Global J. Environ. Sci. Manage. 9(3): 637-652, Summer 2023, Serial #35

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

REVIEW PAPER

Relationship between landscape and river ecosystem services

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ARTICLE INFO

Article History:
Received 09 October 2022
Revised 12 November 2022
Accepted 15 December 2022

Keywords:
Environment
Land use and land cover
River ecosystem services (RES)
Sustainability
Water bodies
Watersheds

DOI: 10.22035/gjesm.2023.03.18

ABSTRACT

andscape dynamics are a consequence of population growth, which can degrade river ecosystem services. Since various countries approved the millennium ecosystem assessment, it has inspired researchers to examine the relationship between landscape and river ecosystem services. Therefore, this study aims to summarize previous studies about landscape and river ecosystem services using a systematic literature review. This study referred to the preferred reporting items for systematic reviews and meta-analysis. Data were obtained from six databases of scientific publications such as Scopus, Pubmed, Directory of Open Access Journals, Scilit, Neliti, and Garba Rujukan Digital. The results show that research on this topic has spread worldwide. Landscape data, reflected in land use and land cover, came from various sources containing geospatial information and is combined with field surveys. There were 3-18 types of land use and land cover and it did not always reflect detailed information about the research area. Meanwhile, nutrient regulation and water quality attracted the most attention for river ecosystem services. The interaction between the two variables is revealed through inferential statistics and modeling. As representations of the natural landscape, forests and grasslands have a positive and significant contribution to river ecosystem services. Therefore, knowledge of landscape and river ecosystem services is a preliminary effort to understand environmental processes in achieving sustainability, also valuable input for conservation and rehabilitation strategies in many countries. This review can be a proper reference for environmental management, especially in the landscape changes related to river ecosystem services.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
109	2	4

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Note: Discussion period for this manuscript open until October 1, 2023 on GJESM website at the “Show Article”.

INTRODUCTION

Population growth is a global phenomenon that significantly impact environmental changes. It triggers pressure on land, resource consumption, waste and garbage pollution, hydrometeorological disasters, and biodiversity (Dede *et al.*, 2019; Widiawaty *et al.*, 2020; Krsulovic *et al.*, 2022). This situation has long been predicted by Thomas Robert Malthus (1766-1834 AD), who stated that population growth would follow the geometric curve and resources referring to the arithmetic flow, it will lead to a complex environmental crisis if there are no serious efforts such as monitoring, evaluation, and planning (Lambin *et al.*, 2001; Ogundari and Otuyemi, 2019; Baud *et al.*, 2021). It is common knowledge that population growth triggers landscape transformations through land use and land cover (LULC) changes. Usually, this is dominated by converting productive agricultural lands into built-up land, while many primary and secondary forests have changed into monoculture plantations (Dede *et al.*, 2022a; Rochadi *et al.*, 2022; Suardi *et al.*, 2022; Tufa and Megent, 2022). Changes in LULC globally have caused 11 million square kilometers (km^2) of forest to be converted into anthropogenic lands (Pitman and Noblet-Ducoudre, 2012). Meanwhile, many productive agricultural lands are reduced for settlement which has another impact as observed in India, China, South America, and Southeast Asia (Nelson *et al.*, 2010). Landscape changes always have some potential impacts on the surrounding environment. On massive scales, they can affect a wider range of ecoregions across administrative borders (Clark *et al.*, 2022). The impacts can be identified with a river ecosystem service (RES) as integrated research in the environmental field. RES is used to determine the ability of natural processes and the components of rivers to provide adequate services for life needs directly or indirectly. It has attracted significant attention since the emergence of environmental degradation and reduced biodiversity in terrestrial water bodies (Camara *et al.*, 2019; Deeksha and Shukla, 2022). Research on ecosystem services is increasingly being intensified in the new millennium era. It is also an inseparable part of the Millennium Development Goals (MDGs) which are now being updated into the Sustainable Development Goals (SDGs). Efforts to determine changes in ecosystem services, including in rivers, are included in the Millennium Ecosystem Assessment (MA), officially published in 2005 by the United Nations (Reid and Mooney, 2016). RES research with various parameters has become the main concern around the world with grants reaching millions of the United States Dollar (USD) (Dufour *et al.*, 2010). This is presumably because human life and civilization are closely related to rivers that provide natural resources. A review conducted by Venkatesh *et al.* (2014) in India found that changes in the densely vegetated landscape can increase run-off and evapotranspiration as well as affect groundwater recharge to decline, but sediment levels in water bodies continued to rise. Another review by Hasan *et al.* (2020) reported that landscape changes have significant impacts on water purification processes and cultural ecosystem services from rivers. Landscape changes in mountainous regions can affect the provision of ecosystem services and their spatial variations (Pătru-Stupariu *et al.*, 2020). Additionally, they are the main trigger for changes in water balance, especially in precipitation and evaporation which then alter runoff, as well as regulating services in rivers (Ekka *et al.*, 2020). Until now, no literature review has systematically examined the relationship between landscape dynamics and RES since the MA ratification in 2005. The previous review article was too general and has not discussed the relationship between the two phenomena from a global perspective. This problem can be explored by compiling research within the systematic literature review (SLR) framework. SLR-based research provides a clear, comprehensive, and minimally biased overview to gain summarized information (Mallett *et al.*, 2012). SLR is very useful in practice for policy formulation, from the fundamental rules to technical guidelines because it contains transparent, reproducible, and precise information (Gazley, 2021; Nurbayani *et al.*, 2022). This study is very important because it summarizes previous research into a single comprehensive study, providing much convenience for other researchers in similar fields (Abdullah *et al.*, 2022; Ilmasari *et al.*, 2022; Kamyab *et al.*, 2022). This effort could understand the relationship between landscape and RES in terms of parameter formulation, data acquisition, and analytical methods for both variables from a case study perspective. Therefore, the study aims to summarize previous research about the relationship between landscape and RES in the world based on an SLR framework published in 2005-2022. This study has been carried out in Indonesia and Malaysia in 2022.

