Appendix

Data

Additional Data Details

All control variable data related to economic factors—including total Gross Regional Domestic Product (GRDP) data and its components—were sourced directly from the Indonesian Central Statistics Agency (BPS). We included two key economic sectors for each district/city: (1) agriculture, forestry, and fisheries, and (2) the processing industry. These sectors were selected given their relevance to the broader inflationary trends and their susceptibility to climate-related factors. The GRDP data allowed us to control for underlying economic conditions that might influence local price levels independent of climatic variations.

Data Collection and Processing Procedures

The rainfall data were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), a dataset established in 1981 that provides high-resolution (approximately 5x5 km) global rainfall estimates. The temperature data were sourced from the Moderate Resolution Imaging Spectroradiometer (MODIS), an instrument aboard NASA's Terra and Aqua satellites. MODIS captures data for the entire Earth every one to two days at varying spatial resolutions (250 m, 500 m, and 1,000 m), offering both fine-grained local insights and broader regional overviews. The choice of these datasets ensures robustness, as CHIRPS and MODIS have been widely validated and utilized in climate studies.

Use of Google Earth Engine (GEE)

To handle the large volume of satellite and climatic data efficiently, we utilized Google Earth Engine (GEE), a cloud-based platform that supports big-data geospatial analysis (Gorelick et al., 2017). During the pre-processing phase, we defined the research area by importing shapefile data from the Indonesian Geospatial Portal, ensuring that the study area matched the administrative boundaries of the 82 selected districts/cities. We also set appropriate date ranges for each dataset. In the processing phase, JavaScript scripts were employed within GEE to extract the relevant climatic indicators for each city at a monthly interval. This step included spatial aggregation to match the resolution of our CPI and economic datasets, as well as temporal aggregation to derive monthly averages or totals as needed.

Quality Control and Methodological Adjustments

In the post-processing phase, we compiled the rainfall and temperature data aligned with the monitoring date and administrative boundaries. Any missing values were inspected and addressed according to standard imputation methods or interpolation techniques to ensure consistent time-series coverage. Such steps were crucial for maintaining data integrity, given that reliable climatic and economic data form the foundation of our regression analysis. While no significant data gaps were encountered, employing these quality checks and aggregation methods ensures that the final dataset is both comprehensive and robust.

Empirical Strategy

Extended Rationale for the Identification Strategy

Our empirical strategy relies on the assumption that rainfall affects inflation but not vice versa. Previous empirical studies support this one-way relationship, indicating that while rainfall can influence various economic outcomes, economic indicators like inflation do not alter rainfall patterns (Maccini and Yang, 2009; Christian et al., 2019; Damania et al., 2020). By exploiting seasonal differences in rainfall across Indonesian districts/cities, we assume unit homogeneity: any two districts/cities facing the same seasonal rainfall differences and control variables would exhibit similar expected seasonal differences in inflation. Formally:

$$E\left[Y_{it\tau_1} - Y_{i\tau_2} \middle| r_{it\tau_1} - r_{it\tau_2}, x_{it}, \alpha_i\right] = E\left[Y_{jt\tau_1} - Y_{jt\tau_2} \middle| r_{jt\tau_1} - r_{jt\tau_2}, x_{it}, \alpha_j\right] \quad (2)$$

Following Linsenmeier (2024), this assumption permits a causal interpretation of the relationship between rainfall and inflation after controlling for fixed effects and observable covariates.

Within-Estimation and Fixed Effects

The within-estimation (fixed effects) approach involves de-meaning each variable by its entity-specific mean, as described in the main text. By focusing on within-unit variation over time, we eliminate the influence of unobserved, time-invariant characteristics. Such characteristics might include geographic location, cultural traditions, long-standing institutional frameworks, or historical factors that could otherwise confound the relationship between rainfall and inflation.

This approach improves the identification of the rainfall-inflation link. Without controlling for these entity-specific unobserved factors, any correlation between rainfall and inflation could be attributed to unmeasured characteristics. By using fixed effects, we ensure that the estimated coefficients represent the impact of deviations in rainfall on deviations in inflation from each district/city's long-term average levels.

