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5D: A GIS-based Approach for Determining and Displaying the Degree of Operational Difficulty of Demining

Clearance operations highly depend on environmental, geographic and socioeconomic conditions. These conditions make demining easier, more difficult or nearly impossible. This article proposes an analytical method called **5D** (Determining and Displaying the Degree of Operational Difficulty of Demining), which classifies degrees of difficulty as low, medium, high or extreme.

by Pierre Lacroix and Rocío Escobar [University of Geneva]

The Geneva International Centre for Humanitarian Demining is collaborating with the University of Geneva to explore the feasibility of displaying the impact of explosive remnants of war in contaminated countries through maps, without revealing the ERW's exact locations. This project, Server for Explosive Remnants of War Information Systems, also aims to develop geographical information system tools and methods to identify where populations are most at risk. In addition, SERWIS endeavors to Determine and Display the Degree of Operational Difficulty of Demining (5D) on account of realistic and measurable terrain criteria, such as land cover, slope, distance to sensitive points of interest, distance to roads, hydrology, etc. By combining such geospatial datasets into a multi-criteria process at the macro level, this project is meant to refine the evaluation of a country or region's demining capacity and help improve demining efficiency. Results provided by the model can act as a good starting point for operational teams that wish to prepare their intervention in the field. Decision-makers can use the model for determining the order in which contaminated areas are to be cleared and which tools should be used.



Land Cover	
11 - Irrigated croplands	120 - Mosaic grassland/forest-shrubland
14 - Rainfed croplands	130 - Closed to open shrubland
20 - Mosaic croplands/vegetation	140 - Closed to open grassland
30 - Mosaic vegetation/croplands	150 - Sparse vegetation
40 - Closed to open broadleaved evergreen or semi-deciduous forest	160 - Closed to open broadleaved forest regularly flooded
50 - Closed broadleaved deciduous forest	170 - Closed broadleaved forest permanently flooded
60 - Open broadleaved deciduous forest	180 - Closed to open vegetation regularly flooded
70 - Closed needleleaved evergreen forest	190 - Artificial areas
90 - Open needleleaved evergreen forest	200 - Bare areas
100 - Closed to open mixed broadleaved and needleleaved forest	210 - Water bodies
110 - Mosaic forest-shrubland/grassland	220 - Permanent snow and ice
	230 - no data

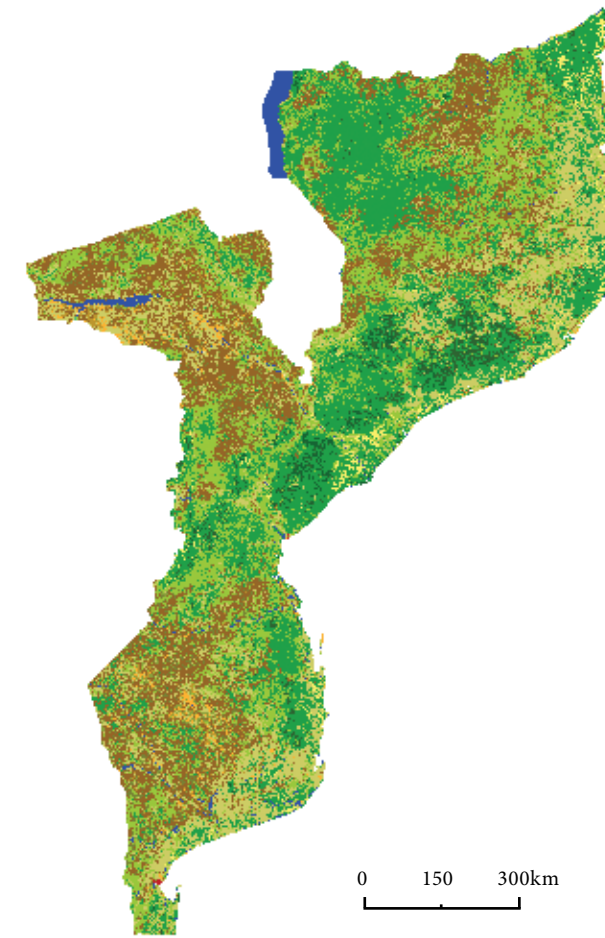
Figure 1. The GlobCover dataset. Figure courtesy of ESA GlobCover Project/MEDIAS-France.

