Multi-Criteria Decision Analysis

Spatial analysis in decision making

Outline

- Introduction

- Basic principles of GIS-based MCDA

- Methods multi-criteria evaluation

- Multi-objective evaluation

Definition

- **Multiple-criteria decision** analysis (MCDA) can be defined as 'a collection of formal approaches which seek to take explicit account of [key factors] in helping individuals or groups explore decisions that matter' (Belton and Stewart 2002).

- **GIS-MCDA** can be thought of as a process that transforms & combines geographical data & value judgments (the decision-maker's preferences) to obtain information for decision making

Suitability analysis & Hazard Map

- The concept of **Suitability analysis** describes the search for locations or areas that are characterized by a combination of certain properties. Often, the result of a suitability analysis is a **suitability map**. It shows which locations or areas are suitable for a specific use in form of a thematic map (e.g. agricultural suitability map).

- The negative variation of the suitability map is the **hazard or risk map**. It segregates areas that are exposed to a specific hazard based on the criteria given (e.g. avalanche hazard maps).

Basic principles of GIS-based MCDA

- Multi-criteria evaluation (MCE) or Multi-attribute decision making (MADM)-With a single objective
  - recommending the site for a new fire station,
  - site suitability analysis for housing development
  - Multi-criteria evaluation (MCE) techniques are required to evaluate the suitability of sites falling within the feasible areas identified using standard GIS overlay procedures. [Carver, 1991]

- Multi-objective evaluation (MOE)- more objective
 - Allocating urban land either to housing or green space

Boolean overlay

- Conjunctive: Accept alternatives if they meet a cut-off value on every criterion

- In each layer there is only binary true/false information (forest / non forest). By logically intersecting this information, the desired locations and areas wanted are determined.

- Example: Criteria (looking for a plot of land)- satisfies all of the criteria.
    - Road   -within 1km
    - Drainage   -within 200m
    - Slope   - less than 15 degree
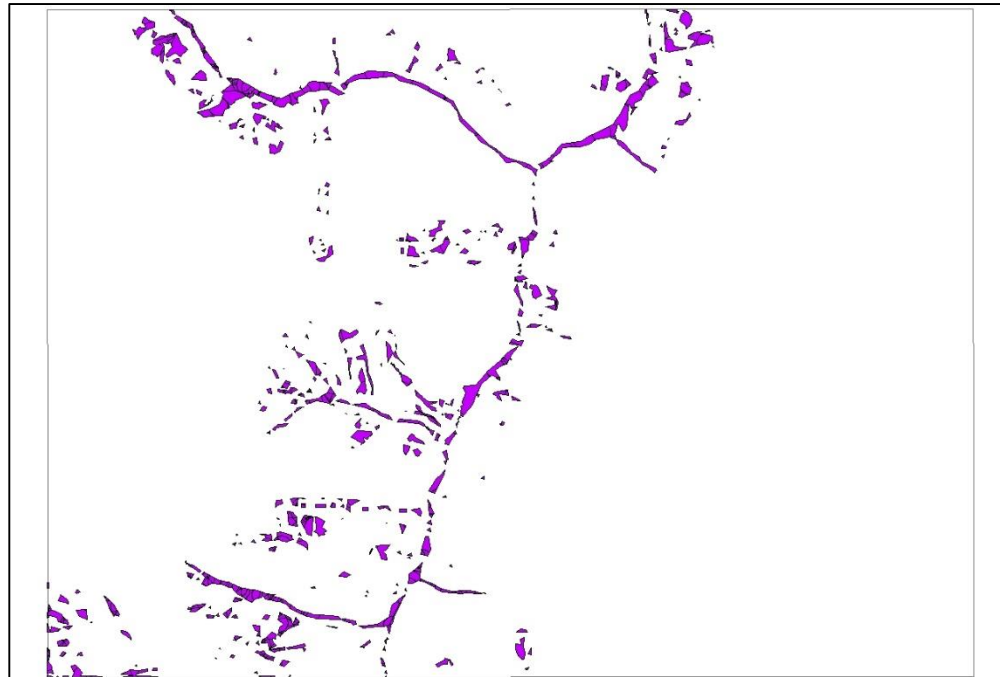   - Intersect

ROAD_1KM

Water_200m

SLOPE<15 degree
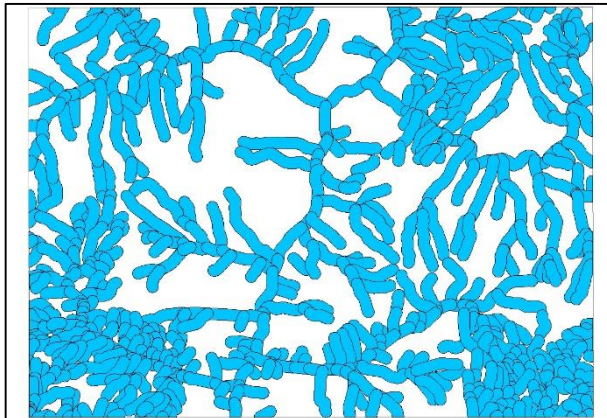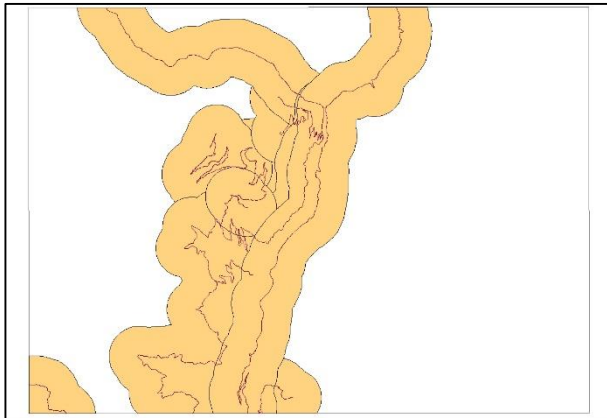
AND

AND

INTERSECT

Boolean overlay

- Disjunctive: Accept alternatives that meet a cut-off value on at least one criterion

- It can also be implemented for spatial problems using binary overlay, where the map criteria layers are combined using a union (logical OR) operation. It is a risk-taking method, because only one criterion must be met.

