



**Cartography of population vulnerability to volcanic hazards and lahars of Mount Pinatubo (Philippines) : a case study in the Pasig-Potrero River basin (province of Papanga)**

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Cartography of population vulnerability to volcanic hazards and lahars of Mount Pinatubo (Philippines): a case study in Pasig-Potrero River basin (province of Pampanga) / Cartographie de la vulnérabilité des populations face aux phénomènes volcaniques et aux lahars du Mont Pinatubo (Philippines) : cas du bassin de la rivière Pasig-Potrero (province de Pampanga)

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## Résumé

Résumé Cette étude a pour objectif d'évaluer la vulnérabilité des populations du bassin de la rivière Pasig-Potrero menacées par les lahars récurrents du volcan Pinatubo (Philippines) à la suite à l'éruption de 1991. À partir d'une campagne d'enquêtes sur le terrain, réalisée entre février et mars 1998, on a pu définir et cartographier différents niveaux de perception du risque, la qualité des comportements potentiels face aux lahars, ainsi que des attitudes en cas d'ordre d'évacuation. Ces données ont ensuite permis de réaliser une typologie et une cartographie de la vulnérabilité dans le secteur d'étude. Il en ressort que si la perception du risque est assez élevée, des problèmes subsistent, notamment en matière d'alerte et de comportements en cas d'évacuation. Le système d'alerte a aussi montré, dans le passé, des carences qu'il convient aujourd'hui de combler. Ces conclusions peuvent guider l'élaboration de scénarios de risque et de catastrophe, utiles à des fins opérationnelles (planification des secours, aide à la gestion des crises, aménagement du territoire...).

## Abstract

Abstract This study aims at assessing the vulnerability of populations in the Pasig-Potrero River basin, who are threatened by the recurrent lahars of Mt Pinatubo volcano (Philippines) in the aftermath of its 1991 eruption. A survey, carried out between February and March 1998, enabled us to define and to map different levels of risk perception, the quality of potential behavioural patterns in the event of further lahars, and attitudes in the event of an evacuation order. It was then possible to work out a classification and to map the patterns of human vulnerability in the study area. This study points out that, while risk perception is quite high, some problems remain, notably concerning the warning systems and the behaviour of the population in the case of an evacuation. These results should assist in elaborating risk and disaster scenarios. They are intended to be used for operational purposes in crisis management such as the organisation of disaster relief, and in land use planning.

# Cartography of population vulnerability to volcanic hazards and lahars of Mount Pinatubo (Philippines): a case study in Pasig-Potrero River basin (province of Pampanga)

## *Cartographie de la vulnérabilité des populations face aux phénomènes volcaniques et aux lahars du Mont Pinatubo (Philippines) : cas du bassin de la rivière Pasig-Potrero (province de Pampanga)*

Jean-Christophe Gaillard\*, Robert D'Ercole\*\*, Frédéric Leone\*\*\*

With the technical and scientific support of the Philippine Institute of Volcanology and Seismology (PHIVOLCS)

### Abstract

This study aims at assessing the vulnerability of populations in the Pasig-Potrero River basin, who are threatened by the recurrent lahars of Mt Pinatubo volcano (Philippines) in the aftermath of its 1991 eruption. A survey, carried out between February and March 1998, enabled us to define and to map different levels of risk perception, the quality of potential behavioural patterns in the event of further lahars, and attitudes in the event of an evacuation order. It was then possible to work out a classification and to map the patterns of human vulnerability in the study area. This study points out that, while risk perception is quite high, some problems remain, notably concerning the warning systems and the behaviour of the population in the case of an evacuation. These results should assist in elaborating risk and disaster scenarios. They are intended to be used for operational purposes in crisis management such as the organisation of disaster relief, and in land use planning.

**Key words:** Philippines, Mt Pinatubo volcano, lahars, vulnerability, risk perception, human behaviour, mapping.

### Résumé

*Cette étude a pour objectif d'évaluer la vulnérabilité des populations du bassin de la rivière Pasig-Potrero menacées par les lahars récurrents du volcan Pinatubo (Philippines) à la suite à l'éruption de 1991. À partir d'une campagne d'enquêtes sur le terrain, réalisée entre février et mars 1998, on a pu définir et cartographier différents niveaux de perception du risque, la qualité des comportements potentiels face aux lahars, ainsi que des attitudes en cas d'ordre d'évacuation. Ces données ont ensuite permis de réaliser une typologie et une cartographie de la vulnérabilité dans le secteur d'étude. Il en ressort que si la perception du risque est assez élevée, des problèmes subsistent, notamment en matière d'alerte et de comportements en cas d'évacuation. Le système d'alerte a aussi montré, dans le passé, des carences qu'il convient aujourd'hui de combler. Ces conclusions peuvent guider l'élaboration de scénarios de risque et de catastrophe, utiles à des fins opérationnelles (planification des secours, aide à la gestion des crises, aménagement du territoire...).*

**Mots clés :** Philippines, volcan Pinatubo, lahars, vulnérabilité, perception du risque, comportements, cartographie.

### Version française abrégée

*L'éruption du volcan Pinatubo, aux Philippines, en 1991, est considérée comme l'une des plus importantes du XX<sup>e</sup> siècle tant pour l'amplitude du phénomène que pour les pertes subies. Depuis lors, de volumineux lahars s'écoulent*

*dans les principaux chenaux d'écoulement drainant les pentes du volcan (tab. 1 et fig. 1). Les lahars de la rivière Pasig-Potrero (province de Pampanga) ont été parmi les plus meurtriers et les plus dévastateurs, notamment pour la municipalité de Bacolor qui a été littéralement rayée de la carte.*

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Une campagne d'enquêtes a été réalisée auprès de 220 personnes afin d'évaluer la vulnérabilité des populations situées dans la zone considérée comme la plus exposée par le Philippine Institute of Volcanology and Seismology (PHI-VOLCS) (fig. 2). Six secteurs d'étude ont été définis selon des critères socio-économiques et leur disposition par rapport au système d'endiguement mis en place par les autorités pour faire face aux lahars de la rivière Pasig-Potrero (fig. 3). L'étude des facteurs cognitifs et comportementaux de vulnérabilité a permis de mettre en évidence une bonne perception du risque liée à de nouveaux lahars et à une éventuelle éruption du Mt Pinatubo (76 % des personnes soumises à l'enquête) (fig. 4). Des différences apparaissent cependant suivant les secteurs et selon l'expérience des populations en matière de lahars (fig. 3 et 4), les secteurs les moins souvent touchés présentant les valeurs les plus faibles. La représentation mentale des zones menacées recoupe quant à elle assez bien la carte d'aléa du PHI-VOLCS (fig. 5). Soixante-dix-sept pour cent des personnes interrogées estiment par ailleurs que de nouveaux lahars se manifesteront dans la rivière Pasig-Potrero.

Les principaux problèmes mis en exergue dans cette étude concernent le comportement des populations en cas de crise (fig. 7). En effet, plus d'un tiers des enquêtés (36 %) se comporterait de manière peu efficace, notamment en ce qui concerne les destinations privilégiées en cas d'évacuation. Le système d'information des populations de bouche-à-oreille et les moyens techniques de prévention mis en place par les personnes interrogées s'avèrent aussi insuffisamment ou inégalement efficaces. En cas d'ordre d'évacuation, 93 % des enquêtés s'avouent toutefois prêts à quitter leur domicile. Les seuls réfractaires se situent à Bacolor où près de 28 % de la population manifestent un attachement très fort à leur village natal (fig. 7). La mauvaise image des centres d'évacuation et de relogement concourt aussi aux comportements récalcitrants. La qualité et l'efficacité du système d'alerte se révèlent également insuffisantes, notamment face aux lahars (fig. 8). Bien que les systèmes d'alerte locaux (sirène, cloche, porte-à-porte, radio...) soient privilégiés, moins de 70 % des personnes interrogées dans certains secteurs ont en effet été prévenus de la menace de lahars pour leur village. Des problèmes logistiques et politiques (multiplication des systèmes d'alerte, taux d'écoute de la radio et de lecture des journaux, intérêts politiques et délictueux...) semblent à l'origine de ces défaillances.

