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The ecological quality of the Abra River watershed in Northern Luzon, Philippines using the remote sensing ecological index (RSEI) model

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ABSTRACT

Ecological quality is an integral facet of the overall state of an ecosystem which relates to how the biotic and abiotic components interact within the environment and how these structure-process complexes translate to the delivery of an array of ecosystem services that support human welfare and development. Modern and useful methods have been devised to assess the ecological quality of largescale ecosystems such as rivers and watershed. Using remote sensing technology, the ecological status of ecosystems can be evaluated and monitored spatiotemporally. This study focuses on establishing the ecological quality of the Abra River ecosystem and its watershed in Northern Luzon, Philippines by analyzing remote sensing data over a two-year period (2020-2021), using the Remote Sensing Ecological Index (RSEI) model. A remote sensing ecological index (RSEI) was formulated using four various sub-indices: the normalized difference vegetation index (NDVI), normalized differential build-up and bare soil index (NDBSI), land surface moisture (LSM), and land surface temperature (LST). The RSEI model was built and acquired using a principal component analysis (PCA) method to integrate the four sub-components. Results showed that the mean RSEI score for the study area is 0.60 (moderate to good) with the NDVI (0.641) and LSM having positive contributions to ecological quality while NDBSI (-0.674) and LST (-0.138) having negative weights to the ecosystem. This study is necessary as there are limited works on the ecological status of the Abra River basin and thus can contribute to responsive efforts to conserve, manage, and protect large-scale ecosystems.

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Email Address: dcsoriano@up.edu.ph
Date received: 05 July 2024
Dates revised: 16 October 2024
Date accepted: 15 May 2025
DOI: https://doi.org/10.54645/2025181IBG-95

INTRODUCTION

River ecosystems and the entirety of its watershed provides a collective array of ecosystem services (Böck et al., 2018) that are vital to human settlements (Feeley et al., 2016). River ecosystems are not spared from the destruction caused by increasing anthropogenic pressures from rapid development. Several studies have shown that river ecosystems carry the brunt of environmental pressures brought about by unsustainable land use changes, overexploitation, pollution, and other human-related activity (Harrison et al., 2016) and may impair the ability of these ecosystems to support the delivery of ecosystem services (Vörösmarty et al., 2010). Acknowledging the importance of riverine ecosystems with the ecosystem services that they offer and the intense environmental pressures that affect their ecological quality, sustainable conservation, protection, and management efforts are needed to support the delivery of ecosystem services continuously for human communities worldwide (Lindenmayer et al., 2007; Paetzold, Warren, and Maltby, 2010).

Human-influenced ecological pressures exist over different scales in terms of time, space, and magnitudes (Levin, 1992; Xu et al., 2018) and the difficulty of understanding the effects of such pressures warrant an effective approach in assessing the ecological quality of the environment especially of large-scale ecosystems such as river basins and watersheds. With the

KEYWORDS

ecological indices, watershed management, principal component analysis, Landsat 8, ecological quality

complexity of riverine ecosystems and how these can contribute to global ecosystem processes (Baldocchi, 2008), a rapid, effective, and consistent method of assessing regional ecosystem quality is needed to inform conservation and management policies. Ecological quality provides a suitable framework for assessing ecosystem components—both structure and function, and their overall status, which is imperative in conservation and management of river basins and watersheds (Zhu et al., 2020). The concept of ecological quality has underpinned its core to the health of biotic assemblages (Karr, 1999) and ecosystem structure (Rapport et al., 1998) but also included the influence of human activities and the ecosystem services that they deliver (Burkhard and Müller, 2008). Zhu et al. (2020) further simplified the concepts, defining ecological functions as the totality of processes that support the delivery of ecosystem services and are influenced by key biological, physical, and anthropogenic factors.

Environmental pressures influence the ecological quality of river ecosystems and their ability to deliver ecosystem services (Brauman et al., 2007; Feeley et al., 2016). Ecological quality can serve as an indicator of ecosystem service delivery, and identifying areas with declining quality due to anthropogenic-induced pressures is important for targeted conservation and protection (Zhu et al., 2020). Comprehensive spatio-temporal assessments of river ecosystems are crucial to identify the specific sections of the landscape and waterscape that need protection and management interventions (Hatfield et al., 2004; Paetzold et al., 2010). Holistic approaches to these are needed to evaluate these ecosystems and feed into conservation, protection, and management strategies (Hu and Xu, 2018; Zhu et al., 2020) highlighting the importance of tools that can assess the variations in ecological quality over space and time.

Understanding, evaluating, and monitoring environmental changes in river ecosystems can be difficult, however, remote sensing technology provides an effective way to evaluate and monitor these changes through high-throughput, periodic collection (Liu et al, 2020). Remote sensing technology can provide detailed information about features and components of ecosystems that are challenging to quantify on the ground (Wiilis, 2015; Shan et al., 2020). For large landscapes and waterscapes such as river basins and watersheds, the Remote Sensing Ecological Index (RSEI) can be used which integrates four key variables or indices—greenness, wetness, dryness, and heat—that uses remote sensing data to assess ecological quality (Xu, 2013; Gao et al., 2021) corresponding to environmental indices which are NDVI, LSM, NDBSI, and LST respectively (Yuan et al., 2021). As most studies on the assessment of largescale ecosystems are based on a specific indicator, usually on vegetation (Gupta et al., 2012; Hengkai et al., 2020), the RSEI detects regional ecological quality conditions (Lian et al., 2022) and provides a rapid and thorough evaluation of the ecological quality, both at spatial and temporal scales of a large ecosystem which can be quite difficult to employ (Lian et al., 2022; Shupu et al., 2022). The RSEI serves as a versatile and objective tool for assessing and monitoring ecological quality across different spatial and temporal scales (Xu et al., 2019; Gao et al., 2020). Because of its versatility, the RSEU has been applied in recent studies to assess ecological quality of watersheds and river ecosystems and offers a high-yield output to evaluate environmental conditions of ecosystems (Yuan et al., 2018; Zhu et al., 2020; Yang et al., 2021; Yao et al., 2022).

While the Philippines actively assesses and monitors watershed conditions through traditional methods like field assessments and water quality monitoring, there has been a dearth of detailed investigation into the use of the RSEI for evaluating ecological quality, especially in riverine ecosystems and watersheds (Rubio et al., 2008; Bestre et al., 2018). Majority of remote sensing studies in the Philippines focus on limited variables and indices such as temperature-related parameters and other environmental factors such as vegetation (Mialhe et al., 2016; Jansen, 2016; Estoque et al., 2020). The RSEI which integrates four variables, offers an efficient way to assess and monitor ecological quality over large areas (Xu et al., 2018; Gao et al., 2020). Its application could address the gaps in current watershed monitoring efforts in the country by providing continuous, up-to-date, and high-throughput assessments for ecosystems such as Abra River where existing studies are lacking or outdated (Bestre et al., 2018).

