Correlation of normalized difference water index and baseflow index in small island watershed landscapes

B Latuamury¹,*, M Talaohu¹, F Sahusilawane¹, W N Imlabla¹

¹ Department of Forestry, Faculty of Agriculture, Pattimura University, Ambon 97123, Indonesia

* E-mail: okky.environmentalscience@gmail.com

Abstract. The utilization of remote sensing data in the field of environmental hydrology is experiencing rapid progress. The Normalized Difference Water Index (NDWI) approach to transforming the water content of various land cover types and its implications for small island watersheds' hydrological characteristics is essential. NDWI is an algorithm used to detect water bodies, with the capacity to absorb visible and infrared wavelengths strongly. This study aims to analyze the correlation between the NDWI water index and the BFI baseflow index in the small island landscape of Ambon City. The Landsat 7 ETM + and Landsat 8 OLI image processing methods use ENVI 5.3 software to transform the NDWI algorithm and the BFI + 3.0 digital recursive filtering (RDF) method for hydrological characterization. The results showed that there was a strong correlation between the NDWI water index and the baseflow index (BFI) for the small island watershed of Ambon city. This result is relevant to the geographic area of Ambon City, which is dominated by the ocean 95% and land area 5%, so the application of the NDWI water index and the hydrological conditions of small island watersheds are significant.

1. Introduction

Ambon City has 2/5 of Ambon Island's total area with a land area of 359.45 km² and an ocean area of 17.55 km² with a coastline length of 98 Km. Ambon City area's topographical conditions cover hilly land areas to steep slopes with a slope of >20° as much as 73%. The land area tends to be flat or sloping with a slope of <20° by 17%, and about 10% are beaches, coasts, and bays. The unique topographical conditions characterize the specific river characteristics of narrow watersheds (DAS) and the main rivers' relatively short lengths. The longest river is Way Sikula in Laha Village with a length of 15.5 km, while the shortest river is Way Tomu and Way Batu Gajah with a length of 1.5 km, which flows in the center of Ambon City [1].

According to the hydrometeorological disaster risk study, Ambon Island is at a score of 156, which is in the high-risk category. In the last five years, Ambon Island's flood hazard's vast potential has experienced floods and landslides, impacting infrastructure damage and casualties and deaths. The possibility of the population exposed to flooding includes the five watersheds of Ambon City due to the river border protection area's condition, crowded with human settlements, and many vulnerable groups.

The water index using the Normalized Differences Water Index (NDWI) is an index modified from the NDVI [2]–[4]. The water content index shows the water content of land recorded by the image [3]–[7]. NDWI and NDVI values are directly proportional. The denser the vegetation density in an area, the higher the recorded NDWI value. NDWI is an algorithm used for the identification of water
bodies. Water bodies strongly absorb visible and infrared wavelengths of light. An NDWI value that is more than zero is assumed to be a water body, and if the NDWI is less than zero, it is considered land [8]–[11]. The water index transformation research by [12]–[16] proves that the water index method has advantages in terms of ease of use. Use and short processing time for coastline data acquisition. Some of the water indices used in this study are NDWI [3], [17], MNDWI [15], [16], [18], and AWEI [11], [15]. The use of the water index algorithm can adjust to specific research objectives. The advantages of the water index algorithm at a particular location can be optimally useful in other sites.

The Normalized Difference Water Index (NDWI), according to [2], [17], [19], [20], is a popular drought index for vegetation humidity. NDWI has been widely used for humidity and dryness identification. According to [9], [21]–[23], NDWI effectively monitors vegetation water content in various studies. [21], [24] conducted a comparison of NDVI and NDWI to monitor vegetation moisture and grassland drought, which resulted in NDWI being more sensitive to vegetation drought. According to [18], [21], [24]. ISODATA performs the clustering and initial classes based on computers' statistical computations, then classifies pixels and modifies the criteria for each category. This process is repeated until the spectral interval (range) between classes is maximum.

The Landsat 8 satellite, known as the Landsat Data Continuity Mission (LDCM), was launched by NASA on February 11, 2013, at Vandenberg Air Force Base, California. This project is a continuation of the previous Landsat satellite mission known as the Continuity Mission. Landsat 8 is a refinement of Landsat 7 with improvements related to the spatial, temporal, and spectral resolution. The advantages of Landsat 8 are especially the specifications of the bands and electromagnetic wave spectrum. The Landsat 8 specifications are mainly in bands 1, 3, 10, and 11. Band 1 (ultra blue) has a lower electromagnetic wavelength than blue waves at a wavelength of 0.43 - 0.45 μm. Other researchers also find the superiority of this band in distinguishing aerosol concentrations in the atmosphere and identifying the characteristics of the appearance of seawater at different depths [3], [15], [25]–[27].