Une synthèse graphique du travail (fig. 9) permet enfin de hiérarchiser les secteurs d'étude selon quatre niveaux de vulnérabilité. À partir de cette typologie, il devient possible de réaliser une carte de vulnérabilité des populations du bassin de la rivière Pasig-Potrero (fig. 10). Les secteurs de Manibaug et de North San Fernando, jusqu'à présent les moins sévèrement affectés, apparaissent comme les plus vulnérables, notamment à cause d'une perception du risque relativement faible et d'un comportement inefficace face aux lahars. Les habitants de San Fernando Town Proper ont une meilleure perception du risque, mais leur attitude face aux lahars reste potentiellement dangereuse. La situation est différente dans le Potrero Stream qui est le secteur le plus gra-

vement affecté par les lahars de la rivière Pasig-Potrero. En effet, si les mesures de prévention mises en place par les enquêtés et leur perception du risque s'avèrent des atouts indéniables en cas de crise, leur attitude souvent réfractaire en cas d'ordre d'évacuation se révèle inquiétante. Les deux derniers secteurs, Betis et Santo Tomas-Minalin, paraissent les moins vulnérables, notamment grâce à une perception du risque élevée et à un suivi massif des consignes en cas d'ordre d'évacuation.

Il apparaît donc clairement à travers cette étude que l'expérience des populations en matière de lahars constitue un atout certain en cas de nouvelles crises, notamment en termes de perception du risque et de connaissance des moyens de protection. L'attention semble devoir être tournée vers la gestion des évacuations et l'information des populations qui s'avèrent défectueuses.

## Introduction

The awakening of the Mount Pinatubo volcano in 1991 signalled what is considered to be one of the most severe volcanic eruptions of the 20th century, killing more than 300 people as a consequence of roof collapses and aftermath epidemics (Pinatubo Volcano Observatory Team, 1991; Wolfe, 1992). The total economic losses due to the eruption probably reached around one billion US dollars by the year 2000 (Leone et Gaillard, 1999). Indeed, since 1991, lahars brought on by the rainy season each year affect the main river channels that drain the volcano. A lahar is a rapidly flowing, relatively thick mixture of volcanic debris and water, typically with 40-80 percent sediment by weight. Most lahars of Mount Pinatubo are caused by rainfall (Janda et al., 1996; Pierson et al., 1992; Punongbayan et al., 1992). The consequences of the lahars are enormous from both a human and economic perspective. While 600 people met their deaths, tens of thousands of families were affected (table 1), and more than 42,000 of them had to be re-accommodated into resettlement centres located within the Central Luzon region (Mount Pinatubo Commission, 1999). Now, 1350 km are still threatened by lahars and associated floods (National Economic and Development Authority Region III, 1997).

Pasig-Potrero lahars (fig. 1), which affect one of the most densely populated provinces of the Philippines (643 inhabitants/km<sup>2</sup> in 1995: National Statistic Office, 1996), have been among the most devastating (Crittenden and Rodolfo, 2000; Umbal, 1997). Thus, the municipality of Bacolor, where the population was in a period of high growth prior to the eruption of Mt. Pinatubo (67,259 inhabitants in 1990 compared to 50,942 in 1980), had a population of less than 9,000 in 1995 (National Statistic Office, 1996; Crittenden, 1997). The remainder of the population has been resettled in centres where conditions are often very difficult. In coping with these difficulties, some inhabitants prefer to return to their home villages that still face the threat of lahars. In spite of widespread criticism by some people in the scientific community and in the media, authorities spent 37 million dollars in 1996 to build a system of dikes as defences

Year	Estimated annual sediment delivery (million m <sup>3</sup> )	Dead and missing	Number of families	Number of damaged houses
1991	805	957	249,371	112,236
1992	555	19	164,400	6,212
1993	505	43	353,658	6,474
1994	310	61	169,295	3,415
1995	187	97	123,792	14,490
1996	161	6	44,597	46
1997	83	26	224,610	285

Table 1 – Damages and casualties of the 1991 eruption and subsequent lahars of Mt Pinatubo (from the data of Sincioco *et al.*, 1999, and Department of Social Welfare and Development Region III, 1998).

Tableau 1 – Bilan des sept premières années de crises liées à l'éruption (1991) et aux lahars du Mt Pinatubo (d'après les données de Sincioco *et al.*, 1999, et du Department of Social Welfare and Development Region III, 1998).

against the lahars. Indeed, only two weeks after its inauguration, one part of the "transverse dike" was seriously damaged (Agapay *et al.*, 1997).

We have tried to assess actual population vulnerability in relation to the volcanic eruption and the subsequent phase of lahar occurrence. As part of this, a survey was carried out to determine the perception of risk within the population

living in the Pasig-Potrero basin, and to assess their behaviour in response to the threat of lahars. The survey also aimed to estimate the burden of economic, social and

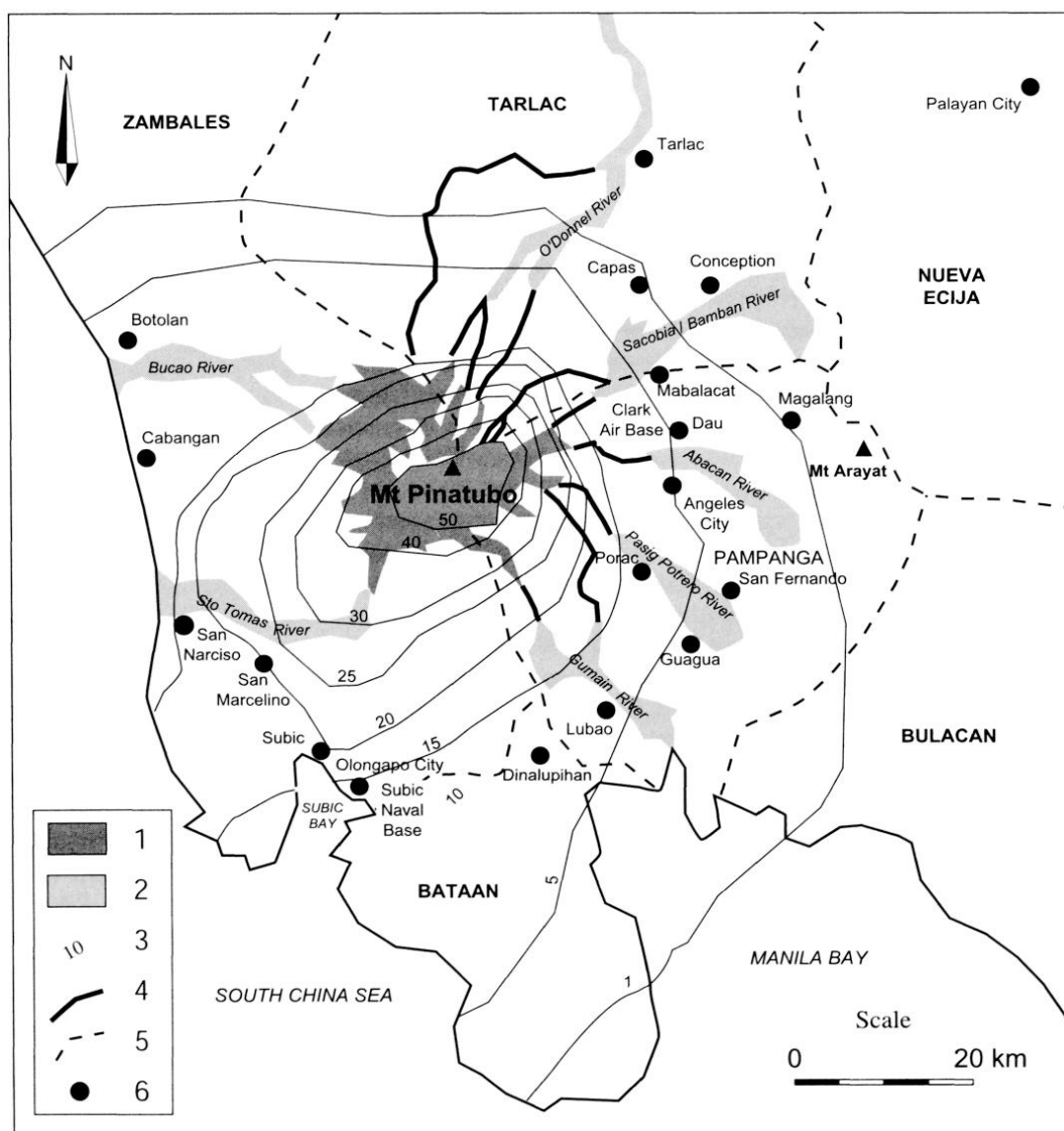


Fig. 1 – Main active lahar channels and other destructive phenomena linked to the 1991 Mt Pinatubo eruption (adapted from Pinatubo Volcano Observatory Team, 1991). 1: June 1991 pyroclastic-flow deposits; 2: lahar deposits; 3: isopachs (in cm) of airfall deposits; 4: active lahar channels; 5: provincial limits; 6: towns.