Search strategy and eligibility criteria

This is SLR-based research conducted in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). The method is intended to create systematic reviews complemented by meta-analyses and provide a more scientific assessment of benefits (Pati and Lorusso, 2018; Basile *et al.*, 2022; Yasuda *et al.*, 2022). Using SLR, the review process will be more transparent, replicable, and scientific for theory development (Shikora and Mahoney, 2015; Franco and Groesser, 2021; Valizadeh *et al.*, 2021). The data for this review were sourced from scientific publications that have been indexed by six databases such as Scopus, Pubmed, Directory of Open Access Journals (DOAJ), Scilit, Neliti, and Garba Rujukan Digital (Garuda) as shown in Table 1. This selection is based on consideration of access and resource capabilities. Apart from Scopus, five other databases provide free services that can be freely accessed by the internet. Scopus and Scilit are managed by commercial publishers–Elsevier and Multidisciplinary Digital Publishing Institute (MDPI). This is different from Pubmed, DOAJ, Neliti, and Garuda which are provided by non-publisher institutions (Mondal and Mondal, 2020; Irawan *et al.*, 2021; Wren *et al.*, 2022). The search method to find literature referred to seven keywords such as "*landscape*", "*land use*", "*land cover*", "*ecosystem services*", "*river*", "*watershed*", and "*water*".

Selection process

Keyword-based searches across the scientific databases found a total of 82 titles but there is a need to select the titles and abstracts to ensure that there are no duplications. This step succeeded in reducing and getting 35 titles included in the 'original research article' containing case reports. Case-study articles contain the application of concepts and theories in real situations, in environmental-related investigations, usually marked by an explicit mention of the research location (Downie and Bernstein, 2019; Devasahayam, 2020; Brimicombe *et al.*, 2022). Meanwhile, original research articles usually provide more detailed information and broader exposure, have undergone through a rigorous peer-review process as well as contain novelty (Kelly *et al.*, 2014; Fernández-Sánchez and Gutiérrez-Arzaluz, 2022; Vadhera *et al.*, 2022). These articles need to be read further to obtain an overview of the research, its scope, and methodology. These works must be published by scientific journals, hence, other publication forms such as proceedings, conference presentations, technical reports, books or chapter books, and students' final projects will not be accepted for this review. Additionally, this selection did not distinguish an article from the writing systematics, because it depends on the publishers' policies.