This study is set out to use remote-sensing satellite datasets to determine the ecological quality of the Abra River basin and watershed, a tropical river basin and watershed ecosystem in Northern Luzon, Philippines. The aim of this study is to assess the ecological quality of the Abra River watershed using RSEI for two seasons over the years 2020 and 2021. The resulting remote sensing ecological index is then mapped to visually account and classify areas of the river basin and watershed in terms of its ecological quality.

MATERIALS AND METHOD

Study Area

The Abra River Basin and watershed (17°30′47″N, 120°23′45″E) spans the three provinces of Abra, Benguet, and Mountain Province of the Cordillera Administrative Region and the province of Ilocos Sur of Region 1 (Ilocos Region) in Luzon, Philippines. The river basin is the 6th largest river basin in the Philippines with an approximate drainage area of 5,125 km^2 and an estimated 12,551 million cubic meter annual run-off (Paringit and Pascua, 2017) (Figure 1).

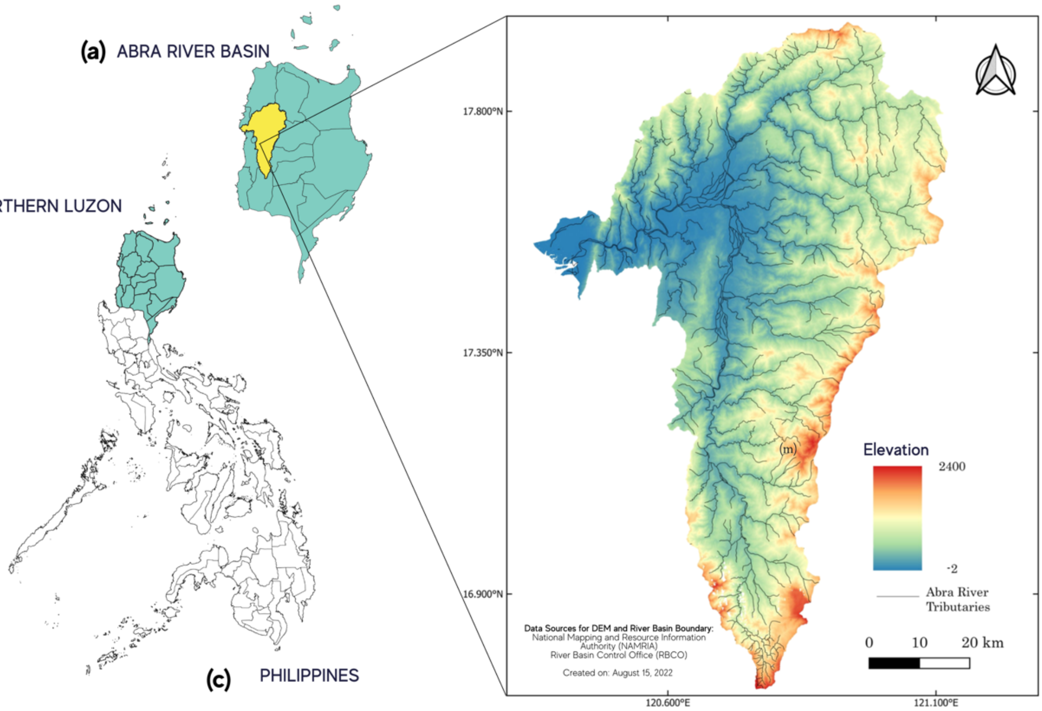

Figure 1: Location and elevation of the Abra River basin and watershed in Northern Luzon, Philippines, showing (a) the Abra River Basin, (b) Northern Luzon, and (c) the Philippines.

A significant portion of the north, east, and southern regions of the watershed is mountainous, with elevations reaching up to 2400 masl while the western part has less rugged topographic features and lower elevation. The topography of the watershed varies from rolling to slightly rugged, with a very small fraction of the watershed that is considerably flat terrain. The headwaters of the river, originating in the province of Abra, flows in a northward direction until it unites with the Tineg River, one of the river's major tributaries. The river meanders in a west-southwest direction towards the province of Ilocos Sur and exits into the West Philippine Sea (Paringit and Pascua, 2017).

Majority of the river basin and watershed falls under the Type 1 category while a small portion in the eastern region of the basin falls under Type 2 category of the Coronas Climate Classification System of the Philippine Atmospheric, Geophysical, and Astronomical Sciences Administration (PAGASA) (Paringit and Pascua, 2017). The entirety of the basin is characterized by two seasons: dry from November to April and wet from May to September. Seasonal rainfall patterns vary annually, with occurrences of extreme weather events every so often. Observed rainfall and weather anomalies are correlated to El Niño and La Niña events. Average rainfall within the basin and watershed is 2500mm-3000mm and varies according to elevation and mean monthly air temperature values range from 23 to 33°C (Paringit and Pascua, 2017).

Data Resources and Pre-Processing Remote Sensing Satellite Data

Satellite imagery obtained from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) datasets, covering a two-year period (2020-2021) were selected and downloaded from the USGS data archive (https://earthexplorer.usgs.gov/). In addition, datasets within the wet and dry season (Section 2.1) of each year were acquired to reflect the differences of ecological quality in both seasons. To capture the complete area of the river basin and watershed, two satellite images were obtained per season per year and were mosaiced. In total, eight sets of Landsat 8 OLI/TIRS satellite images were used in the study. Radiometric calibration, pansharpening, atmospheric correction, and conversion from digital number (DN) to Top of Atmosphere (TOA) reflectance (combined planetary surface and atmospheric reflectance) of datasets were performed in QGIS 3.16 (Hannover) using the Semi-Automatic Classification Plugin (SCP) (USGS 2016; Congedo, 2021). Finally, the satellite images were cropped within the bounds of the Abra River Basin and Watershed boundaries.

The selected spectral bands to calculate for the various indices to be used in making the RSEI included Blue, Red, Near-Infrared (NIR), Shortwave Infrared 1 (SWIR1), and Shortwave Infrared 2 (SWIR2). These bands were chosen due to their effectiveness in capturing different aspects of the landscape, such as vegetation health, water bodies, and land surface characteristics (Xu et al., 2018). The specific wavelengths of the bands used are listed in Table 1.

