Journal of Geographical Studies
Homepage: www.gathacognition.com/journal/gcj5
http://dx.doi.org/10.21523/gcj5

Original Research Paper

Correlating Spatial Pattern of Canopy Greenness Derived from the NDVI with Hydrological Characteristics of Small Island Watersheds

Bokiraiya Latuamury*, **Moda Talaohu**

Department of Forestry, Faculty of Agriculture, University of Pattimura, Jl. Ir. M. Putuhena Kampus Universitas Pattimura, Poka, Ambon, Indonesia.

Abstract

Watershed ecosystem monitoring and evaluation indicators need to factor in land cover/use change rationally and adaptively. Vegetation canopy greenness can be utilized to seek an accurate solution to various land cover/use change issues, for example, by applying the Normalized Difference Vegetation Index (NDVI) algorithm. This research set out to analyze the relationship between the spatial pattern of canopy greenness and small island watersheds' hydrological characteristics. It used NDVI algorithm extraction and BFLOW+ 3.0 filter in the HydroOffice 12.0 program and then examined the two resulting datasets using correlation analysis. The results showed that the spatial pattern of canopy greenness derived from NDVI changed significantly near the river mouth. The densely populated settlements in the coastal stretch continued to sprawl towards mountainous regions, which naturally function as recharge zones. Meanwhile, the hydrological characteristics displayed a fluctuating trend during the observation period (2015-2019). Based on the correlation analysis, canopy greenness patterns and hydrological features form a positive and relatively strong relationship (38.8%). For this reason, ecological shifts in small island watersheds require climate change mitigation and adaptation measures.

Article history

Received: 30 August 2020
Revised: 29 January 2021
Accepted: 23 February 2021

Keywords

Canopy;
Greenness;
Hydrological Characteristics;
Island Watershed;
NDVI;
Spatial Pattern.

Editor(s)

M. A. Siddiqui,
Vijay Bhagat

1 INTRODUCTION

A watershed is a natural system where hydrological-biophysical processes and socio-economic and cultural activities occur (Latuamury *et al.*, 2020). Hydrological-biophysical methods are realistic activities that compose a hydrological cycle (Latuamury and Talaohu, 2020). Socio-economic and cultural activities are human interventions in the natural system (Arnanto, 2015; Wardiningsih and Salam, 2019). These two watershed components are inseparable, given that the demand for water, soil, and forest resources has been persistently increasing as a result of population growth and impacting the hydrological system (Eryani, 2014; Junaidi and Tarigan, 2011). Among the significant causes of disruptions to the watershed ecosystem is the intensity of uncontrolled land-use shift that has worsened the hydrological state, flow regime (especially peak discharge), inter-seasonal discharge fluctuation, and surface runoff coefficient and ultimately led to floods and droughts.

In a watershed, hydrological responses serve as indicators of damage and the basis for monitoring and evaluating the effects of land cover/use change on flow characteristics (Fuady and Azizah, 2013; Paimin *et al.*, 2012). Normalized Difference Vegetation Index (NDVI) is an approach to mitigate the rate of such conversion as it can monitor the degree of canopy greenness or vegetation density over time by analyzing digital brightness levels, which depend on the waves received by digital recording devices of Sentinel (Candiago *et al.*, 2015; Sobrino *et al.*, 2008). Healthy vegetation absorbs more visible (infrared) light waves and reflects substantial amounts of near-infrared light waves.

* Author's address for correspondence
Department of Forestry, Facculty of Agriculture, University of Pattimura, Jl. Ir. M. Putuhena Kampus Universitas Pattimura, Poka, Ambon, Indonesia.
Tel.: +62 81248921894
Emails: okky.environmentalscience@gmail.com (*B. Latuamury* -Corresponding author); talaohu.moda73@gmail.com (*M. Talaohu*).

https://dx.doi.org/10.21523/gcj5.21050101

The use of remote sensing technology in varying satellites and sensors to produce NDVI has increased in many studies in natural resources and the environment. The advancement of remote sensing technology and geographic information systems has been used to implement NDVI in these fields over the last decades. For instance, Gu *et al*. (2008) used MODIS imagery for NDVI and NDWI evaluation to monitor vegetation drought. Escuin *et al*. (2008) utilized NDVI processed from Landsat ETM imagery to assess the severity of fire based on pre-and post-fire conditions. Latuamury and Gunawan (2013) have developed NDVI to analyze the relationship between vegetation density and river base flow recession characteristics, Mekliche *et al*. (2015) utilized it to analyze wheat grain production under two different irrigation conditions, and Gandhi *et al*. (2015) used it for the distribution of humanitarian assistance and natural disaster prediction and assessment. Wilson and Norman (2018) combined NDVI with NDII as part of land and watershed restoration efforts, and Pravita (2019) compared several NDVI transformation algorithms to analyze mangrove area density.

The development of NDVI using Sentinel imagery to understand the hydrological characteristics of small island ecosystems, such as Ambon City in Maluku Province, is under-researched. Simultaneously, spatial databases' availability is vital in planning for regional development as well as land and water resources management. Therefore, this study was intended to analyze the transformation algorithm of canopy greenness using NDVI and its relation to hydrological characteristics in five small island watersheds in Ambon City, Maluku Province.

