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Impact of Climate Change on Sustainable Competitive Advantage of Traditional Salt in Central Java

[1*]Roudlotul Badi'ah, [1]Budi Harsanto, [1]Umi Kaltum, [2]Armen Zulham, [1]Sulaeman Rahman Nidar
[1]Faculty of Economics and Business, Universitas Padjadjaran, Indonesia
[2]Research Center for Cooperative, Corporation, and People's Economy, National Research and Innovation Agency, Indonesia

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ABSTRACT

Indonesia's salt production has great potential, but is still hampered by fluctuations in quality and productivity influenced by weather factors. Dependence on the weather causes instability in salt production results, which impacts achieving salt self-sufficiency. Therefore, this study aims to analyze the influence of climate factors on the productivity and quality of traditional salt in Central Java Province, including temperature, humidity, rainfall, and wind speed. This study uses a quantitative approach, with data collected from 8 salt-producing districts/cities in Central Java with purposive sampling. Climate data was obtained from BMKG, while productivity and quality data were obtained from the Central Java DKP. The analysis technique used panel data regression with the Least Squares (OLS) approach and the Chow, Hausman, and Lagrange Multiplier tests to select the best model. The results showed that rainfall significantly negatively affected traditional salt productivity, while temperature, humidity, and wind speed did not show a significant effect. Overall, climate conditions were shown to affect salt productivity positively. Temperature and humidity have a significant positive effect on salt quality, wind speed has a significant negative effect, and rainfall has no significant effect on salt quality. Overall, climate conditions have a positive effect on salt quality. Rainfall and temperature management are essential to increase salt productivity and quality, while climate factor management will produce optimal results. The development of modern salt production technology that reduces dependence on extreme weather and better management of natural resources and technology can support the achievement of more stable and sustainable salt self-sufficiency.

Corresponding Author
Roudlotul Badi'ah
Email: badiahroudlotul@gmail.com

INTRODUCTION

Indonesia has great potential in salt production because supportive geographical conditions drive it with a long coastline and tropical climate, although this potential has not been optimally utilized. Domestic salt production is still insufficient in terms of quantity and quality, so imports continue to increase, especially to meet the needs of industries that require high-quality salt (Amalyos, 2020; Badan Pusat Statistik, 2024; Widjaja et al., 2021). The national salt requirement reaches more than 4 million tons annually, while domestic production can only meet around 2.5 million tons. Local salt that meets consumption quality standards is only around 700,000 tons per year. In contrast, 50% of the traditional salt is not absorbed by the market and does not meet industrial needs, where imports reach around 3 million tons (Humas BRIN, 2024). This situation highlights traditional salt's weak sustainable competitive advantage, especially in producing industrial standard salt with high productivity to meet the market, especially if imports are limited. Sustainable competitive advantage itself is defined as a long-term market benefit that is rare, valuable, difficult to imitate, and irreplaceable, which is formed through the integration of resources in the process of creating and distributing value compared to competitors, in this case, imported salt products (Pei et al., 2020).

Factors that affect quality and productivity include the traditional technology still used, the lack of facilities and infrastructure, and the influence of weather (Satrio, 2024). The Indonesian government is targeting salt self-sufficiency by 2027, with the Ministry of Maritime Affairs and Fisheries (KKP) trying to overcome weather challenges. The need for salt is estimated to reach 4.9 million tons in 2025. However, most salt production is still carried out traditionally through solar evaporation, often interrupted by rain (Asnawi & Ambari, 2025). Although Indonesia targets self-sufficiency, dependence on the weather makes traditional salt production volatile. In 2023, national production jumped to 2.5 million tons, with Central Java contributing 652 thousand tons as the second largest producer after East Java (Sari & Ika, 2024). However, this achievement occurred during a long dry season triggered by the El Niño phenomenon, not because of a stable production system (CNBC Indonesia, 2023). In traditional salt centers such as Pati, Rembang, Demak, and Brebes, climate factors, including rainfall, dry season duration, air temperature, relative humidity, solar radiation, and wind speed, have been shown to affect the volume, quality, and even cost of salt production. Studies in Rembang and Pati show a strong correlation between solar radiation and low rainfall with the highest productivity, while high humidity and off-season rain reduce NaCl levels and cause crop failure (Ashilah et al., 2022; Bramawanto et al., 2019).