Table 1: Landsat 8 spectral bands and their corresponding wavelength ranges used for the various indices to build the RSEI for assessing the Abra River watershed

Band Name	Band Number	Wavelength Range (nm)
Blue	Band 2	452 – 512
Red	Band 4	636 – 673
Near-infrared (NIR)	Band 5	851 – 879
Shortwave Infrared 1 (SWIR1)	Band 6	1566 – 1651
Shortwave Infrared 2 (SWIR2)	Band 7	2107 – 2294

Supplementary Data

Most recent datasets available on the land cover, administrative boundaries, and digital elevation models (DEM) of the area of interest were obtained from the Department of Environment and Natural Resources River Basin Control Office (DENR-RBCO), the Department of Science and Technology-Advanced Science and Technology Institute (DOST-ASTI), and the National Mapping and Resource Information Authority (NAMRIA) of the Philippines.

Construction of the Remote Sensing Ecological Index (RSEI)

Calculation of Indicators

The RSEI is constructed using four indicators (heat, dryness, wetness, and greenness) corresponding to LST, NDBSI, LSM, and NDVI respectively, derived from remote sensing datasets and is based on the pressure-state-response framework (PSR) using principal-component analysis (PCA) (Hu and Xu, 2018; Xu et al., 2018; Hu and Xu 2019). The summary of selected indicators used in this study is found in Table 2.

Table 2: Summary of selected indictors, their corresponding acronyms, and descriptions

Index	Acronym	Description
Normalized difference vegetation index	***NDVI***	Indicator of quality and quantity of areas covered with vegetation (corresponds to greenness) (Xu et al., 2018; Lin et al., 2019)
Normalized differential build-up and bare soil index	***NDBSI***	Represents human-influenced pressures and is a composite of both IBI and SI (corresponds to dryness) (Hu and Xu, 2019; Zheng et al., 2022)
Land Surface Temperature	***LST***	Represents temperature changes in response to environmental pressures and changes (corresponds to heat) (Qi et al., 2019; Hu and Xu, 2019)
Land Surface Moisture	***LSM***	Represents humidity and moisture changes in response to environmental changes (corresponds to wetness) (Hu and Xu, 2019)
Index-based built-up index	***IBI***	A composite index that detects built-up characteristics in remote sensing images. The IBI index is positively correlated with LST and negatively correlated with the NDVI (Xu, 2008; Zheng et al., 2022)
Soil Index	***SI***	Signifies areas of bare land or sparsely vegetated surface that indicates a possible deforested or abandoned location across the study area (Hu and Xu, 2019)
Remote Sensing Ecological Index	***RSEI***	A synthetic index that can reflect an ecosystem's ecological quality based on a composite of environmental indices (NDVI, NDBSI, LST, LSM) in response to anthropogenic pressures, environmental states, and climatic conditions (Xu et al., 2018)

(1) **Normalized difference vegetation index.** The NDVI has been used as an index to evaluate vegetation cover in ecosystems (Xu and Zhang, 2013; Lin et al., 2019. It is closely associated with plant biomass, leaf area index, and overall vegetative growth and coverage in an area of interest (Goward et al., 2002). The NDVI is expressed as in Eq. (1).

$$NDVI = \frac{(\rho_{NIR} - \rho_{Red})}{(\rho_{NIR} + \rho_{Red})}$$

Eq. 1

(2) **Normalized differential build-up and bare soil index.** Changes brought by urbanization and human activities have replaced the earth's surface with built structures and naked soil surfaces contributing to the dryness that is attributed to diminishing ecological quality. The NDBSI represents the built-up index (IBI) expressed as Eq. (2) and soil index (SI) expressed as Eq. (3) to completely account for the dryness as expressed in Eq. (4)

$$IBI = \frac{\left\{\frac{2\rho_{SWIR1}}{\rho_{SWIR1} + \rho_{NIR}} - \left[\frac{\rho_{NIR}}{\rho_{NIR} + \rho_{Red}} + \frac{\rho_{Green}}{\rho_{Green} + \rho_{SWIR1}}\right]\right\}}{\left\{\frac{2\rho_{SWIR1}}{\rho_{SWIR1} + \rho_{NIR}} + \left[\frac{\rho_{NIR}}{\rho_{NIR} + \rho_{Red}} + \frac{\rho_{Green}}{\rho_{Green} + \rho_{SWIR1}}\right]\right\}}$$

Eq. 2

$$SI = \frac{[(\rho_{SWIR1} + \rho_{Red}) - (\rho_{NIR} + \rho_{Blue})]}{[(\rho_{SWIR1} + \rho_{Red}) + (\rho_{NIR} + \rho_{Blue})]}$$

Eq. 3

$$NDBSI = \frac{IBI + SI}{2}$$

Eq. 4

(3) **Land Surface Temperature**. To account for the influence of heat and temperature in the ecological quality of the ecosystem, the LST values were obtained from two band sets (Bandset 10&11) in Landsat 8 TIRS. A series of calculations were done to extract necessary information from Landsat 8 TIRS data using various properties, such as solar irradiance and vegetation Eq. (5-8) (Hu and Xu, 2019). The final LST index is expressed as Eq. (9)

$$L_\lambda = M_L Q_{Cal} + A_L$$

Eq. 5

$$T_b = K_2 / \ln (K_1 / L_\lambda + 1)$$

Eq. 6

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2$$

Eq. 7

$$\epsilon = mP_v + n$$

Eq. 8

$$T = \frac{T_{sensor}}{\left[1 + \left(\lambda * \frac{T_{sensor}}{\rho}\right) ln * \varepsilon\right.}$$

Eq. 9

(4) **Land Surface Moisture**. The wetness component that represents the land surface moisture from soil and vegetation cover variable can be expressed as Eq. (10). The wetness component was derived from the Tasseled Cap Transformation for Landsat 8 (OLI) (Baig et al., 2014).

$$LSM = (0.1511\rho_{Blue}) + (0.1973\rho_{Green}) + (0.3283\rho_{Red}) + (0.3407\rho_{NIR}) + (-0.7117\rho_{SWIR1}) + (-0.4559\rho_{SWIR2})$$

Eq. 10

Values obtained from the calculation of the four variables were normalized [0,1] before employing PCA as the units and range of the various indicators are different (Xu, 2008; Liu and Li, 2016). Calculations of the various indices and normalization were performed in QGIS 3.16 (Hannover). Final satellite images for the PCA were projected to the WGS 84 EPSG:4326 coordinate reference system (CRS).

