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Geohazards, Tropical Cyclones and Disaster Risk Management in the Philippines: Adaptation in a Changing Climate Regime

Decibel V. Faustino-Eslava[1*], Carla B. Dimalanta[2], Graciano P. Yumul, Jr.[3], Nathaniel T. Servando[4] and Nathaniel A. Cruz[5]

ABSTRACT

Climate change, involving both natural climate variability and anthropogenic global warming, has been a major worldwide concern, particularly with the publication of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change. Considering the archipelagic nature of the Philippines and its being a very minor emitter of greenhouse gases, adaptation to climate change has been the Government's national policy. The importance of expediting these climate change-related adaptation measures was highlighted by a string of geo-meteorological-related disasters, specifically triggered by landslides and floods consequent to Typhoon Parma that hit the country in 2009. We present the geologic conditions that rendered the affected areas, especially in northwestern Luzon, extremely vulnerable to the existent hazards, the meteorological conditions that set off the disaster and the different initiatives that the government and local communities have taken to further prepare the people for possible future disasters. Recognition of the pertinent issues and the extant challenges points to the urgent need for mainstreaming both geo-meteorological-related disaster risk management and climate change adaptation measures in the light of changing climate conditions.

Key words: *climate change adaptation, disaster risk management, geo-meteorological hazards, tropical cyclone, Luzon, Philippines*

INTRODUCTION

In October 2009, barely a week after Tropical Storm Ketsana (local name: Ondoy) brought unusually heavy precipitations and flooded southern and central Luzon in the Philippines, another tropical cyclone Typhoon Parma (local name: Pepeng) entered the Philippine Area of Responsibility (PAR) and caused unparalleled damages to life and property in northern Luzon. Weather-related disasters such as these have repeatedly devastated the Philippines with increasing frequency and magnitude in the past few decades (e.g. *Asian Development Bank (ADB) 2009*; *Lagmay et al. 2006*; Y*umul et al. 2006*). In the last few years alone, the country has experienced climate extremes that brought abnormally heavy precipitations (e.g. tropical cyclones Durian [Reming], Fengshen [Frank], Parma [Pepeng], Ketsana [Ondoy]), extended drought periods (e.g., El Niño periods in 1992-1993, 1997-1998, 2006-2007) or the unusual combination of generally drought conditions punctuated by a series of strong, abrupt tropical cyclones (e.g., four consecutive tropical cyclones Muifa [Unding], Merbok [Violeta], Winnie [Winnie] and Nanmadol [Yoyong] during the 2004 El Niño period) (e.g. *Benson, 2009; Dawe et al. 2009; Lyon et al. 2006; Yumul et al., 2009*). The passage of formerly harmless weather systems, such as the tail-end of the cold front, previously simply associated with cooler temperatures, have also recently become episodes of extensive flooding and landslides (*Faustino-Eslava et al. 2011*). The geographic location and geological features (i.e. faulted and fractured, thick clay and soil cover due to weathering and hydrothermal alteration, among others) of the Philippines predispose this island nation to the effects of seasonal weather disturbances. The usual origin of tropical cyclones in the country is the Philippine Sea which lies to its east. This wide open region, together with the Pacific Ocean, is a major breeding ground for tropical cyclones that often travel westwards into the PAR. Tropical cyclones seldom develop over South China Sea. However, when they do form, they often move northeastward and affect the western section of Luzon. Often, they also interact with the Southwest Monsoon (Habagat) which allows the systems to gather more moisture as they pass over the South China Sea. This frequently results in very heavy precipitations over the western seaboard of the country. Tropical cyclones enter the PAR nearly the whole year, although the period from January to April has lesser probability of experiencing extreme or numerous disturbances. These weather systems just by themselves, at the very least, disrupt normal daily activities. Recently however, the passages of some weather systems in the country have done more than just inconvenience the populace. Many of these devastating incidents resulted from the unfortunate combination of unusually high amounts of precipitation that fell on geologically and geomorphologically compromised regions.

The complex tectonic makeup of the Philippines, as reflected in the variety of geomorphic expressions, is an

[1] School of Environmental Science and Management, University of the Philippines Los Baños, College, Laguna, E-mail: dei_faustino@yahoo.com; rwgmails@yahoo.com (*corresponding author)
[2] Rushurgent Working Group, National Institute of Geological Sciences, University of the Philippines, Diliman, Quezon City, Philippines
[3] Monte Oro Resources and Energy, Inc., Makati City, Metro Manila
[4] Philippine Atmospheric, Geophysical and Astronomical Services Administration, Department of Science and Technology, Science Garden, Quezon City, Philippines
[5] GMA Network News, GMA Network Center, EDSA corner Timog Avenue, Diliman, Quezon City, Philippines

underpinning control to the severity of how much the effects of weather disturbances can be amplified. The Philippines is a composite product of various tectonic processes that involve arc magmatism, ophiolite accretion, ocean formations and closures and arc-continent collisions. These processes are consequent to the position of the archipelago at one of the most complex collision boundaries between Sundaland and the Philippine Sea Plate (**Figure 1**). As a result, a wide range of geomorphic features that reflect these diverse tectonic systems characterize different areas of the country.

Two subduction systems flank the N-S elongate Philippine Mobile Belt (**Figure 1**). At the west, the Manila-Negros-Sulu-Cotabato Trench system is the site of the eastward subduction of the South China, Sulu and Celebes Sea crusts. At the east, the East Luzon Trough-Philippine Trench system marks the entry of the Philippine Sea Plate beneath the archipelago. Along the length of the archipelago, volcanic belts of varying ages formed as a result of these subduction processes. **Figure 2a** shows the distribution of these magmatic centers and their relative degrees of activity. Also impinging into the island arc system is the buoyant Palawan Microcontinental Block (PMB) which is a piece of Sundaland that rifted and eventually rammed into the Philippines. This collision produced a series of mountain belts (e.g. Mindoro Range, Antique Range), structurally controlled volcanic fields (e.g. Macolod Corridor in southwestern Luzon) and regionally extensive metamorphisms (e.g. in Mindoro and Romblon). The net compressive effect of the two subductions and the PMB collision resulted in the development of the left-lateral Philippine Fault Zone (*Aurelio 2000; Besana and Ando2005*). **Figure 2b** is a map of the major fault networks in the country, most of which propagated consequent to the same active compressive conditions. Activity along these fault systems has also led to the formation of fault-controlled lakes (e.g. Lake Danao in Leyte, Lake Mainit in Mindanao) and active volcanic or hydrothermal centers (e.g. Leyte hydrothermal field). These crustal breaks and the numerous volcanic systems have mutually enhanced the effects of hydrothermal alterations in wide areas across the country. This is both a bane and a blessing for this developing nation. Many mountainous regions in the Philippines host mineable resources that developed as a result of hydrothermal mineralization. However, this chemical process also significantly reduces the competence of rocks, accelerates weathering and renders affected areas susceptible to mass wasting, most especially when rains are factored in.

The combination of natural climate processes, geology and geomorphology continually impact both the physical and social landscapes of the country in different ways. Heavy rainfall, landslides, floods and storm swells are natural processes that become disasters when they occur in areas where people settle and where infrastructures are built.

