APPLICATION OF A GIS TO DETERMINATE DEBRIS FLOWS CHARACTERISTICS IN A CITY

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ABSTRACT

Heavy rains appeared during the first week of October 1999 associated with the Tropical Depression number 11 on the Puebla State north and northeast mountains region and on the Veracruz and Hidalgo vicinity States, in the México country. These rains combining with another factors caused 3000 mass movement processes approximately in this region, from shallow landslides to debris flows, affecting 96 municipalities, 16511 houses, 199 schools, 59 federal public buildings, 50 cultural buildings, 8 health centers, damages important on roads, 256 dead people, and 55 disappear people. In particular, the October, 5, 1999 in the Teziutlán, Puebla City, localized in this region, presented 30 shallow landslides and debris flows, which caused 150 dead people. In this article were calculated the debris flow failed angles and their velocities applying the Takahashi's equations (1991) and the stability index for the stony debris flows developing a geographic information system and a digital elevation model. Finally it was compared those results with the measurement angles on the site by Capra et al.

Keywords: geographic information system, debris flow, disaster prevention, digital elevation model.

1. INTRODUCTION

Last days of the month of September and first of October of 1999 rains of extraordinary character in the region of mountains of the north and the northeast of the state of Puebla appeared and in the neigh boring states of Veracruz and Hidalgo, in the country of Mexico, generated by the tropical depressions 11 to 14, which, combined to other factors of genesis, triggered around 3000 processes of removal of mass in the zone, fundamentally alluvium loosening, sliding, flow and combination of the previous ones. These events produced serious deteriorations in the infrastructure of the zone, losses of human lives and disappear, mainly in the populations of Five Gentlemen, Chachahuantla, Teziutlán and Totomoxtla, affecting 96 municipalities, 16511 houses in different degree, 199 schools, 59 buildings federal public, 50 buildings of the cultural patrimony, 8 health centers, great upheavals in the routes of ground communication lines, in addition to 256 dead people and 55 missing ones. Days 4 and 5 of October of 1999 very intense precipitations appeared on the city of Teziutlán, Puebla, being developed around 30 debris flows and superficial ground sliding of different magnitude and type, that produced 150 passed away people. In Figure 1 appears a map of the zone affected by precipitations during these dates in the state of Puebla.

The observed extraordinary precipitations during the first week of October in this region had to different atmospheric systems. The tropical depression 11, which was originated in the Gulf of Mexico, was the fundamental cause of these abnormal rains. At the same time, humid airflows of the Pacific Ocean and the Gulf of Mexico increased the amount of water steam in the atmosphere, which was in intense rain in the states from Puebla, Veracruz and Hidalgo. Finally, tropical wave 35 also had effect on precipitations of day 4 of October.

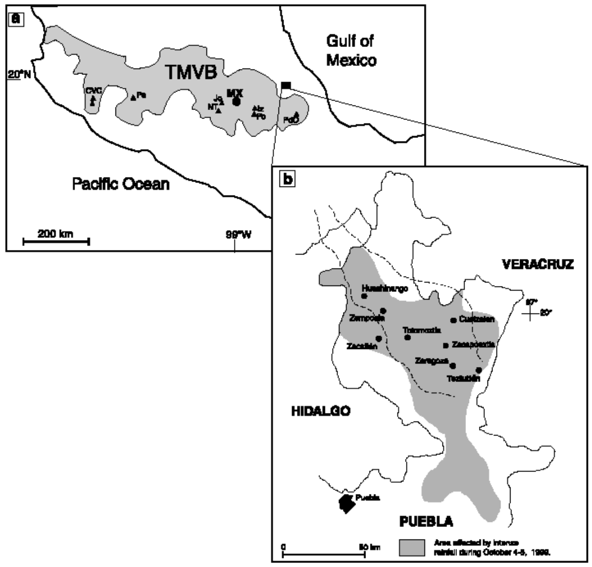

Figure 1: Map of the area affected at October of 1999 by debris flows, (Capra et al.).

2. DEVELOPMENT

2.1 Different processes

Two fundamental types of processes of removal of mass in Teziutl án appeared, during the days of the disaster, described by Capra et al., of the following way.

