International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Vulnerability to Rainfall-Induced Landslide of Three Communities in Infanta, Quezon, Philippines

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Abstract

Four successive tropical cyclones hit the Philippines and brought damages to several towns in the provinces of Quezon and Aurora between November 14 and December 4 in 2004. The municipalities of Infanta, Real, and General Nakar were severely damaged and as a result the communities were exposed to physical risks and experienced socio-economic difficulties. To affect policies and plans in avoiding risks brought about by disasters that may happen in the future, the vulnerabilities to rainfall-induced landslide of the three most devastated barangays in Infanta, Quezon, namely Pinaglapatan, Ilog, and Magsaysay, were determined using an agent-based model.

This study determined the vulnerability of three communities based on the framework that vulnerability is influenced by the amount and intensity of rainfall received by the area in a given time, the conditions of the biophysical characteristics of the area, and the socio-economic profile of the community in the area. A time series model to capture the long-term rainfall pattern in the area was developed with consideration to the occurrences of extreme events. Biophysical studies were conducted on the study sites to determine their respective characteristics using topography (slope and elevation), land-use, and soil type as parameters. Through a respondent-type survey, the socio-economic profiles of the communities were characterized using income, livelihood, participation in social networks, and existence of community early warning systems, among others, as parameters.

Because of the barangays' unique locations along the path of the 2004 landslide event, their respective biophysical characteristics are different from each other. A cluster analysis on the socio-economic parameters found that the communities are clustered into low (Cluster 1) and high (Cluster 2) vulnerabilities. Vulnerability indices generated from the agent-based model showed that those households belonging to Cluster 2 in Barangay Magsaysay were the most vulnerable while those belonging to Cluster 1 in Barangay Ilog were the least.

Keywords: Rainfall-induced landslide; Community vulnerability; Agent-based model/modeling; Landslide vulnerability; Natural disasters

1. Introduction

Significant environmental and socio-economic impacts due to landslides have brought about damage in the Asia Pacific region over the last decade, particularly in countries with mountain ranges such as India, Indonesia, Pakistan, Nepal, Sri Lanka, China, Thailand and the Philippines [1,2,3,4]. In the Philippines, earthquakes and typhoons are the most common causes of landslides [2,5]. Typhoons hit the Philippines at an average of twenty times per year and these extreme rainfall events have been known to cause flooding and landslides in some areas in the country [6,7,8]. In fact, for the past two decades, there have been a high number of areas in the Philippines affected by rainfall-induced landslides (Table 1). The most recent rainfall-induced landslides occurred in Eastern Mindanao in 2012 where more than 6 million people were affected, at least 1,000 people were killed, more than 200 thousand houses were damaged, and about 1 billion US$ of agricultural products, infrastructure and private properties were destroyed [7,9].

Table 1: Rainfall-induced Landslides due to typhoons in the Philippines from 1990-2013 compiled from various sources. The row in bold is the landslide event that happened in the study sites and is caused by a series of four typhoons that came one after the other.

YEAR	**RAINFALL EVENT**		**LANDSLIDE/FLOOD LOCATION**
	International Name	**Local Name**	
2013	Haiyan	Yolanda	Central Visayas
2012	Bopha	Pablo	Compostela Valley, Davao
2009	Ketsana, Parma	Ondoy, Pepeng	Metro Manila, Bicol Region and Central Luzon

2006	Chanchu	Caloy	Guinsaugon, Southern Leyte
2006	Durian	Reming	Albay
2006	Xangsane	Milenyo	Mt. Makiling in Laguna
2004	**Winnie, Muifa, Merbok, Nanmadol**	**Winnie, Unding, Violeta, Yoyong**	**Infanta, Quezon**
2000	Kai-tak	Edeng	Payatas
1999	Olga	Ising	Cherry Hills
1995	Angela	Rosing	Bicol
1991	Thelma	Uring	Ormoc, Leyte
1990	Mike	Ruping	Cebu

In 2009, there were two significant extreme rainfall events in the Philippines: tropical storm 'Ondoy' (Ketsana), which had 4.9 million victims including 501 deaths, and typhoon 'Pepeng' (Parma), with 4.5 million victims including 539 deaths [10,11]. During the same year, the Center for Research on the Epidemiology of Disaster (CRED) listed the Philippines as the world's most disaster-prone country [11]. According to CRED's statistical review in 2009, the Philippines experienced 25 natural disasters followed by China with 16. The report further identified that almost all Philippine disasters were either meteorological or hydrological in nature. More recently, the German Watch ranked the Philippines second in its 2012 Climate Risk Index [7], which indicates the level of exposure and vulnerability to extreme events and should be understood as warning to be prepared for more frequent and/or more severe events in the future.

Hydrological and meteorological disasters are closely related and very often the former is a direct consequence of the latter. A meteorological disaster is defined as an event that is caused by short-lived or small to meso-scale atmospheric processes, which can range from minutes to days. A hydrological disaster, on the other hand, is normally caused by variations in normal water cycle and/or overflow of bodies of water caused by wind set-up [11].

Landslides can be classified under hydrological or geophysical, depending on the mechanism that triggered the particular event. If the landslide was caused by an earthquake or volcanic eruption, it is a dry mass movement and is classified as geophysical disasters. On the other hand, if the landslide was triggered by an extreme rainfall event (e.g. typhoon or storm), it is a wet mass movement and is classified as a hydro-meteorological disaster.

Many studies have been done on community vulnerability, particularly on the effect of a changing climate in the Philippines [12]. Communities have been socially and economically affected by climate variability that the need for vulnerability research emerged. The vulnerability of the physical environment has also been studied and analyzed in different researches [13,8]. However, not much has been done in the Philippines with regards to its communities' vulnerabilities to landslides. Most of landslide vulnerability studies in Asia were conducted in emerging economies like China, Taiwan and India. Finally, based on our knowledge, this is the first study in the Philippines that applied agent-based modeling to investigate landslide impacts. Previous applications of agent-based modeling in the country focused on vulnerability assessment due to land use change and droughts [12].

In the most recent report of the Intergovernmental Panel for Climate Change [13], vulnerability has been defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. The United Nations International Strategy for Disaster Reduction (UNISDR) defines vulnerability as the “characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of hazards” [14]. The susceptibility to hazards is a combination of factors: physical, social, economic, and environmental characteristics of a community. The vulnerability of a community to landslide varies from one place to another, especially within Asia-Pacific [1]. The variability is highly influenced by the geophysical location of the settlements, the disaster preparedness policies and practices adopted by the communities, and the political commitments of the community leaders [1]. This study built on these above-mentioned conceptualizations of vulnerability.

1.1 The Landslide Event in Infanta in 2004

Four successive typhoons (Typhoon Unding, Tropical Depressions Winnie and Violeta and Super Typhoon Yoyong) brought damages to the lives and properties of communities in the towns of Real, General Nakar and Infanta in Quezon and some parts of Aurora and Nueva Ecija between November 14 and December 4, 2004 [15,16]. A volume of 342 mm rainfall and approximately 3m of flood water was recorded by PAG-ASA on November 29, 2004, when the flashfloods happened between six to seven o’ clock in the evening in Infanta, Quezon [15,17]. The heavy rainfall caused slope failure in the mountainous areas of the town resulting to debris flows that filled-up and overflowed Agos River. Approximately 20 million cubic meters of mud and debris flowed down the slopes that almost covered the entire town of Infanta [15]. Only a few studies have focused on the impacts of the landslide events on the communities in the municipality [10,18].

In an assessment done by the National Disaster Coordinating Council of the Philippines, it was reported that more than three million people were affected and about 4.6 billion Php were lost in terms of infrastructure and agricultural damages [19]. Approximately 3 billion Php worth of rice, coconut, corn and other high-value commercial crops was destroyed due to the extreme rainfall events [19].

Because of the damages brought by the disasters of these magnitude to the areas it is now necessary to assess and manage areas that are susceptible to landslides in order to mitigate any associated damage that may occur in future disasters [5]. In the process of the evolution of the disaster management paradigm, the concept of vulnerability emerged.

This study explored the vulnerability of communities to rainfall-induced landslide by taking into account their respective climatic, biophysical and socio-economic characteristic. Living in a country that is visited by typhoons regularly and has a geological foundation that is prone to downslope movement, it is very important to know a community's level of vulnerability to landslides, to be able to minimize the disaster's impacts to properties and human lives. Using agent-based modeling, this study aimed to determine the vulnerability to rainfall-induced landslide of three communities in Infanta, Quezon, Philippines.

2. Materials and Methods

2.1. The Study Site

The study site is located in Infanta, Quezon, at the southeastern part of the island of Luzon in the Philippines. Infanta is located 144 km northeast of Manila and 136 kilometers north of Lucena City. This floodplain lies along the coast of the Pacific Ocean and rests at the foot of the Sierra Madre Mountain Range.

Several barangays within the town were damaged by the landslide event in 2004, but only three barangays were considered namely Magsaysay, Ilog, and Pinaglapatan (Figure 1) because of their respective elevations, locations with reference to Agos River, and extents of damage by the landslide incident. Agos River separates Infanta from the adjacent town of General Nakar.

