Greater Windhoek Metro Flood Risk Mapping Using MCDM and GIS Process

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In 2025, Namibia experienced extreme flooding. It affected various parts of the country, causing damage and loss of life; not even the Capital, Windhoek, was safe [1][2]. However, the flooding was not felt evenly. In some areas, it appeared as if the flooding was not real, while in others, it was a daily threat. This gave me the idea to create a flood risk map of Windhoek so that areas that are at risk can be highlighted. I'm sure the city already has detailed maps with this information; however, I wanted to explore the risks involved as a resident of the city.

I decided to use multi-criteria decision making (MCDM) with geographical information systems (GIS) to create a flood risk map. This involves using various spatially arranged criteria to build a map of flood risk. Using this method, one can create a reliable map at no cost and have the ability to rapidly and repeatedly make changes [3]. This makes it easy for me to make updates and new versions, as I get new information or want to change the study area.

Study Area

The study area is located at 22.35 °S and 22.68°S and 16.91°E and 17.16°E, which has a surface area of 940.08 km2 (Figure 1). The study area contains the city of Windhoek and the land surrounding it. This area was chosen to get a better picture of the flood risk to Windhoek, because the results found using the MCDM and GIS methods are not as accurate at the borders, compared to those for the central areas. In this project, this area is termed the Greater Windhoek Metro. This is not a real-world term, but is used to connect the surrounding areas to the city.

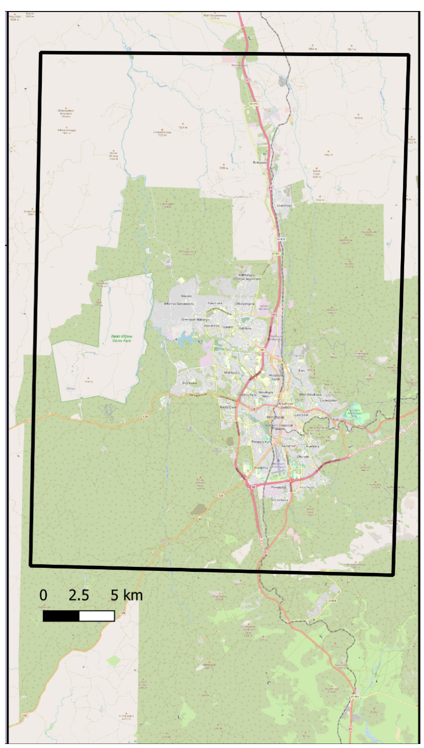


Figure 1. Study area; Greater Windhoek Metro

Methodology

Using the MCDM and GIS approach involves selecting the relevant criteria for the study area. After the criteria have been selected, the raster data for them are found. Various flood risk criteria can be used, with each study using the MCDM and GIS process having different combinations. Each has its pros and cons, but for the project, the criteria selected were the same as in the paper; ***“Flood hazard assessment and mapping using GIS integrated with multi-criteria decision analysis in upper Awash River basin, Ethiopia”*** [4], which is: slope, Elevation, Drainage Density, Proximity to Stream, Land Use/Land Cover (LULC), Average Rainfall and Soil Texture. The criteria were selected as they are easily available.
The selected criteria for the study area were then resampled so that all had a resolution of 30 pixels. They were then reclassified into 5 levels (except soil texture, 3 levels), using QGIS's discrete, equal intervals, where 5 is the highest flood risk and 1 is the lowest, depending on their individual effect on flood risk. The reclassified data is then multiplied by a weight that corresponds to the importance of flooding, and the results are then summed up to create a map of flood risk for the study area. Figure 2 is a graphical breakdown of the process.

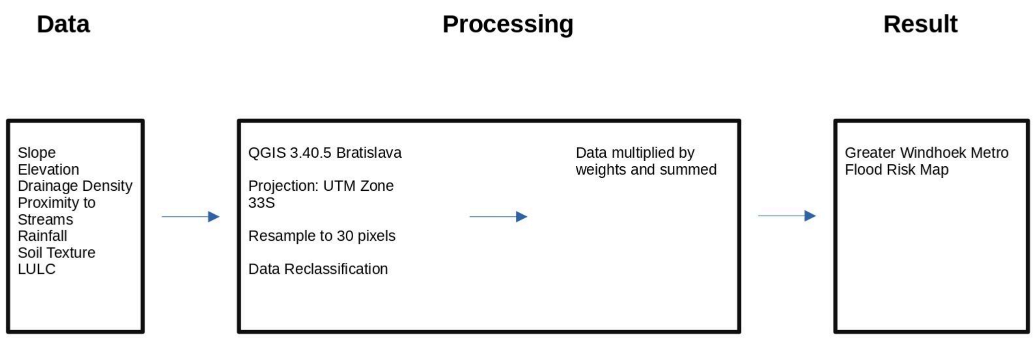


Figure 2. Greater Windhoek Metro Flood Risk Workflow

Data

Elevation

The elevation data was obtained from the Shuttle Radar Topography Mission (SRTM) 30 [5], a digital elevation model (DEM). The elevation was then classified into 5 categories based on the decrease in flood risk with elevation (Table 1).

