# SPECIAL MOBILITY STRAND

## LANDSLIDE HAZARD AND RISK ASSESSMENT
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## Novi Sad, May 2019. godine

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## LANDSLIDES

•Landslides in the broader sense refer to mass movements on slopes and represent geo-hazardous events that can significantly affect the safety of people and their property.

•“The landslide is part of the geomorphologic environment limited by the surface and landslide depth, in which the gravitational displacement of the driven masses into the lower parts of the terrain occurs without losing contact of the sliding mass with a stable substrate.”

•Because of the harmful consequences, in the material sense, and in particular the consequence of the loss of human lives, landslides represent a limiting factor for the use of existing buildings or infrastructure facilities, as well as for the design and construction of buildings.

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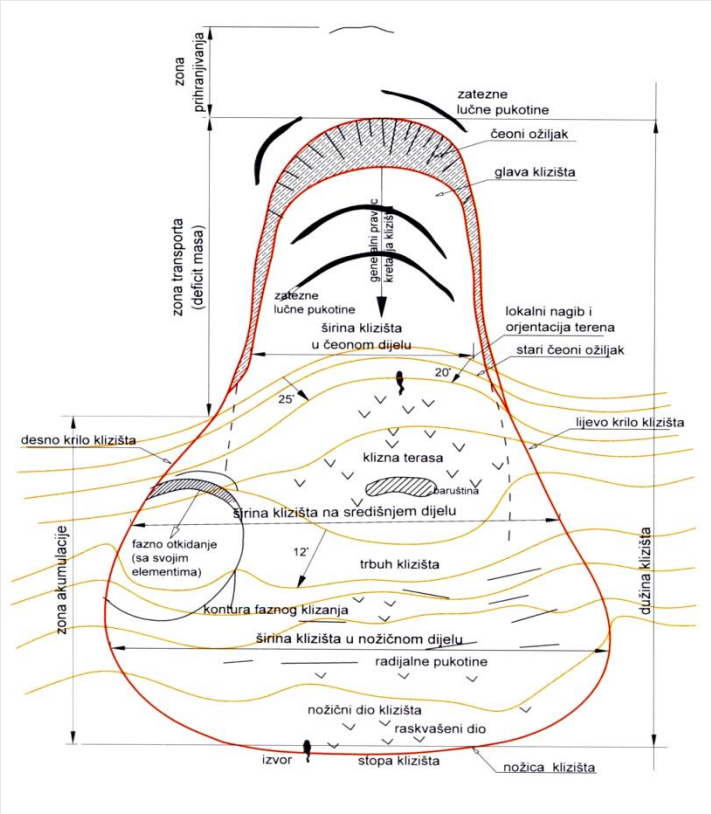


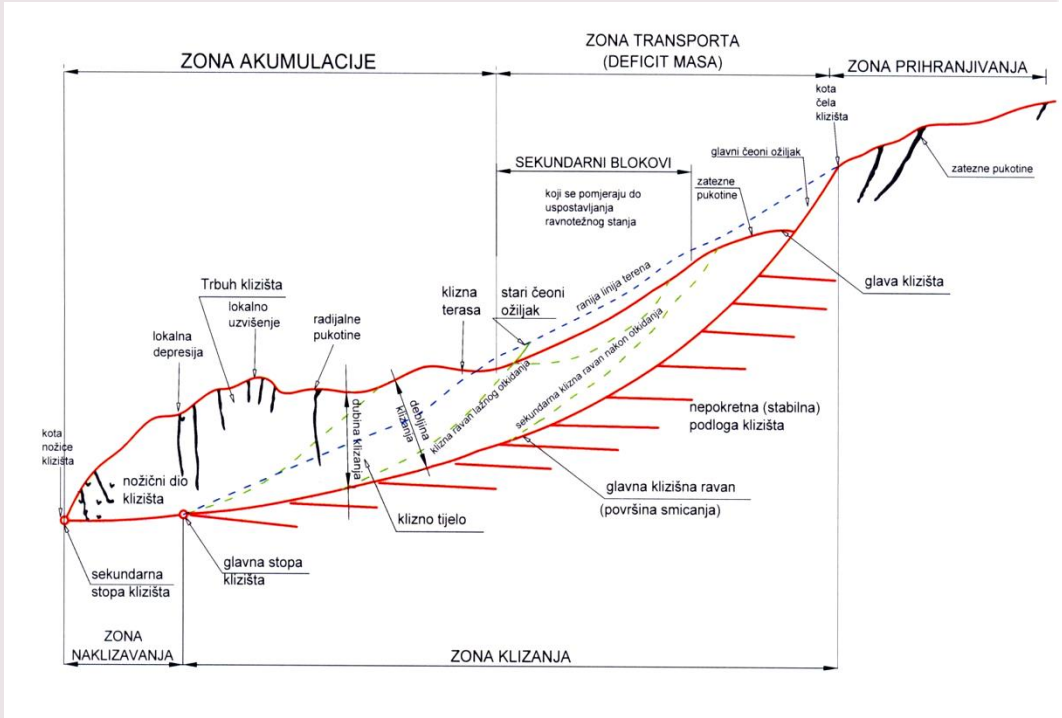


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•The total damage to Tuzla Canton in 2010 amounted to 17.5 million € (the city of Tuzla was 5.2 million €), while disaster after the weather accident in May 2014 € is 444.4 million € in the Tuzla Canton.

•After the May 2014 disaster (Tuzla Canton area):

- 9 people are slightly injured
- 7286 people evacuated
- 35 residential and 50 auxiliary facilities were destroyed
- Flooding of the basement room of 30 schools
- 6.742 landslides activated
- 397 objects were destroyed due to landslides, and 1,801 housing units and 494 additional objects were damaged
- Three schools were damaged by landslides

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•To determine the characteristics of the landslide and posibilites of their occurence in the wider area, as well as the conditions under which instability can occur, it is especially important to pay attention to the following conditions:

- Geological,
- Engineering geological,
- Hydrogeological and hydrological,
- Geodynamic processes,
- Anthropogenic (technogenic).