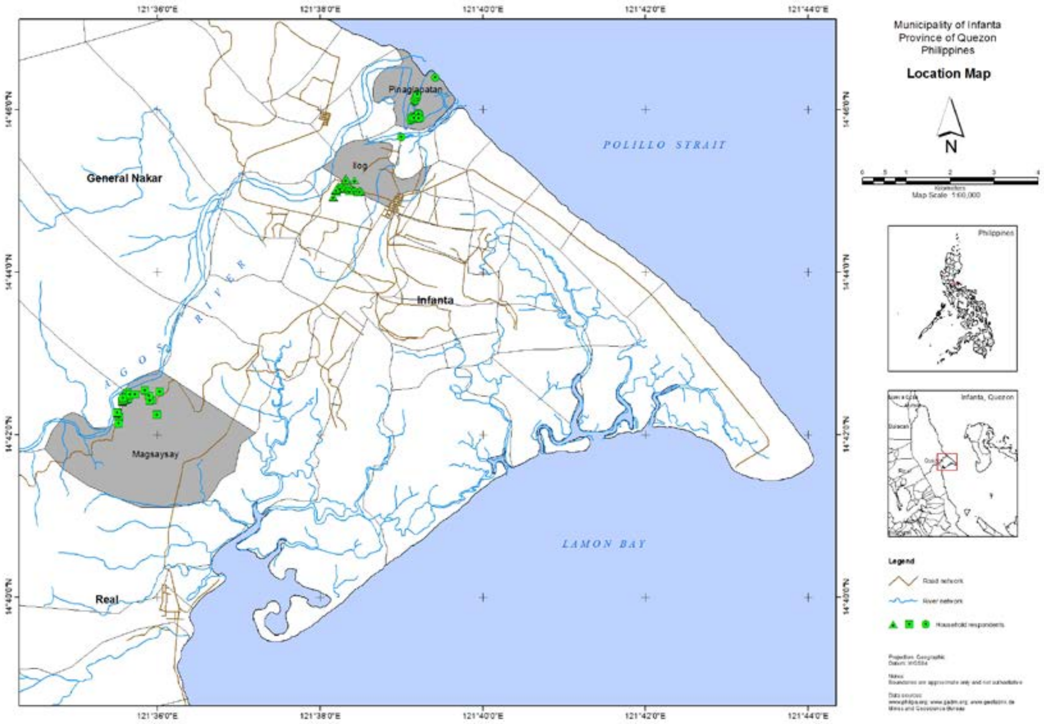

Figure 1: The Study Site in Infanta, Quezon, Philippines. The areas in gray are the administrative (political) boundaries of Barangays Magsaysay, Ilog and Pinaglapatan while the blue lines represent the river system. Agosriver is located beside the three barangays, upstream in Barangay Magsaysay going down all the way to Barangay Ilog and Barangay Pinaglapatan discharging into the Pacific. The symbols in green are the households representing the barangays.

Barangay Magsaysay is located upland and is the highest among the three barangay sites with an elevation of more than 100 masl. It is located around 5-10 km Southwest of Infanta town proper and covers two-fifths of the land area of the whole municipality. It is the largest among the three barangay sites in terms of area and population, having a total land area of 22, 335 ha, and a population of 2,959 people with 701 households [20]. The main sources of income in this barangay are farming and gathering of forest products.

Barangay Ilog is a lowland barangay, with an elevation which ranges from 2 to 36 masl. Ilog is the Filipino word for river, and the barangay was named as such because it is surrounded by the Agos River. It is nearest to the town's commercial area among the three sites at around 1-2 km Northwest of the town proper. Barangay Ilog has a total land area of 156.39 ha and a total population of 1,974 with 414 households [19]. The residents are mostly working on transportation and construction. There is also a significant percentage of the population working overseas.

Barangay Pinaglapatan is one of the six coastal barangays in Infanta, the area where the Pacific Ocean meets Agos River. Being a coastal landform, it has the lowest elevation as compared to the two other sites. It also has the smallest land area among the three at 73.31 ha and the least number of people with a total population of 1,267 and only 246 households. It is located two to three km North of the town proper [19]. The main source of income in this barangay is fishing.

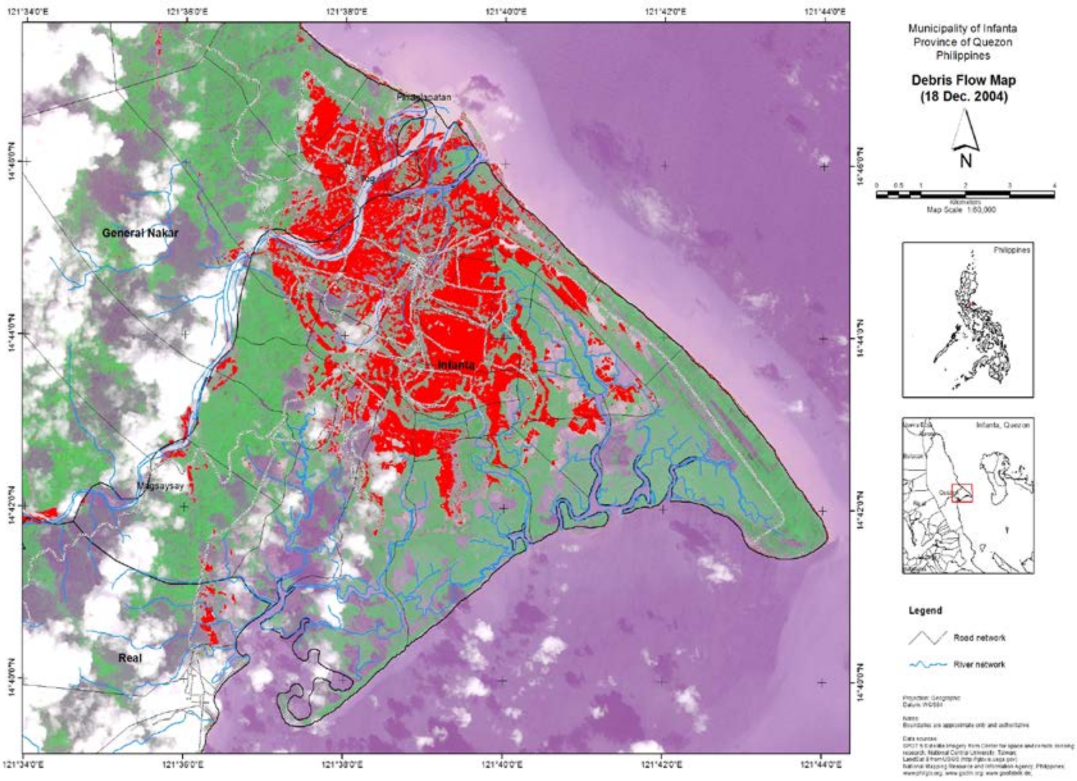

Figure 2: Debris flow in Infanta Quezon after the typhoon-induced floods and landslide.
(Source: [10])

The extent of the biophysical damage of the 2004 flood and landslide event was large, and many parts of the municipality was covered by debris flow (Figure 2). Among the three study sites, Barangay Ilog has experienced largest amount of debris flow, followed by Pinaglapatan. While location of the study sites very much influence the biophysical vulnerability due to debris flow, socio-economic vulnerability depends on the adaptive capacity of the people. For example, on the one hand, although Barangay Magsaysay experienced less debris flow, main sources of their income (i.e. forest products) have been damaged by the floods. On the other hand, many people in Barangay Ilog depend on non-agricultural jobs due to its proximity to the urban center.

2.2. Socio-economic Data Gathering and Processing

A household survey was conducted in each barangay to gather socio-economic data using a semi-structured questionnaire. A total of 107 household survey respondents were computed using simple random sampling by Cochran [21]. These households were classified into different groups using K-means clustering with the following socio-economic parameters: income, livelihood, social networks, and awareness in the existence of early warning systems.

2.3. Rainfall and Biophysical Data Gathering and Processing

Secondary Data was collected from involved government and non-government agencies, as well as from previous studies. The secondary data include paper maps, satellite images, shapefiles (GIS files), and tabulated data.

A GPS survey was conducted to establish the geographic location of the households. This information was overlaid with the other biophysical data. The position of the households was used to show the location of the agents in the model, and was overlayed with the other biophysical data. This was significant for the agent-based model, as the agents were the households and the GPS coordinates were needed to show the location of the agents in the biophysical environment.

The biophysical data of the area was processed through Geographic Information Systems. A spatial boundary that includes the three communities and some parts of the adjacent barangays was created using ArcGIS. The criteria considered for the delineation of the boundary was the location of the barangays and their orientation with reference to Agos River. Based on this, a polygon (rectangle) was formed using ArcGIS, to set the boundaries of the study site. The delineated boundary was also considered as the boundary of the agent-based model. The following biophysical parameters were used in this study: topography (based on slope and elevation), land-use/land cover, and soil type. The biophysical data was derived from secondary sources and from previous studies in the area. These data was processed using ArcGIS 9.2 using Universal Transverse Mercator Zone 51 North map projection and WGS 84 datum.

Rainfall data of the area came from the Philippine Atmospheric Geophysical Astronomical Agency (PAGASA). A predictive rainfall pattern of the area was generated using the autoregressive-moving average (ARMA) model.

2.4. Agent-based Modeling: Integration of rainfall, biophysical and socio-economic data

Landslide Vulnerability: A Function of Biophysical and Socio-economic Parameters

The study was based on the premise that landslide vulnerability is a function of both biophysical and socio-economic parameters, with rainfall as the triggering mechanism (Figure 3). Rainfall can be considered as one of the major drivers in the occurrence of landslide as it affects the slope stability of the soil [22,23]. As rain infiltrates the soil, there is an increase in pore water pressure and the slope stability deteriorates [24]. In the Philippines, rainfall is known to be the primary agent of erosion but there are other factors to be considered such as soil type, vegetation, topography, and farming practices [25].

