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Geographic Information System for Mapping Coastal Inundation Impact to the Sustainability of Agriculture Sector in Pekalongan City, Indonesia

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ABSTRACT

Coastal inundation that is getting farther inland year by year has given a serious problem to the sustainability of farming activities in Pekalongan, but it has rarely been exposed more detail to the public. The aim of this research is to investigate the present effects of seawater inundation to the agriculture sector in Pekalongan coastal area. We focused on the study of coastal inundation dynamics, agriculture area reduction and rice production. Time series remote sensing imageries from google earth satellite were used to analyze the seawater run up between 2003 and 2018. This result revealed that the farthest distance of the inundation in 2018 reached 4.4 kilometers from the coastline in the west part of the city. For the last fifteen years, saline water has reduced almost 380 ha of farm land in the coastal area. That phenomenon has contributed to the rice production lost by almost 173 tons/year during 2003 and 2018. This result has showed a critical condition of agriculture sector in study area, thus some mitigation actions become a necessity thing in order to protect our land as well as food security on the next future.

Keywords: agriculture, coastal area, inundation, seawater.

INTRODUCTION

Agriculture area conversion phenomenon in Indonesia has progressively become a matter of concern over the time and it is expected to be a major threat for the sustainability of food production in the future (Franjaya et al., 2017; Utami and Ahamed, 2018). In this respect, government has decided to address the issue with the enactment of Presidential Regulation Number 59 Year 2019, which consists an instruction of land conversion control by provisioning detailed spatial data related to paddy field area in Indonesia. Converted agriculture land into housing sites has become the most highlighted problem in recent time and it has triggered the government to establish a legal protection to preserve the potential agriculture area. However, land conversion is not only associated with human interference, it is also reported to be the result of natural processes such as seawater flooding.

Agricultural activities in coastal areas are one of the most vulnerable element to be affected by coastal inundation (Addo et al., 2011). Excess amounts of salt content from seawater will adversely influence on extreme salinity that can negatively affect the plant growth and crop yields (Bai et al., 2012; Wang et al., 2018; Thiam et al., 2019). Crop failure is the greatest threat to farmers as it will cost them huge financial loss (Durant et al., 2018). Furthermore, the soils remediation due to salt contamination is too difficult to be obtain so that it will lead to land infertility, decreasing food productivity and even becoming abandoned agriculture area. As the impact, vast areas of cultivable land in the coastal areas has been turned into fish pond/aquaculture or residential areas. All those situations will endanger the agricultural land existence as a food production that supplies the basic human livelihood.

Pekalongan City located on the north coast of Central Java is known to be the most vulnerable to

coastal inundation (Andreas et al., 2017; Ward et al., 2011). Having a gentle morphological beach with the average rate of rising sea levels at 1.2 m, it potentially exposed into wetland flooding and coastal erosion (Wahyudi et al., 2012). The seawater inundation has reported reaching the settlements, industrial site, various infrastructure and agriculture area. In addition, this impact is predicted to be worst due to global warming that leads sea level rise. A preliminary research relating the urban responses and adaptation strategies for managing sea level rise has been conducted by Harini et al (2017). A modelling framework for inundation risk assessment and damage estimation due to sea level rise has been published by Ni'mah et al (2013). In spite of that, a detailed study concerning the impact of sea level rise on the agricultural sector at Pekalongan city due to inundation of agricultural land at Pekalongan coast, has not yet been done. The purpose of this research are 1) to investigate coastal inundation dynamics in Pekalongan City for the last 15 years using high-resolution satellite imagery interpretation, 2) to calculate the agricultural area reduction due to seawater flooding, and 3) to analyze the potential impact to the food productivity loss. These valuable results are considered to determine preferred mitigation action to preserve the sustainability of agricultural sector as well as global food demands.

METHODOLOGY

Area of coastal inundation was identified using satellite imagery displayed by Google Earth. The usage of Google Earth's satellite imagery has some advantages due to its free access, available in high resolution image up to 2 meters in square, provided in time series, and represented in true color imagery. We identified the inundated area through several elements of image interpretation such as tone/color, size, shape, texture, pattern, and site/association. Recorded inundation areas in the true color imagery tend to have darker color as a result, encompass a large area from the coast, smooth texture, unlikely to show a partition pattern which resembles a paddy field, and lastly associated with the surrounding of the fish pond/aquaculture. In order to discover the dynamic movements of the inundation from time to time, the image interpretation shall be done in time series at a year range 2003-2018. Based on the given periodical time, there were 6 google earth image available specifically at 2003, 2006, 2009, 2012, 2016, and 2018.

