Sarah Cloughley (20941873)
GEOG 381 – Lab 103 – Assignment 5

Assignment 5: Suitability of New Small Wind Farms in Waterloo Region

Introduction/Background

This report conducts a Multi-Criteria Analysis to select the locations of two new small wind farms in Southwestern Ontario, specifically Waterloo Region. Through investigating the suitability of wind speed and quality, and important auxiliary factors such as proximity to buildings and roads, the Ontario Government can construct the most optimal farms to bolster the province's renewable energy outputs.

Study Site & Data

This analysis is being done in Waterloo Region, Ontario, Canada. The data includes:

- **Wind Speeds** – MIF data from the Government of Canada's Wind Atlas
- **Waterloo Region Boundary, Roads, Building Footprints, Significant Woodlands, Cities and Towns** – shapefile data from Waterloo Region
- **Runways** – shapefile data from the Government of Canada's CanVec database

I downloaded the annual, 30m wind speed data from Wind Atlas. All datasets have been re-projected to UTM NAD83 17N (to ensure distances are measured in meters) and converted into rasters.

Methods/Process

The flowchart can be found as **FIGURE 1** in the appendices.

The first step in processing the wind speed data was to convert it to a shapefile. I did this using the **Convert Format** tool in QGIS and selecting shapefile for the output. Then, to reduce processing times for raster operations, I used the **Clip** tool to limit the area to only within the region boundary. The inputs were the wind speed and boundary polygons, and the output was a clipped wind speed polygon. I then used the **Polygon to Raster** tool twice, to convert each of mean and standard deviation wind speeds to rasters. The inputs were the wind speed raster, a value field of EU for mean and EU2 for standard deviation, and a cell size of 50 (50m x 50m squares). I chose this cell size since it was a good balance between accuracy and granularity for an area as large as Waterloo region. Additionally, since the minimum distance between turbines is 60m and the max is 300m, you can thus fit roughly 1 turbine every 1-5 squares, which makes the maps easier to interpret. Since the minimum mean wind speed for the region was 4.20 m/s, and the min required for turbines is 4.17 m/s, no area within the region was off limits. I then used **Raster Calculator** to calculate a weighted raster, taking into account both mean and standard deviation of wind speeds. The inputs were the two wind speed rasters, and the expression was `"Mean_Windspeed" * (1 / ("StdDev_Windspeed" + 1))`. I took the inverse standard deviation since a lower value is better (less variation) and added 1 to avoid dividing by 0. By multiplying these values, each cell was normalized, taking into account both the speed and quality of wind, since these are both crucial factors in wind potential.

For processing the auxiliary data, I first used **Euclidean Distance** to create a distance raster for each of the auxiliary features. The inputs were each of the auxiliary polygons and an output cell size of the wind raster, to ensure consistency between datasets. I then used **Extract by Mask** to limit the rasters to inside the regional boundary. The inputs were the distance rasters, the regional boundary polygons, and an extraction area of "Inside". Then, I used the **Set Null** tool to enforce the constraints for each dataset. The input was each of the masked rasters and the conditional statement was `WHERE VALUE is less than or equal to N`, where N was the specific constraint for each feature (ie. 550m for buildings, 70m for roads, 0m for forests). This ensured that all areas that weren't allowed to be built on would not appear in the final raster, since they have no value.

Finally, I used the **Reclassify** tool on each of the output rasters and created 5 equal distance classifications. I chose equal distance since there's a positive linear relationship between wind quality/distance from features and the suitability of wind turbines. Using each of the reclassified rasters as input, I ran the **Weighted Overlay** tool to get my final MCA output. I used weights of 45% for wind speed/quality, 15% for distance from buildings and urban areas, 10% for distance from roads and airports, and 5% for distance from forests.

Results/Discussion

There are two main issues affecting wind farm placement that I considered: the potential output of electricity (ie. best wind speed and quality) and the logistics for construction (ie. least human impact). For the first issue, I chose the criterias of wind speed mean and standard deviation to determine the fastest and most stable locations. For the second issue, I chose to look at distances from existing constructions including buildings, roads, forests, urban areas, and airports. Since wind speed/quality is the most important factor in building fruitful wind farms, I made this factor the majority of the weight. Additionally, since these are small wind farms with few turbines, there is already less of an impact on humans. Of the auxiliary criteria, I ranked distance from buildings and urban areas as most important, since people spend a significant amount of time living and working in these locations. I ranked distance from roads, airports, and forests as less important since these are not as human-centric areas.

