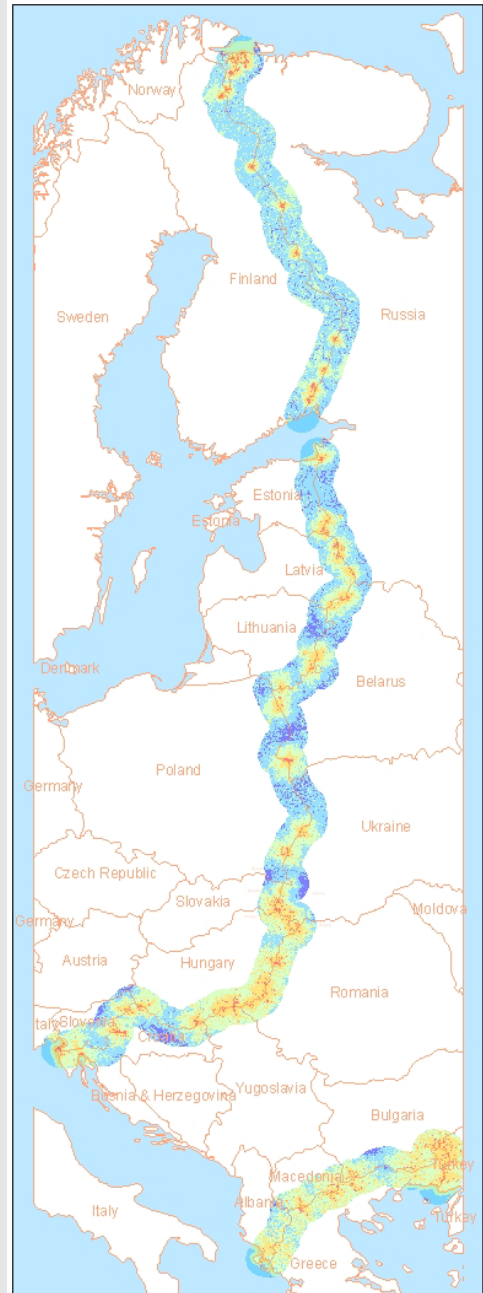




**SPATIAL
PERMEABILITY MODEL
AT THE EUROPEAN
UNION LAND BORDER**

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Abstract

In the frame of the ISFEREA action, the JRC IPSC carried out an analysis of the permeability of the EU Eastern land border to a specific class of illegal migration flows. This analysis is based on a preliminary version of a spatial quantitative model of the “green border”¹ permeability.

This model was built on the assumption that the flow of illegal migrants is function of the geographical permeability of the border and crossing points, the efficacy to control them by the Authorities, and also function of the driving force defined by people's willingness to cross (push and pull factors). The spatial model developed by the JRC attempts to represent in deep only the first part of this equation, while the modularity of the proposed model may allows further development for a more comprehensive explanation the illegal migration phenomena.

With the present release the model uses as input more than 20 spatial datasets ranging from satellite remotely-sensed data, land use land cover, digital terrain model, weather and environmental conditions, presence of population, infrastructures, and physical obstacles, and presence of border control points.

The model is focused on the geographic permeability related to a standard adult person having illegal behavior and deciding to cross the green border by foot. The basic criteria implemented in the current release are built around three concepts: the rapidity of walking allowed by the terrain and the weather conditions (walk), the possibility to hide by the physical environment (hide), and the probability to be stopped by a border police agent (secure).

The geographic permeability is conceptualized as function inverse of the friction surface calculated using fuzzy multi-criteria methodology with a spatial resolution of 1 kilometer. Friction statistics are related to specific spatial contexts around the border lines (from 1 to 50 km) aggregated at the national and sub-national level between different countries.

The model confirms the two major entry routes into Europe: the Ukrainian border and the Turkish section of the Greek border. The model shows also the high sensitivity of the potential corridor of Norway but the high number of border points at this boundary seems to be sufficient to protect this entry point.

The report concludes that, in spite of limitations linked to data collection and availability, the permeability maps which resulted from this study show the high potential of such a model for the analysis of potential and actual migration flows and related policy planning. This tool could provide an opportunity to test different “what-if” scenarios about the driving forces of illegal migratory flows at the external EU land border, to prioritize investments of Member States in border management infrastructures at EU level, and to develop policy advice for relevant internal and external EU policies. This modeling tool can help estimate the impact on permeability of concrete measures, such as changes in the number of border points or number of

¹ Term used to describe a state's land border between checkpoints. A water border (river or coastline) might also be referred to as a “blue border” (IOM, *Glossary on Migration*, 2004).

border guards and in their level of equipment at these particular points. The flexibility of the model also allows for the input of additional data like typology of border points, in order to improve the results. Finally, the development of a more comprehensive model would require the co-operation of and contribution from relevant authorities of the EU Member States as well as FRONTEX.

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I. Introduction

International migration and asylum-seeking are now at the top of the European Union's policy agenda, at national and European level. (Singleton 2006). The reports and resolutions discussed and adopted each year by the United Nations General Assembly reflect the growing political importance of migration interest. Today, one human being out of 35 is an international migrant. According to the UN's Population Division, the number of people who have settled down in a country other than their own is estimated at 175 million worldwide (approximately 3 % of the world population). It is more than twice the figure recorded in 1980. States, exercising their sovereign right to determine who enters and remains on their territory, have to fulfill their responsibility and obligation to protect the rights of migrants.

The enlargement of the EU to ten new Member States on May 1, 2004, raised concerns about border control among old Member States. New Member States are now acting as a "buffer zone" between the EU and its Eastern and Southern neighbours; they have taken over responsibility for controlling the border between the EU and the poorest and most unstable countries on the European continent (the former Soviet republics, Albania and the former Yugoslav republics) which have become important immigrant sending and transit countries and are increasingly used by smugglers and traffickers in human beings. Therefore, enlargement required new Member States to review their migration policies, notably with regard to the countries with which they now share external borders. They have made significant efforts to tighten their borders in order to fight illegal immigration, they are harmonising their entry conditions and visa policies with those of old Member States and are consolidating their asylum systems and introducing measures to combat the illegal employment of foreigners. Additionally, a large amount of EC funding and technical assistance is devoted to border management in new Member States, particularly through the PHARE and TACIS programmes. Funding is also directed towards projects such as fighting human trafficking and bringing the new Member States into the Schengen Information System.

As enlargement has taken place recently, it remains difficult to evaluate its impact on migratory flows. Regarding the free movement of new EU citizens, studies carried out in the years prior to enlargement showed no consensus on migratory projections. Some experts argued that old Member States would be overwhelmed by migrants attracted by higher wages. This argument was particularly strong in countries with borders neighbouring new Member States, such as Germany and Austria, and led to the proposal of a transition period on the movement of labour, giving old Member States the possibility to prevent workers from new Member States to settle and work on their territory for a period of between two and seven years following accession. However, movements of population are not easily predictable and estimates of the number of new EU citizens who will move as a result of enlargement vary to a large extent. Many analysts believe that the effect of enlargement on migratory trends within the EU will be similar to that of the addition of Greece in 1981 and Spain and Portugal in 1986. Those enlargements prompted only small-scale emigration from these countries, despite differences in per-capita income similar to those that exist today between old and new Member States. According to the European Commission,

“the most likely scenario is one in which labour mobility will be moderate to limited and will after a likely short upsurge just after the accession period - with some 250.000 persons per year - start declining again to fall below 100 000 persons per year before the end of the decade.”

The high relevancy of migration studies in this European context is the rationale of the JRC study carried out at the scale of the EU land border. This report refers to the technical part of this general study of migration at the EU land border (Magoni et al. 2006). The study has been built on two pillars: an analysis of existing migration data that has been completed by a questionnaire sent to the border authorities of new EU Member States and a preliminary version of a spatial quantitative model of the “green”² border permeability. This report details the technical specification of the model.

II. State of the Art – border permeability

Whatever the changes in the security paradigm (Florini 2000), scholars are continuously characterizing the security such as a geospatial issue with essentials dimensions as sovereignty, territory and border. Since the first writings of Mackinder Halford “geographical pivot of history” and Lord Curzon “frontiers”, geopolitical order, relative socio-economic or political power and territorial disputes have always been studied through a geographical angle by scholars in Political Geography, International Relations and New Geopolitics (Megoran 2004). Scientists have a responsibility in better defining, and measuring these highly politically sensible dimensions (Paasi 2003) especially in the light of new opportunities provided by measurement instruments like Earth Observation (EO). The fast increasing precision of these data but also the availability of EO processing tools including statistical software and geographical information systems offer new tools to the spatial study of geopolitical issues.

The concept of territory is ethymologically linked to the concept of “power” and to that of sovereignty of the authority (Paasi 2003). The territory can be defined as the portion of space occupied by individuals, social groups or institutions. The sovereignty is the international recognized authority of a government over the territory and people it claims to control (Wood and Milefsky, 2002). Boundaries have been understood as neutral lines that are located between power structures (Paasi 2003) or lines that enclose state territories (Newman 2003). In fact, border security has usually seen as an issue of power and military order but it can be constructed physically and socially as an identity issue (Ackleson 2003). The demarcation of boundaries is fundamental to the spatial identity of people and social groups by separating “us” from “others” (Berg and Saima, 2000), and by creating spatial exclusive entities (Dielh 1999). Moreover, the drawing of these lines is an ongoing social and dynamic construction of the territory (Falah and Newman 1995; Ackelson, 2003; D’Arcus, 2003; Paasi, 2003).

For Pace and Setter (2003), the boundary is the line separating two states and the border is the area surrounding a boundary. The term frontier points at an area where two states converge their interests and not necessarily agree on the territorial limits.

² Term used to describe a state’s land border between checkpoints. A water border (river or coastline) might also be referred to as a “blue border” (IOM, *Glossary on Migration*, 2004).

Borders not only separate but also mediate contacts between states and localities (Berg 2000). The Transborder collaboration or euroregions, in Europe for example, is new spatialisation of the border in a “borderland” (Scott, 2000). “Humankind continue to draw lines” (Falah and Newman, 1995; Berg, 2000) because borders help in the establishment of stable structures for human interaction and thus reduce uncertainty and increase “ontological security” (Schack, 2000). The huge amount of “border drawing” or “territory disputes” studies illustrate the scientific interest for better understand these concepts. But the challenge of these essential scientific understanding lies in the support to political decision makers and in the effort to politically manage the threats to the general security paradigm. Even largely studied in theory and social discourses, the essential geo-spatial concept have been too rarely quantitatively studied (Starr and Most, 1976).

Only a spatial quantitative simulation model allows a systemic representation of the geographical migratory driving forces to test the influence of single or groups of variables on the border flows. Simulation models emphasize the interactions among the components of the system and take into account the quantitative effects of each driving force (Lambin 1994). But a model is always a theory based on assumptions, it represents reality for some purpose (Spedding 1988). Building a model remains a choice between realism (mimic reality), precision (quantitatively correct) and generality (application to different places) (Levins, 1966).

The various simulations are aimed at testing the robustness of the model and the exploratory power of this tool. As the exact description of any real system is virtually impossible (Levins, 1966; Papageorgiou, 1982; Caswell, 1988; Wu et al., 1996), model simulations allow examination of the logical consistency of the model’s responses to simple stimuli (Dorward, 1996). A scenario analysis is a sensitivity test to “plausible variations” in external factors (Land and Schneider, 1987). After a relative test of the robustness, a model can be useful for investment prioritization, and simulation of the impacts of different political decisions. Based on clear assumptions, the objective of building a simulation model is to use this tool to generate “what-if” scenarios to explore hypotheses on the relative roles of driving forces. By performing scenario analysis with such a permeability model we can test some general statements about the understanding of the migratory flows at the EU land border and their environmental factors. Different borders can be compared and we can evaluate and predict the future changes.

“Permeability” is a term borrowed from the physical sciences where it has precise meaning and the process is measurable. The permeability is a magnetic or geological property that measure the ease with which a flux goes in the material. The permeability of a geological stratum is the result of the physical characteristics of the rock as a barrier and the frequency and volume of rainfall. By analogy, we can talk about the permeability across national boundaries. The boundary permeability is the product of the line characteristics (the outcome of legal, geographical, historical and social factors) and the pressures on this line from people, goods, capital, ideas, and so on. Permeability is however most often used as convenient shorthand for trans-boundary collaboration, borderland initiatives, and open-ness. (Blake, 2000). In this study, the border permeability is restricted to the flow of people across a border in a particular location. This flow is proportional to the geographical permeability of the crossing point, but also to the driving force defined by people's willingness to cross.

The spatial model represent the first part of this equation and will be used to test different assumptions on the driving forces of migratory flows.

In august 1999, the International Boudaries Research Units use the term “ permeable” in an international conference untitled Permeable Borders and Boundaries in a Globalising World: New Opportunities or Old Problems? During this event, Blake (2000) stated that Few world maps show boundary disputes. A good starting point may be to indicate broadly the permeability of international boundaries all of which lie somewhere on a spectrum from totally closed to totally open (Blake, 2000). Wood (2000) proposed to integrate cross-border flows to a GIS-linked set of data for emergency operations. . Starr and Thomas (2001) examine for the first time the particular effect of the border on the initiation of the conflict for 301 land borders of the international system. For these authors, the location of states, and spatial concepts as their proximity to others and the sharing of borders, are key variables in studies of international conflicts. In 2002, Starr and Thomas propose a quite new way of using GIS technology to disaggregate the measure of the border impact in the interstate behavior. They define three variables called (i) ease of interaction, (ii) salience and (iii) border vitalness to confront to the militarized disputes and enduring rivalries datasets. Spatial and localized information on the nature of the borders (and) are extracted from different vector and raster datasets. From the correlation of these datasets, they conclude that relations between state with permeable borders have shown a tendency toward interdependence / integration. Starr (2002) use these new concepts of opportunity and willingness to promote cooperation in international relations The use of GIS and maps allow to define more clearly the impact of the border, and not only the sharing of a border length. In fact, Starr (2002) transforms the absolute border length hypothesis of Wesley (1962) in a relative length in terms of population units.

The general purpose of this report is to describe the preliminary JRC model of the EU land border permeability. This model has been created to gain an understanding of the geographical patterns of migration at the European Union green border. After a clear understanding of all the assumptions of this modeling tool, it can be further used to test different “what-if” scenarios about the driving forces of illegal migratory flows or the impact of political decision at this border. Only the geographical component of the permeability is embedded in this preliminary version of the instrument.

III. Study area



Figure 1: political map of EU land border and the buffer zone used as the study area for a permeability model.

The total length of the EU25 eastern land border is over 6000 kilometers. It covers different geographical border situations (Figure 1). The 20 countries of this area are represented by 18 segments of sharing borders (two different neighbours)³. Three parts can be distinguished. The Greek border at the south, the new European countries in the middle and the Nordic countries of Finland and a little part of Norway. Thirty percent of this border is with the Russian Federation. Poland has an external border of 1,140 km with three different countries: Belarus, Ukraine and Russia. Hungary shares a border with four non-EU countries, namely: Ukraine, Romania, Serbia, and Croatia (more than 1,100 km in total). Slovakia has a relatively small external border with Ukraine (less than 100 km), the smallest segment of the overall border. The longest

³ For technical reasons, the external border of the EU (Lithuania and Poland) with the Russian enclave of Kaliningrad was not examined in this study.

one is the 1250km of the Finland border with the Russian Federation. Consequently, the permeability of the external land border, varies greatly from country to country (Table 1).

Table 1 : border sections of the EU land border

	EU-25 country	ENPI country	Length (km)	EU25 length (km)	(%)	Neighbouring length (km)	%		
1	Greece	Albania	256.03	1138.41	19%	256.03	4%		
2	Greece	The FYROM	251.67			251.67	4%		
3	Greece	Bulgaria	444.62			444.62	7%		
4	Greece	Turkey	186.10			186.10	3%		
5	Slovenia	Croatia	456.81	456.81	8%	745.93	12%		
6	Hungary	Croatia	289.12	963.76	16%				
7	Hungary	Serbia and Montenegro	166.50					166.50	3%
8	Hungary	Romania	387.36					387.36	6%
9	Hungary	Ukraine	120.78	94.33	2%	647.86	11%		
10	Slovakia	Ukraine	94.33	813.22	13%				
11	Poland	Ukraine	432.76			509.84	8%		
12	Poland	Belarus	380.47					509.84	8%
13	Lithuania	Belarus	509.84	509.84	8%	1031.82	17%		
14	Latvia	Belarus	141.51	369.20	6%				
15	Latvia	Russian Federation	227.69					285.32	5%
16	Estonia	Russian Federation	285.32	285.32	5%				
17	Finland	Russian Federation	1250.73	1250.73	21%	1937.61	32%		
18	Norway	Russian Federation	173.86	173.86	3%				
	Total eastern land border		6055.00	6055.00	100%	6055.00	100%		

In the present release, the model quantifies the border permeability in cells of 1x1 kilometers size, in a buffer zone of 50km on each side of the 6000 kilometers EU land border. It allows calculating permeability statistics related to specific spatial contexts around the border lines (from 1 to 50 km) aggregated at the national and sub-national level between different Countries.

IV. Available spatial quantitative data

In all model building processes, the first step consists in the assessment of quality, comprehensiveness and drawbacks of existing information sources. Evaluation of existing statistical dataset and satellite imagery have specifically been carried out in this JRC study of migration.

4.1. Migration data

Good quality statistics are important to inform public debate and to assist the development of policy. Since the Tampere Council meeting in 1999, the need for better statistics to support the development of European policy on migration and international protection has been clearly emphasised in official EU documents (Poulain and Singleton, 2006). The EU Council Conclusions in May 2001 stressed the need to improve statistics on migration and asylum. In 2003, the Commission presented a Communication to the Council and the European Parliament, which addressed the objectives outlined in the Council Conclusions in the form of an action plan for the collection and analysis of Community statistics in the field of migration.