Overlaying the inundated areas image from each year and agricultural land use which has been visually interpreted prior has to be done afterwards. Identification on the farming areas mainly used several elements of interpretation which is color dominance in green (planting period) and brown (harvest dates), have a large and wide area, a structural partition pattern and generally associated with irrigation system. Following the growing availability of Geographic Information System with Arc-GIS software, a scheme to map the inundation and its impact including agricultural land use assessment was proposed on this current project. A statistical calculation has to be performed for the purpose in acknowledging the impact of the coastal inundation to the loss of agriculture.

RESULT AND DISCUSSION

Coastal inundation dynamics

Result of the multi temporal interpretation image indicated an increasing trend regarding the furthest distance of the inundated spread to the coastal land in the last 15 years. The dynamics interaction of coastal inundated were evidently visible both in the east coast and west coast of Pekalongan City (Fig. 1), which at some period in 2006 and 2016 the water slightly flowed away back to the shore. From 2003 to 2018, the west side of the Pekalongan city has been experimenting a wider inundated expansion spread than the east side of the city. Affected inundated area at the west side has reached up to 1.8 km from the shore in 2003 and went upward to 4.4 km in 2018, which implied a rise of the spreading area for about 2.6 km to the land. A relatively similar condition has occurred on the east side of the city as a sea-levels rise to 400 m to the land in the last 15 years, where the furthest affected area in 2003 were only take as far as 2.1 km and rise up to 2.4 km in 2018 (Fig. 2).

Agriculture area reduction due to inundation

According to the image interpretation result, the agricultural land in Pekalongan City were changed every year into build up area, fish pond/