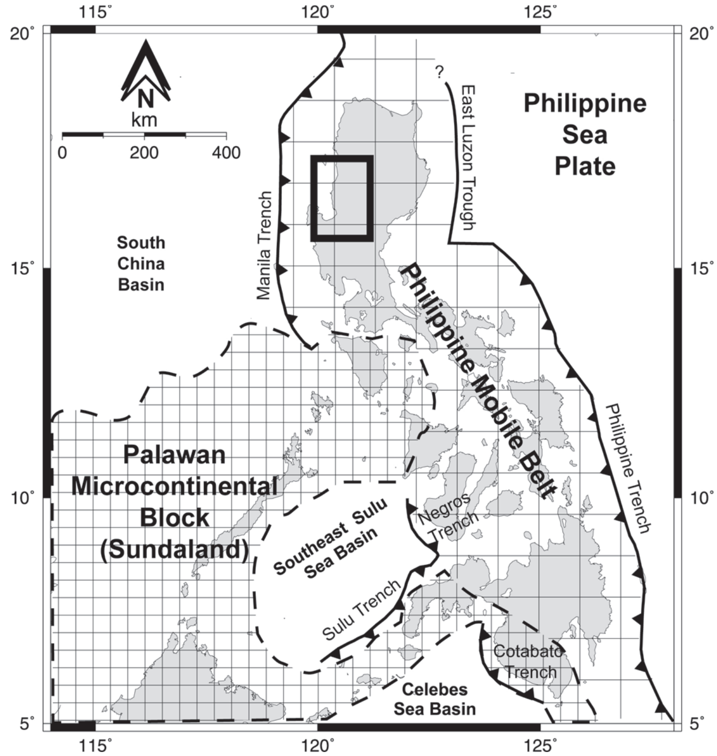

Figure 1. Tectonic map of the Philippines that shows the Philippine Mobile Belt (large grid fill) positioned between the Palawan Microcontinental Block (Sundaland, fine grid fill) and the Philippine Sea Plate. Two subduction systems flank the belt: the Manila-Negros-Sulu-Cotabato Trench system at the west and the East Luzon Trough-Philippine Trench at the west.

Unfortunately, despite the obvious risks involved, communities have expanded into unsuitable locations for various reasons, including the people's deficient appreciation of the actual risks associated with their actions. Therefore, human risk is made more real with an expanding population's increasing need for space, poor implementation of land use plans and disaster risk management programs.

In reality, very few human interventions, by way of risk mitigation, can prevent hazards rooted to geological features and enhanced by weather disturbances from actually occurring. The researchers document the damages wrought by Typhoon Parma to northwestern Luzon with the intention of emphasizing the unequivocal association of the geologic setting of the Philippines and its predisposition to a number of geo-meteorological hazards. Climate projections predict that the frequency of extreme weather disturbances due to the continued warming of the planet to increase (e.g. I*ntergovernmental Panel on Climate Change (IPCC) 2007; Mann and Emmanuel 2006; United Nations Framework Convention on Climate Change (UNFCCC) 2008; Webster et al. 2005*). The Philippines, being an archipelagic, tectonically active, natural hazard-vulnerable nation frequented by various weather disturbances must device appropriate adaptation measures to prepare for these conditions. The

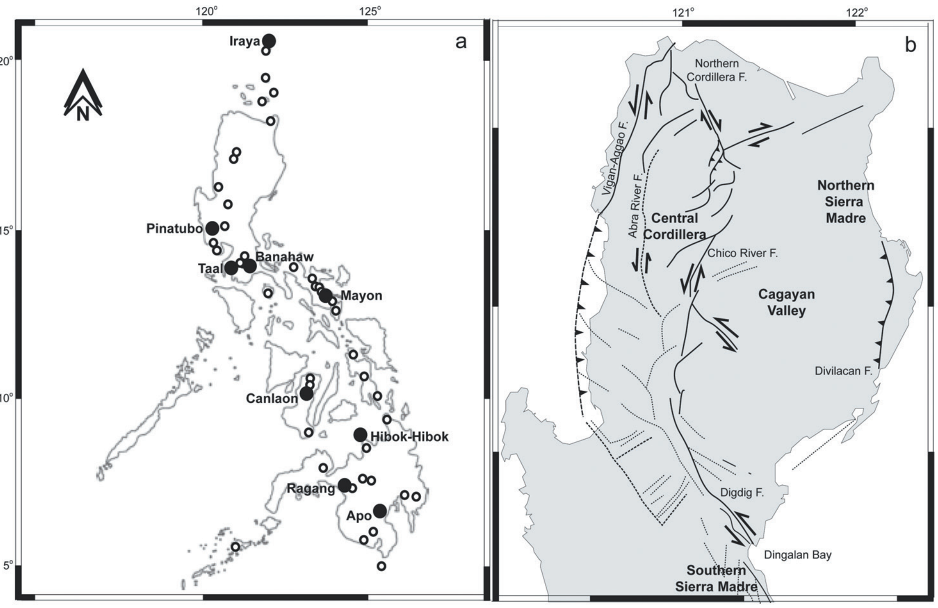

Figure 2. a. Map showing the distribution of active volcanoes in the Philippines (shown by the white circles). Nine of these (shown by the black dots) are the most active with several eruptions in recorded history (*Phivolcs 2008*). b. Map of the major fault networks in Luzon (after *Queaño 2006*).

researchers hope that the information presented can contribute to the global initiative of improving geo-meteorological hazard-related disaster risk management platforms to save lives and properties.

Geologic outline of Northwestern Luzon

The Central Cordillera is a 300 km-long mountain belt that trends N-S and separates the foothills of Ilocos in the west and the Cagayan Basin in the east. More than 50% of this mountain is characterized by slope gradients > 30° at elevations that reach ~3000 m (**Figure 3a and 3b**). The geology of this mountain range, including the foothills of the Ilocos region, is characterized by basal ophiolitic bodies overlain by epiclastic and carbonate sedimentary formations that are cut by various intrusive units (*Queaño et al. 2009*). Most previous investigations into this region have focused on the southern (Baguio) and central (Cervantes-Lepanto) provinces because of the prevalence of economic deposits such as gold and copper (e.g. *Balce et al. 1980; United Nations Development Program (UNDP) 1987; Maleterre 1989; Peña 1992*). More recent investigations that looked into the tectonic history of the region model the Central Cordillera as a magmatic arc associated with the Miocene-Recent subduction along the Manila Trench (*Bellon and Yumul 2000; Queaño et al. 2009*). Comprising this arc sequence are the Cretaceous-Eocene ophiolitic rocks of the Pugo Metavolcanics-Lepanto Metavolcanics-Chico River pillow basalts, the Eocene to lower Miocene sedimentary sequences and various younger intrusive bodies. The older ophiolitic units compose the basement of the Central Cordillera with sedimentary sequences mostly found west of the mountain range. Two main pulses of magmatic activity are recorded in the region. The earlier phase corresponds to the Oligocene Central Cordillera Diorite Complex (*Yumul 1994*) and a later episode preserved as the Middle Miocene Itogon Quartz Diorite (*Maleterre 1989; Wolfe 1981*). Continued influence from the subduction system resulted in a series of later magmatic episodes which produced the 2.5 to 5.9 Ma (*Arribas et al. 1994; Sillitoe and Angeles 1985; Wolfe 1981*) Black Mountain Quartz Diorite (*Balce et al. 1980*) and the Plio-Pleistocene Mankayan Dacitic Complex which includes the 1.5 Ma highly mineralized, intrusive complex in Santo Tomas (e.g. *Imai 2001*). Intrusion of these magmatic bodies not only resulted in the deposition of substantial economic metal deposits. Associated hydrothermal fluids also extensively altered the surrounding regions, turning bedrock materials to clay that, compounded by the tropical climate, hastened the formation of thick soil layers.

