Flood vulnerability impact for food estate potential in Central Kalimantan, Indonesia

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Abstract. Provision of agricultural land to support food security has criteria including optimal crop productivity, adequate intensity, guaranteed water availability (surface water and groundwater) and environmental conditions that are secured to damage (conservation). Food estate in Central Kalimantan will be allocated 30,000 ha or 300 km² in 2020. Since the land allocation for food estate are existed near main rivers, environmental aspect from hydrological issue becomes one major aspect that must be considered. This study assesses potential rice field by using GIS and two dimensional unsteady hydrological model simulation due to flood prone area. Based on this model, vulnerable area could be measured by quantitative method in order to prevent losses act. The results show where composition of existing land use in upstream of each watershed (Barito, Kahayan, Kapuas River Basin) give different maximum peak discharge based on hydrograph curve of each zone of food estate area targeted. Food estate of 30,000 ha overall has less index of vulnerability of flood hazard, where 9% of its total area inundated by Q50 years return period discharge.

1. Introduction
Flood management and forecasting are essential key to success for agriculture sector which is especially better seen in watershed perspective. Flood can be occurred because of land use change accessibility which are not considering soil and water conservation for agriculture. Relationship between land use changes and flooding in river system of watershed form field of research itself. Many studies have shown flood impact and problems are not simply made by land use change in its upstream, but also related to change of vegetation and soil quality and scales of watershed and rainfall events. Extreme rainfall can trigger flood because of out of capacity of river channel to store water. Then not only considering rainfall aspect, but also ecosystems give strongly influence peak of flood and velocities. Land use composition in watershed scale gives different respond to hydrology, such as: 1) changes in soils and vegetation reduce capability of storage, infiltration, evapotranspiration, water content, 2) more impervious surfaces increase rate of water movement of run-off, 3) erosion, sedimentation, and scouring change morphology of river [1].

For agriculture purposes, frequent of floods and weather related events can increase damage to its land productivity and plant. The impact can cause loss of number of plants flushed by water, soil over saturated which impact to plant roots, sedimentation cause debris flow and the damage of existing embankment structure. To reduce flood, many people in rural area in Indonesia still use traditional practice such as constructing floodwalls, rising embankment, dams, and property redemption but it will be more expensive without proper risk mapping analysis. Regarding flood damages in agricultural sector, flood inundation mapping can be utilized for reducing possible damages.
The objective of this study: (1) to simulate flood prone zoning in food estate area based on hydrology analysis; (2) to analyse impact of land use composition inside watershed scale on flood vulnerability and how far flood can affect to agriculture zone losses; (3) to quantify and compare flood losses from vulnerability index across existing land use practices using a case study in candidate province of Indonesian’s new food state centre. The methodology links to hydrological modelling, flood probability analysis, and vulnerability index by depth of water impact to estimate the certain zone to be sustainable.

2. Methods

2.1. Study area

The flood prone area simulations are generated from flood modelling. Initially, a rainfall run-off modelling is conducted to generate flood design hydrograph [9]. Later, a hydraulic model is developed to simulate flood. The study area is located in downstream of Barito, Kapuas and Kahayan River Basin. River basin consists of some land uses where most of swamps and paddy areas are located in downstream of the rivers (figure 1). Total of potential areas for food estate targeted in the basins are 165,000 ha. In 2020, for first implementation will be allocated 30,000 ha (figure 2), the study area are split into two for Pulang Pisau District about 10,000 ha and Kapuas District about 20,000 ha.

Figure 1. Land Use of Catchment Area of Barito River and Kahayan River (Source: Ministry of Environment and Forestry, 2018).

Figure 2. Food Estate of Sub-District Region at River Basin Scale.

2.2. Method of study

2.2.1. HEC-RAS. HEC-RAS is hydraulic model designed by the US Corporation Engineers Hydraulic Engineering Centre to model a river flow [10]. It is a well-established and used to compare with another hydrodynamic model as benchmarked for river simulation model [11]. HEC-RAS has performance to estimate water surface profile along a river in steady and unsteady flow river hydraulic calculation either in 1D or 2D simulation. One-dimensional models are generally very efficient but have disadvantages including the inability to simulate the lateral diffusion of the flood wave and the...
representation of topography as cross-sections rather than as a surface. In two-dimensional modeling, some of the physical constraints seen in a one-dimensional model can be overcome [12]. HEC-RAS with two-dimensional unsteady modelling allows the discretization of the river and its floodplain as a group of individual cells called grid cells and model performs better than 1D [13,14]. The unsteady computation is based on the following mass conservation or continuity equation.

\[
\frac{\partial H}{\partial t} + \frac{\partial H}{\partial x} + \frac{\partial (vh)}{\partial y} + q = 0
\]

Where, \(H\) represent WSE (Water Surface Elevation), \(q\) is the discharge term related to source or sink, \(h\) is the depth of water, \(u\) and \(v\) the velocity components in the \(x\) and \(y\) direction. The diffusion-wave approximation of the momentum equation with eddy viscosity and Coriolis term disregarded, the original equation in the vector form will be as the following equation.

\[g\nabla H = -c_f V\]

Where \(h\) is the WSE, \(V\) is the velocity vector, \(g\) is the gravitational acceleration, \(c_f\) is the coefficient for bottom friction and \(\nabla\) is the differential operator.

