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.

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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 (Arnell, 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 (Gwimi, 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 gene (Bailey-Serres et al., 2010). The sub1 gene has been isolated and bred into rice varieties (Khanh, Linh, Linh, 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; Kourgiolas & 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 (Kourgiolas & 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; Kourgiolas & Karatzas, 2014; Baky et al., 2012) but may not necessarily suggest adaptation options. Flood mapping 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, & Panighey, 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 Lsflood, 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, Gioia, Nole, 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 (Faringit, 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 101,373 (NSCB, 2010). The municipality has an estimated 3799.95 ha of agricultural land, as derived from digitized orthophotos. The rice-producing barangays (villages) are Balucuc, Calantipe, Cansinola, Capalangan, Paligi, Sampaloc, San Juan, San Vicente, Sucad, Sulipan, and Tabuyuc. Barangay Colgante and portions of barangay Paligi 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.
The final DEM used for the model was resampled from the 1-meter resolution DSM into a 5-meter resolution DEM to fit the flood model resolution limit of 12 million cells. The resampled model does not affect the resolution accuracy since the land use of

Fig. 1. Location map of Pampanga.

Fig. 2. LiDAR digital terrain model (DTM) with elevation values and outline of Pampanga River.
the municipality is largely agricultural and does not greatly affect flood behavior as opposed to urban areas (Tamiru & Rientjes, 2005).

3.2. Rainfall and river discharge data

The Rainfall Intensity-Duration-Frequency (RIDF) analysis data for the flood models and the hypothetical, extreme validation model were obtained from the Philippine Atmospheric, Geophysical and Astronomical Administration (PAGASA). The RIDF data were spatially interpolated across the region through the theissen polygon technique in ArcGIS 10.2. Port Area rain gauge station was selected.

To produce the discharge for the flood scenarios, RIDF analysis data gathered by PAGASA and water-level readings from ASTI were used as inputs in the 2D HEC-HMS flood models of Pampanga for the different rainfall-runoff scenarios. Table 1 shows peak values of outflow and rainfall at the Sto. Niño station for the 5, 25 and 100 year return periods.

3.3. Land cover and roughness coefficient

Land cover was manually classified and digitized at a scale of 1:1250 from a combination of orthophotos obtained by UP-DREAM Program from October to December 2012 and stitch maps taken from Google Earth™ (Fig. 5). Land cover classes were assigned with appropriate roughness coefficients based on Chow (1959) and standardized by Brunner (2010).

4. Methodology

4.1. Framework for rice cultivation area mapping (Fig. 3)

4.1.1. Flood model development

The development of the flood models for the Pampanga River Basin was done using LISFLOOD-FP model (version 5.9.6) developed by the School of Geographic Sciences of the University of Bristol. LISFLOOD-FP is capable of integrating 1D and 2D parameters into a single model and can depict not only riverine flooding, but also surface flooding. For 1D parameters, the study used LISFLOOD-FP’s diffusive solver. The diffusive solver models the behavior of the flow of water within a river or stream over time by running the discharge values through the channel and then computing the effects to water depth within the channel in relation to the channel’s cross-section, friction values, and gravity. When the river depth...
reaches the bank, water flows to the adjacent cells within the DEM. The process is described in the 1D diffusive wave equation (1) (Bates, Trigg, Neal, & Babrowa, 2013) where $Q_x$ is volumetric flow rate at a given time $t$ in the $x$ Cartesian direction, $A$ is the cross sectional area of flow, $h$ is the water depth, $g$ is gravity, $n$ is the Manning's friction value, $R$ is the hydraulic radius of the river section, $t$ is time, and $x$ the distance in the $x$ Cartesian direction which can also predict backwater effects. The acceleration solver was used for the 2D parameters which calculated flows between cells as a function of friction and water slopes, and local water acceleration.

\[
\frac{\partial Q_x}{\partial t} + \frac{\partial}{\partial x} \left[ Q_x \frac{Q_x^2}{A} \right] + gA \frac{\partial (h + z)}{\partial x} + \frac{gn^2Q_x^2}{R^{4/3}A} = \\text{local acceleration} + \text{convective acceleration} + \text{water slope} + \text{friction slope}
\]

Input data for the model included the rainfall and discharge data, raster DEM, river profile, channel and floodplain friction, and model time step. Model simulation time was approximated based on discharge duration. The discharge simulation time was identified at 900,000 s (equivalent to 10.4 days). The input data were converted to text formats with specific file extensions that the model would read based on the parameter file. The data requirements and formats are described in Table 2. The model has the capacity to generate time-series output images of inundation extent and depth, maximum depth, hazard maps, flow velocity, and total inundation time. For the purpose of this study, time series output images were used along with the total inundation time. A total of 1500 time series images were produced for each rain return scenario.

