The influence of topographic parameters on avalanche release dimension and frequency

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Abstract: The avalanche hazard map zones in Switzerland are defined by the frequency and the impact pressure of a potential avalanche event. Therefore, it is crucial to be able to accurately estimate the release frequency and, related to the frequency, the release extent for a specific avalanche track. Up to now, avalanche experts have estimated these important input parameters based on their experience and on known historic avalanche events on an avalanche path. However, for most avalanche tracks only incomplete information about historic avalanche events is available, thus there is a large uncertainty concerning avalanche release frequencies and extents.

In order to improve this knowledge, a statistical analysis of avalanche releases on well documented avalanche paths has been performed. In the region of Davos, an almost complete database of avalanche events over the last 50 years exists, that covers not only frequent avalanche tracks but the whole area. Using Geographic Information System (GIS) technologies in combination with Digital Elevation Models (DEM), all avalanche release areas have been analysed with respect to topographic characteristics. Topographic parameters like "slope", "confinement", "aspect" and "distance to the next ridge" are derived from the DEM. The statistical analysis results in general rules and probability distributions for release extents as a function of the frequency and the topographic parameters. The general rules are a valuable aid for the avalanche experts in cases where information about historic avalanche is lacking for a particular track. Furthermore, the probability distributions can be directly used as input for uncertainty modelling of avalanche run-out distances by Monte Carlo methods. In the avalanche winter of 1999 (in the European Alps), the latter topic has been shown to be very important for the further improvement of avalanche hazard maps and for the risk assessment of avalanche hazard in general.

Keywords: release area, topography, release frequency, GIS, statistics, avalanche cadastre

1. Introduction

The definition of a potential avalanche release area is crucial for an avalanche expert who has to estimate the avalanche hazard for a certain site, since it determines - together with the fracture depth - the initial volume of an avalanche. This volume is an important parameter for the development of an avalanche on its way down to the valley bottom. In addition, the topographic characteristics of an avalanche release area is one of the most significant parameters determining the frequency of the avalanche. Until now, avalanche experts have nevertheless only a very rough estimate about how release areas influence the frequency of avalanches. In an avalanche site without a long-term avalanche cadastre, the assumptions are often on a very weak base. It is the aim of this work to improve the knowledge about the relation of the avalanche release area to the frequency and the initial size of an avalanche event, in order that an avalanche expert can apply statistically based rules to complement an avalanche cadastre. A good knowledge of the avalanche frequency is crucial for the avalanche hazard mapping procedure (BFF/SLF 1984). Avalanche hazard maps in Switzerland are worked out by a combination of an analysis of historic events and avalanche calculations (Gruber 2001, Salm and others 1990). Historic avalanche events give an idea of the size and type of avalanche that may occur in the future. However, there is often not enough information available for a particular site to derive a valid statistic of the frequency of avalanches of a specific size. This approach aims to overcome this lack of information by performing a detailed statistical analysis over a large area, where a very good database of recorded avalanche boundaries is available. The concept is to relate patterns of avalanche occurrences to geomorphologic parameters, so that the statistics can be transfer from this well recorded sites onto less known areas using only the geomorphologic characterisation.

2. Method

The three basic steps of this approach are (1) the definition of the potential release areas (PRA) using general rules, (2) their characterisation based on significant geomorphologic parameters and (3) a statistical analysis of the past avalanche events, based on the previously extracted geomorphologic parameters.
In the region of Davos an almost complete database of about 4500 avalanche events over the last 50 years is available on an extent of about 300 km^2. All the avalanches occurred in these years have been recorded and digitalized with significant annotations about each particular events. This makes possible an analysis of all the past avalanche events with the help of Geographical Information System (GIS) technology in combination with Digital Elevation Model (DEM).
An accurate study of the topography is performed in order to find the most representative features which could then be used for the definition of potential avalanche release area.
The whole procedure is thought to be automatic: the simple applications of this procedure to the area of interest can give the results, that is the potential release areas, their characterisation based on topographic parameters and the statistics of the historic events.
The final goal of this work is to give a distribution function for the release area parameter for each defined potential release area characterised by different topographic parameters.
We'll go step by step through the global procedure applied in the test area of Davos.