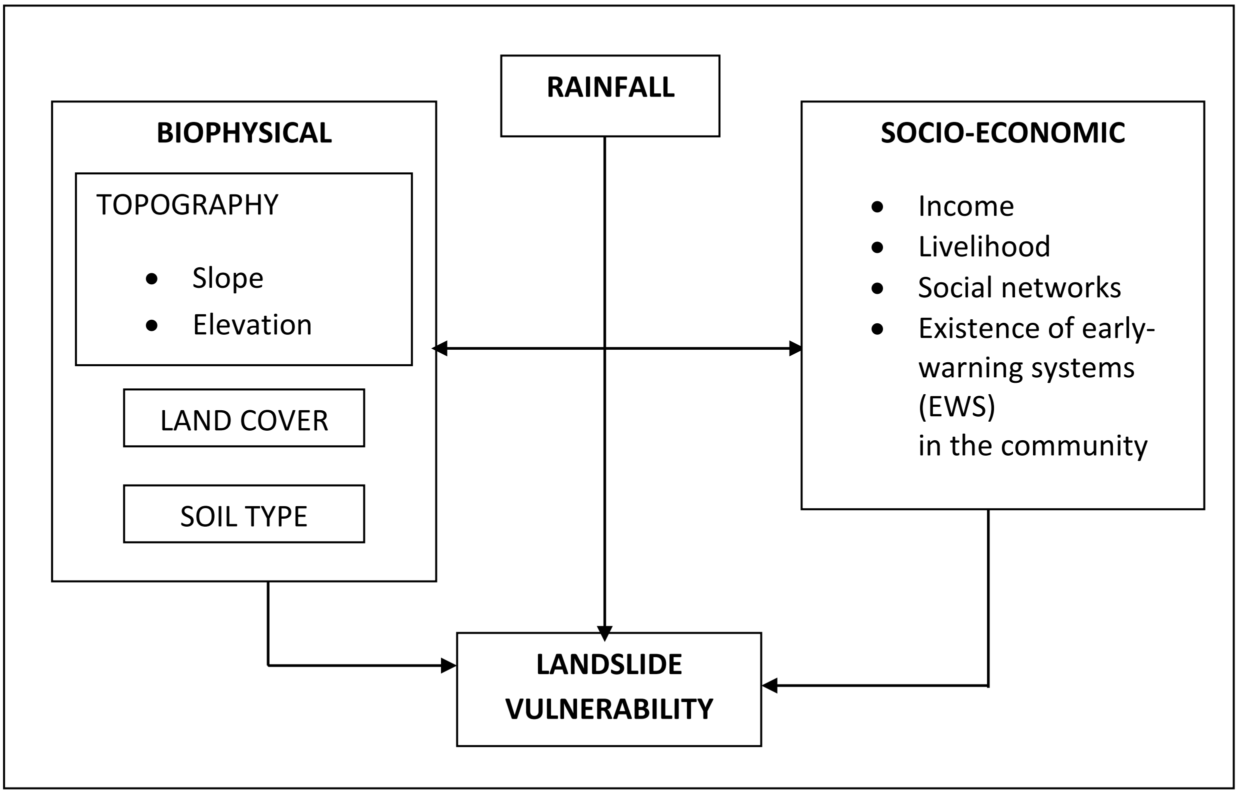

Figure 3: Conceptual Framework of the Study

The study area was characterized using topographic, soil and land-use parameters. Slope and elevation was used to qualify topography. Soil type and land-use was also considered.

A slope with a steady inclination with heavy uncut forest is considered safer than a slope with irregular rise, such as the ones that are due to road construction, or with existing vegetation [26]. There is a specific slope angle which can be considered critical where landslides will most probably occur at certain critical slope angles [28].

The utilization of the land by its inhabitants will affect the soil characteristics in the long run and will have an effect on whether the area will be susceptible to mass movement or not, given an external force, which, in this case, is heavy rainfall. The relationship between landslide and vegetation is very significant in environments exposed to heavy rains [28]. It has been found that the presence or absence of vegetation on mountainous areas has a significant effect on the triggering mechanisms and warning thresholds of landslide [29]. Areas previously burned and has little vegetation are more prone to erosion and the formation of rill, because the soil on the surface of these areas are more exposed to rainfall and runoff [29]. In the same way, severe erosion and debris flow in a lot of burned areas, and in areas which has less dense vegetation and plutonic rocks lying underneath, have been caused by moderately intense rainfall [28]. The presence of vegetation, which depends on land-use, is also directly related to slope stability, as revealed in a number of previous studies. This is particularly evident in shallow landslides [28]. Soil becomes more cohesive with the presence of vegetation because it can enhance cohesion through root matrix reinforcement and soil suction or lower water pressure through evapotranspiration and interception [28]. In places where the original vegetation cover has been removed or modified, landslide activity increases by up to 15% [28]. Instability is greater and erosion is faster in land with bare soil and less dense vegetation, than in forests [28].

A study on landslide susceptibility by [30] identified soil type as one of the factors which affect the susceptibility of an area to rainfall-induced landslide. The simulation of the model generally showed that landslide is mainly influenced by geobiophysical factors such as soil type, slope, atterberg limits, vegetation and land cover, and also affected by the impacts of human activities [30]. The authors of [31] further cited slope angle, proximity to stream, soil erodibility and soil type as significant factors in the prediction of slope movement.

Landslide vulnerability in the rural area is strongly related with the necessary fragility of socio-economic systems in these areas wherein poverty and lack of resources are very common [32]. In finding the linkage between poverty and vulnerability, vulnerability is the characteristic of a person or group combined, and expressed in terms of its relationship to hazard exposure which can be derived from the social and economic condition of the individual, family, or community concerned [33].

The socio-economic parameters considered in this study are the following: income, livelihood, social networks and the existence of an early warning system. The essential independent indicators of social vulnerability are the following: income, gender, race and ethnicity, age, geographic location, home ownership, education, health status and special needs [34]. When one person lacks the key resources in life such as health, education or income, his vulnerability increases [34]. The impacts of climate-related disasters can be seen in the poorest nations of the world and poor groups in developed countries [35]. The authors of [35] cited the following reasons on why poor people are the hardest hit by these impacts: (1) The livelihood of the people is mostly agriculture and fisheries, which are both climate-sensitive sectors. (2) They have limited human, institutional and financial capacity, which makes them less capable to respond to the direct and indirect effects of climate change. (3) Geographically, most of them are located in marginal areas that are more exposed to climatic hazards, like flood plains, or nutrient-poor soils.

More than 95% of all landslide-related disasters and fatalities, and mass movement in general, happen in developing countries [28]. In the rural areas, vulnerability to landslides is very much affected by the essential fragility of socio-economic systems since poverty and deprivation are common in these areas [36]. For farmers, social networks shall play an important role in reducing the farmers' vulnerabilities, no matter what type of adaptation measures are followed [12]. Higher social connectivity increases the opportunities for interaction, thus the larger the size of the social network, the larger the social interaction [12]. In the case of landslide, social networks act mainly as a source of assistance for the affected households during and after the event of the disaster. Three indicators were used to characterize social network in this study: membership in organization, source of assistance during the actual event, and access to credit or loan after the disaster.

The role of early warning systems in landslide management has been increasing in importance. Warning systems in real-time can play a major role in the mitigation of debris-flow hazard through informing the public every time rainfall conditions go up to critical levels and become a trigger for hazardous debris-flow activity [36]. The existence of a warning system gives people the chance to escape, or at the very least, go to safer places. This alters their vulnerability to given event magnitudes [36].

2.5 Agent-based Modeling

The modeling of relationships and interactions between human and natural systems are made possible in Agent-based Modeling (ABM) by defining different decision-making units or agents [37]. These agents can have different characteristics and strategies internally, and they can interact with the other agents and their environment [37]. In ABM, directaccounts of the successes and failures of the stakeholders are immediately available in the programme outputs, since each stakeholder can berepresented as an agent in the programme [38]. The study utilized an existing agent-based model (Figure 4), which was the output of the research project, "Assessing Vulnerability of Communities and Understanding Policy Implications of Adaptation Responses to Flood-related Landslides in Asia".This model was developed using a cross platform multi-agent programmable modeling environment [39].

The agent-based model in Figure 4 was modified to include the socio-economic parameters. The modified agent-based model (MABM) is independent of the previous model, runs on its own, and has its own commands and functions. The MABM was designed for user-friendliness and its user interface is composed of buttons, sliders, switches, choosers, monitors, plots, and windows (Figure 5). Each user interface item calls a corresponding series of commands or a function that the model needs to run. The model integrates rainfall, biophysical and socio-economic parameters to determine the vulnerability of the clusters.

The MABM initializes by setting-up the parameters, and it runs and produces outputs when 'go' is clicked. The model runs the script and it will automatically display the results in the interface. Monitors were used to display the weights of the biophysical and socio-economic parameters. The weights of the parameters were computed through Analytical Hierarcy Process (AHP), which is embedded in the code, and executed within the model once it is run. The model also provides a two-dimensional (2D) view of the GIS maps. After clicking setup, the maps can be shown by clicking 'display'. When the 'display' button is clicked, the specific biophysical indicator is displayed in 2D view.