### 4.2. Model validation

Flood maps showing observed flood events and their extents were used to subjectively validate the resultant flood models by comparing actual flood accounts from key informant interviews (KIs) and focus group discussion (FGD). Observed flood maps were used for visual comparison with the resultant flood models. These maps were gathered from MODIS satellite images acquired on December 4 and 9, 2004 and were digitized using ArcGIS 10.2. In particular, model simulated for Habagat 2013 (south-west monsoon rain) (Fig. 4) event was generated using LISFLOOD-FP for comparison and validation purposes.

![Habagat 2013 maximum flood depth](image-url)
4.2.1. Focus group discussion and key informant interviews

An FGD was conducted with farmers not only to validate the flood maps with their experiences on flooding but also to elicit information about local agricultural adaptation practices and varietal types used. Twenty-five among the invited thirty-six farmers across all barangays (villages) took part in the FGD. These farmers represented nine of the 11 barangays that were mostly agricultural, namely Colgante, Capalangan, Calantipe, San Juan, Cansinala, Tabuyuc, Sampaloc, Balucuc, and Sucad. Despite lack of representation from two barangays, the answers were treated collectively at the municipal level, not per barangay. Activities included introduction of FGD team and participants, overview of the topic, explanation of the FGD process and ground rules, and discussion guided by semi-structured questions. Specific information gathered included (1) historical accounts on flood duration and extent; (2) agricultural adaptation practices; (3) cropping patterns/calendar; and (4) rice varieties being used with respect to characteristics, yield, cost and cultivation area coverage.

In addition to the FGD, semi-structured KIIs were also conducted on multiple visits to obtain information on actual/observed flood records, flood impacts on agriculture, existing agricultural adaptation practices and land use changes, among others. To gather these information, the Municipal Agricultural Officer (MAO), the Municipal Planning Officer (MPO) and a few Municipal Agricultural Technologists (MATs) were chosen for the KIIs because of the depth of their knowledge and experience on the subject on which they were interviewed.

4.2.2. Estimation of existing rice cultivation extent

The rice cultivation area (Fig. 6) for Apalit was digitized from interpretation of land use (Fig. 5) from orthophotos that were taken with the LiDAR data. This was used in conjunction with the rice area maps obtained from IRRI using MODIS images obtained from 2000 to 2012.

4.3. Classification of cultivation areas for rice varieties

ArcGIS 10.2 was used to overlay the map layers of rice cultivation area and the extents of inundation time and mean depth to generate the zone maps. The total area affected by inundation was calculated by clipping the flood extent given total inundation time and mean depth. The average depth over the whole inundation time provides a picture of how depth would affect the rice crop over time. Mean depth was calculated by stacking the water depth result produced from LISFLOOD-FP as raster time-series images and then the image processing software ENVI™ version 4.7 computed the average of those images. Total inundation time and mean depth were integrated using a Python script to produce a raster representing the different depth-duration conditions (Table 3) and was then converted into polygons and overlain with the rice cultivation area. The conditions used in the zoning were based on the depth threshold specified for shallow water rice in Mackill et al. (2010) and the duration threshold based on the short duration submergence specified in Salam, Biswas, and Rahman (2004).

5. Results and discussion

5.1. Flood inundation models

Fig. 7 shows the west-east elevation (section A-B) profile from
the approximate mid-point of the river. It illustrates how Pampanga River is planked by alluvial deposits that act as natural levees which impeded overflow from the Pampanga River. Increased river runoff in the river partly elucidates why no significant overflow was observed during rainfall events as confirmed during the FGDs. The inundation models indicate increase in affected areas for both flood inundation time and mean depth with rain-return period (Figs. 8 and 9). Of particular interest are the expanded coverage of flooded areas located in the southwestern portion with increasing return periods. The apparent absence of overtopping in the inundation models of Pampanga River is consistent with the accounts obtained from the FGD.