Climate is a natural phenomenon driven by several elements: solar radiation, temperature, humidity, clouds, rain, evaporation, air pressure, and wind (Miftahuddin, 2016). Thus, in general, the climate conditions in a place can affect salt-making (Widjaja et al., 2021). The quality of salt is primarily determined by the raw materials and production process, which depend on weather conditions beyond farmers' control (Permodo & Rochwulaningsih, 2022). Climate volatility increases the risk of harvest uncertainty, price fluctuations, and adaptation costs, weakening the bargaining position of smallholder salt farmers against collectors and industry. Therefore, the government's efforts to achieve self-sufficiency can be threatened if climate variability is not appropriately managed (BRIN, 2023). Previous studies generally used multiple linear regression to assess the effect of weather on salt production and found that rainfall is more dominant than season length (Pahlawan et al., 2020). Some also concluded that the dry season increases both productivity and quality (Aldi et al., 2021), while some studies reported that wind speed, rainfall, and temperature did not have a significant effect (Banowati & Firmanzah, 2023). These diverse findings indicate methodological and conceptual gaps because no study has comprehensively linked climate variables with the two main dimensions of sustainable competitive advantage, quality, and productivity, in one model framework.

The novelty of this research lies in (1) integrating the concept of sustainable competitive advantage into salt studies, (2) examining the influence of five main climate variables (temperature, humidity, rainfall, sunshine duration, and wind speed) on salt quality and productivity, and (3) using the panel data regression method to provide clarity on the dynamics between variables, and identifying the best estimation model so that this research can produce a deeper understanding of the relationship between climate and the competitiveness of traditional salt, while also providing an empirical basis for more targeted adaptation strategies.

With this background, this study aims to analyze the influence of climate conditions, including temperature, humidity, rainfall, and wind speed factors, on sustainable competitive advantage in traditional salt production in Central Java Province. This study aims to identify how these climate condition factors affect the productivity and quality of salt produced and to test the relationship between climate conditions and the overall success of salt production. It is hoped that this study can provide deeper insight into the influence of climate conditions on sustainable competitive advantage and provide recommendations to improve the efficiency and quality of traditional salt production in the area.

LITERATURE REVIEW

Sustainable Competitive Advantage

Sustainable competitive advantage is understood as a dynamic process that enables a company to meet current market demands without sacrificing future competitive capacity (Satar et al., 2025), In the context of traditional salt, the most important dimensions are quality and productivity (Alshahrani et al., 2024; Mohiuddin et al., 2025). Sustainable competitive advantage is the primary goal of modern organizations to survive and thrive in an increasingly dynamic market (Mastarida, 2022). Productivity is one of the essential dimensions in creating a sustainable competitive advantage. Productivity is comparing a certain amount of output with a certain amount of input for a specific period (Wiradinata, 2017). Companies that increase productivity will be more efficient and superior in the market competition (Lestari et al., 2021). In addition to productivity, quality also plays a central role in maintaining a competitive advantage. Quality refers to a product or service's overall features and characteristics that can meet stated or implied needs (Heizer et al., 2020). Consistent quality will increase customer satisfaction and market loyalty (Achmad, 2023).

Climate Conditions

Climate is the distribution of weather in a specific period (daily, monthly, annually), which includes averages and extremes (maximum and minimum) or over a relatively long period (Nasrul et al., 2024). Climate elements are defined as statistics of climate elements, such as temperature, rainfall, wind, and humidity, recorded over a period that varies from month to year (Melo & Rahmadani, 2022). Climate change can be interpreted as temperature and weather changes over time (Ainurrohmah & Sudarti, 2022). Changes in climate conditions have a significant impact on various sectors, including human health, ecosystem balance, and decreased production and productivity due to changes in land area and harvest area (Hamida et al., 2024; Sunaryo & Rhomadhoni, 2020; Yuniasih et al., 2022). In traditional salt production activities, climate conditions in a place that can affect salt making, in general, include: 1) Evaporation, a place with a high evaporation rate is required; 2) Wind speed and direction of more than 5 m/second; 3) Air temperature of more than 32°C; 4) 100% sunlight (all day long); 5) Air humidity <50% H; 6) Low rainfall and less frequency of rainy days (long dry season); and 7) Sea tides (Widjaja et al., 2021).

Temperature is the level or degree of heat of molecular activity in the atmosphere expressed in Celsius, Fahrenheit, or Reamur scales (Mufti et al., 2023). Temperature has a significant effect on the productivity of salt production because higher temperatures can accelerate the water evaporation process, so the salt crystallization process becomes faster and more efficient, increasing the productivity of salt production (Arwiyah et al., 2015). In addition, the higher the temperature, the better the quality of the salt produced (Aminullah, 2023).

