Elaboration of gravitational mass movement predisposition chart based on decision support method: part of the city of Ouro Preto, State of Minas Gerais, Brazil

BERENICE BITENCOURT RODRIGUES[1] & LÁZARO VALENTIM ZUQUETTE [2]

[1] Rua Horizontina, 103, Belo Horizonte, Minas Gerais, 30.480-150, Brazil Tel: +55 31 3332 2194
(e-mail: berenicerodrigues@yahoo.com.br)
[2] Geology, Escola de Engenharia de São Carlos/Universidade de São Paulo. (e-mail: lazarus1@sc.usp.br)

Abstract: This work presents the results on the possibility of the occurrence of gravitational mass movements obtained in part of the urban area of Ouro Preto, state of Minas Gerais, Brazil, using the Analytic Hierarchic Process method (AHP) carried out at scale 1:2,000. The decision support systems have been used for the assessment of natural event predisposition because the evaluation is more adjusted to the natural environmental complexity and improve the precision of the results, beyond the possibility of the specific study of the influence of each one of the natural components in the natural processes. It was considered a group of 24 attributes of the environmental components (relief, lithology, unconsolidated material, use and occupation, register of gravitational mass movements). The study permitted the elaboration of the chart of gravitational mass movement predisposition as well as to define the predisposition degree (high, average or low) for each unit.

Résumé: Ce travail presente dês resultats qui on rapport à la possibilité de l´ocurrence de mouvements de masse de gravitations obtenus dans une part de la surface urbainede Ouro Preto, état de Minas Gerais, Brésil, qui utilise le méthode de Procédure Hierarchique Analytique (AHP) dans l´échelle 1:2000. Routines dápui à la décision ont été utilisée pour l´évaluation de prédisposition des évenements naturels parce que ce genre l´évaluations est celui qui mieux s´adapte à la complexité ambiante naturelle et améliore la précision des resultats, outre la possibilité de l´etude spécifique de l´influence naturel dans de procéde naturels. On a consideré un groupe des 24 (vingt-quatre) attributs de composants ambiants (relief, lithologie, matériel non consolidé, utilisation et occupation, enregistrements de mouvements de masse en gravitation l´étude a permit l´élaboration d´une carte de prédisposition des mouvements de masse en gravitations define comme haute, moyenne et baisse pour chaque unité

Keywords: engineering geology, environmental urban geotechnics, land use, mass movement, risk assessment, slope stability.

INTRODUCTION

Urban areas may be considered to form part of a complex system, where human activities are inter-linked with the natural environment. The system evolves dynamically and changes in land use can influence other elements of the system. These changes may include for example, the occurrence of natural events, such as the gravitational mass movements. These events can directly affect urban areas, generating economic, social and environmental damage. However, methods of forecasting natural event, such as mass movements, are complex and are being investigated in different countries, taking into account to the local characteristics for each region.

In developed countries, which have a high quantity of data, forecasting methods may be sophisticated, not only in terms of the models used but also in mathematical and statistical analysis. However, by comparison, in regions where data is insufficient, forecasting methods vary considerably and sometimes data sets are not properly considered.

In Brazil many of these forecasting studies are obtained simple by overlaying maps and the various contributory factors are rated and ranked. This has been complimented by engineering geological mapping which provides a useful source of data.

Ouro Preto, is located in the state of Minas Gerais, Brazil, and has reasonable engineering geological map coverage. Data was selected and evaluated for this region by means of the Analytic Hierarchic Process. This allows the use of qualitative and quantitative data in the analysis. This paper presents the results obtained through the use of Analytic Hierarchic Process in the studies of the gravitational mass movement in part of the urban area of Ouro Preto. The process took into consideration a set of 24 attributes related to gravitational mass movement obtained from a general list proposed by Zuquette (1993).

The principle in the Analytic Hierarchic Process, introduced by Saaty (1977), is to divide a complex problem into simple problems, in the form of a hierarchy of decision. As well as permitting a decision to be made based on qualitative and quantitative criteria. Different and contradictory points of view can be taken into account. As its main advantage, the method not only considers interdependent attributes, related to the objective, but also evaluates the areas in terms of gravitational mass movement predisposition, lowering the subjectivity of the process.

In the Analytic Hierarchic Process the selection consists of its organization in hierarchical levels, in order to have a global view of the relations involved in the process. In the construction of paired matrices in each level of the hierarchy the results of each matrix are compared. The procedures involed in the Analytic Hierarchic Process areas follows:

- Create a hierarchy of decisions, dividing the problem into different levels.
- Define the relative importance of the elements of the decision by means of pairwise comparison. The ranking process defines the type of number to use, and how to accurately combine priorities. Saaty (1990) proposes a relative reference rank varying from 1 to 9. Where 1 refers to the elements in the matrix in the analysis that have the same level of influence in the process and 9 to that with the highest level of influence.
- Determine if the initial data is satisfying in a test of consistency, otherwise, redo the pairwise comparison.
- Calculate the partial relative normalized index of the elements of decision.
- Considering the partial relative normalized index calculate the final index to finish the evaluation and put zones in hierarchies.

