OPTIMIZATION OF SPATIAL PLANNING OF TIDAL SWAMP AREA TO SUPPORT THE COMMUNITY EVELOPMENT OF BUOL REGENCY, INDONESIA

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ABSTRACT

The Government of Buol Regency intends to develop a lowland area of 4688 ha in the Biau, Bukat, Bukal and Momuno sub districts for agricultural, animal husbandry, fisheries and tourism purposes, in order to improve the community's economy. The area is close to the coast line and on the banks of the Buol river, which is affected by tidal movements and flows of several natural rivers. At present only around + 35% of the area is exploited for various purposes including rice fields 1.78%, coconut plantation 14.78%, sago/nipa 13.72%, fish pond 8.64%. Whereas the other areas are left as swamps and bushes. The land properties survey states that the majority of land in the S2 class order (Moderately Suitable) to S3 / N1 (Marginal Suitable / Currently Not Suitable), is quite appropriate and marginal to be developed as agricultural land, especially with restrictions on drainage problems. In a small spot, a small amount of sulfaquents is found. This type of soil has a high pyrite content which when oxidized will be harmful to plants. Most (93%) is the tropaguept soil type which is immature land, the water content is high and the drainage is very inhibited. The total P value and its high cation exchange capacity indicate that the land is potentially fertile. Considering the soil pH between 5.1-6.5 and 6.6-7.3, it can be concluded that the influence of pyrite is not visible, but the effect of saline water intrusion is quite significant, the existence of Nipaplants in several places can be notified.

Hydro-topography condition, the ratio of land elevation to tidal water level, states that almost all land is not flooded by tide, the upstream land elevation ranges between +2.8m ~ +3.0m, the land elevation in the downstream ranges between +1.1m ~ +1.5 m and tidal elevations fluctuate between -0.80m ~ +1.10m. Inundation that occurs is more due to poor natural drainage and flood water from surrounding river. Water governance is planned for the purposes of agriculture, fisheries and tourism taking into account the physical conditions of land and water, as well as external influences, such as tides, saline water intrusion and flooding. Considering hydro-topographic conditions, the irrigation water sources are rainwater, upstream river water and limited tidal overflows. The design of the drainage system is planned to remove excess rainwater and flooding from the surface and avoid the disposal of groundwater needed to maintain soil moisture for plants and avoid saline water intrusion. Flood risk management is one of the considerations in utilizing the floodplain. Cropping patterns are adjusted to the occurrence of floods, to minimize risk of flood. The results of land use planning propose the use of 3026 ha of rice fields, 693 ha of coconut plantations, 238 ha of perennials, 164 ha of sago, 435 ha of fishponds and 207 ha of conservation areas.

Keywords: Lowlands, réclamation, drainage, tidal

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1. INTRODUCTION

The regional government of Buol District wishes to develop a floodplain area in Sub districts of Biau, MomunuBokal and Boka District, for agricultural, settlement and tourist purposes. For these purposes, considering the existing potentials and constraints, spatial planning is needed Some of the area is currently not well maintained due to inundation originating from flood runoff from the Buol river and inadequate drainage systems. The Buol River is the largest river in the region. The Buol watershed is the main catchment in the district, comprising 1662 km2 or almost a third of the district area (Figure 1, after Lusiana, 2015). Floods began to occur frequently after the conversion of many forests into plantations. Until 1994 more than 85% of land cover in the Buol watershed was still dominated by forests. However, in 20 years (1994-2014), the forest area decreased by about 22% to 66.7%. The type of land cover in the Buol watershed that experienced significant changes in addition to forests is oil palm plantations which began to appear around 2000. For approximately 20 years, the area of oil palm plantations has dominated around 18% of the Buol watershed area (Tanika, 2017). Buol is a district located in the northern part of Central Sulawesi, roughly 806 km or 18-hour drive from Palu, the province's capital city. Buol's total area is around 3,562 km2, bordering Toli-Toli district to the west and Gorontalo province to the east.