Elevation range (m)	Class	Risk Level
< 1580	5	Very High
1580-1770	4	High
1770-1960	3	Moderate
1960-2150	2	Low
2150 >	1	Very low

Table 1. Elevation Classification

Average Rainfall

Data was obtained from Worldclim [6]. The precipitation data is from the years 1970 - 2000. The data comes separated into the 12 individual months. The 12 months were summed together for the study area to get the average annual rainfall. The Data was then classified to show that with increased rainfall, the risk of flooding increases.

Average Rainfall range (mm)	**Class**	**Risk Level**
410 >	5	Very High
380 - 410	4	High
360 - 380	3	Moderate
340 - 360	2	Low
< 340	1	Very low

Table 2. Average Rainfall Classification

Slope

Slope is the degree of inclination to the plane and is obtained by processing the DEM data using the slope analysis tool in QGIS. The slope angle affects how water can accumulate in an area with lower angles, allowing water to gather and for longer than at higher angles, which have more runoff. This is why lower angles have a greater risk of being flooded. How the slope angles were classified can be seen in Table 3.

Slope range (degrees)	**Class**	**Risk Level**
< 10	5	Very High
10 - 20	4	High
20 - 30	3	Moderate
30 - 50	2	Low
50 >	1	Very low

Table 3. Slope Classification

Drainage Density

It is the result of the total length of all streams and rivers within the study area divided by the total area of the region of interest. To find the drainage density, the Terrain Analysis Using Digital Elevation Models (TauDem) plugin [7] was added to QGIS. TauDEM uses the DEM data to find streams (rivers included) in the area of interest. The stream data is then dissolved and rasterised using the study area vector. The line density tool was then used to create a raster of the drainage density for the study area (Search radius 1km, Pixel 30 m). **Please note that here is the biggest divergence with the "*Flood hazard assessment and mapping using GIS integrated with multi-criteria decision analysis in upper Awash River basin, Ethiopia*"**. In the paper, the authors state that: *"The density of drainage is a major factor influencing flood hazard. The drainage system that develops in an area is entirely dependent on the slope, the type of bedrock, and the regional and local fracture pattern (Alemayehu 2007; Wondim 2016). The drainage density is an inverse function of soil permeability. A low permeable surface area is prone to high drainage density, and water from precipitation also leads to high runoff and vice versa. As a result, greater drainage density means that the area is less prone to flooding (Chibssa 2007; Wondim 2016). As a result, as drainage density increases, the rating for drainage density decreases."*

I did not agree with this statement, as higher drainage densities indicate an area with impermeable soils, heavy rainfall, and little vegetation, which would lead to a higher risk of flooding [8][9]. Therefore, the decision was taken to directly link higher drainage density with an increased risk of flooding, contrary to the paper. However, a flood risk map was created with increased drainage density, resulting in decreased flooding risk for visualisation (Figure A1, in the appendix, pg 14). From now on, when drainage density is discussed or a figure of it is shown, it will have a DD1 or DD2 in the title. With DD1 (Figure 3: d) Drainage Density DD1) being my interpretation of the criteria, and DD2 (Figure 3: e) Drainage Density DD2) being the original papers.

Drainage Density Range Km/km2	Class	Risk Level
0.0022 >	5	Very High
0.0017 - 0.0022	4	High
0.0011 - 0.0017	3	Moderate
0.0006 - 0.0011	2	Low
< 0.0006	1	Very low

Table 4. Drainage Density Classification

Proximity to Streams

One of the most common factors in flooding is when rivers/streams overflow, and water moves into the surrounding flood areas. This means that the closer one moves to a river/ stream, the risk of flooding increases. The Proximity to Streams was obtained by rasterising the stream location vector data obtained using the TauDem tool. The QGIS proximity tool was then used to create a raster of the distance to the streams for the study location. The raster was classified into 5 categories based on the risk associated with the proximity to the stream (Table 5). Locations closer to streams carry higher risks.