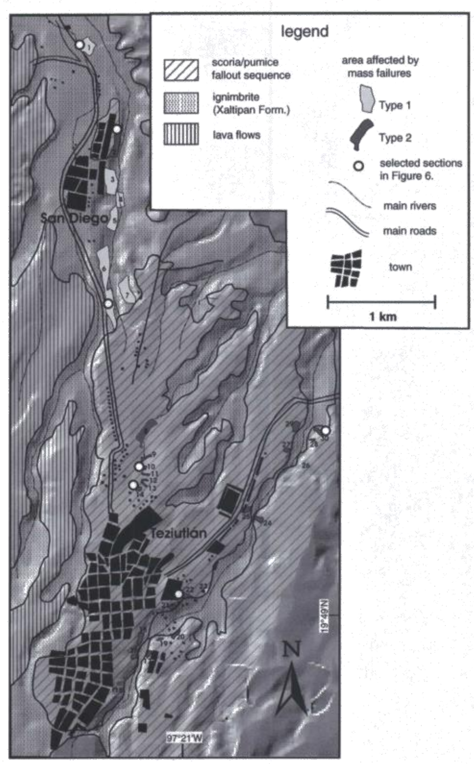

Figure 2: Geologic map of the area affected by debris flows, (Capra et al.).

TYPE 1 six superficial ground sliding in the northeast region, with greater natural slopes of 400 constituted by loose deposits of ignimbrite. The total area affected by these processes was of 0.15 km^2.

TYPE 2 Twenty-four alluvium flows (debris flows) that appeared in zones of defined slopes affluent with natural angles from 17^0 to 46^0. These phenomena mainly affected the south-eastern part of the zone of study, including the urban zone of the city of Teziutlán, Puebla, destroying areas densely populated and agricultural zones. The covered total area was of 0.07 km^2, minor who the one of the events of type 1, but with the enormous difference of which these flows of type 2 produced great material losses and of 150 human lives. The thickness of the material mobilized by these events varied from 0.4 m to 1.5 m.

In table 1 shows the areas, the slopes and the type of escarp of the 30 processes of removal in mass that appeared in Teziutlán, Mexico, whose characteristics were determined in field by Capra et al.

Table 1: Characteristics of process of removal in mass measured in field for each event in teziutlán, puebla, (capra et al. 2003)

Name	Type	Area (m^2)	Natural slope (^{0})
1	1	16,100	40
2	2	17,800	38
3	1	24,500	40
4	1	9,400	40
5	1	16,200	39
6	1	53,500	41
7	1	21,500	41
8	2	22,500	17
9	2	2,200	28
10	2	1,600	35
11	2	900	35
12	2	600	35
13	2	1,000	35
14	2	2,100	35
15	2	3,400	46
16	2	2,100	28
17	2	2,300	28
18	2	4,300	30
19	2	2,200	38
20	2	2,600	25
21	2	2,200	21
22	2	3,900	39
23	1	600	17
24	2	4,000	28
25	2	3,900	18
26	2	200	28
27	2	1,800	28
28	2	1,100	33
29	2	5,000	28
30	2	3,900	30

Geotechnical characteristics of the materials in sites 2 and 22 were determinate: volumetric weights and angles of internal friction, which are show in table 2.

Table 2: Geotechnical characteristics of the materials in sites 2 and 22: volumetric weights and angles of internal friction

Debris flow	γ (KN/m^3)	φ (^{0})	φ (^{0})
2	11.86	35	40
2	14.36	35	40
22	10.7	35	40
22	13.7	35	40

Similarly were determinate on field sediments characteristics of the materials deposited in sites 2 and 22, which are show in table 3 and 4

Table 3: Sediments characteristics of the materials deposited in site 2

Gravel (%)	Sand (%)	Mud (%)	Clay (%)
36.68	59.75	1.57	0
0	1.96	97.74	0.31
0	1.57	94.11	4.32
0	0.35	75.16	24.50

Table 4: Sediments characteristics of the materials deposited in site 22

Gravel (%)	Sand (%)	Mud (%)	Clay (%)
17.38	73.13	9.32	0.16
67.5	32.5	0	0
0	3.44	91.56	5.0
88.33	11.67	0	0

2.2 Mechanical behavior of the debris flows

In recent the three decades a great number of investigators at world-wide level have dedicated great part of their efforts to deal with to understand the mechanical behavior of the debris flows. Japanese investigator Tamotsu Takahashi, in the Institute of Investigation for the Prevention of Disasters in the University of Kyoto, Japan proposed that this type of alluvium flows is classified in the macro viscous rank and the inertial rank, dividing these in four types: rocky or mature, immature, turbulent and hybrid, based on its mechanical properties.