Available information about migration flows of people in EU is mainly provided by open sources. Databases are maintained at a European, OECD and global level by Eurostat, the OECD and the Migration Policy Institute- a Washington DC think tank. The UNHCR's database is the reference source of information for refugees and asylum seekers but not for other types of migrant. Most of these sources provide information on numbers of migrants broken down by country of origin, age and sex as well as the number of asylum applications.

The main obstacles to compile and/or find reliable and comparable data on migration flows include: (i) Migration flows fluctuate rapidly, (ii) The ultimate aim of data sources on migration is generally not to count migrants (e.g. population registers), therefore, the data available is often inaccurate, (iii) It is impossible to determine precisely the number of illegal immigrants entering a country (iv) Countries have a different definition of the term "immigrant" (based on nationality, country of birth, duration of stay etc.) (v) All countries do not consider asylum seekers as immigrants. Thus, although many different potential data sources on migration and asylum are available, the counts of migrants needed for migration statistics cannot be readily extracted from these sources (Magoni et al., 2006). Furthermore, incomplete or missing data, errors or inconsistencies, the differences in data sources and migration definitions at national level can lead to problems of comparability when undertaking European level aggregations and analyses (Poulain and Singleton, 2006). Quality problems may also emerge, which include a lack of suitable documentation to assist correct use of the statistics.

Because of these shortcomings, existing data cannot provide a picture of the European border crossings. To overcome this, the JRC has been carried out a survey by means of a questionnaire sent to the border guards of some of the new Member States of Central and Eastern Europe: Estonia, Latvia, Lithuania, Poland, Slovakia, Hungary and Slovenia. Unfortunately, all the EU eastern border countries are not included in this survey, and the data are not homogenous. The answer rate is high (six above 7 of these countries). But the overall quality of the answers received varies greatly among the different countries. In some cases, they include statistical data and even detailed maps of the country when in other cases they not refer at all to quantitative figures. This study examines movements of persons at official border crossings and between border crossing points ("green border") and stresses the lack of data necessary in order to analyse current legal and illegal migration trends. This study illustrates the information that could be integrated in the spatial simulation model if homogenous provided by border authorities.

4.2. Remote sensing data

The potential use of satellite imagery to monitor environmental changes in border area has been quite largely studied (Rongas et al., 2006), A variety of applications in the fields of flood monitoring, forest fire detection, landslide and subsidence, surface deformation and land cover variations were shown in the last ten years using space optical and radar data. However, the real-time utilization of space borne remote sensing for emergency situations is still a difficult task because of the lack of a dedicated system (constellation) providing a day-to-day revisit of hazardous areas (Sarti et al., 2001). In the context of the flow of people across national borders, no remote sensing indicators were identified to be appropriate for the generalised near-

real time monitoring of all borders around the world, these consisting of heterogeneous land cover types (Stephene et al., forthcoming). Satellite remote sensing has two fundamental drawbacks for direct operational land border monitoring : (i) the repeat frequency and (ii) the highest resolution satellites have very narrow swaths. First, the use of satellites images is limited by the time required to repeat the observation on the same location (repeat frequency). A few examples of borders in desert areas in the Middle East were scrutinized using satellite images at medium resolution (SPOT: 10 m, ASTER: 15 m). The revisit time, that ranging from 12 hours to several days, is not frequent enough for operational use in near real-time border monitoring to detect marks or traces left by possible intruders. For those sensors whose revisit time may be within an acceptable time frame such as for example, the very high-resolution satellite IKONOS (1.5 days), the delivery of the requested image is 60 days. Secondly, the use of very high resolution (sub-meter) satellite sensors (IKONOS, QuickBird, EROS, etc.), although allowing the detection and in some cases the recognition of vehicles and people, is not deemed to be suitable to monitor borders extending along large distances due to their limited swath (around 10 km) and the high cost of these images.

However, it may be possible to use these tools in a restricted manner, controlling specific places where border crossings are known to occur on a regular basis. Using relatively coarse 15-metre resolution ASTER imagery, the Centro di Ricerca Progetto San Marco (CRPSM) demonstrated changes in trails crossing the Iraq-Saudi Arabia border over a 2 year interval (2001 to 2003). Satellite imagery can be used to assess long to medium term-changes on some specific location by providing indicators for traffic. If satellite imagery can not be used directly in the permeability model, these data can be indirectly integrated in the analysis of the flow of people at the borders.

4.3. Geo-spatial data sources

If data provided by satellite imagery can not be used directly, these data can nevertheless be indirectly integrated in the analysis of the flow of people at the borders, through their integration into a geospatial conceptual model of border permeability. The EU land border permeability model is based on a modular geospatial data integration. The modularity means that we can easily add new assumptions or new datasets in a following version. The current version of the EU land border permeability model include mainly open-source geospatial datasets. Because of the regional scale of this European study, the chosen resolution corresponds to the global grid system used to report on elevation (Verdin and Greenlee, 1996), land cover (Bartholome and Belward., 2005), population density (Tobler et al. 1995, Dobson et al. 2000). The 30-arc seconds grid cell is typically used to conduct analysis on global variables.

The Geographical Information System technology is used to integrate and combine different types of data into a common system. The GIS dataset can either be raster or vector data (line, point or polygons). Raster data are represented by a grid and each location is represented by a grid cell, which has a value. Cells form various layers put on top of each other, describing many attributes of each location. With the present release the model uses as input more than 20 spatial data layers ranging from satellite remotely-sensed data, land use-land cover, digital terrain model, weather and

environmental conditions, presence of population, infrastructures, and physical obstacles, and presence of controlling border police (Figure 2).

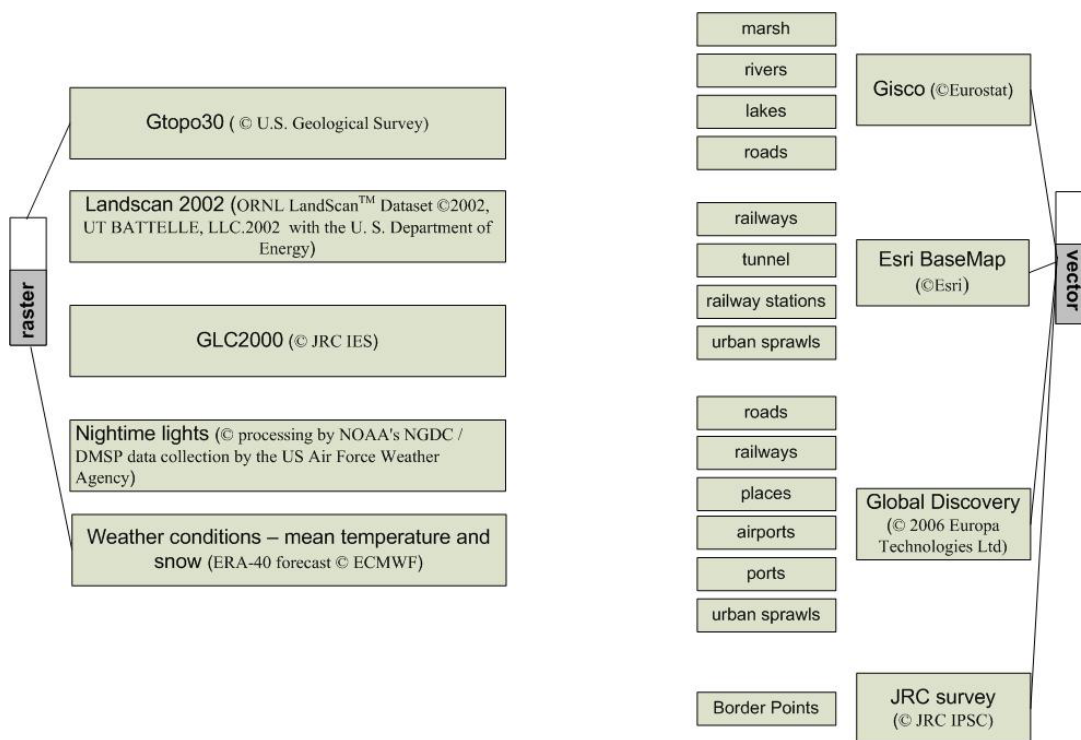


Figure 2: spatial quantitative data sources.

GTOPO30 (Verdin and Greenlee 1996) is a global elevation model (DEM) resulting from a collaborative effort led by the staff at the US Geological Survey's EROS Data Center (EDC) in Sioux Falls, South Dakota. Elevations regularly spaced at 30-arc seconds (approximately 1 km) have been made available in 1996. GTOPO30 is based on data derived from 8 sources of elevation information including vector and raster dataset (Digital Terrain Elevation Data, Digital Chart of the World, USGS 1-degree. The Shuttle Radar Topography Mission (SRTM) delivered a digital terrain model of better spatial resolution and accuracy than traditional free global DEM datasets (van Zyl, 2001). This dataset was obtained from a radar system that flew onboard the Space Shuttle Endeavour during in 2000 is available at a resolution of 1 arc second (<http://www2.jpl.nasa.gov/srtm>, Jet Propulsion Laboratory, NASA/USGS EROS Data Center). Unfortunately this dataset is not available north than 60° of latitude and presents void cells (Dowding et al., 2004). For these technical reasons, the border model integrates the GTOPO30 terrain model that has been largely used and tested in different applications (Gesh and Larson, 1996)(Figure 3a).

Three population densities datasets exist at a global scale (Sutton et al., 2003). The Nighttime satellite imagery as proxy for ambient population density (Sutton, 1998); the Gridded Population of the World (GPW) (Deichmann 1996) and the Landscan global population database (Dobson et al., 2000; Bhaduri et al., 2002). The first provides population density for urban areas only while the latter two for all land masses. GPW was first developed at UCSB/NCGIA on the basis of a large collection of administrative boundaries and relative population counts (Tobler et al., 1995). It was the first global population density dataset and was produced for reference year

1994. GPW-1 has resolution of 5arc-seconds that approximate 5km at the equator. Landscan global population database was developed by Oak Ridge National Laboratory by allocating census counts at 30"x30" cells through a "smart" interpolation based on the relative likelihood of population occurrence (Dobson et al., 2000). Allocation to cell are based on weighting computed from slope categories, from distance from major roads, from land cover, weighted by type with exclusions for certain types, and Nighttime lights of the World, weighted by frequency. Its continuous improvement and the resolution of this dataset are the reasons of the choice of this dataset in the model.

The Global Land Cover for the Year 2000 – GLC2000 - project was carried out to provide information to the International Conventions on Climate Change, the Convention to Combat Desertification and the Kyoto Protocol (Fritz et al., 2003). This dataset has been chosen as a core dataset for the Millenium Ecosystem Assessment to define the boundaries of the different ecosystems such as forest, grassland and cultivated systems. Based on Spot-4 vegetation – VEGA2000- imagery made available By Centre National d'Etudes Spatiales (CNES) and on the comprehensive and standardized Land Cover Classification System – LCCS- provided by FAO (Di Gregorio and Jansen, 2000), more than 30 research teams guarantee the consistency called “agreement scoring” of the resulting dataset. The four 1x1 km spatial resolution global land cover datasets: (i) 1992/1993 IGBP DisCover, (ii) UMD Land Cover, (iii) 2000/2001 GLC-2000 and (iv) Modis land cover vary substantially (Giri et al. 2005). The GLC2000 project adopted a bottom-up approach using the expertise of existing regional classifications that explains the choice of this dataset in our analysis (Figure 3b).

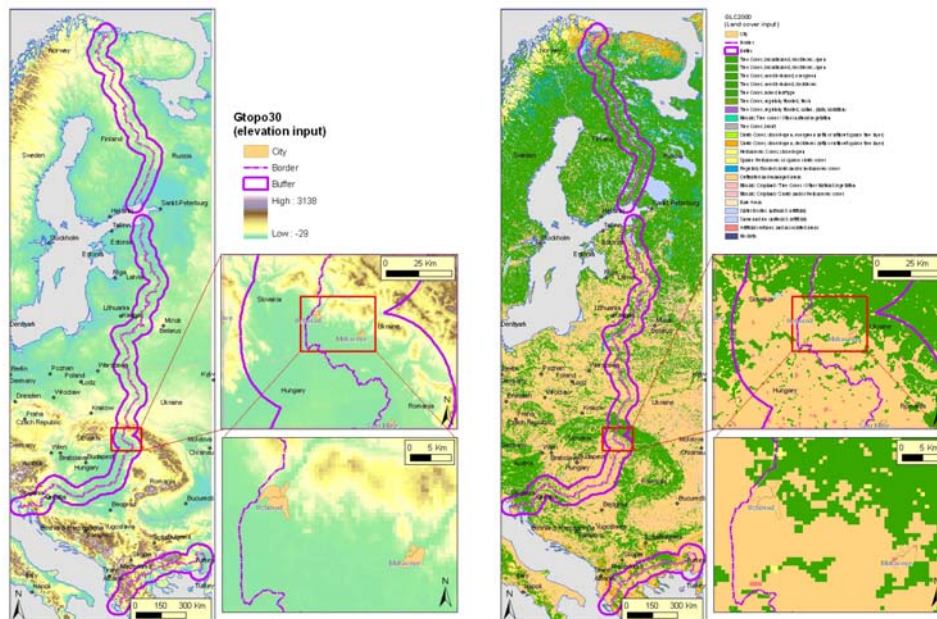


Figure 3 a and b: elevation datasets (Gtopo30 © USGS) (a) and 1x1 km land cover (GLC2000 © JRC IES) (b).

The Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has a unique low-light imaging capability developed for the detection of clouds using moonlight. The OLS also detect lights from human settlements, fires, gas flares

and fishing boats that are not equally distributed across the land surface (Elvidge et al. 2001). A digital-archive for the DMSP-OLS night-time coverage data was established in mid-1992 at the NOAA National Geophysical Center. These data are available at the finest resolution of 0.5x0.5km. The global maps of these different type of lights have been produced in 1992/1993 and 2000. The permeability model integrates the intermediate unfiltered average visible DN of cloud free lights product before the extraction of a 10% frequency threshold.

The objectives of the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-40 project are to produce and promote use of a comprehensive set of global analyses describing the state of the atmosphere, land and ocean-wave conditions from mid-1957 to August 2002 (Simmons and Gibson, 2000). The ERA-40 project applies a modern Variational Data Assimilation technique (used in daily operational numerical forecasting at ECMWF) to the past conventional and satellite observations (mainly NOAA and ERS). A number of partner organisations are also involved to assess the quality of the global analyses. The model uses annual averages of the monthly snow and mean temperatures values provided by this project for the last 30 years (1974-2003) at a resolution of 0.5 degree.

GISCO is the Geographic Information System for the European Commission (http://eusoiils.jrc.it/gisco_dbm/dbm). Originally conceived as a prototype GIS cell that would serve a wide spectrum of users and uses, the GISCO project has developed a service-oriented dimension, namely in geographical database development, thematic mapping, desktop mapping and dissemination of data (Joint Gisco User and technical committee, 2006). Within the framework of GISCO, a large geo-referenced consistent European dataset has been developed and is regularly updated by Eurostat, the European statistical office of the European Commission. This dataset includes topographical data on: hydrography (water patterns, lakes) , altimetry (digital elevation model) , infrastructure data (ports, airports, roads, rail networks) administrative entities (countries, regions) and thematic data on: land resources (land cover, soil data, vegetation, climatic conditions, ...), Community support frameworks (structural funds, INTERREG) , environmental data (coastal erosion, soil erosion, ...) , industrial themes (energy transport networks, location of nuclear power stations, ...) From this dataset, we use the hydrographical data (vector layers of water patterns and lakes).

The Esri World Basemap Data includes data layers from a variety of ESRI products (<http://www.esri.com/>), including ArcAtlas, ArcWorld, Digital Chart of the World, and Data and Maps. ESRI assembled selected data layers from these sources into a Spatial Database Engine (SDE) database to provide a continuous display of basemap data from a small-scale global display to a medium-scale regional display. The World Basemap Data includes Country Boundaries, Coastlines, Administrative Boundaries, Water Bodies, Perennial Rivers, Intermittent Rivers, Populated Places, Major Roads, Major Trails, Capital Cities, Major Cities, Cities, and Airports.

Global Discovery (<http://www.europa-tech.com/gd.htm>) provides vector reference mapping at 1:1,000,000 scale for the entire world. Coverage is provided by a manageable set of layers including places (over 712,000 locations including accented characters and alternative names), up-to-date political maps at two scales (1:1M and 1:3M), coastlines, international borders, some first level administrative borders, time

zones, roads, railways, drainage features (rivers and lakes), airports (including IATA code) and ports (including UN/LOCODE).

V. A spatial multi-criteria model of permeability

A spatial decision support model is an abstraction in 2 dimensions of the reality. It allows the decision maker to study spatial alternatives representations. The reality represented in this permeability model is the suitability of the border to be crossed by a illegal migrant. The EU multi criteria land border crossing model integrates earth observation and geo-spatial technologies with formal decision theory to assess the suitability of the border, or part of it, to be crossed by illegal migrants, based on a presumed cost/opportunity behavioural strategy. The spatial multi-criteria analysis results depend not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process.

Decision support systems (DSS) were first developed in management science in the late 1970s to provide a framework for integrating database management systems, analytical models and graphics in order to improve decision-making processes (Longley et al., 1999). Rather than producing solutions to problems, decision support provides data and predictions in a way that 'informs' what is. The DSS has been extended to the spatial context in the development of Spatial decision support systems (SDSS). The Geographical Information Systems (GIS) technology is used to combine the digital sources and perform geospatial analysis to integrate the different sources in a common analytical system. Analytical analysis are using the GIS processing in association with optimization methods of weighting (Geurs and vanWee, 2004) the different criteria (Multi-criteria decision analysis). On the contrary of the simple binary techniques (good or bad), the weighted suitability models classify the layers on a relative scale and multiply each layer by its relative importance. While decision support is an important functions of a GIS, tools designed especially for his are relatively few in most GIS software. Idrisi includes several modules that help in the construction of the multi-criteria analysis (Eastman 1993).