The Analytic Hierarchic Process assigns values of relative importance to the elements of the problem. The closer the Consistence Index is to 0 (zero), the higher the consistence of the matrix of comparison is:

$IC = (\lambda máx - n) / (n - 1)$

Where λmáx is the maximum eigenvalue and n is the matrix order.

The relationship between the Consistence Index and the Random Index is called Consistence ratio, which must be $\leq 0{,}10$.

A matrix is considered suitable when:

- The maximum eigenvalue (λmax) is approximately equal to its order n. The closer the λmax is of n, the better the result.
- It is considered that the λmax must be closer to the n.
- The Consistence Index must be equal to zero or very close to that, otherwise the matrix must be remade.
- Random Index (RC) must be $\leq 0{,}10$.

BASIC CHARACTERISTICS OF THE AREA

The study area is located in the southeast of the state of Minas Gerais, in the urban area of Ouro Preto, Brazil, at coordinates 655.000 km E to 656.800 km E and 7745.000km N to 7746.600 km N. It covers an area of approximately 2 km^2 (Figure 1).

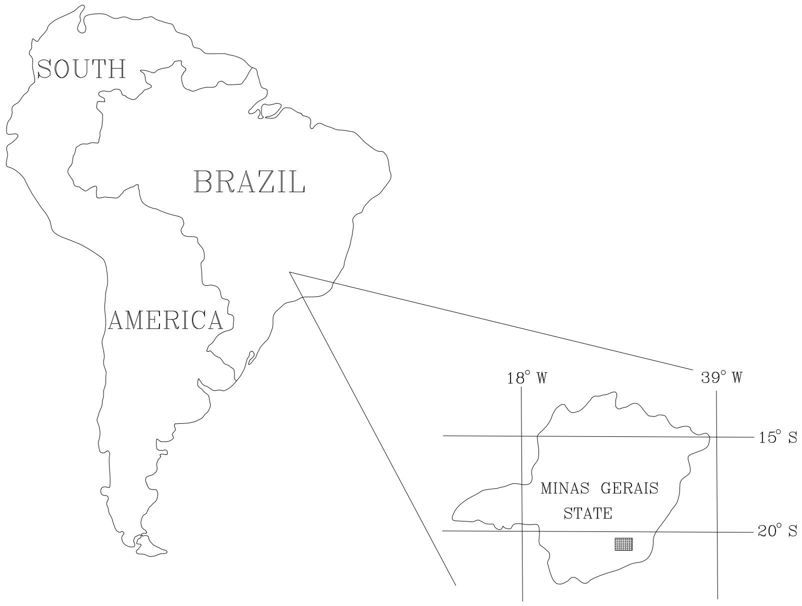

Figure 1. Location of the study area.

The climatic in the region is typically tropical, wet, with dry winters and mild summers. It has an annual average temperature of 18.5°C and an annual average precipitation varying from 1005 mm to 2317 mm. Figure 2 provides a general view of the region showing the development of incised drainage channels and dense human occupation of the lower and middle slopes.

Geologically the area is located within the 'Quadrilátero Ferrífero' region. The bedrock consists of low to medium grade metamorphic rocks (phyllites, schist, and quartzites) which have been extensively fractured due to tectonic ground movements, weathering and erosion.

Figure 2. General view of the study area (upper portion of the photo).

METHODOLOGY

The predisposition of the occurrence of gravitational mass movements was evaluated for the region. This study area was divided into cells measuring 50 m by 50 m and this produced 736 cells. A group of 24 attributes (natural and anthropic) were identified which had a direct or indirect influence on mass movements. A datasheet containing the 24 attributes and their respective classes was developed for each cell.

To apply the Analytic Hierarchic Process four levels of hierarchy were defined (Figure 3). The first level refers to the goal or predisposition to the occurrence of gravitational mass movements. The second refers to the components of the environment, which influence positively or negatively the occurrence of the events. The third refers to the attributes of each selected environmental component and the fourth refers to the classes of attributes.