2 DATA AND METHODS

2.1 Study Area

Ambon city consists of many watersheds, five of which were selected for this research because of their unique spatial dynamics, namely land-cover/use conversion of the riverbank area that has implications for ecological sustainability. The morphometric characteristics of these watersheds and the locations of stream gauge stations are presented in table 1.

2.2 Research Procedure

2.2.1 Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) is a simple numerical indicator used to analyze remote sensing-based measurements and assess vegetation and non-vegetation objects (Latuamury and Gunawan, 2013). It compares the reflections of red (R) and near-infrared (NIR) electromagnetic spectra. Both spectra were selected because they have a more in-depth ability to absorb chlorophyll and thereby reflect vegetation density; also, the near-infrared and red channels can clearly distinguish between vegetation and` non-vegetation objects. In this context, NDVI can be quantified using two mathematical formulations (Chuvieco *et al*., 2005; Sobrino *et al*., 2008). Equation (1) was used to calculate NDVI using Sentinel image data processing in the ArcGIS program.

$$NDVI = \frac{NIR-R}{NIR+R} \quad (1)$$

NDVI produced with equation (1), however, needs radiometric correction, while equation (2) below offers NDVI calculation without having to perform radiometric correction:

$$NDVI = \frac{(NPimd\text{-}NPimd\_min) - (NPm - NPm\_min)}{(NPimd\text{-}NPimd\_min) + (NPm - NPm\_min)} \quad (2)$$

where,

NPimd = pixel values of near-infrared

NPm = pixel values of red

NPimd_min = minimum pixel values of near-infrared

NPm_min = minimum pixel values of red

NDVI calculations always result in a number ranging from -1 to +1. NDVI < 0 indicates water objects (i.e., swamps, lakes, and other depression reservoirs), NDVI=0 reflects built-up areas, such as houses and buildings NDVI=1 shows vegetation objects. Canopy greenness can be differentiated into five classes from the lowest to the highest NDVI values, as presented in table 2.

Table 1. The morphometric characteristics of the observed watersheds

Watersheds	Stream gauge station coordinates		Watershed length (km)	Watershed width (km)	Circumference (km)
	X	Y			
Wae Batu Merah	412023	9592046.6	4.69	2.65	23.12
Wae Ruhu	414316,7	9592304,7	6.46	3.29	47.96
Wae Batu Gajah	410838,4	9589732,2	5.22	2.25	18.49
Wae Batu Gantung	409226,4	9588543,2	4.92	4.24	25.32
Wae Tomu	411234,2	9590862,9	5.10	1.55	12.90

Source: Indonesia Topographic Map (RBI), BPDAS-HL of Maluku Province

2.2.2 Hydrological Characteristics

Watershed characteristics contain specific descriptions of parameters related to morphometric, hydrological, and geological conditions, topography, soil, vegetation and land use, and human occupations (Ekawati *et al.*, 2005; Harjadi and Paimin, 2013). Therefore, a particular method or procedure needs to be formulated as a basis for characterizing a sub-watershed as a whole (Paimin and Pramono, 2009). Watershed develops widely varying characteristics as the product of interactions between many factors that can also consist of several integrated sub-factors. Moreover, they cannot be generalized since every watershed has its unique character and facilitates different interactions between its constituent ecosystems (Paimin *et al*., 2012).

Morphometric characteristics observed in this study included watershed area (km^2), the total length of river network (km), main stream gradient (the difference between the highest and lowest elevations per horizontal distance; km), the elevation of the middle point (m), length of the main stream (km), Circularity Ratio (Rc), Bifurcation Ratio (Rb), form factor, drainage pattern, and landform. These physical characteristics are described in table 3.

Hydrological characteristics of small island watersheds were processed in the HydroOffice 12.0 program using the BFI^+ 3.0 module, specifically Recursive Digital Filter (RDF) and the filtering algorithm proposed by Lyne & Hollick 1979 (Nathan and McMohan, 1990), as summarized in table 4.

3 RESULTS AND DISCUSSIONS

3.1 Canopy Greenness using NDVI Algorithm for 2015 and 2019 Images

The analysis of two Sentinel images recorded in 2015 and 2019 produced details on canopy greenness variation. In 2015, the image showed that the four classes of NDVI in the five selected watersheds had a relatively uniform trend of variation and area of coverage. Wae Ruhu, Wae Batu Gajah, and Wae Batu Gantung Watersheds had a high canopy greenness level, followed by Wae Batu Merah and Wae Tomu. The first three watersheds also had the most extensive area for the medium, low, and very low canopy greenness levels. Overall, high and medium NDVI values dominated the canopy greenness of the watersheds observed in 2015, as summarized in table 4 and figure 1.