Clustering Standard Errors

We cluster standard errors by districts/cities to address potential heteroscedasticity, autocorrelation, and spatial correlation. Heteroscedasticity refers to unequal variances of the error term across observations, which can bias standard error estimates. Autocorrelation can arise because observations within the same district/city over time are not independent, while spatial correlation may occur if neighbouring districts share economic linkages or climate patterns. By clustering standard errors, we allow for arbitrary correlation of errors within districts/cities, thus ensuring that our inference is robust to these issues.

Without cluster-robust standard errors, confidence intervals and hypothesis tests might lead to incorrect inferences. Clustering provides a more realistic portrayal of the uncertainty surrounding our estimates, resulting in more reliable statistical inference.

Controlling for Temperature

In tropical settings, rainfall and temperature often co-vary, reflecting underlying climatic systems. Failing to include temperature in the model could introduce simultaneity bias if temperature also affects inflation. Changes in temperature can alter agricultural yields, influence pest and disease prevalence in crops, and affect energy consumption patterns for cooling (Dell et al., 2012; Burke et al., 2015). By controlling for temperature, we ensure that the estimated effect of rainfall on inflation is not conflated with temperature-driven changes.

Time-Varying Controls and Sectoral Composition

We incorporate a set of time-varying controls to isolate the direct effect of rainfall on inflation:

1. Regional GDP: Capturing economic conditions that vary over time and space, regional GDP controls for overall prosperity, production capacity, and demand for goods and services (Bernanke and Gertler, 1995).
2. Share of Agriculture and Industry: A greater reliance on agriculture can increase the sensitivity of inflation to weather shocks (Timmer, 1980; Gouel and Jean, 2015). Agricultural production heavily depends on rainfall patterns. Meanwhile, the industrial share of GDP might reflect energy-intensive production processes where input costs respond to climatic variability (Nordhaus, 1975).
3. Lagged Inflation: We include lagged inflation to account for inflation persistence (Dornbusch and Fischer, 1993; Ball and Mankiw, 1994; Blanchard, 1986). Past inflation may influence current price-setting behavior, wage negotiations, and consumer expectations. By controlling for this persistence, we ensure the estimated rainfall effect is not capturing the inertia embedded in the inflationary process.
4. Deflators for Agriculture and Industry: Deflators measure price changes within sectors, allowing us to separate rainfall-driven effects from general price movements due to global commodity shocks, policy changes, or technological improvements (Kilian, 2009; Ivanic and Martin, 2008). Controlling for these deflators isolates the specific channel through which rainfall affects inflation, distinguishing it from broader sectoral price trends.

Time Fixed Effects and National-Level Factors

Introducing time fixed effects (δ_t) helps control for national-level dynamics that affect all districts/cities simultaneously. Central bank policies, fiscal measures, global commodity price spikes, and macroeconomic shocks influence inflation uniformly across the country. By including time fixed effects, we remove the impact of these common shocks, ensuring that our identification relies on local variation in rainfall and inflation within the same temporal context.

Without time fixed effects, changes in national policies or global market conditions might confound the relationship between rainfall and inflation. For example, a country-wide subsidy program introduced in a particular year would reduce inflation everywhere, potentially obscuring the local effect of rainfall differences.

Further Discussion on the Rainfall-Inflation Channels

Rainfall affects inflation through multiple channels. On the supply side, variations in rainfall patterns influence agricultural yields. Excessive rainfall during harvest or insufficient rainfall during planting can reduce crop output, raising food prices. Since food comprises a large share of the consumption basket, these price changes can drive overall inflation (Kotz et al., 2022; Odongo et al., 2022).

Transportation and infrastructure networks are also sensitive to rainfall variability, particularly in developing countries. Heavy rains can damage roads, delay shipments, and increase distribution costs. Rising transportation costs pass through to final consumer prices, contributing to inflationary pressures (Blagrave, 2019).

Energy markets may similarly be influenced. Rainfall can affect hydropower generation, alter demand for fuels, or disrupt energy supply chains. Such shifts in energy costs can feed into general price levels, complicating inflation management (Cashin et al., 2017).

Finally, climate anomalies like El Niño introduce irregular rainfall patterns, affecting both energy and non-energy commodity prices. By disturbing typical seasonal conditions, El Niño events can create unpredictable price fluctuations that challenge policymakers. Adapting monetary policy to account for these weather-induced shocks is crucial for maintaining price stability (Heinen et al., 2019).