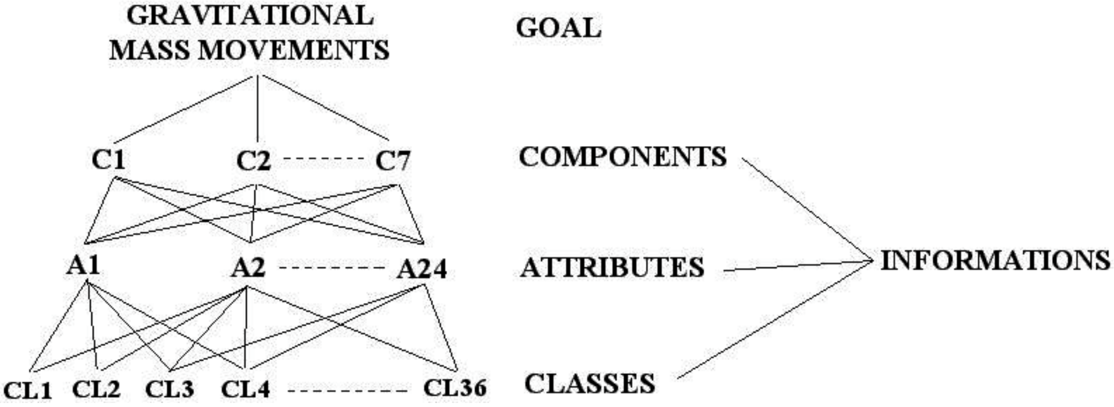

Figure 3. Hierarchy levels to obtain the Final Index of Predisposition for each cell in relation to the occurrence of gravitational mass movement.

To help and conduct the definition of weights more accurately two theoretical models related to security have been taken into consideration. The first model is represented by the following equation:

A [Σ (favorable attributes to stability + attributes that positively affect the favorable ones)] =
B [Σ (favorable attributes to predisposition + potential attributes to the favorable ones to predisposition)]

This model allows considering a time analysis, the space variability of information and different types of information (qualitative and quantitative), since in this way the attributes can be classified in relation to the predisposition of the gravitational mass movements.

The second is based on a set of singular aspects that condition the balance/unbalance for each type of gravitational mass movement considered, such as infinite slope to soil translational landslides, rock falls and fallings, planar landslides and in wedge rock failure, rolling of blocks and flows.

- For soil translational landslides:

  $Fs = \{Cr + C' + [\gamma(Z - hw) + (\gamma_s - \gamma_w)hw]\cos^2 \beta \, tg\phi\} / \{\gamma(Z - hw) + \gamma_s hw] \, sen\beta \cos\beta\}$

  Where Cr is the cohesion to areas with vegetation, C' is effective cohesion, γ is unsaturated specific weight, γs is saturated specific weight, γw is water density, β is declivity, ϕ is effective friction angle, hw is height of underground water and Z is surface depth.

- For Rock Planar Failure:

  $\alpha p = \alpha f \pm 20^\circ$ $\qquad \psi p < \psi f \qquad \Phi p > \alpha p$

  Where αp is the plane dip direction, ψf is slope dip direction, ψp is plane dip, ψf is slope dip and Φp is friction angle of plane

- For Wedge Failure Model:

  $\alpha i = \alpha f +/- (\text{slope face}) \qquad \psi i < \psi f \qquad \Phi > \psi i$

  Where αf is dip direction of face, αa is dip direction of plane “a”, αb is dip direction of plane “b”, αi is azimuth of intersection, ψf is dip of face, ψa is dip of plane “a”, ψb is dip of plane “b”, ψi is plunge of intersection and Φ is friction angle.

- For Toppling Failure:

  $\alpha p = (\alpha f +/- 180^\circ) +/- 20^\circ \qquad (90^\circ - \alpha p) </= (\psi f - \Phi p)$

  Where αp is the plane dip direction, αf is slope dip direction, ψp is plane dip, ψf is slope dip, ψb is slope dip, Φp is friction angle of plane and Φb is base friction angle.

From this paired matrix with the values of relative importance already defined, a Partial Relative Normalized Index for the different components, attributes and classes was obtained through the calculation of a respective eigenvector, considering the consistence index and the consistency ratio for each matrix.

Based on the results obtained, the Final Predisposition Index to the occurrence of gravitational mass movements was calculated for each cell, adding the Partial Relative Normalized Index of the classes, multiplied by the Partial Relative Normalized Index of attributes, and multiplied by the Partial Relative Normalized Index of the components, in accordance with the following equation:

$IFIE_c = {}^1\Sigma_n \, IPRC \times IPRA \times IPRCO$

Where IFIEc is the Predisposition Final Index for cell, IPRC is the Normalized Relative Index of Classes, IPRA is Normalized Relative Index of Attributes, PRCO is the Normalized Relative Index of Components and n are the Components.

To elaborate the predisposition chart a classification was done based on a graduation in which three classes were defined according to its predisposition level: A (high), M (intermediate) and B (low). To define the boundary-values between the classes the average and the standard deviation of the IFIE values for the set of 736 cells was taken into consideration.