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•The causes of landslide formation by their nature can be:

➢Natural causes

1. Physical and mechanical (surface) decomposition of rocks
2. The effects of surface and ground water on the slope,
3. Changing the hydraulic gradient (sudden drop in the surface water level),
4. Erosion processes at riverbed that are the result of a balance disturbance (undercurrent),
5. Slope geometry (slope angle),
6. Stacked material on the slope from the previous landslide process,
7. The spatial position of the rocks of various physical-mechanical properties in the structure of the slope,
8. Increase of soil pressures during large precipitation
9. Soil swamps and process frost - defrosting,
10. Soil drying
11. Natural seismic impacts (earthquakes)
12. Microbs ect.

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➢Technical or anthropogenic causes:

1. Construction of buildings on conditionally stable and unstable slopes,
2. Inadequate execution of earthworks such as: cutting of the slope, construction of embankments on the slope, excavation of open pit mines, channels, foundations, uncontrolled deposit of materials on the slope and other earth works that can lead to disturbance of the slope balance,
3. Degradation of the terrain by degradation and cutting of vegetation,
4. Filtration pressures caused by sudden decrease of water level in artificial reservoirs and canals,
5. Dynamic load of traffic,
6. Human caused seismic effects, such as blasting and vibration, due to the operation of heavy machinery, etc.

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HAZARD AND RISK IN GEOTECHNICS

In professional geotechnical literature, hazard and risk are terminologically different.

- Hazard represents the likelihood of occurrence of potentially harmful natural phenomena.
- The risk represents the expected degree of loss of human life, or the destruction of material assets in natural phenomena that signify the existence of hazard.

ISO standard

- Hazard are insufficiently identified risks, ie hazards that are not adequately assessed in terms of probability of occurrence and the consequences that can cause.
- Risk is a quantified, objectified, computed or determined hazard with a defined probability of events and harmful consequences". Hence, the risk is the probability and quantum (numerical or descriptive) of the named hazard.

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•The sliding process on the slope represents a geotechnical hazard.
•Like any hazard, landslide has its own quantitative measure, expressed through risk that affects material goods and people.
•In order to achieve risk reduction, it is necessary to investigate the elements of the landslide hazard and identify the risk-affected entities (areas).
•The obtained data are used for the production of landslide hazard and risk maps, with clear zoning of the area in terms of hazard and risk, which are used for land use planning in these areas.

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## LANDSLIDE HAZARD AND RISK ASSESSMENT

- **Triggering factors** refer to factors that lead to landslide activation.
- **Zoning** refers to the separation of the surface of the investigated area into homogeneous zones (domains) and their ranking according to the degree of actual or potential susceptibility, hazard or risk.
- **Susceptibility** implies a spatial probability of occurrence of an event, is assessed qualitatively or quantitatively.
- **Vulnerability** is the degree of loss of value of a particular element or set of elements that are exposed to the occurrence of an adverse event. Often it is expressed in a scale of 0 (no loss) to 1 (complete loss).
- **Elements at Risk** are the population, objects, infrastructure, environmental characteristics, cultural values and economic activities in the area affected by the harmful event. Corominas et al. (2015).
- **Geological Hazard** is a geological process or phenomenon that can lead to loss of life, injury or other health effects, property damage, loss of resources for life and services, social and economic disorders, or environmental damage.
- **Risk Management** is a systematic approach and uncertainty management practice, in order to reduce potential damage and losses. (UNISDR, 2015).

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•Needs for developement require the hazard and risk assessment, elimination of limiting circumstances, including the presence of landslides on built slopes or slopes planned for construction.

•Hazard and risk assessment for landslides are usuallly conducted at:

- Regional level (maps of landslide susceptibility, hazard maps and risk maps)
- Local level (landslide cadastres and detail geotechnical research)

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•To assess the risk of landslide occurrence, it is necessary to:

➢Assess the hazard by dividing the area into smaller units and determining the location, intensity and frequency of landslide occurrence. The results are displayed on susceptibility and hazard maps.

➢Assess the vulnerability of each zone. This implies the determination of location facilities, population density, infrastructure facilities, vital economic activities, main and secondary roads, etc.

➢Calculate the expected losses or determine the degree of risk due to the, susceptibility, hazard and vulnerability of the area.

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•Ideally, the landslide map shows:

- Distribution of fossil, calm and active landslides
- Type of instability present on a slope such as rock fall, mud flow, overturning, lateral spacing, landslide
- Type of rock or soil affected by movement
- The likelihood of occurrence of instability determined by the size and extent of the sliding mass
- Evaluation of the impact of different movements on slopes on people, objects, roads, sewage water and other networks.

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•The methods for analyzing the landslide hazard, as well as the input data for making this map, are conditioned by the size of the affected area, which can be:

- Regional area with maps 1: 100000 and lower
- Middle size area with maps 1: 50000 and 1: 25000
- Locally, with maps 1: 10000 and 1: 1000

•Landslide hazard analysis for larger areas (regional and municipal) require the division of the area into homogeneous units within which the scoring of certain impact factors is performed, and the sum of points gives us the size of the hazard and risk for that area.

•For the quantitative assessment of the landslide hazard, deterministic methods for estimating landslide hazard may also be used.

•Such assessment of the hazard, at the local level, are related to the conduct of geotechnical research in the field.