Humidity is the level of wet air conditions due to water vapor (Indarwati et al., 2019; Kusnadi et al., 2020). Humidity has a significant effect on salt productivity because high air humidity can inhibit the evaporation process of seawater, thereby reducing the amount of salt that can be produced. Conversely, low humidity with drier air will support a faster evaporation process and make more salt (Ashilah et al., 2022). The average air humidity also affects the quality of the salt produced (YN, 2007).

Rainfall is the amount of rainwater that falls during a specific period, measured using units of height above the horizontal ground surface, assuming no infiltration, runoff, or evaporation occurs (Ruswanti, 2020). High rainfall has a negative impact on salt production because it can affect soil texture and land suitability for salt ponds (Hamdani & Farmiati, 2022; Mahasin et al., 2020). The higher the rainfall, the lower the salinity (salt content) of seawater, while the lower the rainfall, the higher the salinity (Sulastri et al., 2024).

Wind speed is the distance travelled by the wind or air movement per unit of time, expressed in meters per second (m/s), kilometres per hour (km/h), or miles per hour (mi/h) (Sudarto, 2011). High wind speeds can accelerate the process of evaporation of seawater into salt crystals (Wulandari et al., 2023). The higher the wind speed, the more salt crystallization is produced, but if the wind speed is less than optimal, the quality of the salt product can be affected (Putri, 2022).

Thus, climate change has significantly impacted salt production in various regions, causing changes in weather patterns such as drier summers, longer summers, longer rainy seasons, and high tides, resulting in decreased salt productivity (Rahman & Zulham, 2020). Climate change causes unpredictable weather patterns, including long dry seasons and increased rainfall, directly affecting salt production. For example, in Pangenan District, Cirebon Regency, more dry months correlate with increased salt productivity and farmer income (Halil, 2019). Likewise, in Pati Regency, unpredictable weather, such as long dry and rainy seasons, has caused salt production to decline, prompting farmers to use new strategies, such as tarpaulin and polyethylene, to increase productivity (Rahman & Zulham, 2020).

Based on the theoretical basis and results of previous research that have been explained previously, the research model can be described, and the hypothesis formulated as follows:

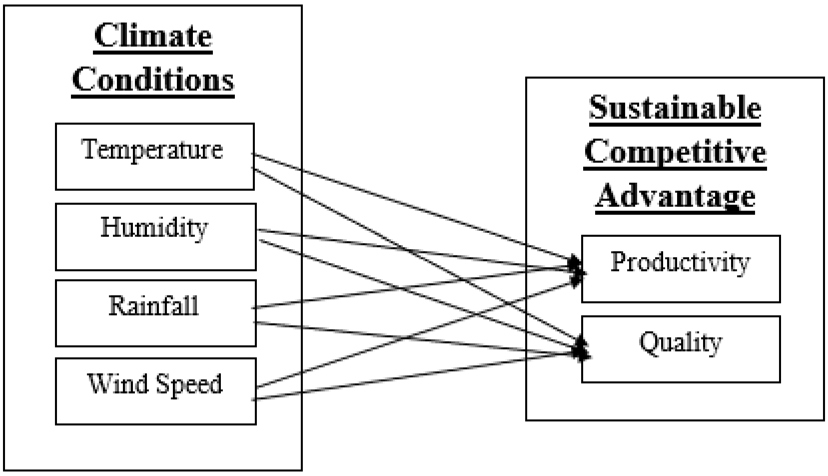

Figure 1. Research Model

Hypothesis:

H1. Temperature has a significant positive effect on Productivity
H2. Humidity has a significant negative effect on Productivity
H3. Rainfall has a significant negative effect on Productivity
H4. Wind Speed has a significant positive effect on Productivity
H5. Climate Conditions (temperature, humidity, rainfall, and wind speed) have a significant positive effect on Productivity
H6. Temperature has a significant positive effect on Quality
H7. Humidity has a significant negative effect on Quality
H8. Rainfall has a significant negative effect on Quality
H9. Wind Speed has a significant positive effect on Quality
H10. Climate Conditions (temperature, humidity, rainfall, and wind speed) have a significant positive effect on Quality

RESEARCH METHODS

Research Design

This study will analyze the relationship of influence built on empirical data that has been hypothesized, namely to test the relationship of influence between climate conditions (temperature, humidity, rainfall, and wind speed) on the sustainable competitive advantage (productivity and quality) of traditional salt in Central Java Province. A quantitative approach will be used to achieve this goal. Quantitative research is a study characterized by a deductive approach to the research process that aims to refute or provide credence to existing theories; involves measuring variables and testing relationships between variables to reveal patterns, correlations, or causal relationships; produces statistical data (usually from large samples) (Leavy, 2017).