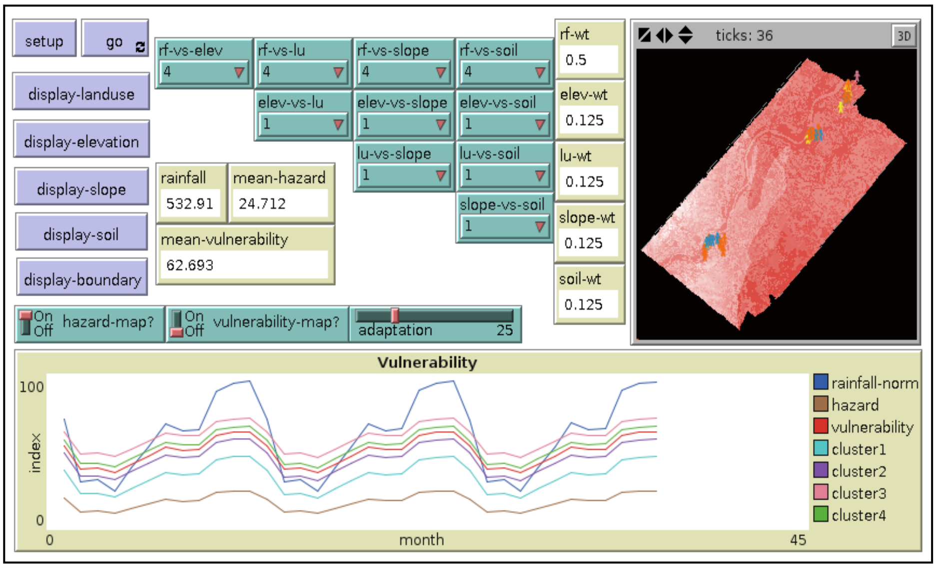

Figure 4: A screen shot showing the user interface of the Prototype Agent-based Model with user-friendly clickable parameters to run the model and color-coded output graphs for enhanced user visualization.

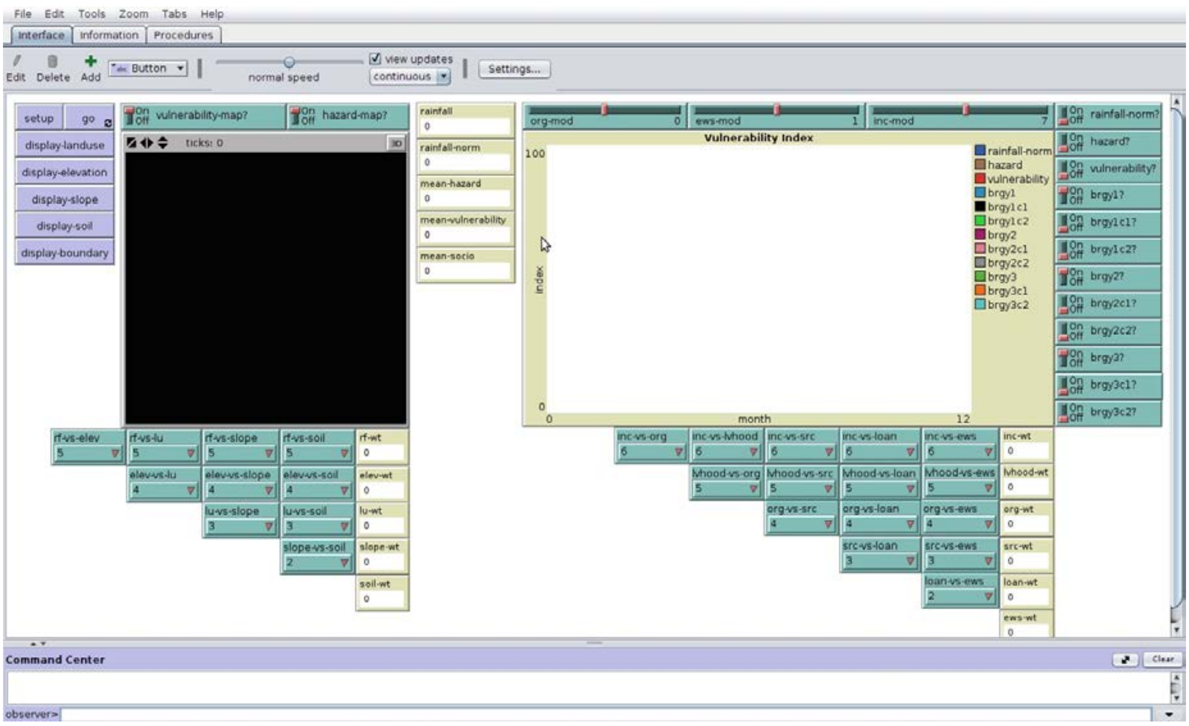

Figure 5: A screenshot of the modified agent-based model (MABM) with expanded parameters

The 2D view's capacity is not limited to displaying the indicators that was used, it can also show how the area changes when the model starts to run, and for this case, the levels of vulnerability can also be seen in the 2D view. When MABM starts to run, the map in the 2D view changes and shows the physical vulnerability of the area through the hazard map, and the vulnerability of the household through the agents. Vulnerability indices are generated and the results are shown in both graph and map form.

3. Results and Discussion

3.1 Biophysical Characteristics of the Barangays

Topography. Generally, around two-fifths of 37% of the total land area of Infanta is level to gently sloping.These flat areas can be found in the low-lying eastern portion of the town and beside Agos River. On the other hand, the higher slopes are located in the western part of the municipality, which comprise the hill (Municipalment of Infanta, 2010).

Around 51% or slightly more than half of the total land area has slopes lower than 18%. This is because Infanta is a floodplain and it is naturally flat.The other half is mainly due to Barangay Magsaysay, wherein there are huge areas of around 8%-18% slope, considered undulating to rolling terrain [20]. In Barangays Banugao, Agos-Agos, Pilaway, Batican and Tongohin, there is a little strip of gently sloping to undulating terrain with 3% - 8% slope [20].

The elevation is lowest in Brgy. Pinaglapatan, which is a coastal village. Ilog is relatively flat and considered the lowland barangay. Since Magsaysay is an upland barangay, it will naturally have a higher elevation than the other two barangays.

The elevation in Barangays Ilog and Pinaglapatan ranges from 2 to 36 masl. These two barangays belong to the flat areas of the municipality. Pinaglapatan lies just right beside Philippine Sea and is the location of the meeting point of the sea and Agos River, the major river in Infanta. Ilog is very near to the center of the municipality, and right in the middle of its low-lying areas. It also lies along the banks of the Agos River.

Barangay Magsaysay, on the other hand, has elevations occurring from a range of as low as 2 masl to as high as 490 masl. The hilly portions of the municipality can be found in this barangay so the highest range is from 304 to 490 masl. This goes down to 190-304 masl, 103-190 masl, 36-103 masl and 2-36 masl. This barangay has both mountainous and low-lying areas. It lies along Agosriver, and also houses some of the densely vegetated areas of the municipality.

Land-use. The land-use of the area in 2008 is largely agricultural lands and forest, with built-up areas. Among the seven land-use classifications of the area, coconut plantations mixed with other crops and shrubs has the biggest area, which occupies 20% of the municipality. Dense vegetation, lands planted with annual crops, built-up areas and grassland with shrubs, follow closely at 18.33, 17.79, 16.6, and 15.6% respectively.

A total of 3,089.19 ha of land are planted with various agricultural crops for the whole study area.Coconut and annual crops dominate this area with a very small portion of fish ponds and salt beds.

A high percentage (18.33%), equal to 1,343.87 ha of the area, is still densely vegetated. This accounts for areas which are still covered with forests. These areas can be found in Magsaysay, the upland barangay. Agricultural lands planted with coconut, annual crops, and other crops, are also evident in the area. There is one part which houses the people and is considered built-up in the barangay.

The other two barangays, Ilog and Pinaglapatan, are agricultural in nature. Ilog houses the largest built-up area, being the one closest to the center of the municipality. A small percentage of fish ponds and salt beds can be found in Brgy. Pinaglapatan.

***Soil type*.** Generally, there are five types of soil that can be found in the municipality of Infanta. These are the following: Hydrosol, Quingua silt loam, Buguey loamy sand, Antipolo sandy clay, and Mountain soils [20]. Three of these are present within the boundary of the study area: Antipolo sandy clay, Hydrosol and Quinga silt loam, but there are only two soil types which falls within the area of the three communities, Antipolo sandy clay and Quingua silt loam.

In Barangays Ilog and Pinaglapatan, the dominant soil type is Quiangia silt loam. This soil type come from alluvial deposits that were washed away from the adjacent uplands which occur in nearly level to undulating terrain [20]. Quingia silt loamis considered secondary soil, and has fair to good internal drainage [20]. It is also known to be suitable for planting of vegetable and orchards and characterized by a heavy friable fine to coarse granular surface.

Quingia silt loamcovers almost the same vast area as hydrosol, and it is considered ideal for the cultivation of major crops such as rice, corn, and coconut; and minor crops like cassava, camote, legumes and several vegetables. Sixteen percent of Infanta’s area is covered by this soil type, and this occurs in the following barangays: Agos-Agos, Banugao, Pilaway, Ilog, Catambungan, Boboin, Bantilan, Poblacion, Ingas, Libjo, Antikin, Silangan, Misua, ComonBatican, Lual, Tudturan, Maypulot, Kawaynin, Balobo, Langas, Anibong, Pulo, Amolungin, Gumian, and Tongohin [20].

The main soil type in Barangay Magsaysay is Antipolo sandy clay, as this type of soil occupies the upland portion of Infanta, and Magsaysay is an upland barangay. It naturally occurs on rolling to hilly and mountainous areas. Antipolo sandy clay covers almost one-fourth (24%) of the municipality’s total land area and occurs along portions of the following barangays: Banugao, Pilaway, Agos-Agos, Batican, Tongohin, Gumian and Magsaysay [20]. Some portions of this barangay, those with lower elevation, are covered with Quinga silt loam and hydrosol.

3.2 Cluster Membership and Characteristics

There were two clusters generated from the cluster analysis based on the socio-economic characteristics (Table 2).

