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A LiDAR-based flood modelling approach for mapping rice cultivation areas in Apalit, Pampanga

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ABSTRACT

Majority of rice cultivation areas in the Philippines are susceptible to excessive flooding owing to intense rainfall events. The study introduces the use of fine scale flood inundation modelling to map cultivation areas in Apalit, a rice-producing municipality located in the province of Pampanga in the Philippines. The study used a LiDAR-based digital elevation model (DEM), river discharge and rainfall data to generate flood inundation maps using LISFLOOD-FP. By applying spatial analysis, rice cultivation zone maps were derived and four cultivation zones are proposed. In areas where both depth and duration exceed threshold values set in this study, varieties tolerant to stagnant flooding and submergence are highly recommended in Zone 1, where flood conditions are least favorable for any existing traditional lowland irrigation varieties. The study emphasizes that a decline in yield is likely as increasing flood extents and longer submergence periods may cause cultivation areas for traditional irrigated lowland varieties to decrease over time. This decrease in yield may be prevented by using varieties most suitable to the flooding conditions as prescribed in the rice zone classification. The method introduced in this study could facilitate appropriate rice cultivation in flood-prone areas.

1. Introduction

Climate change impacts such as flooding pose threats to food production and agricultural communities in Asia. Located in floodplains, majority of rice cultivation areas in the Philippines are susceptible to severe flooding due to excessive rainfall. The Philippines is one of the countries most exposed to typhoons and floods due to its location in the western rim of the Pacific Ocean. An estimated 20 typhoons pass through the Philippine Area of Responsibility (PAR) every year (PAGASA, 2009). These typhoons are usually accompanied by heavy rains which can cause adverse effects particularly flooding.

There are a total of 18 major river basins in the Philippines, covering approximately 36% of the country's landmass (DENR). These river basins provide a natural source of irrigation favorable for agricultural activities, of which approximately 32% of the country's population is involved in (The World Bank, 2012). Areas found within these river systems are regularly flooded compounded by past flood events (Zoleta-Nantes, 2000). Notwithstanding its susceptibility to flooding, many of the country's highly populated areas lie in the banks of river systems, Pampanga river basin included. The effect of climate change has increased the frequency and intensity of flooding events and is projected to have adverse effects on crop production particularly in subsistence sectors (IPCC, 2007). Flooding is considered a major problem particularly for rice production in the Philippines. From 2007 to 2010 alone, an annual average of 23.76 million US dollars of damage to rice farming in the Philippines was attributed to flooding (Israel, 2012). Consequently, flood damage can lead to long term impoverishment of affected individuals (Arnall, Thomas, Twyman, & Liverman, 2013). Farmers are particularly affected because in the long run flood risks affect the viability of crop cultivation as a source of livelihood (Gwimbi, 2009). With 12 million farmers dependent on rice cultivation for livelihood (Altoveros & Borromea, 2007), the need to develop strategies to adapt to changing flood conditions now becomes a great priority (Mitin, 2009).

Although rice are cultivated in flooded fields, prolonged submergence can cause serious damage (Ram et al., 2002).

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Submergence can cause mechanical damage to the plants, but more importantly it inhibits desirable bio-chemical processes of the plant-like photosynthesis (Jackson & Ram, 2003; Ram et al., 2002; Setter et al., 1997). Multiple approaches to address these impacts of flooding to rice have been put in place. One of these is the development of flood-tolerant varieties (Septiningsih et al., 2009) that exhibit desirable physiological traits helpful for the plant's survival (Setter et al., 1997) and are embodied in the sub1-a gene (Bailey-Serres et al., 2010). The sub1 gene has been isolated and bred into rice varieties (Khanh, Linh, Linnh, Ham, & Xuan, 2013) including those available in the Philippines such as the IR64 sub1 (International Rice Research Institute (IRRI) 2009) and NSIC Rc 194 (PhilRice, 2010).

Submergence-tolerant rice varieties can survive up to two weeks of complete submergence without any adverse effects on production (IRRI, 2009). However, while tolerance to submergence is a desirable quality, other traits should be considered for adaptive agricultural strategies. For instance, farmers have other trait preferences such as yield and panicle quality (Manzanilla et al., 2010). Also, depending on the flooding conditions, for instance those that last for more than one week and with depth of one meter or more, would require varieties that are tall or have stems that rapidly elongate (Mackill et al., 2010).