Proximity to Stream Range (m)	Class	Risk Level
< 330	5	Very High
330 - 670	4	High
670 - 1000	3	Moderate
1000 - 1340	2	Low
1340 >	1	Very low

Table 5. Proximity to Stream Classification

Land use/land cover (LULC)

LULC refers to the biophysical cover of the Earth's surface. In other words, it details what the surface of the earth is covered by, i.e. built-up area, forest, crop land, etc. What covers the land is an important aspect of flooding. Certain land cover/uses help mitigate flooding, while others have the opposite effect. Table 6 shows how the different LULCs were classified for the study. This is more of a subjective classification, as each project uses a different method to organise the LULC. In this project, I based the classifications on the following two studies: Hagos et al (2022) [4] and A. Mulu et al (2025) [10]. The LULC data were obtained from the ESA WorldCover project [2021]. / Contains modified Copernicus Sentinel data ([2025) processed by the ESA WorldCover consortium 2021 [11].

LULC	Class	Risk Level
Permanent water, Wetland	5	Very High
Built-up area, Crop land, Bare/Sparse,	4	High
Mangroove	3	Moderate
Tree cover, Grassland, Moss and Lichen	2	Low
Schrubland	1	Very low

Table 6. LULC Classification

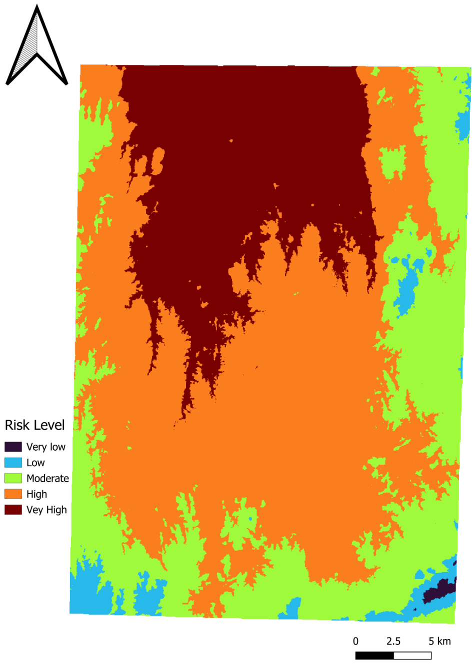
Soil Texture

Soil texture refers to the percentage of clay and sand in the soil. Sand offers better drainage to water; therefore, the higher the sand content of the soil, the lower the flood risk. Clay has the opposite effect; it prevents water from draining. Therefore, the higher the clay content, the slower the speed of drainage and the higher the flood risk. In this project, soil was classified into three categories instead of 5. With high clay content being high risk, sand being low risk and loam (a mixture between clay and sand) being a moderate risk. To create the soil texture raster, first, the g/kg content raster data of soil was found in Soilgrids Common soil chemical and physical properties data [12] for clay and sand. A new raster was made for both by converting the g/kg content of soil into % of total by using the formula $\frac{g/kg}{10} = \%\, of\ total$. The percentage data was then used in the raster calculator in QGIS to create a new raster that classifies the soil into sand, clay or loam. The equation used in the calculator can be seen below. The classified soil texture raster was reclassified into a flood risk raster (Table 7) based on the soils' effect on flooding.

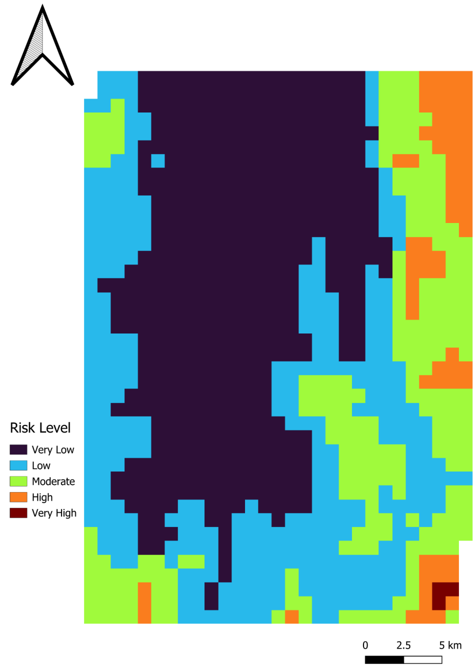
```
(
("Windhoek_area_percentageClayContent@1" >= 40 AND "Windhoek_area_percentageSandContent@1" <= 20) *3
+
("Windhoek_area_percentageSandContent@1" >= 43 AND "Windhoek_area_percentageClayContent@1" <= 20) * 1
+
((("Windhoek_area_percentageClayContent@1" < 40 OR "Windhoek_area_percentageSandContent@1" > 20)
AND ("Windhoek_area_percentageSandContent@1" < 43 OR "Windhoek_area_percentageClayContent@1" > 20)) *
2)
)
```

Soil Texture	Class	Risk Level
3, Clay	5	Very High
2, Loam	3	Moderate
1, Sand	1	Very low