Objectives

Thanks to the human, financial and technological support of international organizations, an area of 52 sq km was cleared in Mozambique between 2002 and 2007, using 15 demining machines. Since 2005, the number of international collaborators and donors has declined, which has decreased Mozambique's demining capacity. In late 2008, the overall mine-affected surface remained at an estimated 10 sq km, while the demining capacity was estimated at 2 sq km per year. According to these

figures, clearance of all mine-affected areas would take approximately five years. This raises a number of challenges. How can this duration be reduced? Which method (mechanical, dog detection or manual) would be most suitable for a given area, and what would be the level of operational difficulty for a given type of machine?

As a hypothesis for our model, we assume that demining is strongly dependent on geographic, environmental and socioeconomic conditions.



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Figure 2. GlobCover dataset for Mozambique. Figure courtesy of ESA GlobCover Project/MEDIAS-France.

Some of them, such as severe gradients and dense and/or high vegetation, may limit the use of certain demining tools. For example, hill-climbing capacity of demining machines is limited to a certain degree of slope. Tiller performance is reduced among dense vegetation and larger tree trunks and is highly dependent on ground softness, rock content and distance to paved roads. Human activity may also influence use of clearance machines. For example, human activity may facilitate mechanical demining, such as the development of roads and bridges providing better access to hazardous areas. When using animal detection methods, complicating factors include terrain, humidity, slope and scent contamina-

tion. All of these factors are also likely to affect the degree of difficulty in employing manual clearance methods, although to a lesser extent. Geographical data that can act as a direct or indirect indicator of the degree of difficulty are available for most of these factors. This paper focuses on mechanical demining, but does not prevent a future focus on other tools or methods. For each tool, developing a model of operational difficulty requires involving both geographers and experts on the tool in question. This enables the identification of appropriate layers of geographical data and the individual role of those layers in the model. For instance, a geographic layer on the ferromagnetic qualities of the soil might be a good



Figure 3. The slope dataset for Mozambique. Figure courtesy of ESA GlobCover Project/MEDIAS-France.

input into a model indicating the difficulty of using metal detectors, but that same layer is likely not useful when estimating the difficulty of using animal detection. Only an expert on manual demining can determine which layers a geographer proposes are relevant for manual demining. These models are also likely to depend on the local environment. The factors that make manual demining difficult in one country are likely not exactly the same in another country.

The primary objective of this article is to present an analytical method—a map—for the evaluation and visualization of the degree of operational difficulty for demining contaminated areas. By weighting various datasets, a new dataset is created and classified into four ordinal categories of demining difficulty: low, medium, high and extreme. From this dataset, macro statistics can be obtained and used in a first step. This first step aims to determine the percentage of land that may be cleared in a region or a country, with a given technique and a specific level of operational difficulty. The percentage of surface deemed extreme to demine is also estimated. In a second step, the interpretation of information regarding operational difficulty may contribute to improving decision-making to better target clearance operations in the field. This method is applicable for demining with machines, animals or human beings.

