INSTITUTO PIRENAICO DE ECOLOGIA, CSIC

REPORT FOR FIRST DAMOCLES PROGRESS MEETING
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1. Summary of the work carried out

The work done can be divided into four sections:

i) Compilation and organisation of basic information for studying and predicting the spatial distribution of debris flows (WP 1). This includes:

- The lithological map of the Aragon and Gallego rivers at a 1:50,000 scale.
- The vegetation map (except the extreme westernmost part of the study area).
- The land-use map, especially the distribution of the historical and actual distribution of agricultural fields.
- A new map on the probability of occurrence of extreme rainfalls in the Aragon and Gallego basins.
- The Terrain Digital Model has allowed to obtain maps of altitude, gradient, aspect, shape of the hillslope and area drained by each debris flow scar.
- In total, 961 debris flows have been identified in the study area. They have been mapped using aerial photographs and field work.

All this information is digitized and implemented in a GIS (ARC/INFO, v.7).

ii) Organisation of a data base and first statistical approach to the problem of spatial distribution of debris flows (WP 1).

All the maps have been stored as a table by dividing the study area into 50 x 50 m pixels. The resulting matrix includes data from the pixels affected and non-affected by debris flows, and accounts with almost 600,000 rows and nine columns (each column corresponding to the factors cited above). A signification test of the differences between the pixels affected and non-affected by debris flows has been made From this information the frequency distribution of debris flows has been obtained. In order to classify the debris flows into different groups, a conglomerate analysis has been used, as well as a discriminant analysis to define the main factors that contribute to the triggering of debris flows.

iii) In order to predict the spatial probability of debris flow occurrence (debris flow susceptibility map), a logistic regression model has been used. The main product of this model are the logistic coefficients, allowing us to know the influence of each independent variable on the probability of occurrence of the dependent variable (debris flows). With the logistic coefficients a predictive model has been built, assigning a probability of occurrence to each pixel. The final result is a continuous variable map (debris flow susceptibility map), to which the map of the observed debris flows can be superposed in order to assess the predictive efficiency of the model (WP 2).

iv) As for field work, measurements of different morphometric parametres of debris flows have been initiated(WP 3).

v) Preparation of different papers and assistance to international and national meetings (WP 5).

1.1. Human resources employed

- Responsible scientist: 4 months
- Researcher (Carlos Martí): 4 months
- Researcher (José Arnáez): 3 months
- PhD student: 7 months
- Technician: 2 months

Total: 20 months

1.2. Activities/months

- Compilation and organisation of basic information: 13 months
- Spatial distribution of debris flows: 2 months
- Debris flow susceptibility map: 2 months

- Morphometric parametres of debris flows: 2 months
- Preparation of papers: 1 month

2. Main results and discussion

The 961 debris flows identified represent an average density of 0.56 cases per square kilometre, but their spatial distribution is very irregular. Table 1 shows, for the different factors considered, the proportion occupied by the whole study area and by the debris flows, as well as the signification of the differences. In most of the cases the differences are highly significant. Fig. 1 also states the contrasts between the study area and the frequency distribution of the debris flows. The differences show the preference in the location of debris flows. Thus, the greatest occurence of debris flows appear to be in gradients between 20 and 30º (average 26.4º), especially between 25 and 30º, where they reach an average density of 1.34 cases/km2. Under 15º there are almost no cases, and this is the same over 40º, where the instability impedes the presence of loose materials, susceptible to be mobilized.

The altitudinal distribution of the study area shows very similar proportions since 500 to more than 2000 m. Debris flows also appear in any altitude, but there is a greater concentration between 1000 and 1400 m, especially between 1100 and 1200 m, where their density arrives to 1.48 cases/km2.

As for aspects, the study area shows a slight trend toward the southern exposures. This trend is much more intendified in the case of debris flows. The southwestern and southern aspects concentrate 45 % of the cases, followed by western (17 %) and southeastern (14 %) ones. In the northern exposures the occurrence of debris flows is very low.