Cirrus cloud detection is also optimal in band 9 with an OLI (Operational Land Imager) sensor at a wavelength of 1.36 - 1.38 μm. Landsat 8 with a thermal sensor has two thermal bands: band 10 (wavelength of 10.6 - 11.19 μm) and band 11 (wavelength 11.5 - 12.51 μm). The spatial resolution of the TIRS (Thermal Infrared Sensor) sensor has a spatial resolution of 100 meters. However, it is resampled to 30 meters to facilitate multispectral data analysis (OLI). Besides, sensor calibration also produces noise, called noise-equivalent-change-in-temperature (NEΔT), as the maximum limit of the resulting error [11], [28]–[31].

The water index characteristics of various land cover types can accommodate the water index's detection in different land cover classes. This study analyzes the water index and hydrology characteristics of small island watersheds unique and vulnerable to disasters' hydrometeorological aspects, based on the advantages of satellite imagery and the water index in various environmental studies. Therefore, this study investigates the Water Index Correlation using the Normalized Difference Water Index (NDWI) approach and the baseflow index for five small island watersheds in Ambon City, Maluku Province.

2. Methods

2.1 Research Area

The research was conducted in five small island watersheds in Ambon City, Wae Batu Merah, Wae Ruhu, Wae Batu Gajah, Wae Batu Gantung, and Wae Tomu watersheds. These five watersheds were chosen considering that the River Flow Measurement Station (SPAS) availability from the Ministry of Public Works of Maluku Province and the spatial dynamics of land changes in the riverbank area are rapid and have implications hydrological conditions of the watershed. The morphometric characteristics of the five watersheds are presented in Table 1.
Table 1. Morphometric characteristic of watersheds in the current study

| Watershed Name        | SPAS Coordinates         | Watershed Length (km) | Watershed Width (km) | Circumference (km) |
|-----------------------|--------------------------|-----------------------|----------------------|--------------------|
| Wae Batu Merah        | 409415.73 9592511.44     | 4.69                  | 2.65                 | 23.12              |
| Wae Ruhu              | 410922.34 9594695.91     | 6.46                  | 3.29                 | 47.96              |
| Wae Batu Gajah        | 408291.73 9591503.334    | 5.22                  | 2.25                 | 18.49              |
| Wae Batu Gantung      | 408291.73 9591235.01     | 4.92                  | 4.24                 | 25.32              |
| Wae Tomu              | 409111.96 9592214.09     | 5.10                  | 1.55                 | 12.90              |

Source: Visual Map of Indonesia, BPDASHL Maluku Province

2.2 Research Procedure

2.2.1 Normalized Difference Water Index

Landsat 7 ETM + and Landsat 8 OLI image processing begins with atmospheric correction using ENVI 5.3 software, especially the FLAASH module [32]–[34]. Water Index, Normalized Difference Water Index (NDWI) is a transformation of the reflectance of the band to extract the water's brightness level, including two algorithms with mathematical equations for NDWI are [2], [19], [35]:

\[
NDWI = \frac{NIR - SWIR}{NIR + SWIR} \\
\text{……………………………………………… (1)}
\]

Table 2. Multispectral characteristics according to LAPAN

| Sensor | Spectral | Wavelength | Spatial Resolution | Plot Width Measure | Temporal Resolution |
|--------|----------|------------|--------------------|--------------------|---------------------|
| LISA   | B1-Blue  | 0.41-0.49µm| 18 m               |                    | 21 days             |
|        | B2-Green | 0.51-0.58µm| 18 m               |                    |                     |
|        | B3-Red   | 0.63-0.70µm| 18 m               |                    |                     |
|        | B4-NIR   | 0.77-0.99µm| 18 m               |                    |                     |

In this study, the red, green, and blue bands were tested on satellite images with a modified formula into the model equation:

\[
NDWI = \frac{Blue \text{ } - \text{ } Red}{Blue \text{ } + \text{ } Red} \\
\text{……………………………………………… (2)}
\]

RNir is the NIR band's reflectance, while R SWIR6 reflects the SWIR band 6 in Landsat 8.