Data extraction

A detailed and careful review of the research methodology is required to ensure the inclusion of articles. Research on landscape dynamics and ecosystem services is always related to descriptive or inferential results. This review placed more emphasis on articles that use a quantitative or mixed approach to provide more apparent results (Garcia *et al.*, 2018; Araya *et al.*, 2020; Sankofa, 2021; Buzási *et al.*, 2022). Furthermore, before considering an article eligible to be included, the entire content, from the introduction to the conclusion must be reviewed to get complete information (Ciric *et al.*, 2018; Albuquerque *et al.*, 2021; O'Brochta, 2022). The inclusion criteria included SLR-based articles showing the relationship between landscape and RES, articulated by visual and numerical evidence. Finally, this process obtained 17 articles as shown in Fig. 1. At this stage, all authors agreed on all criteria that landscape was limited to LULC.

Table 1: Detail of the databases

Database	Web address	Provider
Scopus	https://www.scopus.com/	Elsevier
Pubmed	https://pubmed.ncbi.nlm.nih.gov/	United States National Library of Medicine
DOAJ	https://doaj.org/	Infrastructure Services for Open Access
Scilit	https://www.scilit.net/advanced	MDPI
Neliti	https://www.neliti.com/	Neliti Private Limited
Garuda	https://garuda.kemdikbud.go.id/	Indonesian Ministry of Education

Quality assessment and data analysis

Eligibility assessment of the article's quality for SLR is based on the publication process to avoid non-reputable journals (Wolfram *et al.*, 2020; Chawla *et al.*, 2022). Based on the writing, the article's quality is related to the language used, pictures and tables, mentioning of scientific concepts, and references list (Alhajj, 2012; Ghazavi *et al.*, 2019; Duc *et al.*, 2020). To ensure the quality and avoid subjectivity from the authors, this effort involved three independent investigators with experience in review investigations and are concerned with the environmental research field. They came from the Indonesian State Universities with Legal Entities (PTN-BH), government research institutions, and non-profit think tanks. The investigators assessed the article as the SLR material and discussed their recommendations with the authors. A quality assessment involving external parties is an effort to reduce bias and increase objectivity rather than relying on a single point of view (Jakes *et al.*, 2021). Furthermore, extracted data from selected articles were then analyzed using content analysis to obtain in-depth written information (Khirfan *et al.*, 2020; Martinengo *et al.*, 2022; Mirzaei *et al.*, 2022). This analysis was selected because it provides flexibility for building interpretations and interconnections, emphasizing problems and identifying research gaps (Lee *et al.*, 2021; Huang *et al.*, 2022; Kim *et al.*, 2022).

Landscape assessment

Case studies to uncover the relationship between landscape and RES have spread worldwide and are not concentrated in a specific country. This situation is good because several countries are concerned about environmental sustainability related to rivers after the MA formulation (Mooney *et al.*, 2004; Ranganathan *et al.*, 2008). This review shows that countries in Asia such as China, Indonesia, Malaysia, and Sri Lanka have been interested in this topic. From North to Latin America, Brazil, Canada, Colombia, Costa Rica, Panama, and the United States have initiated this research as an effort to protect and rehabilitate terrestrial-aquatic ecosystems for areas in diverse climatic conditions. Meanwhile, similar investigations have been conducted in France and Spain, closely related to agricultural landscapes. Research from Africa specifically Congo in the Yangambi watershed was included in this review (Chishugi *et al.*, 2021). In terms of area, the median size of watersheds from previous studies was 2,617 km^2 with a range between 6.77 to 176,000 km^2. This implies that landscapes and RES research can be taken from the micro-watersheds to river basins (Poulus, 2011; Sukristiyanti