First consider the suitability maps for each criteria (**FIGURES 3-8**). Wind speed/quality is the best in the Northwest and decreases sequentially as you move southeast. This may be correlated with the higher urbanization in the Southeast, since more built up areas are typically less windy than open farmlands. For buildings, there are very few open areas since even rural areas have farmhouses/barns on their land. Roads are also less concentrated in the Northwest despite covering much of the region, likely due to the higher concentration of forests. For forested areas, there are large empty patches in the center, but this is because these are very urbanized areas and not because they are open. Thus, the best remaining areas are mostly in the North of the region. There are the large urban areas in the center representing Waterloo, Kitchener, and Cambridge, but also many smaller towns scattered throughout the region. This leaves most of the open space near the edges. Finally, there are three airports in the region in the North and East, making the South and West the best locations.

Now looking at the final MCA map (**FIGURE 2**), since wind has the highest weighting, the general consensus is the Northwest is the best location for a wind farm. However, this is also supported by most of the auxiliary datasets as we just discussed. Since the Northwest is the best general area, both of my site selections (Pink and Purple) were from this area. I chose the Pink site since this was the only location that had a suitability rating of 5, meaning it was the optimal location based on the MCA. I chose the Purple site since this was the largest contiguous patch of land with a suitability rating of 4. This means that the most wind turbines can be built in this location. Together, these site selections represent the highest quality and quantity locations within the region. Additionally, having the sites be relatively close together may be helpful in logistics when constructing them, as materials and workers will need to be transported to the same area. Both areas are accessible by existing roads while still keeping their distance from urban settlements. The Pink site covers roughly 2 square kilometers, and the Purple site covers roughly 3 square kilometers. Since a maximum of 5 individual turbines can be built in a small wind farm, approximately 5 will be able to be placed in the Purple site and 3-4 in the Pink site. Each turbine produces approximately 6 million kWh of energy every year, which amounts to powering around 1500 households (Wind, n.d.). Thus altogether, these sites could produce 51 million kWh and power almost 13 000 homes per year. As Waterloo Region is developing a significant amount of residential areas and growing extremely quickly in population, the turbines built on these sites could help to offset the future increase in power needs.

Overall, the selected sites provide optimal wind conditions while also taking into account logistical concerns such as disturbing existing human settlements and environments. They will allow Ontario to generate a much larger amount of clean energy and reduce carbon emissions from unrenewable resources. Finally, the location of these sites in the rapidly growing Waterloo Region can help the province strategize in terms of producing energy locally and reducing energy transportation costs.

Reference

Wind energy frequently asked questions. EWEA. (n.d.). https://www.ewea.org/wind-energy-basics/faq/