- Example: Criteria (looking for a plot of land)- satisfies one of the criteria.
  - Road   -within 1km
  - Drainage   -within 200m
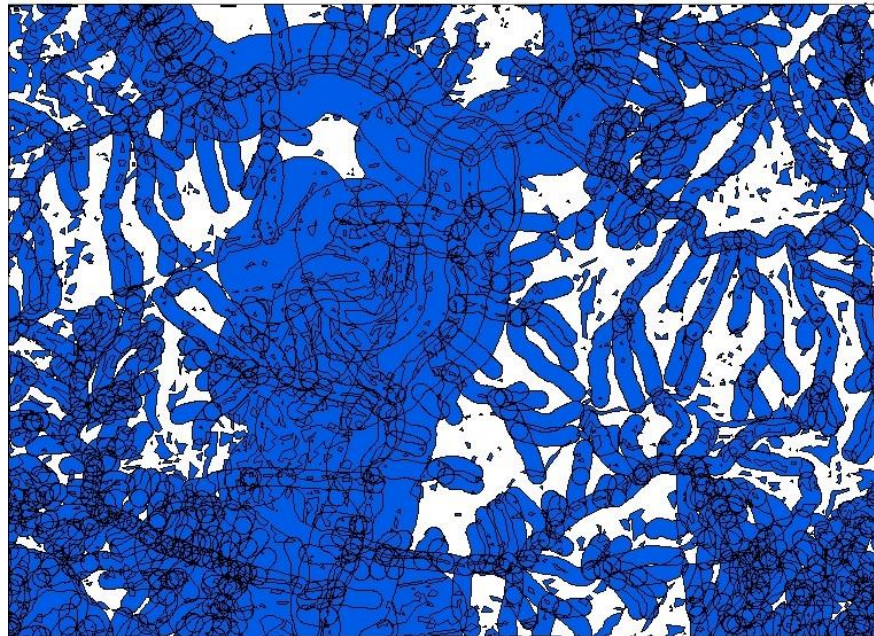 - Slope   - less than 15 degree
  - Union

ROAD_1KM

Water_200m

SLOPE<15 degree
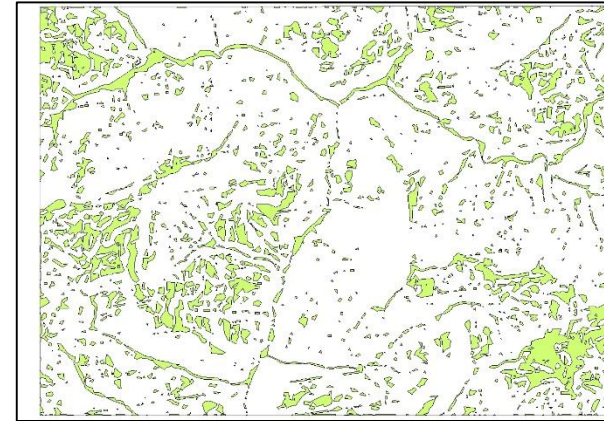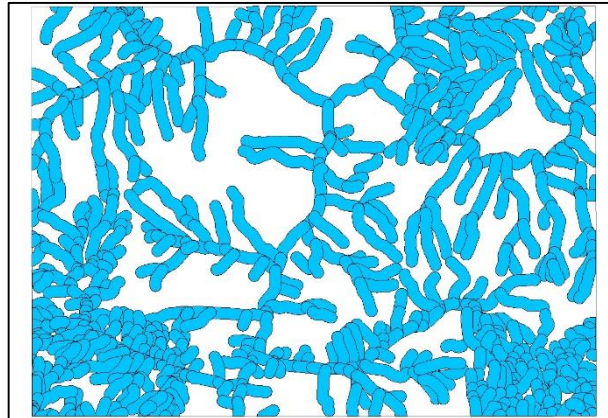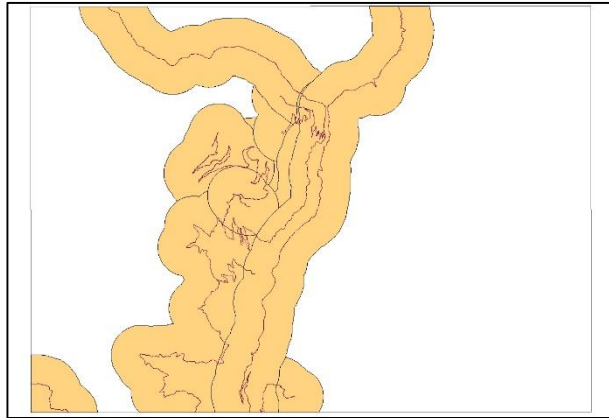
OR

OR

UNION

Methods of Multi-Criteria Evaluation (MCE)

Steps:

1. Define the problem

2. Determine the criteria (factors/constraints)

3. Standardize the factors

4. Determine the weight of each factor

5. Aggregate the criteria

6. Validate/verify the result

Set the goal/define the problem

- the first step of an MCE is the definition of the problem.

- "Which parts of area is suitable for building?"

- "the best site for a new school"

- "the suitable areas for beekeeping"

Determine the criteria (factors/ constraints)

- Criteria are set of guidelines or requirements used as basis for a decision
- Two types: *factors* & *constraints*
- A **factor** is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration
  - *i.e.* distance to road (near = most suitable; far = least suitable)
- A **constraint** serves to limit the alternatives under consideration; element or feature that represents limitations or restrictions; area that is not preferred in any way or considered unsuitable.
  - *i.e.* protected area, water body, etc. (usually represented by a Boolean mask)

Determine the criteria (factors/ constraints)

- The chosen criteria should reflect the characteristics of the desired location or area as closely as possible.

- how much details are needed in the analysis affects the set of criteria to be used
  - *i.e.* main roads only vs. including minor roads; no. of houses vs. no. of residents; etc.

- Criteria should be measurable

- If not determinable, use proxies
  - *i.e.* slope stability can be represented by slope gradient

Standardize the factors/criterion scores

- Set the suitability values of the factors to a common scale to make comparisons possible

- All factor should be of same scale either 1-10 or 0-255 or 0-99 by **Rescale by function**

- **Fuzzy Membership Functions** are used to standardize the criterion scores (0-1)

Determine the weight of each factor

There are several methods

- **Ranking**
  - *i.e.* 3 factors: rank the factors with 1, 2, & 3, where 1 is the least important while 3 is the most important

- **Rating**
  - *i.e.* 3 factors: rate the factors using percentile – Factor 1 with the lowest percentage as the least important & Factor 3 with the highest percentage as the most important

- *Rankings & ratings are usually converted to numerical weights on a scale 0 to 1 with overall summation of 1 (normalization).*
  - *i.e.* Factor 1 = 0.17; Factor 2 = 0.33; & Factor 3 = 0.50;

Determine the weight of each factor (AHP)

- **Pairwise comparison-** Analytical Hierarchy Process **(AHP)** (Saaty, 1980)

- A matrix is constructed, where each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9.

    - where 1 = *equal preference* between two factors; 9 = a particular factor is *extremely favored* over the other

- a weight estimate is calculated & used to derive a consistency ratio (CR) of the pairwise comparisons

- If CR > 0.10, then some pairwise values need to be reconsidered & the process is repeated until the desired value of CR < 0.10 is reached.

- Like in ranking & rating, AHP weights are also expressed in numerical weights that sum up to 1.