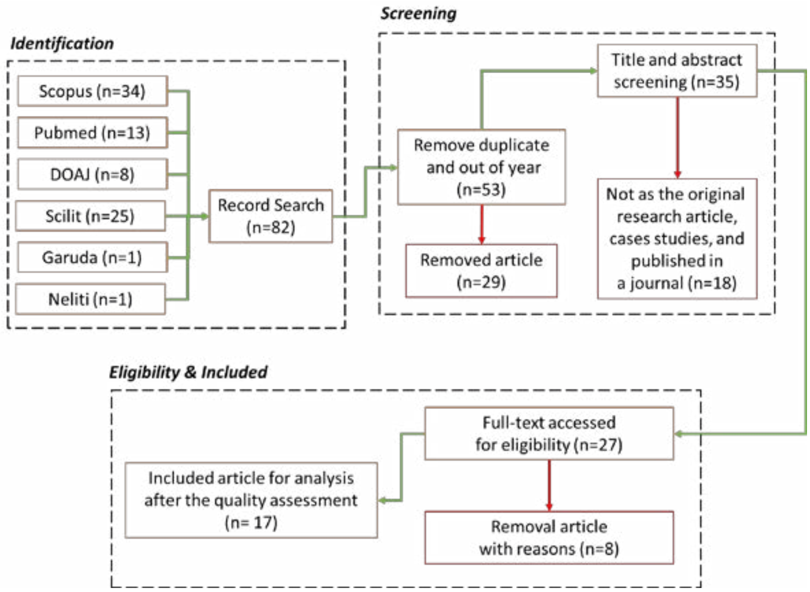

Fig. 1: Selecting processes for articles in the SLR

Table 2: Assessing landscape data for RES research

LULC type	Dataset source	Area (km^2)	Source
Agriculture, forest, cerrado (savanna woodland), regenerating vegetation, and others.	Satellite imageries (Landsat)	176,000	Stickler *et al.* (2009)
Old secondary forest, young secondary forest, and pasture.	Infrared aerial photography, Satellite Imageries (Google Earth) and ground check	35.38	Ogden *et al.* (2013)
Urban land, non-irrigated cultivated land, irrigated cultivated land, forest land, and grass and shrub land.	Analyzed-secondary vectorized data	4950	Sánchez-Canales *et al.* (2015)
Woodland, water, urban built-up area, paddy field, and dry land.	Analyzed-secondary vectorized data (Finer Resolution Observation and Monitoring of Global Land Cover)	2,617	Hao *et al.* (2015)
Forest, grasslands, urban areas, tea, and rice and vegetable cultivation areas.	Satellite imageries (Landsat), topographical maps and ground check	765	Jayawardana *et al.* (2017)
Forest, agroforestry, monoculture tree, annual crops, horticulture, rice field, settlement, shrub and grass, and cleared land.	Measured or modeled data	4,660	Van Noordwijk *et al.* (2017)
Forestry-based reclamation, covering grass, shrubs, water, developed, barren, forest, and pasture.	Satellite imageries (Landsat)	3,429	Gurung *et al.* (2018)
Agricultural, artificial, and natural area	Secondary (Corine Land Cover, ESA Copernicus)	6,775	Raitif *et al.* (2018)
Agriculture, forestry, forest, protected forest, and major freshwater systems.	Field survey	228	Hanna *et al.* (2020)
Dense forest, perturbed forest, cropland, grassland, bare soil and residential, and water bodies.	Satellite Imageries (Sentinel-2B and Google Earth)	430	Chishugi *et al.* (2021)
Forest, wetland, urban, grassland, cropland, and bareland.	Satellite imageries (Landsat) and ground check	2,274	Gao *et al.* (2021)
Native forest both old growth and secondary, agriculture, water body, and other land use.	Satellite imageries (RapidEye and Google Earth) and ground check	4,200	Hilary *et al.* (2021)
Residential area, forest, agriculture, industrial area, facilities, and businesses & services.	Satellite imageries	3401.5	Shehab *et al.* (2021)
Glaciers/permanent snow, bare rock, bare soil, stope, transportation land, construction land, river/canal, reservoir/pond, lake, wetland, dry land, paddy land, grassland, marshy, orchard/perennial plantation, bush fallow, and broad-leaf and mixed forests.	Analyzed-secondary vectorized data (Resources and Environmental Sciences Data Center, Chinese Academy of Sciences in Beijing)	165,383	Liu *et al.* (2021)
Row crops, forest, developed, hay/pasture, water/wetland, and grassland/shrubland.	Analyzed-secondary vectorized data (US National Land Cover Dataset)	20,460	Audia *et al.* (2022)
Agricultural, including cropland, grassland, and urban.	Analyzed-secondary vectorized data (US Census Bureau)	1,345	Campbell *et al.* (2022)
Annual cropping systems, coffee plantations, pastures, abandoned shrubland, and secondary forests.	Analyzed-secondary vectorized data and ground check	125	Galindo *et al.* (2022)

et al., 2018). Differences in the size of research areas affect the landscape details to be analyzed, especially when using geospatial approaches. The details are reflected in the number of LULC types as variables for RES changes, as shown in Table 2. Three types of LULC were involved depending on the human intervention level in the environment such as Ogden *et al.* (2013); Ratif *et al.* (2018), and Campbell *et al.* (2022). These research have a study area that is significantly different in size below 50 km^2 as well as more than 1,000 km^2. Most of the landscape details (18 LULC types) are due to Liu *et al.* (2021), which explored this phenomenon in a river basin covering an area of 165,383 km^2. They used landscape data from the Chinese Academy of Sciences in Beijing.