2.2.2. Hydrological data. The design discharge analysis used a more or equal to the maximum flood return period in the hydrological data series from 2010 to 2019 year. Rainfall analysis was performed based on daily rainfall measurement data in nearly rainfall station around the river basin. An average rainfall area was analyzed using Thiessen polygon [15] method because the availability of data were limited. Furthermore, analysis was continued to determine rainfall probability for return period used Log Normal, Gumbel Type I, Gumbel Type II, and Log Pearson III. The goodness of fit test was used by two ways (e.i Chi-square [16] and Smirnov-Kolmogorov [17] for validating rainfall to vertical or horizontal data deviation). Rainfall intensity was analyzed by Mononobe formulation which is commonly used in Indonesia [18]. In analyzing probable discharge, synthetic unit hydrograph synthetic used 3 (three) methods formulation SCS-Synder, Nakayashu, and ITB-1 [9] to show the differences of peak time discharge for return period \(Q_{2\text{yr}}, Q_{5\text{yr}}, Q_{10\text{yr}}, Q_{20\text{yr}}, Q_{50\text{yr}}, \text{and } Q_{100\text{yr}}\). For commercial asset like agriculture production or industry was planned with \(Q_{50\text{yr}}\) because the higher the return period, the lower the overflow probability will be and reduce flood risk occurred as well.

2.2.3. Analysis of flood river basin. The data analysed are flood water elevation that occurs from the simulation results of water level profile simulation. Water that overflows into the land near the river will be shown, so volume of water that exceeds its river capacity results insource of inundation. Qualitative mapping is set based on flood hazard index, vulnerability index, and capacity index which are divided into four types as low, moderate, high, very high [19].

3. Results and discussion

3.1. Result of hydrological data
Rainfall characteristic from January until December during 10 years period (2010-2019) indicated that station has similar curve when July-August rainfall has minimum amount and increase reaching rain peak season in December (figure 3). In flood discharge simulation, since many stations have hourly data, maximum daily rainfall data are used to generate model into discharge by using some formulation.
Based on rainfall data measurement (table 1), the highest maximum daily rainfall of 144 mm occurred in 2010 and the lowest of 107 mm in 2011. Furthermore, analysis frequency simulated rainfall design which was based on return period for each station and formulated by probability gained rainfall design for whole watershed based on return period $Q_{2\text{yr}}, Q_{5\text{yr}}, Q_{10\text{yr}}, Q_{25\text{yr}}, Q_{50\text{yr}}$ and $Q_{100\text{yr}}$ (table 2). Those rainfalls are input of hydrological model SCS-Synder, Nakayashu and ITB-1 to create synthetic unit hydrograph.

Table 1. Maximum Daily Rainfall at Station.

| Year | Tjilik Riwut’s Station | Sanggu’s Station | Beringin’s Station | Banjar Baru’s Station | Syamsudin Noor’s Station | Average |
|------|------------------------|------------------|-------------------|-----------------------|--------------------------|---------|
| 2009 | 139                    | 113.9            | 135               | 91                    | 109                      | 118     |
| 2010 | 195                    | 101.4            | 152.6             | 159                   | 113                      | 144     |
| 2011 | 148                    | 105              | 95.4              | 96                    | 92                       | 107     |
| 2012 | 155                    | 112.5            | 156.7             | 88                    | 105                      | 123     |
| 2014 | 119.8                  | 98.3             | 160.9             | 214                   | 118                      | 142     |
| 2015 | 148.9                  | 100              | 164.6             | 116                   | 118                      | 129     |
| 2016 | 200                    | 137.5            | 137.4             | 108                   | 99                       | 136     |
| 2017 | 168                    | 121.5            | 142.8             | 87                    | 112                      | 126     |
| 2018 | 100                    | 95.3             | 184.1             | 91                    | 112                      | 117     |
| 2019 | 128                    | 112              | 146               | 97                    | 71                       | 111     |

Rainfall data in 2013 were not completed in some stations, so to harmonize in calculation each station does not use the data. Frequency distributions were calculated to find rainfall probability (figure 4) which also continued to the goodness of fit test Chi-Square and Smirnov-Kolmogorov. Since rainfall data were daily, so then rainfall intensity was calculated by Mononobe’s formulation.
intensities were related to depth of rain per unit time, where general characteristic of rainfall was getting shorter so its intensity tends to be higher.