RESULTS AND ANALYSIS

The area in study was divided into 736 cells of 50 x 50 m, as it is shown in Figure 4, and each cell was identified by a letter representing a line and a number representing a column. The procedure of division in regular units was used due to the difficulties in dividing the area in basins and slopes, for example. The data (attributes and classes) were obtained through work of engineering geological mapping developed by Souza (1996), Bonuccelli (1999) and Zenóbio (2000), with validations and updates of information in terms of samples and temporal aspects, considering the scale of work (1:2,000) and the dimensions of the cells.

Geology

Table 1 shows the main rock types and geological formations that occur in the area. These were determined from field investigations and correspond to the work undertaken in the area by Zenóbio’s (2000). The rock types in the area are classified as ‘soft’ and ‘hard’ rocks. However, localised structures such as folds, faults and mineral veins can change the strength of the rock mass. In general, the strata dip NW to SE regional and folds plunge to the SW (Figure 5).

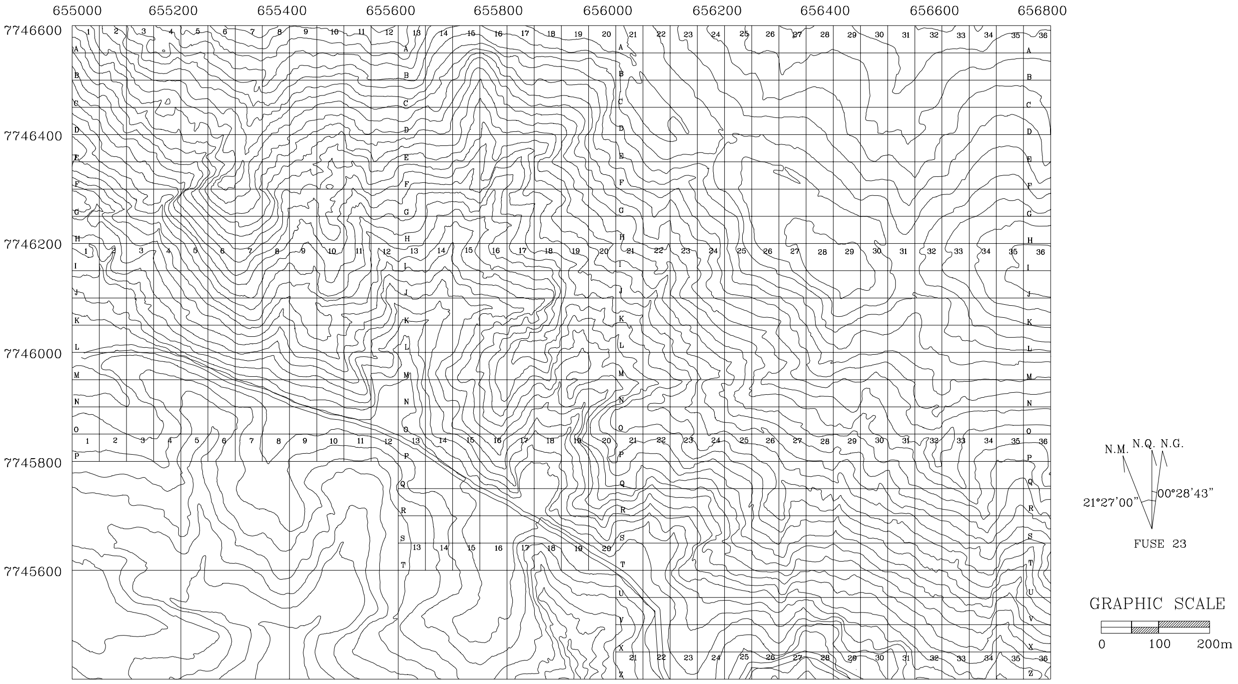

Figure 4. Map of the study area presenting the distribution of cells (minimum area for Decision Taking)

Table 1. Lithostratigraphic column of the area .

Supergroup	**Group**	**Formation**	**Lithology**
	Sabará	-	chlorite-schist
Minas	Piracicaba	Cercadinho	quartzites and phyllites
	Itabira	Cauê	itabirito
	Caraça	Batatal	phyllites
		Moeda	sericite quartzite
Rio das Velhas	Nova Lima	-	quartz-sericite-schist

