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Implementation of Graph Coloring With Region Coloring on the Sulut-Go Map Using the Welch Powell Algorithm

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Abstract

Graph coloring is a technique for assigning colors to vertices so that no two adjacent vertices share the same color. This study implements region coloring on the map of North Sulawesi and Gorontalo (Sulut-Go) using the Welch-Powell algorithm, a method based on the highest vertex degree. The research employs a quantitative-descriptive approach with an algorithmic experimental method. Administrative region data and regional boundary connections in the Sulut-Go provinces are converted into graph form, with regencies/cities as vertices and connecting roads as edges. The procedures include data collection, graph construction, degree calculation, coloring using the Welch-Powell algorithm, and chromatic number determination. The results show that the Sulut-Go map consists of 18 regencies/cities represented as vertices. After implementing the Welch-Powell algorithm, the graph coloring produced a chromatic number of $\chi(G) = 3$, meaning all regions can be colored using only three different colors. The coloring was applied with red, yellow, and green, ensuring that no adjacent regions share the same color. Vertex V15 (Minahasa) has the highest degree, with five connections. This study successfully demonstrates that the Welch-Powell algorithm effectively solves the region-coloring problem on the Sulut-Go map. In conclusion, graph coloring using the Welch-Powell algorithm can be effectively applied to color regional maps, facilitating visual distinction between adjacent areas. The chromatic number $\chi(G) = 3$ indicates the minimum number of colors needed for the Sulut-Go map. This research contributes to the application of graph theory in cartography. Further research is recommended for larger-scale applications such as islands or countries, as well as for edge coloring and social network analysis.
Keywords: graph theory, graph coloring, welch-powell, sulut-go.

INTRODUCTION

Maps are an important medium for conveying geographic information, showing the location, boundaries, and spatial relationships between regions. In the map-making process, a crucial aspect is understanding how adjacent regions are connected to one another, and one effective way to represent this is through the use of color (Park et al., 2020; Schaab et al., 2022). Color helps distinguish between adjacent regions; however, if two neighboring regions share the same color, the visual information becomes ambiguous and potentially misleading (Cipta et al., 2023; Renoult et al., 2017; Stauffer et al., 2015; Y. Wang et al., 2015). Therefore, a systematic method is needed to organize region coloring so that no two connected regions have identical colors (Foggia et al., 2015; Li et al., 2016; Lu & Chen, 2022; Trouillas et al., 2016).

This problem can be modeled mathematically using graph theory, where each region is represented as a vertex and the relationships between regions are represented as edges. This problem is known as graph coloring (Giotis et al., 2015; Li et al., 2016; Trouillas et al., 2016). Graph coloring is a color-assignment technique typically represented by ordered numbers starting from 1, or directly by colors such as red, blue, or green, applied to specific objects in a graph. These objects can represent nodes, edges, or regions (Maftukhah et al., 2020).

One of the algorithms frequently used to solve coloring problems is the Welch-Powell algorithm (Cipta et al., 2023; Rohmah & Ningsih, n.d.; Xu & Sun, 2024). The Welch-Powell algorithm is a type of graph coloring algorithm based on the highest degree of a node, commonly known as Largest Degree Ordering (LDO) (Augusty et al., 2023). According to Soimah and Mussafi (2013), the steps in the Welch-Powell algorithm are as follows: (1) sort the vertices of the graph in descending order of degree (this order may not be unique because multiple vertices can have the same degree); (2) use a single color to color the first vertex (with the highest degree) and other vertices (in descending order) that are not adjacent to it; (3) repeat the process with the next uncolored vertex using the next color; and (4) continue until all vertices are colored.

Graph coloring has been widely applied to solve various real-world problems. In research conducted by Harahap and Khairani (2024), the Welch-Powell algorithm was used to solve a work scheduling problem at Gran Medistra Hospital in Lubuk Pakam. Furthermore, Qomaruddin et al. (2022) applied graph coloring to a map of West Java Province by representing vertices as city names and edges as inter-city connections. These studies demonstrate that graph coloring can be applied to diverse problems, ranging from scheduling to inter-regional mapping (Tan et al., 2019; Tsiotas & Tselios, 2024; Q. Wang et al., 2024; Y. Wang et al., 2023).

Based on this background, the present study aims to apply region coloring to the regencies and cities in the North Sulawesi–Gorontalo region using the Welch-Powell algorithm. This article is expected to provide insight into graph coloring—particularly the Welch-Powell algorithm—and to serve as a reference for solving problems related to inter-regional relationships in North Sulawesi–Gorontalo.