Figure 1. Location of Buol District and Buol Watershed (source: Lusiana,2015)

2. LOWLAND DEVELOPMENT

Inundated Lowland is formed naturally due to continuous rainwater inundation, river water flooding and the absence of natural drainage. Swamp is divided into two types, namely: tidal swamp located near the coast, at the estuary or near the river mouth, its drainage is influenced by the tides of sea water and non-tidal swamps or inland swamps which are located further away from the coast so that they are not affected by the ebb and flow of the sea water. Agricultural development in the lowlands area began a century ago by traditional Bugis and Banjar farmers. Reclamation is carried out by draining inundation water and ameliorates soil maturity. Under natural conditions, without artificial drainage or irrigation, cropping patterns on the flood plains are determined by the depth and duration of seasonal flooding and the length of the rainy season.

The lowland reclamation works were designed in order to protect the areas against inundation during high tides; prevent salinity intrusion, creating an effective drainage system for the area and to remove the heavy run-off from the hinterland watersheds. Some potential and constraints regarding the quality of land, water sources inundation, saline water intrusion, must be considered in the development of lowland areas for agricultural purposes (Suryadi,1996). Soil is basically clay, will be productive after reclamation; Part of tidal lowlands are covered by (potential) soil sulfuric acid and / or peat soil. Land development of acid sulphate soil takes time before a stable situation is reached (Wignyosukarto, 2013); The amount and distribution of rainfall in the rainy season is sufficient for one rainfed crop: Low tidal plains near river mouths, salinity can cause problems for agriculture and drinking water, especially during the dry season; Water management infrastructure must be adapted to these conditions; especially related to soil conditions, hydro-topographical conditions and land suitability conditions.

Hydro-topography can be defined as the field elevation in relation to river or canal water levels at the nearest open water or intake/outlet point. Hydro-topography is a useful indicator for the water management potential of fields (drain ability and irrigability). Drain ability is defined as the water level (surface and/or groundwater) under drainage conditions. The drain ability classification could be use to identify the possible agricultural development of the area (rice crop, dryland crops and tree crops).Land suitability considers several factors that play an important role in choosing type of crop, i.e. tidal irrigation depth, drain ability, salinity intrusion, acidity hazard and peat depth. The acidity hazard, peat depth and salinity intrusion in swampy areas are an important factors for determining the suitability of these areas for agricultural development. The acidity hazard is defined as the depth of pyritic layer from the surface which is relatively stable instead of the pH. Salinity intrusion is defined by the duration of intrusion (month/year) (Boissevain, 1995):

Table. 1. Land Suitability Zoning (Boissevain, 1995)

Criterion	Category	Wetland Rice				Other Crops			
		Tidal Irrigation		Rainfed		Dryland Crops		Tree Crops	
		Present	Potensial	Present	Potensial	Present	Potensial	Present	Potensial
Tidal Irrigation depth	1: > 0.25 m	S2	S1	NA	NA	NS	NS	NS	NS
	2:0.0 - 0.25 m	S1	S1	NA	NA	S3	S2	NS	NS
	3: < 0.0 m	S3	S2	S2	S1	S1	S1	S1	S1
Drain-abilty	1: < 0.0 m	S3	S2	NS	S3	NS	NS	NS	NS
	2: 0.0 - 0.2 m	S2	S1	S3	S2	NS	S3	NS	NS
	3: 0.2 - 0.4 m	S1	S1	S2	S1	S3	S2	Ns	S3
	4: 0.4 - 0.6 m	S2	S1	S3	S2	S2	S1	S3	S2
	5: > 0.60 m	S3	S2	NS	S3	S3	S2	S2	S1
Acidity hazard	1: < 0.25m	S3	S2	NS	S3	S3	S1	S3	S1
	2:0.25-0.50 m	S2	S1	S3	S2	S2	S1	S2	S1
	3:0.50-0.75 m	S1	S1	S2	S1	S1	S1	S1	S1
	4: > 0.75 m	S1	S1	S1	S1	S1	S1	S1	S1
Peat depth	1: < 0.25m	S1	S1	S1	S1	S1	S1	S1	S1
	2:0.25-0.50 m	S2	S1	S2	S1	S2	S1	S1	S1
	3:0.50-0.75 m	S3	S2	S3	S2	S2	S1	S2	S1
	4: > 0.75 m	NS	NS	NS	NS	S3	S2	S2	S1
Salinity intrusion	1:< 2months	S1	S1	S1	S1	S1	S1	S1	S1
	2:2-3 months	S2	S2	S1	S1	S1	S1	S1	S1
	3:3-4 months	S3	S3	S1	S1	S1	S1	S1	S1
	4:4-5 months	NS	NS	S1	S1	S1	S1	S1	S1

