Annual Water Yield Analysis with InVEST Model in Tesso Nilo National Park, Riau Province

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Abstract. One of the problems in Tesso Nilo National Park is deforestation through the opening of oil palm plantations. This can affect the ecosystem services of Tesso Nilo National Park, one of which is as a producer of water. Water yield is a key component of the attributes and processes that produce water-related ecosystem services. The importance of Tesso Nilo National Park ecosystem services as water producers needs to be assessed quantitatively and visualized to explain changes in land cover to changes in these services. The purpose of this study was to analyze the annual water yield in Tesso Nilo National Park. The model used is the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) water yield model. InVEST is a spatially explicit tool for exploring how changes in ecosystems tend to lead to changes in benefits flowing to people. The annual water yield in Tesso Nilo National Park in 2018 was 5731528155.86 m$^3$ or 2729.52 mm. Water yield is strongly influenced by actual evapotranspiration (AET), mean annual rainfall (MAP), and land cover (LC). The land cover that produced the lowest to the highest water yield was mixed acacia, forest, oil palm plantations, bare land and shrubs.

1. Introduction
Tesso Nilo National Park (TNTN) is experiencing ecological, economic and socio-cultural problems due to changes in the function of the forest area which was initially a limited production forest. Strategic issues related to TNTN include encroachment, forest fires, tenure conflicts and wildlife conflicts. Squatters clear land by burning forests to sell and eventually plant oil palm and rubber. This causes the forest area to decrease so that it cannot meet the roaming area of animals. TNTN has a core and jungle zone with an area of 22755.79 ha but has not been able to meet the needs of the elephant's home range with an area of 56631.85 ha [1]. Tenure conflicts are caused by land ownership in the area, definitive boundaries have not been found, unclear boundaries and illegal hamlets. The hamlet was formed by settlers who came from immigrants and made a distinctive settlement [2].

The opening of oil palm plantations through forest encroachment causes changes in land cover. The land planted with oil palm and rubber in 2002-2012 was 52.24 ha with an average expansion rate of 23,251 ha/year [3]. This can affect the ecosystem services of TNTN, one of which is as a water producer. If the forest area decreases and the agricultural area increases, the water produced in the area will
decrease [4]. Water yield is a vital component of the attributes and processes that make water-related ecosystem services. Water yield is the amount of water flow in specific periods such as rainy, monthly or yearly periods [5]. These services contribute to the welfare of society and humans, ensure the development of irrigated agriculture, increase the population, improve living standards, industrial activities and tourism [6].

The importance of TNTN ecosystem services as water producers made this service need to be assessed quantitatively and visualized to explain changes in land cover to changes in these services. This can assist in the effective management and protection of water resources, sustainable development on a regional scale and human well-being [7]. Models play an important role in assessing water-related ecosystem services because they provide a simple quantitative approach for estimating water yields under various conditions, and are very useful at large scales. The model used is The Integrated Valuation of Environmental Services and Tradeoffs (InVEST) water yield model. InVEST is a spatially explicit tool to explore how changes in ecosystems tend to lead to changes in benefits flowing to humans [8]. The purpose of this study was to analyze the annual water yield in TNTN.

2. Methodology

2.1. Research Area
The study area is the Tesso Nilo National Park, which is located in two regencies, namely Pelalawan and Indragiri Hulu, Riau Province with a geographical location of 00° 05' 40" - 00° 20' 47" South Latitude and 101° 35' 21" - 102° 03' 21" East Longitude (Figure 1). The TNTN area has an area of 81,793 ha. The altitude of the TNTN area ranges from 52-175 meters above sea level. High annual precipitation is 2000-3000 mm while the average monthly rain can fall as much as 60 mm. The average yearly number of rainy days is between 120-150 days. Extreme climatic conditions such as drought due to El Nino can cause trees to die [9]. This is used by squatters who burn the forest to open new land.