Data and Sample Size

The population in this study includes all salt-producing regencies/cities in Central Java Province. Meanwhile, the research sample consists of regencies/cities recorded as producers of traditional salt in Central Java Province in 2021-2024 and meets the criteria for complete data. Sampling was carried out using the purposive sampling technique, which is a sample selection technique based on specific criteria, such as completeness of data (Rosadi & Hartini, 2018). Data that met the requirements for completeness of this study were collected from 8 areas producing traditional salt in Central Java Province during the 2021–2024 period. Secondary data used in this study include climate conditions (temperature, humidity, rainfall, and wind speed) in salt-producing areas in Central Java, which were obtained from the official BMKG website (https://dataonline.bmkg.go.id/), as well as data on sustainable competitive advantages (productivity and quality) of traditional salt obtained directly from the Central Java Provincial Maritime Affairs and Fisheries Service (DKP). Central Java is Indonesia's second-largest salt-producing province, with total production reaching 652 thousand tons in 2023 (Catherin, 2024). Therefore, this study is expected to provide a deeper understanding of the climate condition factors that influence the sustainable competitive advantage of traditional salt in Central Java.

Research Model

This study investigates the impact of climate conditions (temperature, humidity, rainfall, and wind speed) on traditional salt's sustainable competitive advantages (productivity and quality). The model used in this study is modified from the research of Pahlawan et al. (2020) which analyzed climate projections (rainfall and season length) on salt production, and the study of Ashilah et al. (2022), which analyzed climatological factors that affect salt production productivity. This modification aims to obtain better results by considering sustainable competitive advantages: productivity (P) and quality (Q). Climate conditions, which include temperature (T), humidity (H), rainfall (RF), and wind speed (WS), act as independent variables. This model is structured as follows:

$$P_i = \alpha + \beta_1 T_i + \beta_2 H_i + \beta_3 RF_i + \beta_4 WS_i + \varepsilon_i$$
$$Q_i = \alpha + \beta_1 T_i + \beta_2 H_i + \beta_3 RF_i + \beta_4 WS_i + \varepsilon_i$$

The key variables for the above estimation are defined in Table 1.

Table 1. Variable Description

Variable Name	Variable Code	Measurement
Independent Variables		
Temperature	T	Average temperature (ºC) The average temperature is obtained from the average air temperature with the calculation formula: (2xTemperature at 07.00 + Temperature at 13.00 + Temperature at 18.00)/4
Humidity	H	Average humidity (%) Average humidity is obtained from the average air humidity with the calculation formula: (2xRH at 07.00 + RH at 13.00 + RH at 18.00)/4
Rainfall	RF	Rainfall (mm) measurement of daily rainfall observed at 07.00 WS
Wind Speed	WS	Average wind speed (m/s) Average wind speed during observation
Dependent Variable		
Productivity	P	Productivity (tons/ha) Total production (tons) divided by land area (ha)
Quality	Q	NaCl content % (w/w) adbk

Analysis Technique

The analysis used to test the effect of climate conditions on sustainable competitive advantage in this study was carried out using panel data regression using the Ordinary Least Squares (OLS) estimation method. There are three approaches used in estimating the parameters of the panel data regression model, namely the Common Effect Model (CEM) or Pool Least Square, the Fixed Effect Model (FEM), and the Random Effect Model (REM) (Alamsyah et al., 2022). Furthermore, the regression model selection for this study was tested through three tests: the Chow Test, the Hausman Test, and the Lagrange Multiplier Test. The best model selected was tested for classical assumptions and parameter tests, and the last stage was model interpretation (Septianingsih, 2022). The data processing process in this study was carried out using EViews 13 software to facilitate more efficient data analysis and management.