The multi-criteria approach is highly modular. Quite simple but also strong assumptions have been fixed at the beginning of this development process to test the permeability modeling approach. The current version of the border permeability model open a frame that can be extended covering for example other typologies of illegal crossing. Note that usually, the choice of assumption is also based on the data availability.

5.1. Basic assumptions of the Border Permeability (BP) model

5.1.1. Friction / permeability Surface

The spatial simulation tool is developed in order to make scenarios about the EU land border permeability (BP) based on the indirect use of satellite imagery in a cost function calculated on a geographical surface. The cost function defines a friction surface along the EU land border. The permeability P is assumed to be the inverse function of the friction F.

$$P(x) = 1 / F(x)$$

5.1.2. Geographical suitability for an illegal migrant walking across the border line

The first step in describing and solving any problem, such identifying the most permeable segments of the border is to structure some rules that will allow a decision about which areas are most susceptible to be crossed or not by an illegal migrant. This process is similar to the suitability and accessibility models with a definition of “easiness with which the land border area is crossed by the illegal migrant”.

The general hypothesis of border crossing assumes that the flow of people across a border in a particular location is function of the geographical permeability of the border and crossing points at that location, the efficacy to control them by the Authorities, and also function of the driving force defined by people's willingness to cross (push and pull factors). The spatial model developed by the JRC formalizes only the first part of this equation so the friction F at the place x is function of a composition of geographical factors G :

$$F(x) = f(G)$$

5.1.3. Green border and resolution

The present release of the EU border permeability model quantifies the friction in cells of 1x1 kilometers size along the 6000 Kilometers of the “green” border.

- (i) The 30x30 arc seconds grid cell is chosen because of the availability of open-source spatial datasets and the general use of this scale to conduct analysis on global variables.
- (ii) The “green border” term is used to describe a state’s land border between BCP’s checkpoints (IOM, 2004). The analysis is thus focusing on the green part of the line.

5.1.4. Typology of illegal crossing

Not all kinds of border crossing are formalized in the model. In its current version, the model is focused on the friction related to

- (i) a standard adult person
- (ii) having illegal behavior
- (iii) and deciding to cross the land border by walking

The border area covered by this surface analysis is based on the average capacity of an adult person walking across the boundary. Generally talking in the European landscape, the average walking distance to be covered by an average adult is around 6km per hour. The 5-6 km area around the border line correspond then to a “last hour” trip before crossing the border, walking at an average speed.

As the model is talking about the green border, the most used way to cross is by foot. Other typologies of border crossing are more related to the analysis of the permeability at the border crossing points (by car, by bus, train, trucks ...) that is not developed in this model.

5.1.5. Multi-Criteria Evaluation pre-processing steps

Decision rules typically involve a process for the *combination of one or more criteria* (factors and constraints) into a *composite index* (Eastman et al. 1993). A criterion is some basis for a decision that can be measured and evaluated. A factor is a criterion

that enhances or detracts from the suitability of a specific alternative. To be combined the different criteria must be homogenous and then pre-processed as followed:

- (i) GIS must have an *unambiguous and common spatial reference* of the stored information.

The spatial reference is given by coordinates or by geographic identifiers and the resolution. Coordinates are unambiguous when the reference system to which those coordinates are related has been fully described. The European Terrestrial Reference System ETRS89 has been accepted by the National Mapping Agencies (NMAs) and the scientific community as the most appropriate European geodetic datum for continental spatial referring tasks (Ihde et al., 2000). The INSPIRE guidance documentation propose to use the ETRS89 as geodetic datum and to express and store, where allowed by accuracy limits, positions in ellipsoidal co-ordinates, with the underlying GRS80 ellipsoid, and to use the Lambert Azimuthal Equal Area coordinate reference system for pan-european statistical analysis and display. The choice of the model resolution is deducted by the data availability as main of the global dataset are provided at 30x30 arc seconds (approximately 1x1km). In the present release, the model quantifies border friction in cells of 1x1km, along 6000 km of border between Norway in the North and Greece in the South. All the dataset are projected and standardized at this resolution (Figure 4).

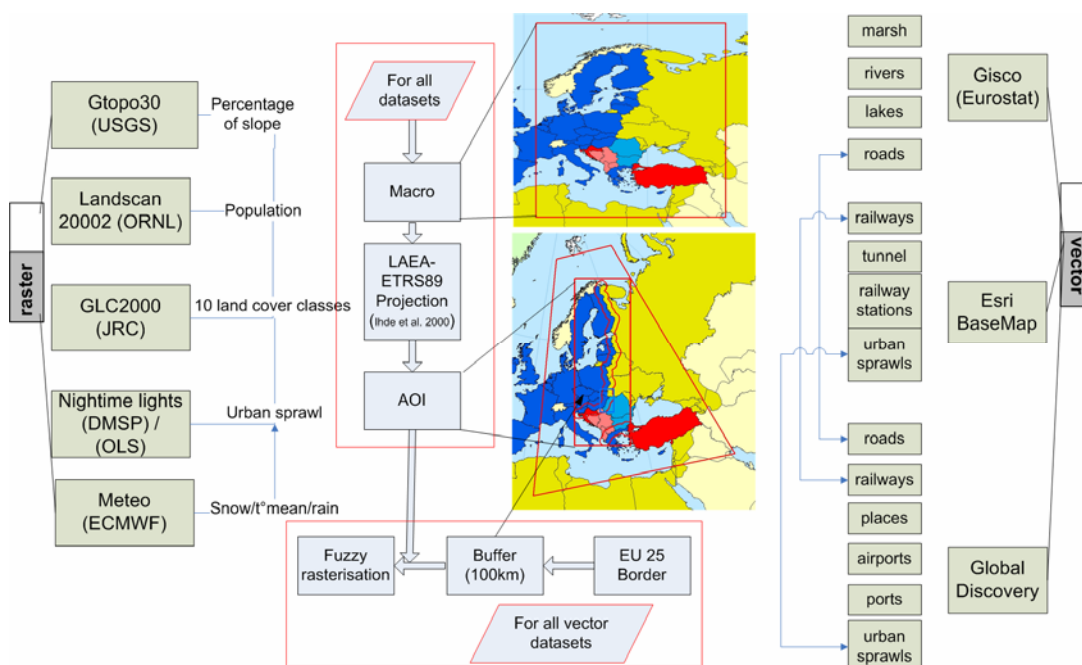


Figure 4: dataset standardization in the EU25 Border Permeability model.

- (ii) GIS must have an continuous raster format.

In order to combine the different layers in the same multi-criteria model, all factors has to be measured on a continuous scale. In GIS, there are two digital map representation techniques : vector and raster. With vector representation, the boundaries or the course of the feature are defined by a series of point that, when joined with straight lines, form the graphic representation of that feature. The points themselves are encoded with a pair of numbers giving the X and Y coordinates in the latitude/longitude system. The attributes of the features are stored in a database link to

the spatial file by a simple identifier. With the raster dataset the graphic representation of features and the attributes they possess are merged into unified dataset, a mesh of grid cells in which we record the condition or attribute of the earth's surface at that point. In a uniform model, the vector datasets have to be transformed in the *raster format* (rasterisation) based on the cell resolution defined (Figure 4). Because of the large size of the vector layers, the information introduced in the GIS consider only a buffer zone of 100km, including the 50km buffer size chosen to produce the results, on each side of the border line.

For the transformation in raster, the values per cell of the different infrastructures vector layers : roads, railways, rivers, tunnels (Figure 5a) are calculated by the density of these linear features in the neighborhood of each output cell . The density is calculated per unit of area using a circle around each raster cell (1km²). The circle is the most isotropic shape, so not introducing spatial “noise” or arbitrary spatial assumptions in the model, to define the area around a point and by extension around a line.

$$\text{Density} = (L1 + L2) / (\text{area of circle})$$

where Lines L1 and L2 represent the length of the portion of each line that falls within the circle.

For the dataset represented by the points (places), the same calculation of density of point feature within the neighborhood refers to the distance in which these place affect the spatial unit of 1km² (Figure 5b). The same type of neighbouring calculation of statistics is used to represent the influence of the polygons (lakes, marsh, urban sprawls) in the surrounding circle area.

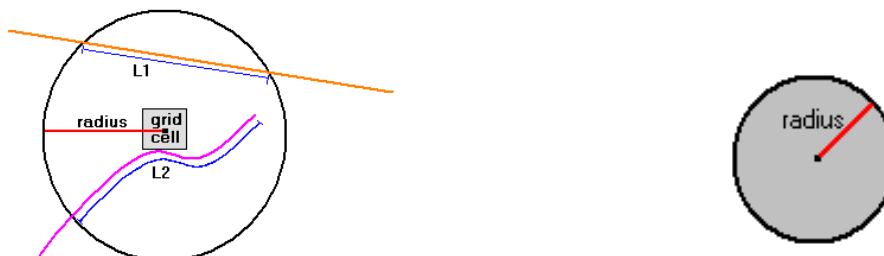


Figure 5 a and b: density calculation of lines (a) and point (b) using the neighborhood values.

(iii) GIS must have an uniform range of values

After this spatial continuous transformation of the different layers; the continuous range of values of each layer has to be transformed in compatible units to be associated in the multi-criteria evaluation (MCE) model. The raster datasets of our model are either reclassified in the range of uniform values or transformed by a *fuzzy function*. For the second transformation, each pixel is affected to a fuzzy membership function like the Sigmoidal, or the linear functions (Eastman et al. 1993) . These function are controlled by four points ordered from low to high on the measurement scale (Figure 6). The first point marks the location where the membership function begins to rise above 0. The second point indicates where it reaches 1. The third point indicates the location where the membership grade begins to drop again below 1, while the fourth point marks where it returns to 0. Points may be duplicated to create monotonic or symmetric functions. The output are scaled from 0-255.

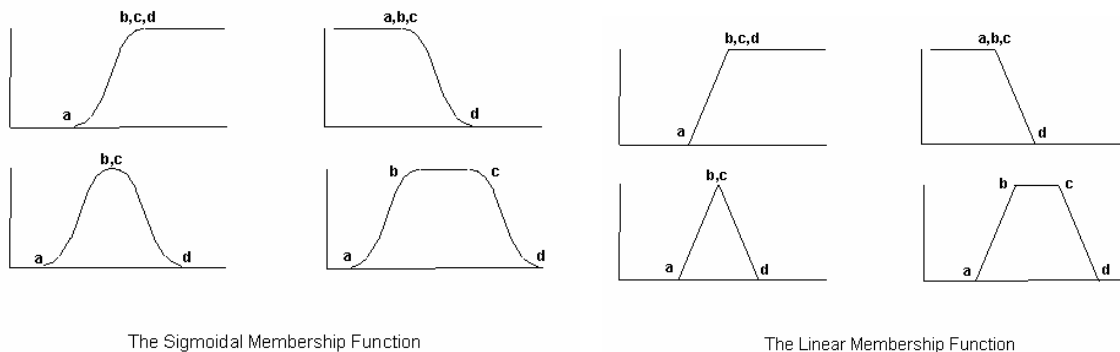


Figure 6 a and b: sigmoid (a) and linear (b) fuzzy functions for the transformation in uniform units

5.1.6. Clustering of criteria

In this study, the high numbers of criteria has driven the necessary clustering of these criteria in order to increase the understanding of the model development. Three clusters has been treated separately in the definition, standardization and evaluation phases of the Multi-criteria evaluation (MCE) procedure and will be described separately below. These three basic criteria are built around three concepts:

- (i) the walking speed allowed by the terrain and the weather conditions (walk),
- (ii) the possibility to hide by the physical environment (hide),
- (iii) the probability to be stopped by a border police agent posted at the border control points (secure).

The overall friction combines these three basic criteria to represent the difficulties encountered by the illegal migrant to illegally cross the border on foot. These three geographical characteristics are measured continuously from GIS layers. The overall friction is created by a multicriteria analysis using a 50km buffer zone as constraint (Figure 7). The Boolean overlay and the weighted linear combination (WLC) strategies are respectively chosen at different stages of the modeling exercise. The previous strategy combines the datasets by means of one or more logical operator such as intersection (AND) and union (OR). The WLC combination is in between these two choices, by means of a weighted average that induce a trade-off of the different values. In our WLC procedures, the simplest choice, of equal weights for each criterion, is used as a pilot test in order to increase the understanding of the basic rules of the model, but other combinations defined by a pair wise comparison matrix can be used to build spatial analysis scenarios.

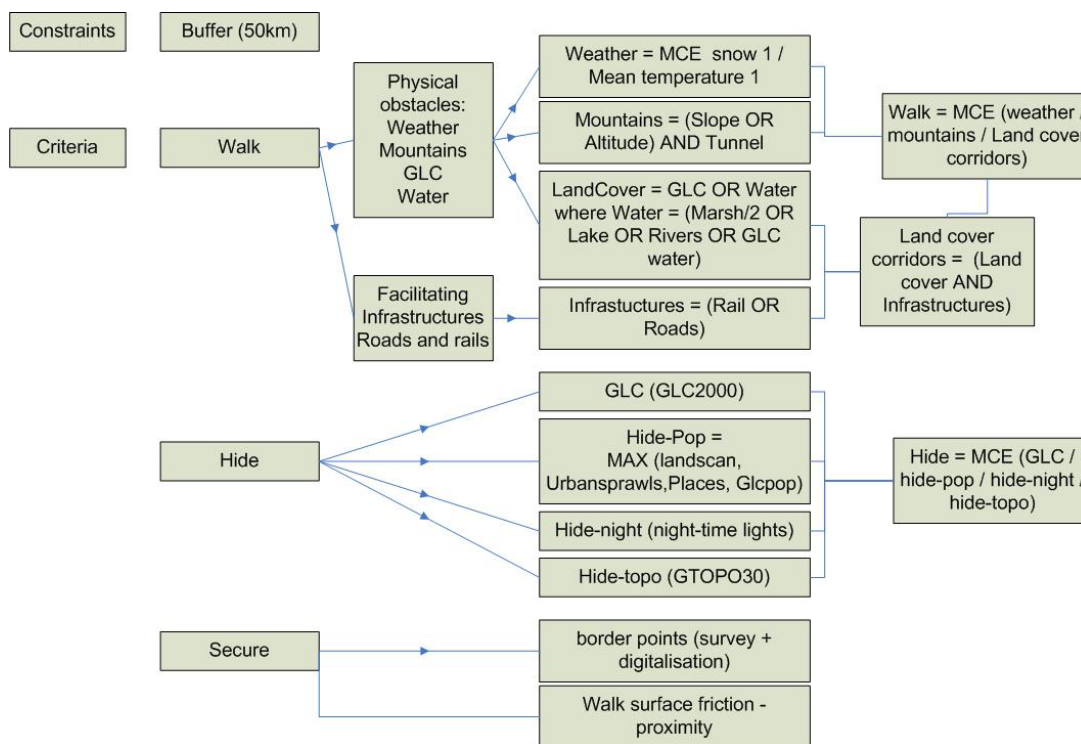


Figure 7: the three clusters criteria in the Multi-Criteria Evaluation (MCE) of the border friction.

5.2. The “walk” cluster

The “walk” basic criteria takes into account the ease of crossing the border area by foot, which is greater on a plain (slope, altitude), in open spaces (land cover) or on roads than on a mountain or in a forest. Rivers, lakes or snow are considered as obstacles. The weather conditions are also taken into account.

The geographical and climatic features that affect the walk criteria (Figure 7) I:

- (i) “weather”, the climatic conditions (snow and temperature),
- (ii) “mountain”, the slope and altitude effects in the mountainous areas acting as a barrier to the progression but counteracted by the effect of the tunnels,
- (iii) “land cover”, the particular accessibility of different land cover types with a particular attention to the additive obstacle of the different water bodies (with a less important effect of the marsh in comparison with the lakes and the rivers),
- (iv) “infrastructure”, the accessibility corridors (roads and railways), where the rail path are seen as corridor that can be used by foot in a less easy way than the roads.

5.2.1. The “weather”

Two datasets provided by the ERA-40 project of the European Centre for Medium-Range Weather Forecasts (ECMWF) provide the average climatic conditions in EU. The snow depth and the mean temperature provided by this project for each month at a resolution of half a degree are firstly projected, aggregated temporally, then

processed spatially to fit to the resolution and extent decided for the model, transformed in a compatible format, and fuzzy scaled :

- (i) all monthly raster dataset are projected in the Lambert Azimuthal Equal Area coordinate reference system “ETRS-1989-LAEA” with a resolution of 50km.
- (ii) a pixel by pixel annual average is calculated for both climatic parameters (snow and mean temperature). Through this temporal aggregation, we evaluate the average obstacles created by extreme weather conditions on the walking suitability, knowing that thickness of snow and mean temperature change throughout the year. The seasonality of the weather impact is not modeled in the current static version of the model.
- (iii) this temporal mean is spatially disaggregated with the nearest neighbor interpolation algorithm to a resolution of 1x1km
- (iv) the two resulting dataset are then cut to the Area Of Interest (AOI) extent and smoothed by the values of the neighboring cells thanks to a local mean calculation of statistics in a circle of 25 cells around each pixel.
- (v) the two spatially standardized dataset are then transformed in a compatible format to be introduced in the MCE calculation.
- (vi) the last standardization is the scaling of the values using fuzzy membership functions. These climatic values are scaled using linear functions that reproduce the variations of the existing dataset. The control points are the minimum and maximum values of the dataset: $a=0$ and $b=10\text{cm}$ for the annual average snow depth (in meters) and $a=-1.6$ and $b=18$ for the annual mean temperature (in °).

These two datasets are finally combined in a MCE with a WLC using equal weights of 1 to represent the annual weather conditions in Europe (Figure 8a).