Three of the most extensive sedimentary sequences in the Central Cordillera are the Bangui, Zigzag and Klondyke Formations (**Figure 4**). The Late Eocene to Late Oligocene Bangui Formation is composed mainly of volcanic sandstones interbedded with varying amounts of conglomerate and mudstones (*Pinet 1990*) that lie unconformable to ophiolitic materials (Ilocos Peridotite). The Late Oligocene to Early Miocene Zigzag Formation is a sequence of conglomerates, sandstones and shales with occasional limestone lenses and interbeds of volcanic flows and tuffs that unconformably overlies the Pugo Metavolcanics (*Peña and Reyes 1970; Tam et al. 2005; Yumul et al. 2008; Dimalanta et al. 2012*). This unit is in turn unconformably overlain by the late Early-Middle Miocene Kennon Limestone. On top of this carbonate sequence is the thick Middle to Late Miocene Klondyke Formation (*Balce et al. 1980*). This unit is

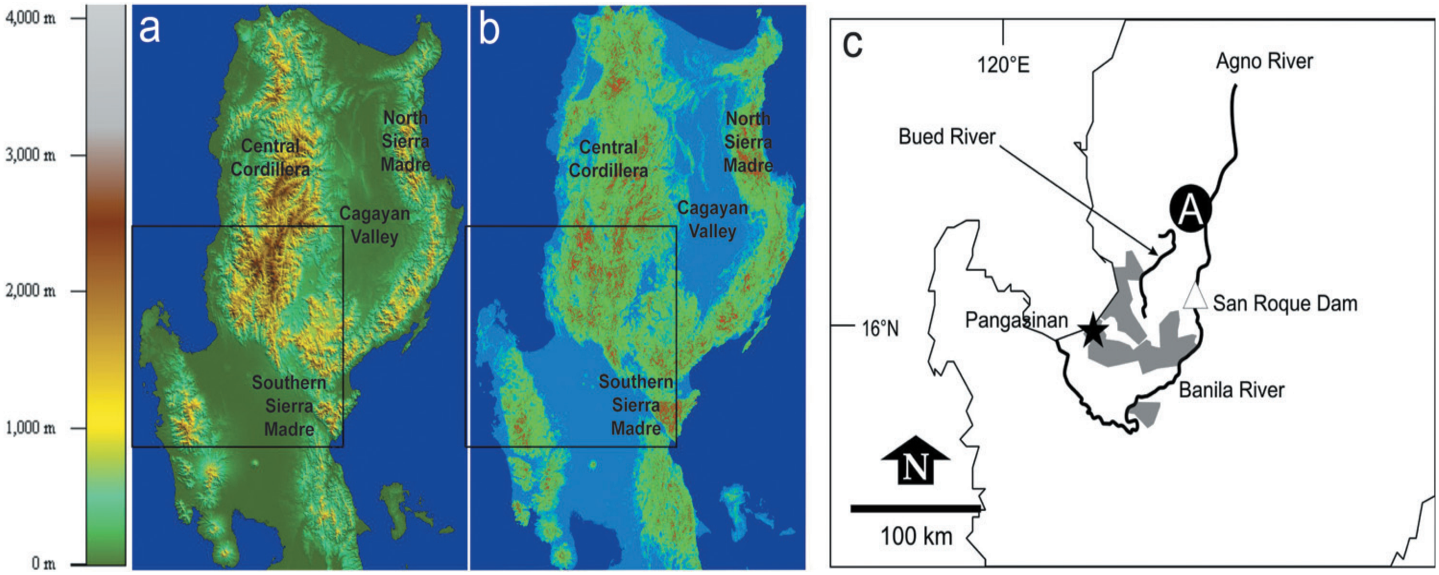

Figure 3. a. Elevation map of Luzon island. In Central Cordillera, peaks reach heights of up to ~3000 m. b. On the slope map, a significant part of Central Cordillera is characterized by slopes greater than 10° (blue – slope <10°, green – slope between 10 and 30°, red – slope >10°). c. Blown up view of boxed area in Figures 3a and 3b. Pangasinan was one of the worst-hit areas in terms of flooding whereas Baguio-Benguet (shown by the black circle marked A) had numerous landslide occurrences due to the passage of Typhoon Parma. Gray-shaded areas are those that were reportedly flooded.