Analytic hierarchy process

	Drainage	Road	Slope
Drainage	1	1/3	1/7
Road	3	1	1/5
Slope	7	5	1
sum	11.00	6.33	1.34

1/11   =0.091
0.333/6.33   =0.053

	Drainage	Road	Slope	weight
Drainage	0.091	0.053	0.106	**0.083**
Road	0.273	0.158	0.149	**0.193**
Slope	0.636	0.789	0.745	**0.724**

Analytic hierarchy process

Calculate the Consistency Ratio (CR)

- CR = Consistency index (CI)/Random Consistency Index (RI)

$$CI = (\lambda_{max} - n)/n - 1$$

- λ_{max} is the Principal Eigen Value; 'n' is the number of factors

- λ_{max} = Sum of the products between each element of the priority vector and column totals.

$$\lambda_{max} = (11*0.083) + (6.33*0.193) + (1.34*0.724) = 3.105$$

$$CI = (3.105 - 3)/3\text{-}1$$

$$CI = 0.0525$$

$$CR = 0.0525/0.58 \; \textbf{CR = 0.09 < 0.10 (Acceptable)}$$

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

18

(Saaty, 1980)

Aggregate the criteria

Weighted Linear Combination is the most commonly used decision rule

- Formula:

$$S = \Sigma w_i x_i \text{ x } \Pi c_j$$

Where:

- S – is the composite suitability score
- x_i – factor scores (cells)
- w_i – weights assigned to each factor
- c_j – constraints (or Boolean factors)
- Σ -- sum of weighted factors
- Π -- product of constraints (1-suitable, 0-unsuitable)

Aggregate the criteria (Weighted overlay)

- A numerical weighting factor is assigned to each thematic layer according to its relative importance compared to all other layers.

- weighted overlay is possible with rasters and vectors just like Boolean overlay

- Example: Applying weight on Binary overlay

Raster model

Vector model

21
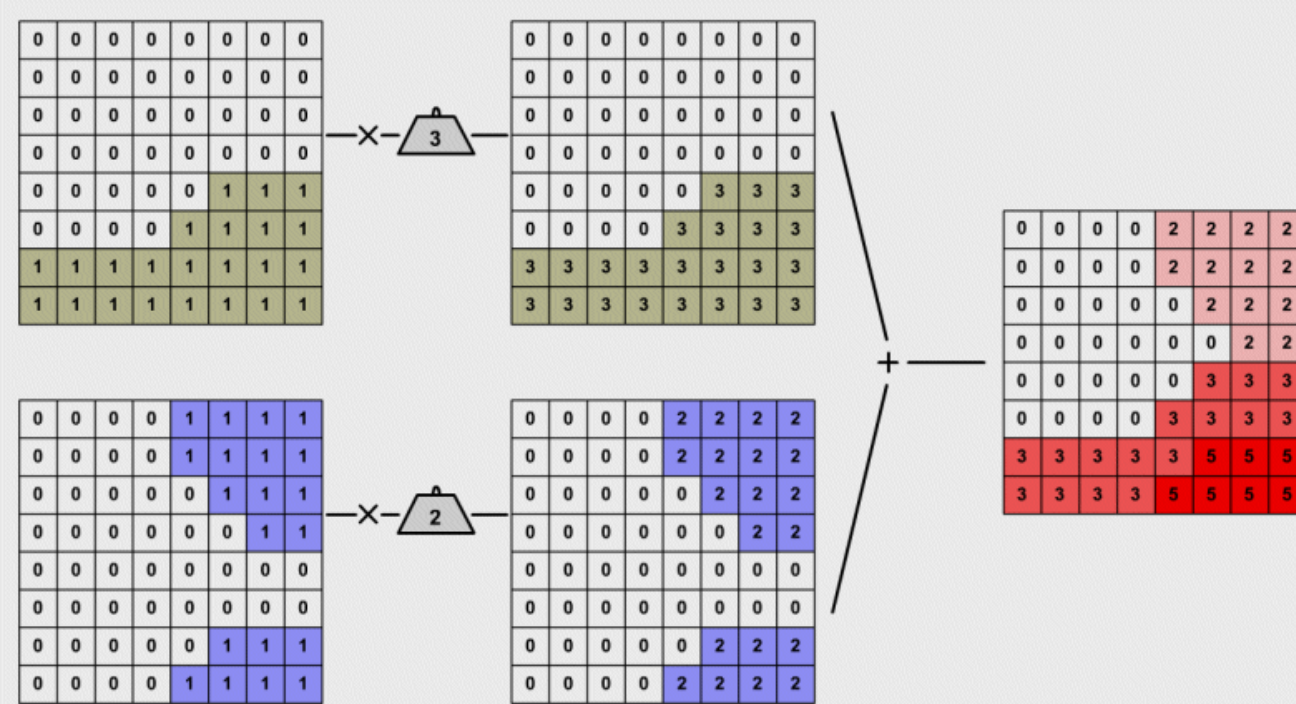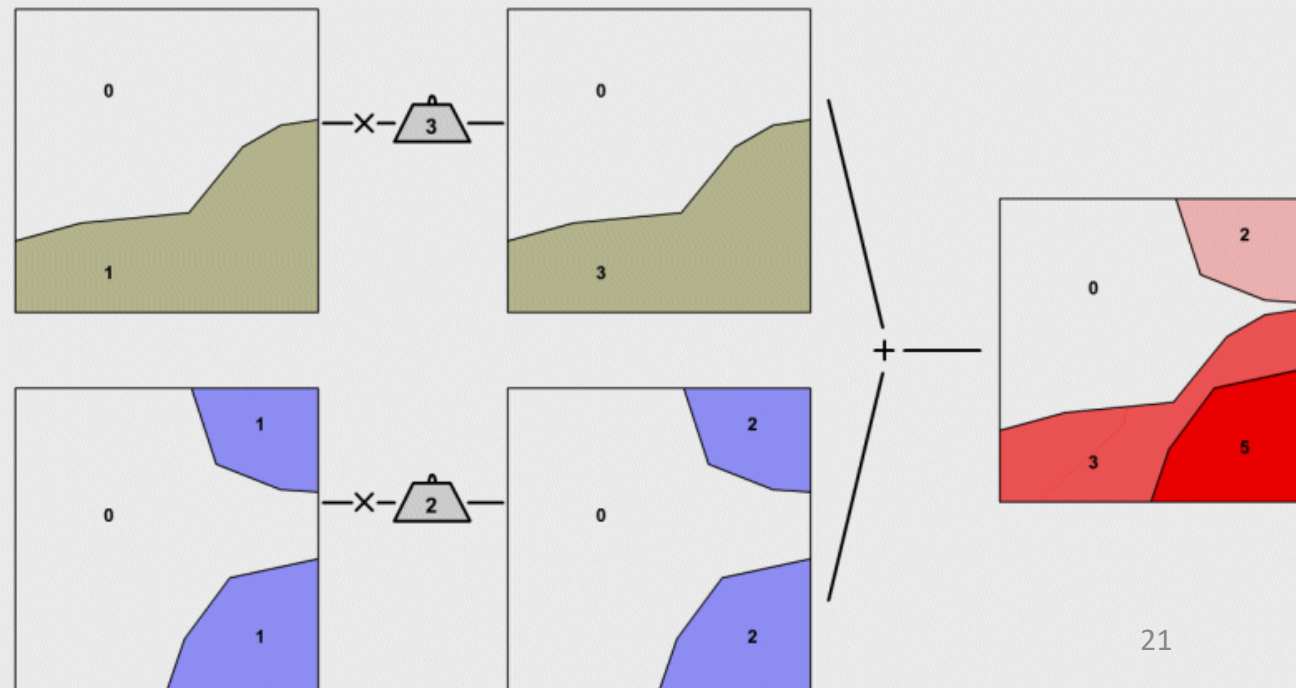
Aggregate the criteria (Weighted linear combination)