The NDWI index is influenced by leaf moisture content, vegetation types, and land cover [2]. The high moisture content of vegetation and a high fraction of vegetation cover will have a high NDWI value. Low NDWI values mean that the vegetation's moisture content is low, and the vegetation cover fraction is also low (Table 2).
2.2.2 Hydrological characteristics of small island watersheds

The hydrological characteristics of the five watersheds of the small island of Ambon City use the Recursive Digital Filter (RDF) method from the hydro office 12.0 software module BFI + 3.0 program and, more specifically, using filtering algorithm [36]–[38] as presented in Table 3.

Table 3. NDWI class according to Gulacsi and Kovacs, 2015.

| NDWI Category | Description          |
|---------------|----------------------|
| 0.6 ≤ NDWI ≤ 0.7 | High water content |
| 0.5 ≤ NDWI ≤ 0.6 | Medium water content |
| 0.4 ≤ NDWI ≤ 0.5 | Low water content   |

Source: Gulacsi dan Kovacs, 2015

Table 4. Recursive digital filter method using the BFI + 3.0 program

| Filter Name           | Mathematical Equation                                                                 | Remarks                                                      |
|-----------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------|
| Algoritma Lynie & Hollick | \( q_{f(i)} = \alpha q_{f(i-1)} + (q_{(i)} - q_{(i)0}) \frac{1-\alpha}{2} \) | \( q_{f(i)} \geq 0, \text{if } \alpha 0.925 \), it is recommended for river flow data filter and implemented in three phases of basic flow, \( q_b = q - q_f \). |

Source: hydrooffice 12.0 module BFI+3.0 [37]

2.3 Data Analysis

Correlation analysis between the two parameters of the NDWI index and the BFI base flow index is carried out to determine the direction of the relationship between the two variables, whether positive or negative and to predict the value of the dependent variable if the value of the independent variable has increased or decreased. The data used is usually an interval or ratio scale. The simple linear regression correlation formula is as follows:

\[ Y' = a + bXn \]  

\[ \text{(3)} \]

3. Results and discussion

3.1 Water content using the NDWI algorithm for the 2015 and 2019 periods

The water content analysis in the Landsat imagery in 2015 and 2019 for the five Ambon City watersheds showed water content variation for the NDWI class. The variation in water content for the period 2015 shows that the five watersheds have a low water content of NDWI -0.949655 to -0.581242 (2636.21 hectares), followed by the moderate water content of NDWI -0.581242 to -0.212828 (1250.13 hectares), and high water content of NDWI -0.212828 to 0.155585 (458.15 hectares). The highest to lowest NDWI water content in a row is the high NDWI class, followed by medium and lastly low, as shown in Table 4 and Figure 1.

Table 5. NDWI water content level in 2015 (in hectares)

| Level of water content | NDWI Class          | Area (Hectares) |
|------------------------|---------------------|-----------------|
| High water content     | -0.212828 to 0.155585 | 458.15          |
| Medium water content   | -0.581242 to -0.212828 | 1250.13         |
| Low water content      | -0.949655 to -0.581242 | 2636.21         |

Source: Landsat 8 Oil image analysis in 2015
The spatial pattern of water content for 2015 shows that the water content class is relatively high in coastal areas with sloping topography. The movement pattern of non-vegetation land, such as settlements and built-up areas, is centered in the coastal zone, the center of the economy and government of the capital city of Maluku Province and Ambon City. The development concentration is centered in the coastal area, the estuary for the five research watersheds, as shown in Figure 1.

Figure 1. The spatial pattern of water content in the five watersheds of Ambon City in 2015

The trend of water content variation for the 2019 period also shows a relatively uniform pattern for the three NDWI classes. The movement pattern of water content in the five research watersheds shows water content for the Batu Merah, Wae Ruhu, Batu Gajah, Batu Gantung, and Wae Tomu watersheds same relative spatial pattern. The variation of all water content classes for 2019 has a more dominant water content in the moderate to high NDWI class, as presented in Table 5 and Figure 2.

| Level of water content | NDWI Class     | Area (Hectares) |
|------------------------|----------------|-----------------|
| High water content     | -0.212828 to 0.155585 | 396.06          |
| Medium water content   | -0.581242 to -0.212828 | 892.81          |
| Low water content      | -0.949655 to -0.581242 | 3055.60         |

Source: Landsat 8 Oil image analysis in 2015

Water content in the 2015 and 2019 period shows that the water content's movement pattern has changed for all study watersheds. The water content experienced a shift in the high water content class, followed by the medium and low water content classes. It can be traced from the direction of changes in the movement of non-vegetation areas, especially the distribution of community settlements, which have begun to shift towards hilly areas. The rate of population growth causes the rate of change in land cover to increase sharply so that the spatial pattern of changes in water content changes significantly.
3.2 Hydrological characteristics of small island watersheds