Cluster 1 is comprised of households with higher income and whose sources of livelihood are both agricultural and non-agricultural. It also has a strong social network, as evidenced by a high number of households with membership in various organizations. The households also have a wide source of assistance during actual disaster event and access to loans, and has taken advantage of this. Majority of the households have relied on the EWS available in their areas.

Cluster 2 is comprised of households with low income, and relies mostly on agricultural livelihood. They are mostly farmers and fishermen, some are livestock-raisers while there are a few charcoal-maker. Very few have other sources of income and options for livelihood. Generally, it has a weak social network because even though most of them are members of organizations, there is still a significant number of households without organizations, sources of assistance during actual disaster, and also no access to loans.

Table 2: Summary of the Socio-Economic Characteristics of the Clusters

CHARACTERISTICS	BARANGAY CLUSTERS								
	Pinaglapatan			Ilog			Magsaysay		
	Cluster 1	Cluster 2	TOTAL	Cluster 1	Cluster 2	TOTAL	Cluster 1	Cluster 2	TOTAL
	n= 25	n=10		n=6	n=33		n=16	n=17	
INCOME									
0	5	1	6	3	3	6	0	1	1
1-10,000	2	2	4	2	5	7	4	6	10
10,001-20,000	2	1	3	0	5	5	1	3	4
20,001-30,000	1	2	3	0	1	1	1	2	3
30,001-40,000	3	3	6	0	1	1	0	1	1
40,001-50,000	3	1	4	0	1	1	1	4	5
50,001-100,000	4	0	4	0	4	4	5	0	5
100,001-200,000	3	0	3	1	10	11	1	0	1
200,001-300,000	2	0	2	0	3	3	2	0	2
300,001-400,000	0	0	0	0	0	0	0	0	0
400,001-500,000	0	0	0	0	0	0	0	0	0
>500,000	0	0	0	0	0	0	1	0	1
LIVELIHOOD									
Others	5	0	5	0	23	23	7	0	7
Livestock raiser and Others	0	0	0	0	2	2	0	0	0
Charcoal-maker and Others	0	0	0	0	0	0	6	6	12
Fisher and Others	13	1	14	0	0	0	0	0	0
Farmer and Others	3	2	5	0	7	7	3	0	3
Farmer, Fisher and Others	4	0	4	0	0	0	0	0	0
Farmer, Livestock raiser	0	0	0	0	1	1	0	0	0

CHARACTERISTICS	BARANGAY CLUSTERS								
	Pinaglapatan			Ilog			Magsaysay		
	Cluster 1	Cluster 2	TOTAL	Cluster 1	Cluster 2	TOTAL	Cluster 1	Cluster 2	TOTAL
	n= 25	n=10		n=6	n=33		n=16	n=17	
and Others									
Farmer, Charcoal-maker and Others	0	0	0	1	0	1	0	0	0
Fisher	0	1	1	0	0	0	0	0	0
Livestock raiser	0	0	0	0	0	0	0	0	0
Charcoal-maker	0	1	1	0	0	0	0	0	0
Farmer	0	3	3	1	0	1	0	9	9
Farmer and Fisher	0	2	2	0	0	0	0	0	0
Farmer and Charcoal-maker	0	0	0	0	0	0	0	1	1
None	0	0	0	4	0	4	0	1	1
NUMBER OF ORGANIZATIONS									
0	4	6	10	2	14	16	3	4	7
1	16	2	18	4	16	20	8	11	19
2	2	1	3	0	2	2	2	2	4
3	2	1	3	0	1	1	2	0	2
4	1	0	1	0	0	0	1	0	1
SOURCES OF ASSISTANCE DURING ACTUAL DISASTER									
None	13	5	18	3	18	21	9	8	17
Private Group	0	0	0	0	0	0	1	0	1
Government/Church/School	4	1	5	1	6	7	3	5	8
Neighbors/Friends	4	3	7	0	3	3	1	3	4
Family/Relatives	4	1	5	1	5	6	2	1	3
2 AND 1	0	0	0	1	0	1	0	0	0
4 AND 2	0	0	0	0	1	1	0	0	0
ACCESS TO LOANS									
None	15	2	17	4	18	22	8	10	18
Private	2	0	2	1	4	5	0	1	1
Government	2	1	3	0	1	1	1	0	1
Cooperatives/Banks	2	0	2	0	3	3	3	2	5
Neighbors/Friends	2	1	3	0	0	0	4	3	7
Family/Relatives	1	1	2	1	6	7	0	0	0
1 and 3	0	0	0	0	0	0	0	1	1

CHARACTERISTICS	BARANGAY CLUSTERS								
	Pinaglapatan			Ilog			Magsaysay		
	Cluster 1	Cluster 2	TOTAL	Cluster 1	Cluster 2	TOTAL	Cluster 1	Cluster 2	TOTAL
	n= 25	n=10		n=6	n=33		n=16	n=17	
1 and 5	0	1	1	0	0	0	0	0	0
3 and 5	1	1	2	0	0	0	0	0	0
4 and 5	0	3	3	0	1	1	0	0	0
EXISTENCE OF EWS									
None	1	2	3	1	3	4	1	2	3
Rain gauge/Water level system/Other traditional system	4	2	6	0	4	4	1	0	1
Batingaw/Batingting/Kampana	1	0	1	1	6	7	1	3	4
Announcemnt (various media)	15	6	21	4	12	16	7	6	13
2 and 1	1	0	1	0	1	1	4	3	7
3 and 1	1	0	1	0	3	3	1	0	1
3 and 2	2	0	2	0	4	4	1	3	4

Cluster 1: High Income, Diverse Livelihood, Strong Social Network and High Level of Awareness on the Existence of EWS

Barangay 1 (Pinaglapatan)**.** The total number of households for Cluster 1 is 25. Twenty percent (5 out of 25) have no regular income, 44% (11 out of 25) has income lower than 50,000. Four households have an income between 50,001-100,000, and there are 5 out of 25 households which earns higher than 100,000. In terms of livelihood, all the households engage in both agricultural and non-agricultural livelihood. Five have other jobs, while 13 are fishermen with other jobs, three are farmers with other jobs and four of them engage in both farming and fishing with other jobs. Barangay Pinaglapatan is a coastal community, and this accounts for more than 50% of the cluster membership which relies on fishing as livelihood.

Eighty-four percent (21 out of 25) of the households are members of various organizations, five of them have more than one organization. Thirteen did not have source of assistance during the actual event, while 12 was able to ask help from the government/school/church, neighbors/friends and family/relatives.

Sixty percent has no access to loans, while the other 40% has loaned from the government, cooperatives/banks, neighbors and friends and family/relatives. One household even loaned from both government and neighbors/friends. There is an early warning system in the area, and almost the whole cluster except for one household get information from various media and *batingaw*, and other traditional systems about the coming disaster.

Barangay 2 – Ilog. Cluster 1 in Barangay Ilog consisted of 33 households, which is 85% of the total number of households (39). This cluster has a high income compared to the others. Fifty-two percent (17 out of 33) have an income greater than 100,000, with 10 households earning between 100,000-200,000. Three households have no regular income, eight households earn between 10,000-50,000, while four between 50,000-100,000. Twenty-three out of thirty-three households have other sources of income, aside from agriculture. Based on the interview, some of these households have members who are working abroad. These members bring high income to the households. The other ten households who engage in agricultural livelihood also have members who have other jobs. Thus, all the 33 households have more than one source of income, making the income higher.

Nineteen out of thirty-three (57%) of the households are members of various organizations, while 42% of the cluster (14 households) have no membership in organizations. Among those have organizations, 16 are members of just one org, while two households have two orgs, and one household has three. Fifty-five percent of the cluster (18 out of 33 households) had no source of assistance during the actual event of the landslide, while 42% (14 out of 33 households) have sought assistance from government/school/church (6), neighbors/friends (3), family/relatives (5), and a combination of institutions and family (1).

Eighteen out of thirty-three households don't have access to loans, while fifteen of them have tried loans from both private (4) and government agencies (1), cooperatives/banks (3), family/relatives (6). EWS is strong in this cluster, since only three out of the thirty-three households are not aware of the existence of such. The other thirty members of the cluster have been informed through the different existing EWS in the area, with announcement from various media being the highest with 12 households, and batingaw following at 6 and rain gauge/water level system/other traditional system with 4. The others have been informed through the combination of the different systems.

Barangay 3 (Magsaysay). Barangay 3 Cluster 1 has a membership of 16 households, almost 50% of the total number of households in the cluster. In terms of income, 56% of the cluster earns more than 50,000 and one of these households has an income greater than 500,000, the highest income among all the respondents in the whole study area. Five falls in the income range of 50,000-100,000, while three in the 100,000-300,000 range. Four out of the sixteen households earn below 10,000 and seven earns 10,000-50,000. The incomes of the all the 16 households come from various sources. There are farmers, fishers, charcoal-makers and livestock raisers, and all of them have other jobs. Out of the 16 households, seven do not engage in agricultural activities. These households have other jobs such as being employees, salesmen and carpenters, among others.

Eighty-one percent of the cluster has organizations, with eight households having one organization, two of them have two orgs, and another two have three, while one has four. The remaining three out of sixteen have no membership in any organization.

No sources of assistance were available during the actual disaster to 56% (9 out of 16 households) of the cluster, while the other 7 households (44%) got assistance from government/church/school, neighbors/friends and family/relatives. The households were divided equally in terms of access to loans, half of the total number of households (8 out of 16) in this cluster had access to loans through government, cooperatives/banks, neighbors/friends and family/relatives, while the other half had no access.

Early-warning system in the barangay existed and 15 out of 16 households were given information about disaster through these systems. Most of the households became aware through the announcement in various media.