(SI = suitable; S2 = nearly suitable; S3 = marginally suitable; NA = not applicable; NS = not suitable)

3. FLOODPLAIN MANAGEMENT.

The project area is located in the floodplain of Buol River. Almost of the lower parts of Buol River are meandering. A meander is a winding curve or bend in a river. Meanders are the result of both erosional and depositional processes. They are typical of the middle and lower course of a river. A river floodplain forms where a watercourse, meandering over a relatively flat area, floods naturally at times of high water level. The river sediment deposited on the flooded area creates a mosaic of wash lands, dry lands and wetlands. The floodplain of a meandering river commonly occupies areas of land on alternate sides of the watercourse. Where this is the case, each part of the river floodplain is a discrete area of land, defined by the river on one side and the rising slope of the river valley sides behind the area subject to flooding on the other.

Sayers et.al (2013) explain the progress of flood plain management. The earliest civilizations recognized the need to live alongside floods, providing flood warnings to those that may be flooded (common practice in ancient Egypt and making flood sensitive land-use planning choices. The requirement for protection and a belief in our ability to control floods started to increasingly dominate attempts to 'deal with flooding'. Throughout the early and mid-decades of the twentieth century, engineers sought to control flood flows and defend areas from flooding. Typically, this was via the construction of extensive levees systems and ring dykes, diversion channels, dams and related structures. The perceived safety of the defended floodplains attracted development (for example, in New Orleans, London and Shanghai). Ecosystem became increasingly starved of the sediments and space upon which they rely (for example, in the Mississippi, Yangtze, Thames, Rhine and Danube), which in turn has affected the ecosystems services they provide. Despite the structural protection and the high price in the loss of ecosystem functions, flood losses continued to increase and the need for change became increasingly apparent. In response, through the latter part of the twentieth century, flood management was recognized not only as an engineering pursuit but also as a social endeavor.

A new approach was needed, one that could not only identify the hazards and the consequences faced by society, but also assess the relative significance of the risks faced and the concepts of Flood Risk Management (based upon a longer term, system-wide perspective) started to emerge. In more recent years, the concepts of risk management have continued to evolve, in particular adopting an adaptive approach to managing flood risks, which works with natural processes, contributes positively to ecosystem services and forms part of an integrated basin or coastal management, is now emerging (WMO 2009, Sayers et al. 2013).

To be effective, flood-management strategies must be implemented across a range of sectorial interests (flood risk, water resources development, energy and so on). This requires national, regional and local governments to ensure multiple policies, regulations and programs that they promote are appropriately integrated, and that work done at one level of government, or in one sector, is in harmony with associated activities in other levels of government and sectors. As such 'sound' flood management planning requires a paradigm of governance that is collaborative and blurs the distinction between the disciplines of spatial, coastal zone, river basin and water resources planning as well as flood defense engineering and environmental management. This is not easy and achieving meaningful horizontal integration is a significant challenge; requiring flood managers who are used to working within 'regulatory instruments along vertical paths of the administrative hierarchy' to 'cultivate more intensive forms of horizontal integration' (Moss 2004).