Lithology shows a great variability in the study area, though the flysch (42 % in total) dominate over the other substrata., followed by mudstones and quaternary deposits. The rest of lithologies represent proportions lower than 10 %. In the distribution of debris flows a preference for the flysch is observed, with 785 cases (82 % in total) and an average density of 1.09cases/km2.

If plant cover is considered, in the study area 26 % corresponds to farmed area (due above all to terraces and glacis of the Inner Depression) followed by scrubs (17 %), oakwoods and holm-oak woods (17 %) subalpine and alpine grasslands (15 %), pine woods (12 %), beech and fir woods (11 %) and reafforested pines (2 %). The distribution of debris flows clearly disagrees with these proportions, showing a preference for the reafforested areas (275 cases, 29 % of the total and 7.5 cases/km2), followed by scrubs (24 % of the cases) and natural pine woods (19 % of the cases). On the opposite, their occurrence is very low in beech and fir woods (6 % of the cases) and in the farmed area (3 %).

Finally, from an agricultural point of view, 29 % of the territory has been historically cultivated, and 71 % has never been farmed. Among the cultivated area, flat fields (10 % of the total) stand out, followed by sloping fields (10 %), and the hillslopes affected by shifting agriculture (7 %). Bench terraced fields had almost no importance (2 %). The distrinution of debris flows shows that the non-cultivated area includes 55 % of the cases, while sloping fields include 28 % of debris flows (273 cases in total, 1.6 cases/km2), and the fields of shifting agriculture, 15 % (1.2 cases/km2).

Table 1 and Fig. 1 suggest that, in the study area, debris flows tend to trigger in sunny hillslopes, beteween 1000 and 1400 m, in gradients between 25 and 30º, in the flysch sector and in areas affected by human activities (old sloping fields, scrub areas and reafforested areas).

The application of a cluster (k-means) to the matrix of data allows us to distinguish three groups of debris flows:

i) The first group includes 681 cases (70. 1 % in total). These debris flows are located at a mean altitude of 1161 m, in southwestern exposures, in gradients around 26º and at a mean distance from the divides of 194 m. They develop preferabily in the flysch sector and in hillopes occupied by scrubs or reafforestations.

ii) The second group includes 63 cases (6.6 % in total). Their mean altitude is 1262 m, with a mean gradient of 25º, in southern aspects and a distance of 685 m from the divides. They also prevail in the flysch sector and in limestones, and are very frequent in sloping fields and shifting agriculture fields, as well as in scrubs.

iii) The third group includes 217 cases (22.6 % in total). These debris flows show a mean altitude of 1752 m and an average gradient of 27.5º in southern exposures and at a distance of 237 m from the divide. This is a group of debris flows preferabily located over slates and quartzites, in subalpine and alpine grasslands and natural pine woods.

In order to define which are the most deterministic variables in the previous groups, a discriminant analysis has been used. Two functions have been selected by the analysis. The first one explains 69.7 % of the variance and the second one 30.3 %. The correlation between variables and discriminant functions suggests that in the function 1 altitude and lithology are the variables conditioning the most the distribution of debris flows, whereas in the function 2 the distance from the divide is the most important.

This information is completed by the logistic coefficients obtained from the logistic regression (Fig. 2). Eight factors (independent variables) appear to be the most conditioning ones:

- The flysch sector
- Quaternary deposits (screes and lateral moraines)
- Quartzites and slates
- Mudstones
- Sloping fields
- Reafforested pines
- Shifting agriculture fields

On the opposite, the following factors act as negative ones:

- Granites
- Sandstones
- Flat fields
- Present farmed area
- Northern exposure
- Beech and fir woods