LULC, as landscape representations that can influence RES dynamics, is generally classified into five types according to the geographic features in each research area. In landscape analysis methods, most data are based on remote sensing from satellite imagery or aerial photography. For historical data, the topographic maps can be used as a reference for landscape analysis (Jayawardana *et al.*, 2017). It is common for individuals to use analytical data provided by reputable research institutes worldwide, typically in vector format. When using raw data from remote sensing imagery (raster files), ground surveys are required to improve accuracy or guide supervised classifications (Gao *et al.*, 2021; Hilary *et al.*, 2021; Galindo *et al.*, 2022). Furthermore, secondary data analyzed in vector files might serve as a reference for performing supervised classification or visual interpretation, especially when there are limitations in the field activities (Gurung *et al.*, 2018). Details of the method and landscape data analysis are presented in Fig. 2.

Even using a multidisciplinary and interdisciplinary approach, landscape monitoring and RES assessment must keep the scientific principles from the original fields. In small watersheds, landscape analysis requires attention to the size of the research area compared to the data scale and resolution. Geospatial analysis on the landscape aspect must pay attention to the accuracy as evidenced by testing with field (ground check) or existing data that has been validated previously in various relevant and credible research (Widiawaty, 2019; Dede *et al.*, 2022b). In large watersheds, which are more than 1,000 km^2, the three LULC types are still acceptable because the data source can come from medium and low-resolution satellite imageries such as the Moderate-Resolution Imaging Spectroradiometer (MODIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS) satellites (Coe *et al.*, 2017; Daramola *et al.*, 2019). This situation can be understood because data sources are limited, also, previous access was not diverse and open. Since 2015, data processing technology based on cloud computing offers various advantages in using resources and providing open data catalogs that allow more advanced landscape

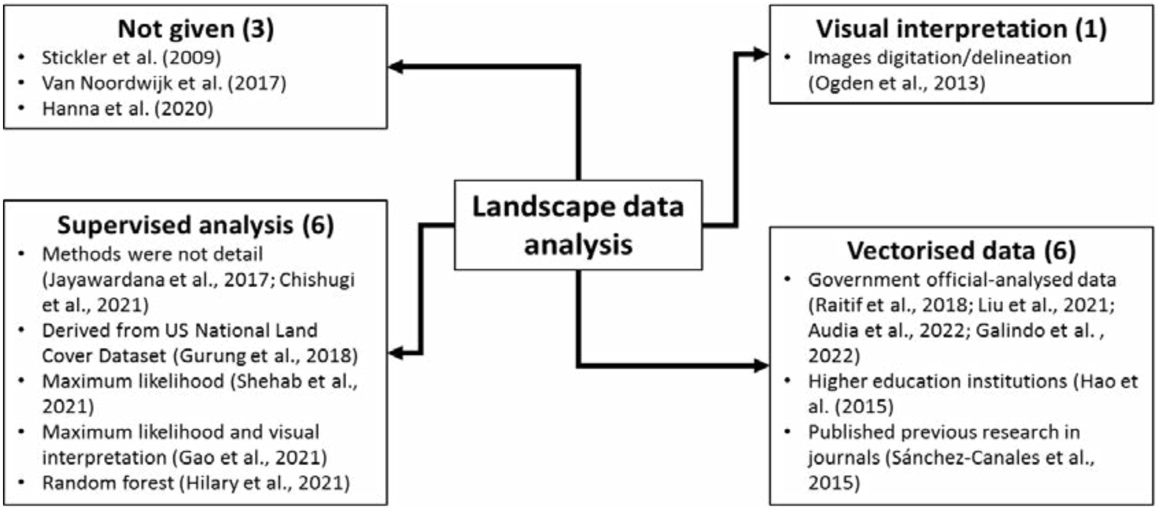

Fig. 2: Analysis method for landscape data

analysis (Dede and Widiawaty, 2020). In relatively small to medium size areas, landscapes can use other sources to obtain more detailed data, such as Landsat series, Sentinel-2 A/B, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Worldview imageries. For more detailed data, aerial vehicles are used but they have implications for the costs of procuring, storing, and processing

