Weather risk prioritization in the carrot supply chain using RapAgRisk: A case study of Mount Lawu Highlands, Indonesia

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Abstract. Karanganyar Regency is an ideal area for horticultural cultivation, particularly carrot. Carrots from this region hold strong economic potential; however, the production system faces various risks that threaten the sustainability of its supply chain. These risks include extreme weather events, pest and disease outbreaks, market price fluctuations, limited credit access, and weak coordination among supply chain actors.This study aims to identify and prioritize weather related risks that require mitigation across each actor in the carrot supply chain in Karanganyar, as well as to assess the level of vulnerability and adaptive capacity of these actors to climate variability. The research used the Rapid Agricultural Risk Assessment (RapAgRisk) method. Data were collected through in-depth interviews, focus group discussions, and field observations involving four actors: farmers, collectors, wholesalers, and retailers. The results show that extreme weather risks, such as heavy rainfall, unstable temperatures, and shifting planting seasons, represent the highest priority across all stages of the supply chain. The highest risk occurs at the production stage, followed by post-harvest and distribution stages. Farmers are the most vulnerable actors due to the direct impacts of weather on yield and product quality, whereas collectors and wholesalers are more affected by supply uncertainty and price fluctuations.

1 Introduction

Karanganyar, located on the slopes of Mount Lawu (3,265 m), is characterized by fertile volcanic soils and a cool humid highland climate that provides ideal biophysical conditions for horticultural production particularly carrot (*Daucus carota*). Carrot farming contributes substantially to the livelihoods of smallholder farmers and supports local value chains including aggregation, transport, and regional market distribution. According to the Central Statistics Agency 2024, carrot cultivation in Karanganyar spans more than 1,700 hectares and contributes significantly to Central Java's highland horticulture output [1]. The region's reputation for producing carrots with high sweetness, bright color, and firm texture strengthens its competitive position within domestic markets.

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Despite these favorable agroecological conditions, carrot farming in Karanganyar is increasingly exposed to climate-related risks. Extreme rainfall, prolonged dry spells, unseasonal temperature shifts, and increased frequency of landslides on steep slopes have been reported to reduce yields and disrupt supply continuity. These weather-related disturbances often lead to post-harvest losses, logistical delays, and higher input requirements for replanting, thereby increasing farmers' vulnerability. Earlier studies indicate that climate variability significantly influences horticultural productivity in tropical highlands, affecting both biophysical growth conditions and broader supply chain performance [2], [3]. In carrot production systems, heavy rainfall accelerates root cracking, fungal infections, and nutrient leaching, while extended dry periods reduce root size and market quality [4].

Existing research on agricultural risk has extensively discussed climate uncertainty, market fluctuations, financial limitations, and institutional constraints across various commodities. However, most studies remain focused on cereals, rice, or large-scale vegetable systems. Research specifically addressing weather risk in carrot production, particularly in mountainous agroecosystems remains limited. Several scholars emphasize that farmers' adaptive capacity is closely linked to climatic exposure, access to information, and local institutional support [5], [6]. Moreover, mountainous horticulture systems have unique vulnerabilities: narrow land parcels, slope instability, limited irrigation infrastructure, and high dependence on local microclimates [7].

To address multi-dimensional agricultural risks, several rapid appraisal tools have been developed, such as Rapid Appraisal for Agricultural Risk (RapAgRisk), which provides a structured approach for identifying, prioritizing, and analyzing dominant risks in smallholder-based supply chains. RapAgRisk has been applied in livestock, staple crops, and mixed farming systems to support decision-making under uncertainty [7], [8]. However, its application in highland horticulture especially carrots, is still scarce, despite its suitability for regions where quantitative risk data are limited, monitoring systems are weak, and risks occur simultaneously along production and supply chain stages.

