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Research Original Article

Contagion Analysis of Plantation Commodity Producing Regions in Aceh Province Using Bayesian Inference

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Abstract
The commodity-producing region is one of the plantation sectors with significant potential for economic growth in Aceh Province. The spread level between commodities owned by regions within the network is called "contagion," which means that one commodity will influence a region, leading to a greater focus on that commodity within the network, and a region will influence other regions. With the diversity of commodities across various areas, a comprehensive analysis and visualization of the network formed among commodity producing regions are conducted using a Social Network Analysis (SNA) approach. Thus, Bayesian inference can reveal the network of each region that has relationships among the variables used to form a graph with the desired representation. This network analysis result can provide an overview of Aceh Province's plantation data through the network graph visualization among commodity-producing regions and the network graph of commodity production levels by region.
Keywords: Aceh; Contagion Analysis; Social Network Analysis

INTRODUCTION
Indonesia is known as an "Agricultural Country" a term that means a country that relies on the agricultural and plantation sectors as a source of livelihood and a driving force for economic development. The agriculture and plantation sectors are highly dominant and support both food needs and community income in Indonesia, as most of its population works as farmers and plantation workers [1]. The Aceh Province is one of the regions with significant potential for developing plantations with a variety of commodities in each district, extensive land areas, and well-suited natural resources. Commodity-producing areas serve as a key sector in plantation efforts, presenting substantial potential for economic growth in Aceh Province [2]. According to data from the Central Bureau of Statistics (BPS) of Aceh in 2022, the plantation area in Aceh Province reached 837,778.02 hectares, involving 826,350 households. There are 21 types of plantation commodities cultivated across 23 districts/cities producing these commodities. Various commodities developed include rubber, coconut, oil palm, coffee, cocoa, nutmeg, betel nut, pepper, patchouli, cloves, sugarcane, tobacco, cashew, kapok, citronella, candlenut, sago, palm, gambier, castor, and cassia [3].

With the diversity of commodities from various regions, it is possible to conduct a comprehensive analysis and visualize the network formed between commodity-producing areas using a Social Network Analysis (SNA) approach [4]. The spread level between commodities owned by regions within a network is called "contagion," meaning that one commodity will influence a particular region, leading to a greater focus on that commodity within the network. Consequently, one region will have an impact on other regions [5]. Using the Bayesian Inference method, it is possible to display the network of each region that has relationships among the variables used to form a graph with the desired representation. However, the issue faced is the lack of visualization related to the data of plantation commodities in Aceh Province obtained from producing regions. As a result, the annual production overview and the largest producing region per year for each commodity are not known. Thus, this network analysis can provide an overview of the plantation production data in Aceh Province through visualizing a network graph of inter-regional commodity-producing areas and a network graph of commodity production quantities relative to the producing regions.

Literature Review

1. Commodity Producing Areas
The commodity-producing regions are one of the agricultural sectors with significant potential for economic growth in Aceh Province. These regions greatly influence production outcomes; therefore, it is essential to depict the best

commodity results each year as an effort to enhance production areas [2]. Thus, the desired results are in accordance with the conditions in the field, even though the productivity appears to have increased. However, the clear increase in productivity is influenced by many factors, especially the suitability of the land in each district in Aceh Province [6].

2. Contagion analysis

Contagion analysis is the process of understanding and analyzing the spread within entities (nodes) in a population (edges). This analysis involves modeling and understanding the relationships between entities in complex networks that can influence the spread. In contagion networks, one influencing factor is density, which is the concept of the completeness and interconnectedness of relationships within the network [7].

3. Social Network Science

Social network analysis (SNA) is a process of analyzing social structures through the use of network science by identifying patterns among entities (nodes) that influence interactions (edges). The dissemination of information within network patterns occurs through interconnected network topologies, rather than through a single interaction. Complex networks are often used to represent the structure of interactions between entities (nodes) in a population (edges) that are distributed within contagion. The structure of nodes and edges will produce visualized and organized patterns of network relationships [5]. In conducting analysis, SNA uses several metrics categorized into Degree Centrality, Closeness Centrality, Betweenness Centrality, and Eigenvector Centrality

4. Bayesian Inference

Inferential statistics is a branch of statistics that deals with analyzing data as probabilities or predictions for drawing conclusions about a population [8]. Inference is derived from the relationships between each node in the structure; any changes that occur in a node will affect the probability values of all nodes directly or indirectly connected to it [9]. Based on the influence obtained, Bayes' theorem is used to calculate the probability of an event occurring. This theorem explains the relationship between the probability (hypothesis) of event H and the fact that event E has occurred [10].

$$P(H|E) = \frac{P(E|H) * P(H)}{P(E)} \qquad (1)$$

Where:

$P(H|E)$ = Probability of hypothesis H given *evidence E.*

$(E|H)$ = Probability of the *evidence E occuring given hypothesis H.*

(E) = Probability of *evidence E.*

(H) = Probability of hypothesis H.

