datasets, but rather how such information can be designed to support public education and enhance user engagement. Dashboards primarily intended for data monitoring and analysis may have limitations when used by members of the general public who lack scientific or technical backgrounds (Few, 2006; Sarikaya et al., 2019). Furthermore, integrating interactive narratives, climate data visualization, and public education objectives requires a design that considers information architecture, interaction flows, and the relationships between scientific evidence and its implications for society (Grainger et al., 2016). Based on these challenges, the research gap addressed in this study concerns the need to develop and evaluate climate information systems that integrate interactive storytelling into dashboard design to support public education and enhance climate change awareness. This gap should be examined through a review of relevant literature to establish the study's position in relation to existing approaches and findings.

Accordingly, this study aims to develop an interactive climate data dashboard that integrates interactive storytelling to support public education and improve awareness of climate change. The proposed system is designed to present climate information through a combination of contextualized narratives, data visualization, and interactive mechanisms that enable users to explore climate change in a more accessible and meaningful manner. The information presented may include temperature trends over a specified period, illustrations of the impacts of climate change on the environment and society, and information about relevant mitigation and adaptation measures. The expected contributions of this study encompass a technical contribution through the development of a dashboard design that

integrates data, visualization, and interactive narratives, as well as an educational contribution through the provision of a more contextualized information medium for the general public. Furthermore, the system should be evaluated to assess its usability, user engagement, and the comprehensibility of the information presented (Bangor et al., 2008; Brooke, 1996). Ultimately, this study is expected to contribute to the development of climate information systems that function not only as data presentation platforms but also as tools for scientific communication and public education, thereby supporting the advancement of climate literacy.

Method

This study employed a descriptive research approach involving four main stages: data collection, data cleaning and preprocessing, data implementation and analysis, and interactive dashboard development. The research was designed to examine historical climate data and transform the analytical results into accessible visual representations through an interactive storytelling approach. This approach integrates data visualization with contextual narratives to facilitate public understanding of climate-related information.

The primary dataset was obtained from the publicly available Indonesia Climate dataset hosted on Kaggle (greegtitan, n.d.): https://www.kaggle.com/datasets/greegtitan/indonesia-climate. The intended observation period covered January 2010 to January 2020, subject to verification against the actual temporal coverage of the downloaded dataset. The processed data were analyzed using Python in Google Colaboratory (Bisong, 2019) and subsequently integrated into Google Looker Studio to develop an interactive dashboard. The research workflow consisted of four sequential stages, as illustrated in Figure 1.

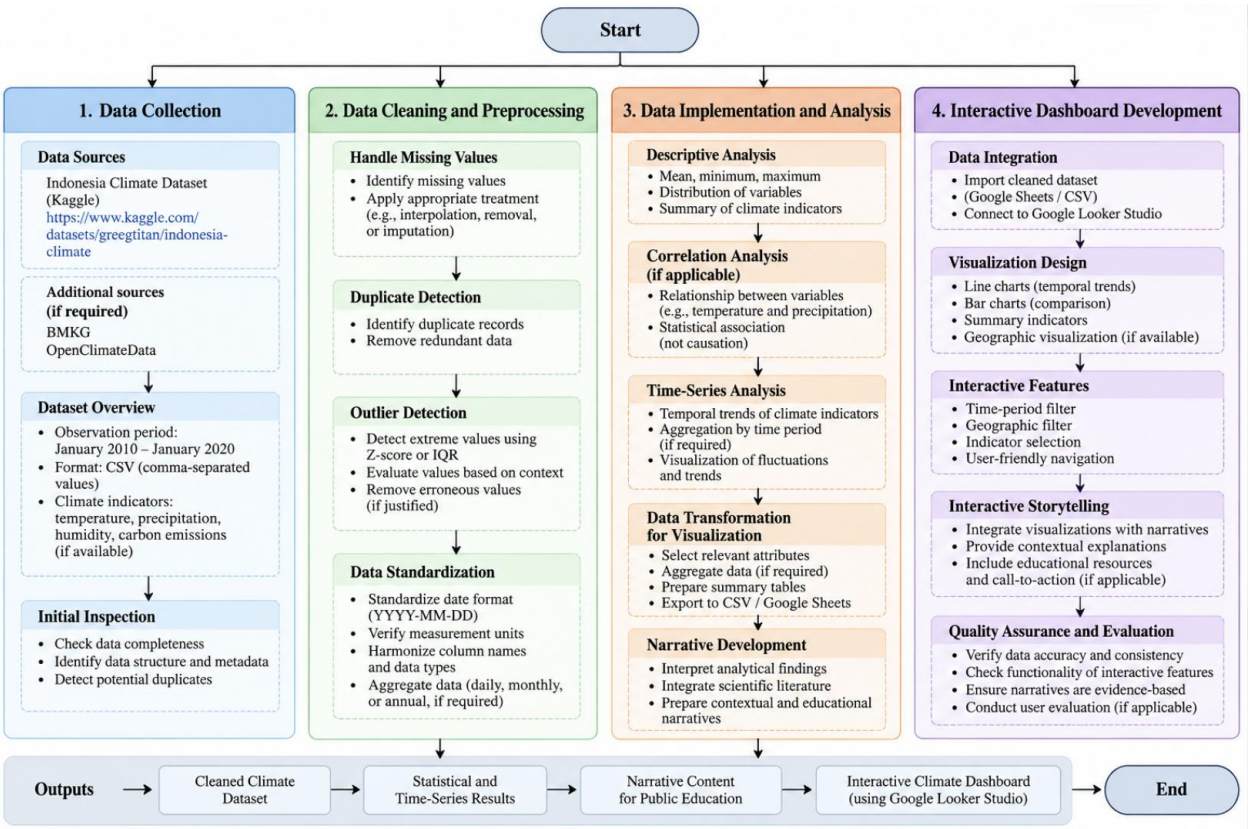


Figure 1. Research Workflow

a. Data Collection

The data collection stage aimed to obtain relevant climate information to support the development of an interactive dashboard for public education. This study used secondary data obtained from the Indonesia Climate dataset available on Kaggle. The dataset was downloaded in CSV (comma-separated values) format for subsequent processing and analysis. The proposed observation period ranged from January 2010 to January 2020; however, the actual coverage, temporal resolution, and availability of individual variables must be verified against the original dataset.