The debris flow susceptibility map (Brabb, 1984; Carrara et al., 1991 and 1995; Guzzetti et al., 1999) resulting from the model of logistic regression shows the irregular spatial distribution of debris flows in the study area. The greatest probabilities of occurrence appear in southern aspects, in the flysch sector, especially in the contact with the marly Inner Depression. This contact occurs by means of an overthrusting fault and a number of fractures contributing to instabilizing this area, especially between the Aragon and Gallego rivers. Within the flysch sector other smaller valleys are also subject to a high probability of occurrence of debris flows, as is the case of the Lubierre, Ijuez and Acumuer valleys, coinciding with sectors intensively affected by historical human disturbations. The Hecho valley (Aragon Subordan river) also shows many favourable hillslopes, due to farming activities in steep slopes (for example, Urdues valley). In the Gallego valley the highest probabilities occur in slopes near the main valley, maybe due to the U-shape inherited from the Pleistocene glacial activity.

Probabilities of occurrence of debris flows very much decrease in the north of the study area, in spite of steep slopes. In the southermost part the probabilities are null due to the smooth gradients, a very limitant factor.

* * *

The procedure used allows us i) to identify the most important factors to explain the triggering of debris flows, and ii) to predict spatially the probability of occurrence of debris flows in a mountain area with a great lithological, topographic and plant cover/land uses variability.

It is well known that debris flows are triggered during high intensity and volume rainstorms (Caine, 1980; Kotarba, 1989; Van Steijn, 1996), but their spatial distribution is not random. This distribution confirms the very important role played especially by the lithology, altitude, aspect and plant cover/land uses. Thus, the flysch sector concentrates the main number of cases identified (82 % in total) due to

i) the presence of alternating beds of sandstones and marls, yielding deep and loose colluvions, and

ii) some areas of the flysch sector appear to be intensively faulted and folded, increasing the instability of poorly sorted material.

The rest of the factors are closely related to the strong disturbations caused by human activities in the hillslopes. This is the case for

i) the southern aspects, which are the most favourable for farming activities in the Central Spanish Pyrenees;

ii) the altitude, between 1000 and 1400 m a.s.l., coinciding with the hillslopes most used for sloping fields and shifting agriculture;

iii) the areas covered by scrubs and reafforested pines, coinciding with eroded areas after centuries of man-induced fires and overgrazing; in fact, reafforestations have been introduced, in general, there where the landscape was affected by intense soil erosion and with evidence of severe degradation (high soil stoniness, open shrub cover...);

iv) the hillslopes covered by sloping fields or subject in the past to shifting agriculture, with scarce structures of human origin for soil conservation.

As a consequence, debris flows are preferabily located in the flysch sector, and, even more, there where human activities have introduced greater disturbations. This is an interesting conclusion, since previous studies in the Spanish Pyrenees (Garcia-Ruiz & Puigdefabregas, 1982; Gonzalez et al, 1995) suggested that debris flows are mainly located in the most disturbed areas, on steep slopes cultivated some decades ago (see also Wu & Swanston, 1980, for debris flows triggered after forest logging). Of course, the gradient is also other limitant factor, though it tends to be a very regular factor, varying scarcely around 25-30º. Debris flows do not occur in hillslopes with smooth gradient (as is the case of the marly Inner Depression), neither with very steep gradients, where natural instability impedes the presence of loose colluvions.

The debris flow susceptibility map on the occurrence of debris flows is very well adjusted to the distribution of debris flows identified with aerial photographs and field work. This map shows the existence of greater debris flow hazards in the flysch sector, especially in southern exposures, providing that the original plant cover has been intensively disturbed. On the opposite, hazards clearly decrease in the southermost part of the study area, as well as in the northernmost part.

Thus, the map allows us to distinguish between

i) Areas with very high probabilities of occurrence of debris flows, even during rainstorms corresponding to relatively low return periods around 15-20 years).

ii) Areas occasionally threatened by debris flows, during very low frequency rainstorms.

iii) Areas exceptionally threatened by debris flows, coinciding with the so called extreme events (more than 100 year return period).

iv) Areas without probabilities of occurrence of debris flows, even during very extreme rainfall events.