The discharge and basic flow calculation results for 2015 and 2019 use the BFLOW hydrooffice12.0 filter module and set the $\alpha$ value of 0.85. The results of the calculation of the average monthly discharge, base flow, and baseflow index for the 2015 period for the Wae Batu Merah watershed are a discharge of 0.39 m³/sec to 0.60 m³/sec; base flow 0.32 m³/sec to 0.43 m³/sec, and a BFI index of 0.79 to 0.94. The Wae Ruhu watershed's hydrological characteristics have an average monthly discharge of 0.139 m³/sec to 1.92 m³/sec; base flow 0.11 m³/sec to 1.15 m³/sec, and BFI index 0.76 to 0.93. The monthly average discharge value for the Wae Gajah watershed is 0.54 m³/sec to 1.02 m³/sec; base flow 0.45 m³/sec to 0.89 m³/sec s, and BFI index 0.79 to 0.92. The hydrological condition of the Wae Batu Gantung watershed has an average monthly discharge of 0.39 m³/sec to 0.75 m³/sec; base flow 0.34 m³/sec to 0.57 m³/sec, and BFI index 0.83 to 0.90; and finally the Wae Tomu watershed has an average monthly discharge of 0.40 m³/sec to 0.77 m³/sec; base flow 0.29 m³/sec to 0.58 m³/sec, and BFI index 0.78 to 0.86. The average monthly discharge variation, baseflow, and baseflow index for the five watersheds were relatively uniform in the 2015 period, as presented in Table 6 and Figure 3.

Table 7. Characteristics of average monthly debit, base flow, and BFI index for the period 2015

| Month    | Wae Batu Merah | Wae Ruhu | Wae Batu Gajah | Wae Batu Gantung | Wae Tomu |
|----------|----------------|----------|----------------|------------------|----------|
|          | Disch. | Base | BFI  | Disch. | Base | BFI  | Disch. | Base | BFI  | Disch. | Base | BFI  | Disch. | Base | BFI  |
| January  | 0.44   | 0.32 | 0.79 | 0.25   | 0.16 | 0.82 | 0.83   | 0.59 | 0.79 | 0.44   | 0.35 | 0.83 | 0.59   | 0.45 | 0.80 |
| February | 0.41   | 0.34 | 0.87 | 0.21   | 0.13 | 0.82 | 0.80   | 0.72 | 0.92 | 0.41   | 0.35 | 0.89 | 0.48   | 0.38 | 0.80 |
| March    | 0.39   | 0.35 | 0.94 | 0.13   | 0.11 | 0.87 | 0.77   | 0.70 | 0.92 | 0.39   | 0.34 | 0.88 | 0.40   | 0.29 | 0.78 |
| April    | 0.59   | 0.42 | 0.88 | 0.23   | 0.17 | 0.83 | 0.81   | 0.67 | 0.88 | 0.59   | 0.45 | 0.87 | 0.52   | 0.41 | 0.84 |
| May      | 0.44   | 0.37 | 0.89 | 0.92   | 0.45 | 0.78 | 0.91   | 0.77 | 0.89 | 0.53   | 0.40 | 0.85 | 0.44   | 0.34 | 0.84 |
| June     | 0.41   | 0.35 | 0.89 | 1.92   | 1.15 | 0.80 | 0.93   | 0.79 | 0.89 | 0.41   | 0.35 | 0.90 | 0.77   | 0.58 | 0.82 |
| July     | 0.39   | 0.34 | 0.90 | 0.70   | 0.41 | 0.80 | 0.98   | 0.82 | 0.89 | 0.43   | 0.35 | 0.89 | 0.52   | 0.39 | 0.79 |
| August   | 0.60   | 0.43 | 0.88 | 0.27   | 0.23 | 0.93 | 0.99   | 0.88 | 0.92 | 0.65   | 0.45 | 0.86 | 0.59   | 0.45 | 0.79 |
| September| 0.42   | 0.36 | 0.90 | 0.31   | 0.16 | 0.76 | 1.02   | 0.84 | 0.89 | 0.44   | 0.38 | 0.90 | 0.48   | 0.34 | 0.78 |
| October  | 0.39   | 0.34 | 0.91 | 0.22   | 0.16 | 0.81 | 0.99   | 0.89 | 0.92 | 0.48   | 0.39 | 0.88 | 0.56   | 0.45 | 0.86 |
Table 8. Characteristics of average monthly discharge, base flow, and BFI index for the period 2019