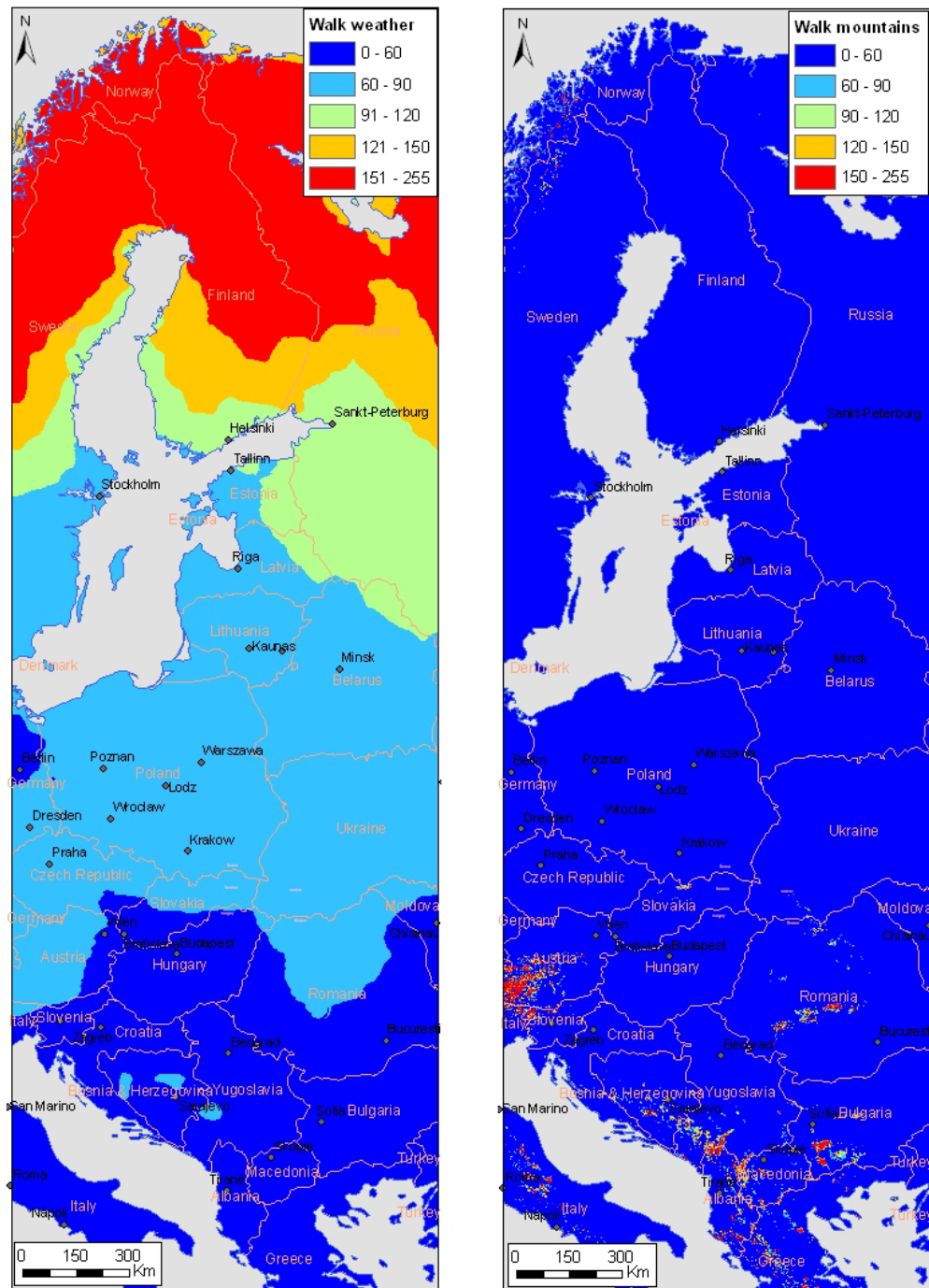


Figure 8 a,b: the two first clusters in the "walk" criteria : weather (a) and mountains (b).

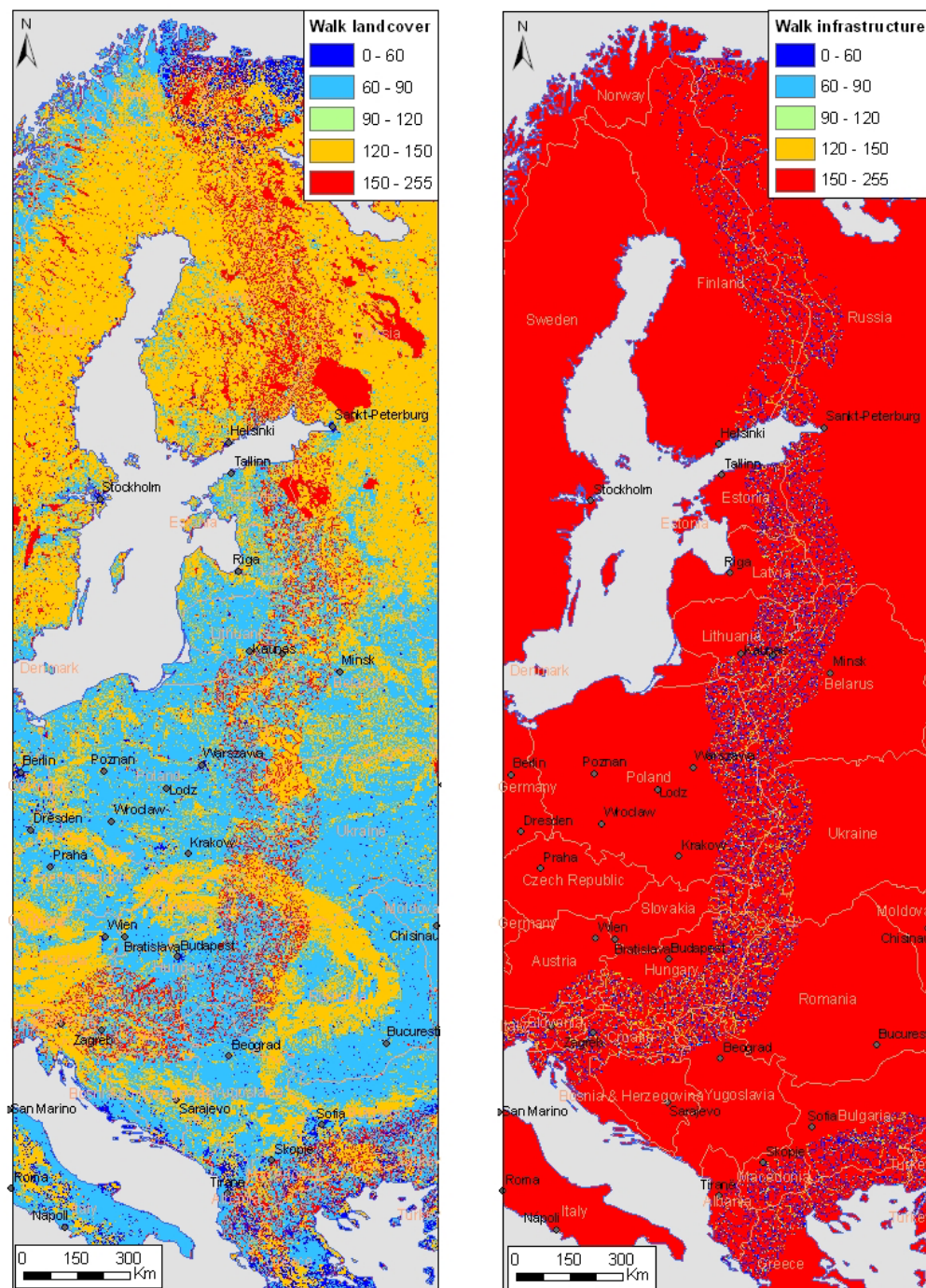


Figure 9 a,b : the two other clusters in the “walk” criteria :land cover (a) and infrastructures (b).

5.2.2. The mountain

The two geographical information layers produced to define the mountainous conditions in EU are both based on the global topographical information of GTOPO30. GTOPO30 is first projected in the LAEA system, extracted at the AOI extent and then needs a particular filling preprocessing because it presents some undefined values. This filling procedure is carried out in three steps: (i) the definition

of void cell (by a spatial mathematical tools detecting the null values) and (ii) the creation of the replacing dataset, (by a neighbouring statistics calculation applied to each pixel), (iii) the filling of the void cells with the values of the second dataset. This filled dataset defines the altitude for each cell of 1km².

The slope information is extracted from this dataset following the average maximum technique with a the 3 x 3 neighborhood moving window. The slope is defined in percentage rather than degree (Figure 10) and vary from 0 to 69% in the Alps environment.

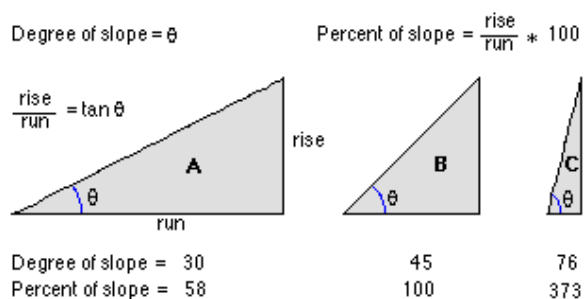


Figure 10: slope expressions in degree or percentage.

These two datasets are then transformed in a compatible format, and fuzzy scaled (see 5.1.5). The minimum and maximum control points of the increasing sigmoid function for the altitude layer are 1000 m and 2500 m. The same type of fuzzy function is chosen for the slope dataset with control points of 20% and 40%. These points signify that below and above these points the effect of the slope and altitude are either stretched to zero or to 255 with an increasing function in between. These points are chosen based on the ease of walking on the mountain for a standard adult person : zero when this parameter doesn't bother the progression (below 1000m of altitude and 20% of slope) and 1 when this parameter is becoming to be a complete barrier to the progression (2500m and 40%). Walking in the mountain becomes more and more difficult from 20% of slope and is seen as impossible after 40%.

This mountainous barrier effect is counterbalanced by the presence of tunnel in these mountains. Then the existence of roads or railways tunnels registered in the Esri base map database is processed in order to be combine to these mountainous information. As this layer is a vector dataset, the standardization steps includes the projection, the extraction of the AOI extent but also the density calculation (see 5.1.5). Resulting from this neighboring spatial analysis, the density of tunnel per 1km² varies from 0 to 0.65meters. The linear decreasing fuzzy function scales these values from 0 to 255 using the 0 and 0.1 control points.

Finally, a two-steps MCE combination of these three layers is carried out to produce the mountain criteria (Figure 8b):

- (i) the MCE of both topographical dataset with equal weights
- (ii) the minimum OVERLAY (AND) of the previous layer and the tunnel one

5.2.3. The land cover

The land cover classification provided by the GLC2000 (see 4.3) is modified by adding three kind of water obstacles to define the land cover suitability of the walk criteria.

After the projection in the LAEA system and the extraction at the AOI extent, the 21 classes of the GLC2000 dataset are redefined in levels of suitability to walk / accessibility (Table 2). These suitability levels are scaled to the uniform 0-255 range of values (Figure 9a).

Table 2 : reclassification of the GLC2000 land cover legend based on the suitability to walk and the number of cells in each category within the AOI

GLC 2000 classes	Number of cells in the AOI	Intermediate groups of classes	Accessibility level	
1	Tree Cover, broadleaved, deciduous, closed	343942	1	0.5
3	Tree Cover, broadleaved, deciduous, open	22589	1	0.5
4	Tree Cover, needle-leaved, evergreen	811797	1	0.5
5	Tree Cover, needle-leaved, deciduous	201	1	0.5
6	Tree Cover, mixed leaf type	427514	1	0.5
7	Tree Cover, regularly flooded, fresh	259	2	0.5
8	Tree Cover, regularly flooded, saline, (daily variation)	0	2	0.5
9	Mosaic: Tree cover / Other natural vegetation	21799	1	0.5
10	Tree Cover, burnt	554	3	0.3
11	Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	3495	4	0
12	Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	118442	4	0
13	Herbaceous Cover, closed-open	97969	5	0.3
14	Sparse Herbaceous or sparse shrub cover	55477	5	0.3
15	Regularly flooded shrub and/or herbaceous cover	85649	2	0.5
16	Cultivated and managed areas	1163370	6	0.3
17	Mosaic: Cropland / Tree Cover / Other Natural Vegetation	112548	6	0.3
18	Mosaic: Cropland / Shrub and/or Herbaceous cover	32757	6	0.3
19	Bare Areas	22474	7	0.3
20	Water Bodies (natural & artificial)	1070003	8	1
21	Snow and Ice (natural & artificial)	1033	9	1
22	Artificial surfaces and associated areas	27008	10	0
23	No data	80	11	no data

The water bodies are really important obstacles to the progression of the illegal migrants and the raster classification – for which one cell belongs to one LC class- can be improved on this subject based on the real digitalization of existing water bodies -from which we can calculate the density of water bodies for each 1km²-. All three vector datasets (Global Discovery, Esri world Base map, Gisco) provide water bodies vector layers, the lakes (polygons) and the rivers (lines). Note that the two first datasets have a world coverage while the GISCO dataset has an European coverage. The comparison of these dataset with existing digital Russian topographic maps available at 200k allow us to qualitatively assess the completeness and reliability of the features digitalized in these dataset (Figure 11). The Gisco (see 4.3) dataset

provides clearly the most exhaustive information at the European scale. Three vector layers (lakes, rivers and marshes) derived from this database are extracted from the two water pattern layers –WPEU1M and WPEU1MLK- to complete the raster land cover classification (Table 3).

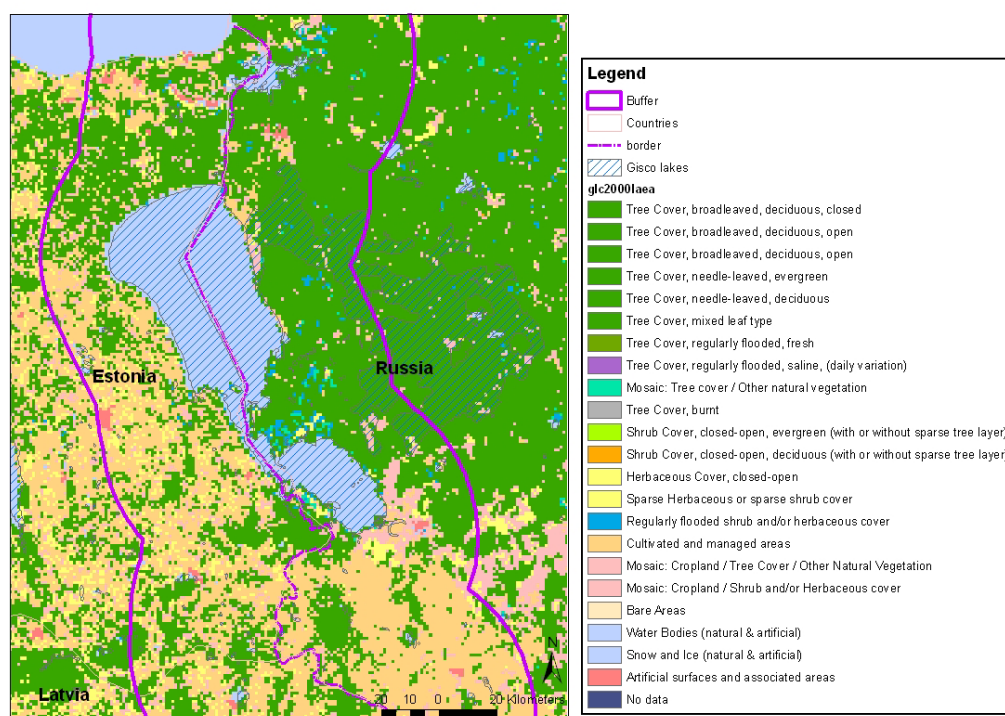


Figure 11 : comparison of the local information available in the GLC2000 and GISCO lake layer at the border segment between Russia and Estonia.

Table 3: the water pattern layers information based on the GISCO database manual - part I - chapter 5 (http://eu soils.jrc.it/gisco_dbm/dbm/p1ch5.htm)

DATA THEME	DESCRIPTION OF CONTENTS	RESOLUTION/ SCALE	SPATIAL EXTENT	VOLUME (Mb)	COPYRIGHT AND SOURCES	REFERENCE CODE
Water pattern Pan Europe, 1 million	Drainage pattern in Pan Europe >126 000 drainage segments (e.g. rivers)	1/1 000 000	Pan Europe	41	Bartholomew Digital Map Data	WPEU1M
Water pattern Pan Europe, 1 million, lakes and other water bodies	Lakes and other water bodies for Pan Europe. >42 000 surface areas (e.g. lakes) and >47 000 line segments (boarders to lakes etc.)	1/1 000 000	Pan Europe	32.5	Bartholomew Digital Map Data	WPEU1MLK

The high level of complexity and the resulting high amount of information available in the GISCO hydrological database, using the Collins Bartholomew Europe 1:1 million database as input, has not been totally exploited in this model because of the broad regional scale of the analysis. From the WPER1M database, we distinguished the primary, secondary, tertiary, other rivers and canal (Table 4). From the WPEU1MLK database of water bodies (polygons), we have extracted the “marshes” that are less difficult to cross by foot than the other water bodies all grouped in the same “lakes” category, including the large rivers (Table 5). After the projection and extraction at the extent of a buffer zone of , the next steps in the standardization of these layers are different because of their line or polygons characteristics.