**Table 2.** Discharge Design Return Period.

| Return Period (Qyr) | Barito SCS-Snyder | ITB-1 | Nakayasu Snyder | Barito ITB-1 | Nakayasu | Kapuas SCS-Snyder | ITB-1 | Nakayasu |
|---------------------|-------------------|-------|-----------------|--------------|----------|------------------|-------|----------|
| 2                   | 11,038.61         | 11,062.33 | 5,159.29        | 5,531.48     | 5,547.91 | 3,254.21         | 4,304.80 | 4,313.12  | 2,500.68  |
| 5                   | 12,854.16         | 12,884.74 | 6,006.00        | 6,441.03     | 6,461.58 | 3,776.43         | 5,011.44 | 5,023.29  | 2,907.78  |
| 10                  | 14,057.22         | 14,091.42 | 6,567.23        | 7,043.74     | 7,066.64 | 4,127.26         | 5,480.21 | 5,493.63  | 3,178.74  |
| 20                  | 15,211.23         | 15,248.90 | 7,105.57        | 7,621.88     | 7,647.03 | 4,463.78         | 5,929.87 | 5,944.79  | 3,438.64  |
| 25                  | 15,580.59         | 15,616.79 | 7,281.67        | 8,372.81     | 7,831.77 | 4,580.46         | 6,074.64 | 6,088.59  | 3,526.37  |
| 50                  | 16,704.97         | 16,747.14 | 7,802.41        | 8,370.21     | 8,398.28 | 4,899.37         | 6,511.90 | 6,528.76  | 3,775.07  |
| 100                 | 17,824.32         | 17,869.86 | 8,324.58        | 8,930.99     | 8,961.24 | 5,225.79         | 6,948.05 | 6,966.37  | 4,027.17  |

Furthermore, each watershed was simulated by rainfall input using formulation of hydrograph unit in which each watershed has different response to reach peak discharge. From analysis of discharge in Barito River (table 2), ITB-1 method tend to give higher response than either SCS-Synder or Nakayasu. Furthermore, in Kahayan River and Kapuas River, ITB-1 method also was higher than that of SCS-Synder or Nakayasu. Q50yr return period was selected as a reference of standard guidance of river infrastructure to prevent floods.

**Figure 4.** Unit Hydrograph Curve of Barito, Kahayan and Kapuas Discharge (m³ s⁻¹) Q50yr return period. Barito’s river has peak discharge at 16,747.14 m³ s⁻¹ by ITB-1 unit hydrograph; Kahayan’s river has peak discharge at 8,398.28 m³ s⁻¹ by ITB-1 unit hydrograph; Kapuas’s river has peak discharge at 6,528.72 m³ s⁻¹ by ITB-1 unit hydrograph.
3.2. Result of flood simulation data

The result showed that in simulation of discharge Q50yr at same time in each river basin has several impacts especially to food estate/paddy cultivated area. The 2D HEC-RAS model solved either the 2D Saint-Venant equations or the 2D diffusion wave equations. Floodplain flow was calculated as 2D diffusion wave. The 2D unsteady flow equations solver in HEC-RAS used an implicit finite volume algorithm, where it allowed more computational time steps than explicit methods and provided an increment of improved stability over traditional finite difference and finite element techniques, which demand less computational time [14]. DEMNAS used has 8.33 m resolution which better than SRTM 1 Arc Sec or ASTER GDEM (30 m) and SRTM (90 m).

Figure 5. Rice Field Land Use around Food Estate Region.

Figure 6. Flood Risk Mapping <1 m Deep around Food Estate Region.

Figure 7. Flood Risk Mapping 1-2 m Deep around Food Estate Region.

Figure 8. Flood Risk Mapping >2 m Deep around Food Estate Region.
In determining flood hazard indexes is based on these conditions: Index 1. <10% inundated area > 2 m : less, Index 2. 10%-40% inundated area > 2m : moderate, Index 3. 40%-80% inundated area > 2m : high, Index 4. 80% inundated area > 2m : very high.

Barito river has the length 1,029.45 km covering the watershed area about 62,929.34 km², Kahayan river has the length of 583.08 km covering the watershed area about 22,531.70 km² and Kapuas river has the length of 589.27 km covering the watershed area about 17,622.81 km². Hydrograph discharge becomes input of unsteady flow in simulation.

In general, rice field in study area has flood depth of less than 1 m (figure 6). Based on simulation, areas flooded more than 2 m (figure 8) are areas districts of Jabiren Raya, Kahayan Hilir, Kapuas Barat, Kapuas Murung, Pulau Petak, Mantangai.

4. Conclusions
The total area of 30,000 ha of food estate has less index of vulnerability of flood hazard which is 9 % of its total area inundated by Q50yr return period discharge more than 2 m. Spatial map of flood modelling gives one step ahead for water management, especially to support food estate to protect it from flood hazard which can lose productivity. The study should be continued with some inputs such as embankment (structural), economic, social or mitigation (non-structural) param in simulating the development of water impact through field to enrich the results at the location.

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