The collected data were examined to identify the available climate indicators, including temperature, precipitation, and other variables relevant to the research objectives. Each variable was assessed in terms of its attribute name, measurement unit, geographical coverage, observation frequency, and temporal range. This initial assessment was necessary to determine the suitability of the dataset for descriptive and time-series analyses (Wilks, 2019).

In addition to quantitative climate data, relevant scientific literature and official publications were used to develop contextual narratives about climate change, its environmental implications, and potential mitigation and adaptation measures. These supplementary sources provided the contextual information required to communicate analytical findings to non-specialist audiences. The Kaggle dataset served as the primary data source, whereas any additional information obtained

from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) or OpenClimateData should be explicitly identified and documented if incorporated into the analysis.

An initial data inspection was conducted to assess dataset completeness, attribute consistency, date formats, potential duplicate records, and the plausibility of observed values (Pipino et al., 2002; Wang & Strong, 1996). The dataset metadata were also examined to verify the number of observations, the number of variables, and the available observation period. The results of this inspection informed the subsequent data-cleaning and preprocessing procedures.

b. Data Cleaning and Preprocessing

Data cleaning and preprocessing were performed to improve the quality, consistency, and suitability of the dataset before statistical analysis. Microsoft Excel was used for preliminary data inspection, while Google Colaboratory served as the primary environment for data processing using Python. The preprocessing procedures included missing-value assessment, duplicate detection, outlier identification, date-format standardization, and measurement-unit consistency checks (Rahm & Do, 2000).

First, missing values were identified by examining the completeness of each variable and determining the proportion of unavailable observations. The treatment of missing values depended on their distribution, frequency, and potential influence on the analysis. Observations with missing values could be excluded when their removal was methodologically justified and unlikely to introduce substantial bias. Alternatively, imputation techniques could be applied when supported by the characteristics of the data (Little & Rubin, 2019; Schafer & Graham, 2002). For time-series data, interpolation was considered only when the temporal structure and characteristics of the relevant variable justified its use. All decisions concerning missing-value treatment should be documented to ensure methodological transparency.

Second, duplicate records were identified to prevent repeated observations from distorting the analytical results. Duplicate detection considered relevant combinations of attributes, such as observation date, geographical location, and climate indicators. Third, outliers were examined using statistical techniques such as the Z-score or interquartile range (IQR), depending on the distribution and characteristics of the variables (Iglewicz & Hoaglin, 1993; Wilks, 2019). Extreme observations were not automatically removed because they might represent genuine climatic events. Removal was justified only when the observations could be identified as erroneous or inconsistent through appropriate verification.

Fourth, data standardization was performed to ensure consistency in date formats, column names, data types, and measurement units (Wickham, 2014). Date fields were standardized to support temporal analysis, while measurement units were checked for consistency across observations. Where necessary, observations were aggregated into daily, monthly, or annual summaries according to the original temporal resolution and analytical requirements. For example, temperature could be summarized using mean values, whereas precipitation could be aggregated using

cumulative values when appropriate for the measurement interval and variable definition (WMO, 2017).

The preprocessing procedures were implemented in Python using Google Colaboratory and appropriate data-processing libraries (Hunter, 2007; McKinney, 2010). Following cleaning, the dataset was re-examined to assess structural consistency, the completeness of analytical variables, and the plausibility of the remaining values. The resulting cleaned dataset was then prepared for statistical analysis and integration into the interactive dashboard.

c. Data Analysis and Implementation

The cleaned dataset was analyzed to characterize the available climate indicators and identify temporal patterns relevant to the research objectives. Google Colaboratory and Python were used as the primary analytical environment. The analysis focused on descriptive statistics and time-series analysis, with correlation analysis applied where the available variables and data characteristics justified its use.

Descriptive analysis was conducted to summarize the characteristics of the dataset using appropriate statistical measures, including the mean, minimum, maximum, and distribution of observations (Wilks, 2019). These measures provided an overview of the observed climate conditions and helped identify relevant information for visualization. The resulting summaries were used to determine which indicators could be communicated most effectively to the intended audience.

Time-series analysis was conducted to examine changes in climate indicators throughout the available observation period. The observations were organized according to their temporal resolution and aggregated when necessary to facilitate comparisons across periods. Temporal patterns were subsequently represented through graphical visualizations, allowing users to examine fluctuations and potential trends in the observed data (Hyndman & Athanasopoulos, 2021). The interpretation of these patterns considered the observation period, data completeness, and characteristics of the variables. Importantly, trends identified in historical observations were not automatically interpreted as evidence of causation or as definitive attribution of observed changes to global climate change (IPCC, 2021).

Correlation analysis was considered to investigate statistical associations between relevant variables, such as temperature and precipitation, when both variables were available and sufficient observations supported the analysis. The choice of correlation coefficient depended on the distribution of the variables and the characteristics of their relationships (Schober et al., 2018). Correlation results were interpreted as statistical associations rather than evidence of causal relationships.

Following the analytical stage, the data were transformed into a structure suitable for visualization. This process involved selecting relevant attributes, standardizing data formats, aggregating observations by time or geographical location where appropriate, and preparing summary tables for graphical presentation. The processed data were then connected to Google Looker Studio through compatible data sources, such as Google Sheets or CSV files imported through supported connectors.

Data implementation also involved preparing contextual narratives based on the analytical findings and relevant scientific literature. Each narrative was designed to explain the displayed indicators, describe the observed patterns, and clarify their potential relevance to climate-related issues. Narrative statements were aligned with the available evidence and supporting references to avoid interpretations that exceeded the scope of the data (Dahlstrom, 2014). Consequently, this stage connected the technical analysis with the communication objectives of the interactive storytelling approach.

d. Interactive Dashboard Development

The final development stage involved constructing an interactive dashboard using Google Looker Studio. The platform was selected to integrate the processed climate data and present analytical findings through accessible and interactive visualizations. The dashboard design emphasized readability, navigational clarity, visual consistency, and the integration of quantitative information with educational narratives (Few, 2006).