Table 4: line water features of the of the GISCO-WPEU1M- layer within the 100km buffer

WPFTCD class	Class name	New class	Occurrence in buffer100km
135641	Canal A	5	88
135642	Canal B	5	247
135643	Canal C	5	1689
141349	Canal A Through Lagoon B	5	1
141351	Canal A Through Lake B	5	3
141352	Canal A Through Lake C	5	12
141379	Canal B Through Lake C	5	23
141391	Canal C Through Lake B	5	7
141392	Canal C Through Lake C	5	29
196254	Canal B Through Lake B	5	3
135659	River Other D	4	27540
141429	River Other D Thru Imperm Fresh Lake	4	7
141432	River Other D Thru Salt Lake C	4	5
141433	River Other D Thru Lagoon B	4	6
141434	River Other D Thru Lagoon C	4	30
141436	River Other D Thru Lake B	4	831
141437	River Other D Thru Lake C	4	12348
141456	River Other Imperm Thru Lake B	4	3
141457	River Other Imperm Thru Lake C	4	20
135644	River Primary A	1	812
135647	River Primary B	1	657
135648	River Primary C	1	512
135661	River Primary D	1	341
141354	River Primary A Thru Imperm Fresh Lake	1	1
141361	River Primary A Thru Lake B	1	86
141362	River Primary A Thru Lake C	1	55
141364	River Primary B Thru Imperm Fresh Lake	1	6
141371	River Primary B Thru Lake B	1	50
141372	River Primary B Thru Lake C	1	91
141389	River Primary C Thru Lake B	1	50
141390	River Primary C Thru Lake C	1	61
141403	River Primary D Thru Lake B	1	23
141404	River Primary D Thru Lake C	1	55
135650	River Secondary B	2	1578
135653	River Secondary C	2	2363
135654	River Secondary D	2	1871
141387	River Secondary B Thru Lake B	2	91
141388	River Secondary B Thru Lake C	2	152
141414	River Secondary C Thru Lake B	2	104
141415	River Secondary C Thru Lake C	2	343
141426	River Secondary D Thru Lake B	2	121
141427	River Secondary D Thru Lake C	2	376
135656	River Tertiary D	3	20128
141439	River Tertiary D Thru Imperm Fresh Lake	3	3
141442	River Tertiary D Thru Salt Lake C	3	3
141444	River Tertiary D Thru Lagoon B	3	11
141445	River Tertiary D Thru Lagoon C	3	19
141446	River Tertiary D Thru Lake B	3	889
141447	River Tertiary D Thru Lake C	3	6097
141493	River Tert Imperm Thru Lake B	3	2
141495	River Tert Imperm Thru Lake C	3	1
196121	River Tertiary Imperm	3	78

Table 5 : polygons water features of the GISCO-WPEU1MLK- layer within the 100km buffer

WPFTCD class	Class name		Number of cell in the buffer
135	MARSH	separate raster layer	1769
135571	LAKE A	1 st level (big water bodies)	40
135572	LAKE B	2d level	282
135573	LAKE C	3d level	7487
135662	IMPERM LAKES (FRESH)	Only 1, in the big buf (hungary)	1
138691	IMPERM LAKE C (SALT)	not in the buffer	0
196114	GLACIER	not in the buffer	0
196123	LAGOON B	not in the buffer (big buffer)	1
196124	LAGOON C	few	50
392231	"WIDE" RIVERS (POLYGONS)	Big river between Yougoslavia and Croatia	12

The 5 layers representing the types of river are :

- (i) spatially transformed in raster layer through the function density of line (see 5.1.5) using the parameters of 1x1km cell size of output and 1 km also for the radius of the circle where the neighbouring calculation is done. This process has been compared to a two-steps procedure using a 100x100m output cell and a resampling at the 1x1km thereafter. The increasing amount of computer time just result in a small number of bordering cells that are taken in the calculation in one or the other solution (Figure 12).
- (ii) The map algebra operator is used to sum all the 5 density layers in one single layer of all the rivers. Resulting from this neighboring spatial analysis, the density of river lines per km² varies from 0 to 2.93 meters/km².
- (iii) The linear increasing fuzzy function scales these values from 0 to 255 using the 0 and 0.65 control points, because of a peak in the frequencies of values in the histogram of this layer.

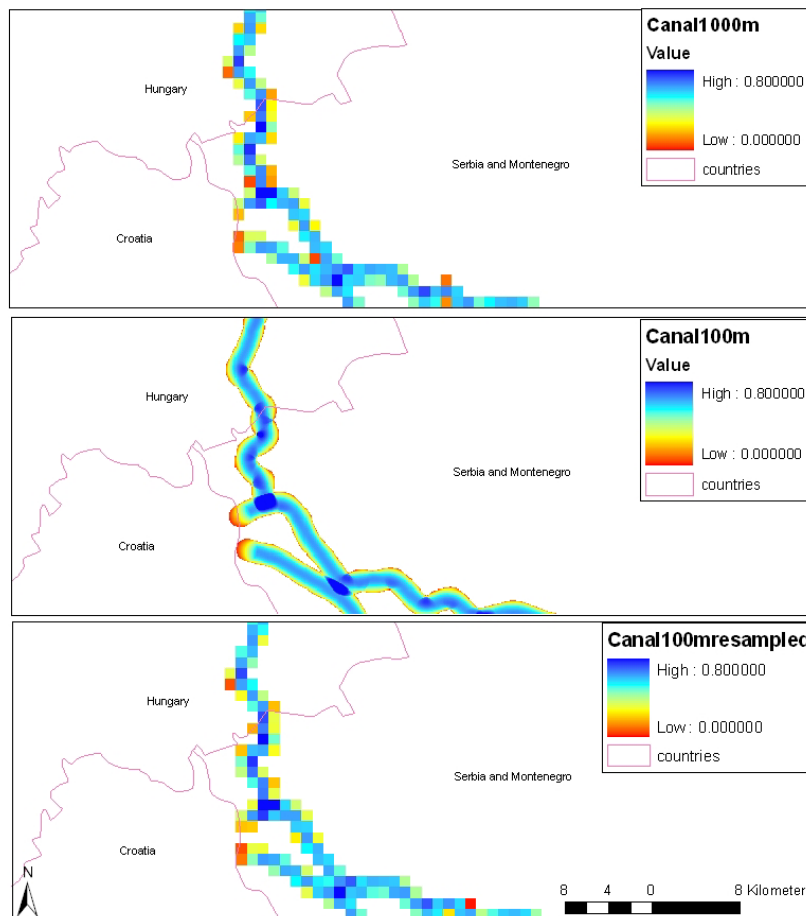


Figure 12: test of a extra resampling step in the line density procedure of the canal layer when choosing the 100x100m instead of the 1000x1000m cell resolution in the parameters.

The lakes and marshes polygons layers are

- (i) first rasterised at 100m
- (ii) reclassified in 0/1 values
- (iii) spatially transformed in raster layer through the function of the local statistical mean (see 5.1.5) using the parameters of 5km for the radius of the circle in the neighboring calculation.
- (iv) resampled at the resolution of 1000x1000m by the nearest neighbor algorithm.
- (v) finally stretch in values from 0 to 255, the fuzzification is not necessary as this dataset is already a continuous density thanks to the neighbouring algorithm.

The combination to create the land cover criteria is done in two steps :

- (vi) Both originally vector and raster types of water layers are combined. The maximum OVERLAY (Marsh/2 OR Lake OR Rivers OR GLC water) takes into account all types of water bodies including the GLC2000 class called water. The “marsh” layer has a weight divided by two in order to distinguish the less difficulties to cross this kind of water bodies relatively to the others.

- (vii) These water bodies are associated to the GLC2000 land cover classification in a maximum OVERLAY (LandCover = GLC OR Water) (Figure 9a).

5.2.4. The infrastructures

The infrastructure are one of the most important criteria in the suitability to cross for the illegal migrants. The roads and railways are the corridor where the ease to cross is the highest. The information are provided in the vector format in two different databases : the Esri European basemap and the Global Discovery (see 4.3.) the roads and railway dataset are processed differently

Whatever the size of the roads, the road infrastructure layer uses the most dense layer of roads to create the density per km². When the datasets are generally coherent for the EU countries, there are big differences in the extension of the coverage in the EU neighbouring countries. The Esri dataset has a more hierarchical structure within the different countries, the Global Discovery is more detailed in most of the neighbouring countries (Table 6). The first same steps as the previous line vector layers are used in the standardization.

- (i) LAEA projection of the complete road Global Discovery dataset,
- (ii) extraction to the buffer size,
- (iii) the density of roads is produced using the parameters of 1x1km cell size of output and 1 km also for the radius of the circle in the neighbouring calculation
- (iv) the 0-2.94 values of density of roads are fuzzy scaled by a linear decreasing fuzzy function with the 0 and 0.65 control points (highest frequency in the histogram).

Table 6 : comparison of hierarchy and number of segments in the ESRI and Global Discovery

Esri basemap	Number of segments	Global Discovery	Number of segments
0=European Highway	2018	210 = Motorway / Highway	91
1=major roads	1831	220 = Primary roads	46
2=roads	1610	230 = Secondary roads	7876
		290 = Track, trails or footpaths	716

As we consider the roads in their facilitating aspect to walk by foot, we consider the railway path in a less easy corridor of crossing. The railway criteria involves another combination process : the union of information contents of ESRI and Global Discovery. As both dataset are not complete at all, we decided to use the information provided by the two sources.

- (i) LAEA projection of both dataset
- (ii) extraction to the buffer size
- (iii) rasterisation at 100m
- (iv) reclassification in 1/0 values
- (v) boolean operation (OR) between each pixels of these two raster dataset
- (vi) neighbouring calculation in a circle of 1km radius
- (vii) resampling at 1000x1000m cell resolution

- (viii) the 0-0.49 values of density of roads are fuzzy scaled by a linear decreasing fuzzy function with the 0 and 0.05 control points (highest frequency in the histogram).
- (ix) division by two of each pixel values to takes into account that the paths are less practical to walk along – meaning that the influence of the road is twice higher than the railway one.

The roads and railway layers are combined in the infrastructure criteria using a Maximum OVERLAY (OR) weighting method (Figure 9b).

5.2.5. The Overall walk criteria

The combination of the 4 groups in the walk criteria is still done in two steps (Figure 13):

- (i) the Minimum OVERLAY (AND) of the land cover and infrastructure criteria
- (ii) the MCE of the previous resulting layer with the two other groups of variables (Figure 8 and Figure 9)

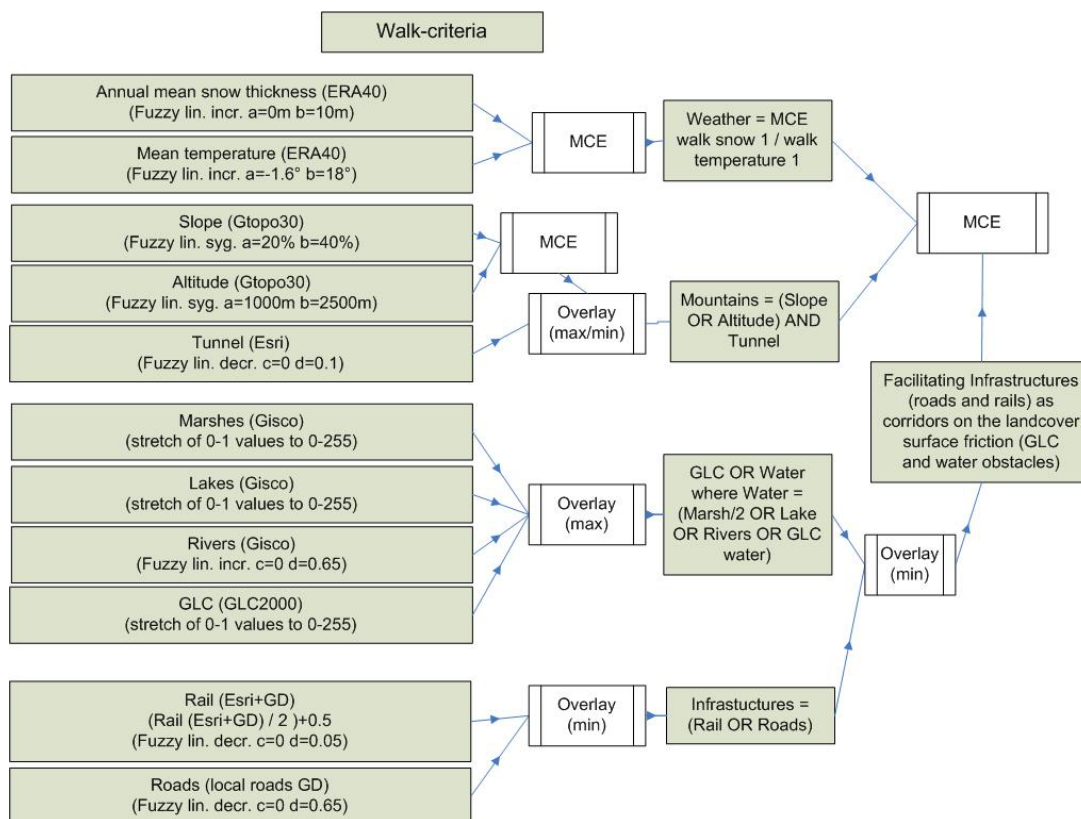


Figure 13: fuzzy scaling, overlay and MCE combinations of the different layers integrated in the walk criteria.

5.3. The “Hide” criteria

The “hide” criterion represents the likelihood for an illegal migrant to remain unseen while he is walking in the border area. This criterion includes the possibility of staying far from inhabited areas (lights at night, urban sprawls, density of population)

where there are more chances of being seen. The assumption there is that illegal migrants usually find refuge in forested areas or mountains.

The “hide” criterion (Figure 7), includes four groups of variables :

- (i) the land cover suitability to hide within different types of vegetation cover.
- (ii) the population effect addressed by all the dataset available to determine the zones of settlement
- (iii) the nighttime lights and
- (iv) the slope derived from the digital terrain model.

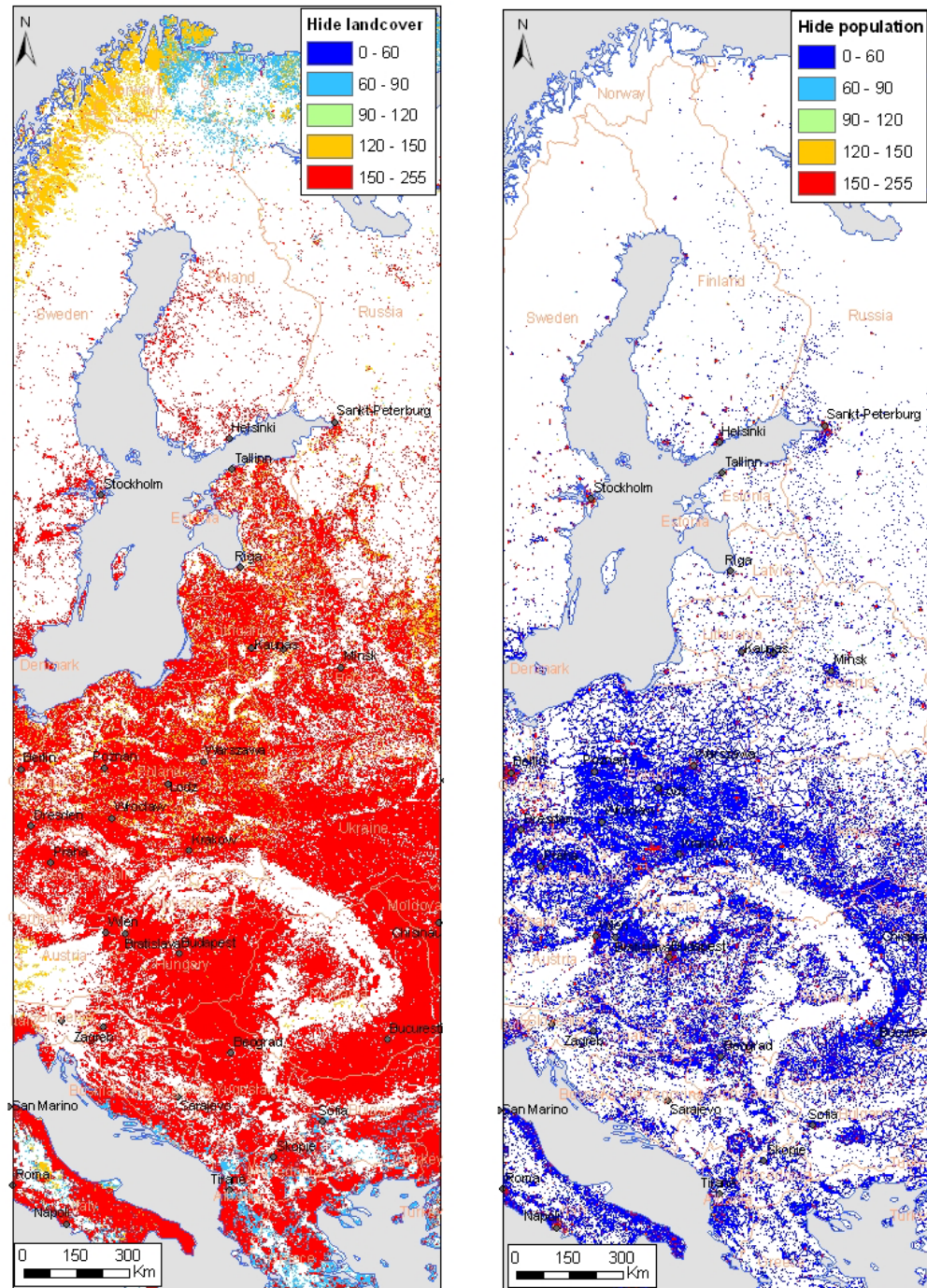


Figure 14 a,b: the two first clusters in the "hide" criteria: land cover (a), and population (b).