Takahashi proposed the following equations to describe to the behavior of the rocky alluvium flows in the inertial rank for one first approach, carrying out the general reductions and adjustments to the constituent relations and general equations.

$$\tan\theta \geq \frac{(\sigma-\rho)c_*}{(\sigma-\rho)c_*+\rho}\tan\phi \tag{1}$$

In other words, equation 1 is the condition that must be satisfied when an alluvium flow uniforms and permanent it down continues moving towards waters, in where the distributed sharp effort in the interstitial fluid is despicable. The experimental dates, nevertheless, demonstrated that the concentration of balance in the flow uniforms permanent is described by means of following equation 2 better than previous equation 1.

$$c = \frac{\rho\tan\theta}{(\sigma-\rho)(\tan\phi-\tan\theta)}(\equiv c_\infty) \tag{2}$$

For a channel very raised it is satisfied,

$$\tan\theta \geq \frac{(\sigma-\rho)c_*}{(\sigma-\rho)c_* + \rho}\tan\phi \qquad (3)$$

On the other hand, Takahashi elaborated the Figure 2 that allows to identify the type of debris flow, or rocky, immature, turbulent or hybrid, all of them in the inertial rank.

Takahashi developed another expression in second approach for rocky debris flows in the inertial rank.

$$\int_1^z dZ = \frac{\rho\tan\theta}{\sigma-\rho} * \frac{1}{(1+1/\lambda)\tan\alpha_o - \tan\theta + \rho\xi^2/(\sigma a\lambda^4\cos\alpha_o)} *(Z-1) \qquad (4)$$

Takahashi also developed to an equation of first approach for rocky debris flows that determines the average speed in the cross-sectional section of these flows.

$$U = \frac{2}{5d}\left[\frac{g\sin\theta}{a\sin\alpha}\left\{c+(1-c)\frac{\rho}{\sigma}\right\}\right]^{1/2}\left\{\left(\frac{c_*}{c}\right)^{1/3}-1\right\} h^{3/2} \qquad (5)$$

The types of debris flows and their corresponding angles of fault according to the criteria of Takahashi were determined, presented/displayed in the Figure 2 and equations 1 to 4 previous ones, for two of the debris flows in the zone of Teziutlán, Puebla, that are located in points 2 and 22, applying the collected data of field for these two sites

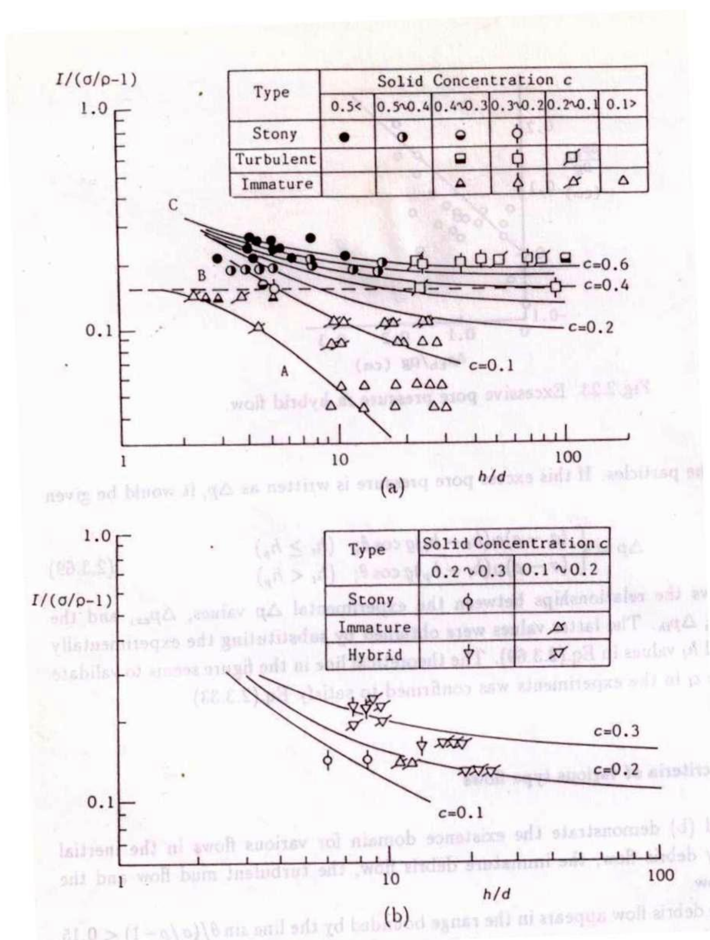

Figure 3: Criterion of classification of several types of debris flows in the inertial rank, (Takahashi, 1991)

2.3 Stability analysis

The stability analysis was based in a method that infinitely has its theoretical bases in the model of stability of an inclined plane (Hammond et al., 1992; Montgomery and Dietrich, 1994).

$$FS = \frac{C_r + C_s + \cos^2\theta\left[\rho_s g(D - D_w) + (\rho_s g - \rho_w g)D_w\right]\tan\phi}{D\rho_s g \sin\theta\cos\theta} \tag{6}$$

The stability analysis derives their classification from stability of the land from input dates, like the topographic slope, the area of specific pick up and the quantification of parameters of the properties of the material (such as the resistance) and of the climate (mainly a hydrological parameter like rain). Each one of these parameters is delineated on a numerical network in the study area.