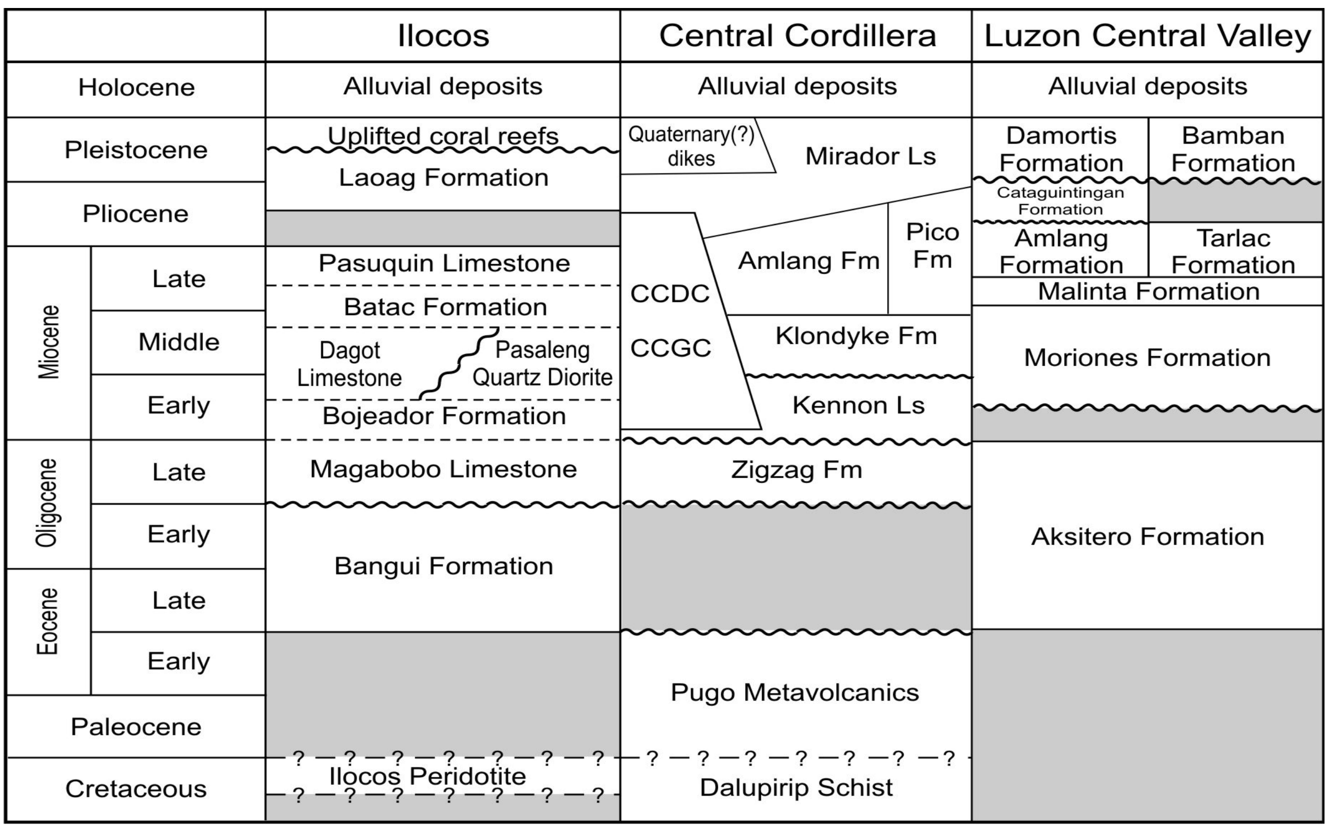

Figure 4. Comparative stratigraphic columns for Ilocos, Central Cordillera and Luzon Central Valley (west side) (modified from Peña, 2008).

characterized by polymictic conglomerates interbedded with sandstones, siltstones, shales and occasional limestone lenses, flow breccias and pyroclastic deposits.

The western slopes of Central Cordillera are underlain by various sedimentary formations that range in age from Late Eocene to Plio-Pleistocene (**Figure 4**). In the western provinces of Pangasinan and La Union, the general stratigraphic relationship of these sedimentary units is as follows: the Middle Miocene Moriones Formation is conformably overlain by the Late Miocene Malinta Formation followed by the Miocene-Pliocene Amlang Formation which is unconformable to the overlying Middle to Late Pliocene Cataguintingan Formation and the youngest units of the Pleistocene Damortis Formation lies unconformable to the older units (e.g. *Dimalanta et al., 2012*). These clastic sedimentary formations are generally composed of interbedded sandstone, shale, conglomerate with minor carbonate or tuffaceous components. As is commonly observed, these younger units are only moderately to poorly indurated which allow them to easily take in water and contribute to increased risks for mass wasting.

The structural networks that characterize northern Luzon are significantly influenced by the activity along the 4 Ma Philippine Fault Zone (*Aurelio et al. 1991; Barrier et al. 1991*). This fault zone passes from Dingalan as a NW-SE trending left-lateral structure that opens up into a series of splays (**Figure 2b**; after *Queaño 2006*) that run through Central Cordillera (*Pinet and Stephan 1990; Ringenbach et al. 1993; Louvenbruck 2003*). The more prominent of these splays include the Vigan-Aggao Fault, the Abra River Fault and the Chico River-North Cordilleran Fault. The Vigan-Aggao Fault is modeled as a left-lateral wrench fault with an increased thrust component towards its northern extensions that resulted in the emplacement of recent coral reefs on top of Holocene alluvium (*Queaño 2006*).

When Typhoon Parma made landfall three times in northern Luzon, the first typhoon in the country's recorded meteorological history to ever do so, physical damages resulted mostly from the numerous landslides in mountainous regions of northern and southern Sierra Madre, Caraballo Range and the Central Cordillera (**Figure 3a**). Flooding occurred along the relatively restricted Cagayan Valley Basin, in locally confined catchment basins (e.g. various villages in Baguio City) and in the wide plains of Pangasinan which forms part of the Agno River Basin (**Figure 3c**). Fieldwork was done mostly in Central Cordillera where more landslide-related damages to infrastructure and lives lost were reported.

Meteorological setting of the Philippines

There are, on the average, 19 to 20 tropical cyclones (TC) that enter the Philippine Area of Responsibility (PAR) with 9 TCs making landfall. The other weather systems that bring rains to the country are the inter-tropical convergence zone, northeast monsoon (from October to March), and southwest monsoon (from April to September) (*Yumul et al. 2008*). Typhoon Parma was a unique tropical cyclone to have ever entered the PAR for it made landfall three times in northern Luzon. Barely three days after Tropical Storm Ketsana exited the PAR, Tropical cyclone Parma (local name: Pepeng) was already spotted hovering outside the PAR on September 30, 2009 (**Figure 5a**). With the Philippines still reeling from the massive flooding in Metropolitan Manila and adjacent areas brought about by Tropical Storm Ketsana, residents of Luzon woke up again to government warnings to prepare and to brace themselves against the possible onslaught of this new weather disturbance. Tropical cyclone Parma entered the PAR as a typhoon (defined to have maximum wind speed greater than 118 kph near the center) and followed a northwestward track in the direction of Cagayan. At 4:00 p.m. of October 1, the eye of the typhoon was located 440 kilometers east of Borongan, Samar (**Figure 5a**). It was reported to have maximum sustained winds of 195 kph near the center and gustiness of up to 230 kph (*NDCC 2009c*). Typhoon Parma first made landfall along the east coast of Cagayan on October 3, 2009 (*NDCC 2009d*). It moved west-northwest at a speed of 24 kph and weakened (maximum sustained winds near the center of 120 kph and gustiness of up to 150 kph) after crossing the extreme portion of northern Luzon. Typhoon Parma slowed down and remained nearly stationary over Laoag City due to a ridge of high pressure area (HPA) near Hong Kong. Typhoon Parma was supposed to landfall in Isabela-Aurora on Saturday afternoon but the HPA pushed Parma in a northeastward direction. Moreover, Typhoon Melor (local name: Quedan) which initially developed over the Pacific ocean, entered the PAR on October 5. Its interaction with Typhoon Parma resulted in a “Fujiwara effect”, a meteorological term for two interacting tropical cyclones, that caused Typhoon Parma to move erratically (**Figure 5b**). The cyclonic orbits of the two weather disturbances caused Typhoon Parma to shift its movement backwards until it made its second landfall at the northern tip of Ilocos Norte on October 6 and then moved inland causing it to weaken into a tropical depression 12 hours later. Typhoon Parma remained quasi-stationary off the eastern coast of Cagayan until it hit and made a third landfall on October 8, this time in Tuguegarao, before finally moving westward (**Figure 5a**).