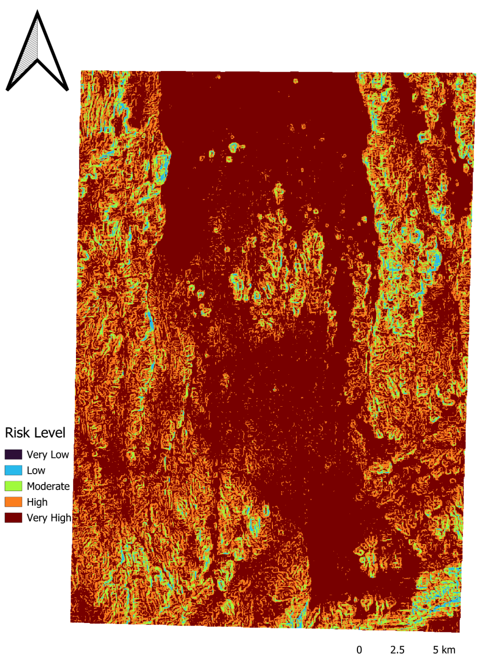
Table 7. Soil Texture Classification



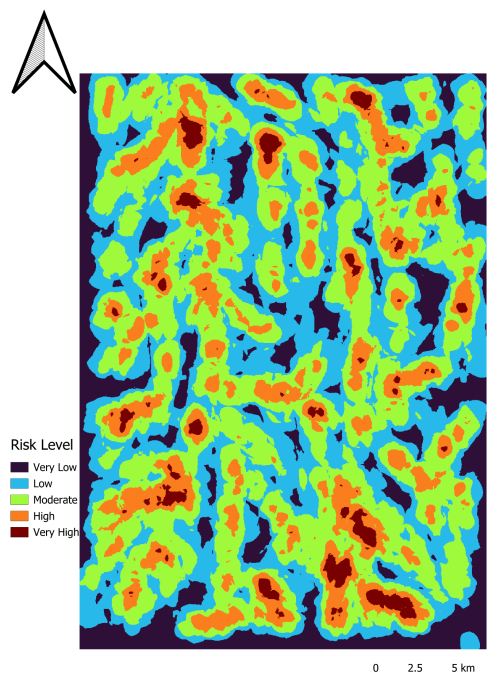
a) Elevation



b) Average Rainfall



c) Slope



d) Drainage Density DD1

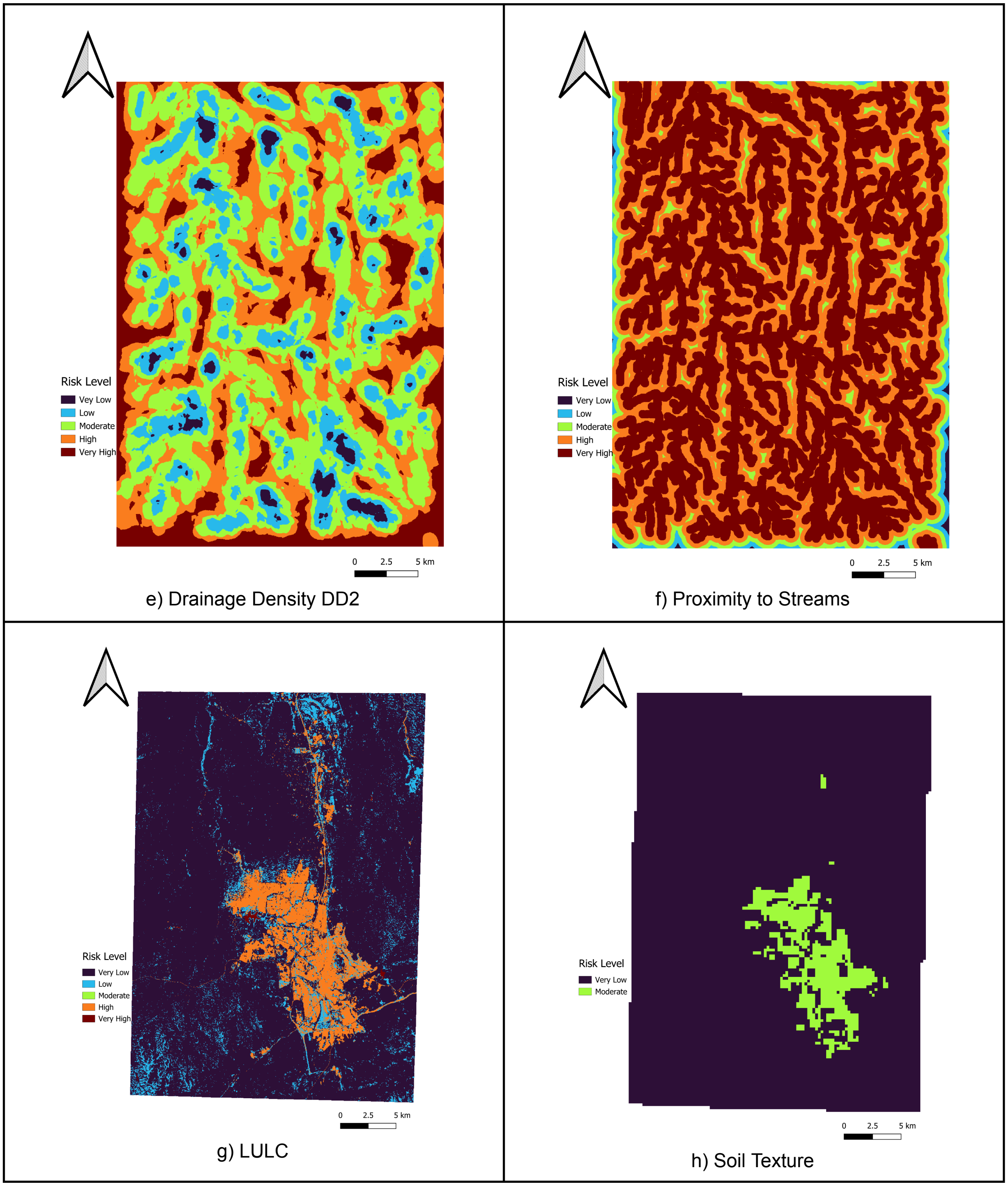