Fig. 1 – Principaux chenaux de lahars actifs et autres agents destructeurs associés à l'éruption du Mt Pinatubo en 1991 (adapté de Pinatubo Volcano Observatory Team, 1991). 1 : dépôts des écoulements pyroclastiques de juin 1991; 2 : dépôts de lahars ; 3 : isopaques (en cm) des retombées aériennes; 4 : chenaux de lahars actifs ; 5 : limites de provinces ; 6 : villes.





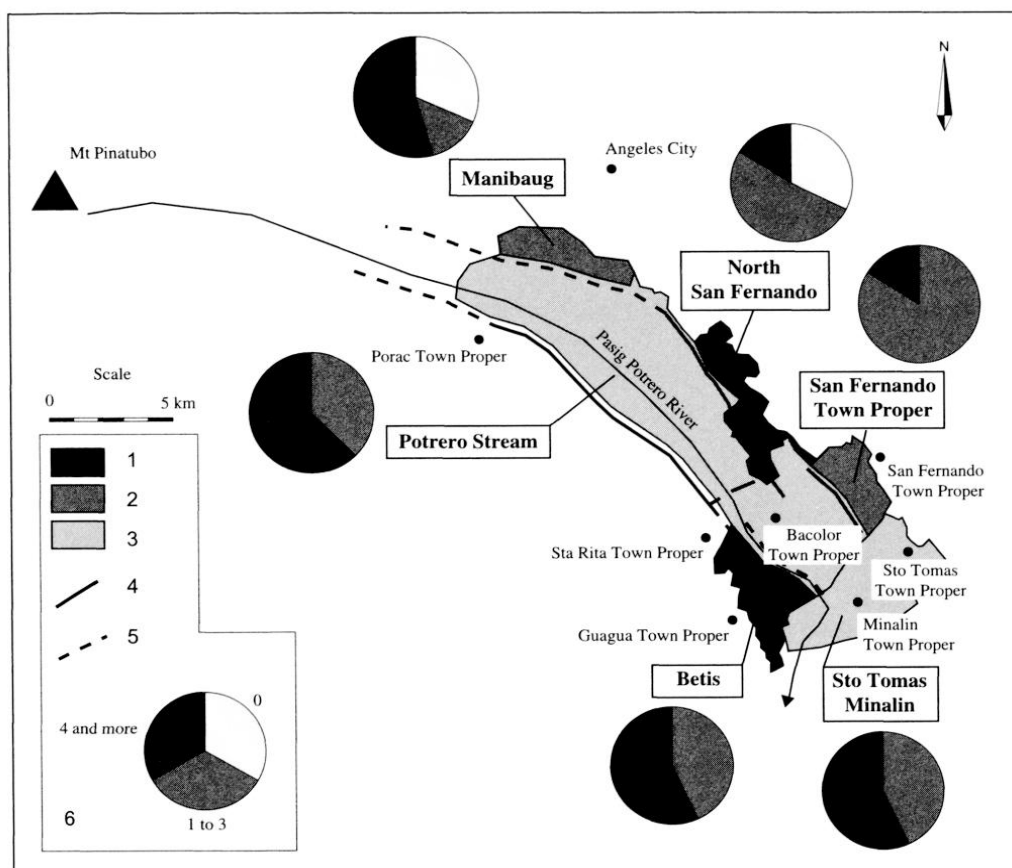


Fig. 3 – The different study sectors defined according to their socio-economic status, their distribution along the dike system and the number of times the surveyed people have been affected by lahars. A) Socio-economic status. 1: highest socio-economic status (students, clerks, learned professions, teachers... / college graduates / less than 2 persons/room); 2: intermediate socio-economic status (workers, craftsmen, drivers, shopkeepers, peddlers / high school graduates / 2 to 3 persons/room); 3: lowest socio-economic status (jobless, farmers, fishermen, housewives / primary school graduates / more than 3 persons/room); B) System of dykes set up to face the Pasig-Potrero lahars. 4: dike with stream-side concrete armour and supposed to be effective against lahars; 5: unarmoured dike made of lahar deposits (effectiveness is questionable); 6: number of times the people surveyed have been affected by lahars (in %).

Fig. 3 – Les différents secteurs d'étude définis selon leur niveau socio-économique, leur disposition par rapport au système d'endiguement et le nombre de fois que les personnes soumises à l'enquête ont été affectées. A) Niveaux socio-économiques. 1 : niveau socio-économique le plus élevé (étudiants, employés, professions libérales, enseignants... / diplômés du supérieur / moins de 2 personnes par pièce du domicile) ; 2 : niveau socio-économique intermédiaire (ouvriers, artisans, chauffeurs, commerçants, marchands ambulants / diplômés du secondaire / 2 à 3 personnes par pièce du domicile) ; 3 : niveau socio-économique le plus faible (sans emplois, agriculteurs, pêcheurs, femmes au foyer / diplômés du primaire / plus de 3 personnes par pièce du domicile) ; B) Système d'endiguement mis en place face aux lahars de la rivière Pasig-Potrero. 4 : digue avec armature bétonnée, supposée efficace contre les lahars ; 5 : digue faite de dépôts des lahars (efficacité remise en cause) ; 6 : nombre de fois que les personnes interrogées ont été affectées par des lahars (en %).