RESULTS AND DISCUSSION

Descriptive Analysis

The results of the descriptive analysis in Table 2 show significant variations in several variables that affect salt production. Productivity (P) has a wide range, with an average value of 63.52 tons/ha and a significant standard deviation (38.37), indicating high fluctuations in productivity levels between regions. Quality (Q), measured by NaCl content, is more stable, with an average of 94.68% and a low standard deviation (2.64%), indicating consistency in salt quality. Temperature (T) averages 28.23°C with slight variation (standard deviation 0.65°C), while humidity (H) has an average value of 78.16% and slight variation (standard deviation 3.32%). Rainfall (RF) shows substantial variations, with an average of 475.90 mm and a standard deviation of 191.61 mm, illustrating weather instability that has the potential to affect production results. Wind speed (WS) also varied significantly, with a mean value of 2.94 m/s and a high standard deviation (3.63 m/s), indicating fluctuations in wind conditions. These data suggest that climatic conditions, especially rainfall and wind speed, significantly affect salt productivity, although the quality is relatively stable.

Table 2. Descriptive Statistics

	Min	Max	Mean	SD	Skewness		Kurtosis	
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Std. error**	**Statistic**	**Std. error**
P	3.90	147.97	63.5241	38.3659	0.6116	0.414	2.5615	0.809
Q	87.19	99.25	94.6784	2.6337	-0.4036	0.414	3.4991	0.809
T	27.15	29.47	28.2322	0.6468	0.0341	0.414	2.2942	0.809
H	73.10	84.26	78.1597	3.8223	0.0872	0.414	1.7278	0.809
RF	184.37	968.25	475.9028	191.6138	0.9252	0.414	3.5628	0.809
WS	1.20	16.73	2.9350	3.6255	3.5915	0.414	13.9651	0.809
N	32	32	32	32	32	32	32	32

The correlation matrix shows the relationship between variables. As shown in Table 3, productivity (P) has a significant relationship with rainfall (RF), with a value of 58.5%, which confirms a moderate/sufficient negative relationship. This indicates that increasing rainfall can reduce salt productivity. However, Q, RF, and WS do not have significant relationships with other variables. Overall, these results confirm the relationship between climate conditions and sustainable competitive advantage, providing a basis for our hypothesis that rainfall has a negative effect on productivity.

Table 3. Pearson's Correlation Matrix

	P	Q	T	H	RF	WS
P	1.00					
Q	-0.238	1.00				
T	0.077	0.053	1.00			
H	-0.150	0.141	-0.931*	1.00		
RF	-0.595*	0.177	-0.383*	0.443*	1.00	
WS	-0.184	-0.091	-0.139	0.250	0.330	1.00

Note(s): Correlation is significant at $^{*}p < 0.05$

Hypothesis Testing

Table 4 presents the results of regression estimations linking climate conditions (including temperature, humidity, rainfall, and wind speed) with productivity. Model 1, which uses the Pooled OLS or Common Effects Model (CEM) approach, shows more reliable results compared to the Fixed Effects (FE) and Random Effects (RE) models, based on the results of the Lagrange Multiplier test that supports the suitability of the CEM model. In addition, the Variance Inflation Factor (VIF) value for all variables used in the model is less than 10, indicating no multicollinearity problem between variables. Conversely, a VIF value greater than 10 would indicate a serious multicollinearity problem, as Sriningsih et al. (2018).

In Model 1, it was found that temperature (T) and humidity (H) had a negative effect on productivity (P), but this effect was not significant at the 1%, 5%, or 10% significance levels. Likewise, wind speed (WS) positively affected productivity (P) but was also not significant at this significance level. This indicates that hypotheses H1, H2, and H4 are rejected. Although climate variables such as temperature, humidity, and wind speed are often considered essential factors in determining productivity in the salt production process, this study shows that these three variables do not have a significant effect. Temperature and wind speed, although they play a role in accelerating the evaporation process, are not always directly proportional to increased salt productivity. Previous research in Kaliori-Rembang District found that high wind speed and temperature did not significantly affect salt quantity (Banowati & Firmanzah, 2023). In addition, air humidity, which is often associated with evaporation rate, did not show a significant relationship with salt productivity. In addition, air humidity, which is often associated with evaporation rate, did not show a significant relationship with salt productivity. Research in Genting Village, Jambu District, Semarang Regency, and at the Salt House showed that humidity did not significantly affect productivity (Rahmawati, 2019), and humidity levels also did not significantly affect the evaporation rate (Nuzula et al., 2023). High air humidity generally occurs in the morning, afternoon, and evening because the ambient temperature drops due to minimal sunlight or the sun has set (Nuzula et al., 2023). Although the humidity and wind speed in the area are below the recommended standards, namely humidity of less than 50% and wind speed of more than 5 m/s, salt production can still occur (Kartika et al., 2021). The ideal humidity for salt production is less than 60% because high humidity can inhibit the evaporation rate, while low humidity can accelerate it. Despite high humidity, salt production is still possible as long as it is supported by the availability of wind to support the mass transfer of water vapor (Nuzula et al., 2023). These results suggest that these climate factors may not be the main determinants of salt productivity in the local context and traditional production methods.

