GIS BASED FLOOD HAZARD AND VULNERABILITY MAPPING: A CASE STUDY OF TIDAL AND RIVER FLOODS IN DOWNSTREAM OF CIASEM WATERSHED, SUBANG-WEST JAVA

Budi Hadi Narendra*, Harris Herman Siringoringo and Chairil Anwar Siregar

Forest Research and Development Center, Jl. Gunung Batu no.5 Bogor, West Java, Indonesia

Received: 7 June 2016, Revised: 19 December 2016, Accepted: 5 April 2017

GIS BASED FLOOD HAZARD AND VULNERABILITY MAPPING: A CASE STUDY OF TIDAL AND RIVER FLOODS IN DOWNSTREAM OF CIASEM WATERSHED, SUBANG-WEST JAVA. Flood events in downstream of Ciasem watershed are believed to occur due to degradation of watershed and mangrove cover. This paper studies the flood hazard and vulnerability caused by tidal and river flood, mainly on vegetation and built up areas as the main element of risk. The observation was focused at downstream of Ciasem watershed, located in MuaraVillage, Blanakan subdistrict, north coastal region of Subang District. Tidal flood hazard was mapped using iteration process in ILWIS 3.4 software while river flood hazard map was made up incorporating elevation, slope and river characteristics using hydrological tools (HEC-geo RAS and HEC-RAS) in ArcGIS 10 software. Those hazard maps were then utilized to determine element of risk covering vegetation and built up areas. Result showed that tidal inundation started to happen in the western area dominated by fish ponds as the main element of risk.When sea level rose up to 90 cm height, settlement areas were experiencing inundation by tidal flood. Ciasem River began to over flow when the river discharge exceeded 160 m^3 sec^{-1} and inundated the paddy fields, fish ponds and settlements. This study indicated that fish ponds and paddy fields having high vulnerability to the flood event while that of settlements and roads depend on the construction materials. Flood disaster risk should be reduced by continuing the land rehabilitation activity, restoring mangrove vegetation, implementing government regulations on management and establishment of aquaculture in mangrove, and carefully considering the construction of coastal protection barriers.

Keywords: Hazard map, river flood, tidal flood, vulnerability map, watershed

PEMETAAN KERAWANAN DAN KERENTANAN BANJIR MENGGUNAKAN SIG: STUDI KASUS BANJIR ROB DAN BANJIR SUNGAI DI HILIR DAS CIASEM, SUBANG-JAWA BARAT. Kejadian banjir di hilir DAS Ciasem diyakini terjadi akibat degradasi DAS dan tutupan mangrove. Tulisan ini mempelajari kerawanan dan kerentanan yang disebabkan banjir rob dan sungai, terutama pada daerah bervegetasi dan daerah terbangun sebagai elemen utama risiko. Pengamatan difokuskan pada hilir DAS Ciasem, terletak di Desa Muara, Kecamatan Blanakan, di pesisir utara Kabupaten Subang. Kerawanan banjir rob dipetakan menggunakan proses iterasi pada software ILWIS 3.4, sedangkan kerawanan banjir sungai dibuat dengan mempertimbangkan elevasi, kemiringan dan karakteristik sungai menggunakan perangkat hidrologi (HEC-geoRAS dan HEC-RAS) pada software ArcGIS 10 Peta kerawanan tersebut digunakan untuk menentukan elemen risiko yang mencakup daerah bervegetasi dan daerah terbangun. Hasilnya menunjukkan banjir rob mulai terjadi di daerah bagian barat yang didominasi tambak sebagai elemen risiko utama. Ketika permukaan air laut naik 90 cm, permukiman mengalami genangan akibat banjir rob. Sungai Ciasem mulai meluap ketika debit aliran melebihi 160 m^3 *detik*$^{-1}$ *dan menggenangi sawah, tambak, dan pemukiman. Penelitian ini menunjukkan bahwa tambak dan sawah memiliki tingkat kerentanan tinggi terhadap kejadian banjir, sedangkan pada permukiman dan jalan tergantung pada material konstruksinya. Resiko bencana banjir seharusnya dapat dikurangi dengan melanjutkan kegiatan rehabilitasi lahan, merestorasi mangrove dan menerapkan aturan pemerintah dalam pengelolaan dan pembangunan.*

Kata kunci: Peta kerentanan, banjir rob, sungai, DAS Ciasem, GIS

* Corresponding author: budihadin@yahoo.co.id

 doi: https://doi.org/10.20886/ijfr.2017.4.1.37-48

I. INTRODUCTION

Coastal management should be wisely done as a part of watershed management. Weak and ineffective control of human activities in watershed management areas such as forestry, agriculture, mining, industry, or other sectors will likely decrease the quality of the environment. Water pollution, erosion, sedimentation, land subsidence, seawater intrusion, shoreline change, silting-up of river estuary, and mangrove degradation are some indicators of environmental degradation found in downstream of watershed. Various materials are contained in the surface runoff flowing from upstream to the coastal area. Some of the materials may increase agricultural soil fertility in downstream area, but on the other hand sedimentation also speed up shallowing of river estuary that trigger flood events in coastal areas (SIPLA, 2012; Valiela et al., 2014).