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| Scale | Areas of Use | Methods | Purpose |
|---|---|---|---|
| < 1:100.000 | > 10.000 km$^2$ | Heuristic approach* | Informing the ruling structures and the public |
| 1:25.000 - 1:100.000 | 1.000 - 10.000 km$^2$ | Heuristic approach* (Statistical methods) | Planning of regional development projects |
| 1:5.000 - 1:25.000 | 10 - 1.000 km$^2$ | (Heuristic approach) Statistical methods * (Deterministic approach) | Planning infrastructure objects |
| > 1:5.000 | few acres - 10 km$^2$ | (Statistical methods) Deterministic approach * | Planning and designing (buildings, roads, ...) |

*Recommended size of the zoning area, the methods for making a landslide map and its purpose depending on the scale of the map.*

** Applicable methods, () may be applicable methods*

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LANDSLIDE HAZARD AND RISK ASSESSMENT IN REGIONAL LEVEL

•A particular type of zoning gives certain data as follows:

➢Landslide Inventory Map - where landslides have already appeared (for each municipality)

➢Landslide Susceptibility Map - where landslides may occur, and which areas are more susceptible to landslides occurrence;

➢Landslide Hazard Map - where and when landslides may occur, or what is the likelihood of a landslide in a particular area;

➢Landslide Risk Map – what are the consequences (damages) of the possible landslide occurrence.

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•Landslide susceptibility maps represent the spatial likelihood of landslide phenomena. They are made in different scales, depending primarily on the purpose and size of the investigated area, as well as on the scale and details of available input data.

•For landslide susceptibility maps in scale 1:100 000, heuristic approach based on engineering experience can be chosen as the optimal approach.

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•Creating landslide susceptibility maps (LSM) is an important step in defining spatial plans for areas in which there is possibility of landslides occurrence.
•The main objective is to define a zone with critical landslide hazard, which creates the preconditions for widespread use of LSM in the region, for better management systems and risk prevention.
•LSM has practical application in providing information to local authorities and citizens in areas such as spatial planning, protection of human health, biodiversity and nature.

•Creating landslide susceptibility also allows:
- definition of zones that are currently or potentially most vulnerable,
- reduction of damage to property and human victims,
- reduction of costs of landslide rehabilitation,
- introduction of measures to reduce the intensity and number of anthropologically initiated landslides and enables the production of other, related basic documents.

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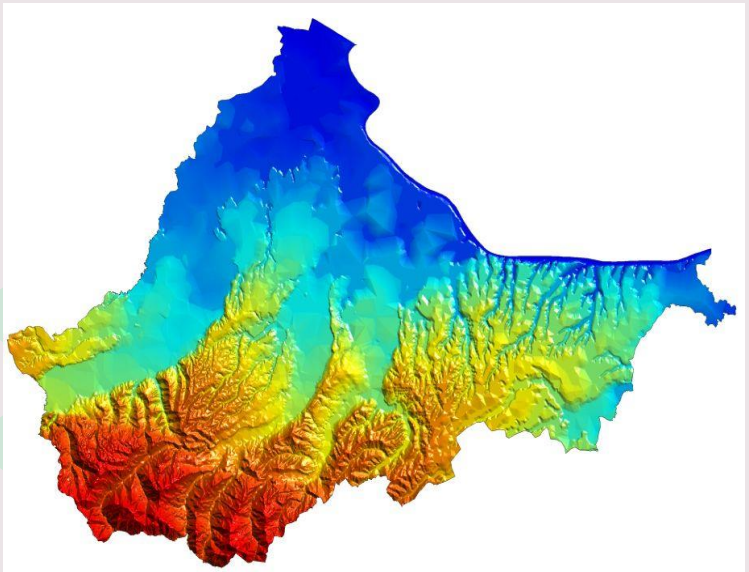
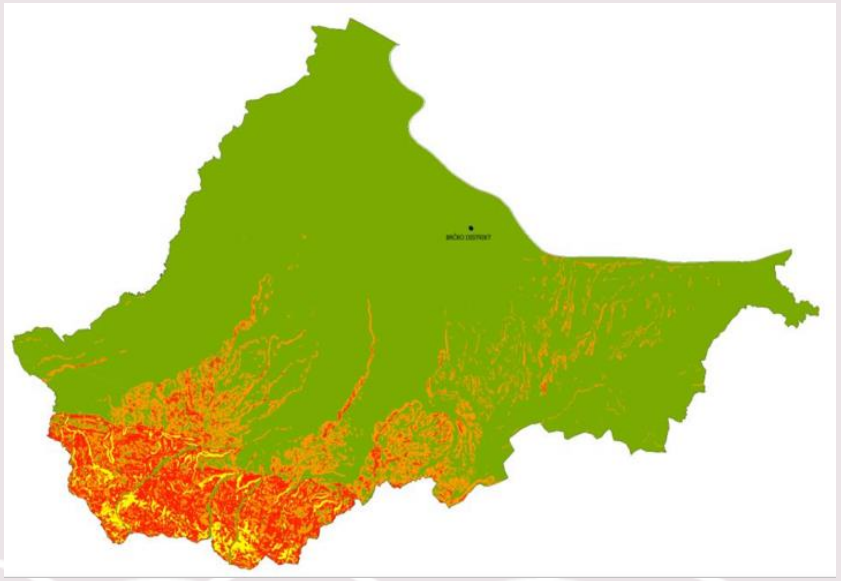
•To create a landslide susceptibility map of a scale of 1: 100,000, the following factor maps are used as input data:

**Slope angle map**

➢can be derived from the digital relief model - DEM (digital elevation model) obtained on the basis of a 1: 25,000 topographic map,

➢the size of the grid cell is 20 * 20 m.