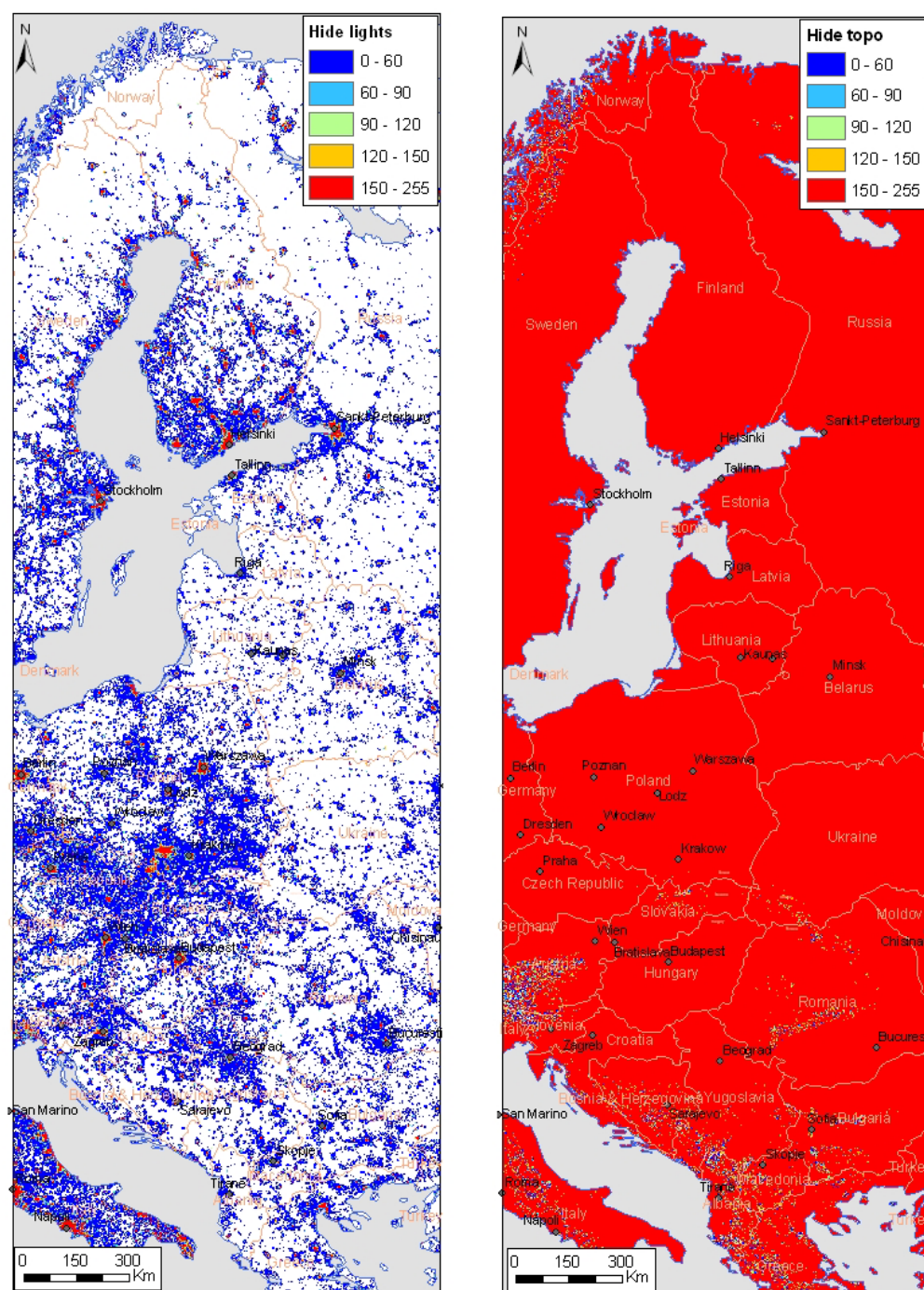


Figure 15 a,b: the two other clusters in the “hide” criteria: night lights (a) and topography (b).

5.3.1. The land cover

The GLC2000 dataset is used to represent the need of the illegal migrant of being unseen during his trip in the border area. The intermediate classes defined in the previous procedure (Table 2) are reclassified into unseen ability levels (Table 7).

These levels are then stretched in the uniform 0-255 range of values to produce the Land cover layer of the MCE calculation of the Hide criteria (Figure 14a).

Table 7 : reclassification of the GLC2000 land cover legend based on the easiness to hide

Intermediate groups of classes	Level of unseen ability
populated /less hidden (10) (water bodies and snow and ice 8/9)	1
open cultivated (6)	0.8
open (tree burnt, herbaceous, 3/5/7)	0.5
shrub / partially forested / flooded (4)	0.3

5.3.2. The population (Hide-pop)

Four data sources (see 4.3.) produce information on the population extent in various spatial formats: the raster landscan worldwide population density, the list of all villages and places (points) in the Global Discovery and Esri vector dataset, the spatial extent (polygon) of the urban sprawls defined in these vector dataset also and the urban land cover class of the raster GLC2000.

The Landscan raster dataset is standardized in several steps :

- (i) projected in LAEA,
- (ii) extracted at the AOI extent,
- (iii) transformed in compatible format and
- (iv) fuzzy scaled with a sygmoidal increasing function saturated at the value of 500 people per km²,

ESRI and Global discovery provide information about the list of places/villages/cities available at worldwide level. The later dataset is chosen because it is more extensive - a twice higher number of centers- (10182/ 5192) (Table 8). The standardization of a point vector dataset involves :

- (i) the projection in LAEA,
- (ii) the extraction in the 100km buffer zone
- (iii) point density spatial calculation (see 5.1.5) using a 1km radius circle
- (iv) fuzzy scaled with a sygmoidal increasing function with the two following control points a=0 and b=1.5

Table 8 : comparison of the number places and their hierarchy in the ESRI and Global Discovery datasets

Esri Places		Global Discovery	
TYPE	Occurrence in the 100km buffer	CLASS	Occurrence in the 100km buffer
Large City	2	1	10
Medium City	22	2	50
Numbered Town Di	4	3	869
Postal Code Area	78	4	1216
Postal Code Poin	1	5	3975
Small City	53	6	4062
Small Village	1331	Sum	10182
Tiny Village	2748		

Town	273		
Town District	320		
Village	360		
Sum	5192		

The urban sprawls are polygons features provided by the two datasets. The standardization of both datasets include :

- (i) the projection in LAEA,
- (ii) the extraction in the 100kmbuffer zone
- (iii) the rasterisation at the resolution of 100m
- (iv) the reclassification in 1/0 values
- (v) the union Boolean operator (OR)
- (vi) the mean neighbouring effect using a 1km radius circle
- (vii) the resampling of this layer at the 1x1km resolution (Figure 16)
- (viii) the transformation in a compatible format
- (ix) the fuzzy scaling of the values using a sygmoidal increasing function with the control points of 0 and 1.

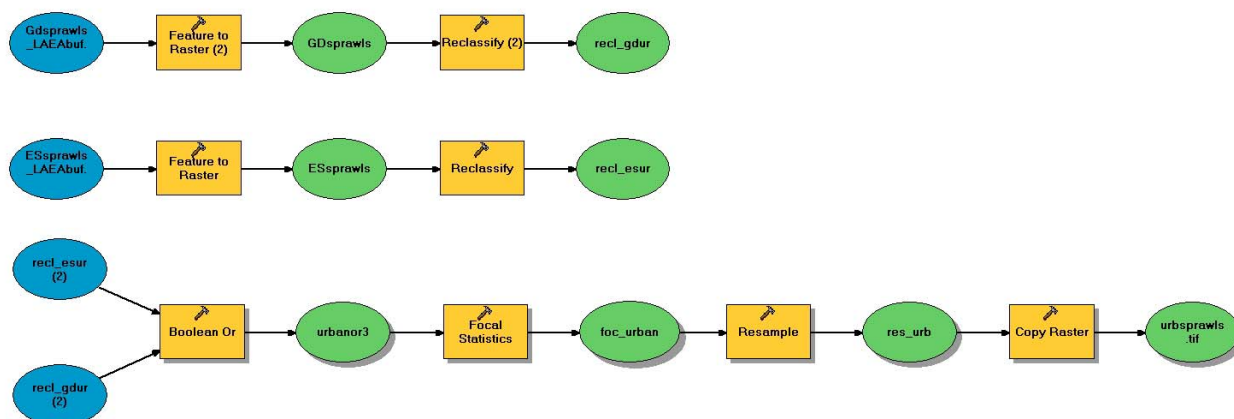


Figure 16 : ArcGIS model including the standardization steps 3-7.

The last dataset that include population information per se is the populated land cover class of GLC2000. This dataset is reclassified with 0/1 values (1= populated class). These four criteria are combined by a maximum OVERLAY (OR) to produce the population layer in the Hide criteria ()

5.3.3. The night lights (Hide-night)

The night time lights dataset (see 4.3.) identify all the types of lights, not only the populated places. This raster layer is standardized in the usual steps

- (i) projected in LAEA,
- (ii) extracted at the AOI extent,
- (iii) transformed in compatible format and

fuzzy scaled with a sygmoidal increasing function saturated at the value of a=0 and b=100 light occurrence per km² to produce the night light cluster of the hide criteria (Figure 15a)

5.3.4. The mountain (Hide-topo)

The illegal migrants often use the mountain effect to increase the difficulty to catch them. This behavior refers to the slope effect of the mountains. The slope layer described in the walk criteria (see 5.2.2.) and created from the GTOPO30 data source (see 4.3.) is used to derive the topographic effect in the “hide criteria”. Only the last fuzzy scaling step is modified. On the contrary of the ease of walk, the ease of being hidden in the mountain is more and more easy from 20% of slope and is seen as maximum after 40%. The fuzzy function is then increasing instead of decreasing. This cluster is the fourth one in the Hide criteria (Figure 15b)

5.3.5. The overall hide criteria (Hide)

The hide criteria combines in a MCE with equal weights of 1 the four datasets (Figure 17).

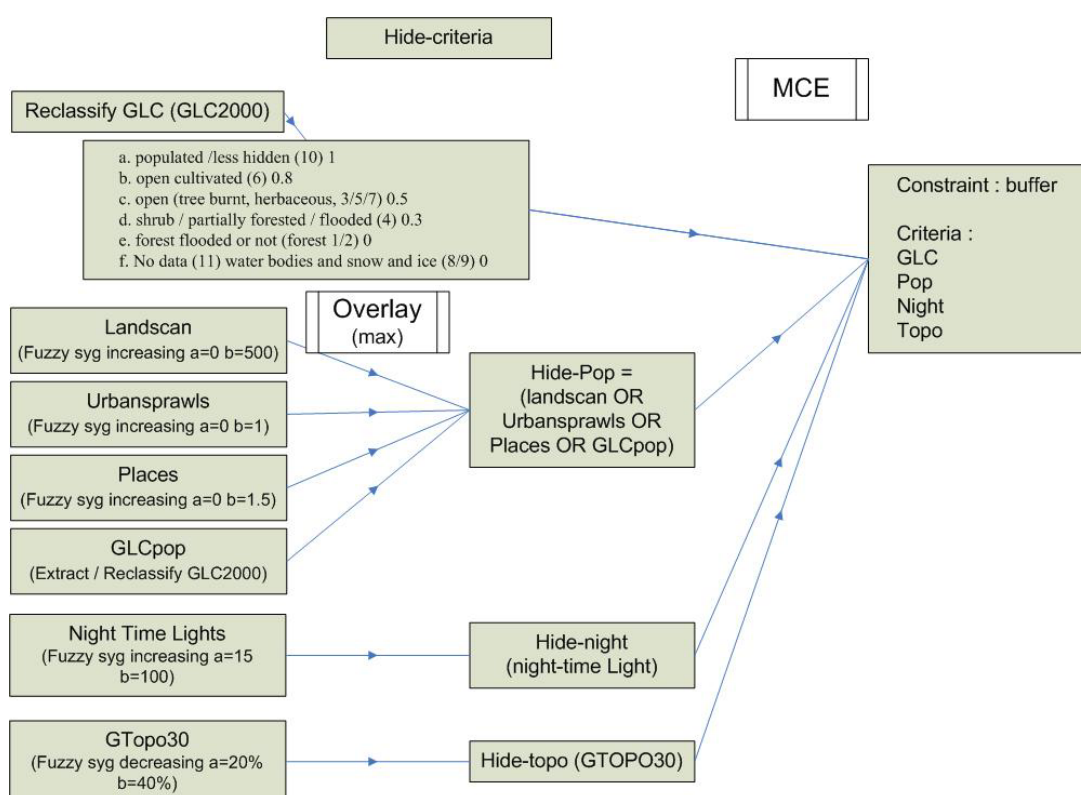


Figure 17: fuzzy scaling, overlay and MCE combinations of the different layers integrated in the hide criteria.

5.4. The “Secure” criteria

The third “secure” criterion refers to the official border crossing points, where migrants can be stopped. The presence or absence of guards has a major importance in the definition of border permeability. Unfortunately, whatever the impact of this criterion on the model behaviour, the input data available are scarce. When data are not provided by the JRC survey, we used the crossing points of major roads and railways as a proxy of the border points (Figure 18). This is a major assumption of our model that has to be improved through collaboration with border authorities or other migration decision bodies. This BCP’s vector layer (point) is transformed in a raster format with a cell size of 1x1km.

Walking in proximity to these border points is not secure for illegal migrants. The border point itself has the infinite friction value and the highest friction values are encountered around the border point. The model doesn't integrate the characteristics of the BCP themselves, but only the green border between each point (see 5.1.5.). The proximity surface is calculated as a cost function on the walking friction. The cost algorithm generates a distance/proximity surface where distance is measured in least cost (in terms of effort for the border guards) in moving over a friction surface (Eastman, 1989). Distances are measured according to the minimum amount of friction that must be accumulated to move from that cell to the nearest source target. Movements are in 8 direction from any cell and diagonal movements produce a cost of 1.41 times the friction value. This concept of distance is clearly different from the Euclidean. The unit of measurement in the output image is "grid cell equivalents"(gce). A gce of 1 indicates the cost of moving through a grid cell when the friction equals 1. It refers to the time used by the guards to capture the illegal migrants. The "walk" criteria surface (see 5.2.) is used as a friction surface after some transformation steps to refer to the cost hypothesis :

- (i) transformation of the friction values in "walking speed" values using standard velocity values. To represent a range of foot velocity varying from 0.2hours/km to 5hours/km (for example the climbing of a rock cliff) the friction values are linearly stretched in a range of 25 levels. This range gives the reference of the minimum friction.
- (ii) These values are converted to real values for technical reasons and indicate the friction of each pixel relative to the base value 1.0.
- (iii) The "cost" function uses a "grow" algorithm with infinite distance.
- (iv) This cost surface is transformed in hours considering that the guards can use another way of transport (usually the car) and then can cover 20km/hour. This transformation is a scalar division by 20.
- (v) The fuzzy linear decreasing scaling transformation is based on the maximum time limit of the aliens pursuit. 20 hours of pursuit necessitate two days that can be seen as a maximal values for one migrant.

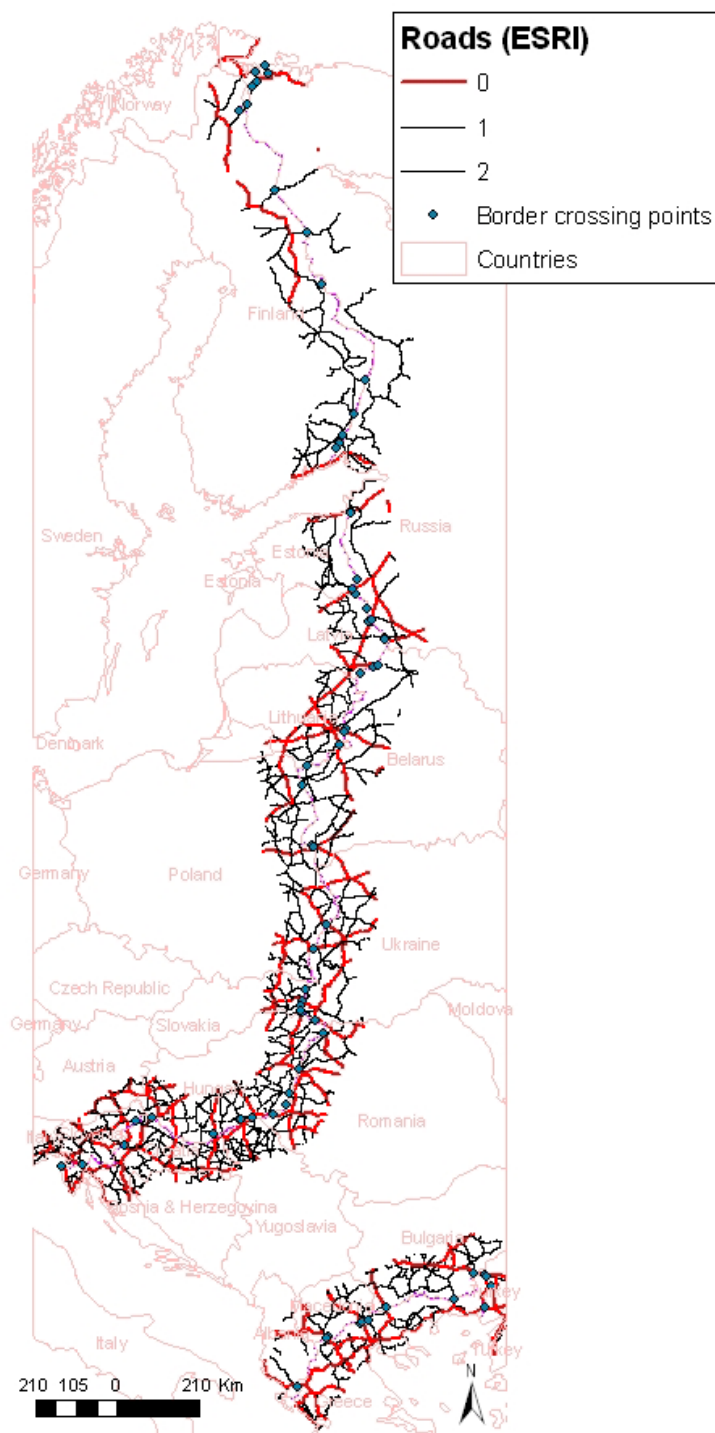


Figure 18 : border crossing points (BCP) as derived from a survey to the Border Authorities and completed by the crossing of main roads and railways.

5.5. The overall friction

The final output of the multi-criteria model is a weighted combination of the three cluster maps, the three basic criteria (Figure 19 and Figure 20) defined as “walk”, “hide”, and “secure” and described above.

