The influence of water balance in mangrove forests growth to mangrove’s degradation and depletion, case study: Southeast Asia

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Abstract. As natural drivers of mangrove forests’ degradation and depletion, mangrove forests’ water balance, as the ability of them to absorb and release water, which is related to mangrove’s coefficient growth, also makes an impact to those circumstances. The intention of this research is to identify the mangrove growth coefficient that used to analyze mangrove’s water balance and to identify the influence of mangrove’s water balance from mangrove’s depletion and degradation. The research is situated at Southeast Asia in 2000 and 2012. As a proxy for mangrove coefficient growth, MOD13A1 V6 satellite imagery that provides vegetation index values were used and will be multiplied by using the linear regression model that establishes the relationship between vegetation index and mangrove coefficient growth. The procedure for quantifying the mangrove’s water balance is carried out by multiplying the mangrove coefficient growth with evapotranspiration data derived from MOD16A2 V5 and then deducting it by precipitation data from CHIRPS V2. The results presented will confirm how these parameters influence the mangrove’s water balance and influential or not against the mangrove’s lost.

1. Introduction
Mangrove forests are woody plants distributed among the intertidal region between the sea and the land in the tropical and subtropical regions of the world [1]. They are productive and biologically important ecosystems because they provide unique ecosystem goods, services to human society, coastal, and marine systems, such as preventing abrasion [2], reducing tsunami impact [3], as an ecosystem for flora and fauna [4], and as a place of carbon traffic [5]. Southeast Asia has an area of mangrove forests with high species richness and structure [6] and widely spread starting from northwest Myanmar, across the islands of Indonesia and the Philippines to Papua New Guinea [7].

Serious attention in terms of enforcement and management needs to be given to the mangrove areas in Southeast Asia since over the past 50 years have been lost [6]. The depletion rate in the mangrove forest from 2000 to 2012 was 4.73%, with an annual rate of loss of 0.39% in the world [8] and clearly, Southeast Asia is the region of most concern. Because of the depletion, mangrove forests face numbers of threats. Those threats will reduce mangrove area that will increase the threat to human safety and shoreline development from coastal hazards, such as erosion, flooding, storm waves, surges, and tsunami [9]. Mangrove loss will also reduce coastal water quality, reduce biodiversity, eliminate fishery habitat, affect coastal habitats, and eliminate a major resource for human communities that rely on mangroves for numerous products and services [10]. Threats that occur can be avoided if the drivers of mangrove depletion are analysed.

The drivers of mangrove forests depletion are anthropogenic and natural changes [11]. As anthropogenic drivers, the rate of mangrove loss has been particularly due to the direct conversion of mangrove include overexploitation by coastal communities and conversion to settlements, tourist resorts, agriculture, and brackish water aquaculture [12]. As natural drivers, climate change, accelerated sea-level rise, meteorological phenomenon, water balance, and other aspects of global change will affect mangrove forests across the globe [13]. This research focuses on natural drivers which constitute a substantial
proportion of predicted mangrove future losses, primarily from the meteorological phenomenon [14]. The meteorological phenomenon affects the water balance of mangrove forest growth that causes the reduction in rainfall levels and an increase in evapotranspiration [15], resulting in depletion of mangrove forest [16]. It is the intention of this research that longer-term studies are needed to determine the influence of water balance in mangrove forests growth to mangrove’s degradation and depletion in Southeast Asia. Thus, adaptation options to avoid and minimize mangrove depletion can be identified.

2. Material and Method

The study area covers all countries in Southeast Asia including Thailand, Myanmar, Vietnam, Cambodia, Malaysia, the Philippines, Brunei Darussalam, Singapore, and Indonesia in 2000 and 2012. Laos is not included in the study area because there is no mangrove ecosystem, while Papua New Guinea is not included in the study area because it refers to ASEAN member countries. For data analysis and synthesis, as a proxy for mangrove coefficient growth, satellite imagery that provides vegetation index values were used and will be multiplied by using the linear regression model that establishes the relationship between vegetation index and mangrove coefficient growth. The procedure for quantifying the mangrove’s water balance is carried out by multiplying the mangrove coefficient growth with evapotranspiration data and then deducting it by precipitation data. As estimation and validation, the linkage between mangrove’s water balance and mangrove’s degradation and depletion will be analysed.