Combination of indicators and Acquisition of the RSEI

The RSEI was formulated by integrating the four indices using a principal component analysis and is represented by the resulting first principal component of the PCA (PC1) (Guo et al., 2017; Geng et al., 2022). This method is effective in assessing the ecological quality of the environment since the contribution of each variable to the RSEI is weighted by its loading to PC1 thus, independent of human factors (Guo et al., 2017; Xu et al., 2018). The RSEI is expressed as in Eq. (11):

$$RSEI = \mathrm{PCA}\big(\mathrm{f(NVDI, LSM, LST, NBSI)}\big)$$

Eq. 11

Results of the PCA were normalized from 0 to 1 and the index is divided into five tiers, each with 0.2 increments. Of the five ecological quality grades, Level 1 represents poor ecological quality and Level 5 signifies an ecosystem in excellent condition, i.e., Level 1 (poor): 0-0.2; Level 2 (fair): 0.2-0.4; Level 3 (moderate): 0.4-0.6; Level 4 (good): 0.6-0.8; and Level 5 (excellent) (Xu, 2013; Wang et al., 2016; Zhu et al., 2020).

RESULTS AND DISCUSSION

Descriptive statistics of the four indicators for the RSEI model of the Abra River basin and watershed

Table 3 summarizes the average index values obtained from satellite images of the study area for each period. The mean NDVI (greenness) values for the study area have generally remained constant throughout the study period however, a slight increase has been observed in the wet season of 2021 with a mean NDVI value of 0.69 for the two-year period. A similar trend is observed in the NDBSI (dryness) with a mean index value of 0.31. The LST (heat) index indicated a steady increase over the period with a mean value at 0.63. Finally, LSM (wetness) values fall within the average of 0.75 over the two-year span. The study area had a 6.5% increase, 3.2% decrease, 18.4% increase, and 9.3% decrease in the NDVI, NDBSI, LST, and LSM values respectively during the dry season (April 2020 and 2021). Comparably, the NDVI, NDBSI, LST, and LSM values had a 14.5% increase, 24.9% decrease, 31.7% increase, and 7.6% increase respectively during the wet season (July 2020 and 2021).

Table 3: Mean index values of the four indicators and the RSEI score of the Abra River basin and watershed. Values of the indices are normalized from 0 to 1.

	NDVI (greenness)	NDBSI (dryness)	LST (heat)	LSM (wetness)
April 2020	0.61	0.31	0.49	0.86
July 2020	0.69	0.36	0.63	0.66
April 2021	0.65	0.30	0.58	0.78
July 2021	0.79	0.27	0.83	0.71
Mean	**0.69**	**0.31**	**0.63**	**0.75**

The RSEI is considered a spatially continuous gauge of ecological quality which is formulated by evaluating and scoring the principal components of the four indicators based on their attributes (Xu et al., 2018). Each of the indicators contributes to the RSEI, and consequently, a reflection of the current ecological quality of the environment. The NDVI and LSM are extensively used to assess the physical and biological components of ecosystems that are related to vegetation, surface water, and a more relatively undisturbed ecosystem (Xu et al., 2018; Zhu et al., 2020). Conversely, the NDBSI and LST indices are components that reveal the impacts of direct and indirect human activity, such as climate change and land use change and development, to the physical substrate such as soils (Hu and Xu, 2019; Zheng et al., 2022). Among the four indices, the NDVI and LSM contribute positively to the RSEI model, while the NDBSI and LST are associated with negative inputs to the index (Eckert et al., 2015; Estoque and Murayama, 2017; Zhu et al. 2020). The mean values of the four indices that were used for building the RSEI model for the study area is reflective of the influence of each of the indicators in determining the ecological quality of the environment (Kamara et al., 2020; Zhu et al., 2020).

Principal component analysis and the ecological quality of the Abra River basin and watershed

The normalized indices were used and integrated through a principal component analysis to determine the ecological quality of the study area using the RSEI model. Table 4 presents the corresponding descriptive statistics for each study period, the PC1 loading for the indices used, and the mean RSEI. The mean RSEI of the Abra River basin and watershed was 0.60 indicating that the ecological quality is relatively high (moderate to good). The coefficient of variation for each study period is approximately 24% indicating moderate variability. Among the four sub-indicators, greenness (NDVI) and wetness (LSM) exhibited positive loadings on PC1, while dryness (NDBSI) and heat (LST) had negative weights on PC1.

Table 4: Principal component analysis (PC1) loading and the RSEI of Abra River basin and watershed. (Std. Dev- standard deviation, COV- coefficient of variation)

	Indicator	*Mean*	*Std. Dev.*	*COV*	*Loading (weight) of PC1*
April 2020	Greenness (NDVI)	0.61	0.14	22.95	0.667
	Dryness (NDBSI)	0.31	0.13	41.94	-0.650
	Heat (LST)	0.49	0.14	28.57	-0.285
	Wetness (LSM)	0.86	0.06	6.98	0.225
	RSEI	**0.60**	**0.16**	**26.67**	**-**
April 2021	Greenness (NDVI)	0.65	0.14	22.95	0.667
	Dryness (NDBSI)	0.30	0.13	41.94	-0.650
	Heat (LST)	0.58	0.13	28.57	-0.285
	Wetness (LSM)	0.78	0.05	6.98	0.225

	RSEI	**0.63**	**0.15**	**23.81**	-
	Greenness (NDVI)	0.69	0.14	20.29	0.647
	Dryness (NDBSI)	0.36	0.14	38.89	-0.680
July 2020	Heat (LST)	0.63	0.12	19.05	0.040
	Wetness (LSM)	0.66	0.10	15.15	0.344
	RSEI	**0.41**	**0.11**	**26.83**	-
	Greenness (NDVI)	0.79	0.11	13.92	0.618
	Dryness (NDBSI)	0.27	0.12	44.44	-0.705
July 2021	Heat (LST)	0.83	0.04	4.82	0.032
	Wetness (LSM)	0.71	0.09	12.68	0.348
	RSEI	**0.72**	**0.14**	**19.44**	-

The results of the PCA are consistent with the works of Eckert et al., (2015) and Estoque and Murayama, (2017) emphasizing that wetness and greenness functions positively influence the RSEI positively while heat and dryness functions negatively influence the ecological quality model. The mean degree of contribution (loading) of greenness (NDVI) to the first principal component (PC1) was 0.641 which was the highest among the four sub-components of the RSEI. This highlights the crucial role of the vegetation coverage in the ecosystem, thus improving the ecological quality of the riverine environment and its associated watershed (Zhu et al., 2020). Wetness (LSM) is also an important aspect in improving the ecological quality (Hu and Xu, 2018) and is generally associated with vegetation as high wetness areas promote more vegetation growth and prevent bare patches of soil over a large extent (Hu and Xu, 2018; Zheng et al., 2020). In addition, the mean degree of contribution of the dryness index (NDBSI) was -0.674 which underscores the detrimental impacts of human activities such as infrastructure development and land conversion to the overall ecological quality of the ecosystem (Shan et al., 2019; Yue et al., 2019; Zheng et al., 2020). Finally, the heat index represented by the LST had a mean PC1 loading of -0.138 which has less significant influence on the RSEI model and to the ecological quality of the watershed however it is plausible that global and regional changes to the climate and extreme heating events (El Niño) could affect the ecological quality of the watershed thus the impacts of human accelerated climate change should not be overlooked (Xu et al., 2018; Zhu et al., 2019; Zheng et al., 2020).