5. Gephi

Gephi is an open-source software used for analyzing patterns in networks or graphs, visualizing networks that display real-time data to explore and understand patterns within network data. Gephi features a flexible and multitasking architecture that provides new possibilities for working with data sets and generating complex visual results [11].

Materials & Methods

1. Data

The object of this research is the statistical results of plantation commodities in Aceh. Therefore, the research data is obtained from the website of the Agriculture and Plantation Office (Distanbun) of Aceh Province. This data is sourced from the Distanbun website because it provides detailed annual data that supports the analysis of commodity yields across the plantation areas of Aceh, enabling an understanding of the distribution of plantation commodity yields.

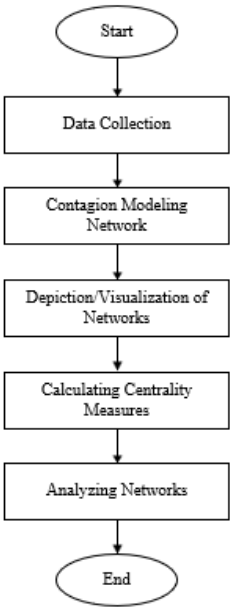
Table 1.Recap of Plantation Area and Production Results in Aceh Province

Year	Commodities	Amount Area (Ha)	Production Amount (Ton)	Number of Farmers (KK)
2017	Rubber	129.660	66.671	101.225
2017	Coconut	101.642	62.832	148.572
…	…	…	…	…
2018	Cocoa	99.341	39.295	127.951
2018	Cloves	25.091	5.315	23.996
…	…	…	…	….
2019	Sugar	4.597	32.905	4.226
2019	Tobacco	2.318	2.149	3.912
…	…	…	…	…
2020	Kapuk	1.285	388	6.130
2020	Candlenut	16.290	9.051	20.722
…	…	…	…	…
2021	Sugar	2.152	970	5.483
2021	Cassiavera	266	101	1.350
…	…	…	…	…
2022	Patchouli	1.321	181	3.301

2022	Serewangi	20.635	3.190	20.127

2. Methods

Based on the image above, the stages of this research can be described as follows:



Picture 1. Research Workflow

Manual Calculation of Bayesian Inference Method

This calculation aims to determine the probability values of the relationships from production data of plantation commodities in the Aceh Province, which consists of 23 producing regions and 21 plantation commodity outputs. The calculation is performed using sample data, where each year there are 4 production data points from the commodity producing regions. This data is presented in a table showing the production results of each commodity in the regions in tons.

Table 2.Results of Bayesian Posterior Inference Calculations for All Commodities

Commodity Relationship		Correlation Value	**Estimasi (P(Data))**	**Prior P (Hubungan)**	**Likelihood**	**P (Data)**	**Posterior**	Result Analysis
Commo-dity **1**	Commo-dity **2**							
Rubber	Coconut	0,084279603	0,7	0,5	0,7	0,6	0,583333333	Netral
Rubber	Palm Oil	0,357589366	0,5	0,5	0,7	0,6	0,583333333	Netral
Rubber	Coffe	-0,197538774	0,6	0,5	0,3	0,6	0,25	Hubungan Lemah
…	…	…	…	…	…	…	…	…
Gambir	Jarak	-0,085062608	0,7	0,5	0,3	0,6	0,25	Hubungan Lemah
Patchouli	Serewangi	0,076496541	0,7	0,5	0,7	0,6	0,583333333	Netral
Patchouli	Jarak	0,041513221	0,7	0,5	0,7	0,6	0,583333333	Netral
Serewangi	Jarak	-0,069153033	0,7	0,5	0,3	0,6	0,25	Hubungan Lemah

Calculating the Bayesian inference value to examine the relationship between palm oil and coffee commodities.