The TNTN area and its surroundings are water catchment areas for several rivers, including the Tesso River in the west, the Segati River in the north, the Nilo River. All three are sub-watersheds of the Kampar watershed, precisely between the Nilo, Segati and Buluh Jaya watersheds in Riau Province.

![Figure 1. The location of study area.](image)

2.1.1. Materials and Tools
The tools used in this research is a set of computers based on Windows OS installed with ArcGIS 10.5 and InVEST 3.9 software. The data collected (Table 1) is 2018 data obtained online by downloading it on the official websites of government and private agencies. The spatial data used is data in raster format with a spatial resolution of 30 m × 30 m and is projected using the World Geodetic System 84 (WGS84).
| No | Data                                                                 | Data source                       |
|----|----------------------------------------------------------------------|-----------------------------------|
| 1  | Soil texture (g/kg), soil organic carbon (g/kg) and Root restricting layer depth (mm) | soilgrids.org                     |
| 2  | Land cover                                                           | Tesso Nilo National Park Office   |
| 3  | Monthly precipitation (mm)                                          | CHIRPS                            |
| 4  | Daily air temperature (°C) minimum and maximum                      | WorldClim                         |
| 5  | Daily solar radiation (KWh / m²) and biophysical table              | FAO                               |
| 6  | Root restricting layer depth                                        | ISRIC                             |
| 7  | Watershed boundary                                                  | Ministry of Environment and Forestry |

2.2. Model Input Parameters

2.2.1 Average Annual Precipitation
Precipitation data were obtained from the Climate Hazards Center (CHIRPS). Each year, the total monthly precipitation is used to create a precipitation map in raster format using spatial interpolation (spline) techniques. Based on the availability of precipitation data, the resulting map is a monthly and annual precipitation map in raster format (.tif). The monthly precipitation map is used to calculate the monthly reference evapotranspiration, which is accumulated into the annual reference evapotranspiration. In contrast, the yearly precipitation map is used to analyze the water yield model.

2.2.2 Average Annual Reference Evapotranspiration
The annual reference evapotranspiration was obtained using the Hargreaves equation which was then made in raster format (.tif) [10]. Annual reference evapotranspiration requires extraterrestrial solar radiation data, maximum and minimum air temperatures and monthly precipitation. Daily extraterrestrial solar radiation, the average daily maximum and minimum air temperature are then accumulated monthly using tabulation data processing software. Each of these data is made a map in a raster format generated using spatial interpolation (spline) techniques. Annual reference evapotranspiration maps were calculated using the raster calculator in ArcGIS.

2.2.3 Root Restricting Layer Depth
The depth of the root boundary layer is the depth of the soil with its physical or chemical characteristics that inhibit root penetration. These data were obtained through the global soil information grid provided by the International Center for Soil Reference and Information (ISRIC) based on depth to bedrock (R horizon) up to 200 cm.

2.2.4 Plant Available Water Content (PAWC)
PAWC is the difference between field capacity and wilting point using the physical and chemical properties of the soil. The following is the equation for calculating PAWC:

\[
\text{PAWC} (\%) = 54.509 - 0.132 \cdot \text{sand}\% - 0.003 \cdot (\text{sand}\%)^2 - 0.055 \cdot \text{SIL}\% - 0.006 \cdot (\text{sand}\%)^2 - 0.738 \cdot \text{clay}\% + 0.007 \cdot (\text{clay}\%)^2 - 2.668 \cdot \text{C}\% + 0.501 \cdot (\text{C}\%)
\]

where sand\%, silt\%, clay\% and C\% are the percentages of sand, silt, clay, and carbon content in the soil, respectively [11].