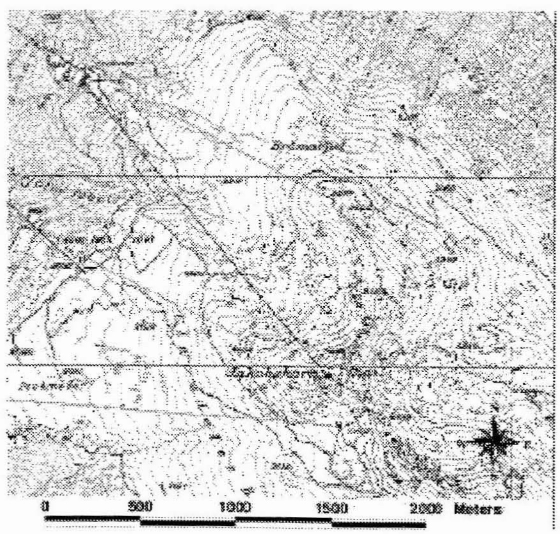


Fig.1 A part of the test area of Davos. (Digital Map Data PM25: © Swiss Federal Office of Topography).

2.1 Definition of the potential release areas

The first step is the definition of the potential avalanche release areas.
Therefore first it is necessary to find general rules based on the most representative topographic parameters.
In general, avalanches can initiate on any slopes with certain topographic characteristics, except where dense forest is present and able to prevent avalanche initiation.
The first important parameter is slope. From literature (Salm,1982) and the analysis of the terrain of the starting zone of past events, the first selection is done considering as potential avalanche release areas only that terrain with a slope angle between 30° and 60° (Fig. 2). The reason for this choice is that on slopes with angle greater than 60° the avalanches are very frequent and of small dimension, since no big deposition without failure is possible on such steep slopes, and on slopes with angle lower than 30° the gravity is not strong enough to initiate an avalanche.

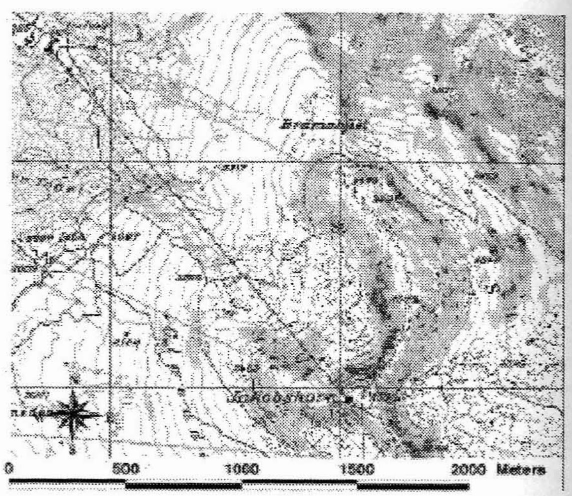


Fig.2 First selection: the grey regions represent areas with a slope between 30 and 60 degree. (Digital Map Data PM25: © Swiss Federal Office of Topography).

After this first selection, parameters like curvature and aspect are used to define different release areas. In GIS curvature is computed in a way that it is separated into two orthogonal components where the effects of gravitational process are either maximized (profile curvature) or minimized (plan curvature). In the present method the plan curvature is used to separate concave areas from convex ones. A lattice resolution of 50m is considered in order to have an idea of the global curvature, loosing all the details linked sometimes more to the inaccuracy of the DTM than to real topographical changes in the curvature.