Spatio-temporal distribution of ecological quality of the Abra River basin and watershed

The ecological quality of the study area is higher (RSEI= 0.62 – good) during the dry season than the wet season (RSEI= 0.57 – moderate). Conversely, the ecological quality of the study area in 2021 is higher (RSEI= 0.68 – good) compared to 2020 (RSEI= 0.51 – moderate) (Table 3) (Figure 2). Several works on remote sensing indices, such as NDVI can be attributed to such results. Accordingly, seasonal variations, erratic rainfall and precipitation patterns, extreme meteorological events, and other influences such as existing canopy cover and vegetation can influence the varying levels of ecological quality in ecosystems (Schmidt and Karnieli, 2000; Wang et al., 2016). Moreover, variability in the ecological quality of ecosystems may be attributed to differences and constant changes in land cover (Xu et al., 2019). Lastly, a study by Gao et al., (2022) highlights the impact of human activity in the ecological quality of ecosystem, suggesting that ecosystems with more frequent human activity results to a lower ecological quality.

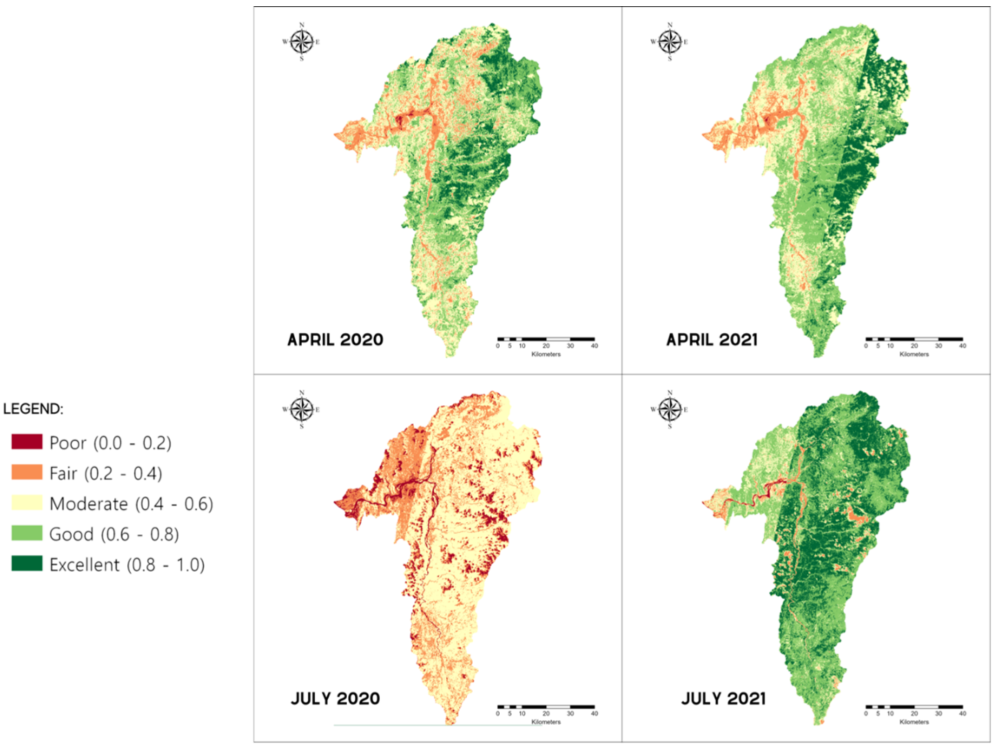

Figure 2: Spatial distribution of the ecological quality grades in the Abra River basin and watershed.

The ecological quality of the study area was relatively high (0.4 – 1.0) in the eastern portions of the watershed, while lower ecological quality was observed in the northwestern regions of the study area (0.0 – 0.4) (Figure 2). The regions with low ecological quality grade were distributed mainly in the north-western region, which were mostly lowsloping valley and plain areas (Figure 1) that are mostly associated with human settlements, both industrial and residential. Areas with high ecological quality grade were in high elevations, usually characterized by undisturbed forest patches and other vegetation. In 2020, approximately 78% of the watershed area was classified as having good ecological quality during the dry season (April). This contrasts with the wet season (July), where only around 63% of the land area fell within the moderate ecological quality classification. In 2021, the ecological quality conditions exhibited some improvement; during the dry season, 75% of the watershed area was classified as good ecological quality. Remarkably, during the wet season in July, the value increased by 84% of the area categorized as being in good condition. This is attributed to low levels of urban sprawl and a low level of human interference coupled with the dynamic nature of ecological quality within the watershed that could be influenced by seasonal variations and lesser anthropogenic disturbance in higher elevations of areas with vegetation. (Wang et al., 2016; Zheng et al. 2020; Gao et al., 2022).

Table 5 summarizes the mean RSEI values and the ecological quality across three elevation classes: low (<800 masl), mid (800-1600 masl), and high (> 1600 masl). The findings exhibit that areas at low elevations have moderate ecological quality having a mean RSEI of 0.52. In contrast, mid-elevation portions of the watershed exhibit a higher mean RSEI of 0.61, corresponding to good ecological quality. Notably, high elevation areas show the highest mean RSEI of 0.67 also classified as good ecological quality. The values suggest that higher elevations are more likely to be associated with more favorable ecological variables and conditions because of the lesser degree of anthropogenic influences and disturbances (Wang et al., 2016).

Table 5: Mean RSEI per Elevation Classes for the two-year period

Elevation Class	Mean RSEI	Ecological Quality
Low (<800 masl)	0.52	Moderate
Mid (800 – 1600 masl)	0.61	Good
High (>1600 masl)	0.67	Good

Overall, the Abra River basin and its associated watershed have a relatively good ecological quality. This state of the ecosystem, however, is not a static condition and is responsive to significant changes in land use and land cover, human activity, and other related instabilities that could affect the ecological quality of the ecosystem. In 2015, the River Basin Control Office of the Department of Environment and Natural Resources (DENR) in the Philippines formulated its Integrated River Basin Management and Development Master plan to address the issues that surround the protection and management of the Abra River basin and its watershed. Problems including pollution, unsustainable extraction of provisioning ecosystem services, unsustainable land use changes and other environmental concerns pose a significant magnitude of environmental pressure to the ecosystem, thus affecting its ecological quality (River Basin Control Office, et al., 2015). Relating the ecological quality of the study area with the delivery of ecosystem services and a thorough evaluation and monitoring of the ecological status, using remote-sensing technology and satellite imagery and on-the-ground field assessments and validation, and stakeholder participation are future initiatives that can supplement the findings and implications of this study.