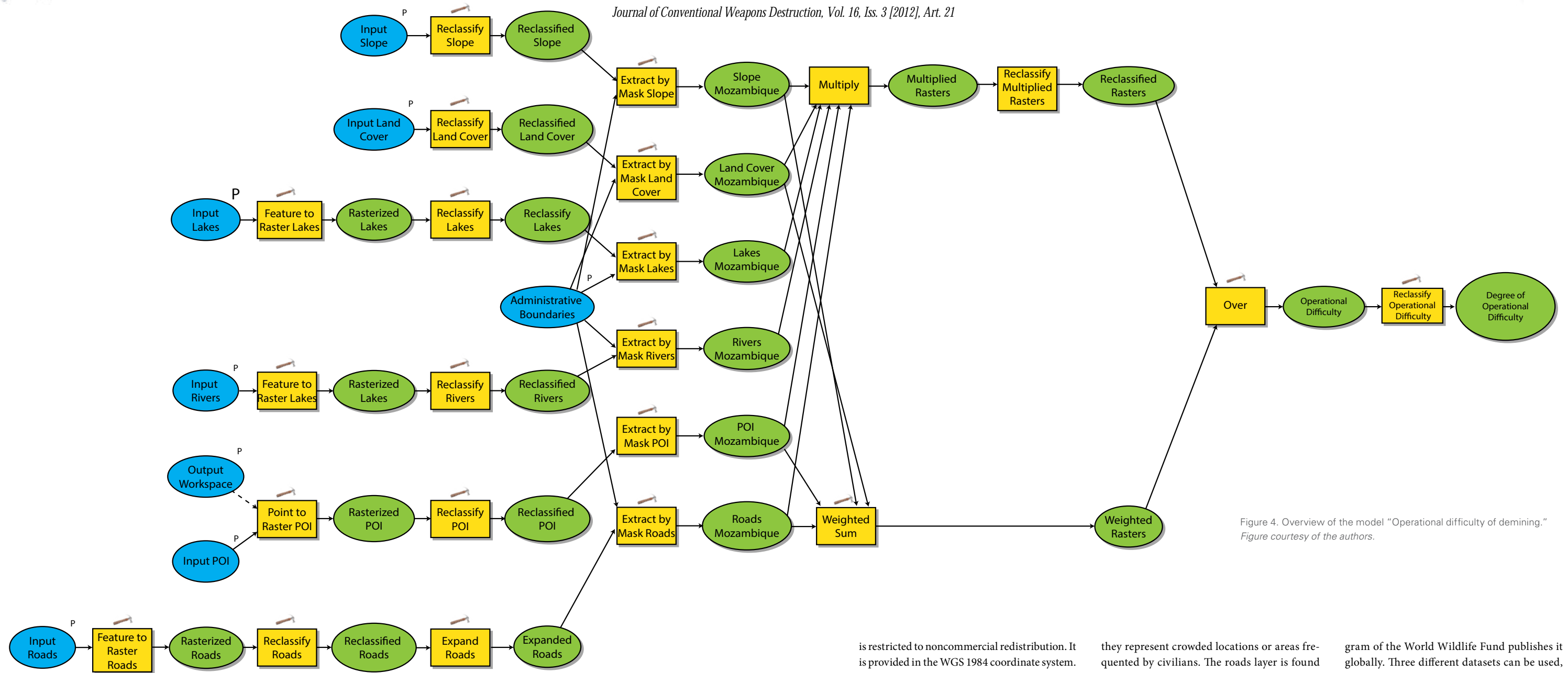


Figure 4. Overview of the model “Operational difficulty of demining.”
Figure courtesy of the authors.

A model was developed in a geographical information system called ArcGIS®, inputted with datasets obtained from different sources and applied to the entirety of Mozambique.¹ This case study focuses on mechanical demining, on the basis of a fictive machine with medium class characteristics (length with flail approximately 4.7 m; weight approximately 8T; working capacity approximately 860 sq m/hr in topsoil, 900 sq m/hr in sand, 840 sq m/hr in gravel) commonly used in many countries.

The model does not aim to estimate financial cost, hence the use of the term **operational difficulty**. A cost assessment would require data collection and analysis on a local level, while the 5D model holds national and regional relevance. For the same reason, the model does not attempt to calculate physical risk.

Inputs

The model contains seven input layers, which can be found on the Internet in the form of free global datasets. These layers include land cover, slope, points of interest, roads, rivers, lakes and national boundaries.^{2,3,4,5,6,7,8} These datasets are described below.

GlobCover Database. GlobCover is a global land cover map available for two periods, December 2004–June 2006 and January–December 2009. Data is missing for only 1% of total land area. GlobCover has been used in many fields of work (e.g., crop mapping, assessment of global forest cover and estimations of biomass burning emissions) and is easy to apply to a country like Mozambique. In the present case, this dataset was used to identify human activity such as farming and urban settlement. GlobCover is freely available online for noncommercial use at a 300 m

resolution (Figures 1 and 2, pages 52–53) in a raster format. Each pixel represents a 300 m x 300 m cell and holds a value indicating the category of land cover found at the position where it is located (see Figure 1, page 52). For instance, Category 14 corresponds to rain-fed croplands, Category 140 to sparse vegetation and Category 200 to bare areas (Figures 2 and 3, page 53). The data is in Tagged Image File Format (.tif), and the spatial reference is the World Geodetic System 1984 (WGS 1984).²