The visualizations were selected according to the characteristics of the available data and the intended communication objectives. Line charts were used to display temporal changes in climate indicators, while bar charts could be used to compare monthly, annual, or geographical observations when the dataset supported such comparisons. Summary indicators were incorporated where appropriate to provide an overview of selected climate measurements or changes during a specified period. The choice of visualization types was guided by the analytical purpose and the characteristics of the information being communicated (Munzner, 2014).

The interactive storytelling approach was incorporated by combining visualizations, explanatory text, and a structured sequence of information. Each visualization was accompanied by a concise narrative explaining the relevant indicator, the pattern observed in the data, and its potential significance in the context of climate change. The presentation was organized to guide users from general information toward more specific data exploration (Segel & Heer, 2010; Shneiderman, 1996). Narratives served as interpretive aids rather than substitutes for the underlying data, ensuring that the information remained evidence-based and transparent.

Interactive features, including time-period and geographical filters, were incorporated where the required attributes were available in the dataset and supported by the dashboard configuration. These features enabled users to customize the displayed information according to their interests and analytical needs. Links to relevant educational resources could also be included to provide access to additional information about climate change, mitigation, and adaptation.

Through the integration of data visualization, contextual narratives, and interactive exploration, the dashboard was designed to function as a digital educational medium that facilitates independent exploration of climate information. The development process therefore focused not only on presenting historical data but also on improving the accessibility and contextual understanding of scientific information for non-specialist audiences.

e. Quality Assurance and System Evaluation

Quality assurance was conducted to ensure that the information displayed in the dashboard was consistent with the cleaned dataset and analytical results. The verification process covered data accuracy, aggregation consistency, temporal coverage, measurement units, visualization labels, and the functionality of interactive features. The accompanying narratives were also reviewed to ensure that their interpretations were supported by the available evidence and traceable to relevant sources.

If the study intends to establish that the dashboard improves public awareness, empirical user evaluation is required as a separate methodological component (Bangor et al., 2008; Brooke, 1996). Such evaluation may include usability testing, assessments of information comprehension, and measurements of climate knowledge or awareness before and after dashboard use. The evaluation procedure should specify the participant characteristics, sampling method, measurement instruments, testing protocol, and statistical techniques used to analyze the results.

If the research is limited to dashboard development and functional verification, the findings should be reported as the development of an interactive data visualization and educational prototype. Improved public awareness should then be presented as an intended benefit or potential outcome rather than an empirically demonstrated effect. This distinction ensures that the study's conclusions remain consistent with the methodology and evidence obtained.

Results and Discussion

The results and discussion of this study are organized into three main themes to provide a systematic understanding of the data processing procedures, the characteristics of the observed climate patterns, and the implementation of an interactive dashboard using a data-driven storytelling approach. The discussion begins with climate data integration, preprocessing, and quality management to establish the reliability of the dataset used in the analysis. It then examines the spatiotemporal patterns of climate variables, including temperature, precipitation, humidity, and wind characteristics, to identify variations across geographical locations and observation periods. Finally, the discussion explores the development of the interactive climate dashboard and its potential to support public education through the integration of data visualization, contextual narratives, and interactive exploration features. This structure connects the technical processes with the analytical findings and their implications for communicating climate information to the public.

a. Climate Data Integration, Preprocessing, and Quality Management

The reliability of climate data analysis depends on the quality of the underlying dataset and the consistency of the preprocessing procedures applied before visualization. In this study, data integration and preprocessing were conducted to consolidate climate observations with geographical and meteorological station information, address missing values, and standardize relevant attributes for subsequent analysis. These procedures established the foundation for the interactive climate dashboard by organizing heterogeneous data into a

structure suitable for statistical analysis and geographical visualization. The original manuscript reports that the integration involved daily climate observations, provincial records, and meteorological station metadata, followed by data cleaning and the implementation of the processed dataset in the dashboard.

The initial stage involved integrating three datasets: daily climate observations (df_c), provincial information (df_p), and meteorological station records (df_s). A left outer join was used to combine these datasets into an integrated structure containing climate measurements and geographical metadata (McKinney, 2010). This integration enabled the climate observations to be associated with administrative regions and meteorological stations, thereby supporting the geographical grouping and exploration of climate conditions in the dashboard. Table 1 summarizes the principal datasets and their reported roles in the integration process.

Table 1. Climate Data Sources and Integration Structure

Dataset	Primary Information	Relevant Attributes	Role in the Study
Daily climate observations (`df_c`)	Daily meteorological measurements	Temperature, humidity, precipitation, and wind variables	Provides the quantitative basis for climate analysis
Provincial records (`df_p`)	Provincial administrative information	`province_id`, `province_name`	Supports regional identification and aggregation
Meteorological station records (`df_s`)	Station and geographical metadata	`station_name`, `region_name`, `latitude`, `longitude`, `region_id`, `province_id`	Supports station identification and geographical visualization
Integrated dataset	Combined climate and geographical information	Climate indicators, administrative identifiers, and station metadata	Provides the analytical dataset for subsequent processing and visualization

The integration structure presented in Table 1 demonstrates the complementary roles of meteorological measurements and geographical metadata. Daily observations provide the quantitative information required to examine climate conditions, while provincial and station records establish the geographical context for interpreting those observations. The integration also supports the development of location-based dashboard filters and maps. However, the reliability of this structure depends on the consistency of the join keys and the completeness of the resulting records. Therefore, the use of a left outer join should be accompanied by verification of unmatched identifiers and duplicate records to ensure that the integration does not introduce unintended data inconsistencies (Rahm & Do, 2000).

Following dataset integration, the study performed data cleaning to identify and address missing values. According to the manuscript, the imputation strategy was selected according to the characteristics of individual variables rather than applying a single treatment to all attributes. Mean imputation was used for average temperature, average relative humidity, precipitation, and average wind speed, whereas median imputation was applied to minimum temperature, maximum temperature, sunshine duration, and maximum wind speed. Categorical

wind direction was treated using the mode, while numerical wind direction was processed using a circular mean.