In order to optimize the use of submergence tolerant varieties, the flooding conditions should be identified and mapped. By identifying the flood extent and duration in rice cultivation areas, potential damage to property and/or crops can be estimated and other countermeasures can be developed (Chau, Holland, Cassels, & Tuohy, 2013; Wang, Colby, & Mulcahy, 2002; Thieken, Merz, Kreibach, & Apel, 2006). Flood conditions are usually characterized through flood inundation modelling and are then displayed through flood hazard maps. The hazard categories used in these maps are a function of the product of depth and extent (Baky, Zaman, & Khan, 2012) and/or velocity (Daffi, Otun, & Ismail, 2014; Kourgialas & Karatzas, 2014; Purwandari, Hadi, & Kingma, 2011; Toriman et al., 2009). These hazard maps are then used for mitigation and preparedness purposes such as hazard assessments (Daffi et al., 2014; Purwandari et al., 2011), flood propagation and hazard estimation (Kourgialas & Karatzas, 2014), risk management (Baky et al., 2012), and flood management (Toriman et al., 2009). These hazard maps can take into consideration possible damage and potential risks to agriculture (Daffi et al., 2014; Kourgialas & Karatzas, 2014; Baky et al., 2012) but may not necessarily suggest adaptation options. Flood modelling has been used to estimate potential impact on agricultural land through either mapping flood extents in different rain return scenarios (Chau et al., 2013) or combining extent with flood duration (Hamdani & Kartiwa, 2014). Flood models have also been used in combination with risk management to specifically optimize rice planning (Samantaray, Chatterjee, Singh, Gupta, & Panighry, 2015) using flood extent, duration, and depth to map suitable environments for specific rice varieties.

Flood inundation models entail the use of flood depth, extent, duration and flow velocity based on advanced algorithm and high-quality data (Samantaray et al., 2015). Flood modelling software such as Lisflood, HEC-RAS, and MIKE typically require rainfall, discharge, topography, and Digital Elevation Model (DEM) data to generate flood models. The accuracy of the models depends on the quality of input data and the quality of DEMs are considered directly proportional to the reliability of the models (Brandt & Lim, 2012). To increase the accuracy of flood models, high resolution DEMs from sources such as LiDAR are highly favored (Sole, Giosa, Nolè, Medina, & Bateman, 2008). LiDAR is a remote sensing technology that uses rapid laser pulses to map out the surface of the earth and can be used to create high resolution terrain and surface DEMs. LiDAR has been widely used because of its vertical accuracy of ± 15 centimeter and spatial resolution of up to 1 meter. The Philippines has recently obtained airborne LiDAR technology (Paringit, Fabila, & Santillan, 2012) to map major river basins, with a much higher degree of accuracy than what is currently available.

Apalit is one of the rice producing municipalities of Pampanga which suffer from prolonged inundation and has a relatively flat terrain due to its location within a flood plain. For the purpose of this study, LiDAR surface models were used in the flood simulation in the municipality of Apalit. Other topographic mapping technologies have difficulty in capturing flat terrains (Sole et al., 2008), but LiDAR is able to produce highly accurate flood models due to its capability to capture gentle terrain changes. The aim of this study is to develop LiDAR-derived flood models to map rice cultivation areas based on depth and duration. The maps allow the identification of suitable rice varieties for each rice cultivation map. The study therefore provides a tool in determining appropriate areas for rice cultivation and in selecting and developing suitable rice varieties based on different flooding condition sets.

2. Study area

The study was conducted in Apalit, one of the 20 municipalities in the Province of Pampanga (Fig. 1). Apalit is located in the south eastern portion of the province and has a total area of 6147 ha with an estimated population of 101,537 (NSCB, 2010). The municipality has an estimated 3799.95 has of agricultural land, as derived from digitized orthophotos. The rice-producing barangays (villages) are Balucuc, Calantipe, Cansinala, Capalangan, Paligui, Sampaloc, San Juan, San Vicente, Sucad, Sulipan, and Tabuyuc. Barangay Colgante and portions of barangay Paligui practice aquaculture through fishponds.

The topography of the municipality is characterized by largely flat and low with slopes ranging from 0 to 3% and an elevation not exceeding 20 m (Municipal Government of Apalit, 2000). It is also alluvial, dominated by streams and rivers attributed to its location within the Pampanga floodplain. The Pampanga River runs through the mid-eastern portion of the municipality and is a source of irrigation in the municipality (Fig. 1). Its cropping cycle runs between the dry season from November to December and the wet season from June to August. An average of 644 mm of rain is experienced during the wet season. The riverine morphology and flat terrain makes the municipality favorable for rice cultivation while rendering it prone to flooding during the wet season. The Pinatubo eruption have also significantly altered flooding conditions (Siringan & Rodolfo, 2003). Flooding is largely characterized by surface water inundation worsened by heavy rainfall during the wet season. This is as verified from the focus group discussion (FGD) and reports from Pampanga River Basin Flood Forecasting and Warning Center (2012).

3. Data used

3.1. LiDAR DEM

The airborne LiDAR data used for the study area was acquired by the University of the Philippines Disaster Risk and Exposure Assessment for Mitigation (UP-DREAM) Program from October to December 2012. The data was processed to produce a 1-meter spatial resolution for the Digital Surface Model (DSM) and the Digital Terrain Model (DTM) (Fig. 2) with a point density of two to three points per square meter. The LiDAR point cloud data was processed and refined using Terra Scan (Terrasolid, Inc.) to eliminate stray points and normalizing elevations throughout the flight paths.