$$P(H|E) = \frac{P(E|H) * P(H)}{P(E)} \qquad (2)$$

$$P(H|E) = \frac{0.3 * 0.5}{0.6}$$
$$P(H|E) = 0.25$$

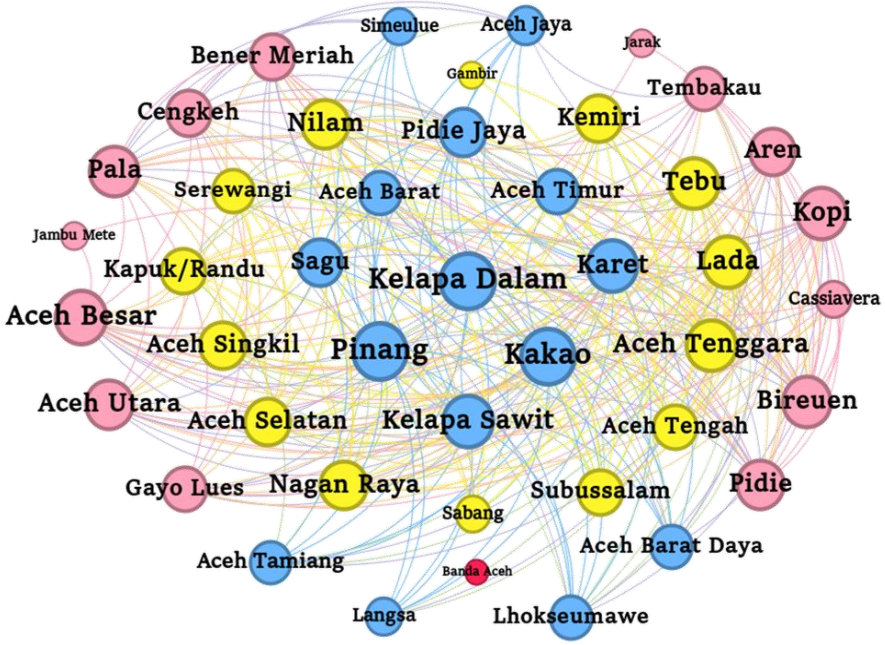
in this study,
P(Relationship | Data) = 0.3 indicates the likelihood value based on data showing a negative correlation.
P(Relationship) = 0.5 represents the prior belief about whether palm oil and coffee are related before examining the data or remains neutral.
P(Data) = 0.6 signifies the total probability of observing this data without considering the relationship.
Based on Bayesian theorem analysis, the posterior result of 0.25 means that the probability of a relationship between palm oil and coffee production, given the existing correlation data, is 25%. This indicates that despite a relatively strong negative correlation (r = -0.22), the probability of a relationship between these two commodities remains relatively low, suggesting that as the production of one commodity increases, the other tends to decrease.

Based on the analysis of Bayes' Theorem, the posterior result of 0.25 means that the probability of a relationship between the production of palm oil and coffee, given the existing correlation data, is 25%. This indicates that, despite a fairly strong negative correlation (r = -0.22), the probability of a relationship between these two commodities is still relatively low, meaning that when the production of one commodity increases, the other commodity tends to decrease. Below is a table of posterior results from the Bayesian inference calculation for all commodities across 23 plantation-producing regions in Aceh Province.

Results and Discussion

The research results obtained are a network analysis in the form of a visual graph of the plantation commodity-producing regions in Aceh Province using a network science approach. This analysis describes the network of a region that has relationships with other regions through the plantation commodities it possesses. From the visualization results, a depiction of the areas with potential for plantation development and the commodities that are the leading sectors in Aceh Province has been obtained. The following is the network analysis graph visualization that has been illustrated using Gephi in this study:

1. Network Graph of Commodity Producing Regions



Picture 1. Network Graph of Commodity Producing Regions

This network visualization illustrates the relationships between nodes representing the production of plantation commodities in various regions. Each node in the network signifies a commodity and the region producing that commodity, with connecting lines (edges) indicating a relationship between them. The connections between nodes are based on the types of commodities produced in a region, and regions are also linked to other regions that produce the same commodities. From the results of the social network analysis (SNA) visualization of the network of commodity-producing regions in Aceh Province from 2017 to 2022, it can be analyzed that Aceh Besar Regency is the largest commodity-producing region (core node) in this network due to the variety of commodities produced in that area. In terms of commodities, the Coconut commodity is the largest (core node) because many plantation regions in Aceh Province produce it. This highlights the significant role of Aceh Besar and the Coconut commodity in the structure of the

plantation network in Aceh Province.