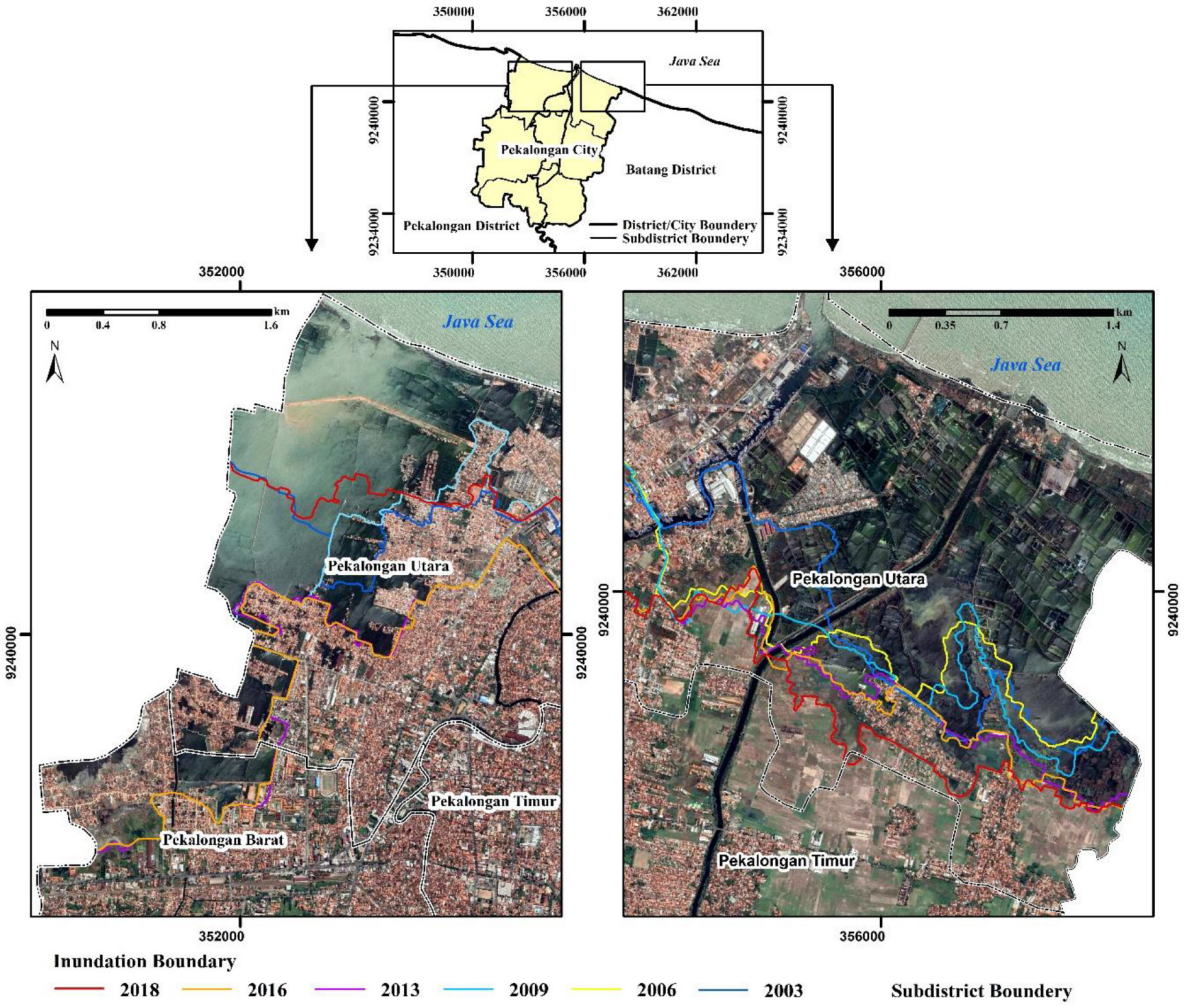

Figure 1. Inundation area identification base on satellite imagery in Pekalongan City since 2003 until 2018

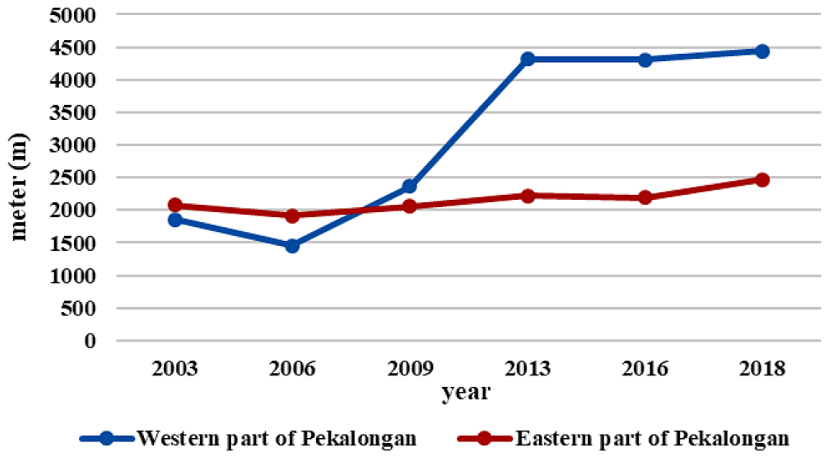

Figure 2. The increasing trend of the farthest distance from sea water run up at Eastern and Western part of Pekalongan City

aquaculture, bare land and inundation zone due to coastal flooding (Table 1). For over 15 years, the first and second factors reducing farm land in the study area were due to coastal inundation and build up area development. They have cut the land up to 381 ha and 301.2 ha respectively. Before 2006 coastal inundation became the second most generating factors of the agriculture land reduction after land conversion into built up area. While during the year between 2006 and 2013, it

Table 1. Total agriculture area reduction due to each factor in during 2003-2018 in Pekalongan City

Landuse change	2003-2006	2006-2009	2009-2013	2013-2016	2016-2018	Total
Agriculture to Inundated area (ha)	48.00	87.7	130.9	9.3	105.1	381.0
Agriculture to Fish pounds (ha)	0.00	9.4	10.5	0.0	0.0	19.9
Agriculture to Build-up area (ha)	77.4	38.9	71.3	9.4	104.4	301.2
Agriculture to Bare land (ha)	3.2	0.0	4.2	0.8	6.21	14.4
Total agriculture area reduction (ha)	128.5	136.0	216.8	19.5	215.7	