| Month   | Wae Batu Merah | Wae Ruhu | Wae Batu Gajah | Wae Batu Gantung | Wae Tomu |
|---------|----------------|----------|----------------|------------------|----------|
|         | Disch. Flow    | BFI      | Disch. Flow    | BFI              | Disch. Flow | BFI |
| January | 0.26           | 0.23     | 0.25           | 0.2             | 0.59      | 0.51 |
|         | 0.92           | 0.92     | 0.92           | 0.92             | 0.92      | 1.00 |
| February| 0.26           | 0.23     | 0.23           | 0.2             | 0.66      | 0.51 |
|         | 0.9            | 0.9      | 0.51           | 0.85             | 0.93      | 0.80 |
| March   | 0.23           | 0.21     | 0.23           | 0.2             | 0.61      | 0.49 |
|         | 0.92           | 1.0      | 0.85           | 0.86             | 0.93      | 0.75 |
| April   | 0.38           | 0.27     | 0.38           | 0.28             | 0.54      | 0.46 |
|         | 0.81           | 0.81     | 0.88           | 0.88             | 0.85      | 0.83 |
| May     | 0.33           | 0.27     | 0.33           | 0.26             | 0.74      | 0.58 |
|         | 0.91           | 0.91     | 0.88           | 0.84             | 0.93      | 0.76 |
| June    | 0.32           | 0.29     | 0.33           | 0.29             | 0.6       | 0.52 |
|         | 0.92           | 0.92     | 0.92           | 0.92             | 0.93      | 0.90 |
| July    | 0.28           | 0.24     | 0.31           | 0.25             | 0.58      | 0.51 |
|         | 0.88           | 0.88     | 0.88           | 0.88             | 0.91      | 0.87 |
| August  | 0.35           | 0.29     | 0.41           | 0.35             | 0.86      | 0.89 |
|         | 0.87           | 0.87     | 0.89           | 0.89             | 0.86      | 0.86 |

Figure 3. The hydrological characteristics of the discharge and baseflow of the five Ambon City watersheds for the 2015 period

The calculation of hydrological characteristics for 2019 shows changes in the five watersheds' three flow components. The Wae Batu Merah watershed's hydrological characteristics have decreased from the previous period with an average monthly discharge of 0.23 m$^3$/sec to 0.38 m$^3$/sec; baseflow 0.21 m$^3$/sec to 0.29 m$^3$/sec, and BFI index 0.83 to 0.92. The Wae Ruhu watershed characteristics also decreased the three flow components, successively discharged from 0.23 m$^3$/sec to 0.41 m$^3$/sec; baseflow was 0.19 m$^3$/sec to 0.35 m$^3$/sec, and BFI index 0.81 to 0.90. The Wae Batu Gajah watershed's hydrological characteristics are the monthly average discharge of 0.53 m$^3$/sec to 0.74 m$^3$/sec; baseflow 0.44 m$^3$/sec to 0.58 m$^3$/sec, and BFI index 0.84 to 0.92. The three flow components for the Wae Batu Gantung Watershed are the monthly average discharge of 0.26 m$^3$/sec to 0.43 m$^3$/sec; base flow 0.21 m$^3$/sec to 0.35 m$^3$/sec, and BFI index 0.83 to 0.91; and finally the Wae Tomu watershed has an average monthly discharge of 0.05 m$^3$/sec to 0.86 m$^3$/sec; base flow 0.03 m$^3$/sec to 0.53 m$^3$/sec, and BFI index 0.70 to 0.84. The variation of the three flow components has decreased, as shown in Table 7 and Figure 4.
The hydrological characteristics (discharge and baseflow) between 2015 and 2019 show a significant change trend. The visualization of hydrological changes is relatively fluctuating from April to June 2015, and there is an increasing flow from July to September 2015. However, from November to December 2015, it is relatively uniform. While the 2019 period's hydrological characteristics show that the visualization of discharge and base flow is relatively consistent in January to June, then in July to September, the flow increases and is relatively uniform in October. However, in November, the flow conditions fluctuate somewhat with decreasing relative flow. Flow conditions in December were relatively fluctuating and increasing. Land cover changes strongly influence the visualization of small island watersheds' hydrological characteristics in the watershed ecosystem. Small island watershed morphometry is a locus that is hydro-morphometrically very vulnerable to changes in the global environment. It is in line with the hydro-morphometric conditions of small island watersheds that affect water systems, especially flood vulnerability and riverbed flow storage and groundwater drainage [39]–[41].