The size of the nodes represents the level of influence (centrality) of each commodity and the producing region, where larger nodes indicate higher centrality values, reflecting the importance of those commodities in the network. The color of the nodes indicates the category or type of commodity, facilitating the identification of interconnected groups. Below is the graph visualization created using Gephi version 0.10.1, utilizing an undirected graph type.
The attributes of the graph in the network are as follows:

Table 1.1. Attributes Graph

Size	*Nodes* : 44 *Edge* : 314
Diameter	4
Density	0.332
Average Degree	14.273
Average Path Length	1.821

In the graph attributes mentioned above, there are 44 nodes and 314 edges. Based on these results, it can be concluded that 44 nodes interact within the network, with a total of 314 interaction relationships. In the network of commodity-producing regions, the diameter is 4, indicating that the distance between nodes in the network is not too far. Therefore, it can be inferred that the likelihood of interaction among nodes becomes easier and less constrained. The attribute of density represents the relational intensity of the nodes within the network when interacting. The higher the density value, the denser the network becomes. The density of the network among commodity-producing regions is 0.332, indicating that the network density is low. Meanwhile, the average degree is 14.273, suggesting that this network has a relatively high level of connectivity. The average path length represents the average distance that must be traversed from one node to another. This network has an average path length of 1.821, meaning that despite the presence of many nodes, the distance between nodes is relatively short, reflecting efficiency in information access among the nodes.

To determine the influential nodes (core nodes) in a network, several centrality measures are used, including degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality.

1) Degree Centrality

Degree centrality is a network measurement used to determine the influence of a node based on direct connections or relationships established among nodes. The higher the degree centrality value of a node, the greater the likelihood that the node will become central and play a significant role in the dissemination of distribution. In networks of commodity-producing regions, degree centrality is used to identify the regions that are most interconnected with commodities, as well as the commodities that are most connected to the producing regions.

Table 1.2 Degree Centrality

No	*Node*	*Degree*	*Degree Centrality*
1.	Coconut	22	0.511627
2.	Coffe	22	0.441860
3.	Greater Aceh	20	0.465116
4.	North Aceh	17	0.395348
5.	Lhokseumawe	13	0.302325

In the network of commodity-producing regions in Aceh Province, the node with the highest degree centrality is the Coconut commodity, which serves as the core node with 22 connections to other nodes in the network. This value indicates that the Coconut node is a staple commodity (universal) since the majority of the regions in Aceh Province produce Coconut plantations. Aceh Besar node serves as a central regional node in the network, having 20 connections to other nodes. This indicates that Aceh Besar is a central production area due to its contribution to the production of various types of plantation commodities, making it a primary region in the plantation sector. By understanding degree centrality, it can be concluded that commodity-producing regions can be prioritized for further development due to their significant influence within the network. These regions can become focal points for the plantation sector in production centers.

2) Closeness Centrality

Closeness centrality is a network measure used to determine the shortest distance of a node to other nodes; the node with the highest value is considered strategic because it can access other nodes with fewer connections in the network. Regions play a role as production centers or meeting points for commodity flows, thus influencing the interaction patterns between regions in the commodity-producing network.

Table 1.3 Closeness Centrality

No	*Node*	*Degree*	*Closeness Centrality*
1.	Coconut	22	0.671875
2.	Cocoa	22	0.671875
3.	Greater Aceh	20	0.651515
4.	North Aceh	17	0.623188
5.	Lhokseumawe	13	0.589041

The nodes representing Coconut and the commodity Coconut are the ones with the highest closeness centrality values. This indicates that the Coconut region acts as a strategic area that is close to other regions, providing quicker access to the centers of the plantation sector in Aceh Province. The Coconut commodity also shows a strong relationship with various other commodity-producing regions, playing a key role in the commodity production network in Aceh Province.

3) Betweenneess Centrality

Betweenness centrality is a network measure used to determine the position of a node that acts as the shortest bridge connecting a node to other nodes within the network. It measures how often a node lies on the shortest path between other nodes.

Table 1.4 Betweenness Centrality

No	*Node*	*Degree*	*Betweenness Centrality*
1.	Coconut	22	0.041057
2.	Cocoa	22	0.041057
3.	Greater Aceh	20	0.068784
4.	Southeast Aceh	19	0.047574
5.	Bireuen	18	0.039799

Based on table 1.4, the node Greater Aceh has the highest betweenness centrality value, indicating that a commodity must pass through Greater Aceh to connect with other commodities. This suggests that Greater Aceh serves as an intermediary in the flow of commodities between different regions. Furthermore, Coconut also acts as a primary connector in the network, where a region must pass through Coconut to connect with other regions .

4) Eigenvector Centrality

Eigenvector centrality is a network metric used to determine the importance of a node in the network based not only on the number of its connections but also on the quality of those connections.

