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NATURAL WET PONDS AS FRESH WATER STORAGE IN TROPICAL ENVIRONMENT

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B. Synonyms (*if applicable*)

Wet Pond; Groves Pond; Blue Water Pond; Rainwater Pond; Space Pond;

C. Definitions

***Natural Pond** is an area that is inundated without human intervention and modification. It can be formed due to wetland topography and geomorphology. Natural pond sources water from rainfall, river flow, tidal flow, groundwater, or combination of it. Natural pond water may remain available either along the year or only during certain events, depends on the pond hydrological processes. Natural pond water is distributed across wetland, dissimilar to lake water that is accumulated from its watershed. **Hydrological processes** are natural phenomena that relate to water cycle and its interaction with land and the lowest layer of the atmosphere. **Tropical wetland** is a landscape located around the earth's equator (Latitude 23.437° N to 23.437° S), which is most of the time inundated or saturated by water. Wetland water quality and quantity determine unique ecosystem that dwells in it. **Water storage** in environmental perspective is the amount of water stored in a landscape, which is necessary to sustain the environment.*

Introduction

A civilization cannot be sustained without water. These anonymous wise words are rooted within societies. According to The Oxford history book (Shaw 2003), The Egyptian civilization dwelt in Nile river basin. The Mesopotamian and The Indus civilizations started nearby water sources too (Morozova 2005; Dixit et al. 2018). Those civilizations left artefacts and structures that were used by ancient people to get and allocate water, such as qanats and aqueducts. These facts reflect the high value of water in human civilizations since old times.

The water issues relevance is imperative regarding to the question whether there will be enough water for 8.5 billion people, the predicted population in 2030 (UN 2019a). The discussion becomes more complex if food security issue is considered. In the other hand, the environmental water needs for sustainable life on land and life below water must be allocated too. These two perspectives define the future clean water demand. The issue of water availability in the tropical area demands further concerns from stakeholders, because of the climate uncertainty existence. The Intergovernmental Panel on Climate Change, in its 5th Assessment Report (IPCC 2014), stated that global climate condition will very likely follow "wet-get-wetter, dry-get-drier" pattern, especially in many regions in tropics. This prediction forces people to think about a better natural way in storing water that may be used to fulfil the future essential water demand.

The longstanding method of storing water in large reservoirs became contentious in recent decades. A large reservoir leads to three distinct risks: i) major scale artificial ecosystem alteration, ii) underestimation of sedimentation, and iii) socio-cultural. In some cases, large dams cut natural animal and microorganism migration pathways along the river and across the reservoir itself (Nyqvist et al. 2017). Thousands of people migrated because their land was inundated, as a consequence of the building of dams (Fu et al. 2010). Although the supply of water from a large reservoir is essential to provide for the high demand of water for domestic and industrial use, it might not be the most sustainable source of clean water in the future, as mentioned by Di Baldassarre et al. (2018) and Eekhout et al. (2020). The land use modification in the watershed may reduce the service age of a reservoir (Schleiss et al. 2016). Scientists started to look for a natural water storage system, as an alternative to the construction of a large dam. One of the proposed solutions is natural wet ponds. In nature, rainwater may stay in ponds for a certain period, before it flows to a river or drainage channel (Putra and Ridwan 2015). River water may also create natural wet ponds on a floodplain, likewise tidal water on a marsh plain (Lanés et al. 2015; Couto et al. 2018). These ponds provide more spatially distributed water storage compared to a large reservoir.

In relation to the importance of water in society, water sustainability concerns will be addressed. The prime concerns will be discussed under The United Nations Sustainable Development Goals (UN SDG) framework. The UN SDGs consist of 17 articles that were to be achieved by the year of 2030 (Colglazier 2015). Water is strongly related to at least 5 of the 17 goals which are Zero Hunger, Clean Water and Sanitation, Climate Action, Life Below Water, and Life on Land. Detail indicators about the important of water for the SDGs are listed in a resolution document adopted by the UN General Assembly on 6 July 2017 (UN 2017). The serviceability of the natural water stores that exist within ponds and their associated ecosystem are described. Some current field-based examples of natural wet pond ecosystem services are presented. The strengths and limitations of natural wet pond conservation clauses are assessed, including the concern about potential human-induced disturbances. The idea of natural wet pond services is proposed as a sustainable natural water storage system. Insights on how society can value natural wet ponds so that it may be beneficial to the Clean Water and Sanitation Goal achievement are promoted.