Appendices

FIGURE 1 – Flowchart

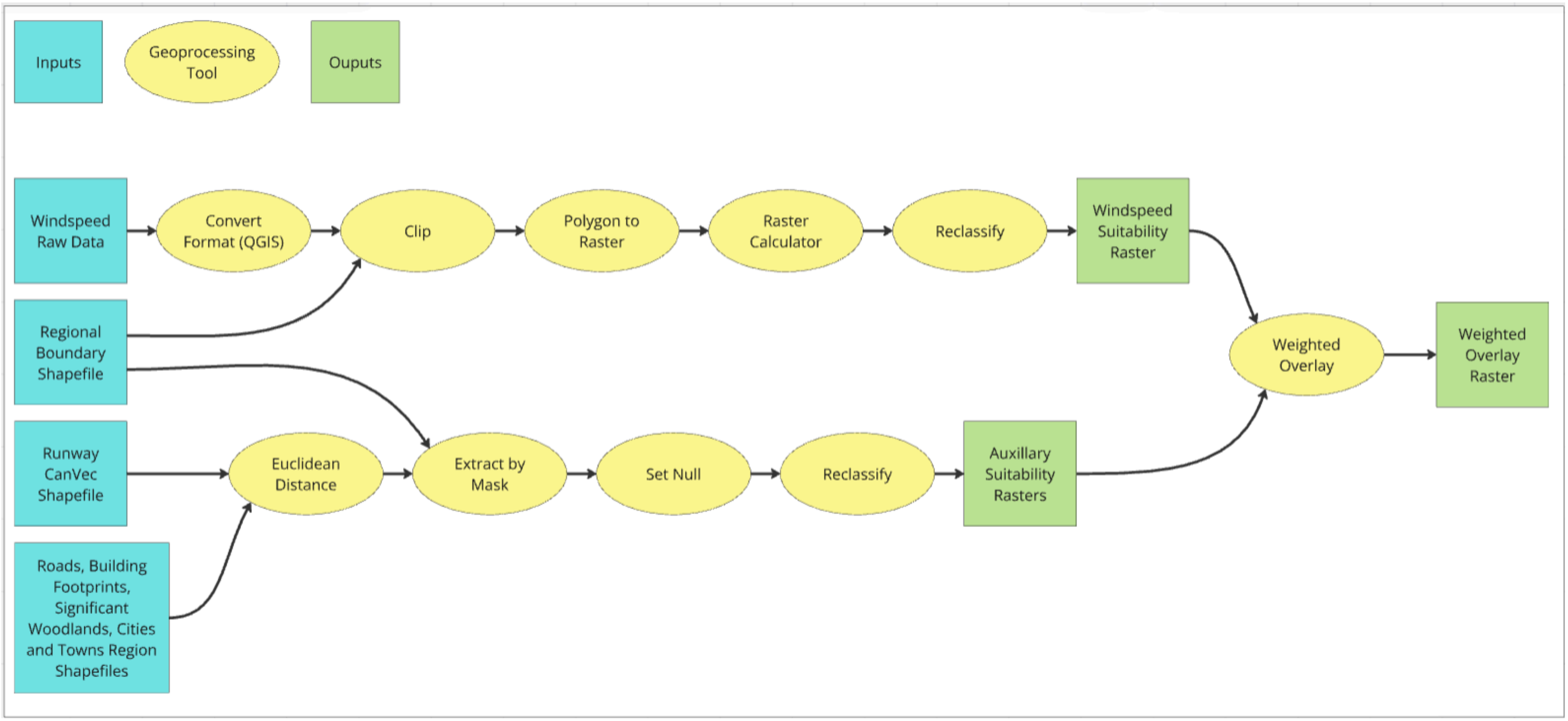

FIGURE 2 – Final