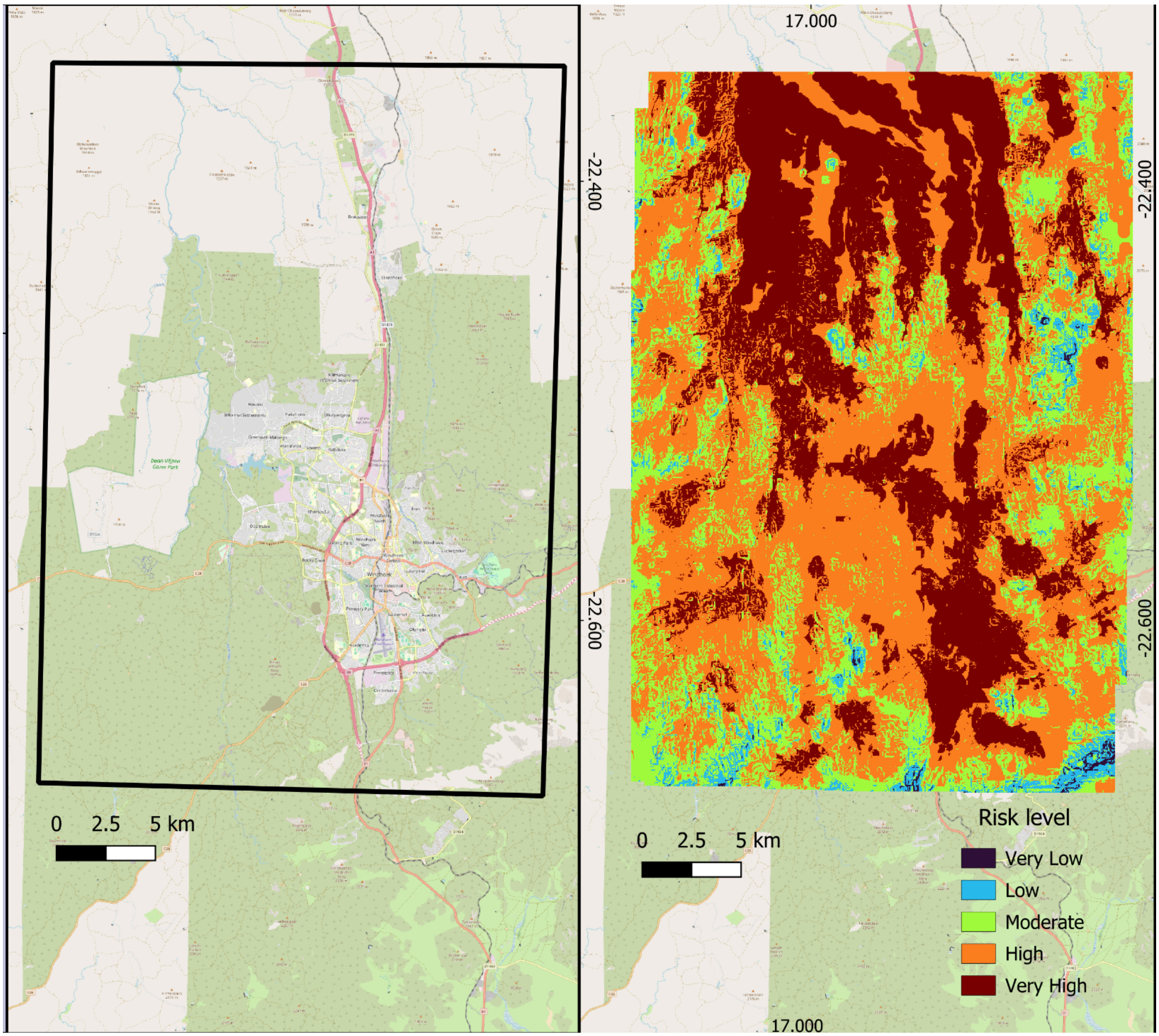
Figure 3. Reclassified Flood Risk Criteria: a) Elevation, b) Average Rainfall, c) Slope, d) Drainage Density DD1, e) Drainage Density DD2, f) Proximity to Streams, g) LULC, h) Soil Texture