Given the increasing climate instability on Mount Lawu's slopes and the lack of horticulture-specific risk assessments, there is a critical need to examine weather risks in carrot supply chains using a context-appropriate, rapid, and participatory framework. Therefore, this study focuses on identifying, prioritizing, and analyzing weather-related risks affecting carrot farmers in Karanganyar using the RapAgRisk methodology. This work fills a notable gap in the literature by providing the first structured assessment of climate-related risks specific to the carrot supply chain in this region and contributes to the development of targeted adaptation and mitigation strategies for highland horticultural systems.

2 Literature review

2.1 Weather risks in highland agriculture

Highland agricultural systems are inherently more vulnerable to climatic disturbances compared to lowland ecosystems due to their distinct biophysical characteristics. Orographic rainfall—where moist air masses ascend mountainous terrain—creates highly uneven and unpredictable precipitation patterns that intensify during wet seasons [7]. Excessive rainfall accelerates soil erosion, increases sediment load, and triggers localized landslides, which degrade soil fertility and reduce effective root-zone depth. Additionally, high moisture environments promote fungal diseases such as *Alternaria* and *Sclerotinia*, which are particularly damaging to carrot crops grown in high-altitude fields.

Temperature variability is another critical challenge. Highland areas frequently experience temperature inversions, sudden cold spells, and extreme diurnal temperature

fluctuations. These anomalies disrupt physiological processes such as germination, photosynthesis, and root development, ultimately lowering productivity and quality. Recent climate assessments in Southeast Asia indicate that ENSO-driven anomalies, including prolonged drought and excessive rainfall have become more intense and frequent, directly affecting horticultural productivity in Indonesia's mountainous regions [9].

2.2 Weather risks in highland agriculture

Weather disruptions affect not only on-farm production but also the wider horticultural value chain. Heavy rainfall during the growing season reduces yields through waterlogging, increased disease incidence, and nutrient leaching. However, the impact extends beyond farm-level losses. Postharvest operations such as cleaning, sorting, grading, and storage are highly sensitive to humidity and temperature. Carrots harvested during excessively wet conditions often exhibit lower dry matter content, reduced shelf life, and higher rates of mechanical damage during handling and transport[2,3].

Transportation networks in mountainous regions are particularly vulnerable. Intense rainfall increases the risk of road blockages, slippery surfaces, and landslides, leading to logistical delays. These disruptions cause inconsistent supply flow to markets, increased spoilage, and heightened price volatility. Downstream actors including collectors, wholesalers, and retailers face difficulties in planning procurement, stabilizing market prices, and meeting consumer demand [9].

3 Material and method

This research was conducted in Karanganyar Regency, Central Java, one of Indonesia's main carrot production centers, producing 338,359 tons on 1,720 hectares in 2023. The study focused on Tawangmangu, Ngargoyoso, and Jatiyoso, which are the leading carrot-producing sub-districts. Karanganyar lies on the volcanic slopes of Mount Lawu, characterized by fertile soils and a cool, humid highland climate ideal for carrot cultivation [10]. Respondents were farmers who had cultivated carrots for at least two years. Simple random sampling was used to select 100 farmers, determined through Slovin's formula with a 10% margin of error. Data were collected through structured surveys and in-depth interviews. 10 collectors, who aggregate produce from multiple smallholder farmers; 7 wholesalers, who distribute carrots to regional markets; 10 retailers, who sell the final product to consumers in traditional and semi-modern markets.

RapAgRisk was applied to rapidly assess weather-related risks along the carrot supply chain through a structured and participatory process. The assessment began with identifying key weather hazards such as extreme rainfall, sudden temperature drops, and shifting seasonal patterns based on farmers' experiences and recent climatic anomalies. These hazards were then evaluated through focus group discussions (FGDs) and interviews, where participants scored each hazard in terms of its likelihood of occurrence and potential severity. To determine overall vulnerability, the study further assessed the exposure, sensitivity, and adaptive capacity of each supply-chain actor, including farmers, collectors, wholesalers, and retailers. Finally, all components were integrated into a combined likelihood-severity–vulnerability matrix to prioritize the most critical risks. This approach enabled a rapid yet comprehensive, multi-actor understanding of climate-related disruptions in highland carrot production.