The Slope Dataset. The slope dataset (Figure 3, page 53) was obtained from the digital elevation model provided by the NASA Shuttle Radar Topography Mission. The DEM data is available in raster format, with a 3 arc-second resolution (90 m approximately), where each pixel contains an elevation value. The DEM can be obtained online in the form of a 5° x 5° tile mosaic (1° is approximately 110 km), and its use

is restricted to noncommercial redistribution. It is provided in the WGS 1984 coordinate system. For an easier download, using the “Topo View” interface is recommended. Slopes are derived from the DEM. Each pixel contains a slope value in degrees or percentages.³

OpenStreetMap. Composed of different datasets—infrastructure, water, forest cover, points of interest, administrative boundaries—this database, OpenStreetMap, is distributed under an open content license. Data is available at the global level in vector format and in WGS 1984. It can be downloaded by country. It was developed on the basis of government and commercial data sources and benefited from the contribution of volunteers worldwide. From this database, the case study on Mozambique uses the points of interest and roads layers. The POI layer stores information about the location of different features such as airports, train stations, schools, hospitals, post offices, shops, telephone boxes, car parks, etc. In the mine action framework, POI are likely to restrict demining activities, since

they represent crowded locations or areas frequented by civilians. The roads layer is found as a line shapefile and contains various categories of roads, from footways to primary roads. Unlike POI, roads are likely to facilitate activities, since they increase the access of demining resources to hazardous areas.⁴

HydroSHEDS. HydroSHEDS data is a hydrological dataset derived from the Shuttle Radar Topography Mission. This dataset includes vector and raster data such as river networks, watershed boundaries, drainage directions and flow accumulation. The HydroSHEDS dataset covers almost the entire globe, but it requires a manual download region by region. It can be used noncommercially. For this case study, the river network was used, provided in the form of river lines stored in shapefiles. The data resolution is 15 arc-seconds, approximately 500 m.⁵

GLWD. The Global Lakes and Wetlands Database was developed on the basis of seven digital maps and attribute datasets for lakes and wetlands. The Conservation Science Pro-

gram of the World Wildlife Fund publishes it globally. Three different datasets can be used, depending on the level of detail required: large lakes and reservoirs (GLWD-1), smaller water bodies (GLWD-2) and wetlands (GLWD-3). For this case study, a combination of Level 1 and Level 2 was used to include lakes with an area > 50 sq km, reservoirs with a storage capacity > 0.5 cu km and smaller water bodies with a surface > 0.1 sq km. All these datasets are provided in vector format (polygons) and for typical scales of use ranging from 1:1,000,000 to 1:3,000,000. The GLWD can be used for noncommercial, scientific, conservation and educational purposes.^{6,7}

All the databases presented above are available at the global level for free in high resolution in the WGS 1984 coordinate system and with a low percentage of missing values (less than 2%). Formats may vary from one dataset to another, but they are all well-known formats (e.g., shapefile, .tif, etc.), readable by many GIS. Table 1 (above) summarizes the main characteristics of these databases.

Characteristics	GlobCover	Slope database CIAT_CGIAR	OpenStreetMap	HydroSHEDS	GLWD
Version	V 2.2 (2009)	V. 4 (2008)	-	-	-
Update frequency	~ 3 years	~ 2 years	Continuously	-	-
Availability	Available online for any noncommercial use	Available online for noncommercial purposes	Available online for free	Available online for non-commercial use	Available online for noncommercial scientific, conservation, and educational purposes
Format	TIFF	ArcInfo ASCII and GeoTiff	Shapefile	Line shapefile	Polygon shapefile
Source	Derived from the Medium Resolution Imaging Spectrometer (MERIS) on board the European Space Agency's Envisat platform	Derived from the digital elevation model (DEM) provided by the NASA Shuttle Radar Topography Mission (SRTM)	Developed on the basis of government and commercial data sources and the contribution of volunteers around the world	Hydrological dataset derived from the SRTM. Developed by WWF's Conservation Science Program	Developed on the basis of seven digital maps and attribute data sets by the University of Kassel, Germany and WWF
Resolution	300 m	3 arc-seconds (Approximately 90m)	-	15 arc-seconds (Approximately 500m)	For typical scales of use from 1:1,000,000 to 1:3,000,000
Extent	All contaminated countries are covered	All contaminated countries are covered. Can be downloaded by tiles of 5°x 5°	All contaminated countries are covered. Can be downloaded country by country	All contaminated countries are covered. Can be downloaded by region	All contaminated countries are covered

Table 1. Main characteristics of the input datasets. Table courtesy of the authors.