4. METHODS

Considering the physical and environmental conditions of the lowland area, the development of these areas will include the work of creating a drainage system to reduce the water level on land, reclaiming or improving soil quality, capturing fresh water from water sources (rain, rivers) for water supply, flood control, preservation of fish and other animal life, conservation of hydrological capacity of lowland areas to support a unified system of water resources. With various objectives and constraints, it is necessary to consider the multi-objectives optimization efforts in choosing a pattern of development, sustainability and stability of development are the most important variables to be considered. Determination of the area of development must consider the possible rate of reclamation process, the level of availability of water resources, land suitability, ecosystem suitability. The most important thing to note is the ability of human resources (farmers) who will employ the reclaimed lowland. The system applied must be in accordance with the level of ability of farmers with a minimum level of risk For this reason, farmers must understand the system developed, believe that the system will be useful and feel that they are part of the system developed. From the experience, to achieve it, takes time to educate, the time needed for the gradual development process.

Drainage network is intended to provide rainwater drainage facilities so that humans or other objects are safe from the danger of flooding during a rainy day. The drainage system must aim to replicate the natural characteristics of rainfall runoff. Environmental impacts of humans must be minimized. Drainage systems are planned to collect rainwater runoff from roads, housing, agricultural land, etc., then carry them through channels, store them temporarily in retention basin, and dispose of at the right time in rivers or other bodies of water without causing adverse effects on the surrounding area. The design of the drainage system must be able to minimize water pollution and maximize environmental benefits. Flood protection must still be done even with a minimum level of service. Some parts of the system can be used for multipurpose, for example flood inundation areas, when dry can also be used for other purposes, provided that it does not change its function as a flood suppression area

The planned drainage system should aim to provide the most cost-effective solutions, especially in terms of maintenance costs. This requires consideration of the overall operational costs of all alternatives. The most appropriate system evaluation must include hydraulic benefits, water quality and the environment.

Topographic surveys are conducted to find out the situation map, land contour and cross section of the existing channel or river, as depicted in Figure 2. The hydrometric survey and river morphology conducted included tidal prediction based on measured tidal previous year. (Figure 3). The results of the survey are use to determine the hydro topographic condition of the area. Hydro topography condition states that almost all land is not overflowed by tide (except during high river discharge), the land elevation in the downstream ranges between +1.1m ~ +1.5 m and tidal elevations fluctuate between -0.80m ~ +1.10m. Consider the upstream land elevation ranges between +2.8m ~ +3.0m, suppose the slope of energy of the flow is about 0.0001, the effect of back water up to the upstream is about 1.5 m above the high tide, means the water level in upstream is about +2.60 m.

The soil survey states that the majority of land in the S2 class order (Moderately Suitable) to S3 / N1 (Marginal Suitable / Currently Not Suitable), is quite appropriate and marginal to be developed as agricultural land, especially with restrictions on drainage problems. In a small spot, a small amount of sulfaquents is found. This type of soil has a high pyrite content which when oxidized will be harmful to plants. Most (93%) is the Tropaguept soil type which is immature land, the water content is high and the drainage is very inhibited. The fertility rate is moderate regarding the total P level and a high value of Cation Exchange Capacity. Considering the soil pH between 5.1-6.5 and 6.6-7.3, it can be said that the influence of pyrite is not visible, but the effect of saltwater intrusion is quite significant, it can be seen the existence of Nipa plants in several places. The land unit as a result of soil survey is depicted in Figure 4.

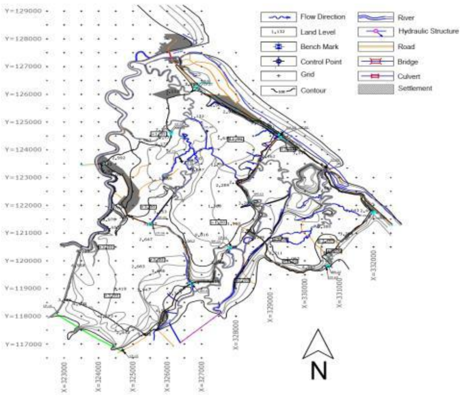

Figure 2. Topographic map of project area. (source: PTWecon Eng.)