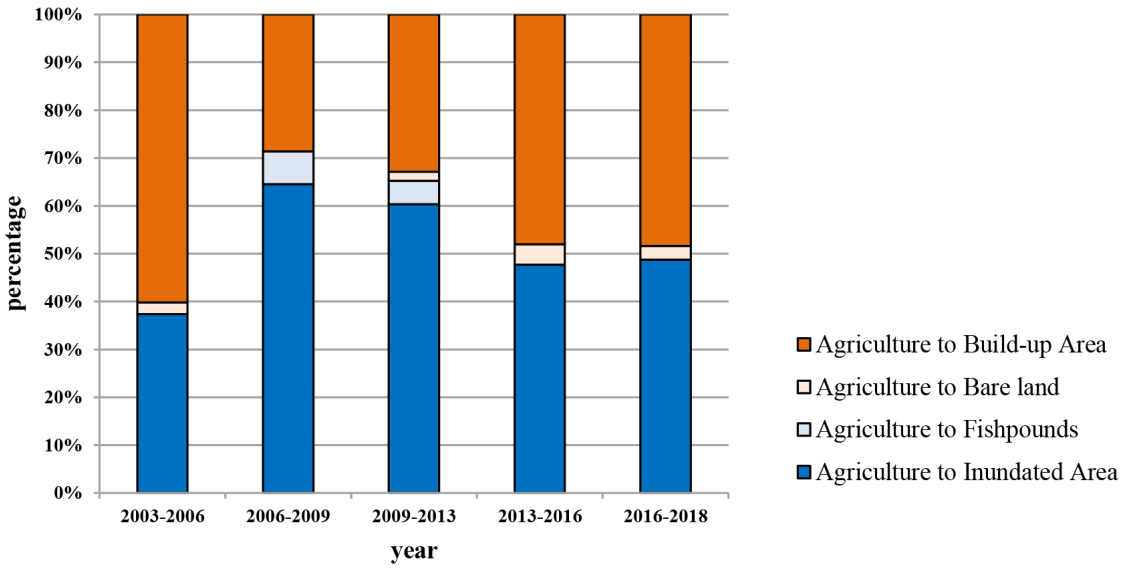

Figure 3. The role of some factors that change agricultural area in Pekalongan City

took place as the first factor reducing agriculture land. Five years afterward, both coastal inundation and built up area have quite same impact on reducing the agricultural land in Pekalongan coastal area (Fig. 3).

The average rate of coastal inundation on its impact to agriculture land reduction in Pekalongan takes about 25.4 ha/year. If there is no action to decrease that threat, the agriculture land might vanish in the next 36 years, even it can be faster due to the settlement expansion as well. These numbers have support Marfai and King 2008 that agricultural area is becoming one of the most vulnerable aspect suffering seawater flooding in Indonesia that must be concern to avoid the immense damage in the future.

The Spatial analysis of agriculture area reduction in Pekalongan City was mapped and represented into Figure 4. The biggest agricultural land reduction occurred in the district of Pekalongan Utara, since the region are mostly made up of coastal zones. While the district of Pekalongan Barat is the second most affected area with the loss of 85.9 ha as the consequence of a massive water movement in the west side since 2013. In the meantime, an 0.6 ha paddy field areas in the district of Pekalongan Timur which were located at approximately 2 km from the shoreline has starting to expose coastal inundation in 2018. Even though the spread was not as rapid as the west side, it still worrisome to farmers considering that Pekalongan Timur district is the central of agriculture area in the city together with Pekalongan Selatan districts.

Food production impact

The fact that agriculture land use has been reduced annually, obviously holds a direct impact on dwindling farmland which affects the rice production. If we use the average rate of national rice production that is 6.8 tons/ha, accordingly the average loss of annual rice production due to coastal inundation in the last 15 years is about 173 tons/year. The decreasing productivity rate will endanger food adequacy in the near future.

The unavailability of sufficient protection against flooding such as embankment has been resulting fluctuate agricultural land inundation. The degradation of fertile soils due to the inundation