Drainage density is an essential factor related to flood vulnerability and groundwater drainage. Likewise, the river branching ratio affects watershed conditions in high peak flood discharge and short recession times. This condition tends to have a high flood susceptibility characterized by high surface runoff but low permeability and infiltration. A bifurcation ratio factor determines the watershed's shape concerning peak flood discharge, fast-rising times, and fast recession times. This condition creates a high vulnerability to small island watersheds [42].

| Month    | September | October | November | December |
|----------|-----------|---------|----------|----------|
| Discharge| 0.29      | 0.27    | 0.3      | 0.29     |
| Baseflow | 0.24      | 0.24    | 0.88     | 0.26     |
|           | 0.9       | 0.94    | 0.31     | 0.9      |
|           | 0.36      | 0.34    | 0.27     | 0.33     |
|           | 0.28      | 0.27    | 0.9      | 0.27     |
|           | 0.89      | 0.87    | 0.9      | 0.89     |
|           | 0.73      | 0.53    | 0.6      | 0.51     |
|           | 0.58      | 0.44    | 0.89     | 0.84     |
|           | 0.87      | 0.27    | 0.25     | 0.25     |
|           | 0.09      | 0.23    | 0.08     | 0.25     |
|           | 0.89      | 0.59    | 0.12     | 0.84     |
|           | 0.8       | 0.37    | 0.84     | 0.36     |
|           | 0.53      | 0.76    | 0.84     | 0.29     |
|           | 0.79      |         | 0.31     | 0.53     |

Source: Hydrological data analysis, 2019
3.3 Correlation of NDWI water content and BFI base flow index

The NDWI water content's spatial pattern shows that the water content shift in the five watersheds during the study period. Land change factor is one of the critical dynamic factors in influencing small island watersheds' hydrologic characteristics. The NDWI water content's spatial pattern correlates with the watershed's hydrological characteristics with a coefficient of determination $R^2$-adjusted 0.382, namely, the NDWI water content index and hydrological characteristics correlate (38.8%). The smaller the SEE, the more precise the regression model will be in predicting the dependent variable.

Table 9. Regression models for the relationship between spatial patterns of water content and hydrological characteristics

| Model | R    | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
|-------|------|----------|------------------|---------------------------|---------------|
| 1     | 0.645$^a$ | 0.416   | 0.382            | 0.103                     | 1.271         |

Remark: predictors: (constant), NDWI algorithm, watershed area (km2), river gradient (m), elevation (m dpal), drainage density (km / km²); dependent variable: flowrate and base flow (m³/sec)

The simultaneous correlation value using the ANOVA test obtained an F-count value = 4.234, more significant than the F-table 2.367 at a significance of 0.001 < 0.05, which means that there is an influence between the NDWI water content on the hydrological characteristics (discharge and baseflow) significantly for the research watershed.

4. Conclusion

The spatial pattern of water content changes in the study period shows that water content changes tend to experience significant coastal area changes. The spatial pattern of shifting the water index has developed, especially in dense settlements in coastal areas. In 2019, the spatial pattern moved to the mountainous area, the water catchment area in Ambon City, and became a concern to affect the small island watershed's hydrological characteristics. The visualization of hydrological characteristics showing trends that have fluctuated in the period of the study. The correlation analysis results show that variations in the spatial pattern of water content and hydrological characteristics of small island watersheds have a strong negative relationship. These results suggest that if the spatial pattern of water content in areas with massive vegetation cover changes will affect the watershed ecosystem's hydrology. Thus, mitigation efforts and adaptation to changes in small island watershed ecosystems need to be accommodated in planning and managing land and water resources in small island areas.

5. Acknowledgment

The authors would like to thank the head and staff of the River Basin Station at Maluku Province for providing the authors with the opportunity to utilize the data recorded at the stream gauge stations installed at the researched watersheds.

References

[1] Latuamury B, Aponno H S E S, Marasabessy H, Hadijah M H, and Imlabla W N 2020 The spatial dynamics of land cover change along the Wallacea corridor in the key biodiversity area Buano Island Maluku, Indonesia, *J. Degrad. Min. Lands Manag.* 7(4) doi: 10.15243/JDMLM.2020.074.2373.

[2] Gao B C 1996 NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space, *Remote Sens. Environ.*, doi: 10.1016/S0034-4257(96)00067-3.

[3] Ji L, Zhang L, and Wylie B 2009 Analysis of dynamic thresholds for the normalized difference water index, *Photogramm. Eng. Remote Sensing* doi: 10.14358/PERS.75.11.1307.

[4] Zarco P J-Tejada, Rueda C A, and Ustín S L 2003 Water content estimation in vegetation with MODIS reflectance data and model inversion methods *Remote Sens. Environ.* doi: 10.1016/S0034-4257(02)00197-9.