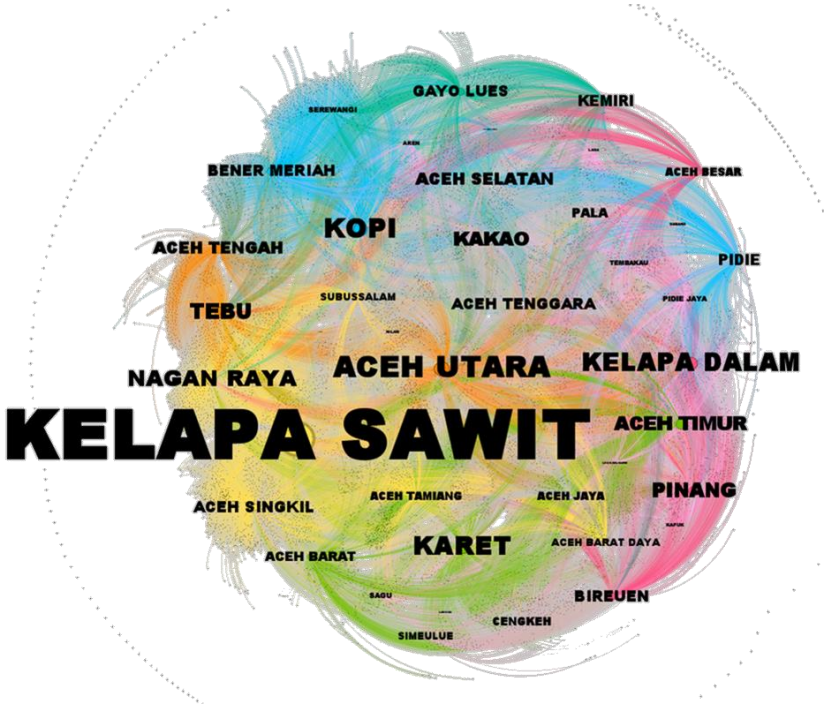
Table 1.5 Eigenvector Centrality

No	*Node*	*Degree*	*Eigenvector Centrality*
1.	Coconut	22	1.0
2.	Cocoa	22	1.0
3.	Greater Aceh	20	0.919812
4.	North Aceh	17	0.879758
5.	Lhokseumawe	13	0.708068

Based on table 1.5, the node of Coconut has the highest eigenvector centrality value, serving as a central node in the formation of the network. This is due to its strategic position in the network, which is not only determined by its large number of connections but also by being connected to other influential nodes with significant connections. Although Greater Aceh plays an important role in the network, its eigenvector centrality value is lower. This indicates that while Greater Aceh is connected to many other nodes, the nodes it is connected to do not have as much influence as those connected to Coconut.

2. Graph of Commodity Production Quantity Network Against Regions

Here is the graph visualization using Gephi software version 0.10.1 with an undirected graph type and using the Fruchterman Reingold layout to arrange the positions of the nodes and edges.



Picture 3.. Graph of Commodity Production Quantity Network Against Regions

This network visualization illustrates the relationships between nodes representing commodities with the highest production volumes and the regions producing the largest quantities. The nodes consist of commodity-producing regions and types of commodities, connected by edges based on the production results of commodities in each region. The connections between nodes are determined by the production volumes of various commodities in each region, highlighting regions that act as central nodes in the network and identifying the types of commodities that are the largest producers in Aceh Province's plantations.

From the results of the social network analysis (SNA) graph visualization of commodity production volumes in Aceh Province's plantation regions from 2017 to 2022, it can be analyzed that among the many types of plantation commodities, the production of palm oil in several regions exceeds the average production compared to other commodities. Thus, oil palm becomes the commodity with the highest production volume. From a regional perspective, North Aceh produces the highest commodity production compared to other regions. Among the various commodities in North Aceh, most plantation commodities yield above-average production, making North Aceh the region with the largest plantation production volume in Aceh Province. Each node in the graph is connected to other nodes based on its interactions. The more interactions a node has, the larger its representation within the graph. The attributes of the graph in the network are as follows:

Table 3.1 Attributes Graph

Size	Nodes : 13.758 Edge : 26.647
Diameter	5
Density	0.000
Average Degree	3.874
Average Path Length	2.896

In the graph attributes mentioned above, there are 13.758 nodes and 314 edges. Based on these results, it can be concluded that 26.647 nodes interact within the network, with a total of 26.647 interaction relationships. In the network of commodity-producing regions, the diameter is 5, indicating that the distance between nodes in the network is not too far. Therefore, it can be inferred that the likelihood of interaction among nodes becomes easier and less constrained. The attribute of density represents the relational intensity of the nodes within the network when interacting. The higher the density value, the denser the network becomes. The density of the network among commodity-producing regions is 0.000, indicating that the network density is low.

