Network Analysis
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Network Analysis
of the flood resilience of the road network around Lucerne

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Research goal

In this project, we aim to analyze and compare the resilience of the road network of 1959 around Luzern and the Kleine Emme to floods using network analysis. For this, we

Data & Preprocessing (GIS)

- Definition of study area: Luzern and Kleine Emme
- Modelling results: Today and 1959, RP 100
    - ASCII files: max height and max velocity
    - calculate max extent and convert to shp
- Cut of data set to buffer area (road network today and 1959, modelling results)
- Road network processing
    - Snap nodes that are closer than 5 pixels (more or less)
        - Point Snapping: snap to point features.
        - End Snapping: snap to the start or end points of lines.
        - Vertex Snapping: snap to the vertices of lines of polygons.
        - Edge Snapping: snap to lines or polygon boundaries.
    - Create a node in the intersection between edges
    - Calculate the length of each line
- Read in the shp files to network
- Run the code for already defined analysis
- Write code for new interesting analysis
- Understand the meaning of results
- Write report/presentation

Data:

- Road network 1959, complete
- Road network 1959, with removed unconnected lines
- Road network 1959, cut according to 100y flood return period
- Road network today, complete
- Road network today, cut according to 100y flood return period

Method: Network Analysis with Python

See the script in the Appendix.

Libraries used: momepy, networkx, geopandas, matplotlib, shapely

We analyzed different network metrics. They are either analyzed node-based or edge based or both. Plotting: color is scaled by quantile → plots are only proportionally comparable.

Closeness Centrality: Measures closeness of a particular node to another node and equals the sum of geodesic distances of a node to all other nodes (by shortest path). Nodes with the smallest average path length are the most central nodes in the network. **Application:** Nodes with high closeness centrality are essential for quick access to other parts of the network. Their failure may isolate certain regions.

Momepy has two different ways of calculating Closeness Centrality:

> **Local closeness:** To measure local closeness we need to specify a radius (how far we should go from each node). We can use topological distance (e.g. 5 steps, then radius=5) or metric distance (e.g. 400 meters) - then radius=400 and distance=length of each segment saved as a parameter of each edge. By default, *momepy* saves length as *mm_len*.
> The weight parameter is used for centrality calculation. Again, we can use metric weight (using the same attribute as above) or no weight (weight=None) at all. Or any other attribute we wish.
>
> **Global closeness**: Global closeness centrality is a bit simpler as we do not have to specify radius and distance, the rest remains the same.

Betweenness Centrality: The number of shortest paths that pass through a node. **Application:** Nodes with high betweenness centrality act as critical connectors. If these nodes fail during flooding, it can disrupt the flow of traffic along important routes.

Straightness: Quantifies the rate at which a path between two nodes in a network follows a straight line, rather than following the network topology. Usually calculated as the length of the shortest path between two nodes divided by the Euclidean distance between the same nodes. **Application**: understand the efficiency of movement through the network.

Results

Attached

Discussion

- **Disconnected streets vs. cut**:
    - Almost no difference is visible, except for the outer parts of the network.
    - Minor differences are related to the scale of colors, and not to the absolute value of the indexes. This is due to the plots showing quantiles. The computation time for the uncut streets was slightly higher because of the larger number of nodes.
- **Flooded vs. unflooded:**
    - Betweenness Centrality is lower in the flooded areas. The main roads have the highest BC. Shortest paths connecting peripheral roads go through the main roads.

    - Less important peripheral roads become more important when main roads with high Centrality measures are flooded. Shortest paths are deviated and get longer, increasing the Betweenness Centrality of other nodes.
    - Straightness decreases (especially in the main flooded area)
- **1959 vs. nowadays**:
    - The computation time for today's street network was substantially higher because of the larger number of nodes.
    - Smoother distribution in the Closeness Centrality: hotspots of the CC indexes are less pronounced in the nowaday's network because there are more roads, making the network better connected overall.
    - For Betweenness Centrality, main roads stay more or less the same. More peripheral roads nowadays with lower centrality indices, main roads have higher Betweenness Centrality because more shortest paths from new peripheral nodes pass through them.
    - Regarding the Straightness, the main change is visible in the flooded area, where there is a decrease in the Straightness. Smaller changes are also visible in the peripheral areas; this could be explained by the extraction of low-straightness roads from the network, which produces a relative increase in the peripheral roads.

Outlook

- For further steps, we propose to generate the plot with absolute values instead of quantiles and to analysis the effect of this change.

- Also, it would be interesting to have a table with absolute and percentage values to facilitate the global analysis of the network, with and without flooded areas. For example, it could look like this table from Casali and Heinimann (2019):

Node-Edge Transition

	Return Period	*Increase*	*Decrease*	*No change*	*Flooded*
Node Betweenness Centrality	100	2933 (44%)	2886 (43%)	857 (13%)	28 (0.4%)
	300	2453 (37%)	3183 (48%)	836 (12%)	232 (3.0%)
Edge Betweenness Centrality	100	4704 (47%)	5091 (51%)	1 (0%)	135 (1%)
	300	4496 (45%)	4885 (49%)	0 (0%)	550 (6%)
Closeness Centrality	100	75 (1%)	6601 (98%)	0	28 (0.4%)
	300	75 (1%)	6397 (95%)	0	232 (3.0%)

Four causes of change in nodes/edges were possible: 1) increase in centrality values, 2) decrease in values, 3) values maintained at the same levels, or 4) exclusion from the network because those nodes/edges were flooded. Changes were calculated as the differences between normalized values in a flood scenario and those under baseline conditions. Percentages indicate the ratio of the number of nodes (edges) to the total number of nodes (edges) when compared with baseline conditions, i.e., 6704 nodes and 9931 edges.

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- Finally, for a better understanding of the network, it would be interesting to analyze further metrics such as the degree centrality, clustering coefficient, and vulnerability indexes, among others.

Related Literature:

Casali Y, Heinimann HR (2019) A topological characterization of flooding impacts on the Zurich road network. PLOS ONE 14(7): e0220338. https://doi.org/10.1371/journal.pone.0220338