CONCLUSION

The RSEI model based on the four sub-indices (NDVI, NDBSI, LSM, and LST) is a rapid and accurate way to evaluate and monitor the ecological quality of large-scale environments, such as riverine ecosystems and its associated watershed. Moreover, the RSEI objectively weighs the contribution of each sub-indicator to reflect the ecological status of the ecosystem. With the RSEI model, it was found out that the current ecological quality of the Abra River basin and watershed was generally high, with a mean RSEI of 0.60 (moderate to good). The spatial distribution of the ecological quality is dependent on factors such as human activity, meteorological events, physical and topographical features, and the integrity of biological components within the ecosystem. It should be noted, however, that the values used for the RSEI values for determining the ecological quality of the Abra River basin and watershed are area specific and should not be employed directly to other study areas. Nonetheless, the pertinent methods described in this paper are not area-specific and can be used to evaluate the ecological quality of other ecosystems under analysis.

This study presents one of the few scientific works on harnessing remote sensing technology to evaluate a vast ecosystem, specifically a riverine ecosystem in the Philippines. The results of the present study could be a baseline study for a deeper understanding of the relationship between ecological quality and the delivery of ecosystem services within regional ecosystems and could facilitate the road to a balanced ecological and socio-economic development and management of the environment and the ecosystem services that the Abra River basin and watershed and other similar watershed in the country.

ACKNOWLEDGMENT

The author is grateful for the support and input of Prof. Shovonlal Roy and Prof. Jess Neumann. In addition, the author expresses gratitude to the DENR River Basin Control Office, NAMRIA, the Department of Biology - UP Baguio, Mr. Timothy James Cipriano, Ms. Iris Anne Ventura, Ms. Kringle Marie Mercado, Ms. Anna Mae Restauro, and Dr. Agnes Amil. Lastly, huge gratitude is extended to the Chevening Scholarship program for supporting the graduate studies of the author that made this research and scientific paper possible.

CONFLICT OF INTEREST

The author declares no conflicts of interest related to this work.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

The author was responsible for all aspects of this work including conceptualization, study design, collection and analysis of data, results interpretation, and in the writing and revising of the manuscript. All work presented in this article are original contributions of the author including the maps, figures, and tables.

REFERENCES

An, M., Xie, P., He, W., Wang, B., Huang, J. and Khanal, R. (2022). Spatiotemporal change of ecologic environment quality and human interaction factors in three gorges ecologic economic corridor, based on RSEI. *Ecological Indicators*, 141, p.109090. doi: 10.1016/j.ecolind.2022.109090.

Baig, M.H.A., Zhang, L., Shuai T., Tong, Q. (2014). Derivation of a tasselled cap transformation based on Landsat 8 at-satellite reflectance, *Remote Sensing Letters*, 5:5, 423-431, doi: 10.1080/2150704X.2014.915434

Baldocchi, D. (2008) ‘Breathing’ of the terrestrial biosphere: lessons learned from a global network of carbon dioxide flux measurement systems. *Australian Journal of Botany*. 56, 1-26. doi: 10.1071/BT07151.

Bestre, E., Lumiquio, A., Napaldet, J. (2018). Water Quality Assessment of Major River Systems in Benguet Province, Philippines. 8. 19-38.

Böck, K., Polt, R. and Schülting, L. (2018). Ecosystem Services in River Landscapes. *Riverine Ecosystem Management*, 413–433. doi: 10.1007/978-3-319-73250-3_21.

Brauman, K.A., Daily, G.C., Duarte, T.K. and Mooney, H.A. (2007). The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annual Review of Environment and Resources*, 32(1), 67–98. doi: 10.1146/annurev.energy.32.031306.102758.

Congedo, Luca, (2021). Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS. *Journal of Open Source Software*. 6(64), 3172, doi: 10.21105/joss.03172.

Duan, W., Maskey, S., Chaffe, P.L.B., Luo, P., He, B., Wu, Y., Hou, J. (2021). Recent Advancement in Remote Sensing Technology for Hydrology Analysis and Water Resources Management. *Remote Sensing*. 13, 1097. doi: 10.3390/rs13061097.

Eckert, S., Hüsler, F., Liniger, H., Hodel, E. (2015). Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. *Journal of Arid Environment*. 113, 16–28. doi: 10.1016/j.jaridenv.2014.09.001

Estoque R.C., Murayama Y., Myint SW. (2017). Effects of landscape composition and pattern on land surface temperature: an urban heat island study in the megacities of Southeast Asia. *Science of The Total Environment*. 577:349–359. doi: 10.1016/j.scitotenv.2016.10.195.

Estoque, R.C., Ooba, M., Seposo, X.T. et al. (2020). Heat health risk assessment in Philippine cities using remotely sensed data and social-ecological indicators. *Nature Communications*. 11, 1581. doi: 10.1038/s41467-020-15218-8.

Feeley, H., Bruen, M., Bullock, C., Christie, M., Kelly, F., Remoundou, K., Siwicka, E. and Kelly-Quinn, M. (2016). Ecosystem services in freshwaters: A literature review. *Environmental Protection Agency*. 187. doi:10.13140/RG.2.2.10420.24968.

Gao, P.; Kasimu, A.; Zhao, Y.; Lin, B.; Chai, J.; Ruzi, T.; Zhao, H. (2020). Evaluation of the Temporal and Spatial Changes of Ecological Quality in the Hami Oasis Based on RSEI. *Sustainability*. 12, 7716. doi: 10.3390/su12187716

Gao, W.; Zhang, S.; Rao, X.; Lin, X.; Li, R. (2021). Landsat TM/OLI-Based Ecological and Environmental Quality Survey of Yellow River Basin, Inner Mongolia Section. *Remote Sensing*. 13, 4477. doi: 10.3390/rs13214477.

Gao, Y. G., Li, Y. H., & Xu, H. Q. (2022). Assessing ecological quality based on remote sensing images in Wugong Mountain. *Earth and Space Science*. 9, e2021EA001918. doi: 10.1029/2021EA001918

Garcia-Moreno, J., Harrison, I.J., Dudgeon, D., Clausnitzer, V., Darwall, W., Farrell, T., Savy, C., Tockner, K. and Tubbs, N. (2014). Sustaining Freshwater Biodiversity in the Anthropocene. *The Global Water System in the Anthropocene*. 247–270. doi: 10.1007/978-3-319-07548-8_17.