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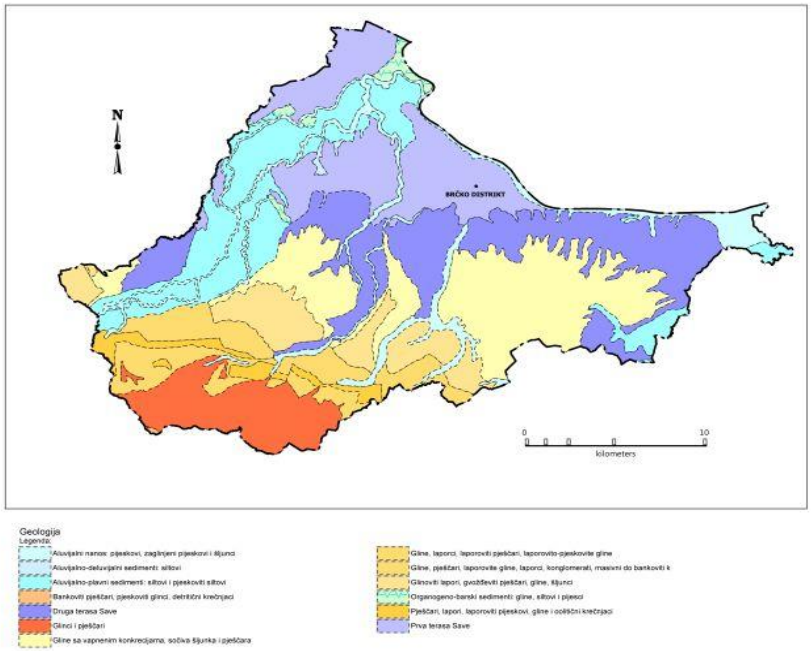
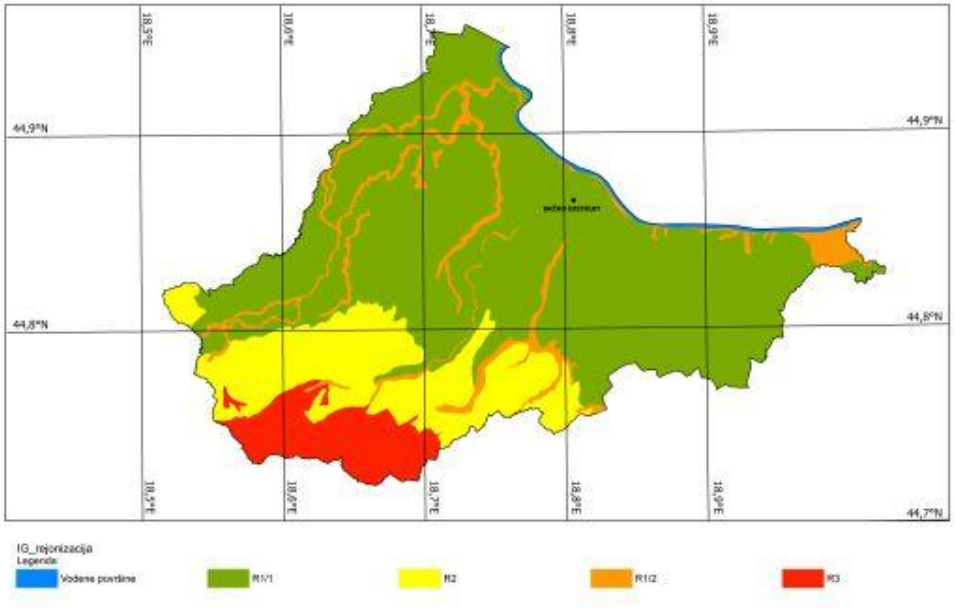
**Map of engineer-geological units**

- created on basic geological maps in the scale of 1: 100,000 which are used for the definition of engineering-geological units,
- units are separated on the basis of engineering-geological features.

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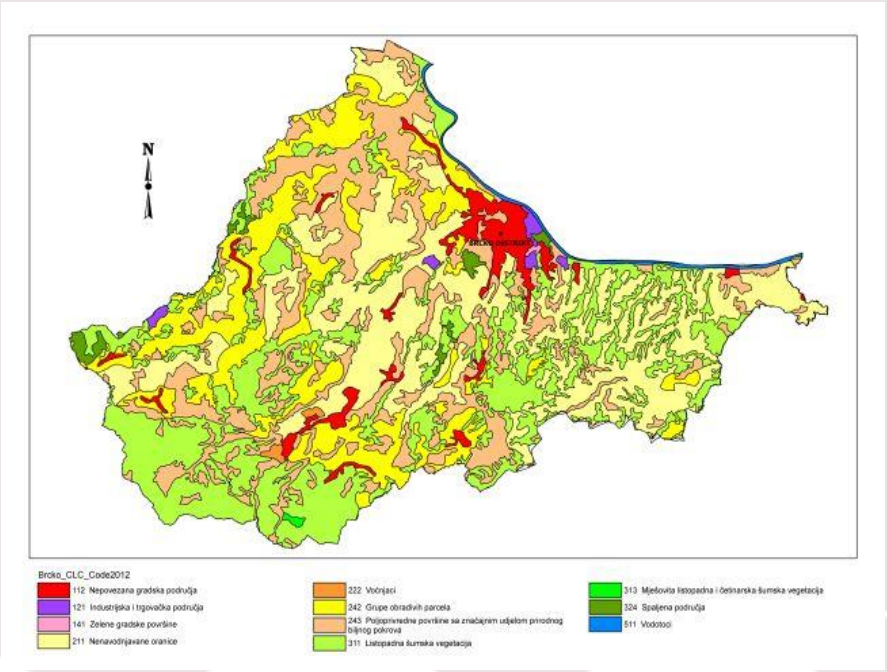
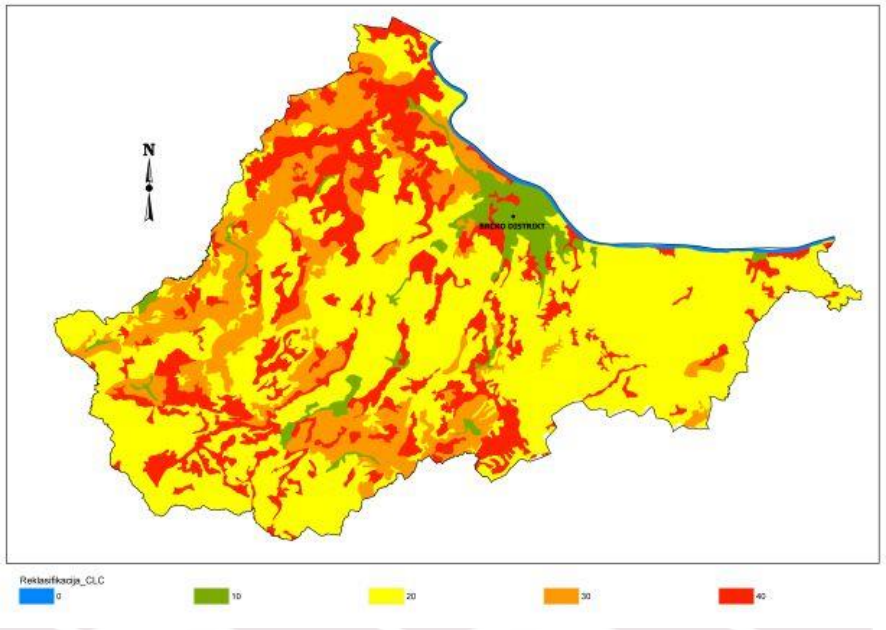
**The land cover map**