Additional Methodological Considerations

The assumption of unit homogeneity is central to our causal interpretation. By positing that any two districts/cities respond similarly to the same rainfall shocks, we ensure that differences in outcomes are due to differences in explanatory variables rather than inherent differences in units. This assumption is supported by controlling for a wide range of variables and using fixed effects to remove unobserved time-invariant heterogeneity.

Should there be any remaining unobserved factors that vary both over time and across districts/cities, the introduction of time fixed effects helps mitigate their influence. By comparing units within the same time period, we ensure that any unobserved factors common to all units at a given point in time do not bias the results.

Main Results

Extended Interpretation of Sectoral and Geographic Variations

The negligible effect sizes observed for rainfall on inflation across various CPI categories highlight the nuanced interplay between local climatic conditions and broad economic forces. While localized rainfall differences might initially seem relevant—particularly given Indonesia's geographic and climatic diversity (Frederick & Worden, 1993; Badan Informasi Geospasial, 2013; Naylor et al., 2007; Hill et al., 2009)—our estimates show that any statistical relationships are economically insignificant once we account for broader macroeconomic controls and time-specific factors.

Diverse sectoral responses to rainfall reinforce this conclusion. Food CPI, which one might expect to be highly sensitive to rainfall-induced supply shocks due to the dependence of agricultural production on weather patterns (Timmer, 1980; Maccini and Yang, 2009; Christian et al., 2019; Damania et al., 2020), exhibits a measurable but minuscule association with rainfall. This minor effect virtually vanishes once we include time fixed effects, suggesting that national-level trends, policy interventions, and market integrations overshadow local climatic perturbations. By the same token, processed food CPI, theoretically less vulnerable to direct climatic shocks because it involves added layers of processing and inter-regional trade (Gouel and Jean, 2015; Heinen et al., 2019), shows similarly negligible impacts. Housing CPI—a sector influenced more by long-term factors such as labor, materials, and structural economic policies—remains largely unaffected by short-term rainfall fluctuations.

Market Integration and Infrastructure as Buffers

Indonesia's extensive inter-regional trade networks, transportation infrastructure, and distribution systems likely buffer local climatic shocks, as suggested by Holtermann (2020), who emphasizes the role of infrastructure in mitigating the economic impacts of weather variability. In well-integrated markets, the effects of localized agricultural shocks can be diluted by imports from other regions, stable inventory management, and flexible supply chains. This market-driven smoothing mechanism ensures that weather-induced price spikes or declines are not fully transmitted to the consumer level, thereby limiting the direct inflationary impact of rainfall variations.

Moreover, government interventions—such as subsidies, storage programs, and logistics support—can dampen local price volatility induced by weather anomalies (Blagrave, 2019). Such policy measures help maintain stable food prices, prevent localized shortages from escalating into broader inflationary episodes, and enhance overall price stability. In effect, these policy buffers reduce the sensitivity of observed inflation rates to transient, location-specific changes in rainfall.

Macroeconomic Dominance over Localized Climate Factors

Our findings that time fixed effects render the relationship between rainfall and inflation statistically insignificant underscore the dominance of macroeconomic and national-level factors. Inflation is often governed by broad conditions such as central bank policies, fiscal measures, exchange rates, and global commodity price fluctuations. For instance, when the central bank adjusts interest rates or when global fuel prices surge, these changes affect prices uniformly across the country. The insignificance of rainfall after accounting for time effects aligns with theories of inflation determination that stress aggregate demand, supply dynamics, and policy settings (Bernanke and Gertler, 1995; Dornbusch and Fischer, 1993; Ball and Mankiw, 1994; Blanchard, 1986).

This interplay between local shocks and national frameworks resonates with evidence from Acevedo et al. (2020) and Dell et al. (2012), who highlight the primacy of macroeconomic stabilization tools in the face of various external disturbances. Similarly, Burke et al. (2015) point out that climatic changes, while impactful at a micro level, often fail to produce large, systemic inflationary movements once robust macroeconomic institutions are in place.

Commodity Price Channels and Climate Anomalies

Climate-related phenomena like El Niño can alter precipitation patterns and introduce atypical rainfall variability. El Niño events have been linked to changes in agricultural production, energy demand, and transportation reliability, potentially influencing consumer prices (Cashin et al., 2017). However, even in the presence of such anomalies, the integrated nature of modern economies and existing policy frameworks can limit their inflationary impact. By ensuring that domestic markets can respond flexibly to weather shocks—via imports, buffer stocks, or supportive monetary and fiscal measures—national-level actions contain the spread of local anomalies into generalized inflation.