However, it is essential to note that these results are regional and may differ in other regions with different environmental conditions and production methods.

Meanwhile, rainfall (RF) has a significant negative effect on productivity (P), with a coefficient of 0.1038 ($p < 0.01$), indicating that increased rainfall can reduce productivity. This result supports hypothesis H3, which states that rainfall negatively affects productivity. This means that the higher the rainfall, the lower the productivity of traditional salt in Central Java Province. Rainfall is the main factor influencing salt production in Indonesia. The research results by Adiraga & Setiawan (2014) found that rainfall negatively and significantly affected salt production in Juwana City from 2003 to 2012. High rainfall levels will negatively affect salt production (Hamdani & Farmiati, 2022). Higher rainfall significantly affects salt production, where the decline in traditional salt production is caused by a shorter dry season, reducing the time for salt farming. In contrast, increased rainfall during the dry season causes the salt crystallization time to be longer (Pahlawan et al., 2020). Based on other studies, the optimal rainfall intensity for salt production is between 1,000-1,400 mm/year, with a long dry season of at least 140 days without rain, which is essential to support good salt quantity (Noviasari et al., 2023). High rainfall can disrupt the production process and cause decreased income (Kamilah et al., 2024). In addition, high rainfall inhibits the crystallization process, reduces production efficiency, and causes instability in salt supply. Therefore, salt production management needs to consider rainfall factors to increase productivity.

In addition, based on the results of the F test, which showed a value of 4.2294 with a p-value of 0.0087, this model is overall significant at a significance level of 1% ($p < 0.01$). This indicates that independent variables related to climate conditions (such as temperature, humidity, rainfall, and wind speed) significantly affect salt productivity. Thus, hypothesis H5 is accepted. The positive coefficient for climate conditions (temperature, humidity, rainfall, and wind speed) supports the hypothesis that optimal climate conditions can increase salt productivity. This finding aligns with previous literature emphasizing climate factors in salt production. Weather conditions also affect salt production, with hot and dry weather supporting increased production (Kamilah et al., 2024). The adjusted R^2 value shows that 29.41% of the variation in productivity (P) can be explained by factors of temperature (T), humidity (H), rainfall (RF), and wind speed (WS), which indicates that the model's prediction of productivity estimates (P) is still relatively weak.

Table 4. Pooled OLS, Fixed and Random Effects Regression Results

Variable	Model 1 Pooled OLS	Model 2 Fixed effect	Model 3 Random effect	Collinearity statistics Tolerance	VIF
Dependent variable: Productivity (P)					
C	860.5043 (0.4167)	-1763.878 (0.3011)	231.4793 (0.8384)		
Temperature	-20.6995 (0.4213)	43.8550 (0.2965)	-5.5545 (0.8402)	0.125	8.019
Humidity	-1.9358 (0.6673)	8.0080 (0.2517)	0.5363 (0.9117)	0.116	8.645
Rainfall	-0.1308*** (0.0008)	-0.0772* (0.0683)	-0.1102*** (0.0031)	0.752	1.330
Wind Speed	0.3335 (0.8512)	0.0452 (0.9844)	-0.2112 (0.9057)	0.822	1.216
Adjusted R^2	0.2941	0.4682	0.1988		
F-Statistics	4.2294*** (0.0087)	3.4815*** (0.0075)	2.9235** (0.0395)		
DW-Statistics	2.1068	3.1765	2.4493		
Lagrange Multiplier test	0.4566				
Sig	(0.4992)				
N	32	32	32		