Table 2. Missing-Value Treatment According to Climate Variable

Variable	Description	Data Type	Reported Treatment
`Tavg`	Average temperature	Numerical	Mean imputation
`RH_avg`	Average relative humidity	Numerical	Mean imputation
`RR`	Precipitation	Numerical	Mean imputation
`ff_avg`	Average wind speed	Numerical	Mean imputation
`Tn`	Minimum temperature	Numerical	Median imputation
`Tx`	Maximum temperature	Numerical	Median imputation
`ss`	Sunshine duration	Numerical	Median imputation
`ff_x`	Maximum wind speed	Numerical	Median imputation
`ddd_car`	Categorical wind direction	Categorical	Mode imputation
`ddd_x`	Wind direction in degrees	Circular numerical	Circular mean imputation

Table 2 illustrates a variable-specific approach to missing-data treatment. The use of means and medians reflects two different imputation strategies, while the mode accommodates categorical observations. The circular mean is particularly relevant to wind direction because angular values are periodic: directions near 0° and 360° represent nearly the same orientation (Fisher, 1993; Mardia & Jupp, 2000). Nevertheless, imputation can affect statistical distributions and correlations, especially when missingness is extensive (Little & Rubin, 2019). For stronger methodological transparency, the final manuscript should report the proportion of missing values for each variable and clarify whether imputation was performed across the entire dataset or within specific temporal or geographical groups.

In addition to missing-value treatment, the manuscript describes the processing of wind-direction measurements. The categorical variable ddd_car was filled using the mode, while the numerical variable ddd_x was processed using the circular mean and subsequently rounded to selected directional categories. The reported directions included 0° and 360° for north, 90° for east, 180° for south, and 225° for southwest.

Table 3. Wind-Direction Processing and Data Standardization

Processing Component	Original Representation	Reported Procedure	Intended Purpose
Categorical wind direction	`ddd_car`	Mode imputation	Fill missing categorical observations
Numerical wind direction	`ddd_x` in degrees	Circular mean imputation	Account for the periodic nature of angular data
Directional categorization	Numerical angles	Rounding to selected directional categories	Simplify the representation of wind direction
Date and geographical attributes	Temporal and location-related fields	Integration with climate and administrative records	Support temporal analysis and geographical filtering

The procedures summarized in Table 3 indicate that data preparation considered the specific characteristics of wind-direction variables. Unlike ordinary numerical variables, angular measurements require circular statistics to avoid misleading averages around the 0°/360° boundary (Fisher, 1993). The subsequent categorization can simplify interpretation in a dashboard, although the selected categories should be defined consistently and applied to all relevant observations. The manuscript also discusses outlier handling in the broader methodological description; however, the supplied results do not specify the actual outlier-detection algorithm, thresholds, or number of records removed. These details should therefore be reported only after they have been verified from the implementation.

After the integration and cleaning procedures, the processed dataset was prepared for use in the interactive dashboard. The manuscript reports that the resulting data were used to visualize climate indicators, with users able to explore temperature, humidity, and other climate parameters according to selected periods, provinces, or meteorological stations. The geographical identifiers and station coordinates also supported spatial visualization and location-based exploration.

Table 4. Data Quality Management and Preparation for Visualization

Quality Dimension	Reported Procedure or Data Feature	Verification Requirement	Relevance to Dashboard Implementation
Dataset completeness	Missing-value identification and imputation	Confirm remaining missing values and document imputation results	Supports consistent summaries and visualizations
Record consistency	Integration of climate, provincial, and station datasets	Check join-key integrity and duplicate records	Reduces the risk of inconsistent regional information
Variable consistency	Variable-specific treatment of numerical and categorical data	Verify data types, units, and value ranges	Supports accurate interpretation of climate indicators
Temporal structure	Daily climate observations and date-related information	Confirm date formats, observation frequency, and temporal coverage	Enables time-based filtering and trend visualization
Geographical structure	Provincial identifiers and station coordinates	Verify geographical identifiers and coordinate validity	Supports spatial mapping and location-based filtering
Visualization readiness	Processed dataset used in the interactive dashboard	Compare displayed values with the processed analytical dataset	Helps maintain consistency between analytical results and dashboard outputs

Table 4 summarizes the quality dimensions relevant to preparing the integrated climate dataset for visualization. Completeness, record consistency, variable standardization, temporal structure, and geographical integrity are important because errors in any of these dimensions may affect the interpretation of the displayed results (Wang & Strong, 1996). For

example, inconsistent geographical identifiers may produce incomplete regional summaries, while incorrect date formats may distort temporal comparisons. Nevertheless, these dimensions represent verification requirements rather than confirmed validation outcomes: the manuscript does not provide quantitative evidence of the remaining missing values, duplicate counts, or validation error rates. Reporting these measurements would strengthen the reproducibility and credibility of the study.

Overall, the data integration and preprocessing procedures established the technical foundation for the subsequent climate analysis and dashboard implementation. The combination of daily meteorological observations, administrative records, and station metadata enabled the dataset to support both temporal analysis and geographical exploration. Furthermore, variable-specific imputation and the treatment of wind direction demonstrated an effort to account for differences in data characteristics. However, the effectiveness of these procedures ultimately depends on transparent reporting of the actual preprocessing results and verification of the integrated dataset. Establishing this foundation is essential before interpreting climate patterns or communicating findings through interactive storytelling, because the credibility of the resulting visualizations depends on the quality and traceability of the underlying data.

b. Spatiotemporal Climate Patterns and Relationships among Climate Variables

The analysis of climate data provides insights into the spatial distribution, temporal variation, and statistical relationships among meteorological variables across Indonesia. Based on the results presented in the manuscript, the interactive dashboard integrates geographical heatmaps, temperature comparisons, monthly summaries, and factor analysis to facilitate the exploration of climate conditions across locations and observation periods. The reported findings encompass temperature, precipitation, relative humidity, wind speed, and wind direction. These visualizations provide a basis for identifying differences between locations and examining the variability of observed climate indicators. However, the findings should be interpreted in relation to the available observations and should not be treated as definitive evidence of long-term climate change without an appropriate temporal analysis and supporting evidence.