In the WLC procedures showed here we have implemented the simplest choice corresponding to the attribution of equal weights for each cluster in order to better understand the assumptions of the model. Alternative scenarios with different configuration of weights will be discussed in a successive publication, together with a sensitivity analysis of the proposed model.

In the present release, the model quantifies border friction in cells of 1x1 km, along 6,000 km of border between Norway in the North and Greece in the South. Also if the minimal spatial entity of the model is the 1x1km cell, the output can be aggregated using different spatial entities. In this case we decided to cut the overall border under assessment in *border segments* having the characteristic to correspond to one and only one country in each side. In this way the statistics calculated for border segments are also consistent with the ones related to the single countries involved.

For each border segment three different spatial contexts “border line”, “vicinity” and “regional” have been selected corresponding to 1, 5 and 50 km of width of the stripe along the border. Friction statistics calculated by aggregation of the 1x1km cells of the model can be calculated for every border segment at the three different spatial contexts. This will allow to better understand the relationship between the border itself and his geographical context.

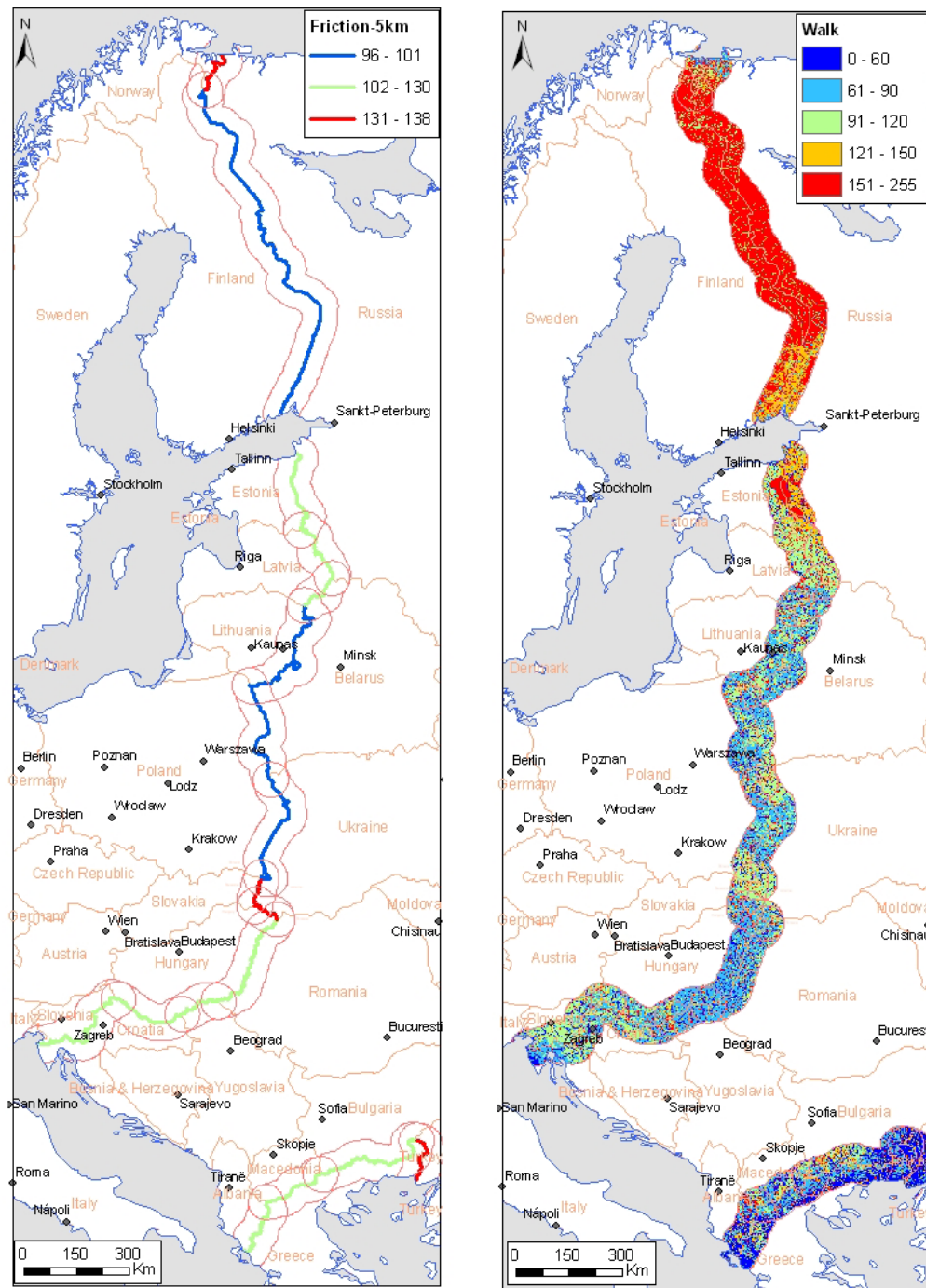


Figure 19 (a,b) : vicinity friction of the EU25 – 5km buffer- (a) and “walk” friction (b).

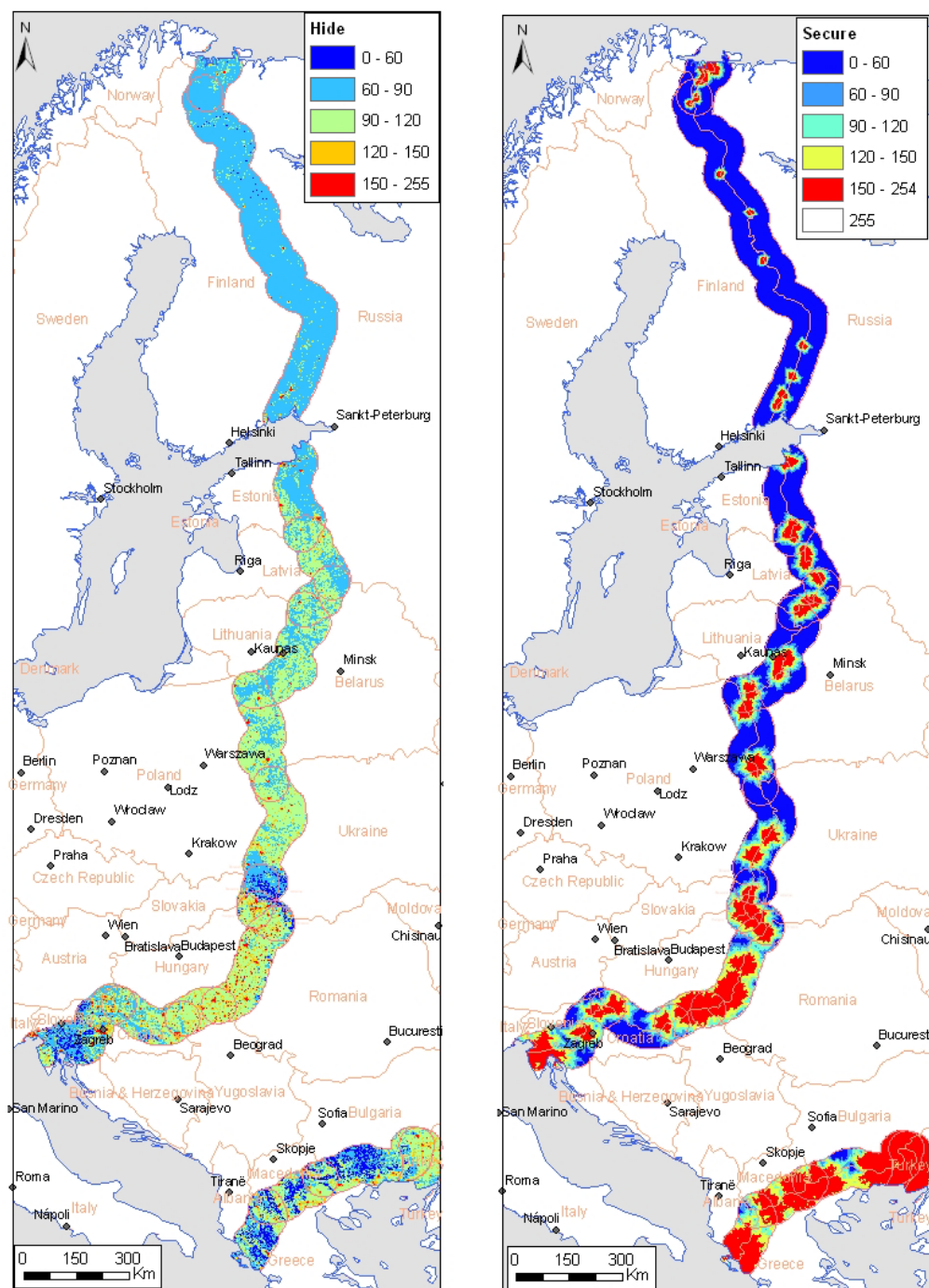


Figure 20 (a,b) : “secure” friction (max=255 at the border points) (a) and “hide” friction (b).

VI. Results and discussion

For each segment of land border, the frictions are calculated in the three buffer zones :

- (i) 50 km, the “regional friction” that represents one day of walk from the border,
- (ii) 5 km, the “vicinity friction”, the last hour of walk for the migrant,

- (iii) 1 km, the “border line” friction.

Interesting results came out of the regional analysis of frictions calculated for each border segments in the three buffer zones. The frictions per segment are compared first for each criteria and then for the three criteria together. By this spatial decomposition we better understand the internal rules of the model as well as the meaning of the friction itself. Through these first clues, we can discuss about the objective of this tool that is build to help the decision process.

6.1. The walk criteria

Figure 21 illustrate the friction values in the first cluster of the “walk” criteria. Border segments are ranked from the south to the north :

- (i) Generally we can observe that it is more difficult to walk at the border line (in the 1km buffer) than in the average of the vicinity and regional spatial contexts,

In fact, the average friction of the border line is almost always more important than the average of the vicinity and regional contexts. In other words we can say that usually the border line results to be more “naturally defended” by geographical features (like rivers, mountains) than the average of the surrounding regions. This first intuitive result of the model is a confirmation that the model seems to capture in the correct way the reality of the problem.

The southern and northern segments are two exceptions in this general pattern. It is easier to cross the 1km of the border line than the larger area around these border segments. These two can be explained by the friction of the sea. The friction is on the average higher at the coast than on the land. The 5km and 50km are affected by this “*coast effect*”. The other maritime segments are two Russian Federation segments. With Estonia, a big lake on the border line counteracts this coast effect. With Finland, the friction of the border at the three different buffer size is very high and similar.

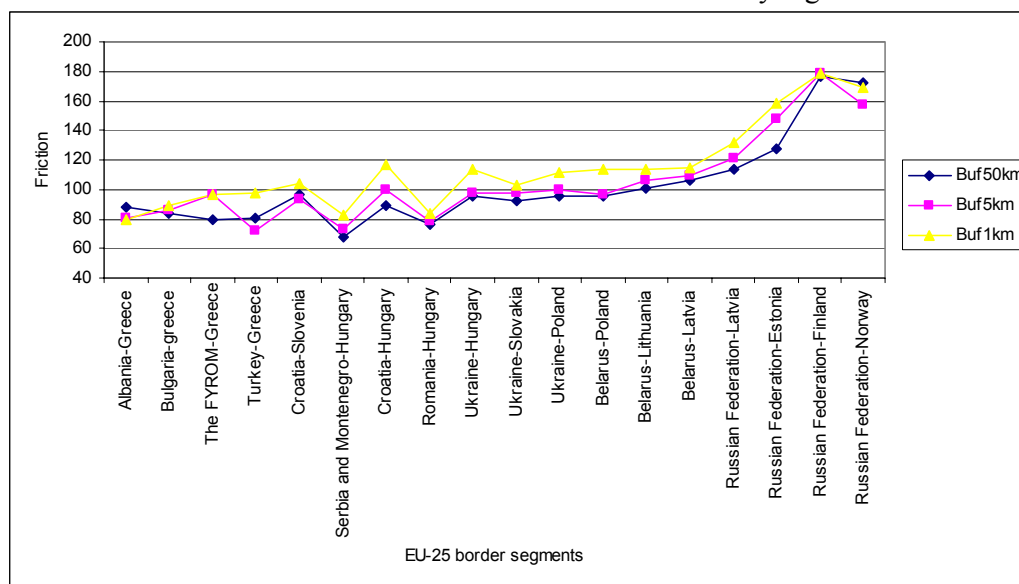


Figure 21: friction values in the three buffer sizes for the first cluster “walk”.

- (ii) Crossing on foot the northern borders is twice as difficult as than the southern ones.

In fact, the “walk” friction is ranging from around 50 (Greece, Hungary) to around 100 (Russian Federation and Estonia, Latvia, Norway)

This result of the model can be explained by the particular characteristics of the Northern regions in terms of land cover difficult to cross and weather conditions that create a sort of natural defense of the border. Figure 21 shows that there is a group of segment where the friction are between 50 and 70 and another group of segment with higher values. In this second group, we find all the Russian Federation segments.

6.2. The “hide” criteria

For the second criteria that represents the easiness for an illegal crossing person to hide (Figure 22), the overall shape of the graph is completely different respect to the “walk” criterion already discussed.

- (i) “There is no increasing trend from South to North but rather a group of where is more difficult to hide in the central Part of Europe”.

This curvilinear shape can be explained by the overall settlement pattern that is much less in the north and the south (Greece) than in the central region where there are more populated places. There is no big difference in values between the least and the highest “hide” friction, almost ranging from friction 80 to 120 comparing to the previous “walk” criterion. A low friction exception is related to the Finland and Norway border segments that are scored around 60 in the “hide” criterion, in accordance with the flat and desert landscape characteristic of these regions.

- (ii) “It is easier to hide on the border line than in the regional spatial context around the border”.

In fact, respect to the “walk” criterion, the “hide” friction is similar in the three assessed spatial contexts for most of the segments. Four exceptions have to be analyzed. In two cases (Ukraine-Slovakia and Fyrom-Greece), the friction in the “regional” context is higher than the friction at the border line.

This in part counter-intuitive result of the model can be partially explained by the spatial resolution of model (1x1 km grid) that doesn’t allow reporting on special devices or situations maybe existing on the border expressly for increasing the “hide” friction but too small in order to be detected and modeled as for example the usual clearing of forest along the border line with stripes of 500 meters or similar.

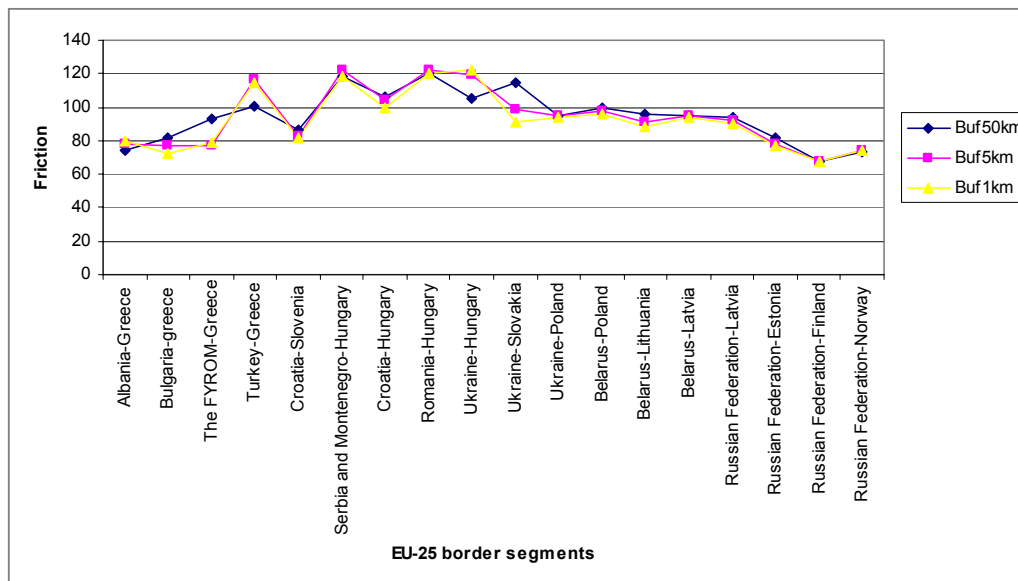


Figure 22: friction values in the three buffer sizes for the second cluster “hide”.

6.3. The “secure” criteria

The last “secure” criteria (Figure 23) combines the effect of the easiness to walk and the cost distance for the border guards to progress from the border points to capture a migrant. Based on the number of hours necessary for each guard to walk or drive on this “friction surface”, we hypothesize that the illegal migrants is defined as “safe” after two days of search by the guards. The figures of this graph can be seen as the level of “security” for the migrant according to the cost distance from the border point. Some observations below:

- (i) “There is a slightly general decreasing pattern from the North to the South, but not so obvious as in the first cluster”.

Nevertheless, the frictions for the 4 segments of Russian Federation and the 2 segments of Belarus demonstrate lower values, especially in term of large “regional” friction. This can be partly explained by the lowest number of border points in the Northern countries. These countries have large areas of lakes, marsh or forest that are difficult to cross for the migrant and where there are few accessibility corridors (roads, railways). The authorities seem to rely on these geographical barriers to limit the number of border points.

- (ii) “For an illegally crossing person it is more secure in the large regional spatial context than in the vicinity spatial context (5km) around the border”.

There are large differences between the friction of the regional spatial context and the two other spatial contexts. The “regional” spatial context friction is systematically lower than the friction of the “vicinity” and “border line” spatial contexts. This intuitive result of the model is the quantification of the fact that usually border points (and so the starting points for the guards) are along the border line, and so larger is the distance from the border line and less is the probability for the illegal intruder to be captured by the border guards. On the contrary, the difference in friction between the

two nearest spatial contexts is very small. The friction along the border is only slightly higher than the friction in the vicinity. This is because from the point of view of the border guards, in homogeneous background the difference in terms of time-cost to move over 1 or 5 km by car is very little.