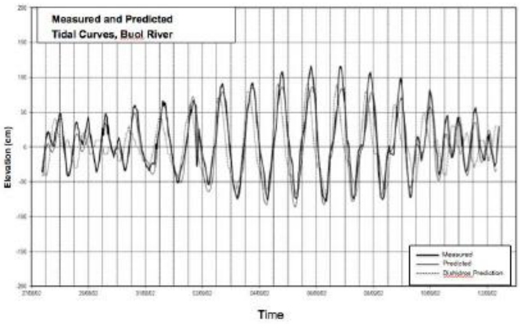

Figure 3. Tidal Curve Buol River (source: PTWecon Eng.)

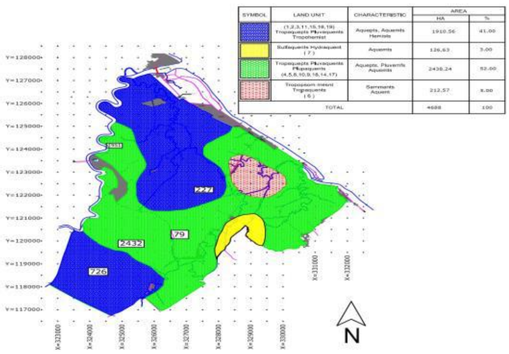

Figure 4. Land Unit (source: PTWecon Eng.)

5. RESULTS AND DISCUSSION

The use of lowland and floodplain is based on sustainable regional development. Potential and constraints considered are, hydro-topographic conditions, soil quality, saline water intrusion, flood and rainfall intensity. As with the development of lowland, water management is more focused on drainage efforts, efforts to dispose of excess water in order to ensure the use of land for farming and settlement. The planned drainage system is a controlled drainage system, so that there is no adverse drainage due to the occurrence of soil subsidence and drying of water sources. A sustainable drainage system that is able to regulate the volume and flow rate of runoff, thus reducing the destructive power of water and the risk of flooding (Graham, 2012). The sustainable drainage system boosts the water infiltration to help preserve water resources, saline water intrusion and river flow in the dry season. In addition, it can reduce water quality and increase evapotranspiration and climate regulation in urban areas. The possible land subsidence has to be estimated because this will affect the design and operation of the water management systems.

Land subsidence is the movement of the ground surface downward. It is not constant in time and not uniform in space. (De Glopper and Ritzema, 1994). Land subsidence can be one of the major factors influencing the potential for agricultural development of an area. Drainage has a direct effect on the rate of subsidence. Subsidence also alters the soil conditions and will affect the future elevation of the project area. Consequently, it will affect the water management systems of the area. Based on the result of surveys, laboratory analysis, several maps were created which are useful for planning purposes, among others are hydro-topographical conditions; land suitability (agriculture) which is based on soil and climatological conditions; water management systems which are based on hydro-topography, drainability, soil type, land suitability and salinity or acidity control; potential yield of the area, based on water management systems and other control parameters. Regarding the land suitability zoning, the future land use is proposed as depicted in Figure 5. This proposed land use is part of the effort on optimizing the spatial planning of this floodplain.

The development of the floodplain is not just a desire to use the floodplain because of it soil fertility, and the need of permanent settlement, but more than a desire to reduce flood damages, it promote opportunities and manage risks adaptively. There is recognition that engineering alone has limitation, effort is also devoted to increasing the resilience of communities and to mitigate lost of ecosystem services. Allowing part of the area, to be inundated at a certain time and certain depth during a flood, is a wise mitigation effort as adaptive floodplain management. Working with natural processes is encouraged to both reduce risks efficiently and achieve gain in ecosystem services.