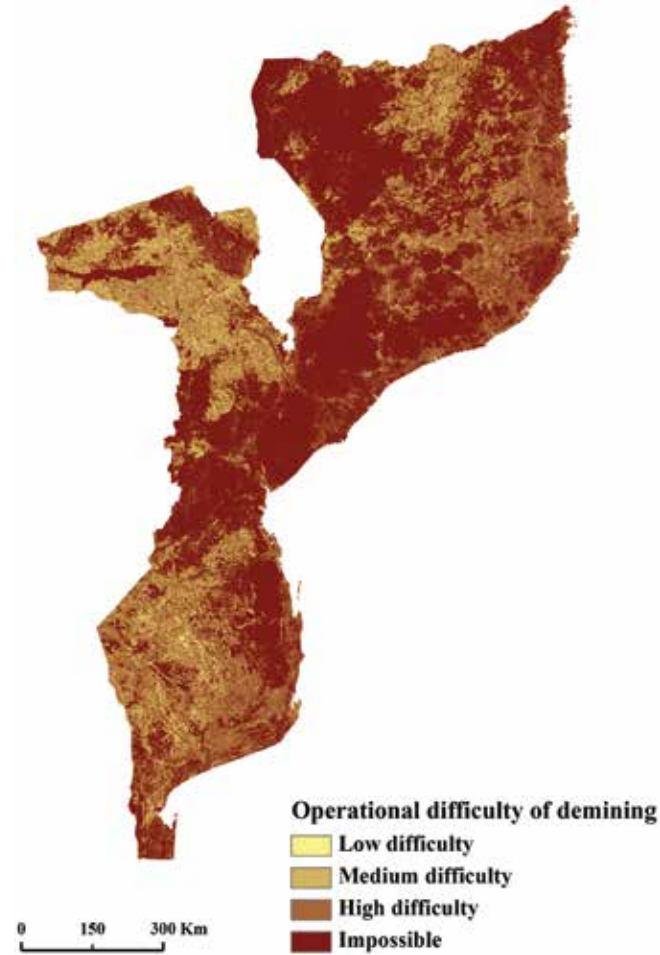


Figure 5. This output raster represents the operational difficulty of demining in Mozambique for a fictive demining machine with medium class characteristics, as is commonly used in many countries. Figure courtesy of the authors.

Category	Degrees of operational difficulty of demining
3	Low
2	Medium
1	High
0	Extreme

Table 2. Degree of operational difficulty of demining. Table courtesy of the authors.

The Model

As shown in Figure 4 (pages 54–55), the model is composed of (1) input data, (2) tools, (3) outputs and (4) parameters.

Input data include Mozambique’s administrative limits and the six layers described above: land cover, slope, POI, roads, rivers and lakes. A blue oval symbolizes each input data in Figure 4.

Orange rectangles represent the model tools in Figure 4. Each rectangle corresponds to a particular step in the model workflow, e.g., extraction on a given area, conversion from vector to raster, raster reclassification, weighting and generation of the final map.

Input data are first extracted on the entirety of Mozambique. A conversion tool is then used to transform the four input vector layers (POI, roads, rivers and lakes) to raster layers for further cell-by-cell analysis. During this conversion, a 200 m resolution is applied to recognize the original data precision (Table 1, above) while keeping the model performing at macro scale. Given that they represent quantitative or qualitative factors not in the same units, the six raster layers need placement on a similar ordinal scale. For this reason, they are reclassified to four categories that are meant to represent the four degrees of operational difficulty (Table 2, above). To do this, each pixel is assigned a value from 0 to 3 (Table 3, page 57). The reclassified layers are weighted and combined to a new “Operational Difficulty” raster. Weights are expressed in percentages (e.g., 20% or 30%; see Table 4, page 57). The higher the weight, the higher the influence the layer is on the degree of operational difficulty.