Suitability

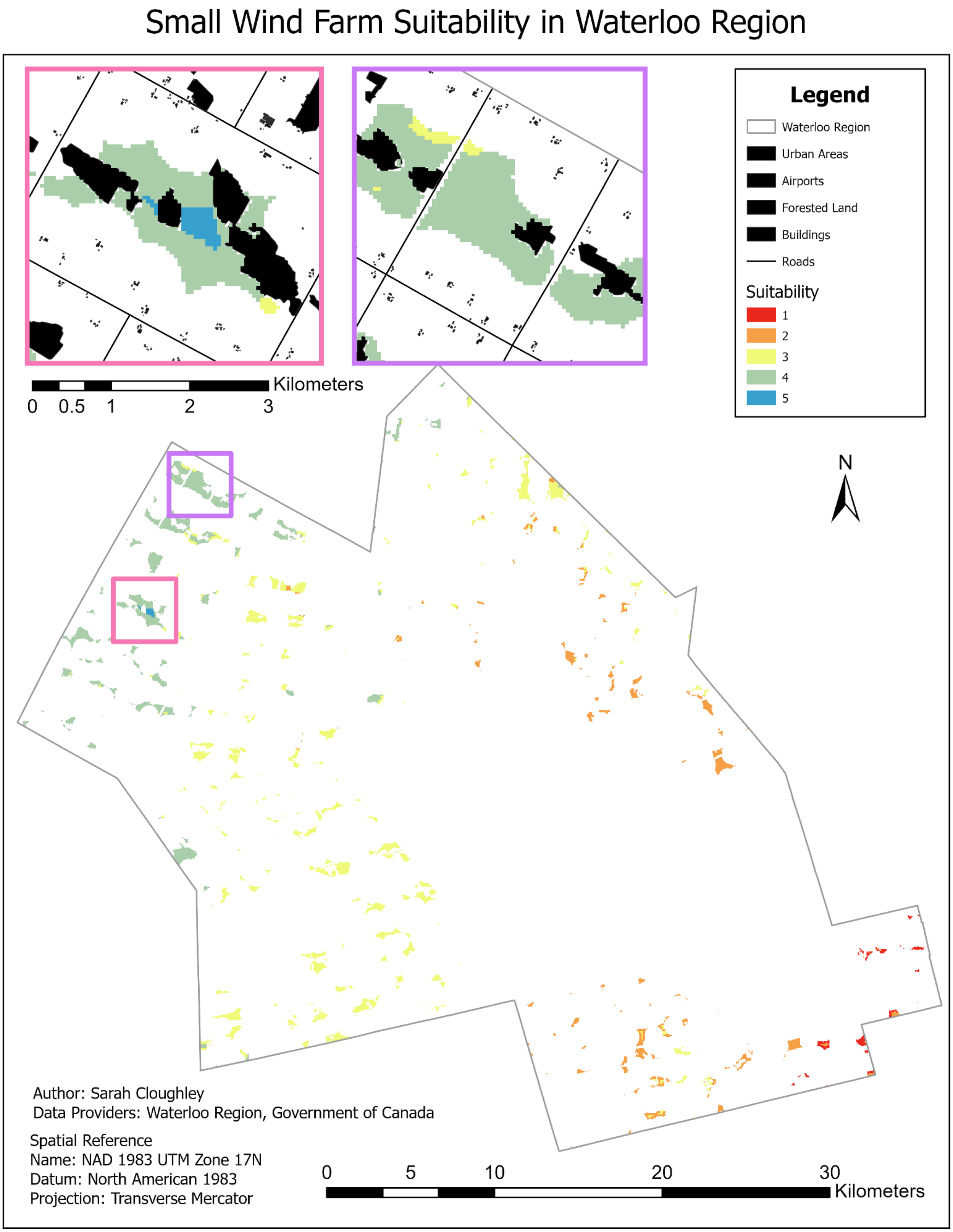

FIGURE 3 – Wind Suitability