In addition to being an unusual weather disturbance for making landfall 3 times, Typhoon Parma was a long-lived disturbance and was within the PAR for 10 days. Furthermore, it existed for more than two days even over rugged terrain. On the average, tropical cyclones formed within the Philippine Sea side spend only 3 to 4 days within the PAR. As a result, large amounts of rainfall were recorded during the passage of Typhoon Parma. Quite interestingly, heaviest precipitation and significant damages occurred when Typhoon Parma was downgraded to a tropical depression and was making its final exit towards the South China Sea. Based on the records of the PAGASA weather stations in Luzon, Baguio City received the largest amount of precipitation during the period October 3 to 9, 2009 (**Figure 6**). The amount of precipitation that fell on Baguio City reached 1,856 mm. This city normally receives only 462 mm of rainfall for the whole month of October. On the first landfall of Typhoon Parma, Baguio City reportedly received 531 mm of rain for a 24-hour period. In addition to Baguio City, other areas which received unusual amounts of rainfall during the passage of Typhoon Parma were Sinait in

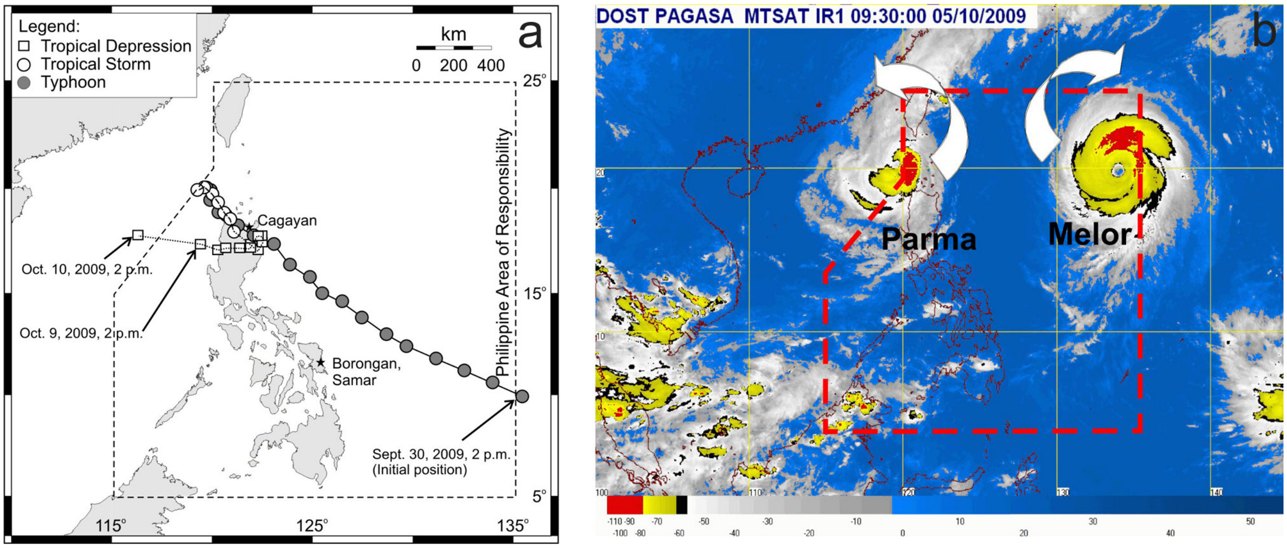

Figure 5 a. Track followed by Typhoon Parma whose erratic behavior caused it to landfall three times. It left the country after staying within the PAR for 10 days. b. MTSAT image received at the DOST-PAGASA station on October 10, 2009. It shows Typhoon Parma interacting with Melor. This interaction caused Parma to return and make its second landfall.

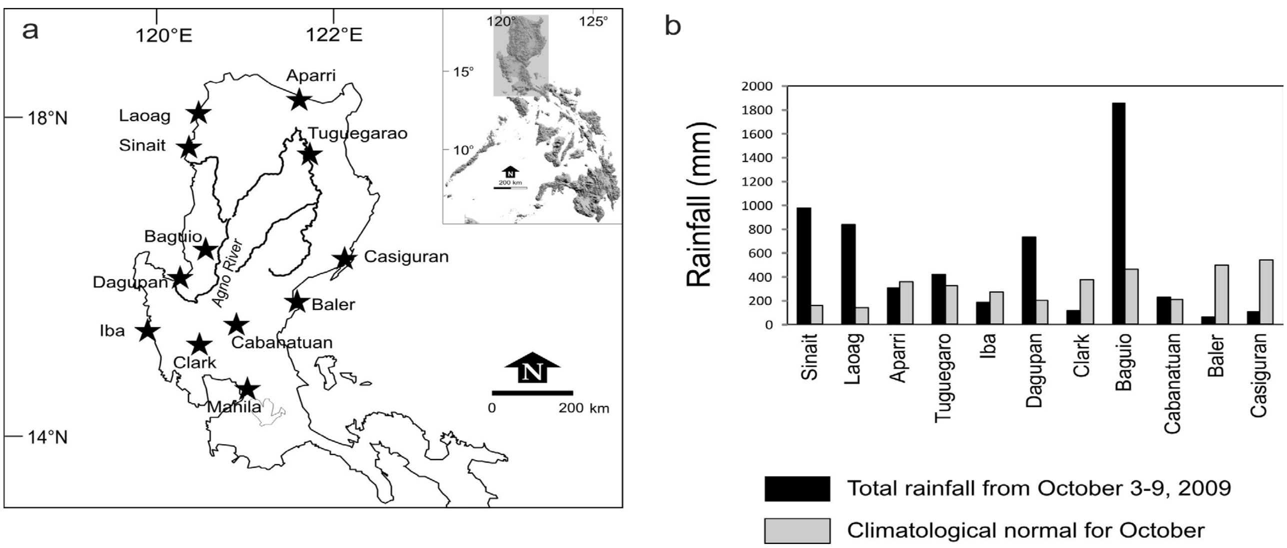

Figure 6 a. Typhoon Parma brought an unusual amount of precipitation as indicated by measurements done in the PAGASA stations (each marked by a black star) in Luzon island. b. Rainfall data from the PAGASA stations are compared with the monthly climatological normals. From October 3 to 9, 2009, Baguio City recorded the highest amount of rainfall.

Ilocos Sur (974 mm), Laoag in Ilocos Norte (833 mm) and Dagupan City (734 mm). The October monthly normal rainfall for these areas is 154 mm (Sinait), 143 mm (Laoag) and 200 mm (Dagupan City) (**Figure 6**). Significant parts of Luzon were heavily flooded and there were various reports of landslide occurrences in several areas especially in the mountain range of northwest Luzon (**Figure 3c**).

METHODOLOGY

Satellite imageries (e.g. MTSAT, NOAA, FY2, MODIS) provided by the Department of Science and Technology-Philippine Atmospheric, Geophysical, and Astronomical Services Administration (DOST-PAGASA) that tracked the path and coverage of Typhoon Parma were used. Meteorological (e.g., rainfall, tropical cyclone information) and calamity-related information (e.g., cost of damages to property, infrastructure and agriculture, number of affected population, etc.) were correspondingly gathered from DOST-PAGASA and the National Disaster Coordination Council (NDCC). Field work was also conducted as soon as the roads that led to the northern provinces of Pangasinan, La Union and Benguet were opened to secure a complete, accurate and objective documentation of the geologic hazards that occurred and their resulting calamities. Field investigations were carried out alongside interviews with the affected communities to correlate first-hand accounts with the observed physical evidence.