Standardise the range of all the variables (note Layers have values between 0 and 1, 1 is most suitable, 0 least)

- **Weight** them according to **perceived importance** (score 1 to 10, 10 as most important) or by AHP

- **Add the layers** and derive a map of nominal suitability

- The location with the **highest score** is the **most suitable**

- GIS raster calculator or weighted sum

Standardised (0-1)   Weighted (0-5)
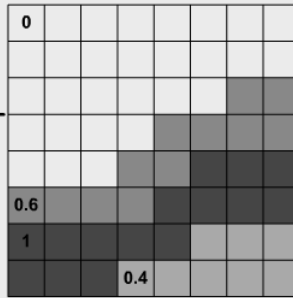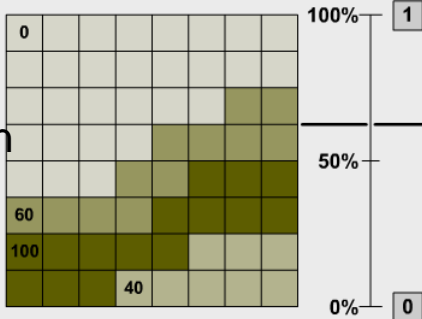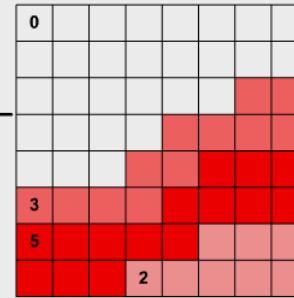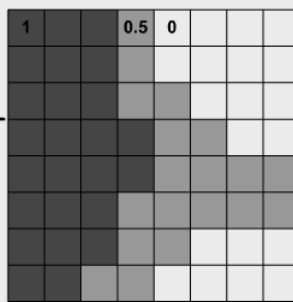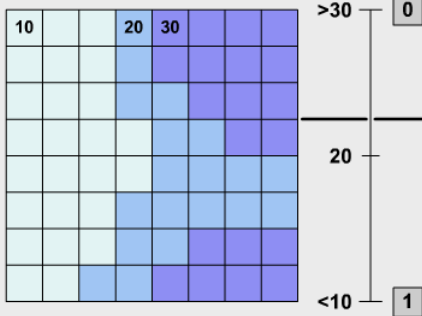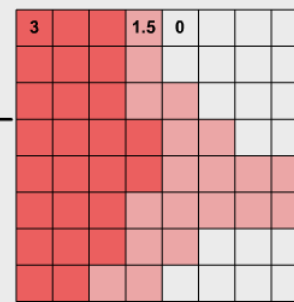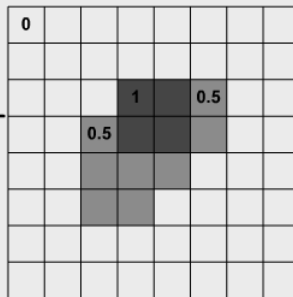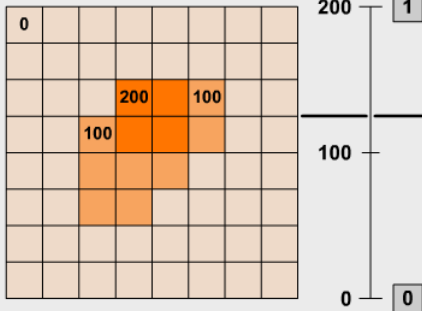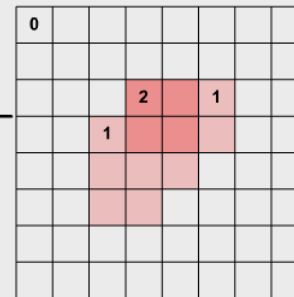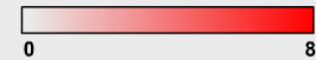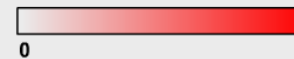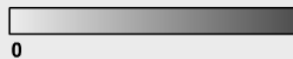
Validate/verify the result

To assess the reliability of the output

- Ground truth verification
  - *i.e.* conduct a field survey to verify sample areas

- Sensitivity analysis
  - How do the following affect the result?
  - altering the set of criteria (plus or minus)
  - altering the respective weights of the factors
  - Is the result reasonable?
  - Does the result reflect reality?

Multi-objective evaluation (MOE)

- When there is more than one goal, MCE is no longer sufficient for use, instead a decision support with multiple objectives (Multi Objective Evaluation, MOE) should be implemented.

- Allocating urban land either to housing (objective A) or green space (objective B)

- The spatial allocation of the urban land on the two uses. White is suitable for neither (A) nor (B). Blue was assigned to (A) and green to (B)and Where blue and green overlay, there is a land use conflict (pink).