Based on the typology, a coastal area has high flood hazard due to low land area that can be below mean sea level, and become an area of river estuary (Mardiatno et al., 2012). River flood (discharge overland flow) or known as delivered flood is caused by surface runoff as a part of the rainfall that flowing from the land to the river system and finally reach peak discharge that cannot be contained by the river channel. River flood in downstream watershed is relatively intense compared to the middle or upper watershed because the slope gradient is relatively low. Beside of river flood, coastal area with low slope gradient is also familiar with tidal flood that mainly happens during high seawater level when areas lower than mean sea level are flooded. The tidal floods are frequently caused by deforestation of mangrove forest and the impacts of flooding can be seen as settlement submergence, house damage, and landscape deformation (Munji et al., 2013). Higher hazard will be happening when river flood and tidal flood occur in the same time.

In the disaster risk management, the risk caused by flood can be reduced or minimized by mitigation actions started with analysis and mapping the vulnerability of the elements at risk. Flood vulnerability analysis using Geographical Information System (GIS) and remote sensing combined with field validation can be done rapidly, easily, and to improve the accuracy of the map. The vulnerability assessment can be assessed with geographical, physical, social, or economic aspects. A flood vulnerability map can be utilized by stakeholders as a consideration in decision making during, before, or after flood events.

This paper studies the level of vulnerability of flooding in coastal areas with major elements at risk being cultivation and built up areas. By knowing the level of flood vulnerability, the government and the community can better anticipate handling of the flood disaster and flood victims so that losses can be minimized. In this study, flood vulnerability assessment will be limited to the geographical aspects of the physical elements of cultivated and built up areas.

II. MATERIAL AND METHOD

Materials used in this study were digital topographical map 1:25000, Quickbird satellite imagery acquired from Google Earth with 2,4 m spatial resolution. The equipments used were soil core samplers, plastic bags, soil drill, GPS, voice recorder, stationery, computer software, and field equipment. The study was located at downstream of Ciasem watershed, and was administratively situated in Muara Village, Blanakan Sub-district, north coastal region of Subang District. The northern coast of Java commonly has inter-tidal swamp formation. This downstream watershed is draining water from two main rivers namely Ciasem River and Cijengkol River. Based on the geologic map of the Pamanukan Quadrangle, Jawa 1209-6 scale 1:100000, the area is composed of river deposits (Qa) consisting of silt, sand, clay, mud, gravel, and sediment of Gempol coastal swamp (Qac) which consists of fine sand, silt, shells of mollusks, and coral. Soil in the downstream area is dominated by alluvial types (Abidin & Sutrisno, 1992).

Tidal flood hazard was mapped using

iteration (looping) technique which was operated in ILWIS 3.4 software. The iteration is a mathematical calculation repeatedly using the previous result as an input for the next calculation until the required results are achieved. Inputs used in this operation were pixel values of digtal elevation map (DEM) showing the land elevation, and data of sea water level. DEM was built from elevation points derived from topographical map at the scale of 1:25000 and detailed elevation points from design map of Ciasem River flood control infrastructure at the scale of 1:2000 (Balai Besar Wilayah Sungai (BBWS) Citarum, 2007). By adding the 29 elevation points from field measurements to the data set those elevation points were interpolated using a moving average technique to produce a digital elevation model (DEM) map. The simulations started from the coastline map as the start folder of iteration. Based on data of the rise in sea level, tidal flood inundation was simulated starting with 10 cm rise in sea water level, then by 20 cm, and continued up to the level when the sea water rise was inundating all of the study area. The resulted raster maps were exported to vector format and overlayed with land cover map to determine the area of each type of inundated land cover.

Soil characteristic plays an important role in predicting the length of inundation or the permeability of the soil. This characteristic is related to the texture of the soil and will also affect soil saturation. Clayey soil absorbs water slower than sandy or loamy soil, therefore it has slower permeability and remain saturated much longer (Sutter, 2008). In this research, soil permeability was measured through laboratory analysis of undisturbed soil samples. A total of 24 soil samples were collected using soil core sampler up to 15 cm depth. The sampling points started from the coast line up to 4.7 km inland. Disturbed soil samples for soil texture analysis were also taken at the same points. Approximately, 1 kg of soil per sample point was placed into a plastic bag and labeled.

Flood hazard areas due to river overflowing were identified by hydrological modeling based on elevation, slope, and river characteristics using hydrological tools (HEC-geo RAS and HEC-RAS) in ArcGIS 10 software (license number 445095). Data and maps of river geometry such as main channel of the river, cross sections, river banks, downstream reach that had been prepared in ArcGIS were exported to be processed in HEC-RAS tool. Cross sections of Ciasem River channel were made at 6 points of river stations (RS). Sequentially point 6 is the first point at downstream. This model used river discharge at upper part as an input, and the output will give information of the flood water characteristics such as extent, height, and current speed.

Since inundation areas and flood height map from previous flood events were not available, the flood height model was quantitatively validated. The validation was done by showing map result to the local community and assessing whether the map extent were in agreement with flood situation as stated by the respondents (Webster & Forbes, 2006). Respondents involved in this validation process were 13 households including one village officer whose job was to take care of disaster victims. Flood event information from one person was always crosschecked against other respondents. Respondent's statement on flood height could be amplified by showing flood mark on the house wall.