2.2.5 Land Cover
The land cover map was obtained from the Tesso Nilo National Park Office, which was classified using the guided classification method. Land cover has five classes, namely mixed acacia, forest, oil palm,
plantsations, bare land and shrubs. The area covered with mixed acacia is an area that previously overlapped PT. RAPP. This incident occurred before the appointment of TNTN in 2004, when the site was managed and managed by PT. INHUTANI IV. After the designation of the national park, the area of the former PT. The RAPP was released and wholly given to TNTN. This is what makes the acacia plantation forest no longer maintained or left naturally so that shrubs grow. The following are land cover classes in Tesso Nilo National Park.

2.2.6. Biophysical Parameters
Biophysical parameters have biological values in the form of plant evapotranspiration coefficient (Kc) and root depth in each land cover classification needed in calculating water yields using the InVEST model (Table 2).

Table 2. Biophysical parameters linked to land-cover characteristics in TNTN

| Description                  | Land Cover Code | Root Depth | Kc  | Land Cover Vegetation |
|------------------------------|----------------|------------|-----|-----------------------|
| Forest                       | 1              | 7000       | 0.87| 1                     |
| Mixed acacia                 | 2              | 7000       | 0.7 | 1                     |
| Bare land                    | 3              | 0          | 0.2 | 0                     |
| Oil palm plantation          | 4              | 1100       | 0.93| 1                     |
| Shrubs                       | 5              | 2000       | 0.4 | 1                     |

Source: [12], [13], [14], [15].

2.2.7. The Zhang Parameter
Zhang's parameter is a seasonal climate factor that shows local precipitation patterns and hydrogeological characteristics. The seasonal factor (parameter Z) is determined according to a coefficient scale from 1 to 10, where 1 represents a seasonal monsoon, 4 means a tropical climate, and 9 illustrates a temperate climate [16]. A smaller Zhang parameter value will increase the water yield, and conversely, a more significant value will decrease the water yield.

2.3. Data analysis

2.3.1 The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Water Yield Model
Prediction of annual water yield using InVEST Water yield model can predict annual water yield for each pixel in a particular landscape [8]. This model can simulate the impact of land cover on WY by including the biophysical components of each land cover class. The WY model is based on the Budyko curve and annual mean precipitation. The annual WY Y(x) for each pixel in a given landscape is calculated using the following equation:

\[ Y(x) = \left(1 - \frac{AET(x)}{P(x)}\right) \cdot P(x) \]

Description:
- \( Y(x) \) = annual water yield (mm)
- \( AET(x) \) = actual evapotranspiration for pixels \( x \) (mm)
- \( P(x) \) = annual precipitation in pixels \( x \) [8]

\[ \frac{AET(x)}{P(x)} \] value for vegetated land cover using the following equation [8]:

\[ \frac{AET(x)}{P(x)} = 1 + \frac{PET(x)}{P(x)} - \left[1 + \left(\frac{PET(x)}{P(x)}\right)^{\omega}\right]^{1/\omega} \]

Description:
- \( PET(x) \) = potential evapotranspiration for pixels \( x \) (mm)
- \( \omega \) = coefficient of water availability for plants as a non-physical parameter that characterizes the relationship between climate and soil properties
The potential evapotranspiration \(\text{PET}(x)\) is determined based on the reference evapotranspiration and the crop coefficient of plants in pixels. \(\text{ET}_0(x)\) reflects the local climatic conditions based on the evapotranspiration of the reference vegetation found in that location. \((x)\) is strongly determined by the vegetative characteristics of the land cover contained in the pixel [14]. The \(\text{PET}(x)\) potential evapotranspiration equation is as follows [8]:

\[
P(x) = \text{ET}_0(x) \cdot K_c(x)
\]

Description:
\(\text{ET}_0(x)\) = reference evapotranspiration of pixels \(x\) (mm)
\((x)\) = The plant evapotranspiration coefficient in pixels

The coefficient of water availability for plants at pixel \(x\) has the following equation [17]:

\[
\omega(x) = Z \cdot \frac{\text{AWC}(x)}{P(x)} + 1.25
\]