4 Results and discussion

4.1 Identified weather hazards in the carrot supply chain

The RapAgRisk assessment identified three dominant weather-related hazards affecting the carrot supply chain in Karanganyar: 1. extreme rainfall; 2. unstable temperature; and 3. shifting planting seasons.

Farmers consistently reported heavy rainfall as the most disruptive hazard due to its direct impacts on soil structure, crop establishment, and disease incidence. Temperature instability, characterized by prolonged cloudy periods, sudden cold spells, and high humidity was reported to reduce crop vigor and increase postharvest losses. Meanwhile, shifts in rainfall onset caused changes in planting calendars, creating uncertainty in input planning and harvest timing.

These findings align with previous studies indicating that highland horticulture is highly sensitive to climate anomalies due to steep slopes, fragile soils, and narrow windows for optimal planting [12].

4.2 Likelihood and severity scoring across actors

Across all supply-chain nodes, extreme rainfall received the highest combined likelihood and severity score. Farmers observed that rainfall patterns have become increasingly unpredictable, often occurring outside normal rainy seasons. Collectors and wholesalers reported that heavy rainfall reduced the quantity and consistency of supply, while retailers raised concerns regarding shortened shelf-life and lower visual quality.

Temperature fluctuations were assessed as moderately likely but highly severe during specific periods, particularly during the early vegetative phase and during postharvest storage. Shifting seasons were rated as moderate in both likelihood and severity but had significant indirect effects such as delayed planting, simultaneous harvest gluts, or mismatched supply-demand timing.

These patterns confirm that climate variability has become a systemic risk factor that propagates from upstream to downstream actors.

4.3 Vulnerability Assessment of Supply-Chain Actors

4.3.1. Farmers: Highest Exposure and Sensitivity

Farmers emerged as the most vulnerable actors due to their direct exposure to rainfall, soil erosion, and temperature stress. Their sensitivity was intensified by reliance on open-field production, limited irrigation infrastructure, and high disease pressure during wet months. Adaptive capacity was relatively low due to limited financial reserves, constrained access to climate information, and dependence on traditional planting schedules.

4.3.2. Collectors: Vulnerability Linked to Supply Variability

Collectors experienced high exposure to supply fluctuations caused by weather disturbances. Although their sensitivity was lower than that of farmers, they reported difficulties in aggregating consistent volumes during extreme rainfall. Their adaptive capacity was moderate; they could adjust buying trips or reject low-quality produce, but they remained dependent on upstream production patterns.

4.3.3. Wholesalers and Retailers: Lower Exposure but High Market Sensitivity

Wholesalers and retailers were less directly exposed to weather hazards but were affected by inconsistent arrival times, higher spoilage rates, and price instability. Their adaptive capacity was relatively higher due to access to storage facilities, larger capital, and diversified supply sources. Overall, vulnerability decreased downstream, confirming the typical pyramid of climate risk distribution in horticultural supply chains.

4.4 Priority weather risks based on RapAgRisk matrix

The integration of hazard likelihood, severity, and actor vulnerability produced a prioritized list of weather risks:

1. **Extreme Rainfall** – *Highest Priority*
   Dominant cause of soil erosion, crop loss, fungal outbreaks, and difficult transportation.Affects all actors; most critical at the production stage.
2. **Temperature Instability** – *Medium to High Priority*
   Reduces crop quality, affects storage durability, and increases physiological defects. Particularly severe for farmers and retailers.
3. **Shifting Seasons** – *Medium Priority*
   Causes inconsistent planting schedules and market supply imbalances. Significant long-term planning challenge.

These results reinforce findings from regional studies that ENSO-driven anomalies significantly intensify highland weather variability [11].