Natural Pond in Tropical Peatland, **Fig. 1.** The natural pond that is inundated during the 2019 wet season in Sebangau National Park, Indonesia.

Natural pond hydrological processes

The natural pond water dynamics are strongly affected by hydrological cycle that occurred in the pond environment. One of the main hydrological cycle components is rainfall. When rainfall occurred, some percentages of the rain can be intercepted among plant leaves and branches. A portion of intercepted rain can be directly evaporated to the air before it reaches ground. Other portions of rainfall can reach ground, whether as a direct drop from the sky or as a remaining intercepted rainfall that is not evaporated. On the ground, rainwater is either infiltrated or transported to the lower topography by means of overland flow. Some percentages of overland flow merge in a natural depression or in a small basin, instead of directly flow to river or drainage channel. This accumulated water creates a natural wet pond. By the time, water leaves the pond either through evaporation, deep infiltration, or outlet overflow. It continues the rest of hydrological cycle processes.

Rainfall is one of the natural pond water sources. In non-arid tropical area, the average annual rainfall rate generally ranged between 1200 mm/ year and 2400 mm/ year (Feng et al. 2013). The annual average rainfall in tropical archipelago areas were higher, which were about 2700 mm/ year in Java and 2800 mm/ year in Fiji (Kumar et al. 2006; Aldrian and Djamil 2008; Adji and Bahtiar 2016; Putra et al. 2019). However, seasonal rainfall accumulation rates may vary, which cause pond water level dynamics. In perennial pond, where pond water is always ponding across seasons, seasonal rainfall strongly affects pond surface water level. In contrast, an intermittent pond can be empty when rainfall water supply is limited.

Open water pond uptake is mainly through evaporation. In wet tropical salt flats in Northern Australia, evaporation rates were about 5 mm/ day (Hollins and Ridd 1997). The measured annual evaporations were around 1300 mm to 1400 mm per year in adjacent locations (McJannet et al. 2012)**.** These data show that around 50% of rainwater was evaporated in an open water pond system. It also indicates that open surface water pond is not an efficient system to store water. The condition is different in natural wet pond, in which the pond system is integrated within wetland. The natural wet pond water is surrounded by plants and trees canopy. The vegetations reduce pond surface temperature and minimize potential evaporation. The wetland vegetation canopy existence may lessen surface water potential evaporation rates by 10 % to 30 % (Mohamed et al. 2012). In contrast, plants absorb water for transpirations that reduce natural wet pond water storage.

Vegetated natural wet pond may retain water for a longer time compared to open water pond. Plant roots create obstacle for water and reduce water surface runoff velocity. The surface roughness coefficient (Manning's coefficient) of natural pond wetland is between 0.03 and 0.1, depends on the pond on surface vegetation (Karim et al. 2016; Rodríguez et al. 2017). This value is between 1.5 and 5 times higher than the roughness coefficient of bare soil surface. It means that flow velocity on natural wetland pond can be between 1.5 and 5 times slower than the one on bare soil surface (computed using Manning's flow velocity equation) (Chow 1959). Water tends to flow in a longer period on natural wetland pond than on bare soil surface, for an equal distance. As a result, there will be a certain amount of water that infiltrates and flows through soil layer. The infiltration rate depends on the pond bed permeability and geomorphology. Tropical peat soil permeabilities are around 7.5 to 471.9 m per day, tested from a case study in a Panamanian peat swamp (Baird et al. 2017). Those are far higher than sandy clay soil bed permeability value, which is around 0.0432 m per day (Chui and Trinh 2016).

Pond in tropical areas

The existence of natural pond in tropical area is integrated to the existence of wetland. The pond water storage supplies wetland ecosystem water needs. It also keeps wetland wet during different seasons and maintains wetland sustainability. In relation to that facts, there are three main pond landforms in tropical area. The first type commonly exists in peat dome. It exists within a configuration of hummocks and hollows (will be further explained later). The second pond type settles on river vicinity, which is integrated to river floodplain. The third type is recognised as coastal pond. It is normally existed on shallow tropical beach areas or deltas.