Table 3: RES parameter and its additional factors

Ecosystem services	Parameter	Additional factor	Author(s)
Nutrient regulation	Phosphate, nitrate, and carbon (C:N, C:P, N:P ratios)	Slope and river morphometric	Gao *et al.* (2021)
Nutrient regulation	phosphate and nitrate	Climate variation	Campbell *et al.* (2022)
Ecosystem services outcomes	Nutrient delivery ratios, sediment delivery, and carbon storage	Financial services (economic valuation)	Audia *et al.* (2022)
Flood control	Water yield	Elevation, slope, and precipitation	Gurung *et al.* (2018)
Soil retention	Sediment export		
Nutrient regulation	phosphate and nitrate		
Regulating	Flood protection, erosion regulation, nutrient regulation, and water purification	Gross domestic product	Liu *et al.* (2021)
Provisioning	Freshwater		
Cultural	Recreation and aesthetics, and intrinsic value of biodiversity		
Nutrient regulation	Nitrite, ammonia, and phosphate	Riparian forest cover (buffer width)	Hilary *et al.* (2021)
Water quality	Biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), *Escherichia coli*, sulfate, phosphate, nitrate, and ammonia	Landscape metrics	Shehab *et al.* (2021)
Water quality	Temperature, potential hydrogen (pH), conductivity, turbidity, and dissolved oxygen	River morphometric, water poverty index, and climatic aspect	Chishugi *et al.* (2021)
Water quality	Total sediment exported	climate-driven parameter and river morphometrics	Sánchez-Canales *et al.* (2015)
Water quality	Temperatures and dissolved oxygen	Surface hydrology and regional climate and carbon sequence	Stickler *et al.* (2009)
Water quality	Clean water, carbon storage, wild foods, recreation, and habitat quality	Watershed types	Hanna *et al.* (2020)
Biodiversity	Terrestrial and aquatic biodiversity		
River health	Catchment and water quality, macroinvertebrate indices and community composition	Catchment-spatial scale and seasonal conditions	Jayawardana *et al.* (2017)
Aquatic insect emergence	The presence of *Trichoptera*, *Chironomidae,* and *Ephemeroptera*	Watershed scale and site scale	Raitif *et al.* (2018)
Flood control	Measured flow persistence derived from measurements in the wettest and driest 3-month periods of the year	Rainfall, infiltration, interception, groundwater, and river morphometric	Van Noordwijk *et al.* (2017)
Hydrological control	Infiltration, runoff, and erosion rates	Rainfall, slope, and aggregate Morphology	Galindo *et al.* (2022)
Water stream flow	High and low flows	Climate, evapotranspiration, groundwater, and leaf area index	Hao *et al.* (2015)
Runoff control	Dry season river runoff, runoff efficiency, and peak storm runoff	Rainfall, catchment runoff, and evapotranspiration	Ogden *et al.* (2013)

information (Aljohani *et al.*, 2021; Gomez *et al.*, 2022; Sunardi *et al.*, 2022). Landscape needs attention to analytical methods to obtain valid and reliable LULC information. Meanwhile, the visual interpretation method promises advanced accuracy although it is time-consuming and requires the ability to explore detailed landscapes in the research area. Supervised and unsupervised classifications are certainly helpful, although they pose challenges in data quality. Ground check or comparison data is a mandatory material when choosing these methods to obtain proper quality in landscape information. Another important factor in landscape data is accuracy testing, the ability to use overall accuracy, overall kappa, producer accuracy, or other assessment (Foody, 2020; Ismail *et al.*, 2020; Ismail *et al.*, 2022). Ideally, landscape analysis uses interval data between 5-10 years thus LULC changes can be known more clearly. Researchers need to pay attention to time or seasonal aspects when using remote sensing data. This timing could affect vegetation greenness, cloud covers, and reflecting values. Without proper data preprocessing, it would influence information quality.