- usually based on the CORINE Land Cover (CLC), in this case 2012 base.
- made according to the CORINE standards that define the output scale 1:100,000
- the minimum mapping area is 25 ha and the minimum width of the polygon 100 m.

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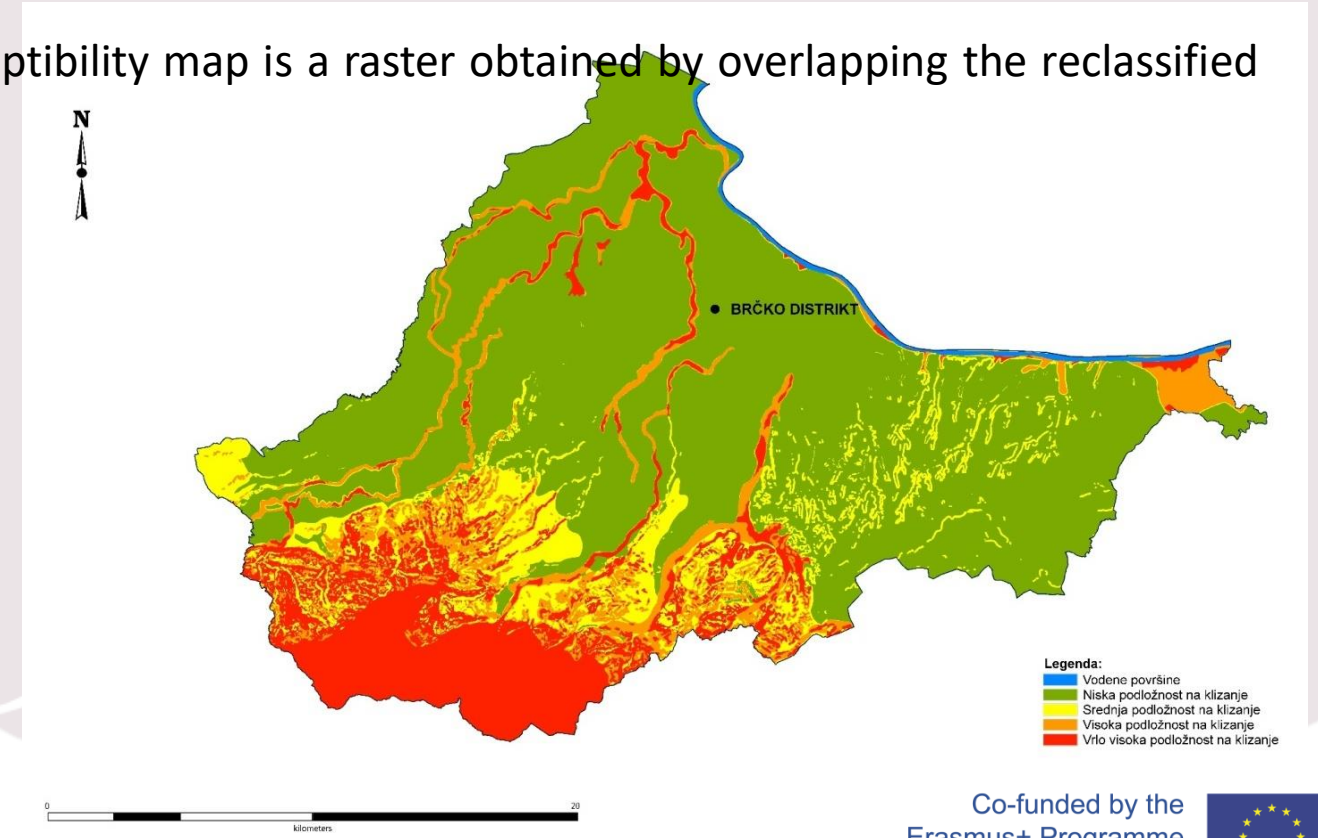
•Generating a landslide susceptibility involves processing and analyzing data through the calculation of factor maps and reclassification of factor maps.
•The influence of each individual factor on landslide susceptibility is defined by weight factors.
•A landslide susceptibility map is a raster obtained by overlapping the reclassified factorial maps.

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## LANDSLIDE HAZARD AND RISK ASSESSMENT IN LOCAL LEVEL

- Landslide hazard and risk assessment for local level usually use the deterministic approach and it is most efficient for areas from few acres to area of whole municipality.
- For landslide hazard and risk assessment for whole municipalities, landslide cadastre is one of the most commonly used methods.
- The landslide cadastre is defined as a collection of basic data on landslides and on landslide surveys carried out according to all its characteristics.
- The formation of a landslide cadastre by a unique methodology represents the first and most important step in further work on the problems of landslide occurrence.
- Landslide cadastre involves the collection of data on landslide elements.

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•The qualitative and quantitative content of a database depends on subjective and objective circumstances:

- level of knowledge of people dealing with landslides,
- the degree and method of landslide research and the economic basis on which data collection is based, which ultimately affects the level of landslide research.

There is no uniform form for the collecting of landslide data, on the basis of which the database is further formed.