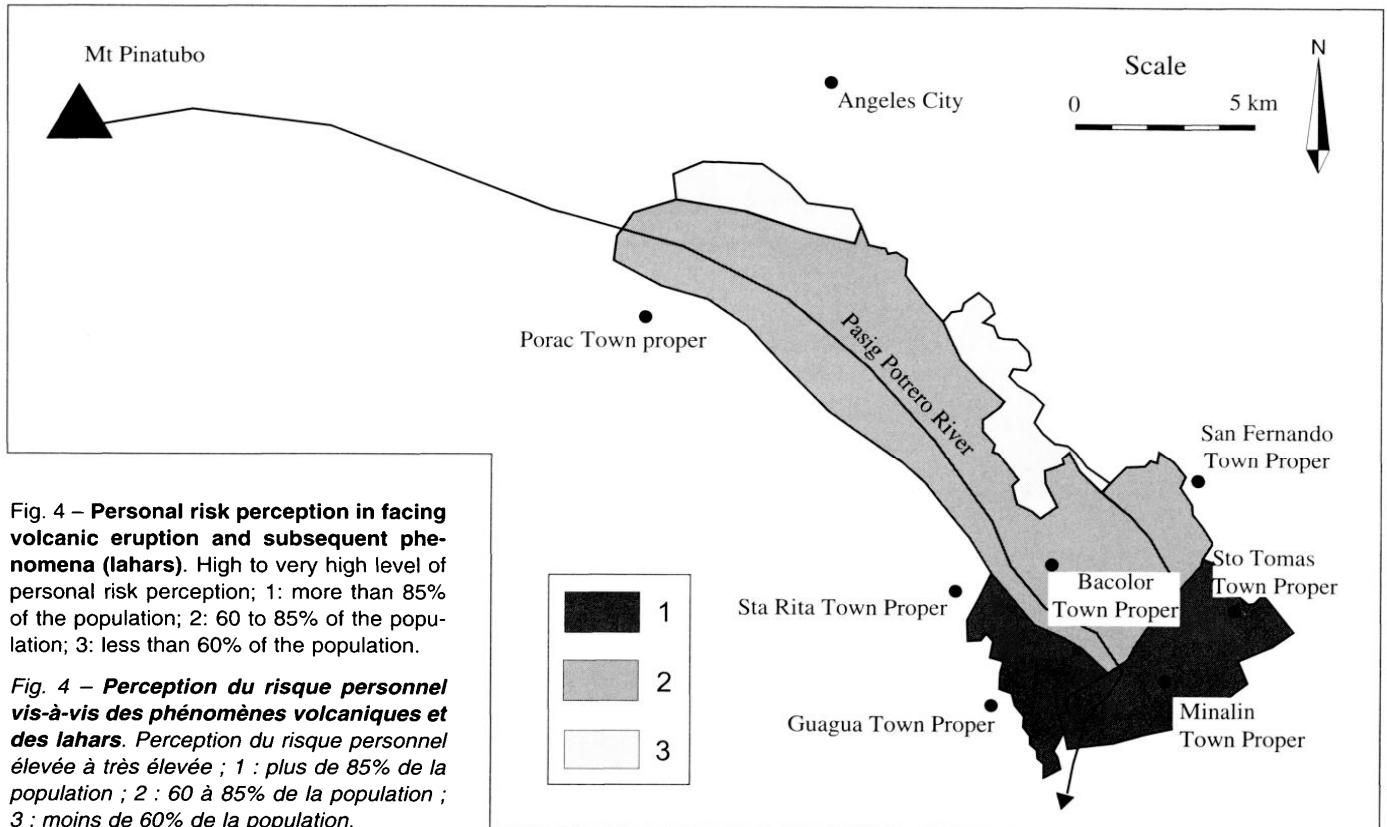
seriously underestimated the risks involved (only 48 to 50% of the population perceived the risk as being high to very high). The urban part of San Fernando and the villages located in the flow channel, concentrated between the arms of the dike system, manifested a high to very high risk perception in just 60 and 78% of their respective populations. This is a worrying finding in view of the extent of volcanic phenomena having already affected the sector and still threatening the area (PHIVOLCS, 1997; Agapay *et al.*, 1997).

If one compares these observations with the number of lahars experienced by the different sectors, it appears that personal risk perception is intimately linked to the number of times that people have been affected. In this way, the most affected sectors (Betis, Santo Tomas-Minalin and Potrero Stream) were those where the risk perception was highest, in contrast to the two least-affected sectors (Manibaug and North San Fernando).

Positioning along the dike system did not seem to play an important role in influencing risk perception. For example, quite different responses were apparent in the sectors of Betis and Manibaug, which are both bordered by the same type of unfortified dike. As such, this parameter was included in the definition of the different study sectors, each of which is bordered by a different type of dike.

In contrast, the mental representation of the area that could be affected in the event of further lahars occurring along the Pasig-Potrero River agrees well with the Philippine Institute of Volcanology and Seismology (PHIVOLCS) hazard map (fig. 2). Bacolor, San Fernando, Santo Tomas, Minalin, Guagua and Santa Rita were cited by more than 95% of the population as being susceptible (fig. 5).

The interviewees were, however, inclined to expand the danger zone to the localities of Porac, Town Proper, and Floridablanca (Porac River basin), which are hardly threatened by lahars because of the location further up the river. Nevertheless, the municipality of Porac is often associated with the lahars by the media and local politicians. This seems to have distorted the reality of the situation in the minds of those interviewed. Concerning Angeles City, the population also tended to confuse the situation with the lahars of the Abacan River, which can affect the North and East parts of the town.



Seventy-seven percent of the surveyed population predicted that the lahars would return during the following rainy season (fig. 6). In agreement with their low risk perception, about 20% of the inhabitants of Manibaug and North San Fernando considered that lahars were a thing of the past. Taking into account the efforts of the authorities and the extent of coverage in the media, one could be reasonably concerned for this part of the population. While it is true that Manibaug Paralay village (Porac), for example, is on the list of the most threatened sectors, it has not yet been significantly affected (fig. 3). It can be seen again in the present example, that experience of individuals appears to be an important factor in the definition of personal risk perception.

### Behavioural attitudes adopted by individuals threatened by lahars

While risk perception was relatively high in the area most threatened by Pasig-Potrero lahars, the attitude of individuals in the event of a crisis is a cause of concern (fig. 7). Indeed, more than one third of the surveyed population (36%) would demonstrate ineffective behaviour that could place lives in danger in the event of a lahar. This is with particular reference to the destinations planned by these people when evacuation would be necessary. Some of them would evacuate to areas that could, themselves, be affected by lahars or floods. In addition to the destinations, which often corresponded to evacuation centres already visited during previous evacuations, the surrounding environs of these destinations and the zones that would have to be crossed to

reach them could also be dangerous. This point has already been highlighted by a PHIVOLCS study that took place following lahars in 1993 (Tayag *et al.*, 1994). It was determined that 101 of the 206 evacuation centres in operation in the Pampanga province at this time were in fact not safe. In this way, it would seem appropriate that the target evacuation centres for each village be first properly defined and that the populations be clearly informed of their location. Indeed, the evacuation plan of the Pampanga province as of January 10, 1997 mentions only the original municipalities of the individuals for each centre (Provincial Disaster Coordinating Council, Province of Pampanga, 1997).

Moreover, while the village councillors quite often know the locations and the centres to where they must evacuate, it appears that this information does not properly filter through to the general population. As such, the system of distribution of information by word-of-mouth between village captains, councillors and villagers should be reviewed. In order to achieve an appropriate response system, the mapping of not only evacuation centres but also of the means of evacuation seems necessary. Indeed, more than 80% of the people surveyed admitted to having already evacuated spontaneously, and apparently under their own means, more or less without any reference to official help.

Otherwise, the effectiveness of structural means of protection adopted by the population is not uniform. While at times very reluctant to evacuate, those persons interviewed from Bacolor had chosen appropriate protective measures, particularly with respect to the elevation of houses on concrete posts (Crittenden and Rodolfo, 2000). Indeed, such precautions had already withstood several rainy seasons and