RESEARCH METHOD

This research uses a quantitative-descriptive approach with an algorithmic experimental method. The focus of this research is the application and analysis of the effectiveness of the Welch-Powell Algorithm to find the chromatic number of a graph representing the administrative regions of North Sulawesi and Gorontalo provinces (Sulut-Go). The research data includes: administrative region data, namely a list of regencies and cities in Sulawesi and Gorontalo provinces; regional boundary data, namely the connections between regions that can be directly traversed; and graph data, namely the results of converting regional boundary relationships into graph form, where each regency/city is represented as a node and the connections between regions as edges. The research steps are as follows:

1. Collect data and literature on graph coloring, regencies/cities in Sulut-Go, and roads connecting them.
2. Create a graph based on the regencies/cities in Sulut-Go, with vertices representing regencies/cities and edges representing the presence or absence of roads connecting them.
3. Calculate the degree of each regency/city.
4. Coloring the Sulut-Go region graph using the Welch-Powell algorithm (Figure 1).

5. Calculating the chromatic number of the Sulut-Go region graph.

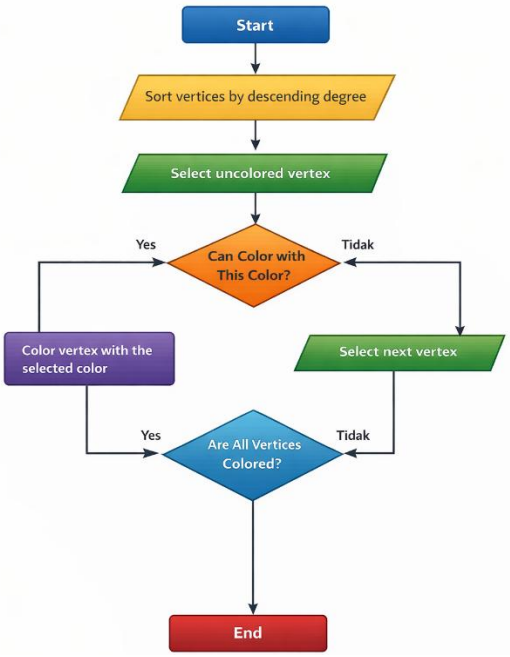

Figure 1: Welch-Powell algorithm in graph coloring
Source: Adapted from Soimah & Mussafi (2013)

This section applies only to experimental research. It contains all matters related to the research steps, research data, and research tools and materials.

RESULTS AND DISCUSSION

In this research, the object of study is the North Sulawesi-Go map, which implements a region coloring using the Welch-Powell algorithm, with districts/cities as nodes and protocol roads as edges. Graph coloring using the Welch-Powell algorithm involves the following steps:

1. Collect data or information in the form of a North Sulawesi-Go map.
2. Represent the North Sulawesi-Go map as a graph with districts/cities as nodes and connected regions connected by an edge.
3. Use the Welch-Powell algorithm to perform the coloring.

To create a graph based on the North Sulawesi-Go map, a map image of the North Sulawesi-Go map is required. The following is an image of the North Sulawesi-Go map.

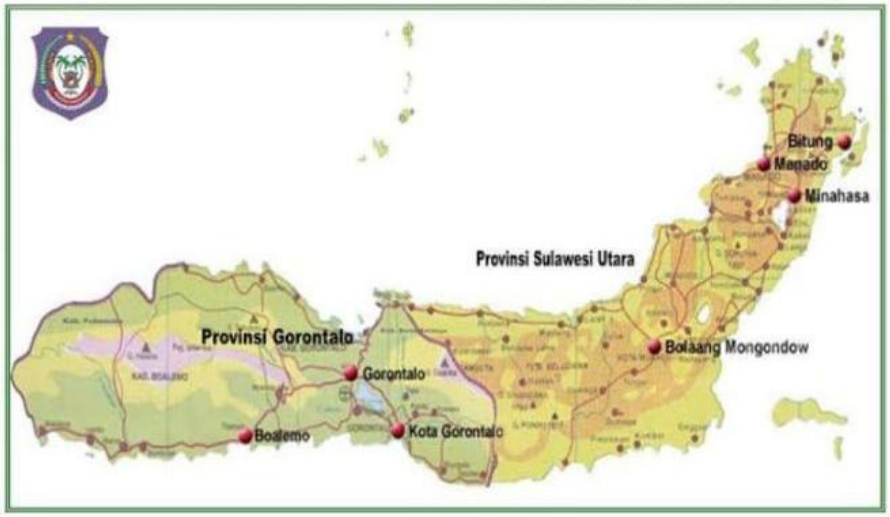

Figure 2. North Sulawesi-Go Map
Source: Google Maps (2026), modified by researcher

Figure 2 shows a map of the provinces of North Sulawesi and Gorontalo, which we represent as the following graph.

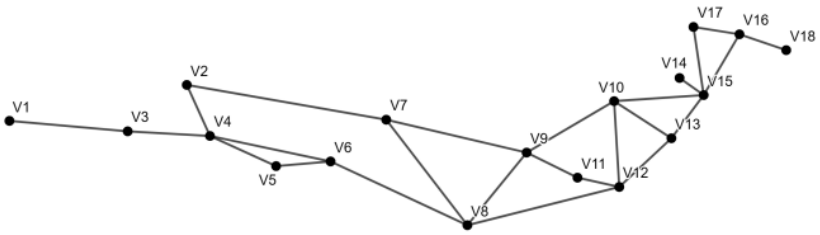

Figure 3. North Sulawesi-Gorontalo map graph
Source: Processed data from Figure 2 (2026)

Based on Figure 3, the map of North Sulawesi and Gorontalo Provinces, represented as nodes, shows 18 regencies/cities. Each regency/city is given a name (V1, V2, V3, …, V18).