Kilian (2009) and Ivanic and Martin (2008) detail how global commodity markets, international trade, and productivity improvements shape local price outcomes. While climate variability may temporarily affect certain commodities, these shocks are rarely isolated from broader market forces. The capacity of global supply networks to redirect commodities and the ability of policymakers to intervene if necessary reduce the inflationary consequences of local climatic events.

Sectoral Deflators, Lagged Inflation, and Other Controls

In the main analysis, we included sectoral deflators for agriculture and industry, as well as lagged inflation, to ensure that estimates of rainfall's impact were not confounded by underlying price trends or price-setting behaviors. Deflators help isolate the component of price changes attributable to sector-specific inputs unrelated to rainfall variations (Gouel and Jean, 2015; Kilian, 2009; Ivanic and Martin, 2008). By controlling for these deflators, we ensure that the estimated relationship between rainfall and inflation does not merely capture shifts in global commodity markets, technological progress in agriculture, or changes in domestic industry productivity.

Lagged inflation is crucial because inflation often exhibits persistence, as documented by Dornbusch and Fischer (1993), Ball and Mankiw (1994), and Blanchard (1986). Without controlling for prior inflation, the estimated rainfall effect might conflate the current period's weather conditions with pre-existing inflationary momentum. Our model thus accurately isolates the marginal effect of rainfall differences on inflation, net of any ongoing inflationary processes.

Temperature Controls and Climate Interactions

The control for temperature differences, highlighted in Dell et al. (2012) and Burke et al. (2015), ensures that the rainfall-inflation relationship is not masked or distorted by correlated temperature effects. Temperature changes can influence agricultural yields, pests, disease prevalence, and energy consumption—each of which can affect prices. By including temperature, we disentangle the distinct roles of rainfall and temperature in shaping inflation, granting more confidence that the negligible rainfall effects are not simply due to omitted climate variables.

Broader Policy Implications

Our results have clear policy implications. Since rainfall variations, even if statistically significant in some models, produce only minor and economically negligible effects on inflation, policymakers should not overemphasize local weather conditions in crafting inflation-management strategies. Instead, stabilizing inflation likely depends more on maintaining sound monetary policies, ensuring flexible and well-integrated markets, and designing adaptive measures that counteract commodity price shocks at the national level.

As highlighted by Kotz et al. (2022) and Odongo et al. (2022), the complexity of translating climate shocks into macroeconomic outcomes is mediated by various economic and institutional filters. Policymakers in countries with integrated markets and robust policy frameworks may find that direct interventions targeting localized weather shocks are less necessary. In contrast, strengthening infrastructure, improving early warning systems, enhancing transportation reliability, and refining commodity storage and distribution networks may yield more substantial benefits in preventing localized climate anomalies from escalating into widespread inflationary challenges.

Comparisons with Cross-Country Studies

Studies like Barrios et al. (2010) show that in settings with less integrated markets and weaker institutions—e.g., certain Sub-Saharan African countries—rainfall trends can have more pronounced effects on economic growth and possibly on price stability. By focusing on

Indonesia, a single-country context with a unified monetary policy, we avoid the methodological complications of cross-country comparisons where differences in governance, policies, and economic structures can bias estimates. This approach aligns with Christian et al. (2019) and Damania et al. (2020), who highlight the importance of considering local market integration and institutional capacity. In an economy like Indonesia's, with relatively strong national-level policy instruments and integrated markets, local climate anomalies have limited capacity to generate significant inflationary pressures.

Robustness Check

Two Way Fixed Effect with Weight

Weighting Methodology

The weights are derived from economic size indicators reported by the Indonesian Central Statistics Agency (BPS). These indicators commonly include Gross Regional Domestic Product (GRDP) or other measures of regional economic activity, serving as proxies for the scale and significance of each district's or city's economy. By assigning larger weights to observations from more economically substantial regions, the estimation more closely reflects the inflationary conditions facing a majority of consumers and producers in the country. In effect, this procedure ensures that cities or districts with greater contributions to aggregate economic output exert proportionally greater influence on the regression results.