Based on the flood-hazard map, delineation of the elements at risk will be performed in the form of vegetation and built up areas. Land use affected by the flood was delineated by overlaying the landuse map with flood hazard map. The boundaries of vegetation and built-up areas as element at risk were studied in this research and were determined through on-screen digitization of Quickbird satellite imagery. Each type of vegetation and built-up area was assessed through field survey. The results of this assessment will be mapped into a flood vulnerability map and analysed spatially to determine the area of each vulnerability level. Vulnerability level shows the loss or damage degree of certain element at risk from occurrence of the flood.

III. RESULT AND DISCUSSION

Flood assessment showed that in the Muara Village, there are two sub villages (kampung) that are often flooded by tidal flood or river flood namely Sindang Laut 1 and Sindang Laut 2, so the physical vulnerability assessment has focused on the elements at risk in both kampungs. The land use of those kampungs was dominated by fish ponds. Settlement areas were located around Ciasem river bank together with paddy field. Details of land cover in the study area are based on high resolution satellite imagery and the result of interpretation is presented in Figure 1.

Analysis of disturbed soil samples showed that the soil in this area has a heavy texture characterized by a high content of clay. Based on the composition of sand, silt, and clay the soil was classified within the class of clay to clayey loam. Only in one soil sample dominated the sand fraction.The easeness of the water to drain into the soil was predicted by permeability measurement of the soil samples. The result of soil permeability measurement ranges from 0.3 to 5.0 cm/hour. High permeability is usually found in soils with light texture or soil that has many pores for drainage. The permeability

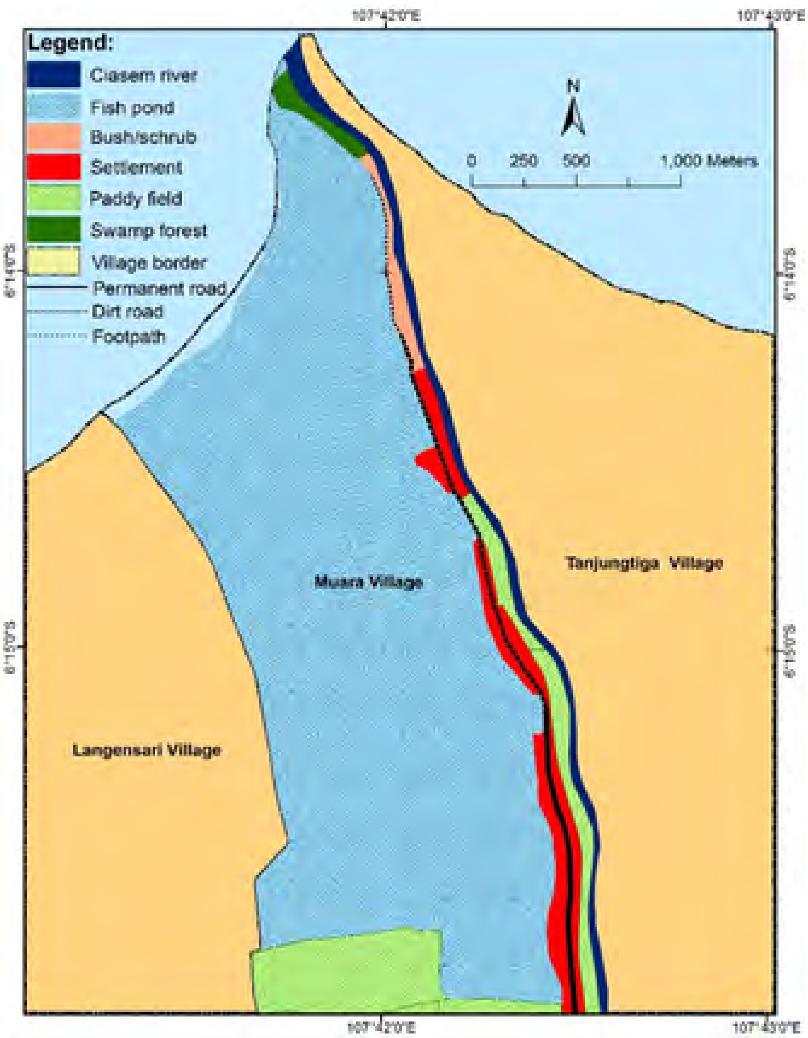

Figure 1. Landcover of Muara Village

values were interpolated to obtain a soil permeability map, and it was used to predict the duration of flood inundation.

A.Tidal Flood Hazard

Tidal flood occurred in the study area is affected by the rising of the sea water level due to daily tides, rising of sea wave height, or a combination of both. Data of the level obtained from Tanjung Priok tidal station belonging to the Geospatial Information Agency showed that the lowest sea water height was 13 cm and the highest was 112 cm. Wave height data of the West Java northern coastal area based on publication of the Meteorological, Climatological, and Geophysical Agency (BMKG) showed that wave heights were of 2 to 3 m with the maximum value reaching 6 m (Ristianto, 2011).

Simulation started with 10 cm rise in sea water level and this study showed that the 160 cm sea level rise would inundate the whole area of kampung Sindang Laut 1 and Sindang Laut 2. Some results of the inundation map generated in each scenario of sea level rise are presented in Figure 2.