Figure 3 shows that node V15 has the highest degree. The names of the regencies/cities and their degrees can be seen in the following table**.**

Table 1. Degree of Regency/City Nodes in North Sulawesi-Gorontalo

No	Name of Regency/City	Node Symbol	Degree
1.	Minahasa	V15	5
2.	Kabupaten Gorontalo	V4	4
3.	Bolaang Mongondow Selatan	V8	4
4.	Bolaang Mongondow	V9	4
5.	Minahasa Selatan	V10	4
6.	Bolaang Mongondow Timur	V12	4

7.	Bonebolango	V6	3
8.	Bolaang Mongondow Utara	V7	3
9.	Minahasa Tenggara	V13	3
10.	Minahasa Utara	V16	3
11.	Gorontalo Utara	V2	2
12.	Boalemo	V3	2
13.	Kota Gorontalo	V5	2
14.	Kotamobagu	V11	2
15.	Manado	V17	2
16.	Pohuwato	V1	1
17.	Tondano	V14	1
18.	Bitung	V18	1

Source: Processed data from Figure 3 (2026)

Once the graph's vertices are sorted in descending order, the next step is to color the first vertex (the one with the highest degree) with the first color, followed by other vertices that are not adjacent to the first vertex. Continue with the remaining colors.

The following is the result of coloring vertices using the Welch-Powell algorithm. It was found that adjacent (connected) vertices (cities) do not have the same color. The resulting vertex coloring can be seen in the following image.

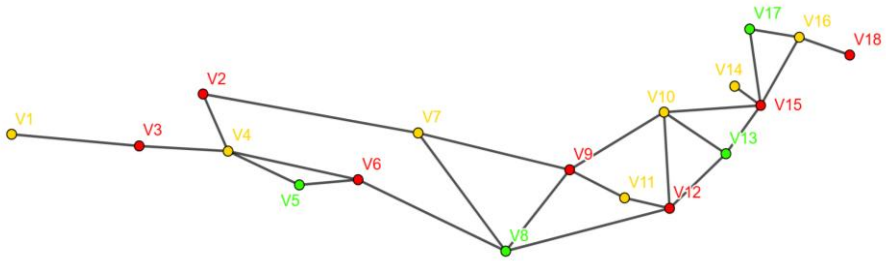

Figure 4. Node coloring on the North Sulawesi-Go map
Source: Processed data using Welch-Powell algorithm (2026)

After the nodes were colored, they were applied to the North Sulawesi-Go regional map, as shown in the following figure and table.

Figure 5. Coloring of regions on the North Sulawesi-Go map
Source: Processed data from Figure 4 applied to base map (2026)

Table 2. Coloring of districts/cities in North Sulawesi-Go

No	Name of Regency/City	Node Symbol	Color
1.	Minahasa	V15	Red
2.	Kabupaten Gorontalo	V4	Yellow
3.	Bolaang Mongondow Selatan	V8	Green
4.	Bolaang Mongondow	V9	Red
5.	Minahasa Selatan	V10	Yellow
6.	Bolaang Mongondow Timur	V12	Red
7.	Bonebolango	V6	Red
8.	Bolaang Mongondow Utara	V7	Yellow
9.	Minahasa Tenggara	V13	Green
10.	Minahasa Utara	V16	Yellow
11.	Gorontalo Utara	V2	Red
12.	Boalemo	V3	Red
13.	Kota Gorontalo	V5	Green
14.	Kotamobagu	V11	Yellow
15.	Manado	V17	Green
16.	Pohuwato	V1	Yellow
17.	Tondano	V14	Yellow
18.	Bitung	V18	Red

Source: Processed data from Figure 4 (2026)

The number of colors used in coloring the Sulut-Go map is 3 colors, namely red, yellow and green. So $\chi(G) = 3$, this number of colors is called the chromatic number and in table 2 the results of graph coloring in each district/city in North Sulawesi and Gorontalo Provinces using the Welch-Powell Algorithm.

CONCLUSION

Graph coloring using the Welch-Powell algorithm can be applied to solve the coloring problem on the Sulut-Go regional map, facilitating the mapping of each region in the North Sulawesi and Gorontalo Provinces. The results of the graph coloring in this study produced three color groups for the regions (regencies/cities) on the map of North Sulawesi and Gorontalo, totaling 18 areas. The chromatic number of the graph map for the North Sulawesi and Gorontalo Provinces is $\chi(G) = 3$, meaning that the district and city areas can be colored using only three colors—red, yellow, and green—where adjacent districts or cities connected by an edge have different colors. Further research based on this study is recommended to explore the application of graph coloring to region coloring, edge coloring, and social network coloring, as well as its implementation for coloring larger geographical entities such as islands or countries.

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