- The conflict area has to be individually decided as to which land use they are assigned. In the simplest case, an area in dispute is assigned to the land use it is better suited (divide the area for both landuse (B) and (A).
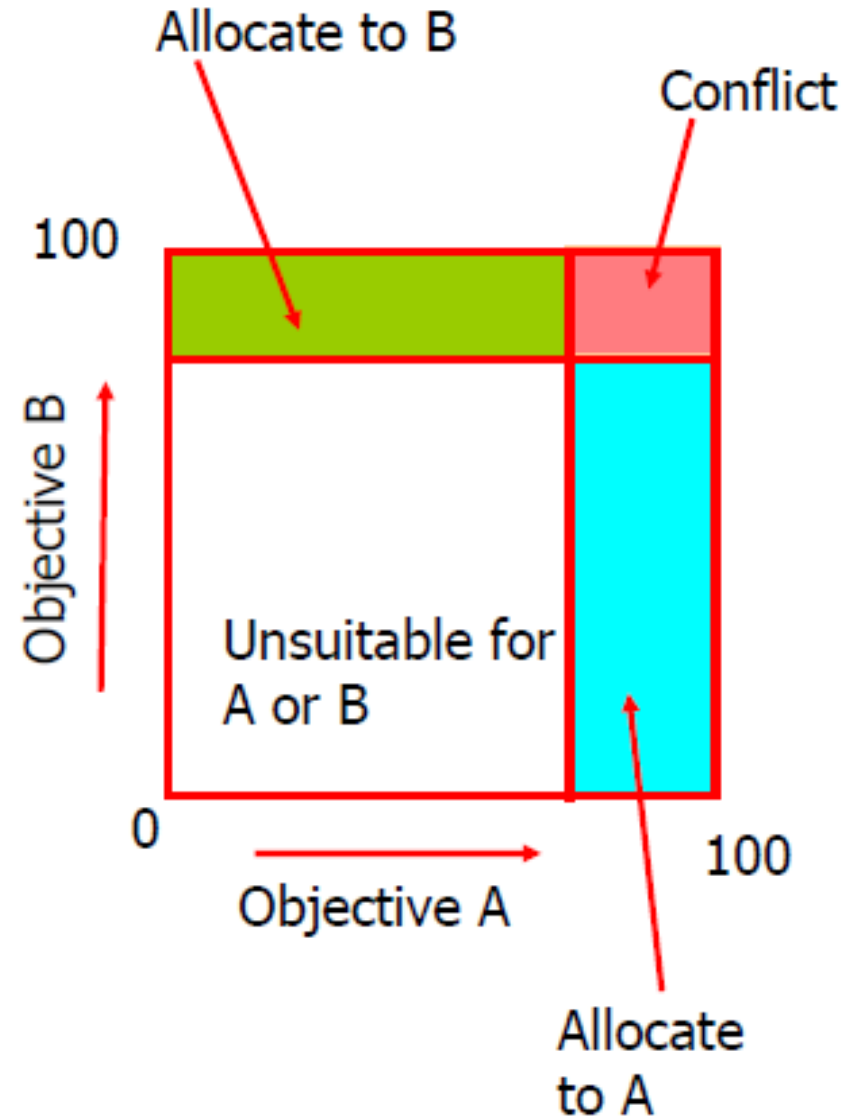
Next: Demonstration on MCDA using AHP for Landslide susceptibility mapping.

Demonstration on MCDA using AHP for Landslide susceptibility mapping.

- Weights by AHP

- Standardized by:

  - Slope- Fuzzy membership

  - Road and Drainage- Rescale by function

- Overlay by Weighted linear combination

Analytic hierarchy process

	Drainage	Road	Slope
Drainage	1	0.333	0.143
Road	3	1	0.2
Slope	7	5	1
sum	11.00	6.33	1.34

1/11	=0.091
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	Drainage	Road	Slope	weight
Drainage	0.091	0.053	0.106	0.083
Road	0.273	0.158	0.149	0.193
Slope	0.636	0.789	0.745	0.724

Model

weight
0.724
0.083
0.193
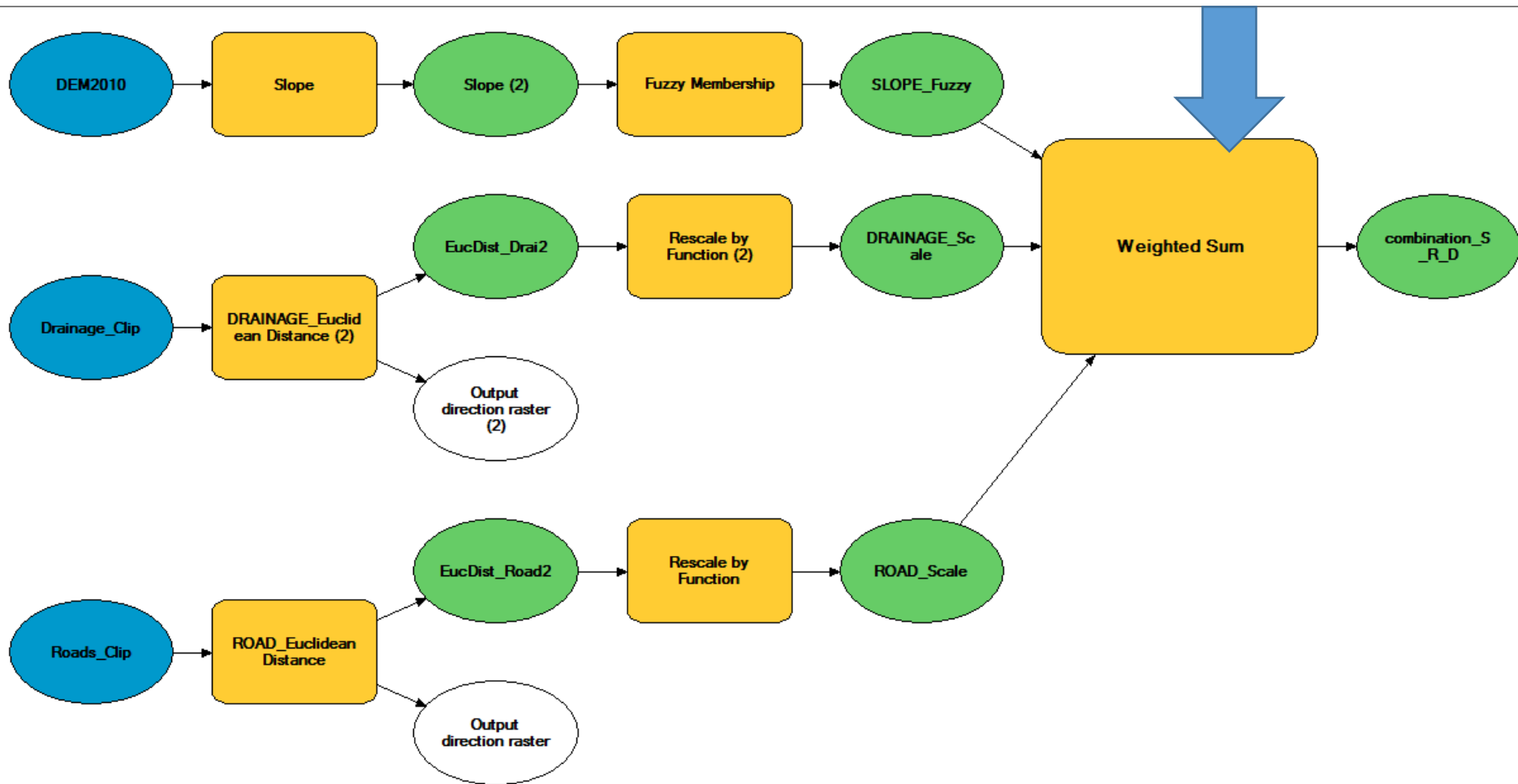
Drainage (rescaled)