5.2. Local rice varieties

There are a total of seven rice varieties that farmers use throughout the year depending on the season, one of which (IR64) is submergence-tolerant. IR64 was introduced and adopted by majority of the farmers in the 1990s, but is no longer being grown due to its low pest tolerance. In contrast, NSIC Rc 150 has a high yield and good eating quality apart from its tolerance to submergence. However, it fell out of usage due to age and thus was discontinued and replaced with other varieties by local farmers according to our interview (Manzanilla, personal communication). With its unintended floodresistant characteristic, NSIC Rc150 may prove to be a better substitute to IR 64 due to its low cost, high yield, and short days to maturity. This enables farmers particularly in the barangays of Balucuc and Calantipe and some portions of Tabuyuc and Cansinala to maximize their resources and have the opportunity to harvest at the most three times a year.

5.3. Observed flood conditions

Contrasting flooding conditions were found between the eastern and western portions of the municipality. The eastern portion has greater flood depths, but recedes faster. Two of the barangays, Calantipe and Balucuc, and some portions of Tabuyuc, Capalangan, and Cansinala do not experience detrimental flooding (Fig. 10) attributed to their comparatively higher elevation as discussed in the FGDs. Barangays in the western portion have shallower flood depths, but have very long submergence periods. The worst case is found in the Barangay of Colgante, where observed flooding lasts between 4 and 7 months. The severe flooding conditions are also seen as a result of the conversion from agricultural lands to fish ponds of a portion of barangays Paligui and Colgante. According to the FGD participants, the continuous outflow of lahar from Mt. Pinatubo and the sea-level rise originating from Manila Bay are major contributors to the constricted stream system which engender the current flooding conditions. It is estimated that

Table 3
Zone value matrix representing the flood depth and duration conditions.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Conditions</th>
<th>Mean total duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≥20</td>
<td>≥7</td>
</tr>
<tr>
<td>2</td>
<td>≤20</td>
<td>≥7</td>
</tr>
<tr>
<td>3</td>
<td>≤20</td>
<td>&lt; 7</td>
</tr>
<tr>
<td>4</td>
<td>≥20</td>
<td>&lt; 7</td>
</tr>
</tbody>
</table>

Fig. 6. Extent of areas planted to rice in Apalit, Pampanga.
around 1500 has or 25% of Apalit will be affected by a two-meter rise in sea level (PEMSEA, 2012).

5.4. Rice cultivation at risk

Rice cultivation in Apalit is at risk as low-lying barangays experience prolonged submergence that extend up to four months during the wet season (June to August). During the FGD, farmers stated that heavy rainfall was the main cause of submergence of rice fields. In a typical year, floods affect between 50% and 80% of rice cultivation areas across barangays. Based on the cultivation zone maps (Fig. 11), increasing trend in flood extents of varying flood depths is observed for 5-year to 100-year rain-return periods. There will also be an increase in submergence period as more intense rains occur more frequently.

Generally, the varying flooding conditions between the eastern and western barangays may indicate the differences in their agricultural practices and adaptation strategies. The eastern barangays such as Calantipe and Balucuc are able to harvest up to a maximum of three times a year because flooding does not affect them while barangays on the western side have reduced their cropping season to only once each year. Farmers in Colgante and Paligui have even resorted to converting their lands to fishponds due to recurring floods.

5.5. Cultivation zone classification

Cultivation areas were classified into four zones (Fig. 12) based on four flooding conditions. Zone 1 is suitable for flood-tolerant varieties and those tolerant to stagnant flooding. Depth and duration in this zone exceed the threshold values set in this study and are least favorable for existing traditional lowland irrigation varieties. Between 10 and 21% of current cultivated land should grow only varieties that can withstand flooding conditions beyond shallow depth and 7-day flood duration limit (Fig. 13). On the other hand, there is a decreasing pattern of extent for traditional lowland irrigation varieties, which means more areas might need to adopt varieties with known submergence tolerance traits that last longer than seven days and in depths greater than 20 cm. Areas which might need of these varieties are located in the south eastern portion mainly in Capalangan and Tabuyuc. Sucad may also adopt these varieties as the area for Zone 3 decreases in the barangay per
Fig. 8. Mean depth for (a) 5-, (b) 25- and (c) 100-year rain-return periods.
rainfall scenario.