Concave areas are differentiated from convex ones (Fig. 3) based on the following rule:

concave areas ≰ plan curvature < -0.2
convex areas ≰ plan curvature > +0.2
flat areas ≰ -0.2 < plan curvature < +0.2

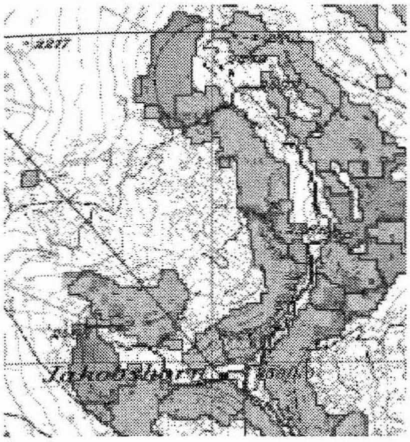
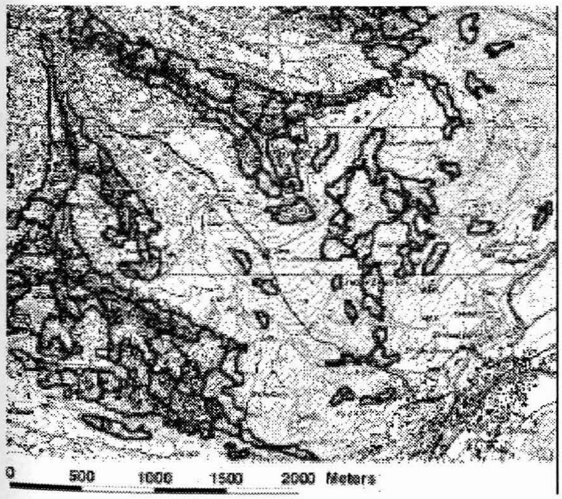


Fig.3 Differentiation of concave (light grey) and convex (dark grey) areas. (Digital Map Data PM25: © Swiss Federal Office of Topography).

Areas not well defined by curvature, considered as flat areas, are then separated through different values of the mean aspect, so that areas facing in different directions are considered independent. To make this concept clearer, let's think about an area with a value of curvature between –0.2 and 0.2. It is considered as a unique flat area, but it could be that part of it is facing SW and another SE; then considering the aspect parameter, it will be divided in two different areas.
In Figure 3 is shown the result of the complete procedure for a part of the test area in Davos.



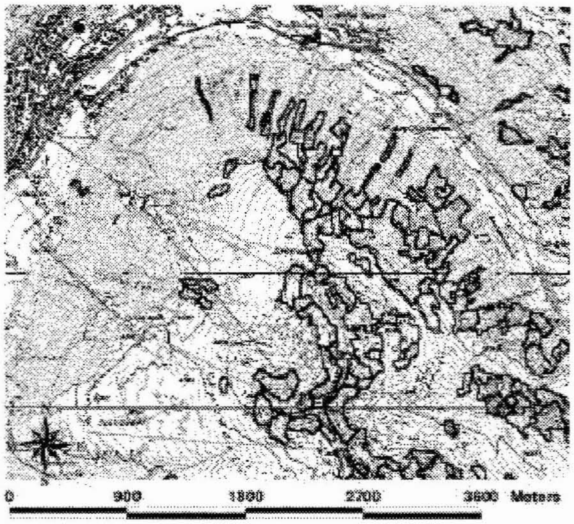


Fig. 4 Result of the automatic definition of the potential avalanche release areas in a part of the test area in Davos: Dorftälli above and Jakobshorn below. (Digital Map Data PM25: © Swiss Federal Office of Topography).

2.2 Geomorphologic characterisation of the PRA

The second step is to perform the more detailed geomorphologic characterisation of the potential release areas resultant from the automatic definition method.
For this purpose, it is better to identify only the most representative area of the PRA and to neglect the boundaries that may differ significantly from the core area and therefore can influence the mean aspect or the curvature in a way that is not wanted. We decided to identify the core of each PRA with the ellipse defined by a special function in GIS (ArcDoc, 2001). In Figure 5 the ellipses for the PRAs in the region of Jakobshorn are shown. The intersection between each PRA and the related ellipses gives the area in which the analysis is performed.
The idea is to find the most representative geomorphologic parameters to give a characterisation of each PRA in order to link these characteristics – in the third step - to different avalanche activities.
In the following we're going to present the second and third step only for some PRAs in the test area, just to explain clearly the procedure.