RESULTS

Situation reports from the NDCC indicate that Typhoon

Parma affected provinces in northern Philippines to as far south as the Bicol Peninsula. The estimated total number of affected population is at 675,681 families which translate to 3,136,965 individuals (*NDCC 2009c*). More than 4,000 houses were totally broken down and almost 35,000 were partially damaged. The total cost of damage to infrastructure, agriculture and private property was at US$ 584 million (US$ 1 = PhP 46.52 as of October 15, 2009). The total cost of assistance for Typhoon Parma-related damages as of November 23, 2009 was estimated at nearly US$ 3 M (*NDCC 2009d*). Majority of deaths reported in the Cordilleras and La Union were largely due to landslides whereas those from other regions were due to drowning (*NDCC 2009c*). In all, 377 people were reported to have lost their lives with the passage of Typhoon Parma. Majority of these casualties came from the Cordilleras (289 persons), La Union (51) and Pangasinan (21).

Figure 7 plots the cumulative rainfall for October 3 to 9, 2009 (**Figure 6b**) over northern Luzon and the different areas reported by local governments and civilians to have been affected by landslides and floods (*ABS-CBN 2009*). Field investigations verified some of these reports and the details of the observations are presented in the succeeding sections. Comparison of this figure with the elevation and slope maps (**Figure 3a and 3b**) show that, as expected, landslides concentrate in elevated areas characterized by high slopes, whereas flooding inundates plains where major tributaries draining the elevated areas collect before exiting to the sea.

Floods

Nearly 60% of the low-lying areas in Pangasinan province were submerged in flood waters because of Typhoon

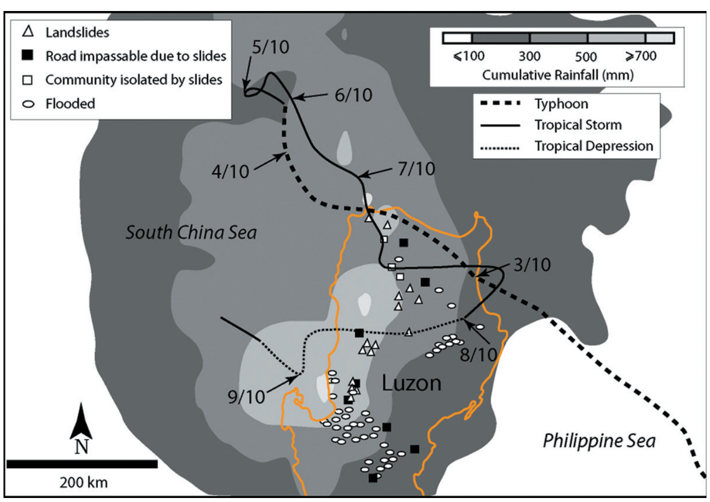

Figure 7. Sites impacted by the passage of Typhoon Parma during the period 3 to 9 October 2009 as reported by radio and television affiliates of the ABS-CBN Network along with calls and text messages of inhabitants of the radio-television network (*ABS-CBN 2009*). Also plotted is the track of the typhoon and the cumulative rainfall estimated by PAGASA.

Parma (*NDCC 2009c*). The Agno and Bued Rivers are two of the largest drainage networks that trace their sources from the Cordilleran region (**Figure 3c and 6a**). Agno River flows southwards to San Manuel, Pangasinan, crosses eastern and central Pangasinan before emptying into Lingayen Gulf. Bued River flows southwestwards into central Pangasinan and enters the same catchment basin as Agno River before also emptying into Lingayen Gulf. Both these river systems, including other smaller rivers that drain from the Cordilleras and Sierra Madres, overflowed starting October 8, 2009 and contributed to the total water budget that inundated central and western Pangasinan. Raging floodwaters of the Bued River caused a section of the Bued Bridge, which connects Pangasinan and La Union, to differentially settle. In central Pangasinan, flood waters reached heights of between 2 to ≥ 3 m and took several days to subside. In addition to the heavy precipitation at these areas, additional factors that may have compounded the flooding were the concurrent release of water from the San Roque Dam of the Agno River and the concomitant high tides.

Towns at the eastern side of Pangasinan province were more severely affected by flash floods. In Rosales, communities along or close to a dike along the Agno River spillway were caught by surprise when rushing waters broke through the concrete dike. This left several towns under more than 2 m of water for nearly 4 days. The force of the floods is evidenced by the amount of damage even to structures of concrete construction (**Figure 8a**). In the town of Umingan, several kilometers of earthen dike that bordered the northwestern edge of the town which protected it from flooding of the Banila River was breached in the evening of 8 October. As a result, riverbank communities were severely damaged by strong currents (**Figure 8b**) and the downtown area, which lies ~4 km to the southeast of the dike, was flooded by more about 1.5 m deep waters. In Baguio City, which lies about 1500 m above sea level, in-land flooding devastated several communities situated in small, localized, catchment basins where flood waters reached nearly 4 m heights in some areas (e.g. Baguio City Camp).

Many upland communities in the Cordilleras experienced flashfloods along very confined stream channels. In the mining town of Antamok, several houses were washed away by strong currents that also carried with it boulders larger than even the houses themselves. Retaining walls built along some of these channels were severely damaged by rock impacts and their bases exposed by undercutting (**Figure 8c**). Other light infrastructures such as concrete dikes, two-lane concrete roads and steel hanging bridges were also easily washed away by the torrents.

Landslides

Hundreds of small to large landslides occurred consequent to the heavy precipitations that accompanied Typhoon Parma. Most mass movements in the Cordilleras and La Union were shallow landslides that resulted from a combination of slumping and sliding of the soil mantle or up to shallow levels of the weathered bedrock. Majority of these occurred as failures of road cut-slopes that were poorly protected or not at all. However, several slopes protected by thick retaining walls also failed despite the structural intervention (**Figure 8d**). The heights of these walls were apparently not enough to contain the total overburden. Several small landslides also occurred where dense numbers of houses had been built. Closer inspection revealed that numerous water pipes and sewerage systems that allowed water to regularly diffuse into the underlying materials may have compromised the holding capacity of the underlying materials.

Numerous landslides blocked or carried away portions of major road networks such as along the Kennon, Marcos and Naguilian highways. These thoroughfares link the Cordilleran region with the rest of northwestern and central Luzon. The 180 km Baguio-Bontoc-Banaue Road, popularly known as the Halsema Highway, was similarly extensively damaged. This mountain road was constructed to link Baguio City and the agricultural areas of Benguet and Mountain Province as well as premier tourist destinations in Ifugao. This thoroughfare was totally closed to vehicular traffic after it suffered an approximately 200 m road cut. Several other total road cuts, in addition to over 50 large slope failures, took nearly two weeks to clear or temporarily restore to conditions that allowed light vehicles to pass. Rock falls with debris avalanches were more commonly observed along the Kennon Road. This highway, which follows the Bued River, was cut along steep sideslopes that consisted of hard, resistant igneous rocks. Landslides along this road were fewer in number but took longer to clear up because of the sheer sizes of the rocks that blocked the road. Landslides along these various road networks occurred as a combined function of the inherently weak underlying rocks, thick soil layers on which the road was built or the absence of the necessary protective engineering measures that should have been built after the roads were cut into the mountain slopes.