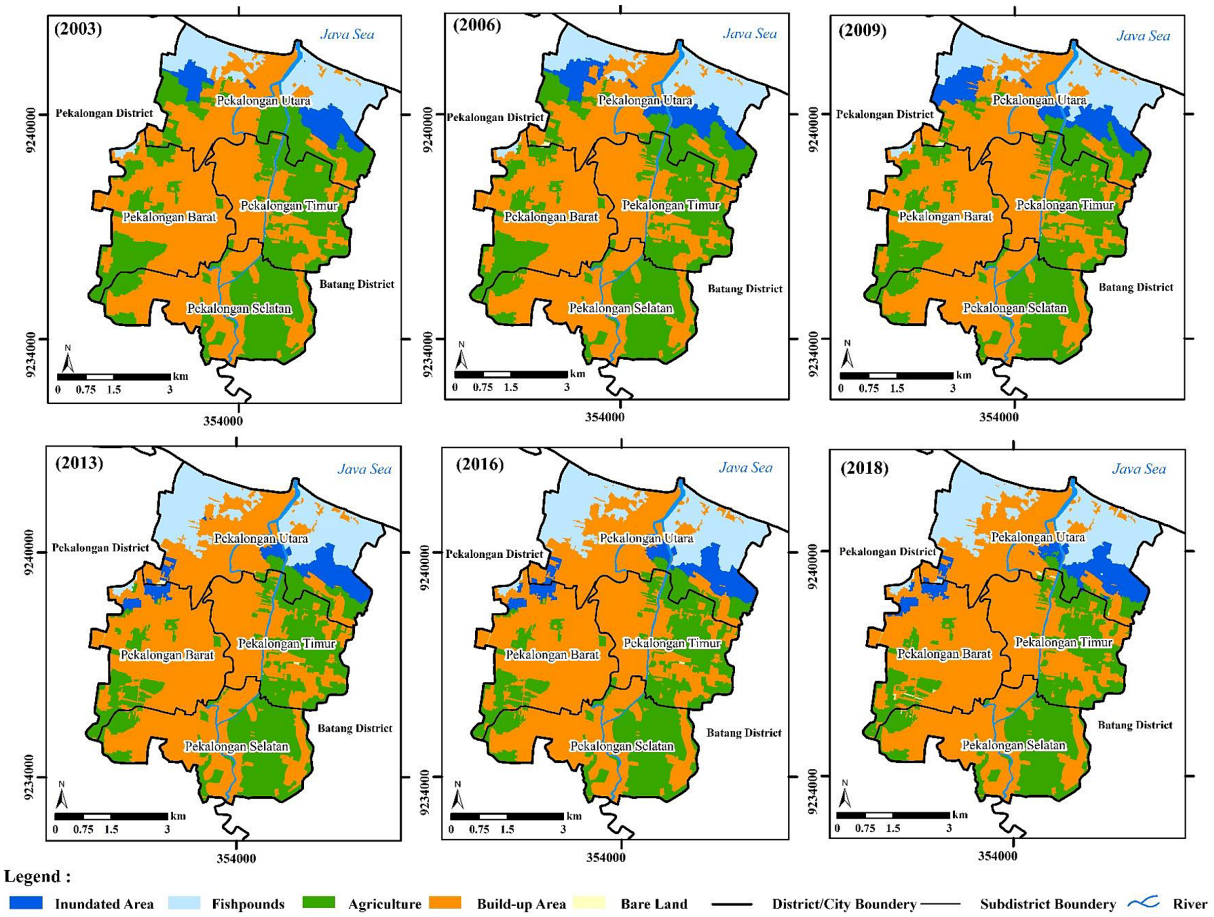

Figure 4. Time-series of Land use mapping since 2003 to 2018 in Pekalongan City

has swelled the maintenance land costs. Farmers who are not facing financial difficulties will undergo desalination through irrigating the land from the river with a water pump. Unfortunately, small farmers cannot afford to undertake the recovery and had to let their land became swamp since there is no economical methods in desalination. Local people usually would have transformed some area with higher rate of salinity into fish pond/aquaculture to continue living up the economic cycle.

Proposed mitigation action

In order to minimalize the damage impacted by coastal inundation phenomenon, it is necessary to step on an actual act both in technical and non-technical ways to sustain the continuity of agriculture sector. To establish an embankment system is an alternative option to prevent the water spread in land (Marfai and King, 2008). The dyke should be built along the shoreline as potentially exposed land to the coastal inundation has been widely spread both in the west side and east side of the city. in other side, non-technical prevention is also needed such as the technology to repair the soil quality from saline water contamination like ever proposed by Jianfeng et al. 2004 or enhance in plants quality to improve the production quantities, despite the number of agriculture land will keep on dropping in every coming year.

CONCLUSIONS

Coastal inundation plays a big role on agriculture area reduction at Pekalongan City since 15 years ago. From the satellite imagery interpretation, the western area of Pekalongan City was experience a massive inundation of coastal flooding and reduce all the agriculture area in the west part of Pekalongan Utara district. The sea water run up in the eastern area tend to move slower but it is also predicted to threaten the central of agricultural sector in the Pekalongan Timur districs. Some mitigation action in the form of structural or non-structural action must be implemented to secure the sustainability of food production in

the future year. This research only focused on the land availability in analyzing the sustainability of agricultural sector, so that future researches are needed to analyze the agriculture sustainability based on other perspective such as from social-culture, economics and regulation condition.