Meanwhile, the average degree is 3.874, suggesting that this network has a relatively high level of connectivity. The average path length represents the average distance that must be traversed from one node to another. This network has an average path length of 2.896, meaning that despite the presence of many nodes, the distance between nodes is relatively short, reflecting efficiency in information access among the nodes. To determine the influential nodes (core nodes) in a network, several centrality measures are used, including degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality.

1) Degree Centrality

Degree centrality is a network measure used to identify nodes that are highly influential based on their direct connections or relationships with other nodes. The higher the degree centrality value of a node, the greater the likelihood of that node becoming a central hub and playing an important role in the distribution of commodities or regions. In the network of commodity production volumes against regions, degree centrality is utilized to identify regions most connected to commodities through the edges representing production volumes generated by each commodity and vice versa, to identify commodities most connected to regions through the edges representing production volumes produced by each region. Below are the top five nodes with the highest degree centrality rankings.

Table 2.2 Degree Centrality

No	*Node*	*Degree*	*Degree Centrality*
1.	Palm Oil	3.275	0.238043
2.	Coffee	1.278	0.092891
3.	Rubber	1.202	0.087367
4.	North Aceh	1.385	0.100668
5.	Nagan Raya	1.040	0.075592

Based on table 2.2, palm oil is the node with the highest degree centrality value, having a direct connection or relationship count of 0.238043. This value indicates that palm oil is a commodity with very strong connections to producing regions that yield above average production volumes. Other commodity nodes with high degree centrality values include coffee and rubber. North Aceh is the region with the highest degree centrality value, at 0.100668. This indicates that North Aceh is strongly connected to commodities, as several commodities in this region produce above-average production volumes. Consequently, North Aceh serves as a central production hub in the plantation sector of Aceh Province.

2) Closeness Centrality

Closeness centrality is a network measure used to determine the shortest distance between a node and other nodes. The node with the highest closeness centrality value becomes a strategic node because it can access other nodes with fewer connections in a network.

Table 2.3 Closeness Centrality

No	*Node*	*Degree*	*Closeness Centrality*
1.	Palm Oil	3.275	0.52806
2.	Areca Nut	929	0.513736
3.	Cocoa	914	0.507549
4.	North Aceh	1.385	0.519492
5.	Southeast Aceh	722	0.508548

Based on table 2.3, the region of North Aceh with a value of 0.519492 and the commodity of palm oil with a value of 0.52806 are the nodes with the highest closeness centrality. This indicates that the North Aceh node plays a strategic role as it is close to various other regions, providing faster access to the central plantation sector in Aceh Province. The palm oil commodity also has proximity to various other commodity producing regions. It can be concluded that the regional nodes act as production or meeting centers for the flow of commodities, thus influencing the interaction patterns between regions in the commodity-producing network, while the commodities themselves serve as the flow between various regions.

3) Betweenneess Centrality

Betweenness centrality is a network measure used to determine the position of a node that acts as the shortest intermediary between nodes connected to one another in the network, measuring how often a node lies on the shortest path between other nodes.

Table 2.4 Betweenness Centrality

No	*Node*	*Degree*	*Betweenness Centrality*
1.	Palm Oil	3.275	0.228398
2.	Coffe	1.278	0.09764
3.	Coconut	1.157	0.086094
4.	North Aceh	1.385	0.104383
5.	Nagan Raya	1.040	0.069969

Based on table 2.4, North Aceh is the region with the highest betweenness centrality value, indicating that a commodity must pass through Aceh Utara first to connect with other commodities. This suggests that North Aceh plays an indirect intermediary role in the flow of commodities from one region to another. Additionally, palm oil also acts as a primary connector in the network, where a region needs to pass through palm oil to connect with other regions. Other nodes with high betweenness centrality values include coffee, coconut, and nagan raya.

4) Eigenvector Centrality

Eigenvector centrality is a network measure used to determine the importance of a node within a

network based not only on the number of its connections but also on the quality of those connections.