The geographical analysis presented in Figure 3 of the original manuscript identifies differences in reported temperature values across Indonesian locations. Surabaya, East Java, is reported to have the highest temperature in the displayed regional table, at 33.7°C, followed by Kolaka, Southeast Sulawesi, and Palu, Central Sulawesi, each at 33.4°C. The manuscript also reports differences in precipitation among selected locations, indicating that high recorded temperatures do not necessarily correspond to the same precipitation levels in the displayed observations.

Table 5. Reported Geographical Differences in Temperature and Precipitation

Location	Province	Reported temperature (°C)	Reported precipitation (mm)	Interpretation based on the manuscript
Surabaya	East Java	33.7	6.3	Highest temperature among the locations identified in the regional table
Kolaka	Southeast Sulawesi	33.4	Not specified	Among the locations with the highest reported temperatures
Palu	Central Sulawesi	33.4	Not specified	Among the locations with the highest reported temperatures
Pontianak	West Kalimantan	33.0	10.7	Highest precipitation among the selected locations discussed
Bima	West Nusa Tenggara	33.0	3.9	Lowest precipitation among the selected locations discussed

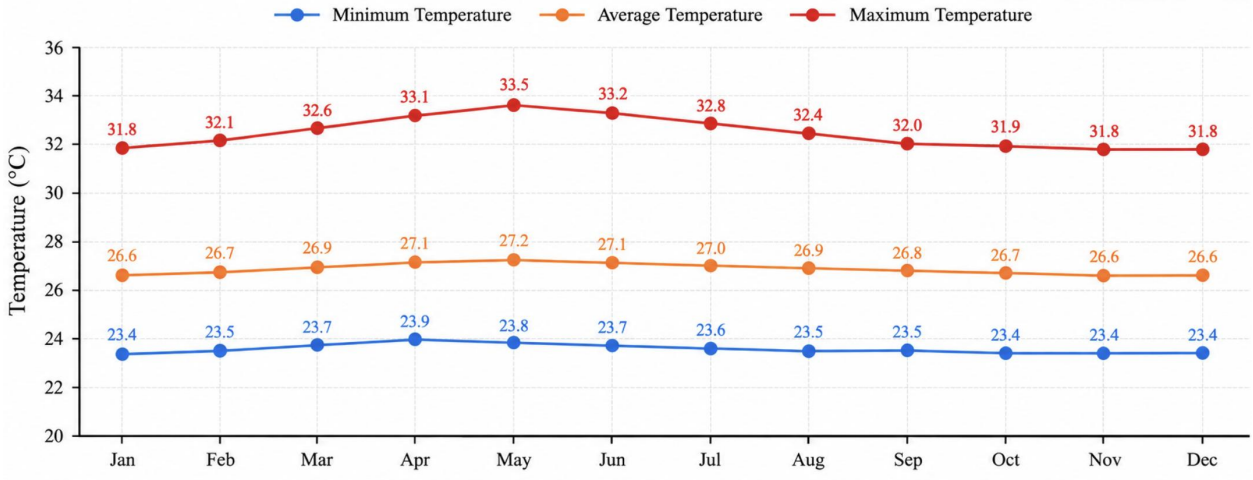
Table 5 highlights geographical variation in the selected temperature and precipitation observations. Surabaya, Kolaka, and Palu are identified as locations with relatively high reported temperatures, whereas Pontianak and Bima illustrate differences in precipitation despite their similar reported temperatures. This comparison demonstrates the value of presenting multiple climate indicators together rather than interpreting temperature in isolation (Aldrian & Susanto, 2003; Supari et al., 2018). Nevertheless, the values should be understood as observations reported for the selected locations, not as established long-term climatic characteristics. The manuscript does not specify the exact observation dates, aggregation periods, or measurement frequencies associated with every value in this table. These details should be verified before the table is used to support broader geographical or climatological conclusions (WMO, 2017).

The monthly temperature analysis in the manuscript examines minimum, average, and maximum temperatures across the 12 months of the year. The reported minimum temperatures range from 23.4°C to 23.9°C, while average temperatures range from approximately 26.6°C to 27.2°C. Maximum temperatures exceed 31.8°C at the reported peak. The manuscript describes an increase in temperature from the beginning of the year toward the middle of the year, followed by a tendency toward stabilization. It also identifies an increase in maximum temperature between March and May.

Table 6. Reported Monthly Temperature Characteristics

Temperature Indicator	Reported Value or Range (°C)	Temporal Coverage	Main Observation
Minimum temperature	23.4–23.9	12 months	Relatively narrow reported variation
Average temperature	26.6–27.2	12 months	Moderate variation in monthly averages
Maximum temperature	Above 31.8 at the reported peak	12 months	Higher values are reported during the peak period
Overall monthly pattern	Exact monthly values not provided	January–December	Increase toward midyear, followed by relative stabilization
March–May maximum temperature	Above 31.8 at the reported peak	March–May	Increase in maximum temperature reported during this period

Table 6 summarizes the monthly temperature characteristics reported in the study and illustrates the distinctions among minimum, average, and maximum temperatures. The relatively narrow range of minimum temperatures contrasts with the higher maximum values, suggesting that the observed temperature distribution varies according to the indicator examined. These differences support the use of comparative visualizations that display the three indicators simultaneously. However, the available manuscript provides ranges and qualitative descriptions rather than a complete numerical series for all 12 months. Consequently, the reported midyear increase should be interpreted as a pattern described by the original analysis, not as an independently verified warming trend. A complete monthly dataset, together with its observation period and aggregation procedure, would be necessary to reproduce the graph and evaluate the temporal pattern quantitatively (Siswanto et al., 2016; Wilks, 2019).



Temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum Temperature	23.4	23.5	23.7	23.9	23.8	23.7	23.6	23.5	23.5	23.4	23.4	23.4
Average Temperature	26.6	26.7	26.9	27.1	27.2	27.1	27.0	26.9	26.8	26.7	26.6	26.6
Maximum Temperature	31.8	32.1	32.6	33.1	33.5	33.2	32.8	32.4	32.0	31.9	31.8	31.8

Figure 4. Monthly Variations in Minimum, Average, and Maximum Temperatures across the Observation Period

Beyond geographical and temporal comparisons, the manuscript presents factor analysis through scatter plots and a circular chart of wind direction. The reported temperature and wind-speed observations are concentrated mainly around 30–33°C and 1–3 m/s, respectively. Temperature and relative humidity observations are predominantly distributed around 30–33°C and 70–85% humidity. The temperature–precipitation plot shows precipitation values fluctuating between approximately 0 and 15 mm within the dominant temperature range. The manuscript reports no clear linear relationship between these variables in the displayed plots.

Table 7. Reported Characteristics and Relationships among Climate Variables

Variable or Relationship	Reported Observation	Numerical Range or Proportion	Interpretation
Temperature and wind speed	Most observations are concentrated within a limited range	Temperature: 30–33°C; wind speed: 1–3 m/s	No strong linear relationship is identified visually
Temperature and relative humidity	Humidity values are concentrated within a relatively narrow range	Temperature: 30–33°C; humidity: 70–85%	Humidity appears relatively stable across the dominant temperature range
Temperature and precipitation	Precipitation fluctuates across the observed temperature range	Temperature: 30–33°C; precipitation: 0–15 mm	No clear relationship is reported from the displayed scatter plot
North wind direction	Most frequently reported wind direction	35.6%	North is the dominant category in the displayed distribution
East wind direction	Second most frequently reported among the specified directions	11.7%	Lower reported proportion than north
West wind direction	One of the more frequently reported directions	10.1%	Lower reported proportion than north and east
South wind direction	One of the more frequently reported directions	9.5%	Lower reported proportion than north, east, and west

Table 7 summarizes the observed distributions of temperature, wind speed, relative humidity, precipitation, and wind direction. The concentration of wind speeds between 1 and 3 m/s and humidity values between 70% and 85% provides a descriptive overview of the observations represented in the dashboard. Meanwhile, the reported variation in precipitation indicates that rainfall values differ even within a relatively narrow temperature range. These observations reinforce the importance of examining multiple indicators when interpreting local climate conditions. Nevertheless, visual inspection alone cannot establish the absence of statistical relationships. Formal correlation coefficients, sample sizes, and statistical significance tests would be required to substantiate claims about the strength of associations (Schober et al., 2018). The reported wind-direction percentages should also be interpreted as the distribution of observations in the analyzed dataset, rather than as a universal pattern for Indonesia.

Taken together, the findings presented in Tables 5–7 demonstrate how geographical comparisons, monthly summaries, and multivariable visualizations can be combined to explore climate variability across Indonesia. The geographical analysis identifies differences among selected locations, the monthly analysis describes variation in minimum, average, and maximum temperatures, and the factor analysis provides an overview of the observed distributions of humidity, precipitation, wind speed, and wind direction. These complementary analytical perspectives help users move beyond isolated numerical values toward a more contextualized understanding of climate observations.

The interactive dashboard supports this process by allowing users to examine climate indicators according to available geographical and temporal filters. As reported in the

manuscript, its visual components include temperature comparisons, geographical heatmaps, scatter plots, and wind-direction distributions.

From a scientific perspective, however, three limitations must be addressed before drawing broader conclusions. First, the observation period and aggregation level associated with each reported statistic should be documented consistently. Second, the numerical discrepancy in the original summary—which reports a national mean temperature of 2.88°C for 2020 despite other temperature statistics being approximately 23–32°C—must be resolved against the underlying dataset.

Third, evidence of temperature variation or association among meteorological variables does not independently establish a long-term climate-change trend or demonstrate that the dashboard improves public awareness. Such claims require appropriate temporal analysis, supporting scientific references, and, for public-awareness outcomes, empirical evaluation involving users (Bangor et al., 2008; IPCC, 2021).

Overall, the reported results provide a descriptive foundation for communicating climate information through interactive visualization. Their principal contribution lies in combining spatial, temporal, and multivariable perspectives within a single exploratory interface. With the underlying numerical data verified and the analytical procedures documented transparently, this approach can support more accessible communication of climate observations while maintaining the distinction between descriptive findings and conclusions that require further empirical evidence.

c. Interactive Climate Dashboard and Data-Driven Storytelling for Public Education

The development of the interactive climate dashboard represents the final stage of the research, in which the processed climate dataset is transformed into a visual and exploratory information system. As described in the manuscript, the dashboard integrates climate observations with geographical information to facilitate the examination of temperature distributions and other meteorological indicators across different locations and observation periods. The system was developed using Google Looker Studio, with visual components including temperature comparisons, geographical heatmaps, analytical plots, and summary information. These components are intended to make climate data more accessible to users who may not have specialized knowledge of meteorology or statistical analysis (Grainger et al., 2016).

The dashboard combines several visualization components to present climate information from complementary perspectives. The overview section provides a general representation of temperature conditions, while the demographic section presents geographical distributions through heatmaps and regional tables. The factor analysis section displays relationships among selected climate variables, and the summary section consolidates key findings. The integration of these components allows users to move from an overview of climate conditions to more detailed exploration of regional characteristics and variable distributions (Sarikaya et al., 2019; Shneiderman, 1996).