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## KATASTAR KLIZIŠTA I NESTABILNIH PADINA

**A POLOŽAJ**

KATASTARSKI BROJ
OI OGK 100 000
TOP KARTA 25000
TOP KARTA 5000
SEL 100
KANTON
OPĆINA
LOKACIJA
KOORDINATE X Y Z
DOPUNSKI PODACI
SKICA
FIRMA
ISPUNIO
DATUM PRVE OBRADE
DATUM DOPUNE

**B OSNOVNI ELEMENTI POJAVE**

POJAVA
NESTABILNA PADINA: L, W, ß, ΔH
TIP POKRENUTOG MATERIJALA: ČVRSTO; DJELOMIČNO ČVRSTO; KOHERENTNO; RASTRESITO; KOMPLEKS

**GEOMETRIJA KLIZIŠTA**

ZAHVAĆENA POVRŠINA: Lr, Wr, Dr, A, L
POKRENUTA MASA: Ld, Wd, Dd, V, ΔH
TIP POKRETA: ODRON, KLIZANJE, TEČENJE, PUZANJE, OSTALO

**OBLIK KLIZIŠTA**

IZDUŽEN
EKVIDIMENZIONALAN
RAŠIREN

**IZRAŽAJNOST KLIZIŠTA**

JASNA GRANICA KLIZIŠTA
NEJASNA GRANICA KLIZIŠTA

**GEOMORFOLOGIJA PADINE**

GEOMETRIJA: L, W, H
OPĆI NAGIBI (ß): <5°; 5°–12°; 12°–32°; 32°–55°
OBLIK PADINE: JEDNOLIČAN; NEJEDNOLIČAN; PRAVOLINIJSKI; KONKAVAN; KONVEKSAN
TERASAST: PRIRODNO; VJEŠTAČKO
VALOVIT
SMJEŠTAJ KLIZIŠTA NA PADINI
GLOBALNA NESTABILNOST: U VRHU; U NOŽICI; U SREDINI
IZLOŽENOST PADINE
VEGETACIJA: PRIRODNA TRAVA, GRMLJE, ŠUMA; KULTURA: PARK, ORANICA, LIVADA, VOĆNJAK, VINOGRAD

**INŽENJERSKOGEOLOŠKI ELEMENT PADINE**

KLIZIŠTE U: MATIČNOJ STIJENI (Ms); KORI RASPADA (Ei); POKRIVAČU (Ci); KOLUVIJALNOJ MASI KLIZIŠTA (Ku); RASJEDNOJ ZONI (R); NASIPU (N)
STANJE KONZISTENCIJE: ČVRSTO; DJELOM. ČVRSTO; KOHERENTNO; RASTRESITO; KOMPLEKS
STRATIGRAFSKA PRIPADNOST MATIČNE STIJENE
GENETSKA PRIPADNOST POKRIVAČA: PADINSKI NANOS; BUJIČNI NANOS; KOLUVIJALNI NANOS
HIDROGEOLOGIJA
POVRŠINSKE VODE
PRIPADNOST LOKAL. DREN. BAZI
DRENIRANJE PADINE
U TIJELU KLIZIŠTA
IZVAN KLIZIŠTA
STAGNIRA VODA
LOKVA
PODZ. VODA U TIJELU KL.: NEMA; MA; VLAŽENJE; IZVOR; KANALIZACIJA
STANJE P.V.: SLOBODNA; ARTEŠKA; SUBARTEŠKA
DUBINA DO P.V. (m)

**C UZROCI I POJAVE**

PRIRODNI FAKTORI: LITOLOGIJA; STRUKTURA PADINE; STEPEN RASPADA; POVEĆANJE GRADIJENTA P.V.; EROZIJA STOPE; SUFOZIJA; POPLAVA; POTRES; OSTALO
LJUDSKI FAKTORI: POVEĆANJE NAGIBA; OPTEREĆENJE U VRHU PADINE; RASTEREĆENJE U STOPI; RUDARENJE; VIBRACIJE; OŠTEĆENJE VODOVODA; ONEMOGUĆENO DRENIRANJE; NAČIN OGRADE ZEMLJE; PROMJENA VEGETACIJE; KOMBINOVANO

**MODEL**

MJERODAVNI INŽENJERSKOGEOLOŠKI MODEL POJAVE

**KINEMATIKA KLIZIŠTA**

TIP KLIZANJA: ROTACIJSKO; TRANSLACIJSKO; SLOŽENO
ODNOS PREMA STRUKTURI PADINE: ASEKVENTNO; KONSEKVENTNO; INSEKVENTNO
STADIJ KLIZIŠTA: AKTIVNO; UMIRENO; STABILIZIRANO; POTENCIJALNO
STAROST: PALEOKLIZIŠTE; STARO KLIZIŠTE; PRVO KRETANJE
PREMA DUBINI KLIZNE PLOHE: POVRŠINSKO; PLITKO; DUBOKO; VRLO DUBOKO
PREMA BRZINI POKRETA: TRENUTAČNO; BRZO; POLAGANO; VRLO POLAGANO
RAZVOJ KLIZIŠTA-UZASTOPNOST: DESTRUZIVNO (PROGRESIVNO); DELAPSIVNO (REGRESIVNO)
DEFORMACIJE: POPREČNE NA SMJER KRETANJA MASE; OTVORENO ČELO KLIZIŠTA SA SKOKOMI: DO 1,0 m; 1,0 - 5,0 m; 5,0 - 10,0 m; PREKO 10,0 m
PODUDARNE SA SMJEROM KRETANJA: TANGENCIJALNE PUKOTINE; RADIJALNE U STOPI; EROZIONA NESTABILNOST; ISPUPČENJE U TIJELU KLIZIŠTA; NAJAHIVANJE U STOPI; PUKOTINE ISTEZANJA (SA ZIJEVOM); PUKOTINE SA SKOKOM