Pond in tropical peat dome is mainly supplied by rainfall water (rain feed). It is because tropical peat dome geomorphology is surrounded by rivers. These boundary rivers do not allow other sources of water to feed the pond. The river generally drains the tropical peat bogs. As all tropical domes are ombrotrophic, there is no ground water supply to it. These condition were also explained by Dohong et al. (2018) and Ishii et al. (2016). A peat dome cross section can be from 20 to 80 km in length. The peat thickness may reach 10 m, as the peat layer lays above low permeable mineral base. These conditions lead to the forming of peat dome microtopography, which consists of hummock (higher peat area) and hollow (lower peat area). The natural wet pond states as interconnected peat dome hollows. While pond water flows slowly across the dome, it creates bigger streams that integrate to each other. Those braided small streams end on any of the surrounding big river. Rain feed pond water is generally high in organic contents. It is acidic and lack of minerals.

Peat dome type natural wet pond can be found for example in Sebangau, Kalimantan, Indonesia. The ponds are settled on Sebagau peat dome. The peat dome is bounded by two big rivers, which are Katingan river and Kahayan river. In the centre of the dome, flows Sebangau River. The peat dome is feed by rainwater. It stores some portions of rainwater and creates natural ponds within peatland hollows. This area is prone to artificial drainage and fire (Dohong et al. 2017). As the water is acidic and lack of minerals, the vegetations in this area are not the same as the ones in tropical forest that grow on mineral soil (Harrison and Rieley 2018). Peat dome pond vegetations are those ones that can live in nutrient depleted environment, such as *Campnosperma sp.* and *Shorea sp.*. The area that is dry during dry season is usually covered by ferns of *Polypodiopsida* class. The area that is inundated all the time is commonly covered by peatland grass species, such as *Lepironia*.

The natural wet pond in tropical area can be found in river floodplain too. This pond type formation mechanism is usually initiated during flood, when river water overflows to river floodplain. In the time when river water retreats, some proportions of flood water may remain on flood plain basin. It can be happened because of either the floodplain basin base permeability is low, or the floodplain basin is laid above a saturated aquifer. These conditions were also mentioned by Bourgoin et al. (2007) and Couto et al. (2018). The basin may also be disconnected from the main river channel due to floodplain microtopography disparity. River floodplain may range from 1 to 40 km in between river levees, which is depending on the size of river valley. Flood plain can be wider than river main channel in some locations, as the river has meanders and braided channels. Due to this condition, pond water supply is mainly sourced from rainfall, ground water, and flood overflow during wet period. During dry period, there might be a portion of shallow sub surface water supply from river main channel to pond. Flood plain pond water is generally fresh water and it is rich in minerals.

Floodplain type natural wet pond can be found for example in Amazon River Basin, South America. Those floodplain ponds store a significant cumulative amount of water and interconnect to one another (Alsdorf 2003). The floodplain ponds interconnections regulate sediment transport in floodplain. Sediment plays important role in modifying floodplain geomorphology and correlates to the periodical existence of floodplain ponds (Bourgoin et al. 2007; Constantine et al. 2014). The flooding routines also enable flora and fauna movements from main channel into ponds and vice versa (Couto et al. 2018). It triggers species diversity in ponds and along the river. Floodplain ponds are mainly covered by tropical riparian forests and herbaceous vegetations (Arantes et al. 2018).

The coastal wet pond can be found in coastal marsh, along shorelines of tropical archipelago, along estuaries, or along deltas. Coastal pond formation is similar to floodplain pond one. However, coastal pond formation is strongly affected by ebb and flood mechanisms (tidal occurrence). Ebb is the condition when water flows from the pond towards the sea (draining), whereas flood is the condition when water flows from the sea towards the pond (filling). Water stays and circulates in the pond, which fluctuates pond water level. Ebb and flood mechanisms allow coastal pond water to have salinity concentrations (called as brackish water).