Table 2. Classification of canopy greenness based on NDVI

Ranges	Criteria
-0.0885 - 0.1186	Very low canopy greenness
0.1186 - 0.3257	Low canopy greenness
0.3257 - 0.5328	Medium canopy greenness
0.5328 - 0.7399	High canopy greenness

Table 3. Morphometric parameters and hydrological characteristics of small island watersheds

No.	Variables	Assumptions in flood susceptibility	Equations/ Methods	Criteria	Classificat-ions
1	Drainage density (Dd) (Seyhan, 1977)	Low Dd: - Low permeability and infiltration - Low erosion and flood susceptibility High Dd: - Impermeable - Severe erosion and high flood susceptibility	$Dd = (\sum L) / A$ Dd: drainage density (km/ km^2) L: total stream length (km) A: watershed area (km^2)	- Very good drainage - Good drainage - Poor drainage, frequently inundated	$Dd < 1$ $1 < Dd < 5$ $Dd > 5$
2	Bifurcation Ratio (Rb) (Horton, 1932)	High Rb: (> / <) or < 1 - Accelerated erosion, low infiltration - High flood susceptibility Low Rb (< / >) or > 1 - Deep aquifer, large infiltration - Low surface runoff	$Rb = N / (Nu + 1)$ Rb: Specified order of stream segments N: number of streams in first order Nu + 1: number of streams in the next higher-order (u+1)	- Not normal, high flood peak, slow recession - Normal, medium flood peak, medium recession - Not normal, high flood peak, fast recession	$Rb < 0.3$ $0.3 < Rb < 0.5$ $Rb > 0.5$

3	Circularity Ratio (Rc) (Horton, 1932) in Seyhan, (1977)	A semi-fully circular watershed produces high peak discharge, with short time to peak, Tc < watershed length	Rc = 12,56 A / l Rc: watershed form A: watershed area l: watershed circumference	- Circular watershed, large Qp, short rising time (Tp), Tc < watershed length, i.e., fast recession - Elliptical watershed, medium Qp, long rising time (Tp), Tc = watershed length, i.e., slower time of recession - Elongated watershed, low Qp, long rising time (Tp), Tc > watershed length, i.e., slow recession	Rc > 0.67 0.34 < Rc < 0.66 Rc < 0.33
4	Flow Discharge Characteristics	Larger peak discharge (Q) means higher flood susceptibility	Q = Qpeak / watershed area Q = discharge per unit of area ($m^3/s/km^2$) Qmax: mean flow discharge (m^3/det) A: watershed area (km^2)	- Very good - Normal - Above normal	< 0.875 0.875 – 1 > 1

Table 4. Recursive digital filter in the $BFI^+3.0$ module

Filter methods	Mathematical equation	Notes
Lyne and Hollick's algorithm (Lyne and Hollick 1979; Nathan and McMohan, 1990)	$q_{f(i)} = aq_{f(i-1)} + (q_i - q_{(i-1)})\frac{1+\alpha}{2}$	$q_{f(i)} \geq 0$, where α= 0.925 is recommended for stream data filter and applied to three base flow phases, qb = q – qf.

Source: $BFI^+3.0$ module of the HydroOffice 12.0 program (Gregor, 2010)

In 2015, the spatial pattern revealed that the high greenness class still dominated areas with steep topography. Meanwhile, non-vegetation objects, such as settlements and other types of buildings, tended to form a cluster along the coastal area, which is the center of government and economic activities in Ambon City (capital of Maluku Province). Figure 1 shows that the spatial pattern in 2015 was composed of physical development concentrated in coastal areas i.e, the river mouths of five watersheds observed.

Like the 2015 pattern, the four classes of NDVI values in 2019 had a relatively uniform trend of variation and coverage area. However, the 2019 data showed a decreasing trend in the area of coverage in all researched watersheds. Nevertheless, Wae Ruhu, Wae Batu Gajah, and Wae Batu Gantung still had a generally high canopy greenness, followed by Wae Batu Merah and Wae Tomu. The first three watersheds also had the most extensive area for the medium, low, and very low canopy greenness levels. Overall, high and medium canopy greenness levels were dominant in the watersheds observed in 2019, as presented in table 5 and figure 2.

Table 5. Classification of canopy greenness derived from NDVI in 2015

Canopy Greenness Levels	Wae Batu Merah (%)	Wae Ruhu (%)	Wae Batu Gajah (%)	Wae Gantung (%)	Wae Tomu (%)
Very low	1.42	0.14	1.84	0.51	1.37
Low	17.48	9.22	9.72	9.51	10.99
Medium	16.33	21.98	15.62	13.96	18.77
High	64.77	68.66	72.81	76.01	68.87
Total	100	100	100	100	100