Note(s): Variables are significant at $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Table 5 presents the results of regression estimation that describe the relationship between climate factors (temperature, humidity, rainfall, and wind speed) and salt quality. Model 1 is a Pooled OLS or Common Effects Model (CEM). The results of the Lagrange Multiplier test indicate that the Pooled OLS or CEM model is more appropriate than the Fixed Effects (Model 2) and Random Effects (Model 3) models because the significance value of the Lagrange Multiplier test is greater than 0.05. Collinearity in this model is detected using the VIF (Variance Inflation Factor) value, which ranges from 1.2206 to 8.6454. All VIF values are below the general limit (10), indicating no serious problem with multicollinearity between independent variables. The results of the Pooled OLS or CEM model indicate that temperature (T) and humidity (H) both have a positive effect on salt quality (Q) at a significance level of 5%. In other words, the higher the temperature, the higher the salt quality tends to increase, and the higher the air humidity, the salt quality also tends to improve. The positive coefficients for both factors indicate that hypothesis H6 is accepted, while hypothesis H7 is rejected.

The hypothesis that temperature has a significant positive effect on quality is supported by previous studies which explain that salt quality, including the percentage of NaCl and its whiteness level, can be influenced by drying parameters such as temperature, air velocity, and drying time, where optimal conditions for these parameters can improve both of these salt quality factors (Amir et al., 2021). In salt production, temperature significantly affects the evaporation rate, where the higher the temperature, the higher the evaporation rate, so salt crystals will form easily (Yoseva et al., 2021). In addition, the higher the temperature and salinity, the faster the salt formation process will be (Hartati et al., 2022). The quality of salt production is also influenced by the salinity and temperature of seawater, where the higher the NaCl content, the better the quality of the salt (Faisol et al., 2022). High temperatures can increase the sodium ion content and decrease the magnesium ion content in salt (Han et al., 2008).

In addition to temperature, humidity also affects the quality of the salt produced. The hypothesis that humidity has a significant negative effect on salt quality is rejected because the study results showed that the higher the humidity, the better the quality of the salt. This finding contradicts existing empirical evidence, which shows that higher average air humidity is associated with poorer salt quality (YN, 2007). The presence of water vapor can cause salt to partially dissolve and then recrystallize, which can change the structure and size of the salt crystals, potentially reducing their quality (Desarnaud & Shahidzadeh-Bonn, 2011; Sato & Hattanji, 2018). For example, humidity of 51% can produce salt with KW1 quality, while humidity higher than that tends to produce salt with KW3 quality (Putri, 2022). Based on these findings, it can be seen that air humidity has a complex effect on salt quality. Although this study generally shows that higher humidity can improve salt quality, other empirical evidence shows the opposite, with higher humidity leading to decreased quality. Therefore, the humidity factor must be carefully considered to produce optimal-quality products in the salt production.

The study showed that rainfall (R) did not significantly affect quality (Q). Although it was hypothesized that rainfall could negatively affect quality, the statistical tests revealed that the effect was insignificant at the 1%, 5%, or 10% significance levels. This means that in the context of this study, changes in rainfall do not have a direct or significant relationship with the variation in quality measured, so hypothesis H8 is rejected. However, several previous studies support the finding that rainfall can affect salt quality in different contexts. Rainfall is indeed one of the main factors influencing the success of a salt harvest, especially in traditional salt production systems that rely on natural evaporation processes. The salt crystallization process requires hot and dry weather for a specific period, so high rainfall can inhibit or even stop the evaporation process of seawater in salt ponds (Kamilah et al., 2024). The decline in salt quality also occurs during the rainy season, such as in the production of KW 3 salt, where seawater mixes with rainwater and mud from rainwater overflow that enters the salt fields, which causes contamination of crystallization and a decrease in the quality of the salt produced (Putri, 2022). However, in modern salt production using technology such as geomembranes and automatic irrigation systems, salt quality can be consistently maintained even in less favorable weather. This more controlled production system reduces dependence on the weather, resulting in better and more stable salt quality despite weather fluctuations, including rainfall (Nompo et al., 2025). Applying semi-modern production technology is also one solution to improving the quality of traditional salt (Badi'ah et al., 2023). Thus, although rainfall has the potential to affect the quality of salt in traditional production, modern technology can reduce this influence, which is in line with the findings in this study that rainfall does not significantly affect quality.