The primary production of this modeled approach of is a stability index, which is the numerical value by means of which it is classified or categorized the stability of the land in each location of the mesh within the area in study. The topographic variables are calculated automatically from the data of the digital model of elevations (MDE). The other parameters of entrance are recognized that they are uncertain, reason why in the model they are specified in terms of the superior limits and inferior of the ranks that they can adopt.

The stability index (SI, by its initials in English, stability index) is defined as the probability that a site is stable assuming the uniform distributions of the parameters on these ranks of uncertainty. This index varies between 0 (more unstable) and 1 (less unstable). When the more preservative set of parameters (destabilizing) in the model is still in stability, the stability index is defined as the factor of safety (relation of the stabilizing forces with respect to the no stabilizing forces) in this place under the set of more preservative parameters, presenting this site a value greater than one.

3. APPLICATION OF GCL MODEL

3.1 GCL Model

The debris flows initiation process is influenced by many factors: morphological, geological, hydrological, plant coverage, topographic, and anthropogenic; it is necessary to establish a methodology that takes into account most of these aspects.

Some researchers have intended to understand the relationship between climate and geomorphologic processes, which trigger debris flows. These works have analyzed the physical properties of the failed slope, the effects of the angle of inclination and soil pore pressure, mechanical movement debris flows and the resulting deposits properties, (SCOTT 1972; WILLIAMS & GUY 1973; HOLLINGSWORTH & KOVACS 1981; ISTOK & HARWARD 1983; PIERSON & COSTA 1987; MONTGOMERY & DIETRICH, 1994; WU & SIDLE, 1995; PACK, 1995; MORGAN et al. 1997; REID et al. 1997; GRIFFITHS et al. 1997; WIECZOREK et al. 1997; TOGNACCA & BEZZOLA 1997; GREGORETTI 2000; IVERSON 2000; CHEN & JAN 200; REID et al. 2003; SAVAGE & BAUM 2003).

Taking into consideration the prevailing factors and models for known debris flows startup as well as the analysis of the works of previous researchers, distributed hydrologic models and using digital elevation models in combination with the model of infinite slope stability and geographic information systems technology, it was developed a model to estimate the potential areas of startup in a debris flow.

3.2 Description of the GCL Model

The proposed model was realized by a computer program, which was developed using some subroutines proposed by Pack, using Arc View GIS 3.3 with Arc View Spatial Analyst extension program, and digital models of elevation. This model predicts the potential stability of a debris flow, uses an equation to the safety factor and Darcy’s law for flow-saturated within the ground, in order to estimate the distribution of pore pressures. The saturated flow refers to the flow where the pores are completely filled with water.

The theory underlying the proposed model was implemented in computerized form. The theory was incorporated in a library of routines of computation that can be called to perform computational tasks, including the calculation of stability and saturation rates (humidity index). In addition the library routines are also available for many basic tasks for the management of the mesh data in the digital elevation model (DEM), model including topographic fill mines, calculation of slopes, and determination of the directions of the flow and definition of drainage area to a specific point. These different routines were written in C programming language and are contained within a file (DLL) dynamic link library.

The spatial or geographical nature of the analysis carried out in the model, printed or on-screen maps are required to play some computer outputs. Instead of creating common routines to provide common geographical analysis skills, the model uses the of geographic information systems (GIS) software itself to handle these tasks.

3.3 Geographic Information System

The According to the requirements necessary for the determination of the initiation areas produced by debris flows in a mountainous region, it was selected the use of the software developed by ESRI to a geographical information system called Arc View GIS 3.3 due its versatility and features, (Shamsi, 2002).

In response to the main factors which triggered the debris flows it was proposed the topics listed below as an integral part of the project of Arc View GIS 3.3, called zoinifluder.apr, and presented in Figure 4.

Layer 1 Topography of the area of study
Layer 2 Surficial hydraulics dates
Layer 3 Soil internal friction angle
Layer 4 Soil density
Layer 5 Soil cohesion
Layer 6 Plants cover (the root of the trees force)
Layer 7 Subsurficial hydraulics dates.