Outputs of the model are the green ovals in Figure 4 and correspond to data generated by the execution of model tools, including the final map on the extreme right of the model. The final map (Figure 5, left) is generated by reclassifying the “Operational Difficulty” raster on a scale from 0 to 3 and is composed of 200 m x 200 m pixels, where each is assigned a value representing an ordinal degree of operational difficulty of demining: low, medium, high or extreme. Areas where demining is set as extreme hold the value 0 and are colored in dark brown (e.g., lakes,

Description	Degree of Difficulty
Globcover	
11 Post-flooding or irrigated croplands (or aquatic)	High 1
14 Rainfed croplands	High 1
20 Mosaic cropland (50–70%) vegetation (grassland/shrubland/forest) (20-50%)	Medium 2
30 Mosaic vegetation (grassland/shrubland/forest) (50-70%) cropland (20-50%)	High 1
40 Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	Extreme 0
50 Closed (>40%) broadleaved deciduous forest (>5m)	Extreme 0
60 Open (15–40%) broadleaved deciduous forest/woodland (>5m)	Extreme 0
70 Closed (>40%) needleleaved evergreen forest (>5m)	Extreme 0
90 Open (15–40%) needleleaved deciduous or evergreen forest (>5m)	Extreme 0
100 Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	Extreme 0
110 Mosaic forest or shrubland (50–70%) / grassland (20–50%)	High 1
120 Mosaic grassland (50–70%) / forest or shrubland (20–50%)	Medium 2
130 Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	Medium 2
140 Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	Low 3
150 Sparse (<15%) vegetation	Low 3
160 Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) — Fresh or brackish water	Extreme 0
170 Closed (>40%) broadleaved forest or shrubland permanently flooded — Saline or brackish water	Extreme 0
180 Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil — Fresh, brackish or saline water	Extreme 0
190 Artificial surfaces and associated areas (Urban areas >50%)	Extreme 0
200 Bare areas	Low 3
210 Water bodies	Extreme 0
220 Permanent snow and ice	Extreme 0
230 No data (burnt areas, clouds, etc.)	Extreme 0
Slope	
0° - 30°	Low 3
30° - 35°	High 1
> 35°	Extreme 0
Roads	
Sites located < 1 km away from a road	Low 3
Sites located > 1 km away from a road	High 1
Points of interest	
POI	Extreme 0
Sites not considered as a POI	Low 3
Rivers	
Inside the river	Extreme 0
Land	Low 3
Lakes	
Inside lakes	Extreme 0
Land	Low 3

Table 3. Classification of the input layers in four categories of operational difficulty. Table courtesy of the authors.

Layer ¹	Weight
Land cover	30%
Slope	30%
Roads	20%
Points of interest	20%

Table 4. Weighting of the input layers. Weights provided in this table are fictive and will not reflect reality. Table courtesy of the authors.

rivers, dense vegetation, high degree of slope, etc.). Areas where demining is considered very difficult are colored in brown and assigned the value 1. A value of 2 indicates medium difficulty (in orange) and a value of 3 indicates low difficulty (e.g., buffers around roads in yellow).

In Figure 4 (pages 54–55), model parameters can be identified by the letter P above a blue or a green oval, offering the user the option of specifying the value before running the model. Administrative limits are placed into parameters, because the model is meant to be applied to any country and region in the world. Environmental, geographical and socioeconomic factors (land cover, slope, POI, roads and hydrology) are applied using parameters as well, because they may influence operational difficulty of demining in different ways for different study areas while using different demining techniques. It is possible to add further parameters to the model: other factors (e.g., human settlements, temperature gradients, conflict zones, etc.), the weights of Table 3, the weights of Table 4, and so on. The underlying complexity of the workflow (Figure 4, pages 54–55) is hidden from the users (e.g., decision-makers and operations) who only interact with the system through this set of parameters (Figure 6, page 58).

Benefits of the Model

The model is a powerful tool that can calculate in 30 minutes an operational difficulty layer of the entirety of Mozambique (about 800,000 sq km), with a 200 m resolution. In addition, the model is flexible, user-friendly and does not require advanced GIS skills from its users.