Greater Windhoek Metro Flood Risk Map

The flood risk raster data needed have all been made. However, they are not all equal in importance; some have a greater importance to flooding than others. This is why weights are used to adjust the criteria to reflect their individual importance. To create the flood risk map, in the raster calculator, the flood risk criteria rasters were multiplied by their respective weights, and the results of each were summed together, creating the Greater Windhoek flood risk map. Table 8 shows how the weights were applied.

Criteria Raster	Weight applied
Slope	0.33
Elevation	0.25
Drainage density	0.16
Proximity to river	0.13
Rainfall	0.07
Soil texture	0.04
LULC	0.02
Total	**1**

Table 8. Flood Risk Criteria Weights



4. Greater Windhoek Metro Flood Risk Map DD1

Results and Discussions

The flood risk map (Figure 4) showed that in the study area, very high risk covered 273.2 km2 (30%), high risk covered 418.6 km2 (46%), moderate risk covered 182.8 (20%), low risk covered 31.1 (3.4%) and finally very low risk covered 2.5 km2 (0.3%). Looking at the map showed that Windhoek has two main zones of High risk, one to the North and one to the South East. These zones are of major interest for flood prevention. The map also indicates that Windhoek as a whole is highly susceptible to flooding, which can be attributed to its geography. The city is located on a plateau surrounded by the Khomas Highland, making it a good area for water accumulation.

Conclusion and Recommendation

This project has demonstrated that using MCDM with GIS, with the relevant flood risk criteria, one can create flood risk maps quickly and effectively with publicly available data for any region in the world. This demonstrates that planning is not bound by more expensive methods and that poorer areas can also have access to flood risk data.

I would recommend a follow-up project.

- Compare the flood risk map to more expansive and detailed maps, such as the ones that the city has and uses.
- Use other flood risk criteria and compare their risk maps to each other to determine their accuracy and best use cases for them.
- Add vulnerability, look at areas in the study area to find people groups that are more susceptible to flooding
- The sensitivity in creating the number of streams appears high. Namibia, being a dry country, should have fewer streams that can cause flooding
- The study area should be a perfect rectangle.

List of Tables

List Of Figures

References

[1] F. Lottering, “Travel warning: Rains and floods Namibia,” Informanté. Accessed: Sep. 05, 2025. [Online]. Available: https://informante.web.na/?p=371882

[2] S.-E. Stender, “Unusual continuous rain: roads impassable, bridge broken,” Namibian.org. Accessed: Sep. 05, 2025. [Online]. Available: https://namibian.org/news/nature-and-environment/roads-impassable-due-to-rain

[3] D. Rincón, U. T. Khan, and C. Armenakis, “Flood Risk Mapping Using GIS and Multi-Criteria Analysis: A Greater Toronto Area Case Study,” *Geosciences*, vol. 8, no. 8, p. 275, Jul. 2018, doi: 10.3390/geosciences8080275.

[4] Y. G. Hagos, T. G. Andualem, M. Yibeltal, and M. A. Mengie, “Flood hazard assessment and mapping using GIS integrated with multi-criteria decision analysis in upper Awash River basin, Ethiopia,” *Applied Water Science*, vol. 12, no. 7, May 2022, doi: 10.1007/s13201-022-01674-8.