2.1. Distribution of Mangrove Forests

Global Distribution of Mangroves (MFW) raster dataset represents the global distribution of mangrove ecosystems in the form of trees and shrubs that specifically grow in the tidal zone of the equator and subtropical regions [17]. This primary data is generated from Landsat satellite images with a spatial resolution of 30 m obtained from 1997 to 2000, while secondary data is based on global mangrove forests [12], national, and local databases. This data used as a base map as a cutting raster to all of the data used in this research with 500m resolution with simple resampling method.

2.2. Identification of Mangrove Forests’ Coefficient Growth

Coefficient growth ($K_c$) is one of the most commonly used methods for water management. Similarities between $K_c$ curve and a satellite-derived vegetation index showed potential for modelling $K_c$ as a function of the vegetation index [18]. Vegetation index used in this research is MOD13A1 V6 with 500 m and 16 days NDVI layer to calculate $K_c$ and modified into monthly. NDVI is an indicator of the density of vegetative cover that it captures most of the variation observed in $K_c$ when there is no water stress condition. A simple linear regression model developed to establish a general relationship calculated from the flux data measured for the different plan by using AmeriFlux towers [18]. The combined relationship between NDVI and the $K_c$ from all modelling locations is:

$$K_c = 1.457 \text{ NDVI} - 0.1725$$ (1)

where 1.4571 and 0.1725 represent the slope and intercept coefficients. The procedure for quantifying coefficient growth from NDVI data should be useful in other regions of the globe to understand regional water management [18].

2.3. Identification of Mangrove Forests’ Water Balance

The processes that contribute to the ability of mangroves to maintain water uptake and limit water loss under different meteorological phenomenon conditions include: (1) calculate the $K_c$ of mangrove; (2) calculate effective precipitation ($P_{eff}$) of mangrove forests area where $P_{eff}$ is the fraction of the total precipitation as rainfall and snowmelt that is available to the plan and does not run off [19]; (3) multiplied mangrove forests’ coefficient growth by potential evapotranspiration then minus effective precipitation; and (4) the result of water balance in mangrove forests becomes available by Equation 1, 2, 3, and 4.
**Water Balance** = \((K_c \cdot E_{pot}) - P_{eff}(Green \ Water)\)  \hspace{1cm} \text{(2)}

\[ K_c = 1.457 \text{ NDVI} - 0.1725 \] \hspace{1cm} \text{(3)}

\[ P_{eff} = \frac{P (125 - 0.6P)}{125} \] \hspace{1cm} \text{if } P \leq 250/3 \text{ mm} \hspace{1cm} \text{(4)}

\[ P_{eff} = \frac{125}{3} + 0.1P \] \hspace{1cm} \text{if } P > 250/3 \text{ mm} \hspace{1cm} \text{(4)}

where \(K_c\) is coefficient growth, \(E_{pot}\) is potential evapotranspiration, \(P_{eff}\) is effective precipitation, and \(P\) is precipitation.

\(E_{pot}\) used here is MOD16A2 V5 monthly at 5 km resolution dataset that estimates global terrestrial evapotranspiration from earth land surface by using satellite remote sensing data that can be used to calculate regional water and energy balance. This research only used total potential evapotranspiration (\(E_{pot}\)) layer defined as the amount of evaporation that would occur if a sufficient water source were available and \(E_{pot}\) is a measure of the demand side. \(E_{pot}\) will be multiplied with \(K_c\) and modified into 500 m resolution with simple resampling method because the mangrove forests’ water balance will be analysed in 500 m resolution. Precipitation data that used here is CHIRPS V2 monthly at 5 km resolution dataset. This precipitation data also modified into 500 m resolution with a simple resampling method as the input to calculate \(P_{eff}\).