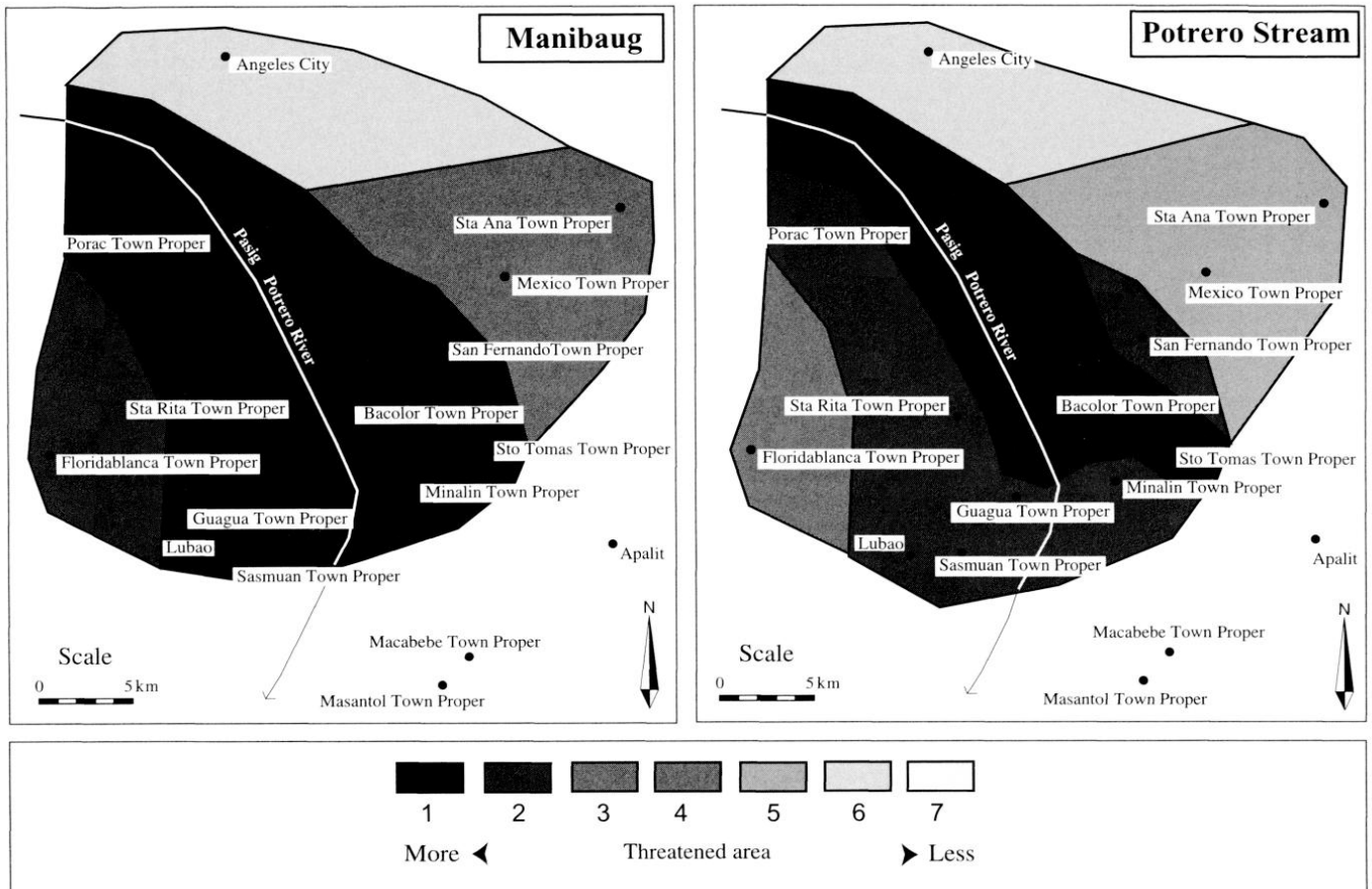
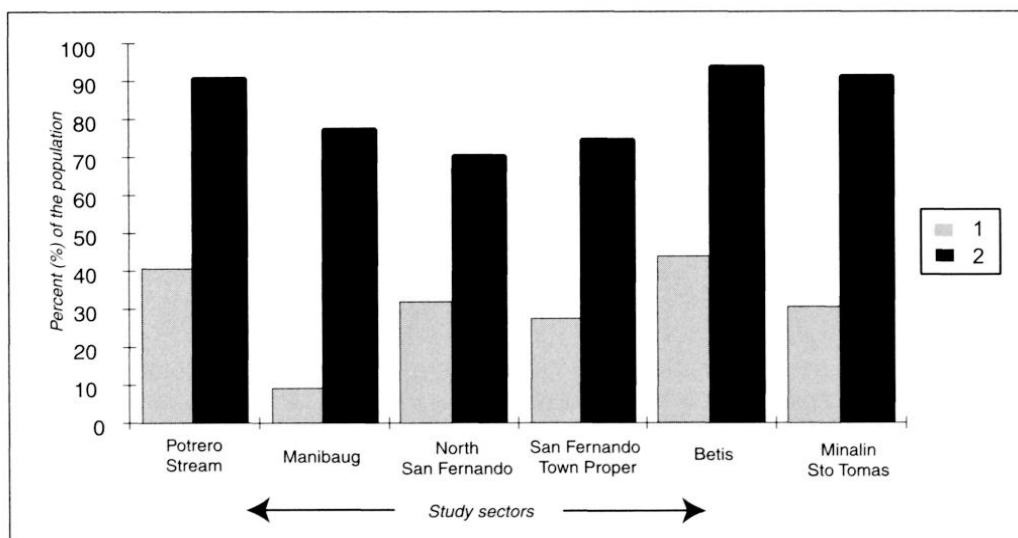


Fig. 5 – Mental representation of the places threatened in case of lahars: cases of Manibaug and Potrero Stream. It should be noted, that in order to assess the mental representation of the places threatened, interviewees had to delimit, the zones which they thought could be affected. Results are expressed as a percentage of persons surveyed. 1: 91-100%; 2: 81-90%; 3: 71-80%; 4: 51-70%; 5: 31-50%; 6: 11-30%; 7: 0-10%.

Fig. 5 – Représentation mentale des espaces menacés en cas de lahars : cas de Manibaug et du Potrero Stream. Il est à noter que, pour évaluer la représentation mentale des espaces menacés, les enquêtés devaient délimiter les zones qu'ils pensaient susceptibles d'être affectées. Les résultats sont exprimés en pourcentage de personnes soumises à l'enquête. 1 : 91-100% ; 2 : 81-90% ; 3 : 71-80% ; 4 : 51-70% ; 5 : 31-50% ; 6 : 11-30% ; 7 : 0-10%.

appear to be a safe form of protection from lahars in contrast to sandbags, widely used in some areas. Indeed, while sandbags can be effective in combating floods, K. S. Rodolfo

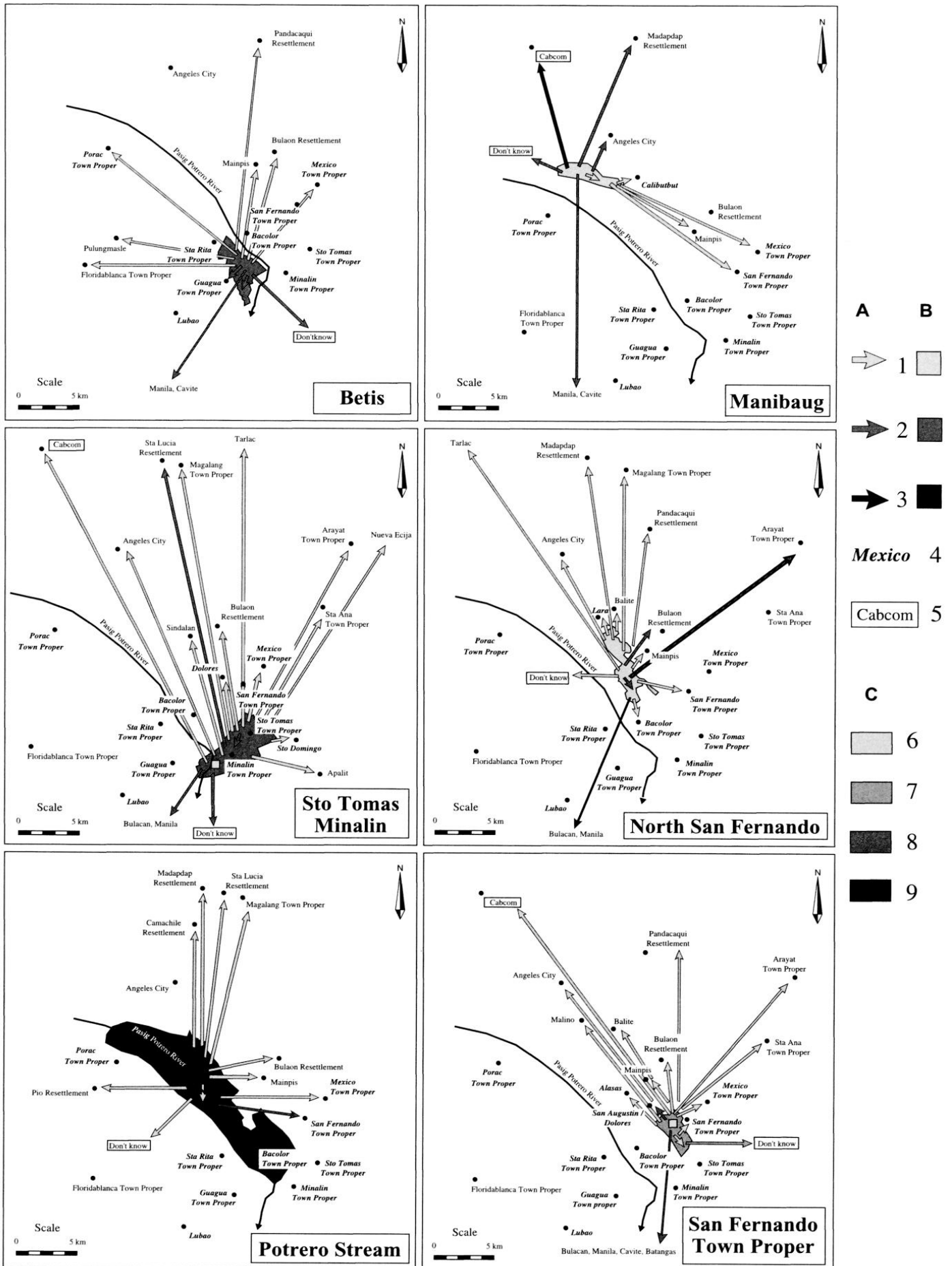
(1995) challenged the effectiveness of their use against lahars, accusing them of increasing the destructive power of the debris flows. Under these circumstances, and faced with



the threat of lahars, the safer and more radical protection measure consists in moving one's home at the onset of the rainy season, as advised by the authorities (Today, 1997). In all,

Fig. 6 – Perception of lahar occurrence probability in Pasig-Potrero and of another Mt Pinatubo eruption. 1: eruption; 2: lahars.