Coastal natural wet pond can be found for example in Niger Delta, West Africa. Several studies using remote sensing data showed that there were significant number of coastal ponds or pools along the delta and the beach (Fasona and Omojola 2009; Odunuga et al. 2013). Most of the ponds were still supplied by proportional amount of fresh water in earlier time (before 1965). However, sea water intrusions were becoming more severe from 1970 to 2010. The ponds were usually separated from sea and river by sand bars. The sand bars location and extend are dynamics by the time. The vegetations in the area are mangroves, grasses, and swamp palms.

Overall, it must be strongly specified that natural pond is not a new pond created by excavating natural base soil in wetland. Wetland soil layer excavation is dangerous as it may drain the wetland (Baird et al. 2017). Natural wet pond exists naturally as a result of wetland topography and geomorphology. Natural pond does not need maintenance by dredging, as natural lake might does (Putra et al. 2013). The waterways in natural pond migrate by the time, following the hydrological states of the wetland (Constantine et al. 2014). However, a degraded natural pond that is revitalized by human action can still be defined as a natural pond.

Pond water storages

The main water sources of natural pond are rainfall, river flow, tidal water, and ground water. The water sources combination depends on topography and geomorphology of the pond. It means that the percentage of water supply from different sources may vary, including its frequency and intensity. All these variations determine pond water level dynamics across time. There might be a period when pond area is flooded, but there could be also a time when only the deeper part of pond has water in it.

On the other hand, natural pond water outflow mechanisms are by evapotranspiration, percolation (deep infiltration), and lateral outflow. Firstly, evapotranspiration is the main outsource of pond water. Water in the open part of pond evaporates as it does in lake or reservoir. However, in the vegetated part of pond, water is less evaporated. It is because the existence of vegetation can maintain environment temperature. Lower environment temperature prompts lower pond evaporation (Mohamed et al. 2012; McJannet et al. 2012). Secondly, natural pond may allow percolation. Beneath the pond permeable layer, there is either low permeable layer or impermeable layer (called as pond's deep bed). The rate of water that goes to deeper ground water depends on pond's deep bed permeability. This deep infiltration mechanism is insignificant in tropical coastal pond, as the coastal pond geomorphology does not allow it (Lanés et al. 2015; Rodríguez et al. 2017). Thirdly, water can flow out through pond outlet as lateral outflow. Wetland pond lateral outflow typically exists during high water level, when the water current is substantial. During low water level, pond outlet is not clearly noticeable. Pond water flows out through sub-surface flow in dry period (Katsenovich et al. 2009; Lanés et al. 2015; Karim et al. 2016).

The largest proportion of natural pond water storage is a dynamic storage. There is only a small period when pond water level is static at certain level. The reason is that average pond water level is significantly shallower than the one in natural lake or in reservoir. It also implies that the pond wet perimeter area changes across seasons, as pond water level also changes. This condition makes natural pond water system to be far different to natural lake or man-made reservoir ones. Lake and reservoir store water across seasons, in which major proportion of the stored water stays in it along seasons.

Interestingly, natural wet pond system does not store water as a dynamic open storage only. It also stores water in roots' spaces and in organic sediments' pores within pond bed layers. This pond bed layers are able to store water due to its porosity (Katsenovich et al. 2009; Kobayashi 2016; Raphael et al. 2019). It stores water as subsurface flow, which has slower velocity than overland flow. Water flows slowly because the water level different (hydraulic gradient) across pond landform is small. The other reason is because roots and organic sediment layers are resisting the flow. Water stays in the pond permeable layers for a certain period, contributing as a temporary water storage (McJannet et al. 2012; Baird et al. 2017). The high porosity of tropical peatland teds to allow more water to be stored in late wet season, providing temporary water storage to the pond and its surrounding in early dry season. This characteristic of tropical peatland differentiates the pond in peatland from the other type of ponds in mineral soil area. It should also be underlined that natural wet pond can store water in its permeable bed layer, only if there is no drainage excavation around the pond environments (Ishii et al. 2016; Evers et al. 2017; Roh et al. 2018). The canal existence induces water level difference and causes water in pond permeable layer to flow faster, leading to pond water level drawdown.