REFERENCES

1. Addo, K.A., Larbi, L., Amisigo, B., Ofori-Danson, P.K. 2011. Impacts of Coastal Inundation Due to Climate Change in a CLUSTER of Urban Coastal Communities in Ghana, West Africa. Remote Sens. 2011, 3, 2029-2050.
2. Andreas, H., Abidin, U.H.Z., Sarsito, D.A. 2017. Tidal inundation ("Rob") investigation using time series of high resolution satellite image data and from institu measurements along northern coast of Java (Pantura). IOP Conf. Series: Earth and Environmental Science 71 (2017) 012005.
3. Durant, D., Kernéïs, E., Meynard, J. M., Choisis, J.P., Chataigner, C., Hillaireau, J.M., Rossignol, C. 2018. Impact of storm Xynthia in 2010 on coastal agricultural areas: the Saint Laurent de la Prée research farm's experience. Journal of Coastal Conservation doi.org/10.1007/s11852-018-0627-8.
4. Franjaya E.E, Syartinilia, Y. Setiawan 2017. Monitoring of landscape change in paddy fields: Case study of Karawang District – West Java Province. IOP Conf. Ser.: Earth Environ. Sci. 54 012016.
5. Harini R., Susilo B., Sarastika T., Supriyati, Satriagasa M.C., Ariani, R.D. 2017. The survival strategy of households affected by tidal floods: The cases of two villages in the Pekalongan Coastal Area. Forum Geografi, 31(1)
6. Jianfeng, Z., Shangjun, X., Jiyue, L., Makeschin, F., Yumin, S. 2004. Agroforestry and its application in amelioration of saline soils in Eastern China Coastal Region. Forestry Studies in China, 6(2).
7. Junhong Bai, J., J. Wang, D. Yan, H. Gao, R. Xiao, H. Shao, Q. Ding 2012. Spatial and temporal distributions of soil organic carbon and total nitrogen in two marsh wetlands with different flooding frequencies of the Yellow River Delta, China. Clean – Soil, Air, Water, 0(0), 1–8.
8. Marfai. M.A., King, K., Singh, L.P., Mardiatno, D., Sartohadi, J., Hadmoko, D.S., Dewi, A. 2008. Natural hazards in Central Java Province, Indonesia: An overview. Environ Geol (2008) 56:335–351.
9. Marfai, M, A., and King, L. 2008. Coastal flood management in Semarang, Indonesia. Environ Geol (2008) 55:1507–1518.
10. Marfai, M.A., and King, L. (2008). Potential vulnerability implications of coastal inundation due to sea level rise for the coastal zone of Semarang city, Indonesia. Environ Geol (2008) 54:1235–1245
11. Novi Maulida Ni'mah, N.M., Fathurrohmah, S., Septriayadi, R. 2013. Risk management of tidal flood inundation in Pekalongan City. Conference paper ICRD 2013.
12. Thiam, S., G.B. Villamorc, N. Kyei-Baffoure, F. Mattyf 2019. Soil salinity assessment and coping strategies in the coastal agricultural landscape in Djilor district, Senegal. Land Use Policy 88, 104191.
13. Utami N.P., T. Ahamed 2018. Spatial analysis to determine paddy field changes in Indonesia: A case study in Suburban Areas of Jakarta. IOP Conf. Ser.: Earth Environ. Sci. 149 012004.
14. Wahyudi, S.I., Ni'am, M.F and Bras, G.L. 2012. Problems, Causes and Handling Analysis of Tidal Flood, Erosion and Sedimentation in Northern Coast of Central Java: Review and Recommendation. International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol:12 No:4
15. Wang, W., Sardans, J., Wang, C., Zeng, C., Tong, C., Bartrons, M., Asensio, D., Peñuelas, J. 2018. Shifts in plant and soil C, N and P accumulation and C:N:P stoichiometry associated with flooding intensity in subtropical estuarine wetlands in China, Estuarine, Coastal and Shelf Science doi: https://doi.org/10.1016/j.ecss.2018.09.026.
16. Ward, P.J., Marfai, M.A., Yulianto, F., Hizbaron, D.R., Aerts, J.C.J.H. 2011. Coastal inundation and damage exposure estimation: A case study for Jakarta. Nat Hazards 56:899–916.