Fig. 6 – Perception de la probabilité d'occurrence de nouveaux lahars dans la Pasig-Potrero et d'une nouvelle éruption du Mt Pinatubo. 1 : éruption ; 2 : lahars.



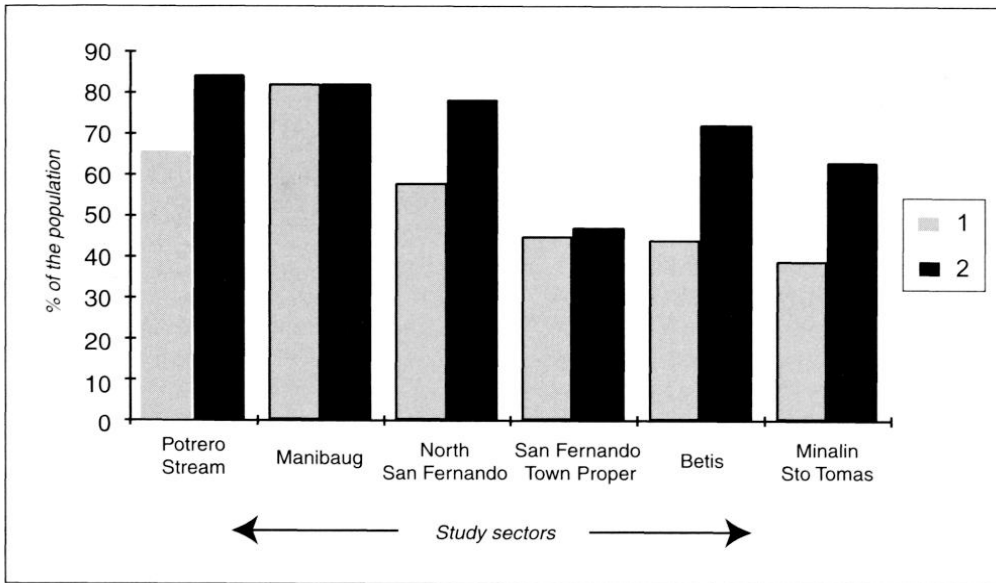


Fig. 8 – Percentage of surveyed persons having received a warning message prior to the 1991 eruption of Mt Pinatubo and in subsequent years when threatened by lahars. 1: eruption; 2: lahars.

Fig. 8 – Personnes soumises à l'enquête ayant reçu un message d'alerte avant l'éruption du Mt Pinatubo en 1991 et avant les lahars des années suivantes. 1 : éruption ; 2 : lahars.

danger presented by lahars and of the impossibility of remaining in the home should it be reached by the flowing debris. Those people who resisted evacuation orders

17% of the surveyed population adopt this approach every June, with more than 30% of the population at Bacolor undertaking such measures (fig. 7).

As for the risk perception factor, the responses adopted in the event of lahars are not uniform across the different sectors. Indeed, almost 50% of those surveyed from Manibaug and San Fernando Town Proper would act in a way that could place them in danger. This figure is more than 30% for the North San Fernando, Betis and Santo Tomas-Minalin sectors. On the contrary, at Bacolor Poblacion (town proper), inside the Pasig-Potrero flow channel, only 19% of the inhabitants interviewed would act in an ineffective way.

### Some constraining factors of a social or technical nature

In the event of an order to evacuate, 93% of those surveyed in the area most threatened by Pasig-Potrero lahars would be ready to evacuate their home. While the risk perception level was not as high as one might like in this sector, the population in general seemed to be conscious of the

Fig. 7 – Quality of attitudes facing lahars in Pasig-Potrero River basin.

A: planned destination in case of an evacuation; B: persons who do not agree to evacuate; 1: 0 to 10% of interviewed population; 2: 10,1 to 20% of interviewed population; 3: 20,1 to 30% of interviewed population; 4: area prone to lahars, muddy stream flows, and/or floods; 5: area or behaviour that can provide dangerous situations for different reasons; C: % of the population whose behaviour in the event of lahars is very effective; 6: 0 to 9%; 7: 10 to 19%; 8: 20 to 29%; 9: 30 to 39%.

Fig. 7 – Qualité des comportements face aux lahars dans le bassin de la rivière Pasig-Potrero. A : destination envisagée en cas d'évacuation ; B : personnes ne voulant pas évacuer ; 1 : 0 à 10% des personnes interrogées ; 2 : 10,1 à 20% des personnes interrogées ; 3 : 20,1 à 30% des personnes interrogées ; 4 : localités menacées par des lahars, des coulées de boue ou des inondations ; 5 : localités ou situations qui pourraient engendrer des situations dangereuses pour différentes raisons ; C : % de la population qui a un comportement très efficace face aux lahars ; 6 : 0 à 9% ; 7 : 10 à 19% ; 8 : 20 à 29% ; 9 : 30 à 39%.

were located mainly at Bacolor, where about one third of those surveyed (28%) were unwilling to leave their home village, particularly for sentimental reasons (affection for the place where they were born, etc.).

While the majority of persons interviewed in the Pasig-Potrero basin were ready to temporarily evacuate their homes, as soon as the threat was over they returned to their homes, more or less resigned to the fact they would have to leave again in subsequent crises. The perception of resettlement centres is revealing. Sixty percent of those surveyed were unwilling to return to them. The main reasons mentioned were a lack of employment (22%), congestion and lack of privacy (20%), attachment to "Mother Earth" (11%), lack of food (10%), and the lack of sanitary installations or running water.

Twelve percent of those surveyed had, however, already lived in permanent resettlement centres prior to leaving them to return to their original villages. These people represented more than 60% of the population of Bacolor and about 5% of the other sectors, with the exception of the populations of Minalin and Santo Tomas, which had not yet been resettled in these centres. When asked to provide reasons for their return, these people also cited the lack of employment prospects (31%), the remoteness of the resettlement centre (21%) and attachment to "Mother Earth" (18%).

The quality of the system to warn the people of volcanic hazards (eruptions and lahars) also appears to present a problem (fig. 8). In 1991, when Mt. Pinatubo erupted, 82 and 76% of those people surveyed at Manibaug and in the Potrero Stream, respectively, had received a warning signal, compared to less than 39% at Santo Tomas-Minalin. With the occurrence of lahars in subsequent years, the observed differences in numbers of people receiving a warning signal are of some concern. Indeed, while the number of persons officially informed at Manibaug (82%) is, if not perfect, at least acceptable and indicative of a certain effectiveness of the response system in this locality, population warning remains a significant problem throughout the other sectors.