**2.4. Mangrove Forests’ Degradation and Depletion**

Global Database of Continuous Mangrove Forest Cover for the 21st Century (CGMFC-21) as high resolution local, regional, national, and global estimates of annual mangrove forest levels using continuous data from 2000 through to 2012 with the goal of driving mangrove research questions pertaining to biodiversity, climate change, food security, livelihoods, fisheries support, and conservation that have been hindered until now by a lack of suitable data [8] used to see the mangrove’s degradation and depletion. CGMFC-21 has a benchmark of mangrove area to MFW with a resolution of 30 m with data presented annually. Same as the MFW data, the resolution must be reduced to 500 m with a simple resampling method.

**3. Result and Discussion**

**3.1. Analysis of Mangrove Forests’ Coefficient Growth**

The value of \(K_c\) is obtained from the results of a linear regression model between a land slope variable with the NDVI value of each pixel shown in Equation 1. The value of \(K_c\) in each country in Southeast Asia ranges from 0.01 to approximately 1.3. This value indicates the rate of growth that mangrove can grow where a value close to 0 states that the mangrove is not growing and a value close to 1.3 states that the mangrove is growing.

Some of the mangrove forests in Southeast Asia follow the dry season and rainy season and some are not. The dry season usually occurs in April to September and the rainy season usually occurs in October to March. As shown in Figure 1 until Figure 4, countries that follow the pattern of these 2 seasons are Cambodia, Myanmar, and Thailand. While other countries such as Indonesia, Vietnam, Brunei Darussalam, Malaysia, and the Philippines are not following the pattern of these 2 seasons.
Pixel value in Cambodia, Myanmar, and Thailand showed that most of the pixels in the shown region follow these 2 seasons. When the dry season occurs, then the value of $K_c$ is mostly red and when the rainy season occurs, then the value of $K_c$ is mostly blue. Pixel value in Indonesia, Brunei Darussalam, Malaysia, and Philippines showed that not all of the pixels are not following these 2 seasons, there are some pixels in some regions that follow and some are not.

3.2. Analysis of Mangrove Forests’ Water Balance

Water balance value is obtained from the results of the linear regression model by Equation 2. $K_c$ as the input data of mangrove forests’ water balance gives an impact where the pattern produced is the same. Cambodia, Myanmar, and Thailand produce the value of deficit and surplus follow the pattern of the dry and rainy season, while Indonesia, Brunei Darussalam, Malaysia and the Philippines are not following the pattern of these 2 seasons.

3.3. Analysis of Mangrove Forests’ Degradation and Depletion

The scientist has already found out that there is deforestation of mangrove forest in Southeast Asia [20] caused by anthropogenic drivers with eight land use classification, but one classification of them named Other which means the reason of mangrove deforestation is not yet known [21]. The relationship between mangrove forests’ water balance and mangrove forests' degradation and depletion is generated by overturning pixels to pixels by dividing them into 4 classifications, as anthropogenic drivers, natural drivers, mangrove on risk, and sustainable mangrove shown in Figure 5.
Figure 5. Relationship between mangrove’s water balance and mangrove’s degradation and depletion.

Anthropogenic or natural drivers means that those values represent the causes of mangrove forests’ degradation. The classification named mangrove on risk means that there is the region where the water balance is deficit but it’s not degraded yet so the policymakers should take steps to prevent mangrove forests’ degradation, hence the mangroves in the region can survive given that so many functions of mangroves to the environment. While sustainable mangrove is for the region where the water balance is surplus and there is no degradation on the site. This research shows that natural drivers (1.85%) have more effect to mangrove forests’ degradation and depletion rather than anthropogenic drivers (1.65%) while mangrove on risk on 30.75% and sustainable mangrove has the highest value on 65.75%.

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