Considering the future land use and the risk of flood management, the layout of water management system is proposed, as depicted in Figure 6. This water management system consists of network of canal, hydraulic structures, and retarding basin (in the lower part of the area). The proposed layout of canal is adapting to the actual natural drainage canal, especially the location of outlet in the Buol River, and the meandering river at the outlet. The slope of energy is the important variable in designing the canal capacity. The canal has double functions, as drainage canal during flood and irrigation canal in the rest of time.

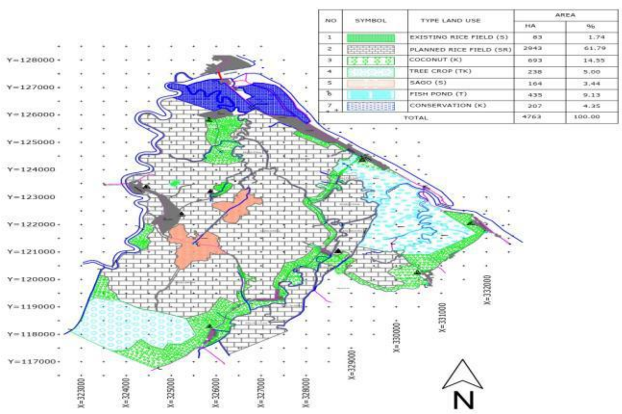

Figure 5. Proposed Land Use (source: PTWecon Eng.)

As a drainage canal, the capacity of the canal determined by the hydraulic modulus, which is calculated as follow:

The drainage modulus for an unit area, n consecutive days:

$$D(n) = R(n)T + n\ (IR - ET - P) - S$$

where :

n = Consecutive days; D(n)= Drainage modulus for n days (mm); R(n)T = Rainfall intensity for n consecutives days with T years return period (mm); IR= Irrigation, (mm/day); ET= Evapotranspiration, (mm/day); P = Percolation, (mm/day); S = Allowable inundation depth, (mm).

As irrigation canal, the desain capacity is depend on the water requirement of the crops, and the maximum water requirement for paddy is about 1 litre/sec/ha. The irrigation design discharge is less than the drainage design discharge. The drainage modulus are 5,67 litre/sec/ha, 4.53 litre/sec/ha, 4.28 litre/sec/ha, for 1 days, 2 days and 3 days of drainage time consecutively. In order to maximize the capacity of drainage considering the small energy lope, the wider canal is preferred than deeper canal.

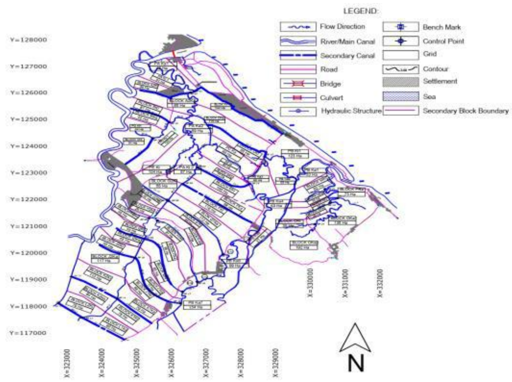

Figure 6. Proposed Layout of Canal Network. (source: PTWecon Eng.)

6. CONCLUSIONS

Lowland development faces more complex problems than developing upland areas. Many variables interact each other in the lowland area. Floods, soil properties, subsidence, saline water intrusion, tide will affect the way land and water management planning in the lowland area.

Land suitability mapping is an indispensable step for planning land use. Land suitability is determined by the potential and constraints that exist on the land, for example hydro-topographic conditions, soil types, saltwater intrusion, flooding. Reducing vulnerability and increasing resilience with engineering efforts can improve land suitability. This will be determined by the economic valuation of the lowland development.