Lighter the colour- closer to the drainage
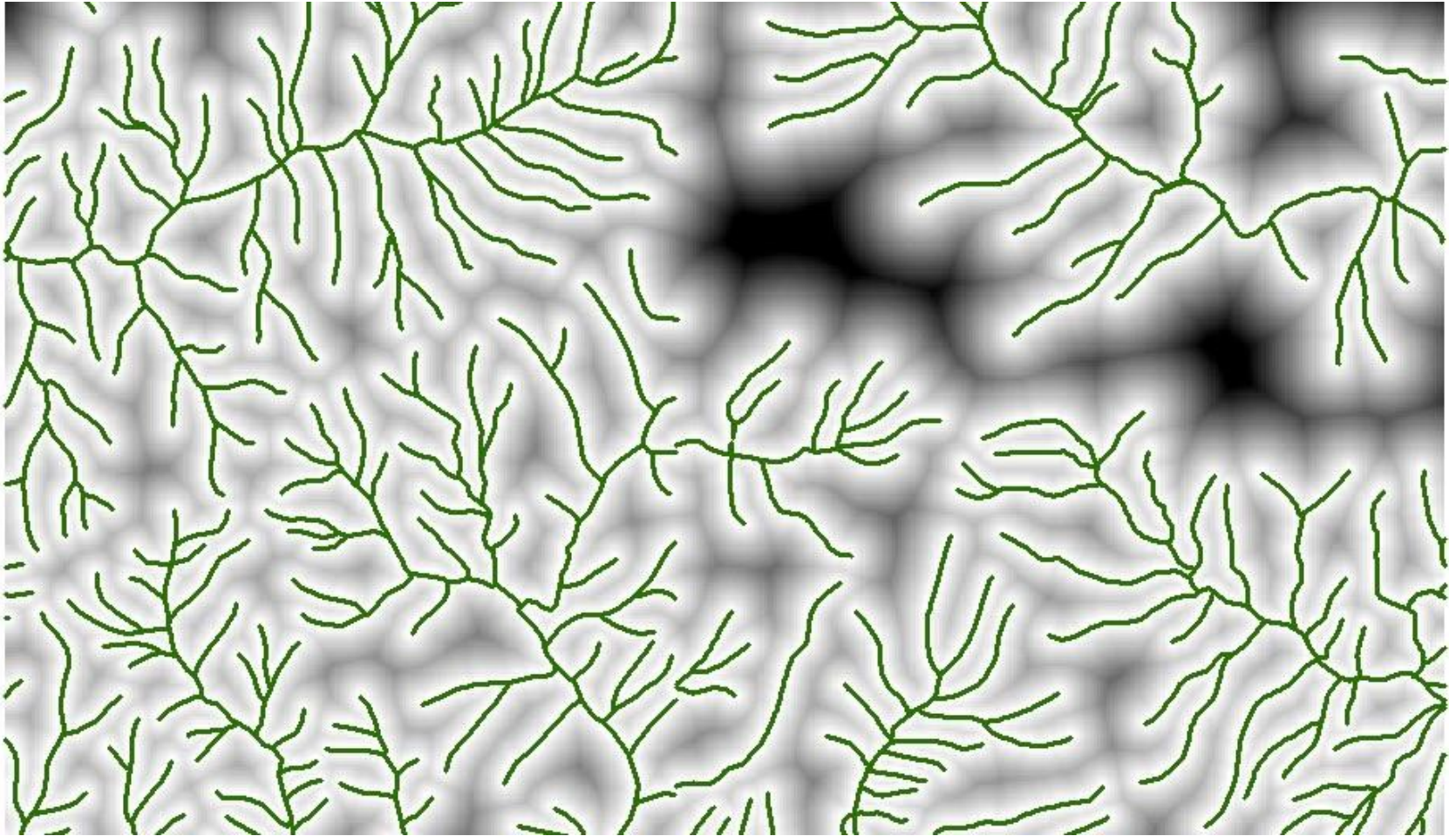
Value