Geng, Jianwei & Yu, Kunyong & Xie, Zhen & Zhao, Gejin & Ai, Jingwen & Yang, Liuqing & Yang, Honghui & Liu, Jian. (2022). Analysis of Spatiotemporal Variation and Drivers of Ecological Quality in Fuzhou Based on RSEI. Remote Sensing. 14. 4900. 10.3390/rs14194900.

Goward S. N., Xue Y., Czajkowski K. P. (2002). Evaluating land surface moisture conditions from the remotely sensed temperature/vegetation index measurements: An exploration with the simplified simple biosphere model. *Remote Sensing of Environment*. 79 (2–3):225-242.

Gupta, K.; Kumar, P.; Pathan, S.K.; Sharma, K.P. (2012). Urban Neighborhood Green Index—A Measure of Green Spaces in Urban Areas. *Landscape and Urban Planning*. 105, 325–335. doi: 10.1016/j.landurbplan.2012.01.003.

Hang, X.; Luo, X.; Cao, Y.; Li, Y. (2020). Ecological quality assessment and the impact of urbanization based on RSEI model for Nanjing, Jiangsu Province, China. *Journal of Applied Ecology*. 31, 219–229. doi: 10.13287/j.1001-9332.202001.030

Harrison, I.J., Green, P.A., Farrell, T.A., Juffe-Bignoli, D., Sáenz, L. and Vörösmarty, C.J. (2016). Protected areas and freshwater provisioning: a global assessment of freshwater provision, threats and management strategies to support human water security. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 26, 103–120.

Hatfield, C., Mokos, J., and Hartman, J.M. (2004). Development of Wetland Quality and Function Assessment Tools and Demonstration. Rutgers University. 1-99.

Hengkai, L.; Feng, X.; Qin, L. (2020). Remote Sensing Monitoring of Land Damage and Restoration in Rare Earth Mining Areas in 6 Counties in Southern Jiangxi Based on Multisource Sequential Images. *Journal of Environmental Management*. 267, 110653. doi: 10.1016/j.jenvman.2020.110653.

Hu, X. and Xu, H. (2018). A new remote sensing index for assessing the spatial heterogeneity in urban ecological quality: A case from Fuzhou City, China. *Ecological Indicators*, 89, 11–21. doi: 10.1016/j.ecolind.2018.02.006.

Hu, X.S. and Xu, H.Q. (2019). A new remote sensing index based on the pressure-state response framework to assess regional ecological change. *Environmental Science and Pollution Research*. 26, 5381–5393. doi: 10.1007/s11356-018-3948-0.

Jansen, L. (2016). A remote-sensing based assessment of ecosystem services for Palawan, the Philippines. [Thesis] Available at: https://edepot.wur.nl/528008.

Kamara, D., Yang, Z., and Yusuf, A.L. (2020). Ecological Geospatial Monitoring and Assessment of Surface Water Environment Using Remote Sensing Ecological Index Model (RSEI) in Freetown, Sierra Leone, from 2010 to 2018. *Global Scientific*. 8. 328-348. doi:10.11216/gsj.2020.12.45978.

Lackey, R. (2001). Values, Policy, and Ecosystem Health. *BioScience*. 51(6), 437. doi: 10.1641/0006-3568(2001)051[0437:VPAEH]2.0.CO;2

Levin, S.A. (1992), The Problem of Pattern and Scale in Ecology: The Robert H. MacArthur Award Lecture. *Ecology*. 73: 1943-1967. doi: 10.2307/1941447.

Lian, Z.; Hao, H.; Zhao, J.; Cao, K.; Wang, H.; He, Z. (2022). Evaluation of Remote Sensing Ecological Index Based on Soil and Water Conservation on the Effectiveness of Management of Abandoned Mine Landscaping Transformation. *International Journal of Environmental Research and Public Health*. 19, 9750. doi:10.3390/ijerph19159750

Lin, Y.Y.; Hu, X.S.; Zheng, X.X.; Hou, X.Y.; Zhang, Z.X.; Qiu, R.Z.; Lin, J.G. (2019). Spatial variations in the relationships between road network and landscape ecological risks in the highest forest coverage region of China. *Ecological Indicators*. 96, 392– 403. doi: 10.1016/j.ecolind.2018.09.016

Lindenmayer, D., Hobbs, R.J., Montague-Drake, R., Alexandra, J., Bennett, A., Burgman, M., Cale, P., Calhoun, A., Cramer, V., Cullen, P., Driscoll, D., Fahrig, L., Fischer, J., Franklin, J., Haila, Y., Hunter, M., Gibbons, P., Lake, S., Luck, G. and MacGregor, C. (2007). A checklist for ecological management of landscapes for conservation. *Ecology Letters.* 11, 78-91. doi: 10.1111/j.1461-0248.2007.01114.x

Liu, X.; Zhang, X.; He, Y.; Luan, H. (2020). Monitoring and assessment of ecological change in coastal cities based on RSEI. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 42, 461–470. doi: 10.5194/isprs-archives-XLII-3-W10-461-2020.

McDonnell, M.J. and MacGregor-Fors, I. (2016). The ecological future of cities. *Science*, 352(6288), 936–938. doi: 10.1126/science.aaf3630.

Mialhe, F., Gunnell, Y., Ignacio, J.A.F., Delbart, N., Ogania, J.L. and Henry, S. (2015). Monitoring land-use change by combining participatory land-use maps with standard remote sensing techniques: Showcase from a remote forest catchment on Mindanao, Philippines. *International Journal of Applied Earth Observation and Geoinformation*, 36, 69–82. doi: 10.1016/j.jag.2014.11.007.

Mu, D., Luo, P., Lyu, J., Zhou, M., Huo, A., Duan, W., Nover, D., He, B., Zhao, X. (2021). Impact of temporal rainfall patterns on flash floods in Hue City, Vietnam. *Journal of Flood Risk Management*. 14 (1), e12668. doi: 10.1111/jfr3.12668.

Müller, F., Hoffmann-Kroll, R. and Wiggering, H. (2008). Indicating ecosystem integrity — theoretical concepts and environmental requirements. *Ecological Modelling*, 130(1-3), pp.13–23. doi: 10.1016/S0304-3800(00)00210-6

Paetzold, A., Warren, P.H. and Maltby, L.L. (2010). A framework for assessing ecological quality based on ecosystem services. *Ecological Complexity,* 7(3), 273–28. doi: 10.1016/j.ecocom.2009.11.003

E.C. Paringit and C. Pascua. (Eds.). (2017), LiDAR Surveys and Flood Mapping of Abra River, in Enrico C. Paringit, (Ed.), Flood Hazard Mapping of the Philippines using LIDAR, Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry – 328pp

Qi, J.D.; He, B.J.; Wang, M.; Zhu, J.; Fu, W.C. (2019). Do grey infrastructures always elevate urban temperature? no, utilizing grey infrastructures to mitigate urban heat island effects. *Sustainable Society*. 46, 101392. doi: 10.1016/j.scs.2018.12.020

River Basin Control Office and Berkman International, Inc. (2015). Integrated River Basin Management and Development Master Plan for Abra River Basin. Quezon City, Philippines: *Department of Environment and Natural Resources*, 1–287.