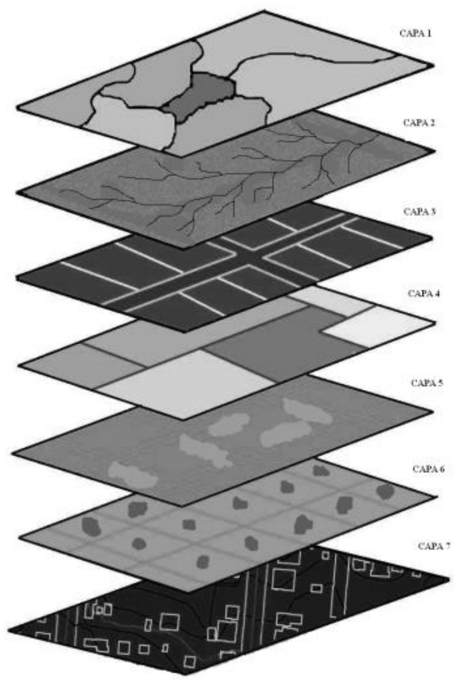

Figure 4: Themes or layers in the 'zoinifluder' project.

3.4 Flowchart of the GCL Model

In order to display graphically the proposed model it presents a diagram of flow in Figure 5.

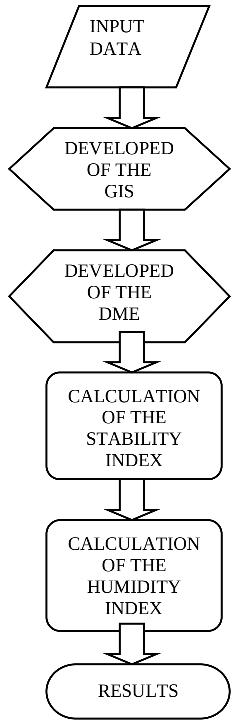

Figure 5: Flowchart of the GCL model

4. RESULTS

Using figure 3 proposal by Takahashi was obtained that as much the debris flow 2 as the debris flow 22 is rocky or mature, therefore was applied equation 3 of Takahashi and the shown angles of fault were obtained in completes row of table 5 and 6, according to each one of the characteristics of the materials in each mature debris flow. It is possible to be observed, comparing these results with the natural angles of the slope in zone 2 (38^0) and in the zone 22 (39^0), that the values calculated with the equation of Takahashi suitably predict the behavior of these two debris flows in the zone of Teziutlán, Puebla, Mexico.

Table 5: Determination of the angles of fault in the debris flow 2

Debris flow	γ (KN/m^3)	φ (^{0})	θ (^{0})
2	14.36	35	34.23
2	14.36	40	39.19
2	11.86	35	33.34
2	11.86	40	38.25

Table 6: Determination of the angles of fault in the debris flow 22

Debris flow	γ (KN/m^3)	φ (^{0})	θ (^{0})
22	13.7	35	33.3
22	13.7	40	38.2
22	10.7	35	28.5
22	10.7	40	33.06

Applying equation 5 of Takahashi and using the presented determinations of field in tables 1, 2 3 and 4 the average speeds of rocky debris flows were obtained and presented in the table 7 and 8, which is not possible to compare since measurements of speeds registered during this event do not exist.

Table 7: Determination of the average speeds in the debris flow 2

Debris flow	γ (KN/m^3)	φ (^{0})	U (m/s)
2	14.36	35	38.63
2	14.36	40	37.08
2	11.86	35	32.59
2	11.86	40	30.79

Table 8 Determination of the average speeds in the debris flow 22

Debris flow	γ (KN/m^3)	φ (^{0})	U (m/s)
22	13.7	35	42.11
22	13.7	40	39.77
22	10.7	35	42.67
22	10.7	40	40.31

5. CONCLUSIONS

Finally the stability of the zone was analyzed, comparing the application of model developed for its use on debris flow (GCL model), with the values obtained by Capra et al.

In the first place the field characteristics necessary were determined; next the digital model of elevations of the zone of Teziutlán, Puebla was acquired in the INEGI (National Institute of Statistic, Geography and Computer science) in Mexico, finally was developed the GIS (geographic information system) required by the commented model.

At the moment preliminary results have been obtained for the stability index (SI) in the zone of study which vary from SI = 0, 78 to SI = 0, 95; those values can be interpreted with a good accuracy for the stability of the Teziutlan debris flow zone, comparing them with the values obtained by Capra et al.

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