Area inundated by tidal flood begun at the northern region and at the 70 cm sea level simulation, the inundation occurred in the western area. Settlements were inundated after sea level rising reached 90 cm. The area inundated by tidal flood for each land cover can be seen in Table 1.

Fish ponds were the largest area of elements at risk inundated by tidal flood. This inundation caused huge losses for the farmers due to damages to pond embankment and loss of cattles. Paddy fields were also an element that was widely affected by tidal flood. At the growing season period, sea water inundation will cause the paddy plants to die. Many farmers have converted their paddy fields into fish ponds due to tidal flood events are getting worse from year to year.

Tidal flood that occurred in the coastal area of Subang may be caused by the accumulation of several factors, such as rising of sea level, conversion of mangrove areas/coastal forests,

Table 1. Area inundated by tidal flood for each land cover

Sea water rising (cm)	Inundated area (ha)					Total
	Bush/schrub	Fish pond	Swamp forest	Settlement	Paddy field	
10	-	187.0	-	-	-	187.0
20	-	187.0	-	-	-	187.0
30	-	187.0	3.7	-	-	190.7
40	-	222.7	4.3	-	-	227.0
50	-	222.7	4.3	-	-	227.0
60	5.8	253.2	4.3	-	122.6	386.0
70	5.8	319.5	4.3	-	236.0	565.7
80	5.8	614.1	4.3	-	236.0	860.3
90	5.8	836.7	4.3	-	236.0	1082.9
100	5.8	1042.9	4.3	56.0	317.3	1426.6
110	5.8	1042.9	4.3	57.9	375.4	1486.5
120	5.8	1042.9	4.3	57.9	375.4	1486.5
130	5.8	1042.9	4.3	57.9	375.4	1486.5
140	5.8	1494.5	4.3	57.9	483.8	2046.4
150	11.7	1573.4	4.3	137.0	486.7	2213.3
160	11.7	1749.5	4.3	153.3	489.3	2408.4