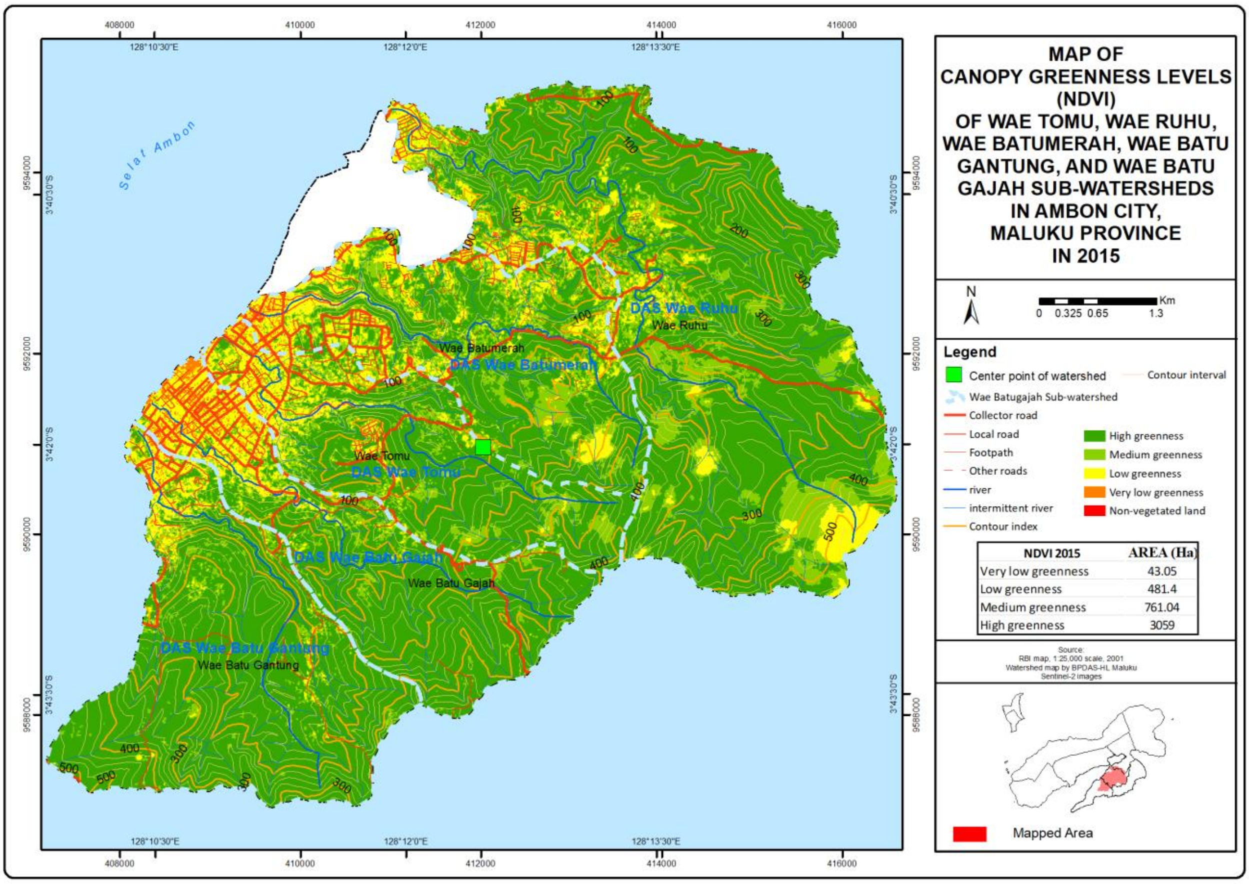

Figure 1. The spatial pattern of canopy greenness derived from NDVI in 2015

Table 6. Canopy greenness levels derived from NDVI in 2019

Canopy Greenness Levels	Wae Batu Merah (%)	Wae Ruhu (%)	Wae Batu Gajah (%)	Wae Gantung (%)	Wae Tomu (%)
Very low	0.13	0.09	0.11	0.11	0.10
Low	14.50	8.08	8.17	9.69	9.71
Medium	39.10	34.82	34.94	31.28	36.35
High	46.26	57.01	56.78	58.92	53.84
Total	100	100	100	100	100