Accounts from the FGD indicate that inundation could extend up to several months. The need for rice varieties also tolerant to stagnant water for weeks to several months regardless of depth tolerance is crucial. A decline in yield will be likely as cultivation areas for traditional lowland irrigated varieties may decrease over time due to expanding flooding and submergence. This decrease in yield may be prevented by planting varieties most suitable to the

Fig. 9. Total inundation time for (a) 5-, (b) 25- and (c) 100-year rain-return periods.
environment as prescribed in the rice zone classification. However, more than one of the conditions can ensue in any particular flood-prone environment. Therefore, it is desirable to develop varieties that have a combination of tolerance traits for flood-prone areas.

Traditional (local) varieties are mostly grown in the municipality despite flood risks. Adoption of submergence-tolerant varieties however presents some drawbacks considering their cost and low tolerance to pest. As some cultivation areas already suffer stagnant inundation of at least a month, medium to deepwater rice varieties might thrive for any flood scenario. However, more than one of the conditions can ensue in any particular flood-prone environment. Therefore, it is desirable to develop varieties which possess a combination of tolerance traits for flood-prone areas when possible. The potential re-adoption of IR64 and sustainability of use of other submergence-tolerant varieties will be critical in the development and accessibility of flood-resistant rice cultivars as their adoption will depend on their productivity, yield, cost and socio-economic factors. Alongside the development of low-cost high-yielding flood-tolerant rice varieties, it is crucial that access to sustainable agricultural services is in place. This, however, will also depend on the availability of developed flood-tolerant cultivars.

6. Conclusion

The study has demonstrated the use of LiDAR technology for producing fine scale flood inundation maps to classify cultivation areas for certain rice varieties, the results of which could facilitate agricultural adaptation and help strengthen food security in Apalit, a rice-producing municipality in Pampanga that is generally characterized by surface flooding. Using LISFLOOD-FP model, inundation depth and duration conditions were simulated from integrating river discharge and rainfall data and LiDAR-based DEM. These conditions were chosen as they are crucial in the survival and productivity of rice varieties. The inundation models provide an illustration of the variation in the extent of flood depth and duration across rice cultivation areas given a rainfall scenario. Based on the models, there is a potential increase in extent of flood depth and duration as rain-return periods increase. The study found that a decline in yield is likely as cultivation areas for traditional lowland irrigated varieties may decrease over time due to increasing depth and longer submergence periods. This decrease in yield may be prevented by growing varieties that are more suitable to the environment as prescribed in the rice zone classification.

Consequently, four zones are proposed. The flood-tolerant varieties and those tolerant to stagnant flooding are recommended in Zone 1 where both depth and duration exceed the threshold values set in this study, meaning flood conditions are least favorable for any existing traditional lowland irrigation varieties. More than one of the flooding conditions can ensue in any particular flood-prone environment, which makes it is desirable to develop rice varieties that possess a combination of tolerance traits for flood-prone areas. Apalit is naturally lowland so medium to deepwater rice varieties might thrive for any flood scenario as some parts of the municipality already suffer stagnant inundation of at least a month during extreme rainfall events.

The flood models and the resultant rice zone maps were designed to take advantage of LiDAR data sets generated through the efforts of Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program of the University of the Philippines and the Department of Science and Technology (DOST). While the findings of the study relies heavily on models, the need for their validation with observed flood information prompted the conduct of FGD. The FGD was also necessary to obtain relevant information on impacts of flood on rice cultivation, current rice adaptation strategies, and varietal types used. Although LiDAR technology offers more accurate topographic detail for specific purposes such as flood inundation estimation, its accessibility and availability present some drawbacks for studies that cover larger scale areas where flooding conditions are critical to rice cultivation. Alternatively, free and
Fig. 11. Recommended varietal types and characteristics per cultivation zone.
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accessible but scale-appropriate DEMs should be maximized using the methodology employed in this study.
prone rice systems in Gazipur, Bangladesh. Los Banos, Laguna (Philippines): International Rice Research Institute.