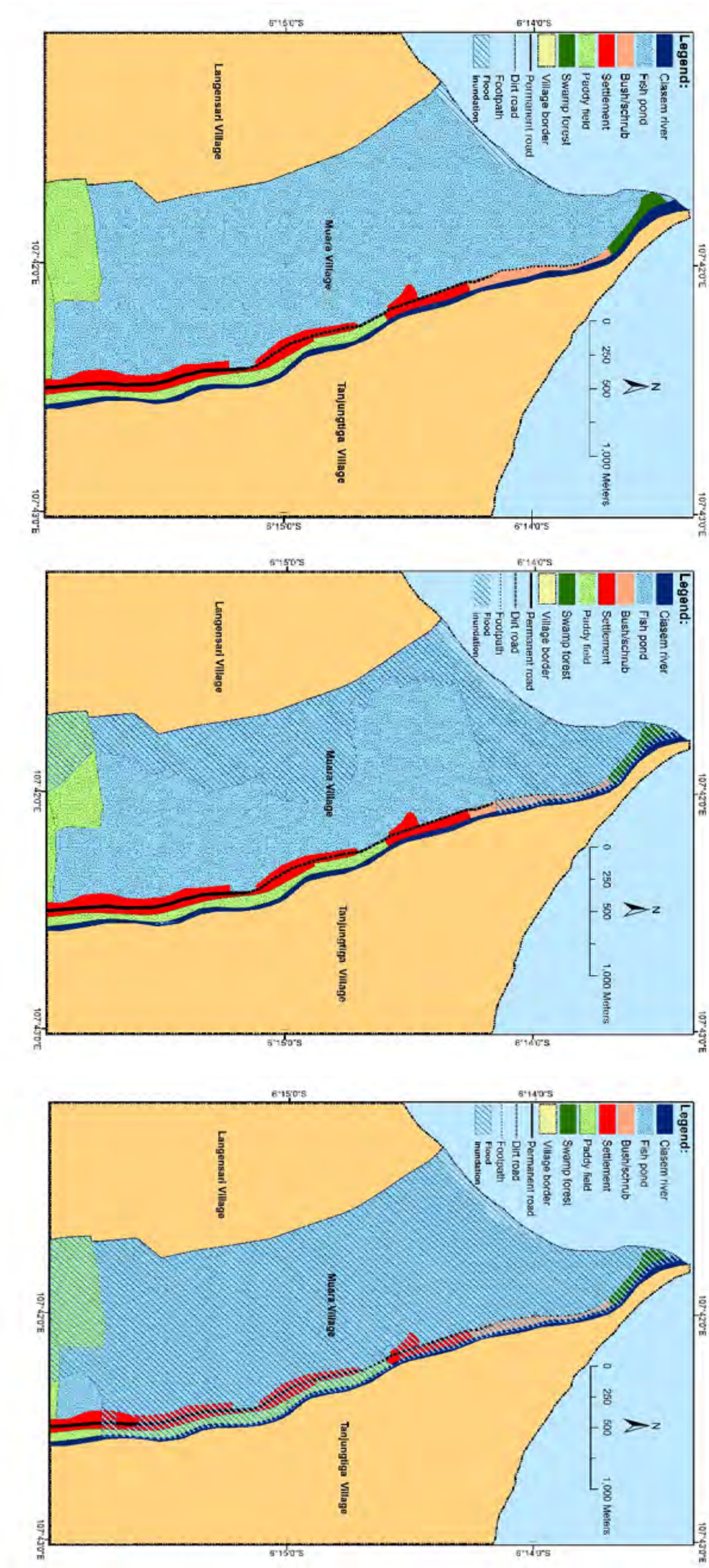

Figure 2. Some maps of tidal flood inundation for each sea-level rise

or any change in coastline due to abrasion or accretion. Sea level rising is the increase of the average sea water level from a reference point on the land as a result of increasing volume of sea water. Based on data of Topex/Poseidon, Jason 1, and Jason 2 satellites, sea level change in the period 1992 – 2012 reach up to 12.9 mm yr^{-1} with an average of 6.9 mm yr^{-1} (Hartanto et al., 2013). This increasing volume can be caused by thermal expansion of sea water due to rising temperatures and melting of glaciers and ice in polar areas (Nurmaulia, Prijatna, Darmawan, & Sarsito, 2005).

Reducing tidal flood risk can be reached by biotic method by making a green belt with mangrove plants and mangrove conversion attempt to suppress existing ones. The mangrove is proven as a biotic structure to reduce sea wave impact and coastline changes. The reduction is about two times larger than area without mangroves, and the function is also effective to protect the coastline from abrasion (Soraya, Suhara, & Taofiqurohman, 2012). By planting an 80 m wide zone of mangrove forest with 0.11 trees m^{-2} (about 1.100 trees ha^{-1}) is sufficient to reduce wave height by 80% and make the method as the most natural and cheapest way to protect coastal area (Hashim & Catherine, 2013). Beside protecting coastal area from high wave, the presence of mangrove forest also offer protection from typhoon and variety of ecological services such as absorption of pollutants and purification of water (Ibharim, Mustapha, Lihan, & Mazlan, 2015).

Abiotic method can be done with technical civil buildings such as the manufacture of the beach wall, groin (coastal protection structure built jutting relatively perpendicular to the direction of the coast), jetty (buildings placed perpendicular to the coast on either side of the mouth of the river which serves to reduce the flow of sediment silting on the beach), breakwaters or offshore breakwaters made parallel to the coast at some distances from the shoreline (Wilisandy & Saputro, 2006). However, the development and selection of the construction type should be considered carefully because the construction would often negatively affect other sides of the shoreline (Hildaliyani, 2011).

B. River Flood Hazard

Flood hazard mapping due to overflowing of river water was carried out by hydrological

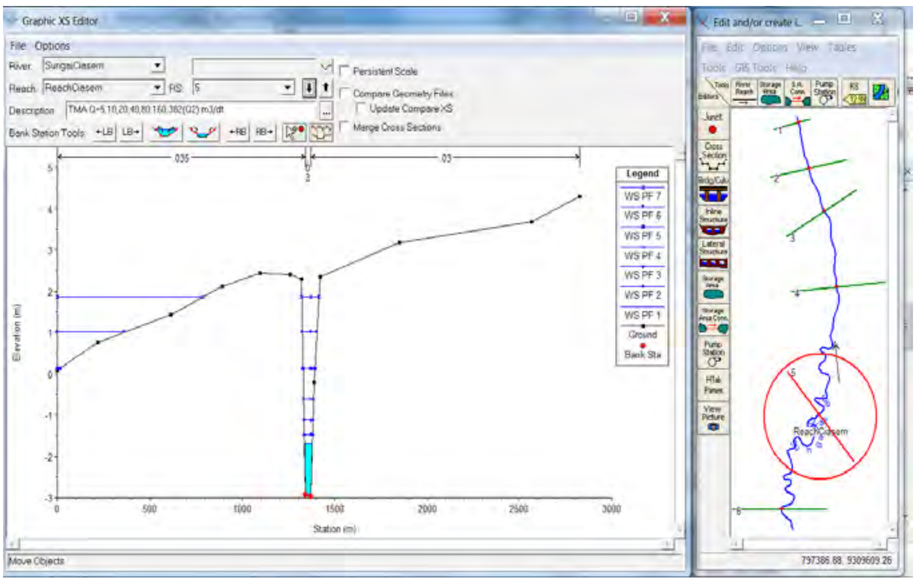

Figure 3. HecRAS output at RS 5 as a result of the first scenario

modeling. River discharge on the upstream side can be determined according to the data in the field or using plan flood discharge based on specific return period. In the first scenario, seven profiles (PF 1 - PF 7) have been tested using streamflow discharge inputs of 5, 10, 20, 40, 80, 160 and 382 m^3/s, respectively. The last profil value (382 m^3/s) was intentionally used and equals the discharge of 2 year's flood return period. HEC-RAS output showed that the river flood began to occur in the profile 6 (debit = 160 m^3/s), which occurs in the area around the river station (RS) 5 as shown in Figure 3. The affected elements at risk were paddy fields, fish ponds and settlements.

In the second scenario, six profiles (PF1 - PF6), the input used maximum flood-plan discharge in the periods of 2, 5, 10, 25, 50, and 100 year with consecutive annual discharge of 382, 464, 519, 589, 641 and 693 m^3/s (Balai Besar Wilayah Sungai (BBWS) Citarum, 2007). HEC-RAS output showed that the flood started to inundate the river banks in the RS 5 for all profiles (PF) as shown in Figure 4.