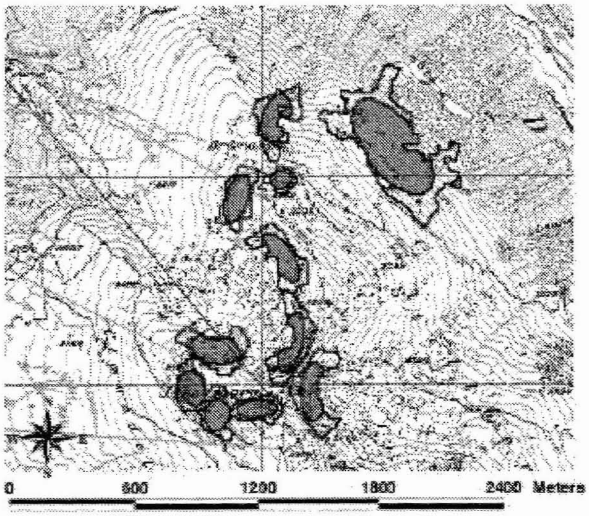


Fig. 5 Area of Jakobshorn: PRAs and related cores used for the characterisation procedure.

The geomorphologic features considered in this work as characterising parameters are:

1. mean slope (in degree)
2. minimum slope (in degree)
3. maximum slope (in degree)
4. curvature
5. mean aspect (in degree clockwise from North)
6. distance to the next ridge (in meter)

The last field of the table refers to ridges. Because all this procedure is an automatic procedure, also the ridges are extrapolated from DEM using GIS technology.
In the appendix table 1 reports the values of the characterising topographic parameters for the 11 considered PRAs.
The idea is to find release area distribution functions for every different potential release areas.

2.3 Statistical analysis of the past avalanche events

The third step is the analysis of past avalanche data and the derivation of the release area distribution functions.
For this study, only PRAs that are visible from the ski-areas of Davos or from the settled areas and the main roads were included, since in remote or hidden regions it is questionable if all avalanches – in particular smaller ones – have been regularly recorded. Because the statistical analysis is aimed at deriving the frequency of avalanches of a specific size, it is mandatory to have a complete database of all occurred avalanches and not only the larger ones.
The statistical analysis compares the size of the release area of each avalanche to the total extent of the corresponding PRA. For each avalanche event, the percentage of the PRA that broke loose during this event is stored and used to derive the release area-frequency distribution for each PRA.

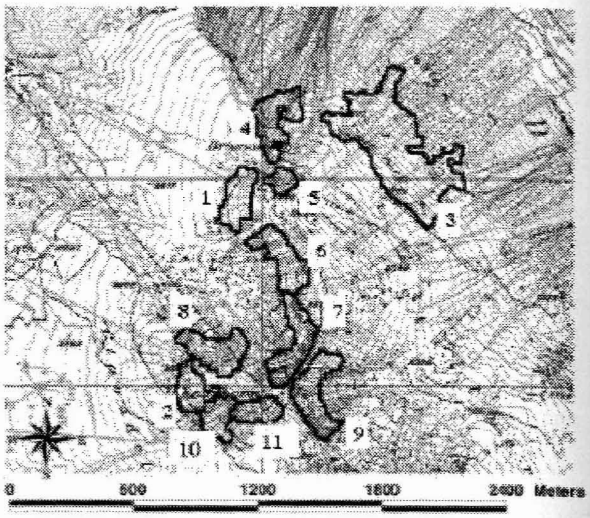


Fig. 6 The test potential release areas are drawn with black lines. Past avalanche events are also shown. (Digital Map Data PM25: © Swiss Federal Office of Topography)