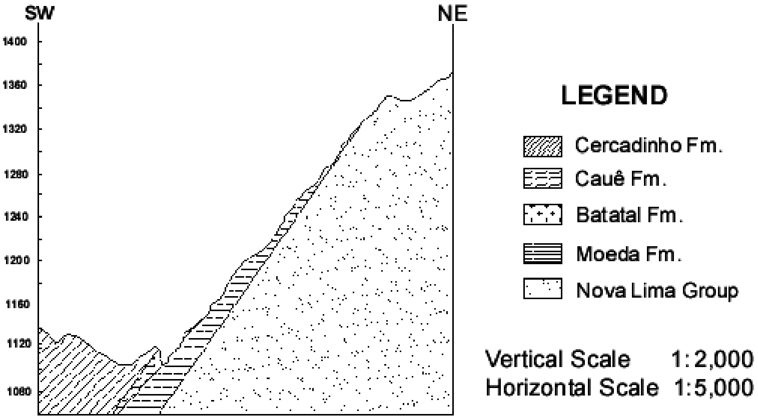

Figure 5. Cross section in the SW – NE direction (After Zenóbio, 2000).

Unconsolidated Material

According to Souza (1996) and Bonuccelli (1999), and based on the classification of weathering degree proposed by ISRM (1981), the soil in the area was classified as V (completely weathered rock or saprolites) and VI (residual soil).

Approximately 40% of the urban area around Ouro Preto contains soils (colluvial, residual and saprolite) which are less than 10m thick. These overlie intensely weathered bedrock (degree IV). The soil textures are predominantly silty, sandy and silty sand. Furthermore, about 16% of the area contains residual laterite originated from the weathering of rocks with high quartz and haematite (such as quartzites, phyllites and iron-rich schist).

Based on these soil characteristics the components, attributes and classes were selected for analyses in terms of gravitational mass movement predisposition as shown in Tables 2a and 2b. The division of components in 7 categories (unconsolidated material, relief 1, relief 2, soil uses, vegetation, lithology and characteristics of gravitational mass movement features in slopes) are due to the conditions of the study area, as well as the mechanisms considered for the different types of gravitational mass movement (translational landslides, falls of rocks, rolling of blocks and flows).

T**able 2a.** Components, attributes and classes, and respective Partial Relative Normalized Index

COMPONENTS	**PARTIAL RELATIVE NORMALIZED INDEX**	**ATTRIBUTES**	**PARTIAL RELATIVE NORMALIZED INDEX**	**CLASSES**	**PARTIAL RELATIVE NORMALIZED INDEX**
LITHOLOGY	0.101521	A – PREDOMINANT TYPE	0.209652	1 – SCHIST	0.237288
				2 – QUARTZITE	0.091404
				3 – ITABIRITO	0.140436
				4 – PHYLLITE	0.530872
		B – COMBINED TYPES	0.209652	1 – QUARTZITE/SCHIST	0.112658
				2 – QUARTIZITE/ITABIRITO	0.075316
				3 – QUARTZITE/SCHIST/ITABIRITO	0.244304
				4 – PHYLLITE/QUARTZITE/ITABIRITO	0.567722
		C – SPATIAL RELATION	0.209652	1 – INTERBEDDED	0.571709
				2 – ASSOCIATED	0.142764
				3 – LENS	0.285527
		D – MECHANICAL RESISTENCE	0.3710430	1 – WEAK	0.229419
				2 – HARD	0.059322
				3 –INTERCALLED HARD/WEAK	0.185835
				4 – LOOSE	0.525424
UNCONSOLIDATED MATERIAL	0.17576	A – TYPE	0.353003	1 – COLLUVIAL/TALUS	0.204767
				2 – SANDY MATURE RESIDUAL	0.106292
				3 – CLAYED SILT MATURE RESIDUAL	0.062134
				4 – SANDY RESIDUAL	0.136772
				5 - CLAYED SILT RESIDUAL	0.053146
				6 – SANDY SAPROLITE	0.155139
				7 – CLAYED SILT SAPROLITE	0.048066
				8 – EARTHFILL	0.217663
				9 – NONE	0.016022
		B – MECHANICAL RESISTENCE CHARACTERISTICS	0.165964	1 – A5 (ISRM) –SAPROLÍTE SOIL	0.077798
				2 – A6 (ISRM) – RESIDUAL SOIL	0.063694
				3 – COLLUVIAL	0.295723
				4 – COMPACTED EARTHFILL	0.203822
				5 – WASTES DEPOSITS	0.247953
				6 – ALLUVIAL	0.066424
				7 – NONE	0.044586
		C – THICKNESS	0.310854	1 – < 2 m	0.594156
				2 – 2 TO 10 m	0.222078
				3 – > 10 m	0.129221
				4 – NONE	0.054545
		D – POTENTIAL FAILURE DISCONTINUITY	0.170179	1 – UNCONSOLIDATED/ROCK MATERIAL	0.401504
				2 –RESIDUAL SOIL ON SAPROLITE SOIL	0.213033
				3 – GEOLOGICAL DISCONTINUITIES	0.158396
				4 – GEOLOGICAL CONTACTS	0.109774
				5 – OTHERS	0.079198
				6 – NONE	0.038095
RELIEF 1	0.32109	A – DECLIVITY	0.700955	1 – < 10%	0.034607
				2 – 10 TO 30%	0.053719
				3 – 30 TO 45%	0.094525
				4 – 45 TO 70%	0.155992
				5 – 70 TO 100%	0.257231
				6 – > 100%	0.403926
		B – TOPOGRAPHIC AMPLITUDE	0.19324	1 – < 10 m	0.055345
				2 – 10 TO 20 m	0.094411
				3 – 20 TO 35 m	0.155182
				4 – 35 TO 50 m	0.255562
				5 – > 50 m	0.439501
		C – SLOPE LENGHT	0.105805	1 – < 20 m	0.087995
				2 – 20 TO 35 m	0.15676
				3 – 35 TO 70 m	0.272145
				4 – > 70 m	0.087995