High : 1

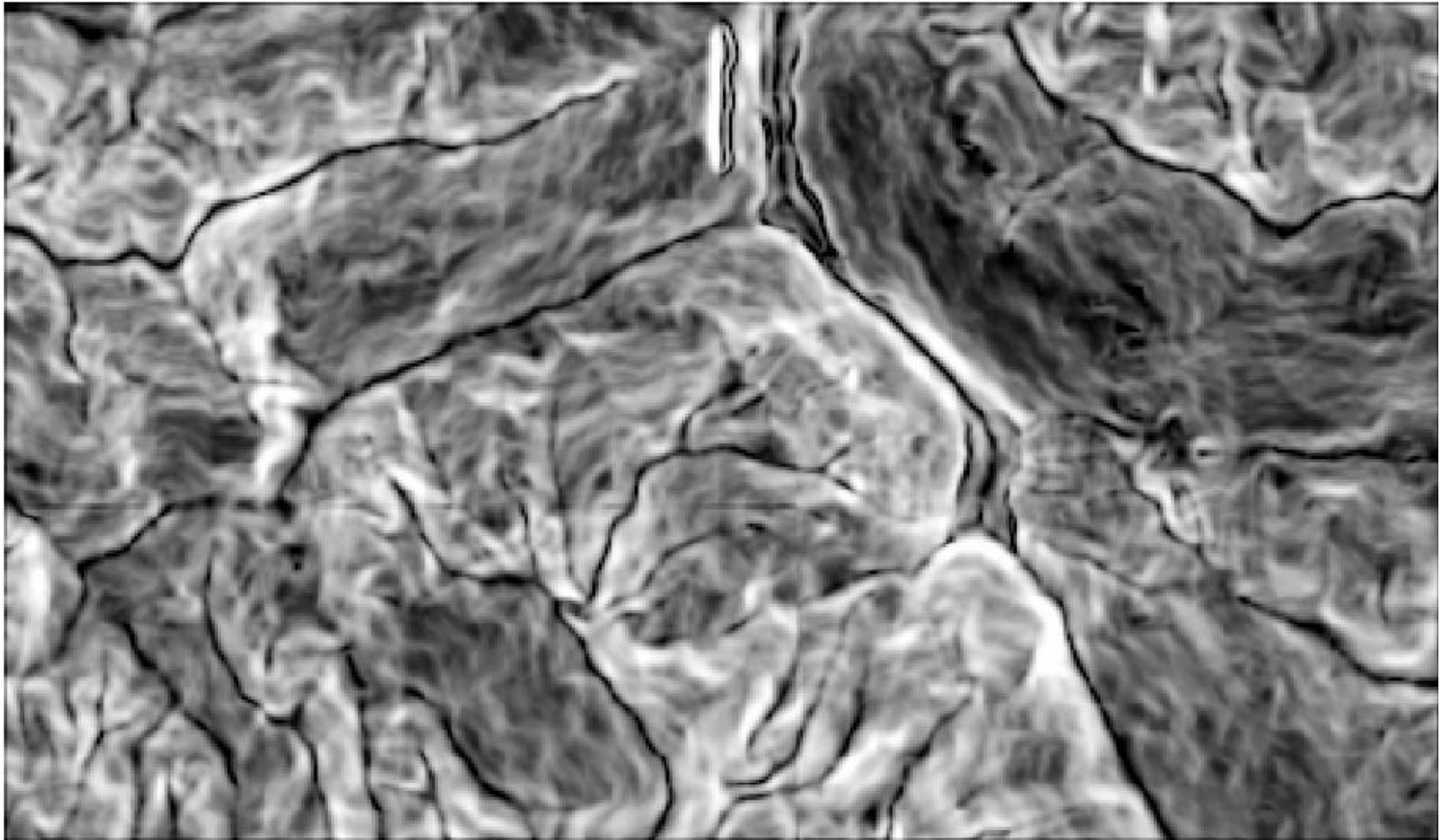Low : 0 ——— Drainage

Distance to Road (rescaled)
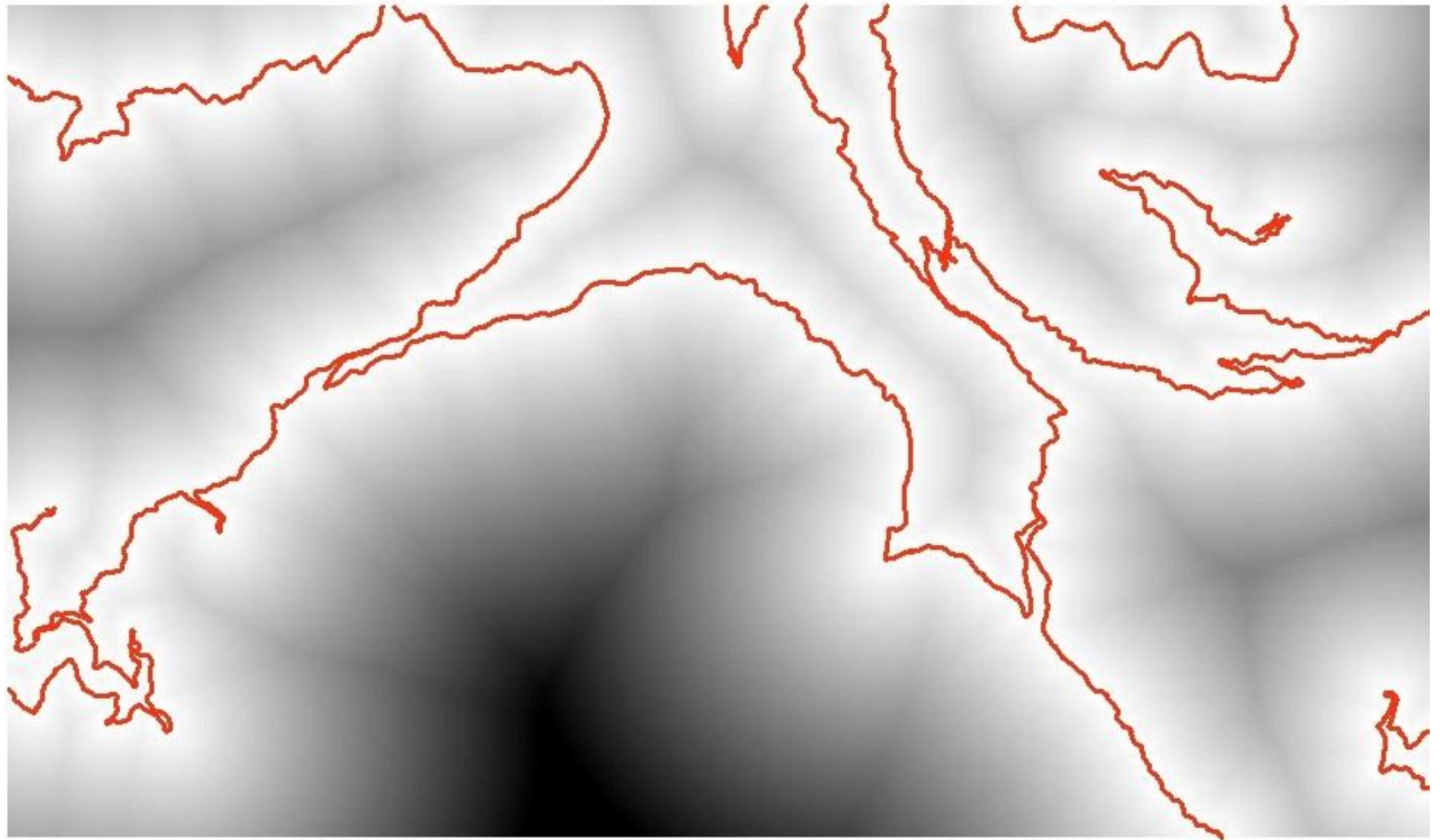
Value
High : 1
Low : 0

Lighter the colour- closer to the road
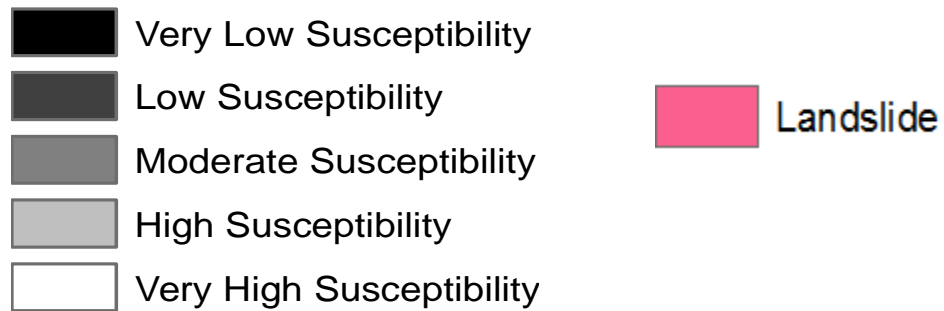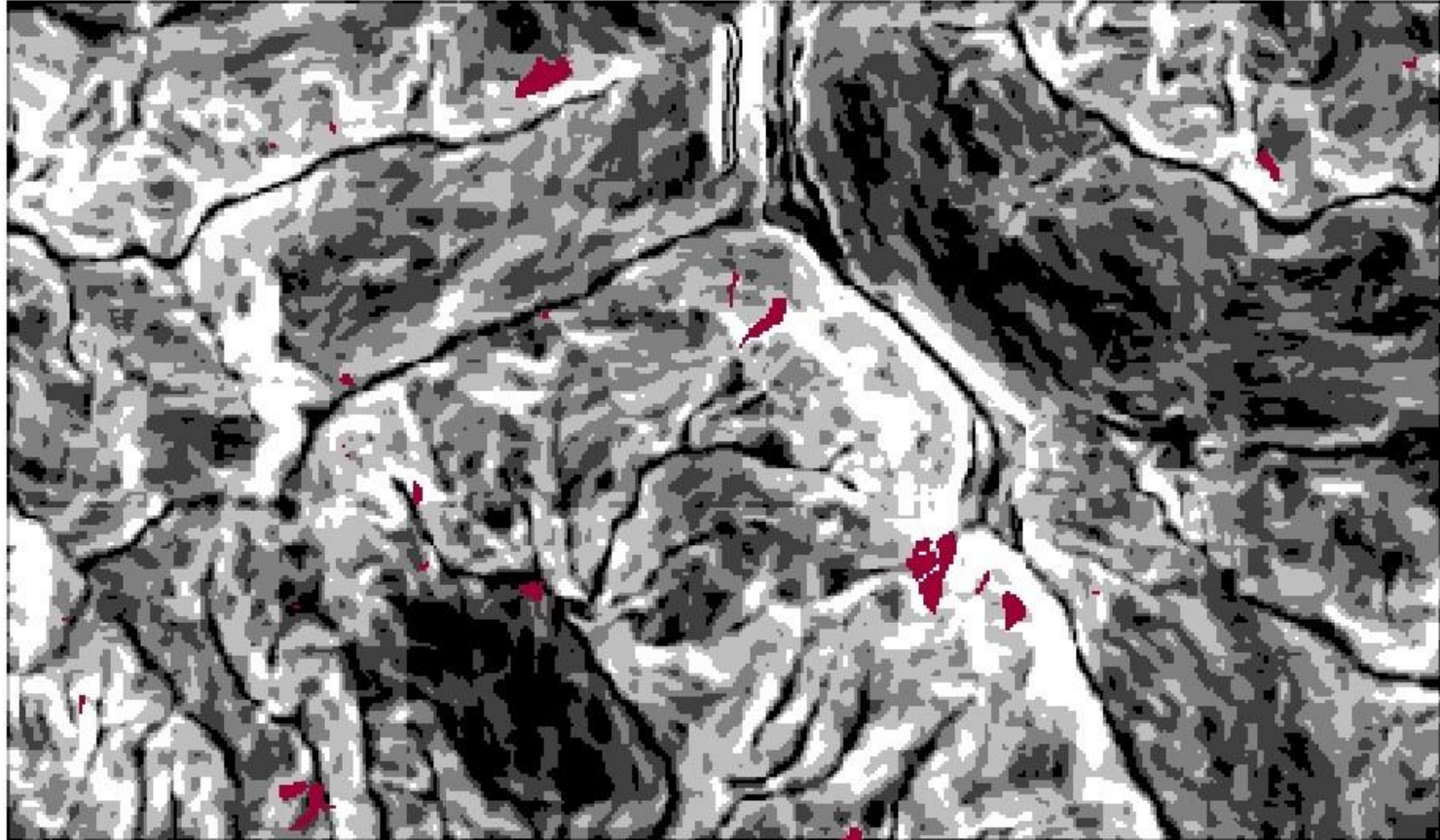
Roads