**D ŠTETE I SANACIJA**

OBJEKTI NA KLIZIŠTU I NEPOSREDNO UZ:
STANJE I BROJ: NEOŠTEĆEN; UGROŽEN; DJELOM. OŠTEĆEN; SRUŠEN
STANOVI
GOSP. OBJEKTI
JAVNI OBJEKTI
INDUSTRIJSKI OBJ.
SAOBRAĆAJNICE: CESTA; PRUGA
INSTALACIJE: PODZEMNE; NADZEMNE
POTPORNI ZID

DIREKTNA ŠTETA / INDIREKTNA ŠTETA
BEZ ŠTETE
MINIMALNA
MALA
SREDNJA
VELIKA
JAKO VELIKA
KATASTROFALNA

JBO
DOKUMENTACIJA

**PROGNOZA I POSTUPCI**

PROGNOZA: TENDENCIJA SMIRIVANJA; TENDENCIJA ŠIRENJA; STABILIZIRANO; NEIZVJESNO
POTREBA ZA OSKULTACIJAMA: UGRADNJA REPERA; UGRADNJA INKLINOM; OSTALO
POTREBA ZA ISTRAŽIVANJIMA: POTREBNA; NEOPHODNA
POTREBA ZA SANACIJOM: NIJE NEOPHODNA; SAMO PREVENTIVNA; PO SMIRENJU KLIZANJA; NEOPHODNA I NEODLOŽNA
OCJENA USPJEŠNOSTI SANACIJE: NIJE SANIRANO; USPJEŠNO SANIRANO; NEUSPJEŠNO; DJELOMIČNO
MJERE SANACIJE: UREĐENJE POVRŠINE; DRENIRANJE; POTPORNE KONSTR.; KOMBINACIJA; OSTALO

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•For landslide hazard and risk assessment for areas up to few acres, geotechnical research is one of the most commonly used methods.

•This type of risk management is used for planning and design of roads buildings etc.

The purpose of geotechnical research is to provide reliable information on the slope material in the construction area.

•Data that should contain geotechnical investigations, are related to the following facts:

- Geological conditions for the formation of soil
- Hydrogeological aspects of the area,
- Geotechnical characteristics of the soil in the slope
- Characteristics and type of landslide (if existing), its direction, intensity and speed of movement,
- Geodetic surveys
- Position, shape and properties of the potential sliding plane or landslide zone,
- Possible causes of landslide and causing consequences.

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•The scope and content of geotechnical investigations is adapted to:

➢Purpose of research,

➢The size of the landslide or potential area for landslide occurrence due to the construction,

➢Complexity of the problem,

➢Dangers and damages that may be caused by a slide,

➢The degree of earlier research of the area and the knowledge of basic geological, hydrogeological and geotechnical aspects.

•Phases of geotechnical research works are:

➢Preliminary research

➢Detailed research

➢Supplementary or control research.

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•Data that are important for risk assessment on the slope are:

➢Geological and geomorphological characteristics of the slope

➢Hidrogeological conditions

➢Engineering geological and geotechnical characteristics of the slope.

Probe ditch for sampling

Probe drilling with sampling

Shear device (lab tests)

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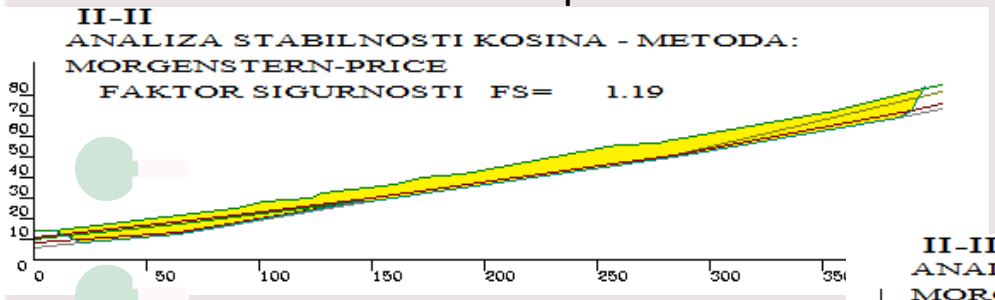
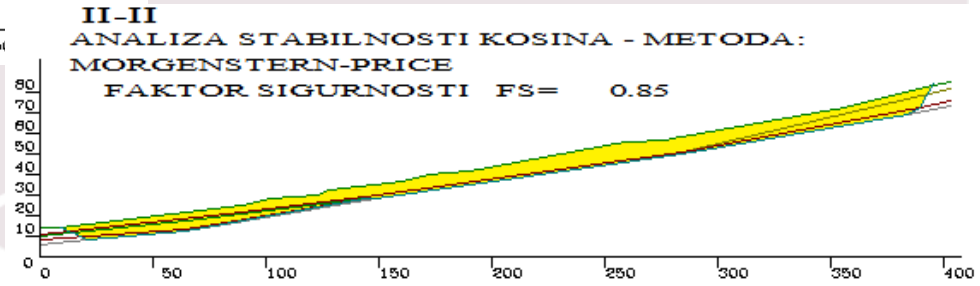
•In selecting resistant soil parameters in stabilitiy analysis, a deterministic or probabilistic approach can be used.
•Stability calculation is preformed for the conditions in which the slope will be found after the execution of the construction works.
•The quantitative stability estimate is given by the coefficient or safety factor Fs.
•There is a certain value that represents the boundary between the stability and instability areas.
•This limit value that separates the two areas is Fs = 1.

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•The required safety factor that usually has a value greater than 1 and depends on several different factors:

➢The significance of the object, where the required safety factor increases with the character of the object,

➢The volume and reliability of the results of the performed works,

➢Methods used to analyze and calculate the stability of the slope, where the value of the required safety factor is inversely proportional to the quality of the method, ie, its precision.

| FS allow | | Risk of human losses | | |
|---|---|---|---|---|
| | | Negligible | Average | High |
| Risk of economic losses | Negligible | 1.1 | 1.2 | 1.4 |
| | Average | 1.2 | 1.3 | 1.4 |
| | High | 1.4 | 1.4 | 1.5 |

FS for recurrency time of 10 years; for higher risks and soft ground conditions, add 10% increase in FS

Recommended safety factor for reccurence time of 10 years; forr higher risk and soft conditions increase od safety factor 10%.