[5] “Namibia SRTM DEM 30meters.” Accessed: Sep. 01, 2025. [Online]. Available: https://www.africageoportal.com/datasets/ed3e881f0fd74b639e0d7d4cfa5c823f/about

[6] “WorldClim.” Accessed: Sep. 01, 2025. [Online]. Available: https://www.worldclim.org/data/worldclim21.html

[7] Utah State University, “David Tarboton: Hydrology Research Group-Terrain Analysis Using Digital Elevation Models (TauDEM) Version 5.” Accessed: Sep. 05, 2025. [Online]. Available: https://hydrology.usu.edu/taudem/taudem5/

[8] A. Chissende, M. S. Mehmood, A. Huo, P. Lou, and Z. Wang, “Riverine flood susceptibility assessment using drainage basin morphometry in the Bahe River,” *International Journal of Disaster Risk Reduction*, vol. 117, p. 105181, Feb. 2025, doi: 10.1016/j.ijdrr.2025.105181.

[9] Y. A. Berrezel, C. Abdelbaki, A. Megnounif, M. Saber, M. E. A. Benabdelkrim, and N. Kumar, “Assessment of flood risk using integrated GIS and analytic hierarchy process in the Mekerra basin, Northwestern Algeria,” *Journal of African Earth Sciences*, vol. 233, p. 105830, Jan. 2026, doi: 10.1016/j.jafrearsci.2025.105830.

[10] A. Mulu, S. B. Kassa, M. L. Wossene, S. Adefris, and T. M. Meshesha, “Identification of flood vulnerability areas using analytical hierarchy process techniques in the Wuseta watershed, Upper Blue Nile Basin, Ethiopia,” *Scientific Reports*, vol. 15, no. 1, Aug. 2025, doi: 10.1038/s41598-025-13822-6.

[11] D. Zanaga *et al.*, “ESA WorldCover 10 m 2021 v200,” Zenodo. [Online]. Available: https://zenodo.org/record/7254221

[12] L. Poggio *et al.*, “SoilGrids 2.0: producing soil information for the globe with quantified spatial uncertainty,” *SOIL*, vol. 7, no. 1, pp. 217–240, doi: https://doi.org/10.5194/soil-7-217-2021.