[5] Estallo E L 2012 Effectiveness of normalized difference water index in modelling Aedes
aegypti house index, *Int. J. Remote Sens.* doi: 10.1080/01431161.2011.640962.

[6] Jackson T J 2004 Vegetation water content mapping using Landsat data derived normalized difference water index for corn and soybeans, in *Remote Sensing of Environment* doi: 10.1016/j.rse.2003.10.021.

[7] Wibowo A, Sukoco B M, Harianto T, and Djajadihardja Y S 2015 Ekstraksi Kandungan Air Kanopi Daun Padi dari Data Ground Field Spectrometer dan Airborne-Hyperspectral, pp. 12–25.

[8] Delbart N., Kergoat L, Le Toan T, Lhermitte J, and Picard G 2005 Determination of phenological dates in boreal regions using normalized difference water index, *Remote Sens. Environ.* doi: 10.1016/j.rse.2005.03.011.

[9] Kaplan G and Avdan U 2017 MAPPING AND MONITORING WETLANDS USING SENTINEL-2 SATELLITE IMAGERY, in *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* doi: 10.5194/isprs-annals-IV-4-W4-271-2017.

[10] Suprayogi A and Sasmito B 2018 Kajian Ekstraksi Unsur Dalam Identifikasi Tutupan Lahan Berbasis Layer Stacking Indeks Citra (Studi Kasus: Kecamatan Wedarijaksu, Kabupaten Pati) *J. Elipsoida* 01(01) 26–32.

[11] Zhou Y 2017 Open surface water mapping algorithms: A comparison of water-related spectral indices and sensors, *Water (Switzerland)* doi: 10.3390/w9040256.

[12] Mallinis G, Emmanoloudis D, Giannakopoulos V, Maris F., and Koutsias N 2011 Mapping and interpreting historical land cover/land use changes in a Natura 2000 site using earth observational data: The case of Nestos delta, Greece, *Appl. Geogr.* 31(1) 312–320 doi: 10.1016/j.apgeog.2010.07.002.

[13] Schmitt K, Albers T, Pham T T, and Dinh S C 2013 Site-specific and integrated adaptation to climate change in the coastal mangrove zone of Soc Trang Province, Viet Nam, *J. Coast. Conserv.* doi: 10.1007/s11852-013-0253-4.

[14] Van De Griend A A and Owe M 1993 On the relationship between thermal emissivity and the normalized difference vegetation index for natural surfaces, *Int. J. Remote Sens.* doi: 10.1080/01431169308904400.

[15] Rokni K, Ahmad A, Selamat A, and Hazini S 2014 Water feature extraction and change detection using multitemporal landsat imagery *Remote Sens.* doi: 10.3390/rs6054173.

[16] H. Xu 2006 Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery, *Int. J. Remote Sens.* doi: 10.1080/01431160600589179.

[17] Acharya T D, Subedi A, and Lee D H 2018 Evaluation of water indices for surface water extraction in a landsat 8 scene of Nepal, *Sensors (Switzerland)* doi: 10.3390/s18082580.

[18] Yang X, Zhao S, Qin X, Zhao N, and Liang L 2017 Mapping of urban surface water bodies from sentinel-2 MSI imagery at 10 m resolution via NDWI-based image sharpening, *Remote Sens.* doi: 10.3390/rs9060596.

[19] Zha Y, Gao J, and Ni S 2003 Use of normalized difference built-up index in automatically mapping urban areas from TM imagery, *Int. J. Remote Sens.* doi: 10.1080/014311603409487.

[20] Yang H, Wang Z, Zhao H, and Guo Y 2011 Water body extraction methods study based on RS and GIS, in *Proceedia Environmental Sciences* doi: 10.1016/j.proenv.2011.09.047.

[21] Chen X L, Zhao H M, Li P X, and Yin Z Y 2006 Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes,” *Remote Sens. Environ.* doi: 10.1016/j.rse.2005.11.016.

[22] McFeeters S K 1996 The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features, *Int. J. Remote Sens.* doi: 10.1080/01431169608948714.

[23] Parsa M, Dirghayu D, and Harini S 2019 Pengembangan Metode Klasifikasi Lahan Sawah Berbasis Indeks Citra Landsat Multiwaktu (Development of Paddy Field Classification Method Based on Multi-Temporal Indeces of Landsat Images ), *J. Penginderaan Jauh dan Pengolah. Data Citra Digit.* 1(1) 35–44.