Table 8. Main Dashboard Components and Their Analytical Functions

Dashboard Component	Visualization Type	Information Presented	Intended Analytical Function
Overview	Temperature comparison chart and geographical heatmap	Temperature indicators and geographical distribution	Provides an overview of climate conditions
Demographic analysis	Geographical heatmap and regional detail table	Temperature and selected climate indicators by location	Supports geographical comparison
Factor analysis	Scatter plots and circular chart	Relationships among climate variables and wind-direction distribution	Facilitates exploratory analysis of variable patterns
Summary	Consolidated text and numerical indicators	Selected climate statistics and analytical findings	Summarizes the principal information presented in the dashboard
Data mart	Monthly data table	Minimum, average, and maximum temperature values by month	Supports inspection of the data underlying temporal visualizations

Table 8 demonstrates how the dashboard organizes climate information into distinct but complementary analytical views. The overview supports initial exploration, the demographic component emphasizes geographical differences, and the factor analysis component enables inspection of relationships among meteorological variables. Meanwhile, the summary and data mart provide consolidated findings and monthly numerical information. This structure can help users navigate between general patterns and more detailed observations. However, the effectiveness of this arrangement in improving comprehension depends on the accuracy of the displayed values, the clarity of the labels, and the consistency between the visualizations and the underlying dataset (Harold et al., 2016).

Interactivity is a central feature of the developed dashboard because it enables users to examine climate information according to their specific interests. The manuscript reports that users can select a year and geographical location to explore climate indicators and their spatial distributions. The integration of provincial identifiers and meteorological station metadata further supports location-based visualization. Station coordinates, including latitude and longitude, are used to support geographical mapping and the exploration of climate conditions at specific observation locations.

Table 9. Interactive Dashboard Features and Their Intended Functions

Interactive Feature	User Input or Interaction	Information Displayed	Intended Benefit
Year filter	Selection of an available year	Climate observations associated with the selected year	Supports temporal comparison
Location filter	Selection of an available geographical location	Climate information for the selected area	Enables localized data exploration
Regional heatmap	Examination of geographical areas on the map	Spatial distribution of displayed temperature values	Helps identify geographical differences
Regional detail table	Inspection of listed locations and their values	Location-specific climate measurements	Supports detailed regional comparison
Station-	Selection or examination of	Station metadata and	Connects climate measurements with

Interactive Feature	User Input or Interaction	Information Displayed	Intended Benefit
based exploration	available meteorological stations	associated climate observations	observation locations

Table 9 summarizes the dashboard's reported interaction capabilities and their potential analytical applications. Temporal and geographical filters allow users to narrow the displayed information, while the heatmap and regional detail table provide complementary methods for examining spatial variation. Station-based exploration connects meteorological observations to their geographical context. These functions can make climate information more relevant to individual users because the displayed information can be explored according to a selected period or location. Nevertheless, the table describes intended functionality rather than measured usability outcomes. The manuscript does not provide quantitative results from user testing or evidence demonstrating that these features independently improve public awareness.

The geographical component is particularly relevant because climate observations are associated with specific administrative areas and meteorological stations. The integration of station coordinates and provincial identifiers enables spatial exploration at different geographical levels. However, geographical visualization should be interpreted carefully: a heatmap based on station observations represents the distribution of the values included in the dataset and should not automatically be interpreted as a complete representation of climate conditions across all areas of Indonesia. The spatial coverage and density of observations should therefore be considered when interpreting the displayed patterns (Aldrian & Susanto, 2003).

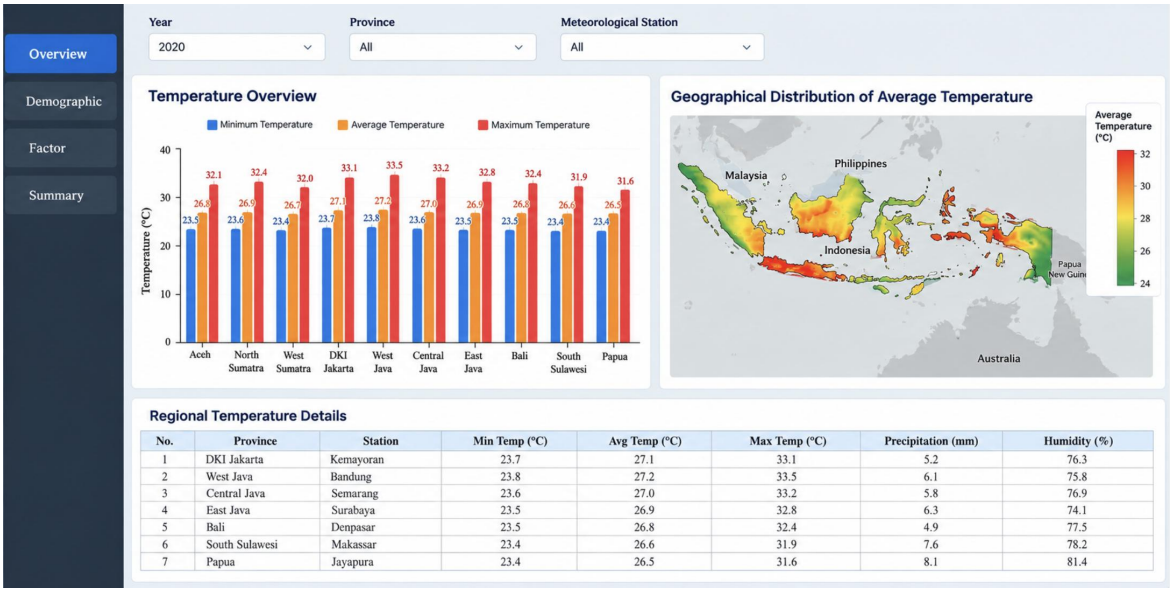


Figure 5. Interactive Climate Dashboard Showing Geographical Temperature Distribution, Regional Comparisons, and User-Selectable Filters

Beyond its visualization functions, the dashboard is intended to support data-driven storytelling by connecting analytical results with contextual explanations. In this approach, charts and maps serve as the evidential basis for a narrative that helps users understand what is being displayed, how the observations differ across locations or periods, and why the information may be relevant to everyday life (Dahlstrom, 2014; Segel & Heer, 2010). The manuscript positions the dashboard as an educational resource for communicating climate conditions and increasing public understanding of climate-related issues.