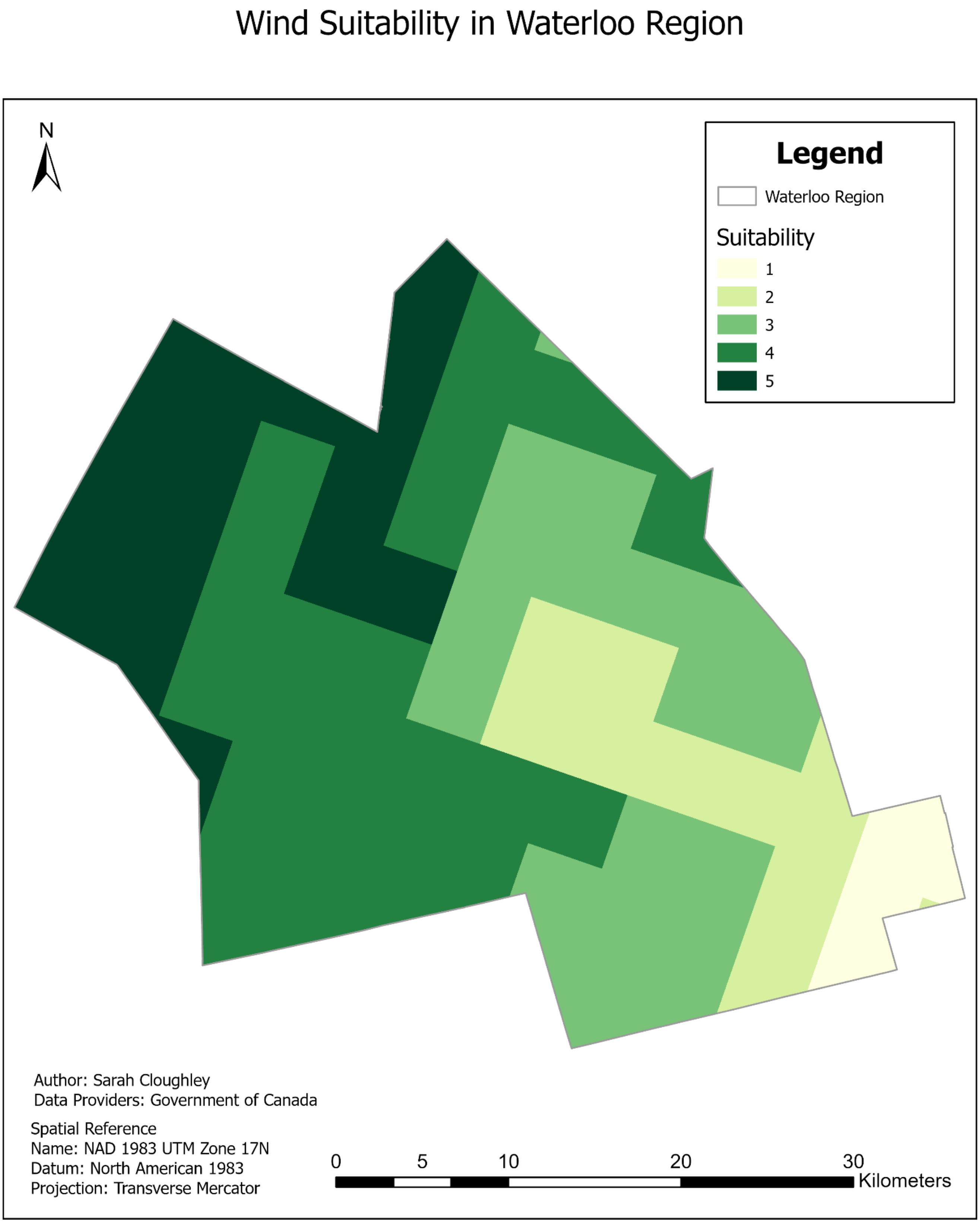

FIGURE 4 – Buildings Suitability

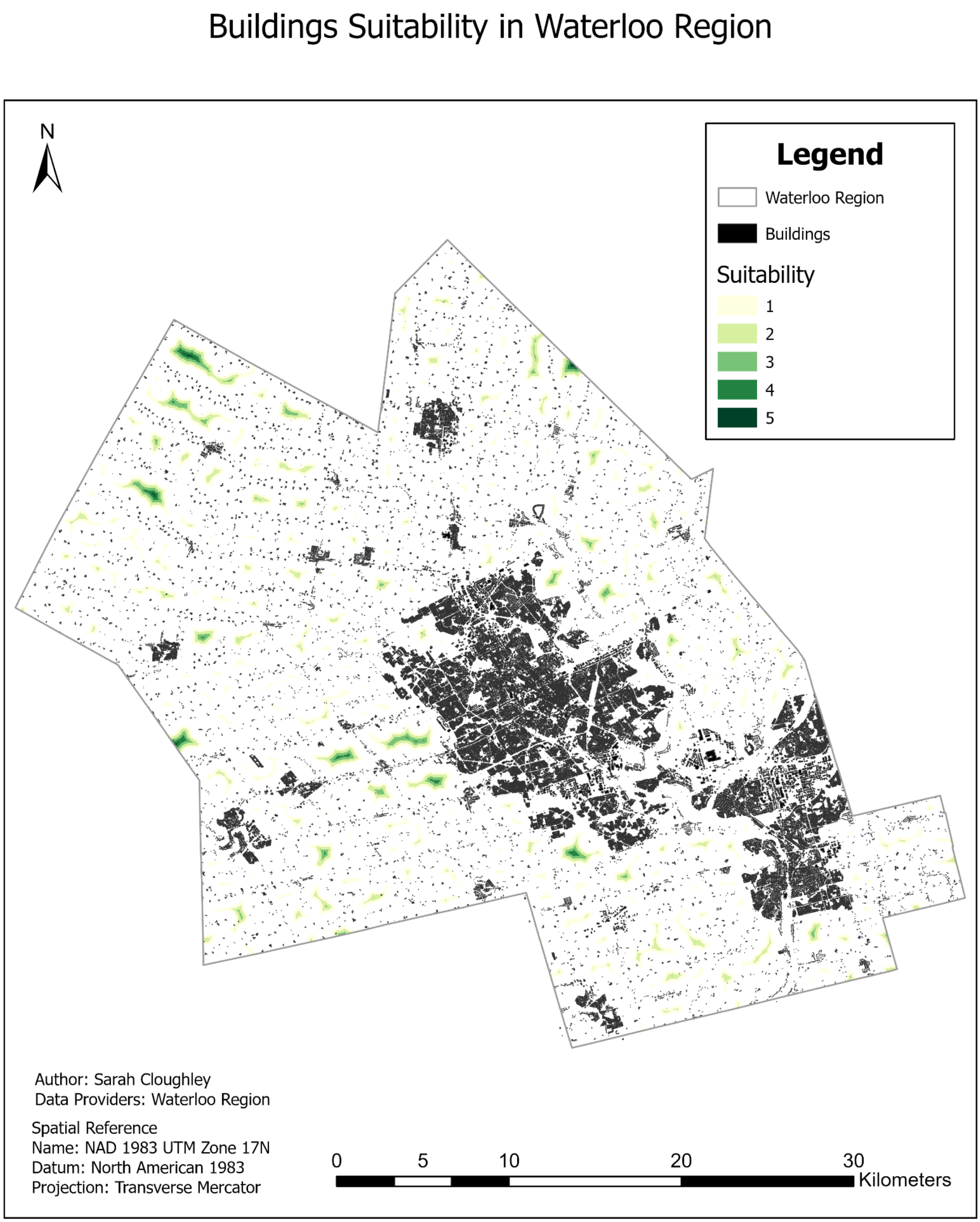