[24] Huete A, Didan K, Miura T, Rodriguez E P, Gao X, and Ferreira L G 2002 Overview of the radiometric and biophysical performance of the MODIS vegetation indices, *Remote Sens. Environ.* doi: 10.1016/S0034-4257(02)00096-2.
[25] Li W 2013 A comparison of land surface water mapping using the normalized difference water index from TM, ETM+ and ALI, Remote Sens. doi: 10.3390/rs5115530.

[26] Maria Octarina T, Dewa Nyoman I, Putra N., and Kadek Ayu Wirdiani N2019 Penginderaan Jauh Pemrosesan Data Satelit Landsat 8 Untuk Deteksi Genangan, J. Ilm. Merpati (Menara Penelit. Akad. Teknol. Informasi), 7(1) 77 doi: 10.24843/jim.2019.v07.i01.p09.

[27] Roy D P, Boschetti L, and Trigg S N 2006 Remote sensing of fire severity: Assessing the performance of the normalized burn ratio, IEEE Geosci. Remote Sens. Lett. doi: 10.1109/LGRS.2005.858485.

[28] Myneni R B 1997 Estimation of global leaf area index and absorbed par using radiative transfer models, IEEE Trans. Geosci. Remote Sens. doi: 10.1109/36.649788.

[29] She X, Zhang L, Cen Y, Wu T, Huang C, and Baig M H A 2015 Comparison of the continuity of vegetation indices derived from Landsat 8 OLI and Landsat 7 ETM+ data among different vegetation types, Remote Sens. doi: 10.3390/rs71013485.

[30] Villar R G, Pelayo J L, Bantugan J, and Opiso E 2017 Algorithm for modeling agricultural land cover classification and land surface temperature,” in GIS&T 2017 - Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management.

[31] Zhai K, Wu X, Qin Y, and Du P 2015 Comparison of surface water extraction performances of different classic water indices using OLI and TM imageries in different situations, Geo-Spatial Inf. Sci. doi: 10.1080/10095020.2015.1017911.

[32] Ahn K H and Merwade V 2016 Role of watershed geomorphic characteristics on flooding in Indiana, United States, J. Hydrol. Eng., 21(2) doi: 10.1061/(ASCE)HE.1943-5584.0001289.

[33] Dutta D, Das S N, Sharma J R, and Radhakrishnan K 2001 Watershed Morphometry and Land Characteristics for Watershed Hydrological Response Analysis: A Remote Sensing and GIS-based Approach, Ann. Arid Zone, 40(1).

[34] Mangan P, Haq M A, and Baral P 2019 Morphometric analysis of watershed using remote sensing and GIS—a case study of Nanganji River Basin in Tamil Nadu, India, Arab. J. Geosci. 12(6) doi: 10.1007/s12517-019-4382-4.

[35] JRC 2011 NDWI (Normalized Difference Water Index), Product Fact Sheet.

[36] Eckhardt K 2008 A comparison of baseflow indices, which were calculated with seven different baseflow separation methods,” J. Hydrol. 352(1–2) 168–173 doi: 10.1016/j.jhydrol.2008.01.005.

[37] Gregor M 2010 Manual: Bfi+ 3.0.” Department of Hydrogeology, Faculty of Natural Science, Comenius University Bratislava, Slovakia, Slovakia.

[38] Wang L and Qu J J 2007 NMDI: A normalized multi-band drought index for monitoring soil and vegetation moisture with satellite remote sensing, Geophys. Res. Lett. doi: 10.1029/2007GL031021.

[39] Balzan M V, Potschin-Young M, and Haines-Young R 2018 Island ecosystem services: Insights from a literature review on case-study island ecosystem services and future prospects,” International Journal of Biodiversity Science, Ecosystem Services and Management 14(1) doi: 10.1080/21513732.2018.1439103.

[40] Scandurra G, Romano A A, Ronghi M, and Carfora A 2018 On the vulnerability of Small Island Developing States: A dynamic analysis, Ecol. Indic. 84 doi: 10.1016/j.ecolind.2017.09.016.

[41] Sith R, Watanabe A, Nakamura T, Yamamoto T, and Nadaoka K 2019 Assessment of water quality and evaluation of best management practices in a small agricultural watershed adjacent to Coral Reef area in Japan, Agric. Water Manag. 213 doi: 10.1016/j.agwat.2018.11.014.

[42] Jazwa C S, Duffý C J, Leonard L, and Kennett D J 2016 Hydrological Modeling and Prehistoric Settlement on Santa Rosa Island, California, USA, Geoarchaeology, 31(2), doi: 10.1002/gea.21532.