In the case of Buol lowland development, where the influence of the Buol river flood is significant, efforts to evaluate the risk of flood are very necessary. As Sayers (2014) said, risks do not remain constant in time and all of their dimensions are subject to change – either through exogenous pressures (for example, climate change or socio-economic development largely beyond the influence of the flood manager) or in response to purposeful intervention (insurance regimes or indeed levees). Some changes act to increase risk (for example, development in the floodplain, loss of a communities flood memory, etc.). One of 10 golden rules proposed by Sayers (2014) is promote some flooding as desirable. Floodplains provide a fertile area for agriculture and a variety of ecosystem goods and services to society, including natural flood storage. Making room for the river and the sea, utilizing the natural ability of this space to accommodate floodwaters and dissipate energy, maintains vital ecosystems and reduces the chance of flooding elsewhere.

Regardless the risk of flood, the lowland area of 4763 ha is planned spatially to accommodate existing rice field 83 ha, new rice field 2943 ha, coconut plantation 693 ha, tree crops 238 ha, sago 164 ha, fish pond 435 ha and conservation area 207 ha.
Changes in forest land cover of 2.2% per year will affect the increase in the Buol River flood discharge. This flood threat needs to be considered in preparing the flood management strategy in Buol Floodplain. The development of sustainable lowland Buol can follow one of the 10 golden rule of Sayers (2014), which is to provide flood path in the floodplain, by allowing part of the development area to be flooded during a flood. This can also be overcome by adjusting the cropping pattern so that there are no plants during the flood (June-July and November-December).

7. REFERENCES

Anonim, 2018, Planning for reclamation of water-friendly swamps, Buol District, Interim Report, PT Wecon Engineering, Bandung Indonesia.

Boissevain,W.,1995, WaterManagement zoning ntidallowlands.,Paper presented in the Tecnical Meeting on Water Management Zoning and Application of GIS related to tidal swamp development. Ministry of Public Works, Jakarta, Indonesia.

Graham, A.,Day J., Bray B., Mackenzie S., 2012. *Sustainable Drainage Systems*. London: Wildfowl & Wetlands Trust

Moss, T.,20,04. The governance of land use river basins: Prospects for overcoming problems of institutional interplay with the EU Water Framework Directive. Proceedings of the Journal of Land Use Policy, 21 (1), 85–94. http://dx. doi.org/10.1016/j.landusepol.2003.10.001.

Lusiana B, Tanika L, Amaruzaman S, Leimona B. 2015. Potential and challenges in developing payment for ecosystem services scheme in Buol District, Indonesia. Working Paper 211. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. DOI: http://dx.doi.org/10.5716/WP15722. PDF

Sayers, P.,Galloway, G., Rowsell,, E.P., Li Yuanyuan, Shen Fuxin, Chen Yiwei, Wen Kang, Tom Le Quesne, Lei Wang &Yuhui Guan ,2014, Strategic flood management: ten 'golden rules' to guide a sound approach, International Journal of River Basin Management, DOI: 10.1080/15715124.2014.902378. http://dx.doi.org/10.1080/15715124.2014.902378

Sayers, P., et al., 2013. Flood risk management: a strategic approach [online]. Asian Development Bank, Manila; China General Institute of Water Resources and Hydropower Planning and Design, Ministry of Water Resources, Beijing; UNESCO, Paris; WWF International, Gland Switzerland. Available from: http://www.adb.org/sites/default/files/pub/ 2013/flood-risk-management.pdf

Suryadi, FX., 1996, Soil and water management strategies for tidal lowlands in Indonesia, PhD Disertation, Delft University of Technology, A. A. Balkema Publishers, Old Post Road, Brookfield, VT 05036-9704, USA (Fax: 802.276.3837)

Tanika L, Lusiana B. 2017. Dampak Perubahan Tutupan Lahan terhadapKondisiHidrologi di Das Buol, KabupatenBuol, Sulawesi Tengah: Simulasi dengan Model Genriver. Working Paper 261. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. DOI: http://dx.doi.org/10.5716/WP17146.PDF

Wignyosukarto,B.S.,2013, Leaching and flushing of acidity in the reclamation of acid sulphate soil, Kalimantan, Indonesia, Journal of Irrigation and Drainage, Volume 62, October 2013, Wiley online library, https://doi.org/10.1002/ird.1777.