Rubio, C.J.P., Jeong, S.-M. and Lee, J.-H. (2008). The State of Water Resources in the Philippines. *Proceedings of the Korea Water Resources Association Conference*. pp.82–91.

Schmidt, H. and Karnieli, A. (2000). Remote sensing of the seasonal variability of vegetation in a semi-arid environment. *Journal of Arid Environments*. 45(1), 43–59. doi:10.1006/jare.1999.0607.

Shan, W.; Jin, X.; Ren, J.; Wang, Y.; Xu, Z.; Fan, Y.; Gu, Z.; Hong, C.; Lin, J.; Zhou, Y. (2019). Ecological environment quality assessment based on remote sensing data for land consolidation. *Journal of Cleaner Production*. 239, 118126. doi: 10.1016/j.jclepro.2019.118126

United States Geological Survey (USGS). (2016) Product guide: provisional LANDSAT 8 surface reflectance product. *Department of the Interior, U.S. Geological Survey.*

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R. and Davies, P.M. (2010). Global threats to human water security and river biodiversity. *Nature*, 467(7315), 555–561. doi: 10.1038/nature09440

Vrsmarty, C.J., Pahl-Wostl, C., Bhaduri, A., (2013). Water in the anthropocene: new perspectives for global sustainability. *Current Opinion in Environmental Sustainability*. 5 (6), 535–538. doi: 10.1016/j.cosust.2013.11.011

Wang, R., Gamon, J., Montgomery, R., Townsend, P., Zygielbaum, A., Bitan, K., Tilman, D. and Cavender-Bares, J. (2016). Seasonal Variation in the NDVI–Species Richness Relationship in a Prairie Grassland Experiment (Cedar Creek). *Remote Sensing.* 8(2), 128. doi:10.3390/rs8020128.

Wang, S.Y., Zhang, X.X., Zhu, T., Yang, W., Zhao, J.Y., (2016). Assessment of ecological environment quality in the Changbai Mountain Nature Reserve based on remote sensing technology. *Process in Geography*. 35, 1269–1278. doi: 10.18306/dlkxjz.2016.10.010

Wu, S., Gao, X., Lei, J. Zhou, N., Guo, Z., Shang, B. (2022). Ecological environment quality evaluation of the Sahel region in Africa based on remote sensing ecological index. *Journal of Arid Land*. 14, 14–33. doi: 10.1007/s40333-022-0057-1

Xu H.Q. (2013). A remote sensing urban ecological index and its application. *Acta Ecologica Sinica*. 33(24): 7853–7862. doi: 10.5846/stxb201208301223

Xu H.Q., Zhang T. (2013). Assessment of consistency in forest-dominated vegetation observations between aster and Landsat ETM+ images in subtropical coastal areas of Southeastern China. *Agricultural and Forest Meteorology*. 168:1–9. doi: 10.1016/j.agrformet.2012.08.012

Xu, H., Wang, M., Shi, T., Guan, H., Fang, C. and Lin, Z. (2018). Prediction of ecological effects of potential population and impervious surface increases using a remote sensing based ecological index (RSEI). *Ecological Indicators*, 93, pp.730–740. doi: 10.1016/j.ecolind.2018.05.055

Xu, H.; Wang, Y.; Guan, H.; Shi, T.; Hu, X. (2019). Detecting Ecological Changes with a Remote Sensing Based Ecological Index (RSEI) Produced Time Series and Change Vector Analysis. *Remote Sensing*. 11, 20: 2345. doi: 10.3390/rs11202345.

Xu, H.Q. (2008). A new index for delineating built-up land features in satellite imagery. *International Journal of Remote Sensing*. 29, 4269–4276. doi: 10.1080/01431160802039957.

Yang, X., Meng, F., Fu, P., Zhang, Y. and Liu, Y. (2021). Spatiotemporal change and driving factors of the Eco-Environment quality in the Yangtze River Basin from 2001 to 2019. *Ecological Indicators*, 131, p.108214. doi: 10.1016/j.ecolind.2021.108214.

Yao, K., Halike, A., Chen, L. et al. (2022). Spatiotemporal changes of eco-environmental quality based on remote sensing-based ecological index in the Hotan Oasis, Xinjiang. *Journal of Arid Land*. 14, 262–283. doi: 10.1007/s40333-022-0011-2.

Yuan, B.; Fu, L.; Zou, Y.; Zhang, S.; Chen, X.; Li, F.; Deng, Z.; Xie, Y. (2021). Spatiotemporal change detection of ecological quality and the associated affecting factors in Dongting Lake Basin, based on RSEI. *Journal of Cleaner Production*, 302, 126995. doi: 10.1016/j.jclepro.2021.126995.

Yue, H., Liu, Y., Li, Y., Lu, Y. (2019). Eco-environmental quality assessment in China's 35 major cities based on remote sensing ecological index. *IEEE Access* 7, 51295– 51311. doi: 10.1109/ACCESS.2019.2911627

Zheng, X., Zou, Z., Xu, C., Lin, S., Wu, Z., Qiu, R., Hu, X., Li, J. (2021). A New Remote Sensing Index for Assessing Spatial Heterogeneity in Urban Ecoenvironmental Quality Associated Road Networks. *Land*. 11, 46. doi: 10.3390/land11010046.

Zhu, Q., Guo, J., Guo, X., Chen, L., Han, Y. and Liu, S. (2020). Relationship between ecological quality and ecosystem services in a red soil hilly watershed in southern China. *Ecological Indicators*, 121, p.107119. doi: 10.1016/j.ecolind.2020.107119.

Zhu, W., Wang, S., Luo, P., Zha, X., Cao, Z., Lyu, J., Zhou, M., He, B., Nover, D. (2022) "A Quantitative Analysis of the Influence of Temperature Change on the Extreme Precipitation," *Atmosphere*, 13(4), 612. doi: 10.3390/atmos13040612.

Zhu, Y., Luo, P., Zhang, S. and Sun, B. (2020). Spatiotemporal Analysis of Hydrological Variations and Their Impacts on Vegetation in Semiarid Areas from Multiple Satellite Data. *Remote Sensing*, 12(24), 4177. doi: 10.3390/rs12244177.