Information obtained from HEC-RAS subsequently exported to ArcGIS format to map the flood area and the inundation height as shown in Figure 5. The flood inundation map was overlayed with land cover maps, and the areas of each inundated land cover were tabulated as shown in Table 2.

The best way to mitigate river flood hazard is to avoid any permanent settlement in these locations and gradually relocate the inhabitants to safer place. If relocation leads to deadlock situation, different technical protection should be done to manage the threat to the settlements, such as development of a levee system that directs the water away from the most densely populated areas or dams further upstream to absorb peak flows (Appelquist & Balstrøm, 2014). For future planning, the Government should control flooding event by allocating a buffer zone along the coastline without human settlement. Mangrove forests should be protected to minimize sedimentation shallowing the head of the estuary as a cause of flooding (Ellegaard et al., 2014)

C. Validation

Qualitative validation revealed that most of the area inundated by tidal or river flood in the map was agreed by all respondents. They remembered that during the big flood

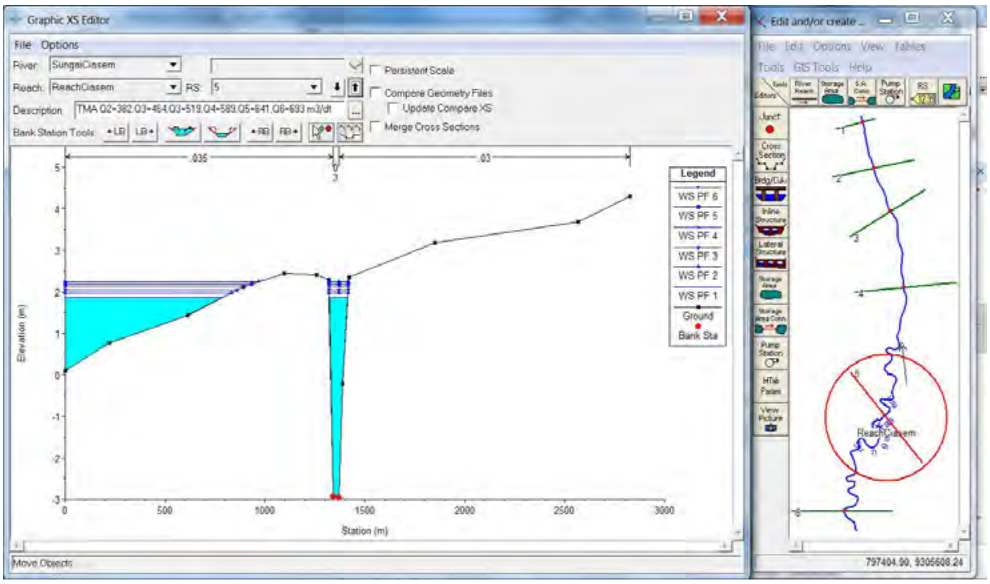

Figure 4. Inundation height on each cross section for the maximum flood-plan discharge in the periods of 2, 5, 10, 25, 50, and 100 year in river station (RS) 5

Table 2. Inundated area of each land cover type for every two years of river flood planning

Inundation height (cm)	Inundation area for each land cover (ha)					Total
	Bush/schrub	Fish pond	Swamp forest	Settlement	Paddy field	
< 40	11	815	4	45.6	369.9	1247
40 – 60	17	1039	4	45.6	369.9	1476
60 – 80	17	1262	4	45.6	369.9	1700
80 – 100	17	1622	4	97.4	390.4	2133
100 – 120	17	2359	4	155.4	443.7	2980
120 – 140	17	3255	4	246.5	564.4	4088
140 – 160	17	3324	4	292.1	730.9	4370
> 160	17	3394	4	337.7	745.9	4500