Description:
\(\omega(x)\) = Coefficient of water availability for plants in pixels \(x\)
\(Z\) = seasonality factor/Zhang coefficient
\(\text{AWC}(x)\) = volume of water content available to plants (mm)
\(P(x)\) = annual precipitation in pixels \(x\)

\(A(x)\) determines the amount of water that can be retained and released in the soil for use by plants. This parameter is influenced by the type and texture of the soil and the depth of the roots. This parameter is estimated as the result of the Plant Available Water Capacity-PAWC, the minimum root restricting layer depth and vegetation rooting depth. PAWC is the available water capacity of plants obtained from the difference between field capacity and wilting point [8]. Here is the equation to get AWC.

\[
\text{AWC}(x) = \text{Min}(\text{rest. layer. depth, root. depth}) \cdot \text{PAWC}
\]

Land cover has actual evapotranspiration \(A(x)\), which is calculated directly from the reference evapotranspiration \(\text{ET}_0(x)\) and has an upper limit determined by precipitation. The actual evapotranspiration equation is as follows [8].

\[
\text{AET}(x) = \text{Min}(Kc((x)) \cdot \text{ET}_0(x), P(x))
\]

Description:
\(\text{AET}(x)\) = actual evapotranspiration in pixels \(x\) (mm)
\(\text{ET}_0(x)\) = reference evapotranspiration in pixels \(x\) (mm)
\((x)\) = The plant evapotranspiration coefficient \(x\)
\(P(x)\) = annual precipitation in pixels \(x\)

Reference evapotranspiration (mm/month) was calculated using the modified Hargreaves equation [10].

\[
\text{ET}_0(x) = 0.0013 \times 0.408 \times \text{Ra} \times \left(\frac{\text{Tmax} + \text{Tmin}}{2}\right) + 17 \times ((\text{Tmax} - \text{Tmin}) - 0.0123 \times \text{P})^{0.76}
\]

Description:
\(\text{ET}_0(x)\) = reference evapotranspiration in pixels \(x\) (mm/month)
\(\text{Ra}\) = extraterrestrial solar radiation (MJ/ (m², day))
\(\text{Tmax}\) = maximum daily average air temperature (°C)
\(\text{Tmin}\) = average daily minimum air temperature (°C)
\(\text{P}\) = annual precipitation (mm/month)
3. Results

3.1. Annual Water Yield di Taman Nasional Tesso Nilo

The water yield model in InVEST requires simpler inputs compared to other hydrological models, one of which is the Soil and Water Assessment Tool (SWAT). This causes InVEST to be more recommended for use in areas with limited data, but InVEST cannot describe seasonal water yield variations because the parameters are accumulated annually [18]. The annual water yield in TNTN in 2018 was 5731528155.86 m$^3$ or 2729.52 mm. Water yield is strongly influenced by precipitation, reference evapotranspiration and land cover. The following is a map of the distribution of precipitation, reference evapotranspiration and land cover in TNTN (Figure 2).

![Figure 2](image)

Figure 2. Precipitation (a), actual evapotranspiration (b), land cover (c) and annual water yield (d) in Tesso Nilo National Park.