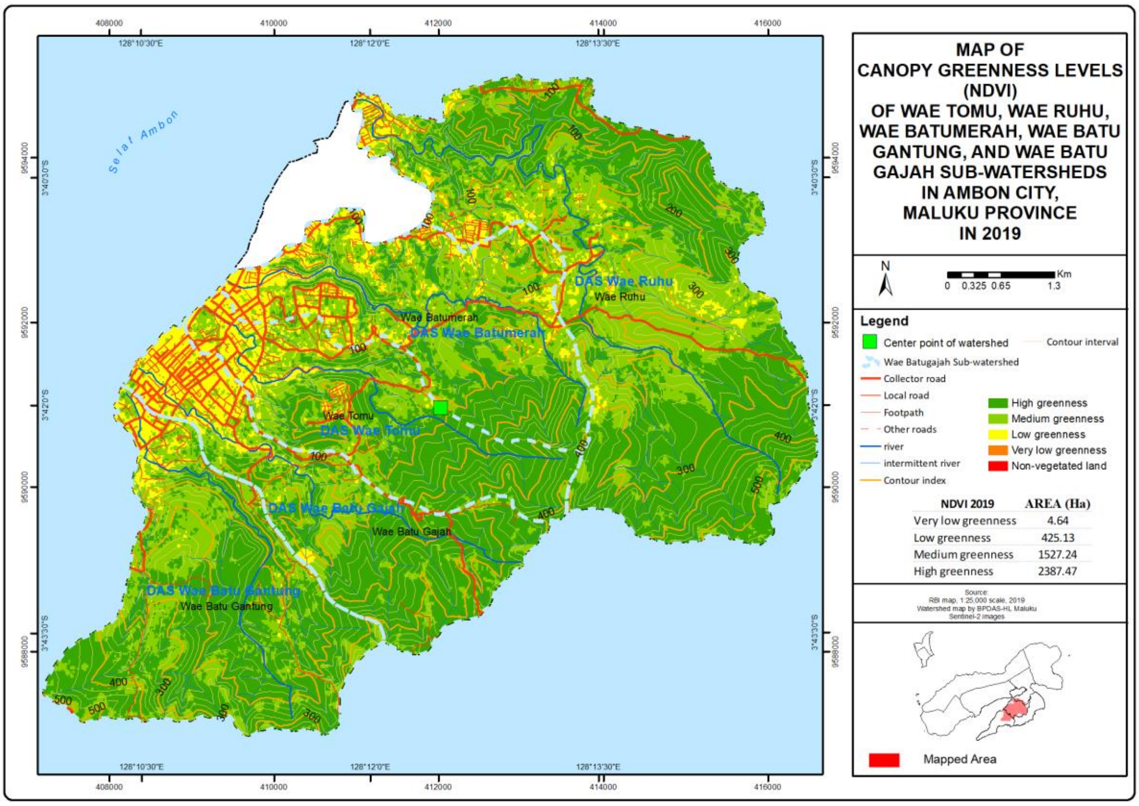

Figure 2. The spatial pattern of canopy greenness derived from NDVI in 2019

Based on the calculation results, differences in canopy greenness level between the 2015 and 2019 data indicated a trend of change in all classes of NDVI for all researched watersheds. The most significant change was found in the high greenness class, followed by low and very low classes, while the medium class in all watersheds experienced an increasing trend. These results can be traced to the changes in the direction of non-vegetated land growth, especially settlements that had started to sprawl into the mountainous areas in the east. Due to population growth and regional development in Ambon City, changes in the spatial pattern of canopy greenness have become categorically significant.

Analysis of GeoEye image with a 30m resolution using the 5m zone buffering from the river identified the spatial pattern of built-up land, which was dominant along the riparian zones on either side of the river in the five watersheds observed. The riparian zones, especially in the middle part and estuary of these watersheds, were occupied by settlements, government buildings, and centers of trade and economic activities, with high to very high building density. Their existence, therefore, disrupts the function of a riparian zone, which supposedly protects against floods and droughts.

3.2 Morphometric and Hydrological Characteristics

3.2.1 Morphometric Properties

Analyses of satellite images and topographic maps (Rupa Bumi Indonesia) found that the small island watersheds in Ambon city, Maluku province, were mainly characterized by the narrow and short mainstream. They also had a unique hydrological system that was responsive to existing climate change mitigation and adaptation strategies or generally similar to the ecosystem of other small island watersheds. The results of these analyses are summarized in table 6.

Table 6 shows that all watersheds had relatively small areas, with the most extensive and smallest areas identified in Wae Ruhu and Wae Tomu, respectively. Wae Ruhu had the highest average slope (12.34 m), while Wae Batu Gajah had the lowest (0.49 m). The longest main river (11.87 m) was found in Wae Ruhu, whereas the shortest (5.64 m) was in Wae Batu Gantung. Both Wae Batu Merah and Wae Batu Gajah had the highest circularity ratio, i.e., 12.56. Furthermore, the five watersheds' morphometric characteristics included stream gradients ranging between 300 m and 500 m, drainage density of 2-3 km/km^2, bifurcation ratio of averagely 0.9, and pinnate drainage pattern.

Drainage density (Dd) is a morphometric parameter indicating the effects of hydrological systems of a watershed on flood susceptibility and base flow/groundwater drainage. The five watersheds had excellent drainage density, with Dd varying from more than 1 to 5. The bifurcation ratio was more and less than 1, meaning that the watersheds are not expected as they experience a very high flood peak and have a short recession time. Moreover, they tend to have high surface runoff but low permeability and infiltration, precursors of high flood susceptibility. The bifurcation ratio of the five watersheds was 0.9. In other words, they have a round shape with very high peak discharge (Qp) and relatively short rising and recession times, all of which contribute to increased susceptibility to flooding.

3.2.2 Hydrological Characteristics

Based on the stream discharge and base flow calculations were performed using the BFLOW filter module of the Hydro-office 12.0 program (with α 0.85). The results of the analysis of the average monthly discharge, base flow, and base flow index for 2015 for the five watersheds show an average discharge of 0.51 m^3/sec - 0.57 m^3/sec; base flow 0.51 m^3/sec - 0.57 m^3/sec, and a BFI index of 0.52-0.59. The calculation results of the average monthly discharge, base flow, and base flow index for the 2019 period for the five watersheds are an average discharge of 0,51 m^3/sec - 0,57 m^3/sec; base flow 0.51 m^3/sec - 0,57 m^3/sec, and a BFI index of 0.52 - 0,59. The stream and base flow rates of the five watersheds during the research period are visualized in table 7 and figure 3.

As seen in figure 3, the watersheds observed were characterized by the stream, and base flow rates significantly changed in the 2015-2019 period. In 2015, these flow components showed fluctuating rates from April until June and an increasing trend from July until September but then tended to hover around 1 m^3/s throughout November and December. Meanwhile, in 2019, they were steady from January until June and had a similar increasing trend until October but tended to fluctuate with a relatively decreasing trend in November, before soaring up to 9.63 m^3/s (discharge) and 2.28 m^3/s (baseflow) in December.

In small island watersheds, the visualization of hydrological characteristics in 2015 and 2019 is primarily determined by the ecosystem's land-use dynamics. Morphometric properties are the locus of small island watersheds that are highly vulnerable to global environmental changes according to the hydro-morphometric perspective. The same case applies to hydro-morphometric conditions that affect small island watersheds, hydrological systems, especially concerning flood susceptibility and base flow/groundwater drainage.