Deep-seated landslides also occurred in areas that had previously developed fractures or fissures consequent to the 1990 Digdig Fault earthquake. The high amount of precipitation brought by Typhoon Parma set off mass movements at many of these places. One of the largest slides that claimed the most number of lives at one area occurred at Puguis in Benguet (**Figure 8e**). This community was built on a topographic depression that serves as a transient drainage/stream pathway. Residents disclose that after the 1990 earthquake, huge fissures developed at the top of this hill. Thus, the Mines and Geosciences Bureau had declared the area as landslide-prone due to the deeply weathered underlying rocks and the presence of numerous fracture zones (*Queaño, pers. comm., 2009*). Despite the warnings, residents chose to ignore them as most of the damaged houses were only very recently built. As a result, more than 10 concrete houses were carried downhill by the landslide and the assorted debris covered several more houses at a lower-lying community (Little Kibungan). The collective number of deaths from the Puguis and the Little Kibungan communities exceeded 150 individuals. Numerous similar massive landslides occurred in the mining town of Antamok where thick soil mantles gave way after days of sustained rainfall (e.g. **Figure 8f**).

DICUSSION

Geohazards, triggering factors and impacts

The interplay of geologic, geomorphic, meteorological and other anthropogenic factors all contributed for the odds of the different geohazards to develop into real disasters. The type of underlying rocks, degree of weathering and alteration, thickness of soil mantle and the presence of fractures or other planes of weaknesses are geological features that have huge impacts on the tendency of slopes to fail. Slope angles, the number and size of drainage networks and various other geomorphic features can either contribute to or abate the chances for certain disasters to develop.

To a large extent, the intricate fault systems of the Central Cordilleras control the river, gorges and valley patterns. Agno River, its headwaters and several of its large tributaries are some of the most prominent of these fault-controlled drainage networks in the region. Because of the structural control, Agno River flows for a long distance along a relatively confined channel with almost no expansive banks to spill over before it empties into the flatlands of Pangasinan. This array therefore, maximizes the amount of water delivered into Pangasinan. Agno River, in addition to other river networks with shorter spans but similar drainage efficiencies, all contributed to the excessively high budget of runoff that caused the flooding of this region.

Apart from the structural control, the composition of the rocks and soil in the upland areas of the Cordilleras also influenced the total water budget delivered into the downstream regions. The capacity of the ground to absorb water is directly related to the underlying geology. Hydrothermal alteration affected sizeable areas of the Central Cordilleras that resulted into significant clay alteration. Clay-rich materials are impermeable, as are the soils developed on them. Hence, areas that they underlie are susceptible to rapid runoff and greatly enhance the potential for serious flooding downstream.

Towns in central Pangasinan, including a few

Figure 8 a. Concrete structures were torn away by flood waters of the Agno River when a section of its dike broke. This house was dislodged, as were other structures of similar relatively sturdy construction. b. Several houses built close to the earthen dike of the Banila River in Umingan, Pangasina, were totally washed away in the evening of October 8, 2009. c. A retaining wall along a relatively constricted stream channel in the mountainous town of Antamok was severely damaged by rushing flood waters that carried huge boulders and assorted debris. The black arrow points to what remains of this retaining wall and the white arrow show the undercutting of its foundations. In the foreground, a bamboo bridge was constructed to temporarily replace a hanging bridge that was carried away by the flashflood. d. Several slopes protected even by thick retaining walls also failed despite the structural intervention. Photo was taken along a major thoroughfare in Baguio City. The white dashed line traces the original height of the collapsed retaining wall. e. A view of the landslide that originated from Puguis and travelled to the lower lying community of Little Kibungan in Benguet Province. The houses provide a scale to the magnitude of this catastrophic landslide. More than 10 large, concrete houses were totally damaged and carried downhill by this mass movement and over 150 casualties were reported.

moderately developed cities, were also built on deltaic environments which are naturally prone to flooding. The influx of water from the uplands, the nearly horizontal terrain and the concomitant high tides all contributed to the flooding and its protracted emptying into the bay.

The risk level for landslides to occur in the Central Cordilleras is extremely high because of the prevalence of steep slopes, hydrothermally altered rocks and numerous structural weaknesses. Thus, geomorphology and geology predisposes the region to landslide hazards. The presence of the faults or fractures improves water infiltration and increases the rate by which rocks lose coherence. Mass movement during the torrential rains of Typhoon Parma was significantly enhanced by the presence of these structures. Weathering is also accelerated by these structural weaknesses. Hence, combined with tropical conditions favorable for accelerated weathering, the Cordilleras is characteristically underlain by thick soil mantles that blanket relatively weak bedrocks. Eastern La Union, which is underlain by mostly sedimentary units, is similarly prone to mass movements despite the gentle slopes and moderate vegetative cover. Anthropogenic influences, such as increased overburden in the form of concrete structures, changes to topography to accommodate infrastructure and housing needs or the presence of structures that induce faster weathering or erosion of underlying soil such as leaky drainage/sewage pipes, contributed to the higher occurrence of landslides in populated areas.

The mountainous Cordilleran region is widely known to be frequently affected by landslides. However, in October 2009, the number, magnitude and overall character of the mass wasting disasters wrought by Typhoon Parma have never quite been experienced before. The unusual protracted presence of the typhoon also exposed the region to extended periods of heavy precipitation and strong winds. This resulted in the supersaturation of the thick soil cover that started to fail by the early afternoon of October 8 at different localities. Various studies have shown that antecedent rainfall and soil moisture conditions are critical factors in shallow slope failures for rainfall events longer than two consecutive days (e.g., *Guzetti et al. 2008; Larsen 2008; Lee et al. 2008*), which is exactly what happened in October 2009. Prior to the entry of Typhoon Parma, Luzon had already been subject to intensive rainfall consequent to Tropical Storm Ketsana. Therefore, the ground was still significantly wet, with barely a few days to let moisture evaporate, when Typhoon Parma entered. Therefore, in October 2009, antecedent, protracted, heavy rainfall was the potent meteorological trigger which exploited the geologic-geomorphic vulnerabilities of the northwestern Luzon region that resulted in extensive floodings and numerous landslides.

Tropical cyclones and climate change

The large uncertainties in climatic conditions brought about by global warming and climate change have resulted in greater difficulties in terms of dealing with the associated geohazards. Different numerical models that look into future world climatic scenarios have yielded interesting but somewhat conflicting results (e.g., *Holland and Webster, 2007; Dairaku et al. 2008; Knutson et al. 2010*). Recent projections on tropical cyclones indicate a decrease or no change in the frequency of tropical cyclones, but a likely increase in the average maximum wind speeds of tropical cyclones (*Knutson et al., 2010*). More problematic, however, is the projection being made in terms of rainfall rates (the amount of precipitation that falls on a single occasion) which are expected to increase by up to 20% (e.g. *Emanuel 2005; Bengtsson et al. 2007; Knutson et al. 2010*). This could mean that the atypically high amounts of precipitation brought by Typhoon Parma may become the norm for future weather systems in the region.

Reservations regarding the reality of climate change are difficult to entertain in the light of numerous recent weather events do not fall within usually expected characteristics. In the last few years alone, the Philippines has experienced consecutive tropical storms during a supposedly dry El Niño season (e.g., 2004, 2006), dry spells during supposedly wet El Niña periods (2007), a typical storm paths (e.g., Typhoon Frank) and extremely wet weather systems (e.g., January 2009 tail-end of the cold front; Tropical Storm Ketsana and Typhoon Parma). Typhoon Parma itself is a radical example of such unusual weather events with its protracted persistence over the region, the multiple times it made landfall and the unusual amount of precipitation it carried. Therefore, although the duration, frequency and intensity of typhoons are not straightforward confirmation of climate change, these, combined with other climatic evidence support the concept of changing world climatic patterns. More importantly, while the idea of climate change in the context of global warming consequent to anthropogenic sources continues to be debated, extreme weather events continue to devastate vulnerable countries such as the Philippines.