River ecosystem services and its relation with landscape

For many RES research, regulating services have become different individuals' primary choices. The key to understanding these services in rivers referred to nutrient regulation that analyzes various nutrient content ranging from phosphate and nitrate/nitrite (Hilary *et al.*, 2021; Campbell *et al.*, 2022). Few research also included other parameters such as carbon (Gao *et al.*, 2021; Audia *et al.*, 2022), sediment content and clean water, as well as aesthetics elements (Liu *et al.*, 2021; Karbassi and Pazoki, 2015) as presented in Table 3. The ecosystem services coupled with water quality present parameters related to physicochemical properties. However, a water quality investigation by Shehab *et al.* (2021) found other parameters including an abundance of Escherichia coli, nutrients, and ammonia. Other parameters were also discovered by Hanna *et al.* (2020), which presented information on habitat quality, foods chain, and terrestrial biodiversity. There is a growing interest in aquatic biodiversity ranging from microorganisms, benthos, and insects. In ecosystem services related to water balance, there are similarities between run-off and changes in discharge. When linked to the landscape, these parameters are initial assessments to understand flood events in the watersheds (Alivio *et al.*, 2019). Nutrient regulation focused on nitrate and phosphate are known as indicators of aquatic ecosystems' productivity and food chains. Biological, physical, and chemical parameters are crucial to understanding environmental changes that will affect water resource quality. It is related to the quality standard for usage by people with various needs. The difference in parameters can be caused by the research capabilities such as costs, human resources, instruments, and laboratories.

Perennial landscapes have been demonstrated to maintain and increase RES in nutrient regulation, runoff control, water supply, and water quality as shown in Table 4. Aside from densely-vegetated lands, grassland has a similar ability, although its impact on RES is not as strong as forest. Chishugi *et al.* (2021) found that grassland strongly affects temperature, aquatic dissolved oxygen, and pH regulation. Agricultural land and built-up areas are cultural landscapes, but the presence of crops certainly has advantages because of its ability to create an agroecosystem that enhances RES (Hao *et al.*, 2015; Ratif *et al.*, 2018). This review revealed an interesting phenomenon where riparian vegetation positively impacted water quality and temperature (Stickler *et al.* 2009). Landscape changes impact increasing air temperature which triggers the weathering processes of rock and soil as well as biogeochemical cycles in the surrounding area (Karbassi *et al.*, 2015). Landscape changes have implications for the reduced densely vegetated areas and decreased ecosystem functions for the community. Economically, this phenomenon can be detrimental to agricultural businesses, increasing electricity consumption for cooling, and also damaging goods and buildings. The loss of habitat and its biodiversity will impact people's livelihoods, thus efforts to maintain the landscape needs responsibility for all stakeholders. For RES studies, especially if researchers use the water quality parameters, they can include discussions about quality standards in each country by referring to guidelines and regulations from relevant institutions and ministries, both at the local and national levels. Meanwhile, interactions between landscapes and RES are determined by inferential statistical techniques such as regression models, analysis of variance, bivariate correlations, probability analysis,

Table 4: Significant relation of landscape and RES

Landscape type	RES Parameter	Method	Author(s)
Perennial cover	Reduced perennial covers decreased the levels of nitrate and phosphate	Mathematical modeling	Campbell *et al.* (2022)
Forest	Deforestation adversely affected water yields and nutrient levels	Multiple linear regression (MLR) and Akaike Information Criterion (AIC)	Gurung *et al.* (2018)
Grassland, cropland, forest, and wetland	Landscape changes influenced nutrient levels in river water	Multiple linear regression (MLR) and Directional index	Gao *et al.* (2021)
Landscape fragmentation	Landscape fragmentation influenced RES changes	Geographically weighted regression (GWR) and Ordinary least square (OLS) regression	Liu *et al.* (2021)
Forest	Forest was able to reduce the peak run-off by 35%	Sponge-effect hypothesis, hydrograph analysis, and probability analysis	Ogden *et al.* (2013)
Water bodies, forest	Clean-water provision, carbon storage, habitat quality, and tree diversity were significantly higher in and around streams surrounded by forest	Generalized linear models (GLMs), analysis of variance (ANOVA), Kendall rank correlations, and permutational multivariate analysis of variance (PERMANOVA)	Hanna *et al.* (2020)
Forest, degraded land	Forests are more effective in slowing water flow in the four watersheds in Southeast Asia	Pair-wise comparison test and GenRiver model.	Van Noordwijk *et al.* (2017)
Grassland, forest	Grassland has a strong influence on temperature, dissolved oxygen of water and pH. Forest is related to turbidity, conductivity, and pH properties	Analysis of variance (ANOVA), Pearson's correlation test, and simple linear regression (SLR) models	Chishugi *et al.* (2021) Karbassi and Heidari, (2015)
Agricultural, forest, and abandoned land	Forest affected hydrological services than abandoned land (42% of variance explained), especially runoff and sediment	Analysis of variance (ANOVA) with Tukey tests	Galindo *et al.* (2022)
Forest	Chemical water, including conductivity and total dissolved solids, is mostly governed by the land cover	Principal component analysis (PCA), bivariate regression analysis, and multifactorial ANOVA	Jayawardana *et al.* (2017)
Grassland	Expansion of grassland reduced annual nutrient and sediment loss. It also increased soil carbon sequestration over 10 years	Land use scenario modeling	Audia *et al.* (2022)
Riparian forest cover (buffer length)	Riparian forest cover had a more positive effect on water quality parameters than others. The greater support for influencing water quality based on its length ranged from 1000 meters > 500 meters > 100 meters (m)	Principal component analysis (PCA), Akaike Information Criterion (AIC), and R2 formulation for mixed models	Hilary *et al.* (2021)
Agricultural landscape	Agricultural landscape influenced emerging drymass of aquatic insects	linear mixed model (LMM) with a Gaussian distribution and Akaike Information Criterion (AIC)	Raitif *et al.* (2018)
Forested and cultivated non-irrigated land	Land cover management played in decreasing the sediment loads	Spearman's rank correlation, sensitivity analysis, and USLE model	Sánchez-Canales *et al.* (2015)
Urban area, agricultural lands, forest	Urban and agricultural lands were associated with water quality deterioration, and vice versa for forests	Pearson's correlation and cluster analysis	Shehab *et al.* (2021)
Riparian zone vegetation	The absence of a densely-vegetated landscape triggered higher temperatures and lower dissolved oxygen	REDD scenario model	Stickler *et al.* (2009)
Cropland and urban areas	LULC changed contributed 82-108 % to the stream flow	Z-statistics (Mann-Kendal) and sensitivity analysis	Hao *et al.* (2015)