FIGURE 5 – Roads Suitability

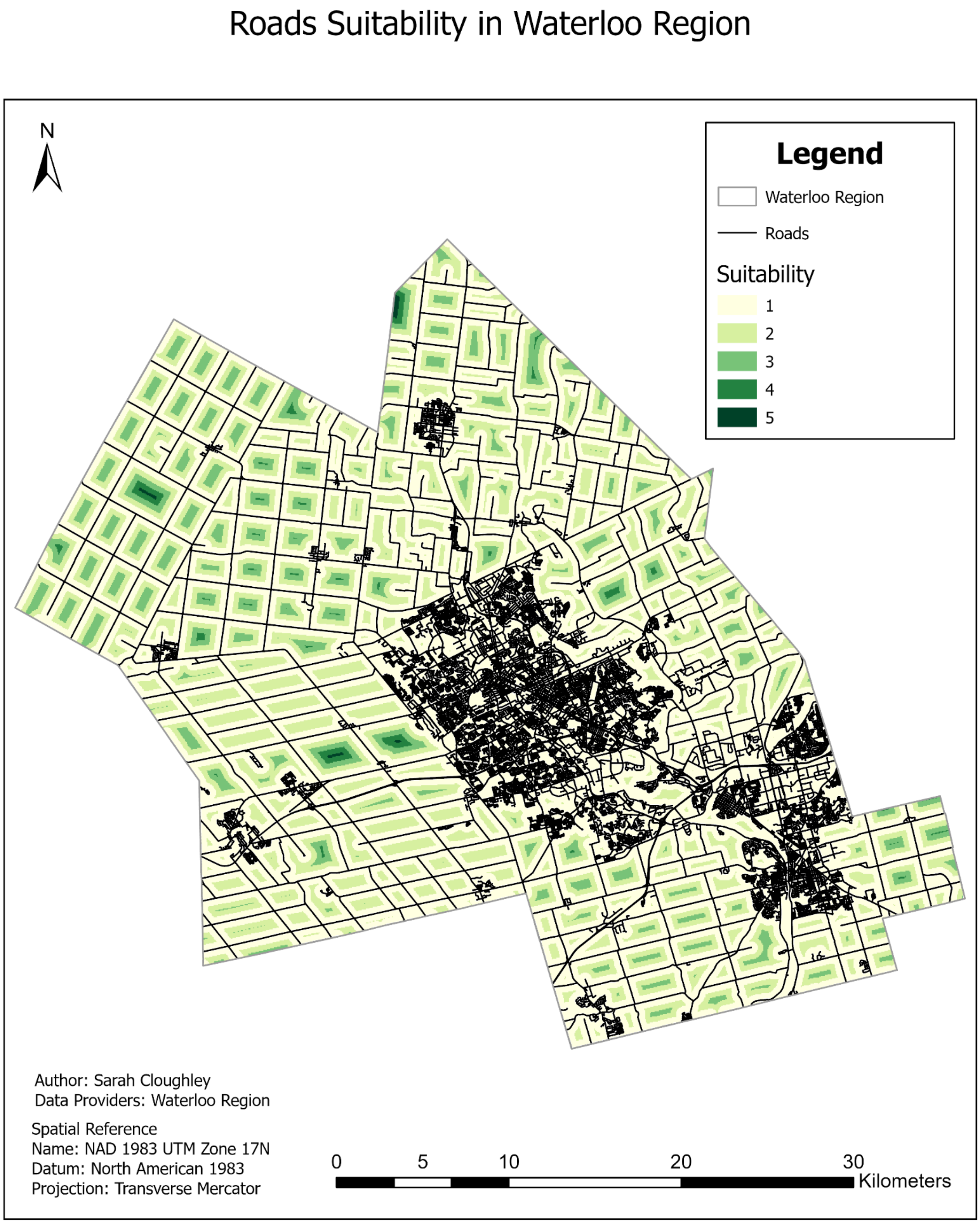