Table 2b (continuation...). Components, attributes and classes, and respective Partial Relative Normalized Index

COMPONENTS	**PARTIAL RELATIVE NORMALIZED INDEX**	**ATTRIBUTES**	**PARTIAL RELATIVE NORMALIZED INDEX**	**CLASSES**	**PARTIAL RELATIVE NORMALIZED INDEX**
RELIEF 2	0.145349	A – CURVATURE (V/H)	0.467279	1 – LINEAR/CÔNCAVE	0.161087
				2 – CONVEX/CÔNCAVE	0.139819
				3 – CÔNCAVE/CÔNCAVE	0.269791
				4 – LINEAR/CONVEX	0.086254
				5 – CONVEX/CONVEX	0.034659
				6 – CÔNCAVE/CONVEX	0.081134
				7 – LINEAR/LINEAR	0.057503
				8 – CONVEX/LINEAR	0.039779
				9 – CÔNCAVE/LINEAR	0.129972
		B – POTENTIAL PATH	0.160161	1 – 1 CELL CONTRIBUTION	0.093057
				2 – 2 CELL CONTRIBUTION	0.150916
				3 – 3 CELL CONTRIBUTION	0.197203
				4 – 4 CELL CONTRIBUTION	0.225169
				5 – MORE 4 CELL CONTRIBUTION	0.333655
		C – NUMBER OF SURFACES	0.095293	1 – 1	0.095293
				2 – 2	0.160161
				3 – 3	0.277268
				4 – > 4	0.467279
		D – SLOPE POSITION	0.277268	1 – HIGHEST PORTION	0.217178
				2 – INTERMEDIATE PORTION	0.49816
				3 – LOWEST PORTION	0.284663
VEGETATION	0.046959	A – TYPE	0.599856	1 – SAVANA	0.241964
				2 – ROCK WITH SAVANA	0.138515
				3 – FRUIT PLANT	0.120397
				4 – FOREST	0.499123
		B – PORCENTAJE OCCUPIED BY VEGETATION	0.4001440	1 – < 5%	0.054003
				2 – 5 TO 20%	0.10864
				3 – 20 TO 70%	0.280813
				4 – > 70%	0.556544
LAND USES	0.033095	A – TYPE	0.230769	1 – HABITATIONAL CONSTRUCTION	0.402792
				2 – PUBLIC STRUCTURES	0.217846
				3 – COMMERCIAL CONSTRUCTIONS	0.129611
				4 – PARKS	0.110668
				5 – AGRICULTURE	0.080259
				6 – NONE	0.058824
		B – PORCENTAJE OCCUPIED BY USES	0.307692	1 – < 5%	0.402792
				2 – 5 TO 20%	0.217846
				3 – 20 TO 50%	0.129611
				4 – 50 TO 90%	0.110668
				5 – > 90%	0.080259
		C – MAN-MADE SLOPES	0.461538	1 – < 2	0.055521
				2 – 2 TO 5	0.106675
				3 – 5 TO 10	0.310044
				4 – >10	0.52776
GRAVITATIONAL MASS MOVEMENT FEATURES	0.176208	A – NUMBER OF FEATURES	0.420648	1 – NONE	0.052872
				2 – 1	0.108355
				3 – 2	0.246736
				4 – > 2	0.592037
		B – TYPE	0.27732	1 – NONE	0.016807
				2 – ROCK PLANAR FAILURE	0.192877
				3 – SOIL TRANSLATIONAL LANDSLIDES	0.251701
				4 – COMPLEX MOVEMENT	0.17487
				5 – EROSION	0.041617
				6 – PIPING	0.060824
				7 – EARTHFILL	0.071228
				8 – WASTES	0.09964
				9 – ROCK FALL	0.090436
		C – AFFECTED AREA	0.119165	1 - NONE	0.035223
				2 – < 25%	0.097413
				3 – 25 TO 50%	0.159604
				4 – 50 TO 75%	0.264172
				5 – 75 TO 100%	0.443588
		D – ACTIVITY DEGREE	0.182867	1 - NONE	0.067342
				2 – ACTIVE	0.494636
				3 – DORMANT	0.290822
				4 – STABLE	0.147199