It holds national and regional relevance, and is potentially applicable to any mine-affected country. Since environmental, geographical and socioeconomic conditions vary from one country to another, the input data, the area of study and the weights can be set as the model’s parameters. Other parameters (e.g., human settlements, temperature gradients, soil types and characteristics, elevation, conflict zones, etc.) can be added as inputs according to data availability and user needs.^{9,10}

The main output of the model is a map. With it, users have an overview of the situation in their area of work at a glance. The map can also be overlaid with other information such as hazardous areas, population densities, internally displaced populations, etc.

Zonal statistics can easily be derived from the

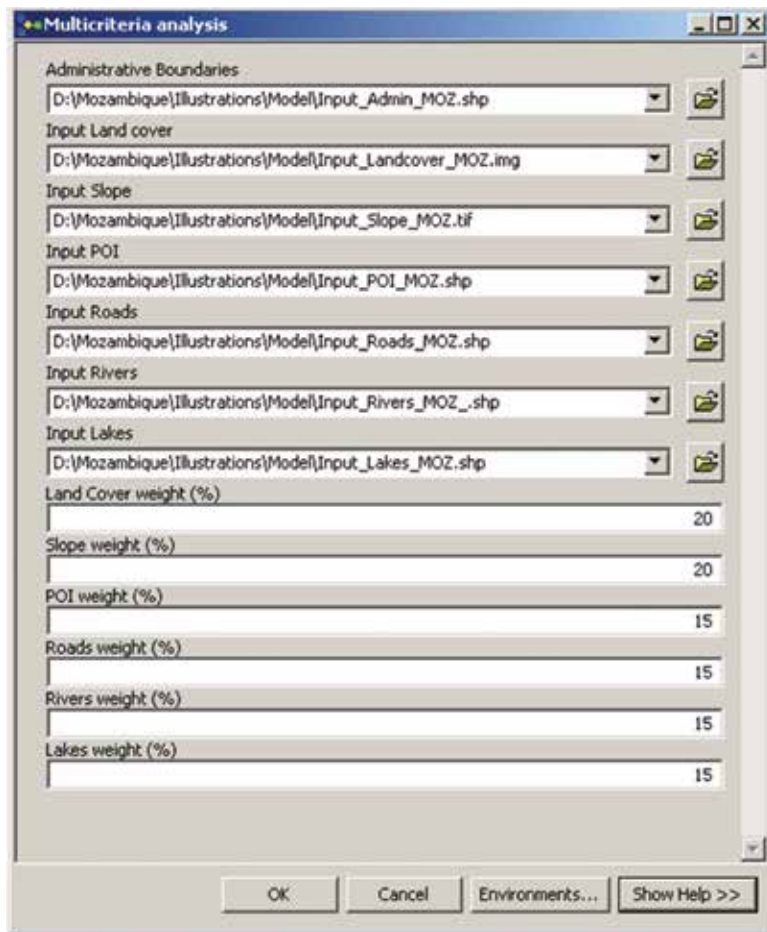



Figure 6. Parameters provided to users at the execution of the model.
Figure courtesy of the authors.

output raster map for each degree of operational difficulty. For example, the overall surface with a low degree of difficulty is directly read into the output raster. This kind of information may be significant for decision-makers and operators, especially in financial terms. With further work, in fact, this model opens the possibility to estimate the financial implications of their operational choices.

Conclusion

The 5D model is a first approach for modeling an operational difficulty of demining at a macro level. The model was developed in ArcGIS® Desktop, which is readily available in most mine-affected countries. Users interact with the model via an intuitive and graphical interface by using a set of parameters that can be modified each time the program runs, especially the area of study and input factors. Even if the workflow may seem complex, using the model does not require intensive GIS skills.

The resulting map is a good starting point

for decision-makers and operators to refine their evaluation of the degree of operational difficulty and improve efficiency in their work. However, this tool is intended as a guide, and real world political or economic factors may lead to or prevent demining activities in a way that may disagree with the tool. In addition, deminers should be aware that modification of one parameter could affect the outputs of the model significantly. 

See endnotes page 67



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