Cluster 2 – Low Income, Agricultural Livelihood, Weak Social Network and Moderate Level of Awareness on Existence of EWS

***Barangay 1 (Pinaglapatan)*.** Cluster 2 in Barangay Pinaglapatan is composed of 10 households. The income of nine out of these ten households is less than 50,000, while the remaining other household has no income.

Since the location of Pinaglapatan is very close to the sea, the main livelihood of the residents is fishing. In this cluster, seven out of the ten households rely on agricultural activities for their subsistence: farming, fishing, livestock raising and charcoal making and a combination of farming and fishing. The remaining three are also farmers and fishers with other sources of income.

Sixty percent have no organization while the rest are members of local organizations. The other 40%, two have one organization, the other two have two and three organizations, respectively.

There is an equal divide with regards to sources of assistance during the actual event. Five out of ten found no source of assistance, while the other half was able to ask assistance from the following: government/church/school, neighbor/friends and family and relatives. Three out of the five households with assistance got this from neighbors and friends.

Eighty percent of the cluster membership has access to loans, while the other two has none. Out of the eight, four are distributed among government, neighbors/friends, one got help from private groups and family, another one from cooperatives/banks and family, the remaining three from neighbors/friends and family.

Eight out of the ten households are aware of the existence of early-warning system and have taken advantage of announcements from different sources and the traditional systems.

***Barangay 2 (Ilog)*.** Six out of the total households consist Cluster 2 of Barangay 2. Five of these have income lower than 10,000 Php with three having no income at all. There is one household with higher income at 100,000-200,000 Php. Four has no source of income or livelihood, while the other two rely on farming, charcoal-making and other sources.

In terms of membership in organization, 66% (4 out of 6 households) have one organization, while the other 44% have none. Half has no source of assistance, while the other half got assistance from government/church/school, family/relatives and from both government and private groups.

Sixty-six percent of the households has no access to loans while the other two has access from private groups and family/relatives. EWS exists and five households got info about disaster from these systems, majority through announcement from media. The other one from the *batingaw/batingting/kampana*,and another one has no idea that EWS in the area exists.

Barangay 3 (Magsaysay). Cluster 2 of Barangay 3 is composed of 17 households. Sixteen out of these seventeen (94%) households have income lower than 50,000, with six falling in the range of 1-10,000. The remaining one household has no income. Sixty-five percent (11 out of 17 households) have jobs which are related to agriculture, with nine of these being farmers. The remaining six households have other jobs.

Thirteen have organizations while the other four has none. Out of the 13, 11 has one organization and the other two has two. Fifty-three percent have sources of assistance, ranging from government agencies/church/school to neighbors/friends and family/relatives.

Loans are accessible to seven out of seventeen (41%) households, from cooperatives/banks, neighbors/friends and family/relatives. The other 10 out of 17 (58%) had no access to loans. Fifteen out of the seventeen households are aware of the existence of EWS and have used it, while the other two was not given information about disaster.

3.3 Vulnerability of Communities

In terms of socio-economic parameters (Table 3), there are only two classifications: Cluster 2 has high vulnerability and Cluster 1 has low vulnerability, but since the biophysical character (Table 4) of the area where the cluster is located was also considered, the clusters for each barangay will still have a different vulnerability based on its location. Figure 6 shows the distribution of the household membership in each cluster among the three barangays.

Table 3: The socio-economic characteristics of the barangay clusters using to the following parameters: income, livelihood, strength of social network as determined by access to loans, source of assistance during actual event, membership in organizations, and existence of early-warning systems.

BARANGAY CLUSTER (ranked from most to least vulnerable)	INCOME	LIVELIHOOD	SOCIAL NETWORKS			EARLY WARNING SYSTEMS
			ACCESS TO LOANS	SOURCE OF ASSISTANCE DURING ACTUAL EVENT	MEMBERSHIP IN ORGANIZATIONS	
Barangay Magsaysay Cluster 2 (b3c2)	Low	Farmers and Charcoal-	No access	No source of assistance	More than half are members of orgs	Has EWS

		makers				
Barangay Ilog Cluster 2 (b2c2)	No source of income	Majority has no job	No access	No source of assistance	Majority do not have orgs	With EWS
Barangay Pinaglapatan Cluster 2 (b1c2)	Majority less than 50,000	Fishing/ Agricultural	No access	Has various sources of assistance	Almost all are members of orgs	With EWS
Barangay Magsaysay Cluster 1 (b3c1)	Majority less than 50,000	Diverse livelihood	Has access	Has various sources of assistance	Half are members of orgs	With EWS
Barangay PinaglapatanCluster 1 (b1c1)	Ranges from 0-300,000	Rely heavily on fishing	Has access	Has various sources of assistance	Almost all are members of orgs	With EWS
Barangay Ilog Cluster 1 (b2c1)	Ranges from 0-200,000	Farming, Fishing, Charcoal-making	Has access	Has various sources of assistance	Almost all are members of orgs	With EWS

Table 4: The Biophysical Characteristics of the Barangay Clusters according to the following parameters: topography as determined by slope and elevation, land-use, and soil type

BARANGAY CLUSTER (ranked from most to least vulnerable)	**TOPOGRAPHY**		**LAND-USE**	**SOIL TYPE**
	ELEVATION	**SLOPE (deg)**		
Barangay Magsaysay,	Upland	9-45	Dense vegetation,	Antipolo sandy clay

Cluster 2 (b3c2)			Coconut mixed with crops and shrubs	
Barangay Ilog, Cluster 2 (b2c2)	Lowland	0-3	Built-up, Grasslands mixed with shrubs	Quiangua silt loam
Barangay Pinaglapatan Cluster 2 (b1c2)	Coastal	0-3	Built-up, Coconut mixed with crops and shrubs	Quiangua silt loam
Barangay Magsaysay Cluster 1 (b3c1)	Upland	9-45	Dense vegetation, Coconut mixed with crops and shrubs	Antipolo sandy clay
Barangay Pinaglapatan Cluster 1 (b1c1)	Coastal	0-3	Built-up, Coconut mixed with crops and shrubs	Quiangua silt loam
Barangay Ilog Cluster 1 (b2c1)	Lowland	0-3	Built-up, Grasslands with crops and shrubs	Quiangua silt loam

There is no single barangay that is vulnerable as a whole. The clusters are distributed in such a way that in one barangay, one cluster is highly vulnerable while the other is not. The vulnerability ranking was based on the vulnerability plot that was generated after running the MABM (Figure 7). In the interface of the MABM, vulnerability is also shown in the map with varying shades of red, the darker shade reflecting a higher degree of vulnerability and the lighter shade shows less vulnerability (Figure 8).

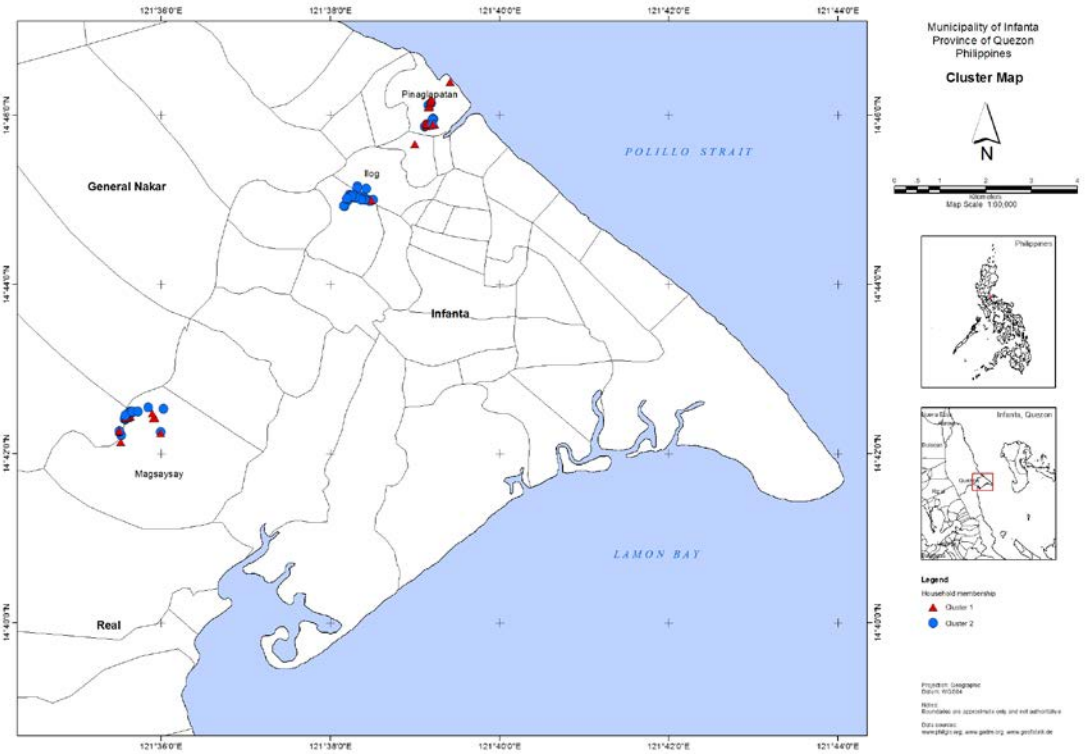

Figure 6: The map showing the membership of the households in cluster 1 and 2 distributed in the three barangays.