When the calculations of the IFIE for all the cells were completed, the graph presented in Figure 6 was elaborated with the distribution of cells in relation to the obtained values. The maximum and minimum values found for the IFIE calculated for all the study area were, respectively, $IFIE_{max}$=37,062 and $IFIE_{min}$=9,073 with average and standard deviation of 21,035 and 4,585, respectively.

Figure 7 presents a space distribution of values referring to the Final Index of Predisposition of the Cell for the total set of cells that had been grouped in categories, frequency and percentage of cells per category and are presented in Table 3.

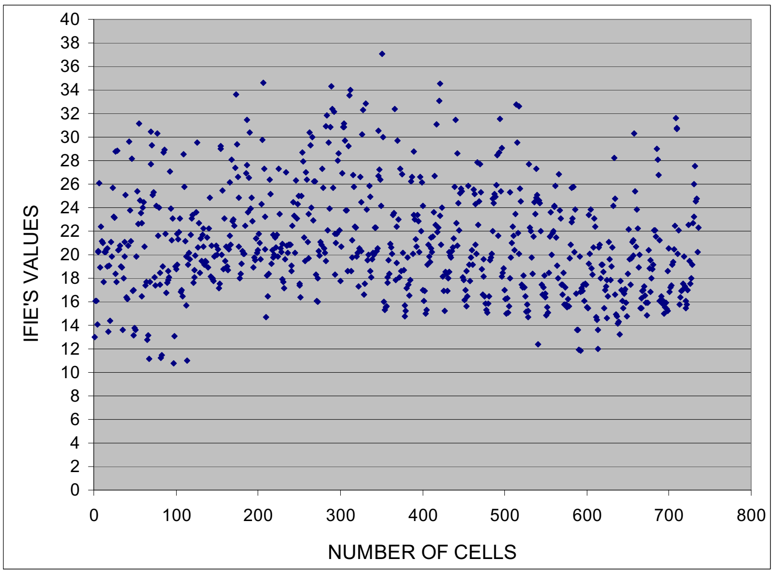

Figure 6. Distribution of cells according to the values of IFIE.

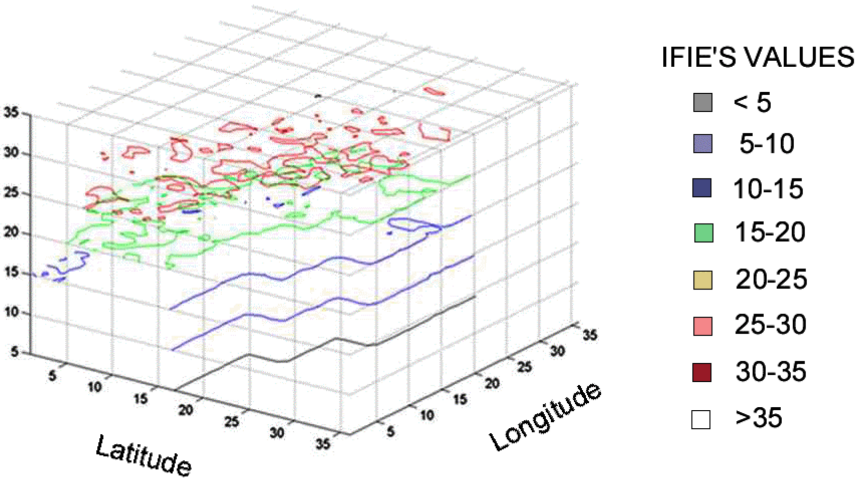

Figure 7. Distribution of IFIE values for the study area.

Table 3. Categories, frequency and percentage of cells in each category defined according to the Final Index of Predisposition of the Cells (IFIE).

IFIE VALUES	FREQUENCY (Number of cells)	PERCENTAGE
31 - 37.062	23	3.125
28 - 31	45	6.11413
25 - 28	72	9.782609
23 - 25	78	10.59783
20 - 23	178	24.18478
18 - 20	137	18.61413
15 - 18	163	22.14674
13 - 15	29	3.940217
12 - 13	3	0.407609
9.73 - 12	8	1.086957

The study enabled the classification of each cell according to their degree of predisposition to gravitational mass movement, and using these individual values a zonation was developed considering 3 categories of predisposition.