Table 10. Interactive Storytelling Elements and Their Educational Roles

Storytelling Element	Implementation in the Dashboard	Supporting Information	Intended Educational Role
Contextual introduction	Overview of climate indicators	General climate observations	Establishes the context for exploring the data
Geographical narrative	Heatmap and regional comparisons	Location-specific climate measurements	Connects climate information with geographical contexts
Temporal narrative	Monthly and yearly temperature visualizations	Historical observations across available periods	Helps users examine changes over time
Analytical explanation	Scatter plots and variable summaries	Observed distributions and relationships	Supports interpretation of the displayed evidence
Summary narrative	Consolidated indicators and key findings	Selected analytical results	Reinforces the main information conveyed by the dashboard
Educational links or actions	Supplementary resources, where implemented	Relevant educational material	Provides opportunities for further learning and engagement

Table 10 illustrates how the dashboard's visualization components can be organized into an educational narrative. The contextual introduction establishes the subject, geographical comparisons connect observations with particular locations, and temporal visualizations support the examination of historical variation. Analytical explanations and summaries then help users interpret the displayed evidence. This structure is consistent with the objective of making climate information more accessible through a combination of visual and textual communication. However, educational effectiveness depends on the accuracy and clarity of the narrative, the appropriateness of the selected visualizations, and the user's ability to interpret the information. The manuscript describes the dashboard's educational purpose but does not report a formal assessment of learning outcomes or changes in awareness.

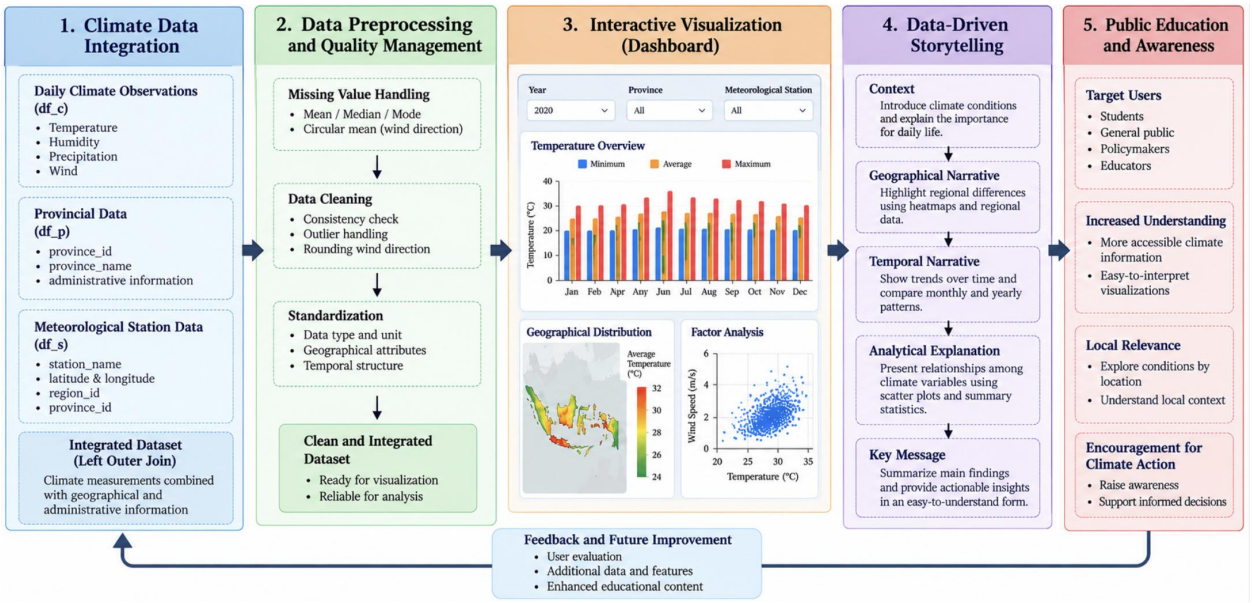


Figure 6. Interactive Storytelling Framework for Communicating Climate Data through Contextual Narratives and Visual Exploration

The integration of climate data, interactive visualization, and contextual narratives provides a potential mechanism for communicating scientific information to a broader audience (Moser, 2016). Rather than requiring users to interpret isolated numerical values, the dashboard presents information through complementary visual representations and geographical and temporal exploration. This design can support the interpretation of local climate observations and provide a starting point for further learning about environmental conditions and climate-related risks.

Nevertheless, the distinction between system functionality and educational effectiveness is important. The existence of an interactive dashboard does not, by itself, establish that users acquire more knowledge or develop greater climate awareness. To demonstrate these outcomes, future evaluation should measure information comprehension, perceived usability, and changes in climate-related knowledge or awareness among representative users. Such evaluation could also investigate whether different narrative structures or visualization formats affect users' ability to interpret climate data (Bangor et al., 2008; Brooke, 1996).

Overall, the dashboard developed in this study integrates geographical visualization, temporal exploration, analytical summaries, and contextual storytelling into a single information environment. The system's principal contribution lies in translating processed climate observations into a structured and interactive format that can support public-facing climate communication. Its potential educational value is promising, but claims concerning improved public awareness should remain provisional until supported by empirical evaluation. This distinction strengthens the scientific validity of the discussion while identifying a clear direction for subsequent research.

Conclusion

This study developed an interactive climate data dashboard that integrates climate data visualization, geographical exploration, and data-driven storytelling to support public education on climate change. The research process involved climate data collection, preprocessing, statistical analysis, and dashboard implementation using Google Colaboratory and Google Looker Studio. The integration of climate observations with geographical metadata enabled the presentation of meteorological indicators through complementary visualizations, including temperature comparisons, geographical heatmaps, monthly summaries, and plots illustrating relationships among climate variables. The incorporation of contextual narratives and interactive features provides a structured approach to communicating climate information in a more accessible and informative manner. However, the findings primarily demonstrate the potential of the developed dashboard as a digital educational medium rather than empirically verified improvements in public awareness. Therefore, future research should evaluate the dashboard through usability testing and user-based assessments of climate knowledge, information comprehension, and awareness before and after its use. Such evaluations would provide stronger empirical evidence of the effectiveness of interactive storytelling in climate communication and establish a more robust foundation for developing accessible, data-driven educational tools to support public understanding of climate change.

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