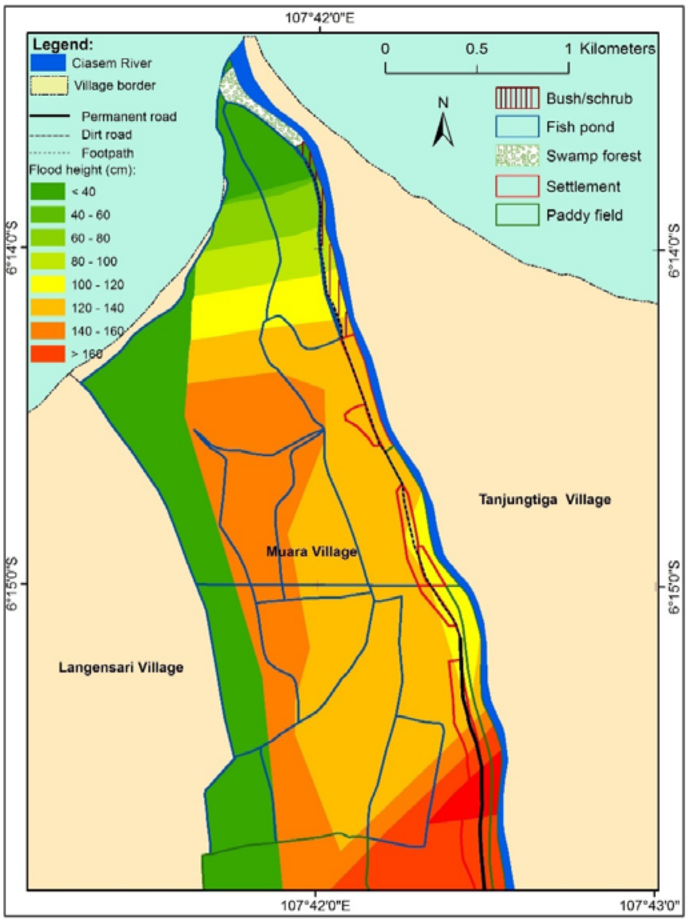

Figure 5. Inundation height caused by river flood

in December 2012, all areas were inundated in their kampung and was already noted in the map. Each respondent stated the height of the flood in their houses and on the land elevation. They also provided flood height information on the road or other public facilities, as well as duration of the inundation. During the severe flood, the inundation could stay upto two weeks, but some people experienced the inundation for only two hours.

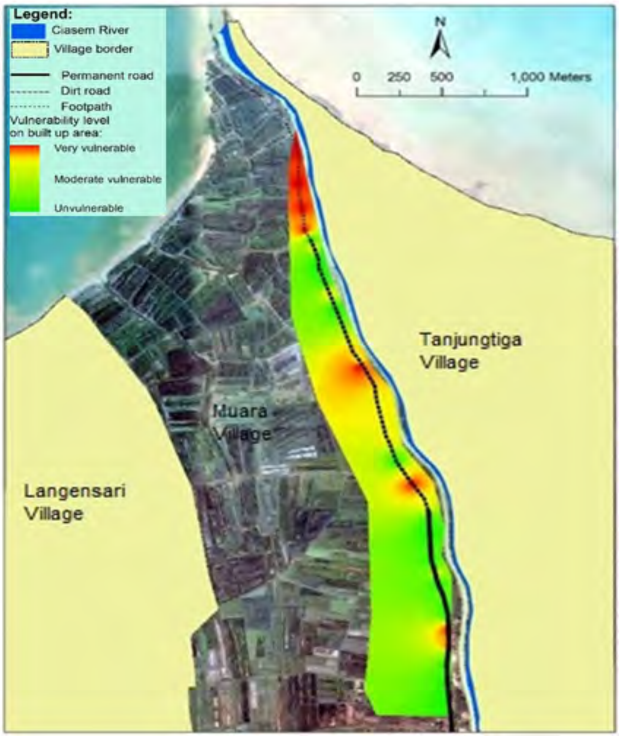

Figure 6. Level of vulnerability based on settlements and road conditions

D. Vulnerability of Elements at Risk

River and tidal inundation maps were overlayed with land cover map to get the area of each element at risk. The built up areas cover residential areas, roads, and fish ponds while vegetated areas were paddy field, bush/shrub, and coastal forests (mangroves). Field observations found that only the settlements and roads had different levels of vulnerability to the flood inundation, while the others were not different.

Based on field observation, the vulnerability level was divided into three classes those who were nonvulnerable, quite vulnerable, and very vulnerable. Non-vulnerable settlement was categorized as a house made of permanent brick wall or a building with two floors. Quite vulnerable buildings were semi-permanent buildings with brick walls at the bottom up to one meter height and the rest was made from woven bamboo. The very vulnerable houses were constructed using woven bamboo wall and using wood or bamboo as poles. When flood comes, this type of house will be heavily damaged and very humid. Road vulnerability was distinguished by its construction. Nonvulnerable roads were made of asphalt or concrete layers. Quite vulnerable road was dirt road with compacted stone layer, and the very vulnerable road was footpath constructed using only hardened soil. The physical condition of the element at risk in the form of settlements and roads mapped using GPS and scoored with a value of 1 up to 3, representing nonvulnerable up to very vulnerable level. The scoring results were interpolated to obtain a map of the vulnerability level as shown in Figure 6.

The vulnerability map illustrates that high vulnerable areas are located in the north and partially in the middle. The northern part area will be inundated firstly during tidal flood, and it was included in the inundated area in case of river flood. On that northern part, there is a settlement cluster with houses made of woven bamboo, and the road type is only footpath. Northern and middle areas should receive more attention during flood event, not only they are vulnerable from the physical aspect, but also their socioeconomic conditions need also to be attended to.

IV. CONCLUSION

Based on the physical conditions, Kampung Sindang Laut 1 and Sindang Laut 2 are prone areas to the flood hazard either caused by river or tidal floods. The condition is exacerbated by the decline in mangrove cover and high sedimentation in the estuary of the Ciasem River. Tidal inundation started in the north and followed in the western part with the fish ponds as the main element at risk. At 90 cm sea level height, the settlement started to inundate. Ciasem river flood started to occur when river water discharge reached 160 m^3/s with paddy fields, fish ponds and settlement as the main element at risk. Paddy fields and fish ponds have the largest area of flood risk. Based on the physical condition, those two elements have the same high vulnerability to flood while settlements and roads have different vulnerabilities depending on the construction materials. Settlements and roads in the north and center parts have higher flood vulnerability than the other parts.

Flood disaster risk should be reduced by continuing the land rehabilitation activity, restoring mangrove vegetation, implementing government regulations on management and establishment of aquaculture in mangrove, and carefully considering the establishment of coastal protection construction.