5 Conclusion

This study applied the RapAgRisk framework to identify and prioritize weather-related risks affecting the carrot supply chain in the highland agroecosystem of Karanganyar, Central Java. The findings reveal that extreme rainfall, temperature instability, and shifting planting seasons are the most significant climate hazards, with the highest impacts occurring at the production stage. Farmers were identified as the most vulnerable actors due to their direct exposure to climatic variability, limited adaptive capacity, and strong dependence on open-field cultivation. Downstream actors—collectors, wholesalers, and retailers—experienced lower exposure but remained sensitive to inconsistent supply volumes, fluctuating prices, and reduced product quality.

The RapAgRisk assessment proved effective in rapidly diagnosing multi-actor vulnerability and generating a prioritized list of critical climate risks. The results underscore the need for targeted adaptation interventions, such as improved drainage and soil conservation practices, access to reliable climate information, flexible logistics, and enhanced postharvest handling systems. Strengthening coordination across supply-chain nodes is essential to minimize systemic disruptions triggered by weather anomalies.

Overall, this research contributes to the growing body of literature on climate risk management in highland horticulture and offers a practical, participatory methodology for supporting climate adaptation planning in ASEAN mountain regions. The insights produced can guide policymakers, farmer groups, and agribusiness stakeholders in designing interventions that enhance the resilience and sustainability of carrot value chains under increasing climate uncertainty.

References

1. Badan Pusat Statistik Jawa Tengah, Provinsi Jawa Tengah Dalam Angka 2024 (BPS Jateng, 2024)
2. A. S. Fibrianto, Management model of ecotourism-based forest village community land to increase local economic in Karanganyar, Indonesia. Geojournal of Tourism and Geosites . **37**, 3 (2020). https://doi.org/10.30892/gtg.37327-729
3. M. R. Afany and N. A. H. J. Pulungan, The impact of horticulture farming practices in Andisols forest on organic-P content, Tawangmangu, Central Java. IOP Conference Series: Earth and Environmental Science. **215**, 1 (2018). https://doi.org/10.1088/1755-1315/215/1/012007
4. M. D. Il Islam, A. Rahman, M. N. I. Sarker, M. S. R. Sarker, and L. Jianchao, Factors influencing rice farmers' risk attitudes and perceptions in bangladesh amid environmental and climatic issues. Polish Journal of Environmental Studies. **30**, 1 (2021). https://doi.org/10.15244/pjoes/120365
5. M. Wang, P. Childerhouse, and A. Abareshi, Global logistics and supply chain integration in the digital era: a focus on China's Belt and Road Initiative. **22**, 2 (n.d.). https://doi.org/10.1108/JILT-03-2023-0018
6. D. Karnawati, T. F. Fathani, S. Ignatius, B. Andayani, D. Legono, and P. W. Burton, Landslide hazard and community-based risk reduction effort in Karanganyar and the surrounding area, central Java, Indonesia. Journal of Mountain Science. **8**, 2 (2011). https://doi.org/10.1007/s11629-011-2107-6
7. FAO, World Food and Agriculture – Statistical Yearbook 2022 (Food and Agriculture Organization of the United Nations, Rome, 2022)
8. M. S. Hossain, G. M. M. Alam, S. Fahad, T. Sarker, M. Moniruzzaman, and M. G. Rabbany, Smallholder farmers' willingness to pay for flood insurance as climate change adaptation strategy in northern Bangladesh. **338**, (n.d.). https://doi.org/https://doi.org/10.1016/j.jclepro.2022.130584
9. N. Albaar, I. W. Budiastra, and Y. Hariyadi, Influence of Secondary Packaging on Quality of Carrots During Transportation. **9**, (n.d.). https://doi.org/10.1016/j.aaspro.2016.02.149
10. A. N. Afifah, S. Marwanti, and Agustono, Food security analysis based on the proportion of food expenditure and energy consumption of carrot farm households in Tawangmangu Karanganyar. **905**, 1 (n.d.). https://doi.org/10.1088/1755-1315/905/1/012052
11. D. Pan, M. He, and F. Kong, Risk attitude, risk perception, and farmers' pesticide application behavior in China: A moderation and mediation model. **276**, (n.d.). https://doi.org/10.1016/j.jclepro.2020.124241