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•Analysis and assessment of the slope conditions prior to the construction of geotechnical facilities is a very effective method of eliminating the hazard and risk associated with the occurrence of landslides on the slope.

•This enables:

- implementation of preventive measures,
- reduction of risk for existing constructions
- economical construction

•Preventive measures include the following works and activities:

- Proper surface drainage from the slope and around the zone of the slope,
- Capture of the water source above excavation,
- Biological protection of newly built slopes,
- Removal of the route of the water supply and sewage network from the slope or from the part of the slope above the cuttings,
- The correct selection of the slope angle in function of time.

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•Permanent remediation measures

➢ if the landslide is activated, the risk to people and material goods becomes evident,

➢represent the construction of remediation objects of different types, which will provide optimal results of the rehabilitation,

➢need to provide the required stability of the slope and exploitation safety of the objects for long period of time.

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## CONCLUSION

- The landslides as phenomenon is a complex process that arises due to the presence of a number of influencing factors in a particular area.
- The risk associated with landslides is increasing every year.
- Assessment of hazard and risk associated with landslides is the basis for planning the urbanization of certain areas.
- Only systematic studies of hazard and risk can be preventive measure in order to eliminate or significantly reduce the risk of landslides.
- The first step in analyzing the hazard and risk of landslides is research at the regional level, which should point to high risk zones.
- Hazard and risk analysis at the regional level, which clearly defines areas with a high risk for the landslide, allows to steer the research at the local level.
- In this way, considerable savings are made of the financial resources required for the execution of geotechnical works.

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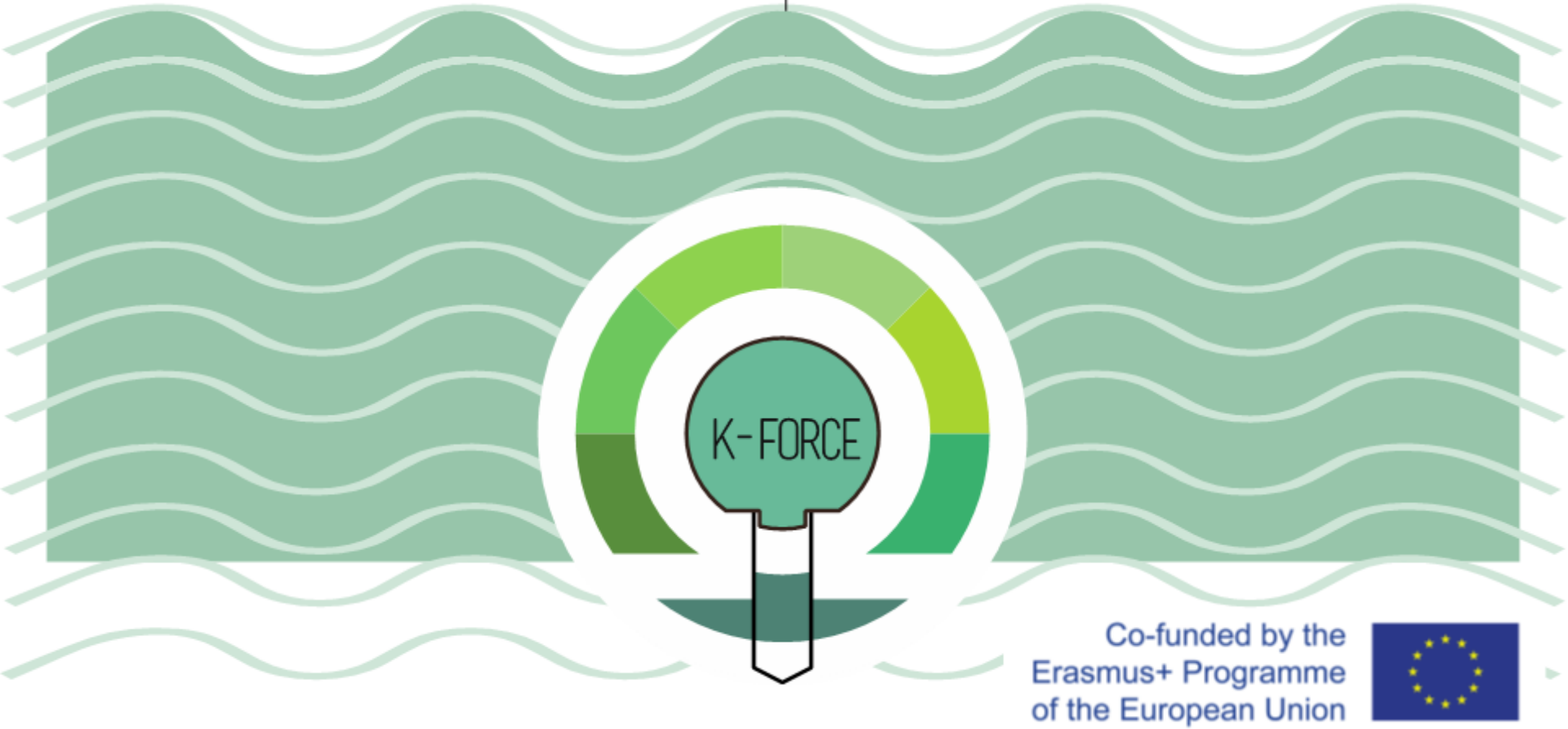


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# Thank you
# for your attention

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**Knowledge FOr Resilient soCiEty**

## QUESTIONS

1. How landslides effect people and urban development?
2. Which are the main causes of landslide formation?
3. What are basic steps in order to assess the hazard and risk of landslide occurrence for each new or existing urban area?
4. How do we assess hazard and risk in regional level?
5. What approach is most common in hazard and risk assessment in regional level?
6. How do we assess hazard and risk of landslides in local level?
7. Which method is the most accurate in landslide hazard and risk assessment?
8. Why is it important to first do the regional, then local hazard and risk assessment?

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