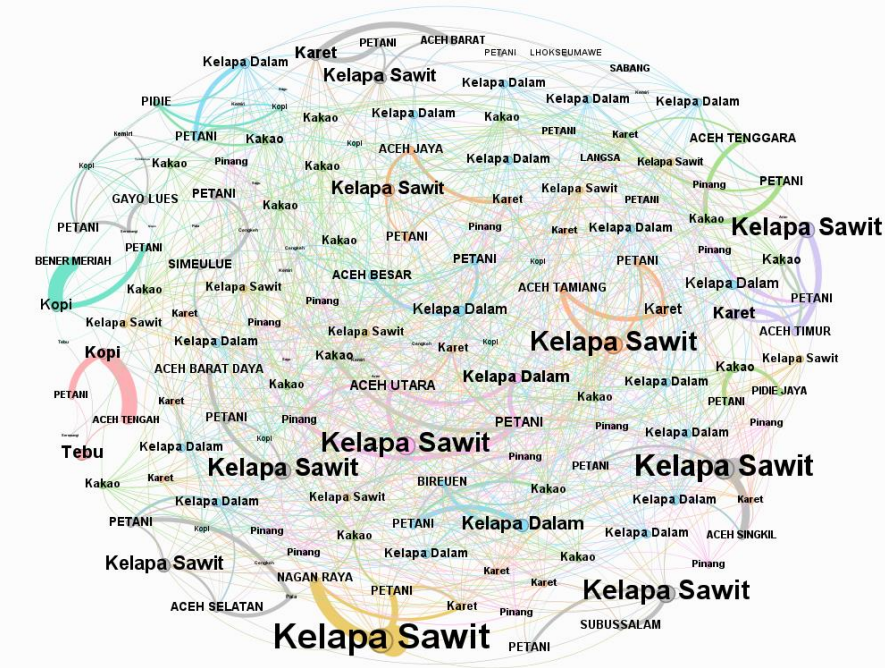
Table 2.5 Eigenvector Centrality

No	*Node*	*Degree*	*Eigenvector Centrality*
1.	Palm Oil	3.275	1.0
2.	Coffe	1.278	0.323308
3.	Rubber	1.202	0.296573
4.	North Aceh	1.385	0.387364
5.	Nagan Raya	1.040	0.322308

Based on table 2.5, palm oil is the node with the highest eigenvector centrality value, playing a central role in the formation of the network. This is due to its strategic position in the network, determined not only by its large number of connections but also because it is linked to other influential nodes. Although North Aceh plays an important role in the network, its eigenvector centrality value is lower, indicating that while North Aceh is connected to many other nodes, these connected nodes do not have the same level of influence as the nodes connected to palm oil.

3. Graph of the Network of Production Volume Against the Number of Farmers and Area Size of Commodities

Here is the graph visualization using Gephi software version 0.10.1 with an undirected graph type and using the Fruchterman Reingold layout to arrange the positions of the nodes and edges.



Picture 4. Graph of the Network of Production Volume Against the Number of Farmers and Area Size of Commodities

This network visualization illustrates the relationships between nodes to identify regions that are efficient in land utilization, commodities with the intensity of farmers' involvement, and regions with high potential that require optimization in commodity management. The interconnections between nodes representing regions and commodities can be visualized based on the relationships between commodity production results, commodity area size, and the number of farmers involved. Nodes are connected by edges that represent these variables, creating a network graph that shows production quantities influenced by the number of farmers and land area.

From the results of the social network analysis (SNA) visualization of the network between production volumes, number of farmers, and land area in Aceh Province in 2017, it can be analyzed that palm oil and sugarcane are commodities that generate high production levels despite having small land areas and involving fewer farmers. This indicates that regions producing palm oil and sugarcane can maximize land use efficiency. On the other hand, coffee produces lower yields despite having vast land areas and fewer farmers, indicating that to increase production, coffee-producing regions need to increase the number of farmers. Rubber, coconut, clove, and nutmeg have significant potential due to the large land areas and many farmers involved, but their production remains low. This shows that, even though these regions have sufficient resources, further development of these commodities is needed to achieve maximum production. Each node in the graph is connected to other nodes based on its interactions. The more interactions a node has, the larger its representation within the graph. The attributes of the graph in the network are as follows:

Table 3.1 Attributes Graph

Size	*Nodes* : 1.681 *Edge* : 2.162
Diameter	7
Density	0.081
Average Degree	2.572
Average Path Length	2.926

Based on the graph attributes above, it can be concluded that there are 1,681 nodes interacting within the network with a total of 2,162 connections. To determine the influential nodes (core nodes) in a network, several centrality measures are used, including degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality.