Drainage density is a primary determinant of flood susceptibility and groundwater drainage. Likewise, the bifurcation ratio determines the shape of a watershed, which reflects flood peak discharge (high or low), time to peak (fast or slow), and recession time (short or long). The combination of high flood peak, quick time to peak, and short recession time induce high surface flow rates but low permeability and infiltration, causing small island watersheds to be highly susceptible to floods.

Table 7. Morphometric characteristics of small island watersheds in Ambon City, Maluku Province

Watersheds	Area (km^2)	Mean Slope Gradient (m)	Stream Gradient (m)	Length of Main Stream (km)	Drainage density (km/km^2)	Circularity Ratio (CR)	Bifurcation Ratio (BR)	Drainage Pattern
Wae Batu Merah	7.04	5.15	359.70	6.83	3.28	12.56	0.95	Pinnate
Wae Ruhu	15.80	12.34	524.98	11.87	3.03	9.04	0.98	Pinnate
Wae Batu Gajah	6.35	0.49	324.98	6.58	2.91	12.56	0.95	Pinnate
Wae Batu Gantung	8.63	5.84	264.17	5.64	2.93	7.51	0.95	Pinnate
Wae Tomu	5.62	4.89	349.98	6.14	3.16	5.47	0.93	Pinnate

Table 8. Characteristics of average monthly discharge, base flow, and BFlow index for the period 2015 and 2019

Name of watershed	2015			2019		
	Discharge	Base flow	BF index	Discharge	Base flow	BF index
Wae Batu Merah	0.51	0.53	0.52	0.51	0.53	0.52
Wae Ruhu	0.53	0.55	0.55	0.53	0.55	0.55
Wae Batu Gajah	0.57	0.57	0.59	0.57	0.57	0.59
Wae Batu Gantung	0.52	0.51	0.53	0.52	0.51	0.53
Wae Tomu	0.52	0.52	0.53	0.52	0.52	0.53

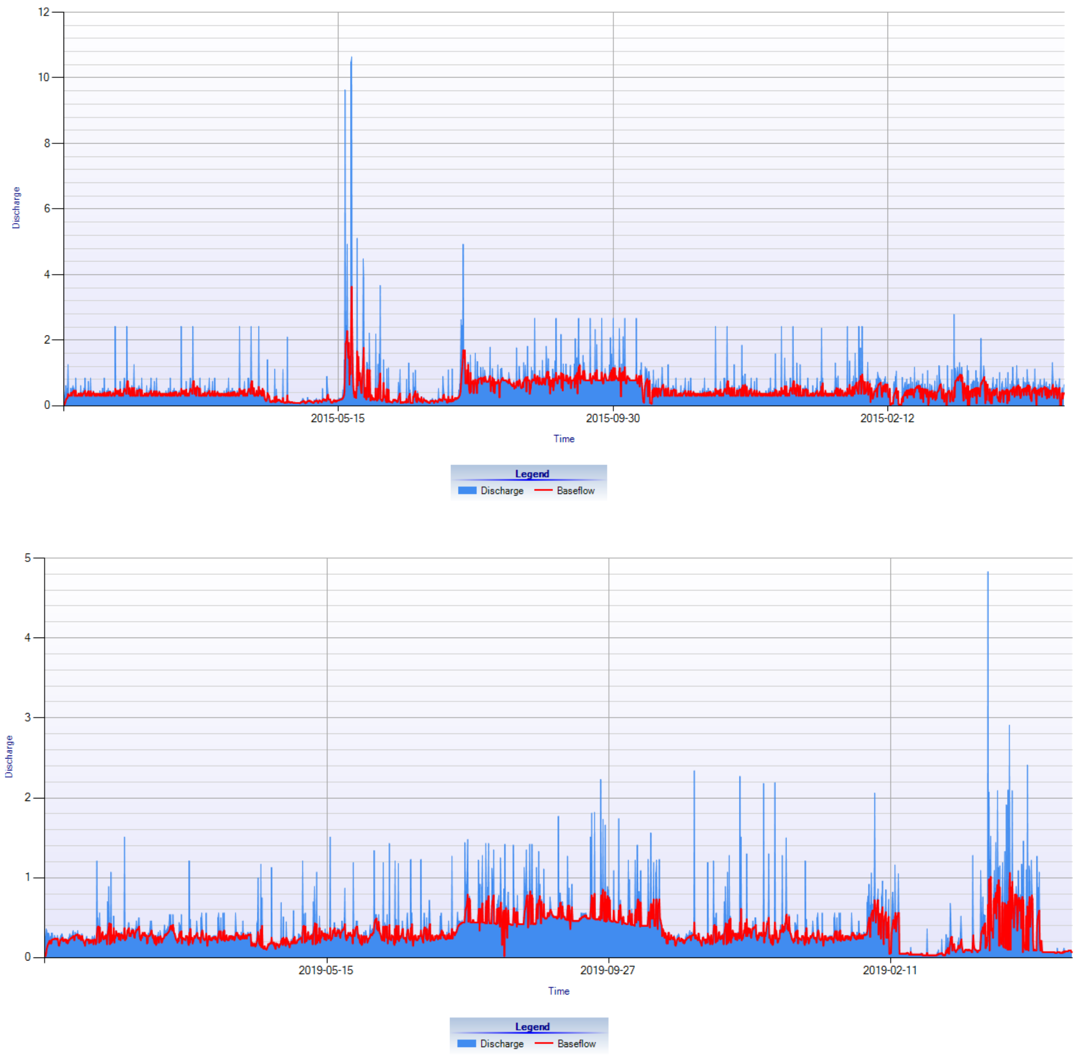

Figure 3. Visualizations of hydrological characteristics: Stream and base flow discharge in 2015 (top) and 2019 (bottom)