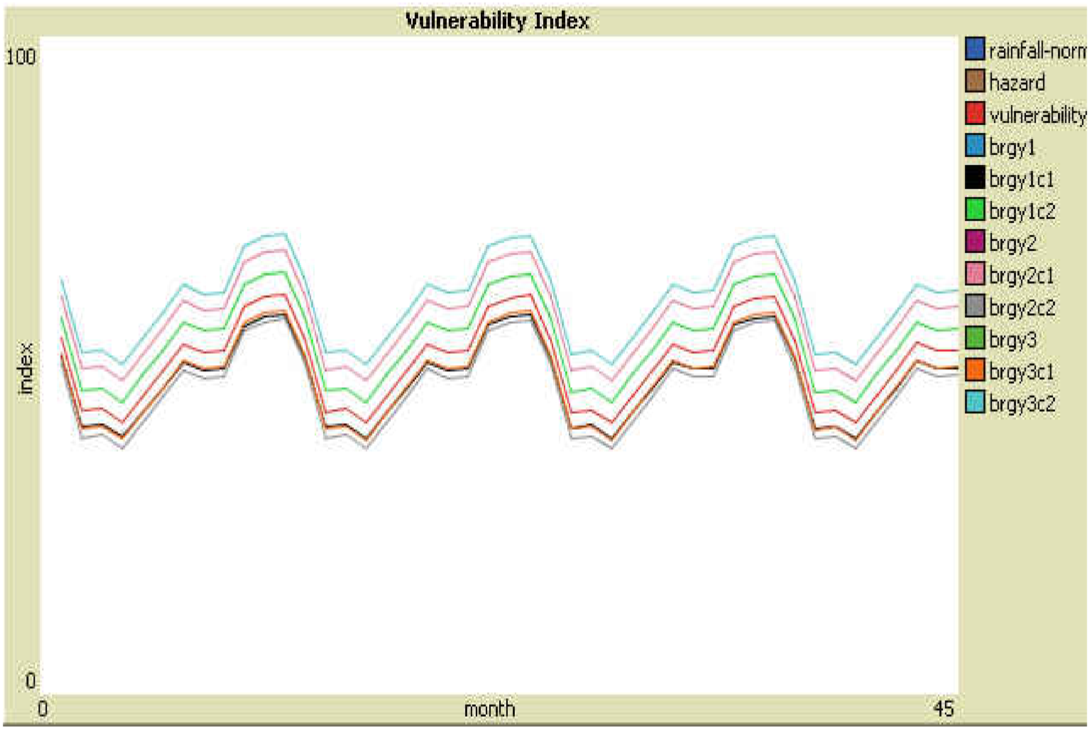

Figure 7: The graph of the vulnerability indices of the communities as generated from the modified agent-based model (MABM).

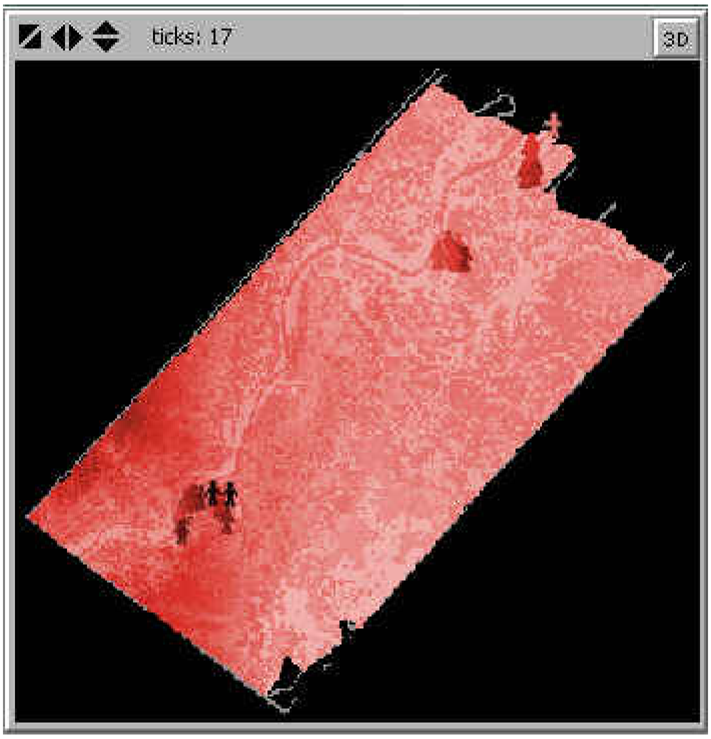

Figure 8: A window in the interface of the modified agent-based model (MABM) showing the vulnerability of the barangay clusters in varying shades of red. As the shade becomes darker, the vulnerability is higher.

Cluster 2 in Barangay 3 (b3c2), the most vulnerable cluster, is located in the upland barangay, Magsaysay. In terms of biophysical characteristics, it is highly vulnerable to landslide. The location has a high elevation, the area is mountainous, and the slopes can go as high as 24-45 degrees. It is comprised of 17 households. Most of the households have low income, and all households except one who has no job, are farmers and charcoal-makers. They also do not have access to loans and no sources of assistance during the actual event. More than half of the households are members of organizations, but only one household has more than one organization.

Cluster 2 in Barangay Ilog (b2c2) is the second most vulnerable cluster and consists of six households. Ilog is located in the lowland, and is relatively flat, compared to Brgy. Magsaysay. Majority of the households in this barangay, which belongs to the other cluster, is not highly vulnerable. The six households included in this cluster is an exemption to the characteristic of the whole barangay. This cluster has a very weak social network as most households have no access to loans and no sources of assistance during a landslide event. Majority does not have organizations as well. Three out of six has no source of income, and two earns less than 10,000 Php a year.

Cluster 2 in Barangay Pinaglapatan (b1c2) is the third most vulnerable among all the clusters, and is the least vulnerable in Cluster 2. It is comprised of ten households, with income less than 50,000. The main livelihood is fishing as the area is close to the sea. Majority engage in agricultural livelihood, and very few have other options for subsistence. Social network is not very strong, while most households are aware of EWS. The area is also vulnerable physically as it is also prone to flooding. Though in terms of landslide, it is safe since it is located in a low elevation and slope of the area is relatively flat. But in terms of socio-economic factors, b1c2 is vulnerable, thus it is still considered as a highly vulnerable cluster.

Cluster 1 in Barangay Magsaysay (b3c1) has low vulnerability, but it is the most vulnerable within the cluster. The area where the cluster is located is vulnerable physically, but the socio-economic characteristics of the households balances this, thus the cluster has low vulnerability compared to the other cluster in the barangay. It has a membership of 16 households, almost 50% of the total number of households in the cluster. The income of the households has a wide range but majority falls below 50,000. Four out of the sixteen even earns below 10,000. The households have several options for their livelihood, aside from agriculture. Social network is strong since half of the respondents have membership in organizations, access to loans, and were able to seek assistance during the actual disaster.

Cluster 1 in Barangay Pinaglapatan (b1c1), second to the least vulnerable cluster, rely heavily on fishing for their livelihood. Thirteen out of 25 are fishermen with other jobs, 3 are farmer with other jobs and 4 engage in both fishing, farming and have other jobs as well

Cluster 1 in Barangay Ilog (b2c1) is the least vulnerable cluster among the six clusters. Barangay Ilog is the least vulnerable among the three barangays and Cluster 1 of Barangay 2 proves this further. This cluster is comprised of 33 out of 39 households, representing majority of the barangay. This means that the whole barangay, as represented in this study, except for 6 members is not highly vulnerable. B2c1 is a high income group with 10 households, which is almost one-third of the whole cluster, earns 100,001-200,000 yearly. Twenty-three out of 33 have other jobs, others are even abroad serving as OFWs. Only eight of the households rely on farming for livelihood, and these households have other sources of income. Being located in the lowland area, this cluster is not highly vulnerable physically.

4. Conclusion and Recommendations

Landslide is triggered by natural disasters such as earthquake and extreme rainfall events and this cannot be controlled or prevented. However, the impacts of landslides can be minimized by knowing the level of the vulnerability of the affected communities. The two clusters generated in terms of socio-economic parameters shows only two levels (high and low) vulnerability, but incorporating the biophysical characteristics would further classify the vulnerability of the communities considered in this study.

The municipality of Infanta was severely damaged in the 2004 rainfall-induced landslide event. This study analyzed the vulnerability of three of the barangays mostly affected by this event. By determining the vulnerability of the communities, the adaptive capacity of the community can be increased to lessen the impacts of future landslide events. The results strengthened the premise that the vulnerability of a community to rainfall-induced landslide is a function of both biophysical and socio-economic parameters. The topography characterized by slope and elevation, land-use and soil-type affects the vulnerability of the community since these are contributing factors to the landslide itself. As presented in this study, the most vulnerable cluster is found in the upland barangay with sloping terrain and mostly agricultural land-use, while the least vulnerable is located in the lowland.

The communities have inherent characteristics that make them vulnerable or not to rainfall-induced landslide. They can increase their capacity to adapt to rainfall-induced landslide by increasing their income and diversifying their livelihoods, strengthening their social network and having an effective early-warning system in their area.

The results of this study were presented to the stakeholders in the area last year, and the local government and communities better understood their vulnerability to rainfall-induced landslides. The authors further recommend the use of these results in planning for the municipality's disaster risk reduction and management. The results can also be used by decision-makers for crafting policies and for preparing the communities for future landslide events.

Agent-based modeling as a methodology in determining landslide vulnerability allowed for the integration of rainfall, biophysical and socio-economic characteristics of the communities. Using other methodologies to produce inputs for the model complements ABM and produced results that incorporated the characteristics of the communities with the biophysical properties of their area. It is recommended to update the model as the need arises. The agent-based model is dynamic and it can easily be improved for future use.