ACKNOWLEDGEMENT

The authors would like to acknowledge the contributions of all respondents involved in the study. We thank Hadi Suddiana, Iskandar, and Usman Sopian for field assistance, as well as Manjela Eko Hartoyo for GIS guidance.

REFERENCES

Abidin, H. Z., & Sutrisno. (1992). *Geologic map of the Pamanukan Quadrangle, Jawa 1209-6*. Bandung: Geological Research and Developments Centre.

Appelquist, L. R., & Balstrøm, T. (2014). Application of the Coastal Hazard Wheel methodology for coastal multi-hazard assessment and management in the state of Djibouti. *Climate Risk Management*, *3*, 79–95. doi:10.1016/j.crm.2014.06.002

Balai Besar Wilayah Sungai (BBWS) Citarum. (2007). *Detail design of Ciasem River flood control infrastructure in Subang District (in Bahasa Indonesia)*. Report. Bandung: BBWS Citarum

Ellegaard, M., Nguyen, N. T. G., Andersen, T. J., Michelsen, A., Nguyen, N. L., Doan, N. H., … Lund-Hansen, L. C. (2014). Temporal changes in physical , chemical and biological sediment parameters in a tropical estuary after mangrove deforestation. *Estuarine, Coastal and Shelf Science*, *142*, 32–40. doi:10.1016/j.ecss.2014.03.007

Hartanto, P., Nurmaulia, S. L., Prijatna, K., Geodesi, T., Ilmu, F., Fitb, K., … Itb, F. (2013). Steric and eustatik effect contributions to sea level change based on altimetry satellite argo and grace satellite data within 1992-2012 period (The Study Area : The Western Pacific Ocean). *Indonesian Journal of Geospatial* , *1*(2), 1–16.

Hashim, A. M., & Catherine, S. M. P. (2013). A laboratory study on wave reduction by mangrove forests. *APCBEE Procedia*, *5*, 27–32. doi:10.1016/j.apcbee.2013.05.006

Hildaliyani, U. (2011). *Analysis of tidal flood inundation area on the north coast of Jakarta using SPOT and ALOS imagery data(in Bahasa Indonesia)*. Bogor: Departmen of Geophysic and Meteorology, FMIPA-IPB.

Ibharim, N. A., Mustapha, M. A., Lihan, T., & Mazlan, A. G. (2015). Mapping mangrove changes in the Matang mangrove forest using multi temporal satellite imageries. *Ocean and Coastal Management*, *114*, 64–76. doi:10.1016/j.ocecoaman.2015.06.005

Mardiatno, D., Marfai, M.A., Rahmawati, K., Tanjung, R., Sianturi, R.S., & Mutiarni, Y. S. (2012). *Flood and tidal flood multirisk assessment in Pekalongan Utara Sub District (in Bahasa Indonesia)*. Yogyakarta: Faculty of Geography

UGM.

Munji, C. A., Bele, M. Y., Nkwatoh, A. F., Idinoba, M. E., Somorin, O. A., & Sonwa, D. J. (2013). Vulnerability to coastal flooding and response strategies: The case of settlements in Cameroon mangrove forests. *Environmental Development*, *5*(1), 54–72. doi:10.1016/j.envdev.2012.10.002

Nurmaulia, S. L., Prijatna, K., Darmawan, D., & Sarsito, D. A. (2005). *Preliminary study of sea level changein the sea of Indonesia based on Topex satellite altimetry 1992-2002* (in Bahasa Indonesia). Bandung: Scientific group of Geodesy, Faculty of Civil and Environmental Engineering, ITB.

Ristianto. (2011). *Coastal vulnerability to the sea level rise* (Master Thesis) (in Bahasa Indonesia). Universitas Indonesia, Jakarta.

SIPLA. (2012). Watersheed (in Bahasa Indonesia). Retrieved, from www.sipla.pksplipb.or.id on 3 September, 2012

Soraya, D., Suhara, O., & Taofiqurohman, A. (2012). Shoreline changes due to mangrove forest damage in the Blanakan and Legonkulon sub district, Subang (in Bahasa Indonesia). *Jurnal Perikanan dan Kelautan*, *3*(4), 355–364.

Sutter, F. C. (2008). *San clemente dam seismic safety project: environmental impact statement*. USA: United States Army Corps of Engineers.

Valiela, I., Bartholomew, M., Giblin, A., Tucker, J., Harris, C., Martinetto, P., … Stone, T. (2014). Watershed deforestation and down-estuary transformations alter sources, transport, and export of suspended particles in Panamanian mangrove estuaries. *Ecosystems*, *17*(1), 96–111. doi:10.1007/s10021-013-9709-5

Webster, T.L., & Forbes, D. L. (2006). Airbornne laser altimetry for predictive modeling of coastal storm-surge flooding. In L.L. Richardson & E.F. LeDrew (Eds.), *Remote sensing of aquatic coastal ecosystem processes* (pp. 157–182). Springer Netherlands.

Wilisandy, G., & Saputro, H. (2006). *Study of coastal erosion mitigation planning in Slamaran, Pekalongan City* (in Bahasa Indonesia). Semarang: Department of Civil Engineering, Faculty of Engineering, Universitas Diponegoro.