1) Degree Centrality

Based on the graph visualization results, degree centrality is used to identify direct relationships between nodes within the network. The nodes with the highest degree centrality are the palm oil commodity node and the north Aceh region node, which have a significant influence within the network. The palm oil node has numerous connections through edges representing the number of farmers, land area, and its interconnections with other palm oil nodes in various producing regions. Thus, palm oil becomes a leading commodity that significantly contributes to total production and serves as a primary focus in various plantation-producing regions of Aceh Province. The north aceh node, as a region producing various types of commodities, has many direct connections to various nodes related to production volume and land area of each commodity produced. North aceh is a strategic region serving as a link between commodities and resources, meaning any changes occurring in north aceh could impact the overall relationship patterns within the network. Below are the top 5 nodes with the highest degree centrality values in the network.

Table 3.2 Degree Centrality

No	*Node*	*Degree*	*Degree Centrality*
1.	Palm Oil	65	0.414012
2.	Sugarcane	31	0.197452
3.	Coconut	29	0.184713
4.	Aceh Utara	24	0.152866
5.	South Aceh	23	0.146496

2) Closeness Centrality

Based on the graph visualization, closeness centrality is used to measure the shortest distance between a node and other nodes. The nodes north aceh and the commodity cocoa have the highest closeness centrality values in the network. This indicates that north aceh is a major producing region with numerous connections to various commodity nodes, linked through the edges of land area and the number of farmers for each commodity. Thus, north aceh holds a strategic position, being closer to many other nodes in the network. North aceh also has indirect relationships with other regions through production volume, creating shorter interaction paths and enabling faster influence on other nodes. Cocoa is a commodity produced in various regions within the network, with varying intensities of farmers and land areas. This makes the cocoa node a central node connecting multiple regions, resulting in a shorter average distance to all other nodes in the network. Below are the top 5 nodes with the highest closeness centrality values in the network.

Table 3.3 Closeness Centrality

No	*Node*	*Degree*	*Closeness Centrality*
1.	North Aceh	24	0.420912
2.	South Aceh	23	0.413158
3.	Aceh Jaya	21	0.396465
4.	Cocoa	22	0.391521
5.	Coconut	29	0.387654

3) Betweenness Centrality

Based on the graph visualization, betweenness centrality identifies nodes that act as the closest intermediaries between pairs of other nodes. North Aceh and cocoa are the nodes with the highest betweenness centrality values. North Aceh plays a strategic role as a major production area with numerous connections to various commodity nodes, linked through edges representing land area and the number of farmers for each commodity. This positions north aceh as the main connector in the distribution of various commodity nodes produced in this region. Cocoa, on the other hand, is a commodity produced in various regions within the network, with diverse land area and farmer intensity. This makes cocoa a connector between regions through production quantities, allowing one region to connect with another. Below are the top five nodes with the highest betweenness centrality values in the network.

Table 3.4 Betweenness Centrality

No	*Node*	*Degree*	*Betweenness Centrality*
1.	Cocoa	22	0.051151
2.	North Aceh	24	0.040423

3.	Coffe	29	0.036646
4.	South Aceh	23	0.033233
5.	Greater Aceh	22	0.026353

4) Eigenvector Centrality

Based on the graph visualization, eigenvector centrality is used to measure the importance of a node within a network. Coconut is the node with the highest eigenvector centrality value, as it holds significant potential in the network and is connected to various strategically important regional nodes. This is due to its strategic position, not only because it has many connections but also because it is linked to other influential nodes within the network. Below are the top 5 nodes with the highest eigenvector centrality values in the network.

Table 3.5 Eigenvector Centrality

No	*Node*	*Degree*	*Eigenvector Centrality*
1.	Coconut	22	1.0
2.	Cocoa	21	0.810526
3.	Palm Oil	51	0.627701
4.	Arecanut	17	0.306719
5.	Rubber	17	0.290367

Conclusions

The conclusions drawn from the three visualized graphs provide an overview of the plantation distribution patterns in Aceh Province.

1. Commodity Producer Region Network**:** This network identifies relationships between regions based on the commodities they produce. Regions with strong connections to many other areas, either as major producers or suppliers of commodities, tend to have large market potential. These regions are often strategic points for distribution policies or logistics management.
2. Commodity Production Volume by Region Network**:** This network illustrates the relationship between production volume and specific regions. Regions with high production volumes tend to have efficient land-use capabilities, as they can produce large amounts of commodities in a limited area. This indicates the potential for further development in these regions through mechanization or new technologies.
3. Production Volume, Number of Farmers, and Area Network**:** This network shows the relationship between production volume, the number of farmers, and the area of commodities. Commodities with strong ties to the number of farmers indicate a high dependency on labor. These commodities may require more attention in terms of farmer training or skill enhancement.

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