Our hypothesis is that release areas with different geomorphologic characteristics have different avalanche activities and so different release area-frequency distribution functions.
The graphics in the appendix show the result of the statistical analysis of the past avalanche events for the 11 PRA in the area of Jakobshorn shown in Figure 6.
The results reveal that there is similarity in the release area distributions for PRAs with similar topographic features. For example PRA 4, 10 and 11, except for the aspect, have the same kind of curvature and are all close to ridges. The release area distributions for these PRA cover all the classes of the percentage of the PRA with most of the events in class 1 (0-10% of the PRA). In general slightly concave or flat areas (PRA 4, 5, 6, 10, 11) have a distribution with the above mentioned characteristics.
Even in the small numbers of area-frequency distributions shown in the appendix, the influence of specific parameters is recognisable. PRA with a high mean slope angle and a concave curvature (PRA7,8,9) have higher numbers of small percentages of PRA than less steep and flatter PRA.
The fact that in almost every distribution the class 1 is the most frequent one could also be the result of the way of calculating the release area. Due to the fact that in the GIS-cadastre the older avalanches are not always stored as polygons but only as the centre line of an

avalanche, we expanded it in relation to its length to obtain its release. Often, this release area covers only 10% of the whole PRA. We could not ignore these avalanches, because they are important for the frequency analysis, but there is uncertainty concerning the avalanche width of these avalanches that has to be kept in mind in the interpretation of the results.
Another reason for the high amounts of smaller percentages is that PRA are defined in a way, that they cover also very large, infrequent avalanche events. Therefore it is only natural that small avalanches occurred more frequently than bigger ones.
In summary, this preliminary analysis indicates that mean slope, curvature and distance to the ridge are the most important parameters that influence the avalanche release area frequency. Convex potential release areas have usually a low avalanche activity and often only a small share of the whole PRA is released. Within flat or slightly concave PRAs the avalanches release areas are more equally distributed over the whole range of PRA percentages in comparison to convex and concave PRAs. Higher average slope angles lead to frequent release of small avalanches.

3. Conclusion

An automatic procedure to analyse potential avalanche release areas and to relate them with release frequency is necessary to have a good common basis to then derive then the statistics.
This preliminary method for the definition and characterisation of potential avalanche release area gave encouraging results. In fact PRAs with similar or different topographic features have respectively similar and different distributions of historical avalanches.
However, the method for the characterisation of the PRA is only a first evaluation; it has to be refined, also considering other geomorphologic parameters, for example the size of the PRA.
Within the statistical analysis about the frequency-area distribution of avalanche releases, it is important to study the effects of the single parameters in more detail in order to recognize the influence of the most relevant ones more precisely. For this purpose it is also necessary to include additional parameters to the characterisation of the PRA.
Although this method is still under development, it could already be a valuable help for an avalanche expert who has to assess the avalanche hazard in a certain site, where for example only a few avalanche events occurred in the past. The method is providing him an objective tool for the definition of the avalanche release area and then, as an expert, he can combine the results of this procedure with the analysis of the few available avalanche data and the evaluation in loco of the starting zone.
The final goal of this study is, that the distribution function for the release area can be directly used as input for uncertainty modelling of avalanche run-out distances and impact pressures by Monte Carlo methods.

Acknowledgement. Funding for this research has been provided by European Union via the Swiss Foundation for Education and Science (BBW). We would like to thank Andreas Stoffel for his important help concerning GIS problems.