FIGURE 6 – Forests Suitability

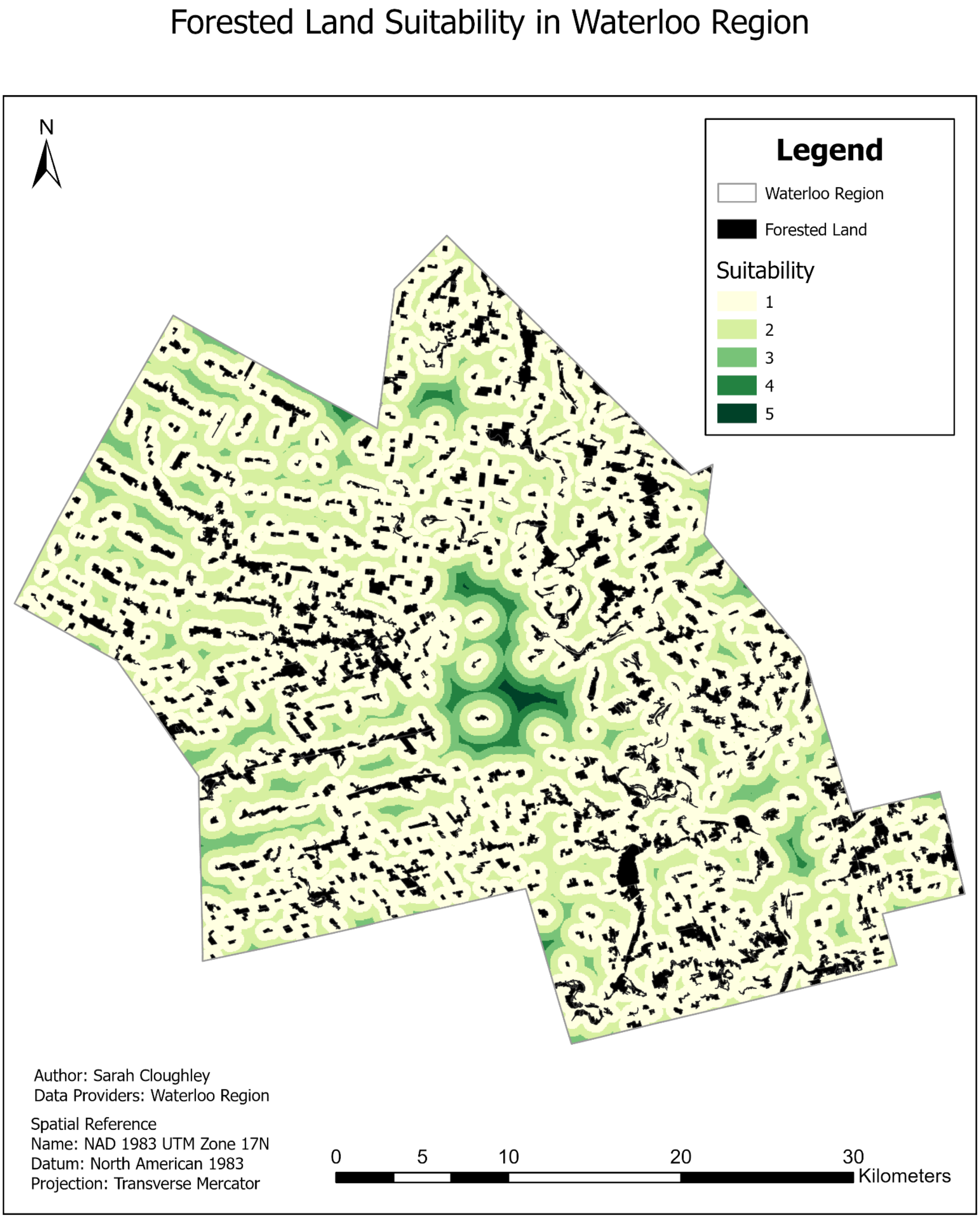

FIGURE 7 – Urban