Mitigating Heteroskedasticity and Improving Policy Relevance

Weighted estimations can help address heteroskedasticity by giving less relative weight to observations with higher variance—often smaller and more volatile local economies—thereby stabilizing estimates of the regression coefficients. Since larger economies tend to produce more stable and representative indicators, weighting by economic size ensures that the model's estimates better capture the dynamics within regions that play an outsized role in determining national economic outcomes.

From a policy standpoint, the weighted model can be more informative. National policymakers, who typically focus on broader macroeconomic management rather than localized fluctuations in small markets, may find weighted estimates more aligned with policy-relevant aggregates. If rainfall variations had shown a significant influence on inflation in weighted models, policymakers might have considered tailoring interventions or macroeconomic tools to address regionally concentrated weather shocks. However, as the weighted results remain statistically insignificant, it reinforces the conclusion that local climatic factors exert minimal influence on national-level inflationary pressures.

Connection to Data Quality and Measurement

In practice, the assignment of weights depends on the availability and reliability of data from BPS. Since BPS conducts regular surveys and publishes detailed statistics on regional economic activity, these data provide a robust foundation for constructing weights. Any changes or improvements in economic data reporting (e.g., more detailed sectoral breakdowns, improved GDP estimates, or updated regional economic accounts) can enhance the precision and interpretability of the weighted results.

Consistency with Unweighted Results

The fact that weighting does not alter our principal conclusions—seasonal rainfall differences remain insignificant in explaining inflation even when larger economies receive more weight—is a testament to the robustness of the findings. Regardless of whether the estimation treats all districts or cities equally or adjusts for their economic significance, the conclusion holds: rainfall variations do not materially influence inflation dynamics under the two-way fixed effects specification.

Placebo Test

The placebo test is designed to verify whether our main results could be artifacts of model misspecification or random chance. By randomly shuffling the rainfall data across districts/cities, we create a situation where no true causal link exists between rainfall and inflation. If the model were prone to detecting spurious correlations, we would see a higher-than-expected number of significant coefficients for rainfall. Conversely, if the model is appropriately specified, the number of significant outcomes should align with the nominal Type I error rate (5% in our study).

Implementation Details

Randomization Procedure: For each of the 100 iterations, we randomly permute the seasonal rainfall differences across districts/cities while holding the original inflation data fixed. This ensures that any observed correlation between the permuted rainfall and inflation is purely due to chance.

- Model Specification: We maintain the same regression framework used in the main analysis, including fixed effects, as well as the same set of control variables. The only difference is that the independent variable capturing seasonal rainfall differences, $(r_{it\tau_1} - r_{it\tau_2})$, is replaced by a randomly assigned version, $(\tilde{r}_{it\tau1}^{(k)} - \tilde{r}_{it\tau2}^{(k)})$, in each placebo iteration k.
- Clustering of Standard Errors: We cluster the standard errors at the district/city level in each iteration, mirroring the methodology in the main analysis. This step accounts for any potential heteroskedasticity and serial correlation within districts/cities over time.

Interpreting the Results

Significance Threshold: We count the number of times the rainfall coefficient is statistically significant at the 5% level. Under the null hypothesis of no real effect, approximately 5 out of 100 iterations would yield a false positive.

Comparison with Expectations: If the number of significant findings substantially exceeds 5, it may indicate model misspecification or an overfitted relationship. If the count is near 5, the model appears robust, as it is not systematically producing spurious results.

Study Outcomes: The results show that composite inflation and housing inflation exactly match the expected threshold of 5 significant outcomes, while food inflation yields 6 and processed food inflation 7. Although slightly above 5, these counts still remain near the expected value, suggesting only marginal sensitivity to random noise.

Possible Extensions

Alternative Randomization Schemes: Researchers could explore alternative permutations (e.g., block randomization by region or time) to verify that findings are consistent across different approaches.

Multiple Comparison Adjustments: Given multiple dependent variables, one could consider multiple testing corrections (e.g., Bonferroni adjustments) to account for the increased chance of false positives across several outcomes. However, the close alignment with the 5% threshold in our test suggests that such corrections are unlikely to alter the overall conclusions.

Overall, the placebo test reaffirms the robustness of the main model by demonstrating that it does not systematically detect a relationship where none exists. The slight deviations for food and processed food inflation (6 and 7 significant outcomes, respectively) are minor and do not undermine the broader validity of the findings.