To define the degree of predisposition, the extreme limits, the average and standard deviation values were taken into consideration. Consequently, the limits defined were: high degree (A) with values superior to 23, medium degree (M) with values between 23 and 15 and low degree (B) with values less than 15. The distribution of these classes in relation to the study area can be observed in Figure 8.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
A	B	M	M	B	B	M	B	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
B	M	B	M	B	B	B	B	B	M	M	M	M	M	A	A	A	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
C	M	M	B	B	B	B	M	M	M	M	M	M	M	A	M	A	M	M	M	A	M	B	M	M	M	M	M	M	M	M	M	M	M	M	M	M
D	B	B	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	A	A	M	M	B	M	M	M	M	M	M	M	M	M	M	M	M	M
E	M	M	M	A	A	A	M	M	M	M	M	M	M	M	M	M	M	A	A	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
F	M	M	M	M	A	A	M	M	M	M	M	M	M	M	M	A	A	A	M	M	M	M	M	M	M	M	B	M	M	M	M	M	M	M	B	M
G	A	A	A	A	A	M	M	A	M	M	M	M	M	M	M	A	A	M	M	M	M	M	M	M	M	M	M	M	B	M	M	M	M	M	M	M
H	M	A	M	A	A	M	M	A	M	M	A	M	M	M	M	M	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	M	M	M
I	M	A	M	A	A	M	A	M	M	M	M	A	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	B	M	M	M	B	B	B	M	M
J	M	A	M	M	M	M	M	M	M	A	A	A	M	M	M	A	M	A	M	M	M	A	M	M	M	M	A	A	M	M	M	M	M	M	M	M
K	M	M	A	M	M	M	M	M	M	A	M	A	M	M	A	A	A	A	M	M	M	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M
L	M	M	A	A	A	M	M	M	M	M	A	A	A	M	A	A	A	A	A	M	A	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M
M	M	A	M	A	A	A	A	A	A	A	A	A	A	A	M	A	M	A	A	M	A	A	M	M	M	M	M	M	M	A	A	M	M	M	M	M
N	M	M	A	M	M	A	A	A	M	M	A	A	A	A	A	A	A	A	M	A	A	A	A	M	A	A	M	M	M	M	M	M	M	M	M	M
O	M	M	M	M	A	M	M	M	M	A	A	A	A	M	A	M	A	A	A	A	M	A	A	A	A	A	M	M	M	A	M	M	M	M	M	M
P	M	M	M	M	M	A	M	M	M	M	A	A	M	M	A	A	A	A	A	A	M	M	M	A	M	A	M	A	A	A	M	A	M	M	M	M
Q													A	M	A	A	A	M	M	A	M	M	A	M	A	A	A	A	A	M	A	A	M	M	M	M
R													B	M	M	M	A	A	M	A	A	A	M	A	M	A	A	A	A	A	M	A	A	M	M	A
S													M	M	M	M	A	A	A	A	M	M	M	M	A	A	A	A	M	M	B	M	A	M	M	A
T													M	M	M	M	A	A	A	A	M	M	A	A	M	M	M	A	M	B	B	B	M	M	A	A
U																					A	A	A	M	A	A	A	B	M	B	B	B	A	A	A	A
V																					M	M	A	A	A	A	M	A	A	B	B	B	M	A	A	A
X																					A	A	M	A	A	A	A	A	A	M	M	B	M	A	M	M
Z																					M	A	A	A	M	A	A	M	A	B	M	B	M	M	M	M

Nº OF CELLS	CLASSES	PERCENTAGE
217	Upper (A)	29,48
479	Middle (M)	65,08
40	Lower (B)	5,43

Figure 8. Distribution of classes of predisposition to gravitational mass movements.

The distribution of classes presented a percentage of around 30% of cells classified as having high predisposition to gravitational mass movements, 65% of cells with average predisposition and 5% with low predisposition.

CONCLUSION

The driving factors which influence mass movements, at Ouro Preto, Brazil, were identified and listed as attributes and classes. This provided a good spatial differentiation considering the degrees of predisposition obtained for the set of cells. The Analytic Hierarchic Process (AHP) allowed the study of data in accordance to the different processes of gravitational mass movements.

When investigating both natural and anthropogenic events (such as slope instability) it is necessary to consider all of the complex factors which may influence that event. If only some of the influencing factors are considered then this may present an oversimplification of the problem. The Analytic Hierarchic Process presented in this paper enables all of the quantative and qualitative factors to be analysed and therefore this enables prediction to be undertaken more accurately.

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Corresponding author: Prof Dr.Berenice Bitencourt Rodrigues, Rua Havana, 90/201, Belo Horizonte, Minas Gerais, 30.575-050, Brazil. Tel: 00 21 55 31 3378-3648. Email: berenicerodrigues@yahoo.com.br.

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