Acknowledgements

The authors would like to acknowledge and thank the Asia-Pacific Network for Global Change Research (APN) for funding the research project entitled "Assessing Vulnerability of Communities and Understanding Policy Implications of Adaptation Responses to Flood-related Landslides in Asia" where this study was anchored. Special thanks also goes to the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development under the Department of Science and Technology (PCAARD-DOST) for the additional research support. Our sincere and deep gratitude goes to the people of Infanta, the local government unit, the Infanta Integrated Community Development Assistance Incorporated (ICDAI Inc), and the residents of the three barangays for their active participation and cooperation during data gathering, and for the warmth extended and the wisdom imparted to the researchers.

References

[1] K. Sassa and P. Canuti. *Landslides – Disaster Risk Reduction*. 2009. Berlin Heidelberg: Springer.

[2] D. Guha-Sapir, P. Hoyois and R. Below. *Annual Disaster Statistical Review 2013: The numbers and trends*. 2014. Brussels: CRED.

[3] UNESCAP (United Nations Economic and Social Commission for Asia and the Pacific). (2012). *Statistical*

yearbook for Asia and the Pacific 2012. [On-line]. Available: http://www.unescap.org/stat/data/syb2012/ index.asp. [Mar. 27, 2015].

[4] Hiwasaki, L., E. Luna, Syamsidik and R. Shaw. "Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities." *International Journal of Disaster Risk Reduction,* vol. 10, pp. 15–27, 2014.

[5] S. Lee and D. G. Evangelista. (2006, July). "Earthquake Induced Landslide Susceptibility Mapping using an Artificial Neural Network." *Natural Hazards and Earth Systems Sciences.* [On-line]. 6, pp. 687-695. Available: www.nat-hazards-earth-syst-sci.net/6/687/2006/nhess-6-687-2006.html [Mar. 21, 2015].

[6] A.R. Salvacion, L.A. Acosta, A.B. Asaad, M.V.O. Espaldon and M.L. Lapitan. "Mapping Tropical Cyclone Risk in the Philippines using Historical Track Record." Internet: http://www.researchgate.net/profile/Lilibeth_Acosta/publication/271850240, 2014 [Mar. 13, 2015]

[7] L.A. Acosta, E.A. Eugenio, P.B.M. Macandog, D.B. Magcale-Macandog, E.K. Lin, E.R. Abucay, A.L. Cura and M.G. Primavera. "Loss and damage from typhoon-induced floods and landslides in the Philippines: Community Perceptions on climate impacts and adaptation options." *International Journal of Global Warming*, 2014.

[8] G. Yumul, C. Dimalanta, N. Servando, N. Cruz. "Abnormal weather events in 2009, increased precipitation and disastrous impacts in the Philippines." *Climatic Change*, April 2013.

[9] E.A. Eugenio, L.A. Acosta, D.B. Magcale-Macandog, P.B.M. Macandog, E.K. Lin, J.M.A. Eugenio and J. Manuta. "Adaptive capacity of Philippine communities vulnerable to flashfloods and landslides: Assessing loss and damage from typhoon Bopha in Eastern Mindanao" *International Journal of Sustainable Development,* reviewed, 2014a.

[10] E.A. Eugenio, L.A. Acosta, E.R. Abucay, P.B.M. Macandog, D.B. Magcale-Macandog, J.M.A. Eugenio and E.K.H. Lin. "Livelihood adaptation to impacts of extreme events in the Philippines: A decade after the typhoon-induced disasters in Infanta, Quezon." *International Journal of Disaster Risk Reduction,* submitted, 2014b.

[11] F. Vos, J. Rodriguez, R. Below, and D. Guha-Sapir. *Annual disaster statistical review 2009: The numbers and trends*. 2010. Brussels: CRED.

[12] L. Acosta-Michlik, and M.V.O. Espaldon. "Assessing Vulnerability of Selected Farming Communities in the Philippines Based on a Behavioural Model of Agent's Adaptation to Global Environmental Change." *Special Issue of the Global Environmental Change*, vol. 18, pp. 554–563, 2008.

[13] Intergovernmental Panel on Climate Change. (2014). *Climate Change 2014: Synthesis Report.* [On-line]. Available: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf. [Mar. 27, 2015].

[14] United Nations International Strategy for Disaster. (2009). *United Nations International Strategy for Disaster Reduction. Terminology on Disaster Risk Reduction.* [On-line] Available: http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf. [Mar. 31, 2015].

[15] R.P. Orense, S.E. Sapuay and E.B. Billedo. "Investigation of Sediment Disasters caused by Heavy Rainfall on November–December 2004 in Quezon Province, Philippines." *Journal of Natural Disaster Science*, vol. 3(183), pp. 365-366, 2004.

[16] J. Gaillard, C. Liamzon and J. Villanueva. "'Natural' disaster? A retrospect into the causes of the late 2004 typhoon disaster in Eastern Luzon, Philippines." *Environmental Hazards*, vol. 7, pp. 257-270, 2007.

[17] R.V. David, and J.C. Felizardo. *Alternative Local Disaster Countermeasures for Agos River, Infanta, Quezon. Department of Public Works and Highways*. Manila, Philippines, 2005.

[18] Asuero, M.P., G.L.M. Nelson, M.V.O. Espaldon, L.A. Michlik, D.M. Macandog, N.M. Lalican, E.R. Abucay, M.C. T. Malenab, J.P.P. Talubo. "Social Characteristics and Vulnerabilities of Disaster-Prone Communities in Infanta, Quezon, Philippines." *Journal of Environmental Science and Management* 15(2), pp. 19-34, 2012.

[19] National Disaster Coordinating Council. "Final report on the After- effects of Destructive Tropical Cyclones ''Unding'', ''Violeta'', ''Winnie'' and ''Yoyong''." Internet: www.ndcc.gov.ph., 2004 [Mar. 2, 2015].

[20] Municipal Government of Infanta. www.infanta.gov.ph. 2014 [Mar. 2, 2015].

[21] Cochran, W. G. *Sampling Techniques, 3rd Edition*. Canada: John Wiley & Sons. 1977.

[22] R. P. Orense. "Slope failures triggered by heavy rainfall." *Philippine Engineering Journal*, vol. 25(2): pp. 73-90, 2004.

[23] A.S. Daag, N. Tungol, M. Peralta and O. Cruz. "Landslide and Flash flood Critical Rainfall Threshold Determination and Hazard Mapping: Terminal Report of the Study in Panaon Island, Southern Leyte and Surigao City." Department of Science and Technology, Philippines. 2006

[24] G.Wang and K. Sassa. "Factors affecting rainfall-induced flowslides in laboratory flume tests." *Geotechnique*, vol. 51(7), pp. 587–599, 2001.

[25] H.A. Adornado, M. Yoshida, H.A. Apolinares. "Erosion vulnerability assessment in REINA, Quezon Province, Philippines with Raster-based Tool Built within GIS environment." *Agricultural Information Research*, 8(1), pp. 24-31, 2009.

[27] B. Papathoma-Köhle, B. Neuhäuser, K. Ratzinger, H. Wenzell, and D. Dominey-Howes. "Elements at risk as a framework for assessing the vulnerability of communities to landslides." *Natural Hazards and Earth*

Systems Sciences, vol. 7, pp. 765–779, 2010.

[28] F. Karsli, M. Atasoy, A. Yalsin, S. Reis, O. Demir, C. Gokceoglu. "Effects of land-use changes on landslides in a landslide-prone area." *Environment Monitoring Assessment*, vol. 156(1-4), pp. 241-255, 2009.

[29] R.L. Baum and J.W. Godt. "Early warning of rainfall-induced shallow landslides and debris flows in the USA." *Landslides*, vol. 7(3), pp. 259-272, 2010.

[30] E.R.Abucay, D.M. Macandog, M.V.O., Espaldon, F.C. Monsalud. "Modeling the Spatial Distribution of Rainfall-Induced Landslide Susceptibilities in Infanta, Quezon, Philippines." *Journal of Environmental Science and Management*, vol. 15(3), pp. 28-39, June 2012.

[31] A. Nandi and A. Shakoor "A GIS-based landslide susceptibility evaluation using bivariate and multivariate statistical analyses." *Engineering Geology*, vol. 110(1-2), pp. 11-20, 2012.

[32] D. Alexander. *Landslide Hazard and Risk* (ed. M. Crozier and T. Glade). New Jersey: John Wiley and Sons, 2005.

[33] S. Yodmani. "Disaster Risk Management and Vulnerability Reduction: Protecting the Poor," presented at the Asia Pacific Forum on Poverty, Social Protection Workshop 6: Protecting Communities: Social Funds and Disaster Management, Asian Development Bank, Manila, Philippines, 2001.

[34] B.D. Phillips, W.C. Metz and L.A. Nieves. "Disaster threat: Preparedness and potential response of the lowest income quartile." *Environmental Hazards*, vol. 6, pp. 123-133, 2005.

[35] T. Mitchell and T. Tanner. *Adapting to climate change: challenges and opportunities for the development community*. Report for Tearfund, 2006.

[36] T. Glade and M. Crozier. *The Nature of Landslide Hazards and Risks. Landslide Hazard and Risk* (ed. M. Crozier and T. Glade). New Jersey: John Wiley and Sons, 2005.

[37] D. Valbuena, P. Verburg, A. Bregt, and A. Ligtenberg. "An agent based approach to model land-use change at a regional scale." *Landscape Ecology*, vol. 25(2), pp. 185-199, Jan. 2010.

[38] Stockholm Environment Institute (SEI). *Agent-based Modeling of Vulnerability*. Poverty and Vulnerability Programme. GECAFS Project.

[39] Wilensky, U. (1999). *Netlogo*. Center for connected learning and computer-based modeling. [On-line]. Evanston, IL: Northwestern University. Available: http://ccl.northwester.edu/netlogo