High “secure” friction values are around 200, while most of the border segments have friction values above of 150. Interesting low values are related to Poland, Lithuania and Estonia (around 100). The lowest friction value is related to the border with Finland, that is apparently the border with the most distant border points in Europe.

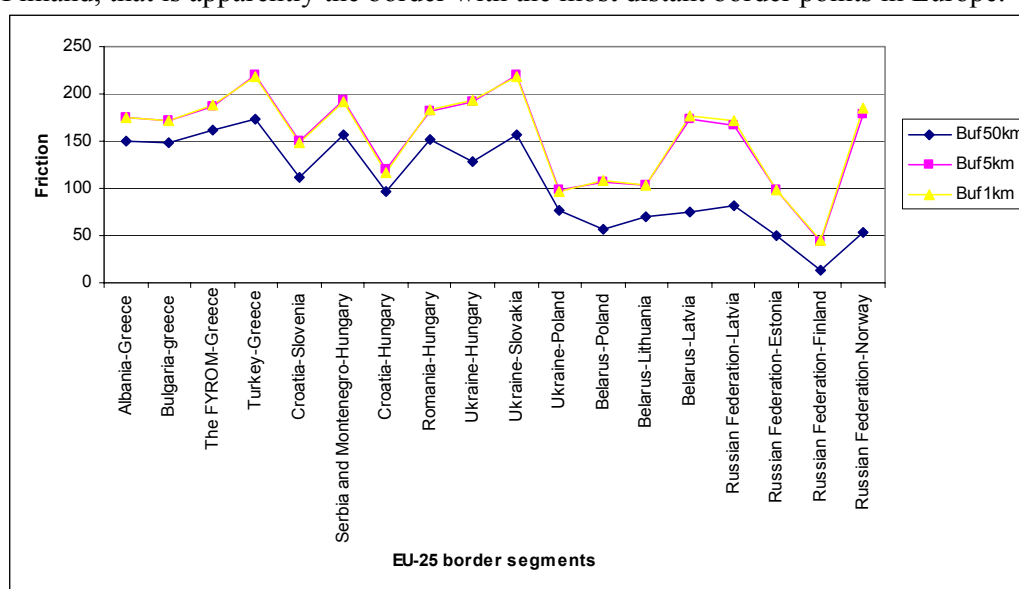


Figure 23: friction values in the three buffer sizes for the third cluster “secure”.

The friction values are changing drastically from one country segment to the other. We can identify a ranking of the countries according to the friction in the vicinity (Figure 24).

- (i) “low values of friction show that the migrants can move away from the border guards on this large area of difficult natural environment”

The segment between Russian Federation and Finland is the longest one but also the most secure one. The other northern countries like Estonia, Poland and Lithuania also highlight relatively low friction. Latvia is an exception in these northern countries with average values of secure friction. But we can notice that the friction values in the geographical context for Latvia are largely lower than the friction at the border and at a level similar to the other northern countries.

- (ii) “high values of insecurity reflect a high probability to be captured by the border authorities”

The boundary between Ukraine and Slovakia is the most “insecure” border segment from the migrant point of view. In fact, the Ukrainian border is always seen as a corridor of migration inside EU. Because of this historical pattern of migration, the forces involved in the security (number of BCP’s) are specially developed in this area and the model integrate this fact. All the borders of Hungary present also high figures of “insecurity”. The borders between Greece and Turkey or between Serbia/Montenegro and Hungary are also highlighted by this criteria. These results can be further discussed in taking into account the degree of accession of these countries in the European process.

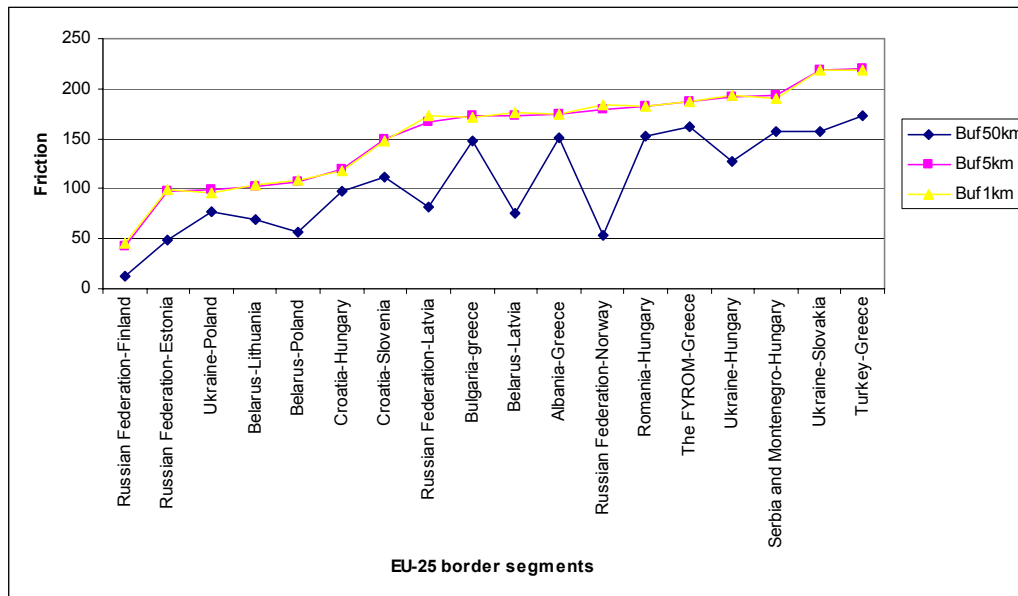


Figure 24: friction values in the three buffer sizes for the third cluster “secure” ranked following the vicinity friction values.

6.4. The general friction

The combination of the three criteria provides an “overall friction”, where each criteria has the same weight (Figure 25).

- (i) “Increasing friction values from the regional to the border line spatial contexts”

In most cases, friction increases with buffer size decreasing from the regional friction - 50km - to the border friction -1km- (Figure 25). The lowest values - less difficulty for the illegal migrant to cross on foot - applies to the regional friction. For each border segment, the values of friction in the 50 km area are much lower than the values in the two other buffer zones. In general, the border line frictions are also slightly but generally higher than in the vicinity friction. In that pattern, the model works logically as it considers that it becomes more difficult for a migrant to walk and to cross on foot as she/he is approaching the boundary.

- (ii) Smoothing of the overall friction values

The values of the overall frictions range from 144 to 83 in the three spatial contexts (Figure 25). The mean value of these three frictions for the 18 border segments is 113. Compared to the total range of values from 0 to 256 (fuzzy byte standardization – 5.1.4.) defined for each criteria (Figure 19 and Figure 20), these 30 scores deviations from the maximum and minimum values are limited. These deviations are no larger than 12% (30/256). This is explained by the fact that the three combined criteria (walk, hide, secure) represent very different phenomenon and consequently opposite behavior of the model, and then the average tends to flatten the distribution curve. The same additional and smoothing effect can be illustrated in the ranking of the segment friction values.

(iii) North-South trends

The overall friction for the countries ranked does not show a clear increasing or decreasing trend from the South to the North. However, there are more clear opposite trends from the South to the North in the three criteria (Figure 19 and Figure 20). The clear increasing ease of walking from North to South is counterbalanced by the opposite trend in the probability to be stopped at the border control points. In other words, it is “easier to walk” in the South because there are fewer natural obstacles but the border is also “less secure” because of a higher number of border crossing points. We can say that the two frictions have a balancing / smoothing effect that explains the small differences in the average total friction values.

(iv) Some security patterns

The ranking and clustering of these 18 boundaries segments of the EU-25 border illustrate some specific patterns of security concern (Figure 25).

- The lowest average friction value is the regional friction of the Belarus-Poland segment. Quite similar low values of regional friction can be seen in all the North segments from Poland to Norway. These northern regions could be seen as easier to cross by an illegal migrant according to the composition of the three criteria.
- The maximum average values are 144 for the border line frictions of the Greece-Turkey segment and 143 for the border line frictions of the Russian Federation/Norway and Ukraine-Hungary.

The size of the interval between the regional low friction and the border line friction also illustrates some specific patterns. For most of the border segment, the three frictions values differ from each other of about 10 scores, except in four cases: Greece-Turkey, Ukraine-Hungary, Latvia and Russian Federation-Norway. With a low regional friction, the Russian Federation-Norway border shows also one of the highest border line friction values. The high values in the secure criteria refer to a high level of protection at the border line. It is mainly the number of border points that creates this high level of protection. This illustrates the importance of the number of border points or the quality of the policing capacity in the model but also in the permeability context in general.

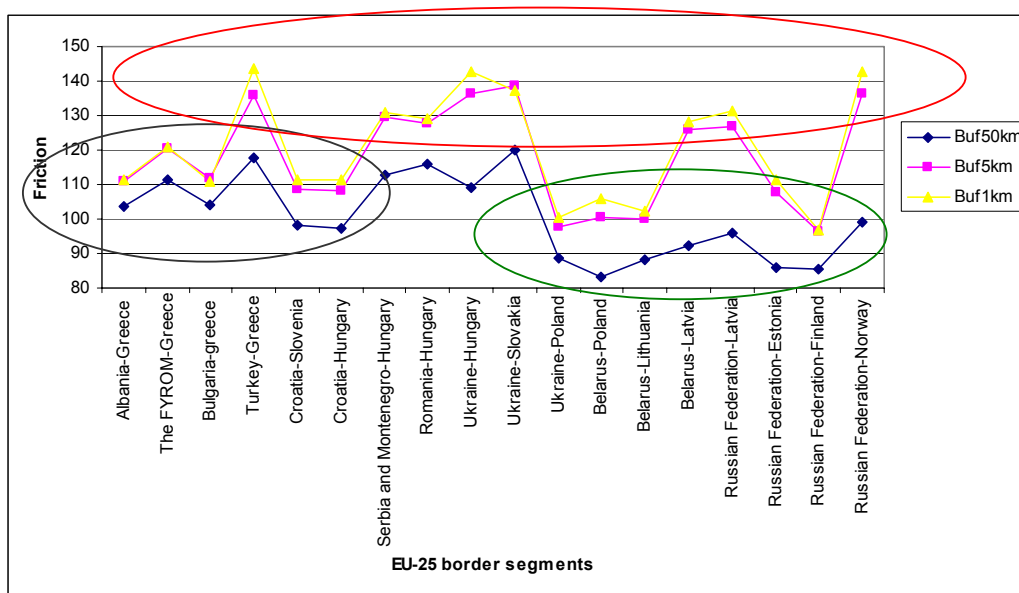


Figure 25: overall friction values for the 18 border segments of the EU25 Border Permeability model.

Through the vicinity friction - that represents the most important last hours of the border crossing journey of the migrants – these same groups of border segments can be scrutinized (Figure 19a). The logical value of the model can be compared to the existing information about the geographical corridors existing throughout the EU.

- The lowest level of overall friction is calculated for the *Finnish border*. The specific case of the Russian Federation-Finland border is an example of the balancing effects of the “secure” and “walk” criteria. This border is highly permeable (low friction) for the migrants in the point of view of their security because of the low number of border control points. Only 12 BCPs have been registered for the 1,250 km of this border segment (see 5.4). In the “walk” criteria on the contrary, we can see high friction values that illustrate the natural protection of the border due to natural obstacles like lakes, rivers, marsh but due also to the low density of road and railway networks, these northern regions can be seen as “naturally protected”.
- The highest values of the vicinity friction (Figure 19a) can be seen in four segments that have already been identified by the high score deviations and these patterns are really interesting to compare with existing information about migration routes.

The *Ukraine border sections with Slovakia and Hungary* present high levels of friction for potential migrants. The Ukrainian border is usually seen as one of the major entry routes into Europe.

The northern border segment of the EU-25 line is the *corridor of Norway* that is an important crossing point because Norway does not belong to the Schengen area but is located in Europe, and entering through Norway can be seen as an easy option to enter the EU-25. However, this is not true according to the results of the model. With a high “walk” friction, a low level of “hide” friction, the resulting overall friction for the migrant remains high for this border segment because of high values in the secure criteria due to the high number of BCPs (6 for 175km). This border is well

protected. This cluster of high level friction results mainly from their pattern in the “secure” criterion that is clearly linked to the number of border control points and the attention given by border authorities to these particular segments.

High levels of friction are also detected at the *Turkish section of the Greek border* where the border line friction is particularly important. This indicates also a high protected frontier with border authorities considering this zone as a potential migration corridor.

VII. Discussions and conclusions

The permeability maps which resulted from this assessment illustrate the high potential of these spatial modeling analyses. It has illustrated some patterns and corridor of permeability. Some intuitive aspects of the border permeability respect to illegal intruders have been confirmed and quantitatively estimated by the model.

This tool could allow to quantitatively describe the permeability of the border related to illegal intruders and distinguish between internal boundaries (with a growing level of permeability) and the external boundaries which tend to become less permeable. This is of high interest in the European Union (EU) where we can find the greatest concentration of open borders in the world (Blake 2000).

The quantitative and spatial nature of the model may allow to estimate the effort needed by the different countries for the border control, to find gaps and to prioritize investments, and to estimate the impact on the overall border permeability due to alternative choices (building a new road, clearing a part of the forest or similar). Another possible use of the output of the model is to forecast the most probable point of arrival inside the EU territory of illegal intruders coming from a known departure point (or vice versa discovering the most probable departure point by knowing the point where they have been cached by the border guards) by least-cost path analysis using the calculated friction surface.

However, an important issue regards the difficulties encountered to obtain ground truth information to check the validity of the index of border permeability developed. Validation of these friction figures could be carried out for example by the help of medium resolution data or collecting statistics about illegal border crossing that are spatialized at least at level of border segment.. The test of robustness carried out in this study are based on the logic of the model behavior and first result in the border segments, more complete robustness assessment will be carried out as follow up of this activity. Scenario analysis can be settled to evaluate the sensitivity to changes of the different criteria and the changes in the results. In particular, the third cluster of criteria has a great impact on the fact of crossing or not the border line. And the data used to set up this criteria are really inhomogeneous. Scenario analysis can be settled to test the number of guards at the border post or the level of technology of these guards.

Because of its modular and multi-criteria approach, the border permeability model has an open logical frame that can be extended covering other basic options. Where they are available, additional data input, like the presence of special control devices along

the border (fences, electric sensors), or the legal constraints related to border crossing could be integrated as additional criteria contributing to refine the overall model. Some of these data have been gathered during the survey carried out at the JRC but there are not complete enough, future work could be put in the improvement of the model. This qualitative survey analysis also brings some clues to understand the political, economic and social driving forces of migration flows. This understanding can further be used to build some “what-if” questions about the assessment of the impact of EU development or migration policies.

Beyond the current geographical and thematic scope of the model, this modular modeling approach can be adapted to consider the permeability of maritime areas, including coastal areas. The land accessibility criteria (land cover friction, digital terrain model, slope, ..) are similar to the land permeability ones, but they have to be distinguished based on trajectories of migration, from one country to the other. The basic specific criteria that have to be added to the land permeability model include : (i) the coastline accessibility (high, low, sand, rock ...) from the sea and the land sides, (ii) the distance over friction (cost distance) as a function of sea condition (seasonally), weather conditions (seasonally), wind and streams, (iii) types of infrastructure (road, ports,) on both sides, and the monitoring of the coastline (place and number of coastal guards, and special devices, radar). As seen in the land permeability survey (Magoni et al. 2006, forthcoming), the gathering of homogenous information about border control presents a lot of difficulties.

Finally, a more comprehensive border permeability model has to be defined in close collaboration with relevant border authorities of Member States which have to input information about driving forces and spatial patterns of international migration.

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Abstract :

In the frame of the ISFEREA action, the JRC IPSC carried out an analysis of the permeability of the EU Eastern land border to a specific class of illegal migration flows. This analysis is based on a preliminary version of a spatial quantitative model of the “green border” permeability.

This model was built on the assumption that the flow of illegal migrants is function of the geographical permeability of the border and crossing points, the efficacy to control them by the Authorities, and also function of the driving force defined by people's willingness to cross (push and pull factors). The spatial model developed by the JRC attempts to represent in deep only the first part of this equation, while the modularity of the proposed model may allows further development for a more comprehensive explanation the illegal migration phenomena.

With the present release the model uses as input more than 20 spatial datasets ranging from satellite remotely-sensed data, land use land cover, digital terrain model, weather and environmental conditions, presence of population, infrastructures, and physical obstacles, and presence of border control points.

The model is focused on the geographic permeability related to a standard adult person having illegal behavior and deciding to cross the green border by foot. The basic criteria implemented in the current release are built around three concepts: the rapidity of walking allowed by the terrain and the weather conditions (walk), the possibility to hide by the physical environment (hide), and the probability to be stopped by a border police agent (secure).

The geographic permeability is conceptualized as function inverse of the friction surface calculated using fuzzy multi-criteria methodology with a spatial resolution of 1 kilometer. Friction statistics are related to specific spatial contexts around the border lines (from 1 to 50 km) aggregated at the national and sub-national level between different countries.

The model confirms the two major entry routes into Europe: the Ukrainian border and the Turkish section of the Greek border. The model shows also the high sensitivity of the potential corridor of Norway but the high number of border points at this boundary seems to be sufficient to protect this entry point.

The report concludes that, in spite of limitations linked to data collection and availability, the permeability maps which resulted from this study show the high potential of such a model for the analysis of potential and actual migration flows and related policy planning. This tool could provide an opportunity to test different “what-if” scenarios about the driving forces of illegal migratory flows at the external EU land border, to prioritize investments of Member States in border management infrastructures at EU level, and to develop policy advice for relevant internal and external EU policies. This modeling tool can help estimate the impact on permeability of concrete measures, such as changes in the number of border points or number of border guards and in their level of equipment at these particular points. The flexibility of the model also allows for the input of additional data like typology of border points, in order to improve the results. Finally, the development of a more comprehensive model would require the co-operation of and contribution from relevant authorities of the EU Member States as well as FRONTEX.



The mission of the Joint Research Centre is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of European Union policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.