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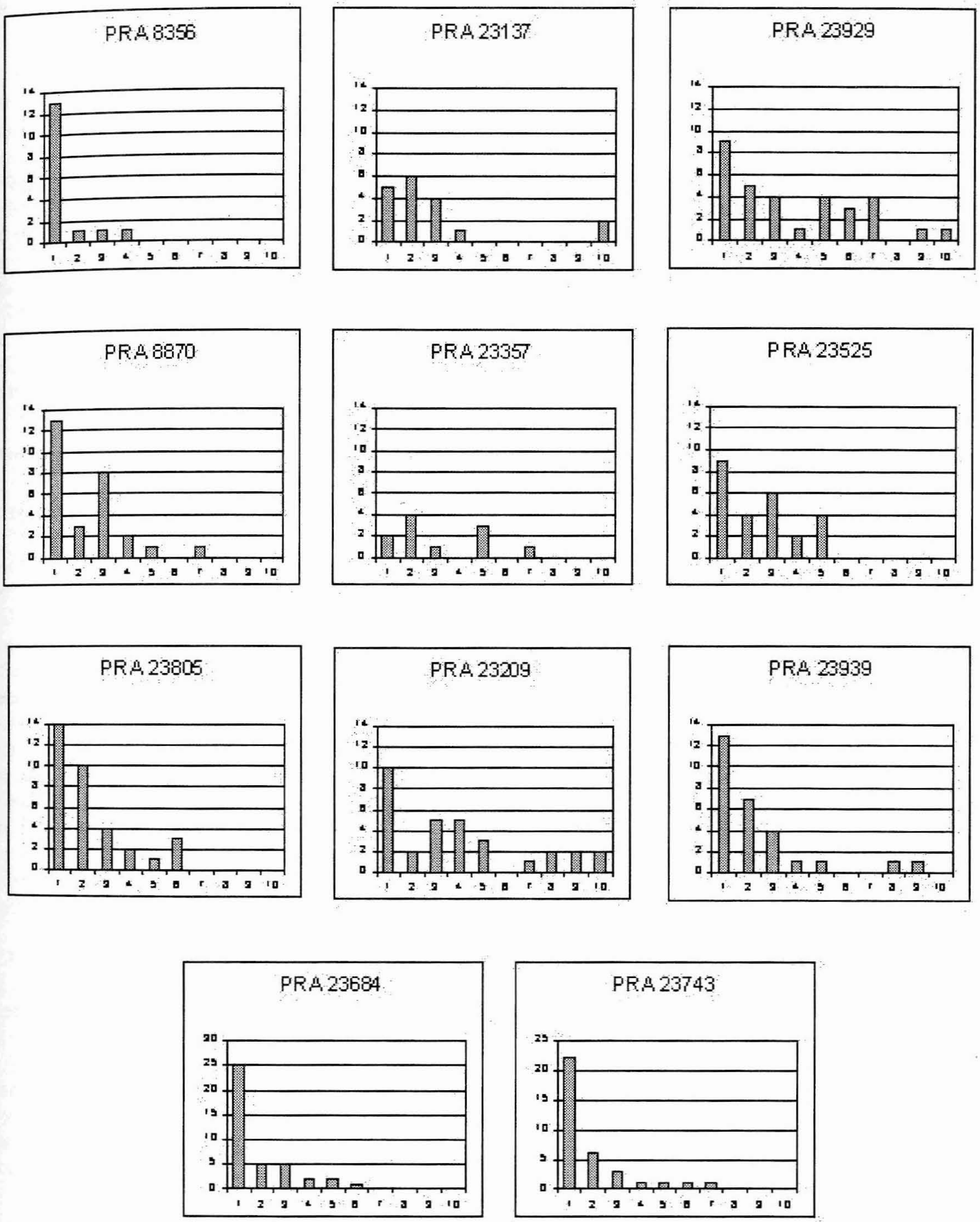
Appendix

***Table 1**. Characterisation of the 11 potential avalanche release in the test area of Davos.*

PRA CODE	MEAN SLOPE	MIN SLOPE	MAX SLOPE	MEAN ASPECT	DISTANCE TO RIDGES	CURVATURE
8366 (1)	34.6	30.2	40.2	276	100	Convex
8870 (2)	33	29.9	36.8	252	0	Convex
23137 (3)	36.3	20.4	50.6	49	500	Flat
23209 (4)	35.9	30	44.2	42	0	Slightly concave
23357 (5)	34.9	30.7	38.9	18.5	0	Slightly concave
23525 (6)	35.7	30.2	43.5	247	60	Slightly concave
23684 (7)	37.4	30	47.6	304	0	Concave
23743 (8)	36.1	30.1	44.4	352	20	Concave
23805 (9)	38.2	30.1	49.2	88	0	Concave
23929 (10)	33.7	30	39.6	225	0	Flat
23939 (11)	37.5	30.1	45.1	194	0	Slightly concave

Figure 1. Release area distribution for the 11 PRA, in the region of Jakobshorn.. On the y-axis there's the number of avalanches with a release area of a certain percentage of the total potential release area (x-axis). On the x-axis class1 means 0-10% of the total PRA and class 10 means 90-100% of the total PRA.



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