3. Next Project activities

Task 1. Correction and validation of the debris flow susceptibility map
Once the debris flow susceptibility map has been obtained, it is necessary to introduce some modifications in order to include debris flows in the alpine and subalpine screes, a question that has not been adequately solved up tp now. On the other hand, a validation of the procedure will be made in the upper Esera valley, constructing a new susceptibility map and contrasting it with the real occureence of debris flows.

Task 2. Preparation of two papers to be (tentatively) published in *Mountain Research and Development* and *Geomorphology*. The first one, dealing on the factors explaining the spatial distribution of debris flows, and the second one on the development of a debris flow susceptibility map.

Task 3. Field work on the morphometric characteristics of the debris flows. This task has been initiated last summer and will be continued until summer 2001. It consists in taking information on size, gradient and runout and plant cover characteristics of a large number of selected debris flows.

Task 4. Initiation of a data base with the information obtained in Task 3.

Task 5. Preparation of the first year scientific and administrative-financial report.

Timetable for the different tasks:

Task 1: From October 2000 until April 2001
Task 2: From September 2000 until December 2000 (the first paper will be sent to MR&D in November 2000)
Task 3: Will continue until summer 2001
Task 4: From March 2001 henceforth (it would be finished at the end of summer 2001)
Task 5: January 2001

4. References

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5. Publications

Arnaez, J., Marti-Bono, C., Begueria, S., Lorente, A., Errea, M.P. & Garcia-Ruiz, J.M. (1999): Factores en la generacion de crecidas en una cuenca de campos abandonados, Pirineo Central. *Cuadernos de Investigacion Geografica,* 24: 7-24.

Begueria, S. & Lorente, A. (1999): Distribucion espacial del riesgo de precipitaciones extremasen el Pirineo aragones occidental. *Geographicalia,* 37: 17-36.

Garcia-Ruiz, J.M., Begueria, S. & Lorente, A. (in press): Eventos hidrologicos de baja frevcuencia en el Pirineo Central espanol y sus efectos geomorfologicos. *Serie Geografica.*

6. Papers presented in meetings

- Begueria, S., Lorente, A., Marti-Bono, C., Garcia-Ruiz, J.M. & Arnaez, J.: Comparing flood behaviour in forested and deforested mountain catchments, Central Spanish Pyrenees. 29th International Geograpgical Congress, 14-18 August 2000, Seoul.
- Lorente, A., Begueria, S. & Garcia-Ruiz, J.M.: Factors explaining the spatial distribution of hillslope debris flows in a mountain area. 29th International Geographical Congress, 14-18 August 2000, Seoul.
- Garcia-Ruiz, J.M., Lorente, A., Gonzalez, P., Valero, B., Marti-Bono, C. & Begueria, S.: El mega-slump de Biescas, Pirineo Central, y su posible contexto temporal. VI Reunion Nacional de Geomorfologia, 17-20 September 2000, Madrid.
- Lorente, A., Begueria, S. & Garcia-Ruiz, J.M.: Factores en la distribucion espacial de coladas de piedras, altos valles del Aragon y del Gallego, Pirineo central espanol. VI Reunion Nacional de Geomorfologia, 17-20 September 2000, Madrid.
- Garcia-Ruiz, J.M., Marti-Bono, C. & Valero, B.: Check-dam failures as sediment source during an extreme event. XXV General Assembly of the European Geophysical Society, 24-29 April 2000, Nice.
- Begueria, S. & Lorente, A.: Predicting and mapping extreme rainfall events in a mountain area, Central Spanish Pyrenees. XXV General Assembly of the European Geophysical Society, 24-29 April 2000, Nice.

7. Keywords

Debris flows, Spatial distribution, Hazards, Spatial prediction, Environmental factors, Human-induced factors, Central Spanish Pyrenees.