Table 9. The regression model correlating the spatial pattern of canopy greenness with hydrological characteristics

Model	R	R Square	Adjusted R Square	Standard Error of the Estimate	Durbin-Watson
1	0.645[a]	0.416	0.382	0.103	1.271

Notes: predictors: (constant), NDVI algorithm, watershed area (km^2), stream gradient (m), elevation (m asl), drainage density (km/km^2); dependent variable: stream and baseflow discharge (m^3/s)

3.3 Relationship Between Canopy Greenness and Hydrological Characteristics

The spatial pattern of canopy greenness, as derived from NDVI, showed a trend of change during the study period. Land-use change is a dynamic factor that significantly influences the hydrological characteristics of small island watersheds. These results are also apparent in the visualization of the hydrological characteristics of the five watersheds.

The relationship between the spatial pattern of canopy greenness (NDVI) and the hydrological characteristics of a watershed, including stream and base flow discharge, is marked by the coefficient of determination (R^2). In the summary model, the adjusted R2 value was 0.382, and the hydrological characteristics could be explained by the model (38.8%), as seen in table 8. Also, with the Durbin-Watson value of 1.271, the model assumes that independence is met. The smaller the SEE, the closer the regression model to predicting the dependent variable accurately.

The ANOVA yielded a simultaneous correlation value, namely F-count= 4.234, which was higher than F-table= 2.367 at a significance of 0.001<0.05. This figure indicates that the canopy greenness levels derived from NDVI affect the hydrological characteristics (stream and base flow discharge) significantly in the five selected watersheds.

4 CONCLUSION

The spatial pattern of canopy greenness tends to experience significant changes in the estuary or river mouth, and in 2019, the densely populated settlements in the coastal stretch had also sprawled into the adjacent mountainous area. This landform, however, functions as one of the water recharge zones in Ambon city, and it is feared that the land-use change will affect the local hydrological characteristics. This result is consistent with the visualization of hydrological characteristics that shows a fluctuating trend during the study period (2015-2019). Based on the statistical analysis, variations in the spatial pattern of canopy greenness have a strong positive relationship (38.2%) with the hydrological characteristics of small island watersheds. Therefore, land and water resources management and planning in small islands need to incorporate mitigation and adaptation to any changes in the watershed ecosystems.

ACKNOWLEDGMENTS

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.

FUNDING AGENCY

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

ABBREVIATIONS

BFI: Base Flow Index; **BFLOW**: Base Flow; **BR**: Bifurcation Ratio; **CR**: Circularity Ratio; **Dd**: Drainage density; **NDII**: Normalized Difference Infrared Index; **NDVI**: Normalized Difference Vegetation Index; **NDWI**: Normalized Difference Water Index; **NPimd**: Pixel Values of Near-infrared; **NPimd_min**: Minimum Pixel Values of Near-infrared; **NPm**: Pixel Values of Red; **NPm_min**: Minimum Pixel Values of Red; **Qp**: Peak Discharge.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Arnanto, A., 2015. Pemanfaatan transformasi normalized difference vegetation Index (NDVI) Citra Landsat TM Untuk Zonasi Vegetasi Di Lereng Merapi Bagian Selatan. *Geomedia: Majalah Ilmiah Dan Informasi Kegeografian*, 11(2), 155-170. DOI: https://doi.org/10.21831/gm.v11i2.3448

Candiago, S., Remondino, F., De Giglio, M., Dubbini, M. and Gattelli, M., 2015. Evaluating multispectral images and vegetation indices for precision farming applications from UAV images. *Remote Sensing*. DOI: https://doi.org/10.3390/rs70404026

Chuvieco, E., Martín, M. P. and Palacios, A., 2002. Assessment of different spectral indices in the red-near-infrared spectral domain for burned land discrimination. *International Journal of Remote Sensing*. 23(23), 5103-5110. DOI: https://doi.org/10.1080/01431160210153129

Chuvieco, E., Ventura, G., Martín, M. P. and Gómez, I., 2005. Assessment of multitemporal compositing techniques of MODIS and AVHRR images for burned land mapping. *Remote Sensing of Environment*, 94(4), 450-462. DOI: https://doi.org/10.1016/j.rse.2004.11.006

Ekawati, S., Paimin, P., Purwanto, P. and Donie, S., 2005. Monitoring dan evaluasi kondisi sosial ekonomi dalam pengelolaan daerah aliran sungai: Studi kasus di sub das progo hulu. *Jurnal Penelitian Sosial Dan Ekonomi Kehutanan*. 2(2), 171-181. DOI: https://doi.org/10.20886/jpsek.2005.2.2.207-214

Eryani, I., 2014. Potensi air dan metode pengelolaan sumber daya air di daerah aliran sungai sowan perancak kabupaten jembrana. *Paduraksa*, 3(1), 32-41.