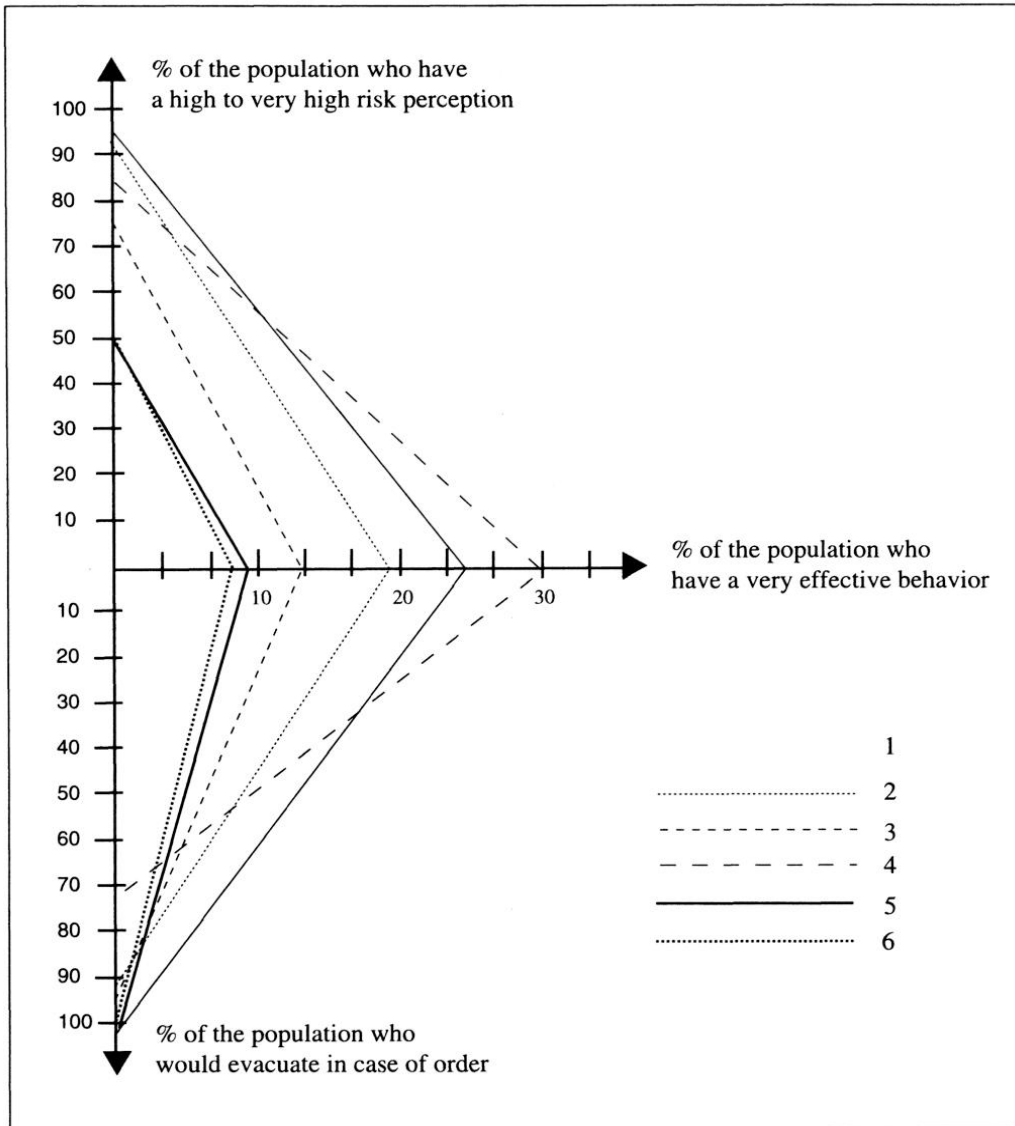


Fig. 9 – Graphic synthesis of vulnerability of the different study sectors. 1: Manibaug; 2: North San Fernando; 3: Potrero Stream; 4: San Fernando Town Proper; 5: Sto Tomas/Minalin; 6: Betis.

Fig. 9 – Synthèse graphique de la vulnérabilité des différents secteurs d'étude. 1 : Manibaug ; 2 : North San Fernando ; 3 : Potrero Stream ; 4 : San Fernando Town Proper ; 5 : Sto Tomas/Minalin ; 6 : Betis.

Apart from institutional management problems, which will not be addressed here, it is possible that other logistical factors are responsible for delays in communicating information to the threatened localities. For example, the direct accessibility of the population via radio is endorsed by the listening rate, the level of which varies significantly across the different sectors: from 95% at Manibaug to only 67% at Santo Tomas and Minalin. This would suggest that one third of the population in this latter zone are unable to be kept informed of developments by this method. In

This is especially so at Santo Tomas-Minalin and San Fernando Town Proper where less than 70% of those surveyed had been warned of the threat of a lahar strike. Nevertheless, the alert seemed better in 1992 (Cola, 1996; Tayag *et al.*, 1996). The actual situation is maybe due to the multiplicity of warning signals for several years and to the subsequent possibilities of confusion.

Local warning signals (sirens, bells, door-to-door, radio, etc.) are, however, widespread. It would nevertheless be desirable to define a unique signal for each village and to inform the population of its distinguishing features. Indeed, surveyed people often mention that several forms of warning are used in their village without them knowing exactly which one would be employed in subsequent warnings. This could be a source of confusion in the event of an emergency.

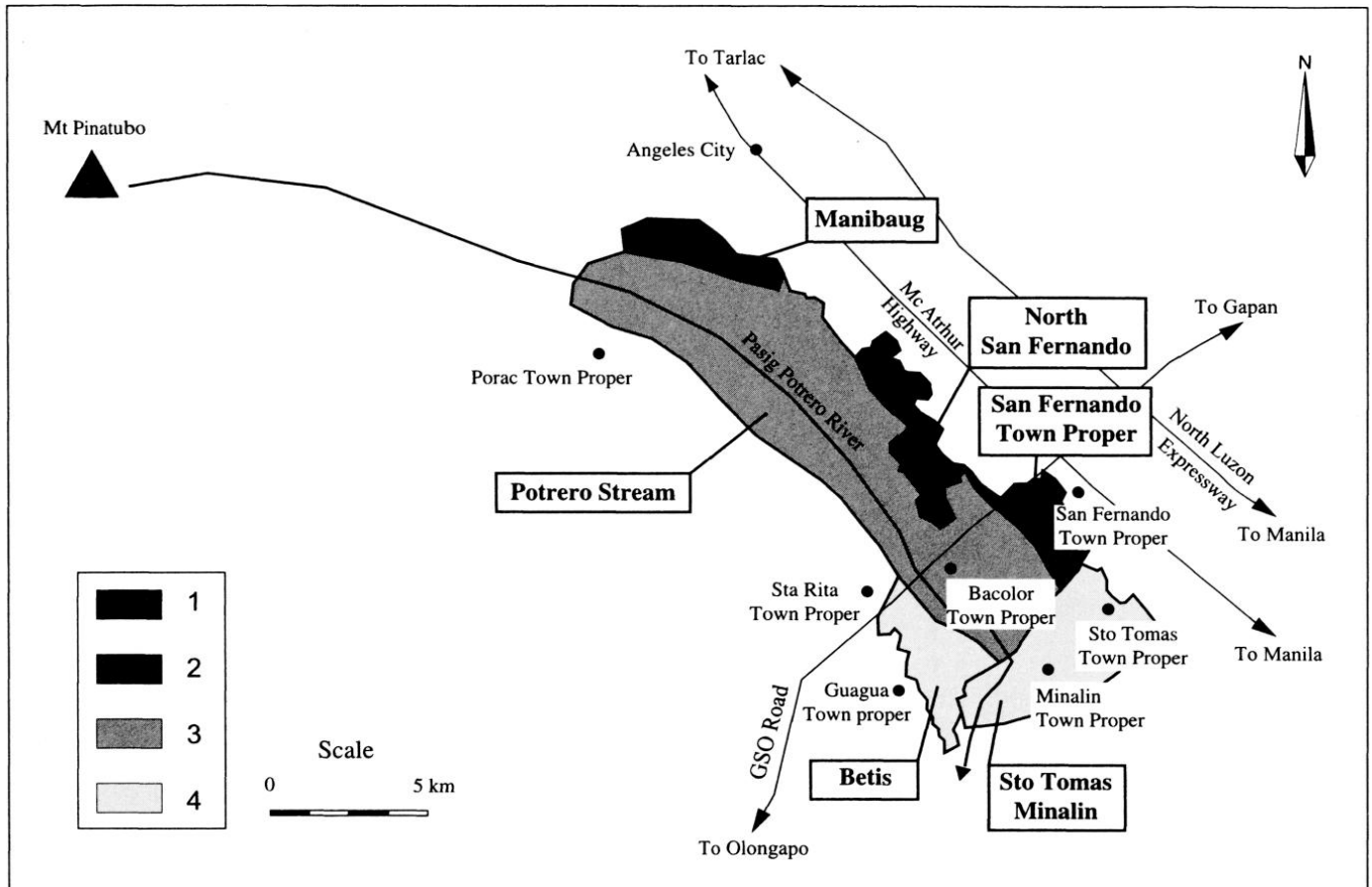
Furthermore, while only the Regional Disaster Co-ordinating Council (RDCC) is authorised to order the evacuation of a threatened area, it seems that other warnings, given for different reasons (political, nuisance, etc.) can interfere with this process, causing yet more confusion (The Philippine Journal, 1997; Jimenez, 1997; Regional Disaster Co-ordinating Council Region III, 1998).

the same way, television is not watched regularly by 28% of the population of Potrero Stream. While it is also impossible to obtain newspapers in some parts of the Pasig-Potrero basin, the English language barrier renders them of little use. Within this framework, the method of diffusion of warning signals must become one of the primary concerns of governmental institutions, in particular via the exhaustive dissemination of official information to the general population.