Overall, natural pond water commonly has its basic function of maintaining wetland wetness. In a low storage condition, pond can also function as an effective natural landform to capture rainfall. The pond can save water during the following dry days and resist surface runoff towards adjacent river or channel. A certain amount of water can be stored for a longer period in wetland. In the dry season, when there is lack of water supply to natural wetland pond, pond water is continuously reducing. Nevertheless, pond may still provide reserved water to the wetland vegetation, stored in pond's porous bed layer.

Linking Natural Pond and SDGs

In refers to the natural pond hydrology discussion earlier in this review, natural wet ponds can be addressed as a promising water storage solution. In link to that, this section will profoundly reveal natural wet pond prospective contributions related to indicators that are stated in the UN SDG Resolution (UN 2017).

Pond supports wetland ecosystem

Natural pond reduces water stress level in watershed. It is because natural pond stores additional quantity of water, in the wider watershed hydrological system. This statement bluntly explains that natural wet pond water storage is not for direct abstraction. Mainly, it is function as a conservation resource in a bigger watershed perspective. Natural wetland ponds existence supports more proportion of water bodies with good ambient quality in watershed.

Natural wetland pond contributes in keeping wetland to remain optimally wet. Natural wet pond increases chance for ecosystem to sustain and to grow (Evers et al. 2017). Pond might still provide water to wetland ecosystem until the beginning of dry season. The high permeability of pond base layer allows nutrients circulation in wetland. It also allows water to reach wider extent in wetland at some crucial times. It supports vegetations that grow on wetland perimeter to have a bigger chance to survive. It promotes wetland enlargement. Moreover, it reflexes sustainable use of terrestrial (inland) freshwater. Optimum pond water storage is important to be targeted. If water availability in a wet pond is more than the pond capacity for a long period of time, vegetation in the pond might be changed. Some young wetland vegetations may not sustain against a long period of inundation. Some seeds may not grow under water. In contrast, if water level in pond is below pond's permeable layer for a long time, the condition is not beneficial for pond ecosystem. The old vegetation could be drying, whereas young seeds die. The risk of fire is high in a dry wetland condition (Evers et al. 2017; Dohong et al. 2018).

Tropical natural wetland ponds are houses of many fish species. The fishes live permanently in the pond or using pond as safe breeding environment (Arantes et al. 2018; Couto et al. 2018). Wet ponds maintain genetic diversity of flora and fauna in the wetland. It is important to the continuation of wetland food web. The genetic diversity in tropical wetland area can be maintained and getting better, once again if the wetland is in optimum wetness condition. A disturbance to a certain member population in the food web, will echo to many other members population too (Lanés et al. 2015; Arantes et al. 2018). This condition, for instance, may cause wetland food web top stratum predators' migration to other places for food hunting, even to human habituated area.

It is more environmentally friendly to store water in distributed natural pond wetlands, instead of storing water in a large reservoir. Pond water will still supply the downstream of watershed through infiltration or channel flow processes, so that it might support farming in the downstream area. Agriculture cannot use water directly from natural wet pond, as the water might be too acidic, lack of minerals, or containing bacteria. In the other way, efforts on storing water in natural pond contribute to a more adaptive agriculture against extreme drought and flooding condition in the downstream area. Natural wetland pond can slow overland flow, enhancing the chance for water to deep infiltrate rather than to flow directly to the river (Constantine et al. 2014; Ishii et al. 2016; Raphael et al. 2019). A higher watershed capacity in storing rainwater up to a certain limit, means a lower risk of flooding in the downstream area. The flood risk case is commonly parallel with drought risk case, as both are strongly related to climate anomalies. If more water is available in watershed, drought impacts might be lessened. The downstream area agriculture may use water that naturally passes through wet pond outlet.