Escuin, S., Navarro, R. and Fernández, P., 2008. Fire severity assessment by using NBR (Normalized Burn Ratio) and NDVI (Normalized Difference Vegetation Index) derived from LANDSAT TM/ETM images. *International Journal of Remote Sensing*, *29*(4), 1053-1073. DOI: https://doi.org/10.1080/01431160701281072

Fuady, Z. and Azizah, C., 2013. Tinjauan daerah aliran sungai sebagai sistem ekologi dan manajemen daerah aliran sungai. *Jurnal Lentera*, 6, 1-10.

Gandhi, G. M., Parthiban, S., Thummalu, N. and Christy, A., 2015. NDVI: Vegetation change detection using remote sensing and GIS - A case study of Vellore District. *Procedia Computer Science*. 57,1199-1210. DOI: https://doi.org/10.1016/j.procs.2015.07.415

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

Gu, Y., Hunt, E., Wardlow, B., Basara, J. B., Brown, J. F. and Verdin, J. P., 2008. Evaluation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data. *Geophysical Research Letters*. DOI: https://doi.org/10.1029/2008GL035772

Harjadi, B. and Paimin, P., 2013. Teknik identifikasi daerah yang berpotensi rawan longsor pada satuan wilayah daerah aliran sungai. *Jurnal Penelitian Hutan Dan Konservasi Alam*. 10(2), 163-174. DOI: https://doi.org/10.20886/jphka.2013.10.2.163-174

Horton, R.E., 1932. The role of infiltration in the hydrologic cycle. *Trans. Am. Geophysic Union*, 14, 446-460. DOI: https://doi.org/10.1029/TR014i001p00446

Junaidi, E. and Tarigan, S. D., 2011. Pengaruh hutan dalam pengaturan tata air dan proses sedimentasi daerah aliran sungai (das) : Studi kasus di das cisadane. *Jurnal Penelitian Hutan Dan Konservasi Alam*. 8(2), 155-176.

DOI: https://doi.org/10.20886/jphka.2011.8.2.155-176

Latuamury, B., 2013. Hubungan antara indeks vegetasi ndvi (Normalized Difference Vegetation Index) dan koefisien resesi baseflow pada beberapa subdas propinsi jawa tengah dan daerah istimewa yogyakarta. *Jurnal Teknosains. 2*(2), 71-92. DOI: https://doi.org/10.22146/teknosains.5998

Latuamury, B., and Talaohu, M., 2020. Variations in baseflow recession curves as a function of land-use change in the Keduang Watershed, Wonogiri Regency, Jawa Tengah Province, Indonesia. *Journal of Geographical Studies*, 3(2), 54-67. DOI: https://doi.org/10.21523/gcj5.19030202

Latuamury, B., Parera, L. R. and Marasabessy, H., 2020. Characterizing river baseflow recession using linear reservoir model in Alang Watershed, Central Java, Indonesia. *Indonesian Journal of Geography*. 52(1), 22-28. DOI: https://doi.org/10.22146/ijg.43565

Lyne, V. D. and Hollick, M., 1979. Stochastic time-variable rainfall runoff modelling. Hydrology and Water Resources Symposium. Institution of Engineers, Australia, Perth, 89-92.

Mekliche, A., Hanifi Mekliche, L., Aidaoui, A., Monneveux, P. and Hwazen, A. S., 2015. Grain yield and its components study and their association with normalized difference vegetation index (NDVI) under terminal water deficit and well-irrigated conditions in wheat (Triticum durum Desf. and Triticum aestivum L.). *African Journal of Biotechnology*, 14(26), 2142-2148. DOI: https://doi.org/10.5897/ajb2015.14535

Nathan, R. J. and McMahon, T. A. 1990. Evaluation of automated techniques for base flow and recession analysis. *Water Resources Research*, 26(7), 1465-1473. DOI: https://doi.org/10.1029/WR026i007p01465

Paimin, S. and Pramono, I. B., 2009. Teknik mitigasi banjir dan tanah longsor. In *Tropenbos International Indonesia Programme, Indonesia.*

Pravita, D., Armijon, A. and Murdapa, F., 2019. Perbandingan algoritma transformasi normalized difference vegetation index (NDVI) dan enhanced vegetation index (EVI) Untuk analisis kerapatan lahan mangrove.

Seyhan, E.,(1977. *Mathematical simulation of watershed hydrologic processes*. Geografisch Instituut der Rijksuniversiteit te Utrecht.

Sobrino, J. A., Jiménez-Muñoz, J. C., Sòria, G., Romaguera, M., Guanter, L., Moreno, J., Plaza, A. and Martínez, P., 2008. Land surface emissivity retrieval from different VNIR and TIR sensors. *IEEE Transactions on Geoscience and Remote Sensing*. DOI: https://doi.org/10.1109/TGRS.2007.904834

Wardiningsih, S. and Salam, B. F., 2019. Perencanaan RTH sempadan sungai ciliwung di kawasan kampung pulo. *NALARs Jurnal Arsitektur*. 18(1), 65-74. DOI: https://doi.org/10.24853/nalars.18.1.65-74

Wilson, N. R. and Norman, L. M., 2018. Analysis of vegetation recovery surrounding a restored wetland using the normalized difference infrared index (NDII) and normalized difference vegetation index (NDVI). *International Journal of Remote Sensing*, *39*(10), 3243-3274. DOI: https://doi.org/10.1080/01431161.2018.1437297

******