The results showed that the mean annual precipitation (MAP) determines the amount of water provided by nature, while land cover (LC) determines the amount of water that is converted into WY and the amount of water that is stored as groundwater. Areas with high rainfall tend to have high WY and with modifications by land cover factors that determine actual evapotranspiration (AET) [19]. The quality of the WY InVEST model is strongly influenced, especially the rainfall [4]. Changes in land cover can modify hydrological values in the form of evapotranspiration, infiltration and water retention, and water available for rivers and groundwater resources [20]. WY with different land cover illustrates different hydrological effects. This is because the WY InVEST Model calculates each pixel in the landscape as annual rainfall minus actual evapotranspiration and is determined by vegetation characteristics in each land cover [21]. The land cover that produced the lowest to the highest WY was mixed acacia, forest, oil palm plantations, bare land and shrubs (Table 3).
Mixed acacia and forest have the lowest WY with almost the same value because they have high AET and lower MAP in the area. Oil palm plantations produce greater WY than forests. This is influenced by low AET and high MAP. AET is a water yield reducing factor which is largely determined by climatic parameters such as maximum and minimum air temperature, solar radiation, rainfall and land cover conditions [10]. Rainfall is directly proportional to the yield of water. The lower the rainfall, the lower the water yield by considering the modification by land cover factors that determine the actual evapotranspiration [19]. Forest land cover in general plays a role in improving soil physical properties due to the activity of soil fauna, roots and high organic matter content, causing the infiltration rate to be higher than other land covers [22]. This indicates that the forest land cover will have more soil and moisture than the other cover. Oil palm cover makes the soil more compact, resulting in greater runoff and reduced groundwater reserves. This results in the deposited water being unable to penetrate well-compacted and eroded soils and a large amount of water leaving the landscape as runoff and less water available for groundwater recharge [23]. Large-scale conversion of natural forests to oil palm plantations causes or increases water scarcity on a regular basis.

WY produced by bare land cover is mainly in the form of surface runoff. This can have an impact on decreasing infiltration capacity and increasing runoff, erosion and sedimentation. Shrubs dominated the land cover and produced the highest WY. Shrubs are pioneer vegetation that first grows when the forest is damaged by humans or nature. The shrub is dominated by grasses and Acacia mangium species. WY produced by shrubs is higher than forest because it has lower AET. Lower water loss capacity was associated with lower leaf area [24,25] and lower canopy interception [26]. WY produced by shrubs is higher than bare land. The capacity of water loss through surface runoff is lower than that of bare land. Still, the combination of grasses and woody plants is able to hold water so that groundwater reserves are more significant.

TNTN has experienced changes in land cover since before the appointment until now. Land that has been infringed can be directly planted with oil palm if oil palm seeds are available and are not known by TNTN official. If this cannot be fulfilled, the bare land is left alone so that shrubs vegetation grows. Mixed acacias often experience fires caused by extreme weather during the dry season or intentionally burned by encroachers. This is what makes mixed acacia land cover can turn into bare land. Forests are the most vulnerable land cover class to convert into bare land. Changes in land cover affect ecosystem services, namely annual water yields that are part of the hydrological cycle of the catchment [27]. Deforestation and expansion of agricultural land such as oil palm plantations causes increased annual runoff, evapotranspiration, river flow, groundwater depletion and lateral flow [28]. This ultimately leads to more frequent and larger floods. Land cover transformation around watersheds can change the volume of flooding and runoff components so that floods occur more frequently and are more severe [29].

4. Conclusion
The annual water yield in Tesso Nilo National Park in 2018 was 5731528155.86 m³ or 2729.52 mm. Water yield is strongly influenced by mean annual precipitation (MAP), actual evapotranspiration (AET) and land cover (LC). Mixed acacia and forest yielded the lowest WY with almost the same value. This is because the MAP is low but the AET is high in the region. Forests generally play a role in improving soil physical properties and have more groundwater and soil moisture than any other cover.
Oil palm plantations produce greater WY than forests. This is influenced by high MAP but lower AET. Soil compaction in oil palm plantations causes more surface water to run off than water is absorbed to be used as groundwater. WY produced by bare land cover is mostly in the form of surface runoff. This can have an impact on decreasing infiltration capacity and increasing runoff, erosion and sedimentation.

Shrubs cover resulted in higher WY than forest because it had low AET due to lower interception leaf area of the canopy. The capacity of water loss through surface runoff is lower than that of bare land, but the combination of grasses and woody plants is able to hold water so that groundwater reserves are more significant. Deforestation and expansion of agricultural land lead to increased annual runoff, evapotranspiration, river flow, groundwater depletion and lateral flow.

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