Areas Suitability

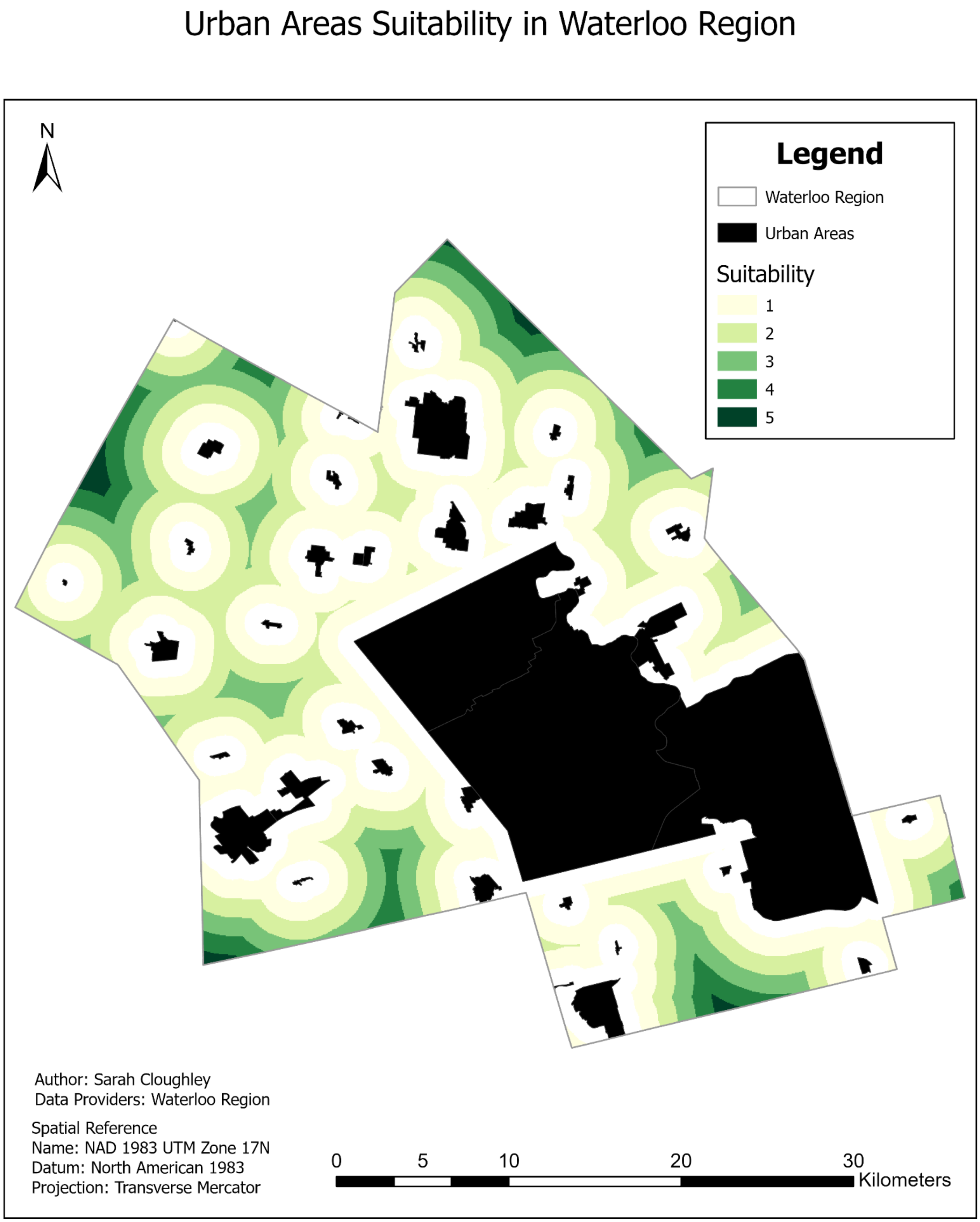

FIGURE 8 – Airports Suitability