Appendix

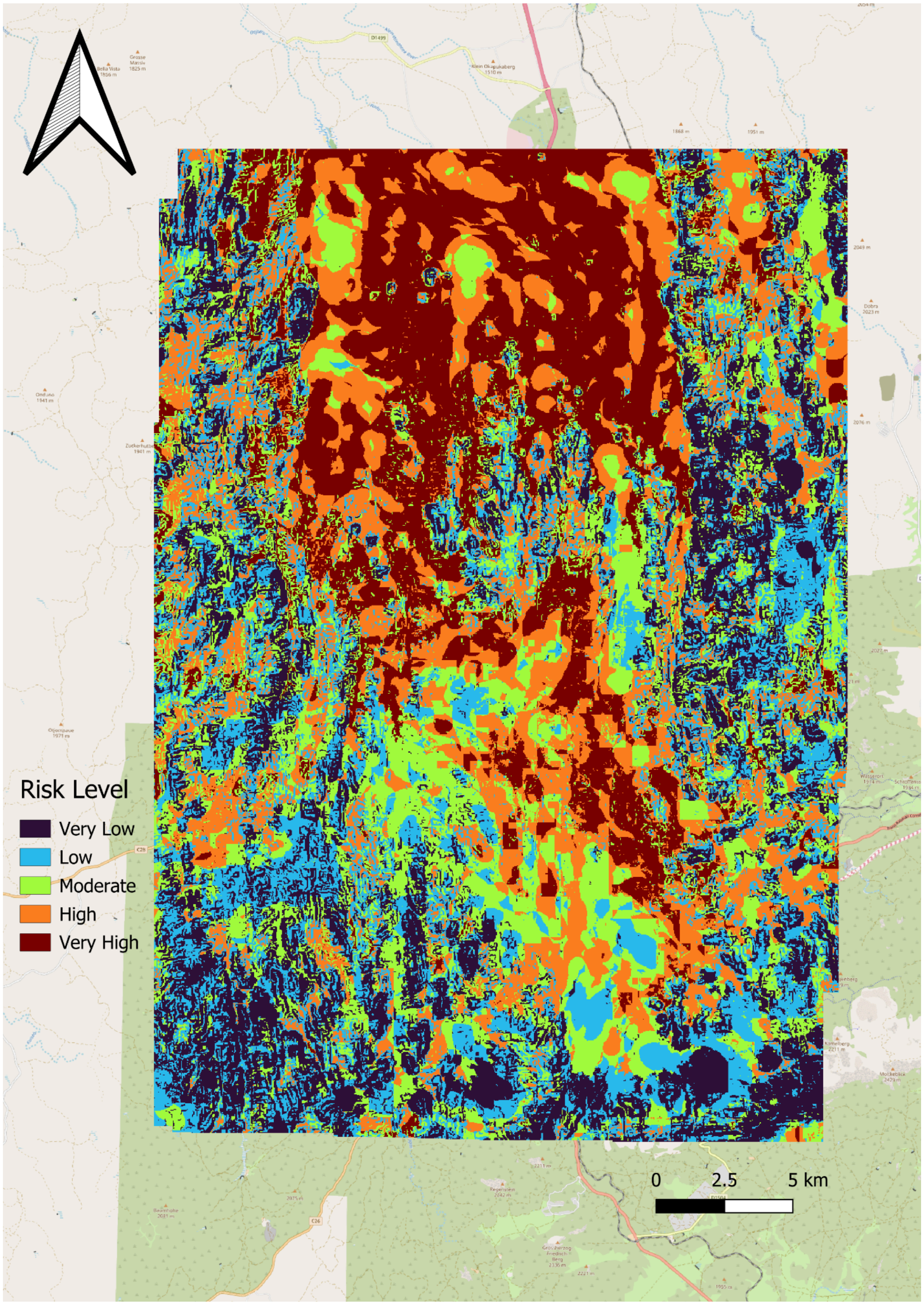


Figure A1. Flood Risk map DD2

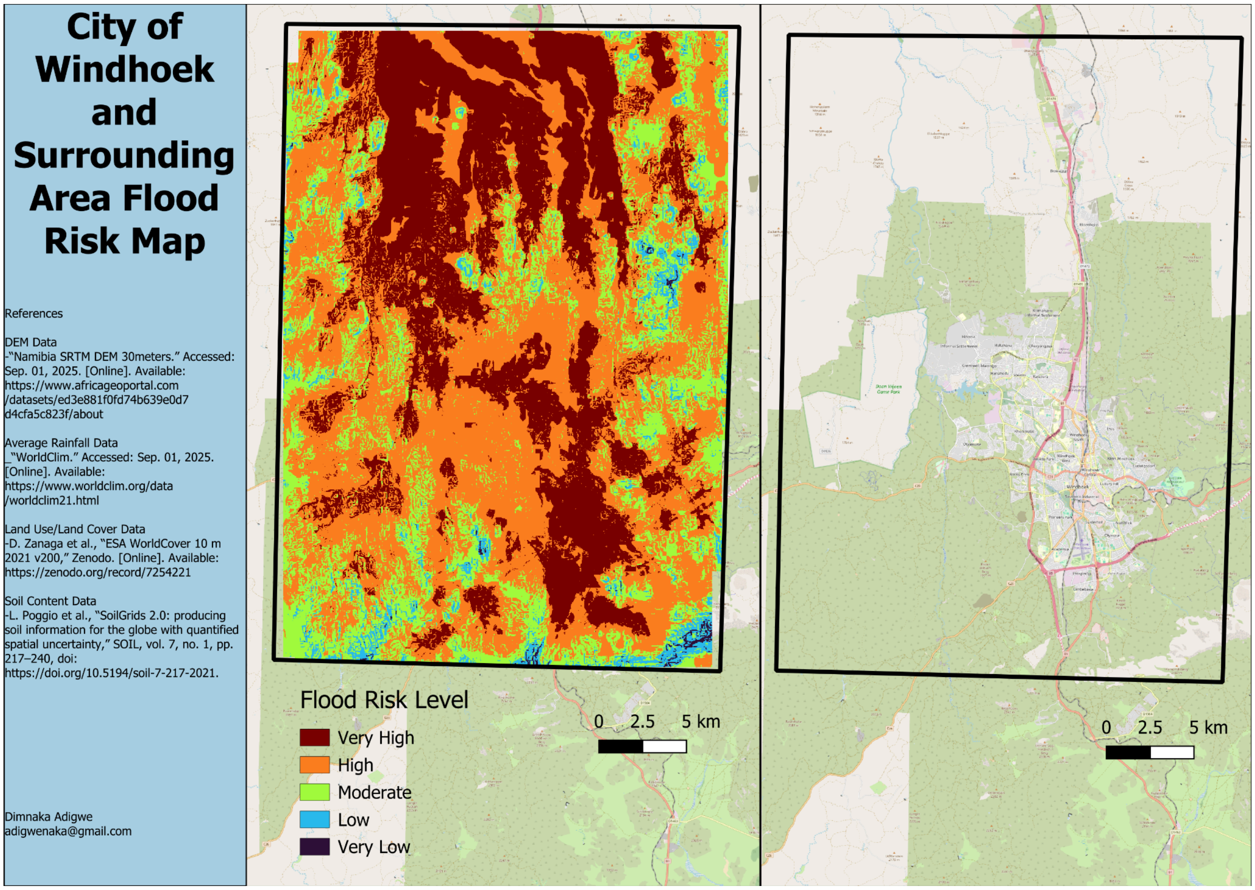


Figure A1. Flood Risk Map DD1 Poster