Disaster risk reduction and management in the Philippines

Climate projections indicate that rainfall rates will likely increase in the very near future consequent to climate change. This is cause for serious concern in the Philippines where most previous devastating landslides were triggered by excessive rainfall. Already, the combined geological and meteorological setting of the country makes it one of the most disaster-prone countries in the world. In the report by *Kirschbaum et al.* (*2010*), the Philippines ranked within the top 5 countries with the highest percentage of landslide reports for the years 2003, 2007 and 2008. This will be exacerbated by the continuous growth in the country's population, the lower estimate of which as of 2009, was at 94 million. This means that a significantly large number of people are exposed to various potential geohazards and are likely to be negatively affected when floods and landslides occur.

These projections and the country's numerous past experiences with landslide and flood disasters have led to a huge progress in establishing disaster risk reduction and management systems in many places across the country. This is in part due to the concerted efforts from the national to the local levels of government, international and local non-government organizations, the academe and other private organizations, to organize communities and establish avenues for relaying weather-related information.

Geology and geomorphology are two of the most crucial factors that contribute to the occurrence of flood/landslide events. Mitigation measures in most develop countries often involve expensive engineering interventions. However, for a developing country such as the Philippines, the best course of action is to mainstream disaster risk management efforts and ultimately, develop efficient climate change adaptation measures (e.g *UNISDR 2008; Birkmann, et al. 2009; Christoplos et al. 2009*). This involves the installation of additional early warning systems (EWS) in tandem with the improvement of human resource capacity to manage these systems. Such initiatives have been undertaken at both at the national and local government levels. Automatic weather stations, water level gauging stations with remote monitors and corresponding warnings posts with the appropriate communications systems have been installed in Metropolitan Manila after it was severely devastated by Tropical Storm Ketsana (*Lazcano 2009*). It is expected that similar early warning systems will be installed in other major river systems around the country.

PAGASA has generated projections of temperature and rainfall changes in the Philippines for the timeframes 2020 and 2050 using the PRECIS (Providing Regional Climates Impact Studies) model (*PAGASA 2011*). Three emission scenarios, A2 (high-range), A1B (mid-range) and B2 (low-range), based on the IPCC Special Report on Emission Scenarios (IPCC SRES) were used to run the models. Results from these models are now being used by various government agencies and research institutions in quantifying adaptation strategies. The DOST has also funded a number of weather and climate forecasting projects that include the on-line DOST Nationwide Operational Assessment of Hazards (Project NOAH; http://noah.dost.gov.ph/) and ClimateX (http://climatex.ph/). Both these systems use a combination of information from various sources and weather data from PAGASA to provide 6- or 3-hour lead-time warnings in terms of rainfall rate and distribution.

The READY Project is a multi-agency initiative that was launched in 2006 and included activities such as multihazard identification and disaster risk assessment, community-based disaster preparedness and mainstreaming of risk reduction into the local development process. The Office of the Civil Defense – National Disaster Coordinating Council serves as the project's implementing agency and cooperating government agencies include the Philippine Institute of Volcanology and Seismology – Department of Science and Technology (PHIVOLCS-DOST), Philippine Atmospheric, Geophysical, Astronomical Services Administration (PAGASA-DOST), Mines and Geosciences Bureau–Department of Environment and Natural Resources (MGB-DENR) and National Mapping Resource and Information Authority (NAMRIA-DENR). Other cooperating partners include the Local Government Units and SMART Telecommunications. Important outputs from the READY project include the generation of geohazard information of the entire country mapped at 1:50,000 scale. Because of the clear benefits from being able to provide these maps to local communities, the national government recently put to task the MGB-DENR to generate 1:10,000 geohazard maps. Results of these studies are currently being incorporated in revising existing land use plans that take into consideration the geologic-geomorphic characteristics of an area.

Over the past few years, the Philippine government has enacted several laws targeted to increase the country's resilience to calamities brought about by changing climatic conditions. In 2009, the Climate Change Act (Republic Act 9729 of 2009) was passed. It allowed for the creation of the Climate Change Commission (CCC) of the Philippines that is tasked to oversee the mainstreaming of climate change into government policy formulation and establishment of the framework strategy and program on climate change (climate.gov.ph). The CCC has since created the National Framework Strategy on Climate Change, the National Climate Change Action Plan and guidelines for the Local Climate Change Action Plan. The Philippine Disaster Risk Reduction and Management Act of 2010 (Republic Act 10121 of 2010) provides the legal bases for policies, plans and programs of the government that deal with disasters. The National Disaster Risk Reduction and Management Plan (NDRRM) was devised consequent to RA 10121 to cover four thematic areas: 1) Disaster Prevention and Mitigation, 2) Disaster Preparedness, 3) Disaster Response and 4) Disaster Rehabilitation and Recovery. In 2011, Republic Act 10174, also known as the People's Survival Fund, was passed in order to provide resources aimed at supporting ground-level DRRM work of local governments and communities.

Because of the recentness of these legislative initiatives, their effectiveness has yet to be tested, some are even still in the process of developing their implementing rules and regulations. In the end, implementation of these laws and DRRM plans remain to be the crucial step in reducing the effects of natural disasters to human communities. People are more receptive of government policies if they have a fair appreciation of how those policies can benefit them. Therefore, the strengthening of public education campaigns through the intensified dissemination of information to local government units, educational institutions and the popular media should form part of these disaster management efforts. By educating the populace, evacuation efforts can be facilitated with greater ease and, when absolutely necessary, relocating communities will less likely face resistance.

CONCLUSIONS

The geographic and geologic settings of the Philippines make this archipelagic nation susceptible to a number of hazards. The chance for these hazards to materialize into disasters is further aggravated by meteorological factors, specifically extreme weather events involving tropical cyclones, that can cause massive flooding and landslides. Typhoon Parma wreaked havoc in northwestern Luzon that resulted into massive loss of lives and properties. This tropical cyclone made landfall in the country three times, a first for the Philippines since meteorological recorded history. Its extended stay in the country (ten days) is considered atypical as most tropical cyclones normally exit the PAR after two or three days. Hence, Typhoon Parma tested to the fullest extent the disaster risk management capacity of the national and local governments and the resiliency of the people themselves. In response, the national government has also taken legislative steps to ensure the long-term sustainability of DRRM initiatives by passing several laws pertaining to climate change adaptation and DRRM. However, the effectiveness of these laws remains to be tested as these were mostly just recently enacted. Nonetheless, it is recognized that mainstreaming climate change adaptation into the development plans of local communities and strengthening their disaster risk management platforms would involve heightened information, education and communication campaigns, improving the efficacy and comprehensibility of early warning systems and developing climate-proofed land use plans. These measures need to be considered and implemented with haste to reduce the many uncertainties that accompany our uncertain future climate.

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