Slope degree (rescaled)

Value

High : 1

Low : 0

Lighter the colour- steeper the slope

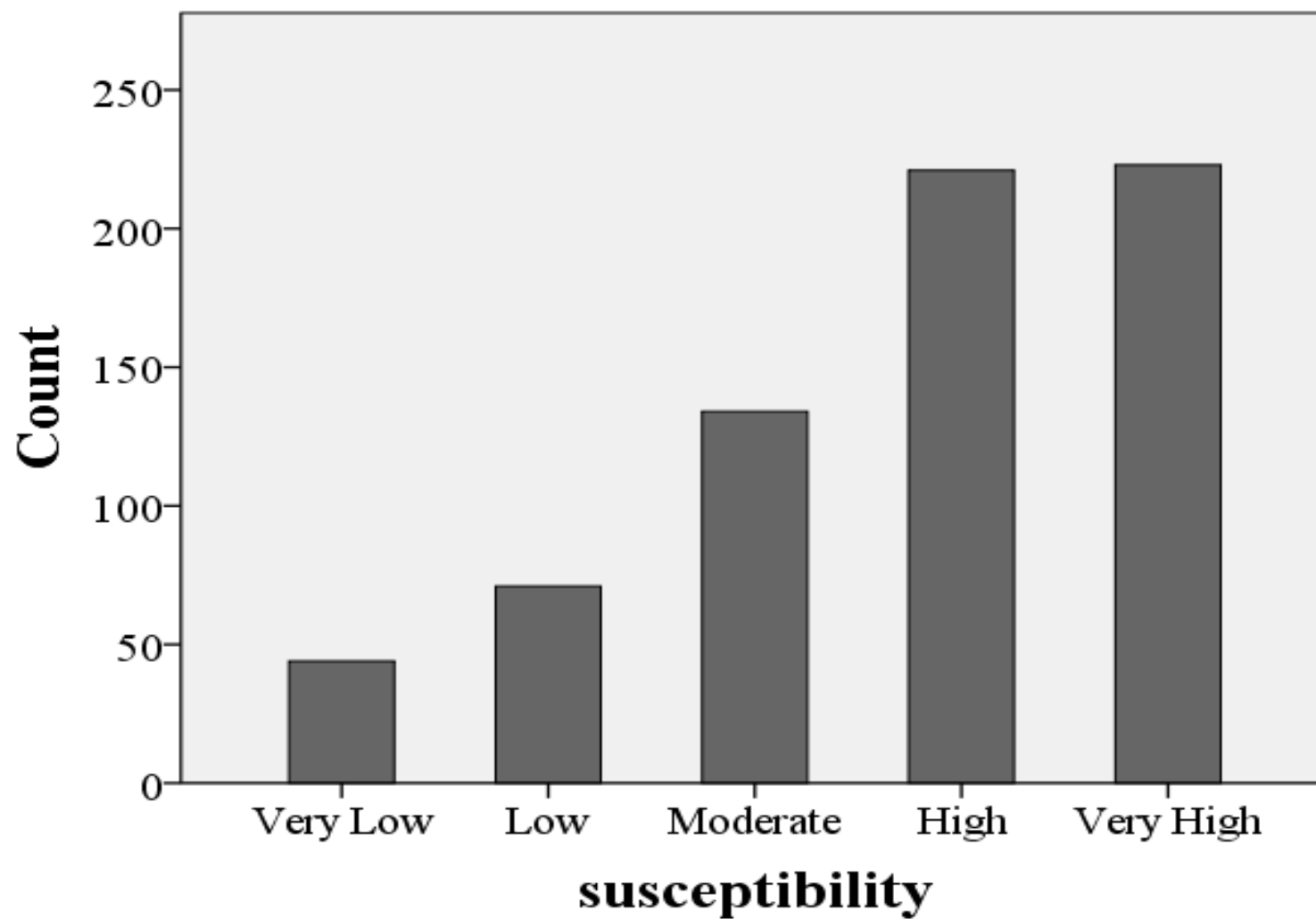# Landslide susceptibility mapping (LSM) with existing landslide

■ Very Low Susceptibility

■ Low Susceptibility

■ Moderate Susceptibility

■ High Susceptibility

□ Very High Susceptibility

■ Landslide

Validation

-by overlaying the existing landslide on the LSM

	Frequency of Landslide pixels	Percent	Cumulative Percent
Very Low	44	6.3	6.3
Low	71	10.2	16.6
Moderate	134	19.3	35.9
High	221	31.9	67.8
Very High	223	32.2	100
Total	693	100	

Validation

Thank you