Meanwhile, wind speed (WS) significantly affects the quality of salt production, as seen in this study, where a significant negative coefficient at a significance level of 10% indicates that increasing wind speed can reduce the quality of salt produced. These results lead to the rejection of hypothesis H9. Previous studies have also shown that salt production becomes more difficult in areas with unstable wind speed variations, such as the South Coast of East Java. Fluctuating wind speed changes cause instability in the evaporation rate, which ultimately disrupts the crystallization process and reduces the quality of the salt. Amin et al. (2024) also revealed that unstable wind speed variations in the area inhibit salt crystallization. In the experimental tunnel column, the wind speed ranged from 0.4 - 3.9 m / s, which is lower than the wind speed outside the tunnel, which ranges from 1 - 9.5 m / s. The semi-closed condition of the tunnel causes only a little wind to enter from both openings. Wind speed does have a significant influence on the evaporation process in salt ponds. High wind speed can accelerate salt production, as Prayitno et al. (2023) stated. However, higher wind speeds do not always increase cooling efficiency or production due to other factors, such as decreased effectiveness of evaporative cooling pads and more vigorous mixing of hot air with the surrounding airflow (Akinaga et al., 2018). However, wind speeds of around 3 m/s are sufficient to provide adequate cooling in a salt production system, although changes in wind direction remain a problem that needs to be addressed. One solution is to use a double evaporative cooling wall structure that can protect the plant from wind reversals without significantly increasing costs.

The F-test results show an F-statistic value of 3.9761 with a significance value of $p < 0.05$. This indicates that the overall regression model is significant, which means that the climate condition factors included in the model (such as temperature, humidity, rainfall, and wind speed) significantly affect salt quality. Thus, Hypothesis 10 is accepted. The positive coefficient for climate conditions (temperature, humidity, rainfall, and wind speed) supports the hypothesis that optimal climate conditions can improve salt quality. This finding aligns with previous literature stating that climate and weather conditions affect the duration of salt production and the quality of the salt produced (Aldi et al., 2021). The Adjusted R^2 value shows that 27.75% of the variation in quality (Q) can be explained by the factors of temperature (T), humidity (H), rainfall (RF), and wind speed (WS), which indicates that the model's prediction of quality estimates (Q) is still relatively weak.

Table 5. Pooled OLS, Fixed and Random Effects Regression Results

Variable	Model 1 Pooled OLS	Model 2 Fixed effect	Model 3 Random effect	Collinearity statistics Tolerance	VIF
Dependent variable: Quality (Q)					
C	-172.2322 (0.0248)	-172.6031 (0.1573)	-162.8089 (0.0750)	0.125	8.019
Temperature	6.3786** (0.0012)	6.6635** (0.0321)	6.2654** (0.0068)	0.116	8.645
Humidity	1.1052** (0.0014)	1.0051** (0.0490)	1.0273** (0.0103)	0.752	1.330
Rainfall	0.0024 (0.3264)	0.0017 (0.5588)	0.0016 (0.5210)	0.822	1.216
Wind Speed	-0.2416* (0.0585)	-0.0710* (0.6640)	-0.1595 (0.2414)		
Adjusted R^2	0.2775	0.4360	0.1799		
F-Statistics	3.9761** (0.0116)	3.1785** (0.0120)	2.7002* (0.0517)		
DW-Statistics	1.6605	2.6774	2.2020		
Lagrange Multiplier test	1.2753				
Sig	(0.2588)				
N	32	32	32		

Note(s): Variables are significant at $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

CONCLUSION

Based on the study's results, rainfall significantly negatively affected the productivity of traditional salt in Central Java Province. At the same time, temperature, humidity, and wind speed did not significantly affect productivity. However, overall climate conditions were proven to have a positive effect on the productivity of traditional salt. On the other hand, temperature and humidity significantly positively affected salt quality. At the same time, wind speed significantly negatively affected salt quality, and rainfall did not significantly affect salt quality. Overall, climate conditions positively affect the quality of traditional salt. These findings emphasize the importance of managing climate factors to support sustainable competitive advantage by increasing the productivity and quality of traditional salt in Central Java Province.

The managerial implications of this study are the importance of rainfall management in increasing productivity and temperature management in improving quality. Managing climate factors is also essential in increasing the productivity and quality of traditional salt. In addition, developing and applying technologies that can reduce dependence on extreme weather conditions, such as modern salt production technology, must be considered a more efficient adaptation effort. To increase the competitiveness of traditional salt, better management of natural resources and technology can be the key to achieving more stable and sustainable salt self-sufficiency.

Recommendations for future research include conducting further analysis on the influence of other climate factors that may not have been comprehensively identified and examining the impact of modern salt production technology on salt productivity and quality in the face of unpredictable weather. Further research can also expand the scope of the region and related variables to produce more representative and applicable findings in the context of sustainable traditional salt production.

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