Meanwhile, human induced nutrients to the wet land can be a challenge to wet pond. It must be considered prudently in relation to wet pond conservation goal. If the nutrient rich water amount that enters pond is more than pond's capacity to filter it, there might be a risk of eutrophication (Sarkar et al. 2020). The excessive nutrient state will lead to over grow of certain species occurrence, which is again may affect food web balance. It indicates that excessive nutrient supply from human induced activities must be avoided. Those activities are excessive use of detergent, chemical fertilizer, and the untreated organic waste disposal. Another human action that gives detrimental impacts to wetland pond water storage is drainage canal creation. The drainage canal in tropical wetland will drain the pond in a short period of time. The draining mechanism occurs if there are water level differences between natural pond and canal. It is also because pond permeable layer can easily flows water due to its high porosity (Baird et al. 2017; Dohong et al. 2017). Although rainfall might compensate pond's drained water loss during wet season, drainage canal will significantly drop pond's water level during dry season. It is because there is limited water supply to the pond, whereas wetland water is drained by canal substantially. This drainage canal impact must be anticipated to keep the wetland wet.

Local people participation in conservation

The social dimension of natural wet ponds sustainability calls for local community participation. It is based on facts that local communities are the subject of wetland conservation. They are strongly connected with the ecosystem and they have wetland conservation preferences inherited from their ancestors. It is hard for any regulation to be implemented if local people basic needs are not acknowledged sincerely. It does not mean that regulation should admit human disturbance to environment. It is more related to the concept of living in harmony with the nature, as proposed in several studies (Llausàs and Nogué 2012; Vélez et al. 2018; Jaramillo et al. 2019). The concrete examples are the livelihood of Badui tribes in a forested wetland in Java island (Prawiradilaga and Soedjito 2013), Dayak tribes in Borneo peat dome (Ifrani et al. 2019), Pantaneiros people in Brazilian Pantanal (Arts et al. 2018), and Noongar people in Western Australia wetland (Wooltorton et al. 2018). Those tribes live from wetland resources by practicing sustainable living for years without destroying wetland environment. They think that forested wetland is their mother nature. Tribal people believe that wetland needs to be protected so that their livelihood can be sustained. They tend not to take more than wetland can provide as they consider seasons and periods to schedule their harvest. They believe that over abstraction will cause wetland anomalies. This traditional wetland management is different in comparison to machinery and business-oriented wetland management approaches.

The local tribal people should be self-sustained communities so that they can play their crucial role as wetland guardian front liners. They are the one that traditionally live in around wetland. They are wetland guards and the first witnesses of any event that happened in their environment (such as forest fire, illegal logging, or sudden species population reduction). They have the knowledge of indigenous species and native medicinal herbs that exist in the area. Local tribal people empowerment and training tend to create a better resilient society that live in harmony with nature (Aguilar-Støen and Moe; Crevello 2004; Takeuchi et al. 2016).

Future Perspectives

In reference to the UN SDG progress report 2019 (UN 2019b), efforts to achieve the proposed goals are still in distant from the target, especially for the water related goals. This review presented a small reflection on the importance of sustainable water storage, specifically the tropical wetland water storage in natural ponds. It is important to conserve the wetland, as a paying back mechanism for the ecosystem services that humans have been benefited from so far. Therefore, as also strongly advised in the UN SDG progress report (UN 2019b), all stakeholders must increase current budget allocation in wetland conservation, to maintain wetland's function as sustainable natural fresh water storage. It is also important to ensure that the wetland coverage grows larger in the next decades, so that it will contribute more to the achievement of Clean water and Sanitation goal by 2030. Finally, the participation of local people is crucial in wetland conservation. Governments must guarantee that local wisdom and values are accommodated in wetland conservation master plans. This understanding will hopefully bring the water related SDGs accomplishment back on the track towards the targeted year of 2030.

Cross-References

- *Water Conservation (Soil and Water Conservation and Sustainable Development by Bantider, A., Haileslassie, A., Alamirew, T., Zeleke, G.)*
- *Ethics in Water Management (Ethics in Water Resource Management: Roles, Frameworks and Principles by Cendón Flórez, Y., Pippa, R.)*
- *Water in Tourism Sector (Water Use in the Tourism Accommodation Sector by Llausàs, A.)*
- *Water Quality (Citizen Science and Water Quality Monitoring: Evidence from Dublin and Beyond by Hegarty, S., Slaimi, A., O'Connor, N., Regan, F.)*
- *Freshwater Ecosystem (Contribution of Citizens to Preserving Local Freshwater Ecosystems by Feio, M., Ranta, E., Odume, O.)*

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