### Graphic synthesis of vulnerability

Figure 9 shows a comparison of the studied sectors as a function of the different behavioural factors. From these diagrams, it is possible to study the shape of the polygons formed in order to obtain a hierarchy of situations of vulnerability. These diagrams highlight four main types, which serve as a basis for mapping population vulnerability in the Pasig-Potrero basin (fig. 10).

1) Firstly, Manibaug and North San Fernando have the highest degree of vulnerability due to a very low personal risk perception and to attitudes in dealing with the threat of lahars that are likely to place the inhabitants of these locali-



**Fig. 10 – Vulnerability of populations in the Pasig-Potrero River basin.** 1: area with a high degree of vulnerability, due to a misguided perception of risk and ineffective behaviour when facing the threat of lahars; people will respond well to an order to evacuate; 2: area with a moderate degree of vulnerability, due to a misguided perception of risk and ineffective behaviour when faced with the threat of lahars; people will respond well to an order to evacuate; 3: area with a low degree of vulnerability, due to a reasonably accurate perception of risk, and a very effective behaviour when faced with the threat of lahars; problems could appear if there was an order to evacuate; 4: area with a low degree of vulnerability, due to a very accurate perception of risk and very effective behaviour in the event of an order to evacuate; attitudes to the threat of lahars could be improved.

**Fig. 10 – Vulnérabilité des populations du bassin de la rivière Pasig-Potrero.** 1 : secteurs fortement vulnérables à cause d'une faible perception du risque et de comportements peu efficaces face aux lahars ; cependant, les ordres d'évacuations seraient massivement suivis ; 2 : secteurs moyennement vulnérables ; la perception du risque n'est pas très élevée et les comportements face aux lahars sont peu efficaces ; par contre, les attitudes en cas d'ordre d'évacuation seraient conformes aux consignes ; 3 : secteurs faiblement vulnérables ; la perception du risque est assez élevée et les comportements face aux lahars sont plus efficaces que dans les autres secteurs ; cependant, des problèmes pourraient apparaître en cas d'ordre d'évacuation ; 4 : secteurs faiblement vulnérables grâce à une perception du risque élevée et à des comportements opportuns en cas d'ordre d'évacuation ; cependant, les attitudes face aux lahars pourraient être améliorées.

ties in serious danger. In the event of an evacuation order, however, these populations seem be likely to follow official instructions. In this situation, a concerted effort must be made to inform the inhabitants of these regions of the hazards posed by Mt. Pinatubo and its associated lahars. It should be noted that these sectors, while highly vulnerable, are the least affected sectors of the study area, with almost one third of the persons interviewed in these zones never having been personally affected by lahars. Nevertheless, it would appear that these populations are less threatened than those of the Potrero Stream located on the lahar flow channel.

2) The inhabitants of San Fernando Town Proper manifest a higher risk perception but their attitude in coping with the threat of lahars is still of some concern. Nevertheless, this population would be likely to follow official instructions in the event of an order to evacuate. While the level of vulne-

rability here is lower than that of the sectors mentioned above, informing the population, particularly about the use of sandbags, remains a major problem.

3) The situation is different for the Potrero Stream area where some difficulties could appear in the event of an order to evacuate. However, this is compensated for by the significant number of very effective responses shown in facing the threat of lahars (particularly concerning the practice of raising houses on concrete posts). The risk perception is also higher. Thus, it appears that the most threatened and the most affected sector has a relatively low level of vulnerability. As such, the importance of prior experience in explaining the attitudes of people appears clearly to be the case concerning the inhabitants of the Pasig-Potrero flow channel, who must deal annually with the threat of lahars. Here, it is more the people's opinion of the authorities than the



effective dissemination of information to the inhabitants of the region that could be improved. This is particularly the case where justification of the reasons for choices made regarding preventive measures, if this is possible, should be considered by the authorities.

4) Other sectors where the degree of vulnerability is quite low are Betis and Santo Tomas/Minalin. Indeed, the risk perception is very high in these zones, and official instructions would be followed in the event of an order to evacuate. However, attention should be focused on responsive attitudes in dealing with the threat of lahars. These could be improved, particularly at Santo Tomas and Minalin. It is interesting to note that these two sectors exhibit very different socio-economic characteristics (fig. 3). Thus, it appears that living standards are not a major indicator of vulnerability in the Pasig-Potrero basin.

## Conclusions and research perspectives

The findings of this study point out that the inhabitants of the zone most threatened by Pasig-Potrero lahars—according to PHIVOLCS (1997)—reveal level of vulnerability that cannot be disregarded. The most vulnerable people seem to be those whose personal experience of lahars is the lowest. In view of the above, it would seem very appropriate to focus attention on those sectors that have not yet been widely affected (Manibaug and North San Fernando).

While extensive research about global vulnerability has already been achieved (Blaikie *et al.*, 1994; Coburn *et al.*, 1994; D'Ercole, 1998; Lavell et Franco, 1996; Maskrey, 1993), only a couple of case studies have focused on human vulnerability facing volcanic hazards. They could provide elements of comparison with Mt Pinatubo. Studies of D'Ercole (1991 and 1996), D'Ercole and Rançon (1994) and Dibben and Chester (1999) were conducted around volcanoes, which have been dormant for years (respectively Mt Cotopaxi in Ecuador, Montagne Pelée in Martinique and Mt Furnas in the Azores). Research carried out around Mt St Helens and compiled by the University of Delaware (1990) counts among the very few studies that document public perception of volcanic hazards in times of crisis. These studies highlight the burden of personal experience in assessing population vulnerability and promoting mitigation measures.

In the Pasig-Potrero River basin, if the actual context of the crises and their annual recurrence is an asset in terms of risk perception and knowledge of means of protection, the reactions of inhabitants continue to be influenced by certain preconceptions and are submitted to certain parameters that belong more to the institutional domain. Attention seems to be focused on evacuation management, which could be improved through a more rational allocation of evacuation centres, which would accommodate evacuees of Pasig-Potrero basin. A cartography of these shelters and also of the evacuation means seems necessary. Furthermore, a problem remains concerning the dissemination of information, especially when of an official nature. Indeed, the actual system, in particular that at a local level, shows some limitations. All of this forms

part of what we know as institutional risk management. It would thus seem appropriate for authorities to work on at local a scale as possible (village) so as to better adapt to local specificities which, as mentioned above, define different levels of vulnerability according to the different sectors.

The production of a map describing vulnerability here proves to be an operational support for the authorities. Indeed, such a map can directly lead to maps giving advice for preparative measures, such as those produced in the region of the Cotopaxi volcano in Ecuador (D'Ercole, 1991, 1996).

With this aim in view, it would be interesting to improve and compare this typology with other sectors where the threat of volcanic hazards is different, and to carry out the same type of survey in other watersheds draining Mt Pinatubo. As part of this, the same kind of study at village level would be a significant improvement. Indeed, we have just seen evidence that an analysis at this level would be the most effective in terms of defining preventive actions.

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