and comparison tests. These interactions are also revealed through mathematical modeling, Akaike information criterion (AIC), principal component analysis (PCA), sensitivity analysis, REDD scenarios, permutation, and cluster analysis. According to Sánchez-Canales *et al.* (2015), a few non-parametric models can be considered an alternative to determining the interaction of these phenomena. The choice of quantitative method should be related to data characteristics. Hence, disclosing relationships between variables are accurate (Nurbayani and Dede, 2022). MA focuses on everything humans receive from ecosystems. The relationship between the two phenomena is interrelated and the assessment of ecosystem services can be addressed to the needs of each region (Carpenter *et al.*, 2009). Various RES parameters are associated with the research objectives as dependent variables. Samples for observing RES parameters are typically found in streams and water bodies, but terrestrial objects closely associated with aquatic ecosystems can also be observed. Most important in the research are samples selection and handling up to laboratory testing (Nerem, 2017). The sample selection can refer to river morphometry, landscape variations, climate, and stream pattern (Poulos, 2011). The number of samples in RES is generally not very large because it is related to the processing resources and cost.

Sampling for RES related to aquatic ecosystems such as nutrient regulation and water quality is divided into two approaches, 1) point sources; 2) non-point sources. The difference can be seen from the sampling location map when the researcher collected data on a segment (at least two points) without an inlet, this is the point sources. However, if the sampling points were spread regardless of the inlet and outlet, it means that the study referred to non-point sources. Several investigations only revealed one type of ecosystem service because other options are currently minimal. Furthermore, RES selection must have scientific justification when the indicators are quantitatively linked to the landscape or LULC. The relationship between landscape and RES can be determined using many methods such as descriptive and inferential statistics, as well as numerical/scenario modeling. The data characteristics must be appropriately understood before choosing a relational analysis while ensuring accuracy and the interpretation of results. Data types and their distribution have implications for parametric or non-parametric methods (Espejo, 2005; Riaz *et al.*, 2016; Laureano-Rosario *et al.*, 2021; Widiawaty *et al.*, 2022). For research that uses modeling and scenarios, attention must be paid to training-testing data, model testing, and sensitivity to produce robust information (Susiati *et al.*, 2022a; Susiati *et al.*, 2022b). Besides, modeling the interaction between landscape and renewable energy is neither underfitting nor overfitting, hence, a fit model must be achieved in every modeling study (Gu *et al.*, 2016; Ying, 2019; Viana *et al.*,2022), although it comes from simplifying environmental phenomena. From previous research, this review has revealed the relationship between landscape and RES can be divided into two types ie influences and correlations. The influence is characterized by using spatial/mathematical modeling, variance, comparisons, and regression analysis. This is different from correlation, it can use the Pearson, Kendal-Tau, and Spearman-Rank methods.

CONCLUSION

Landscapes and RES reviews from the elected articles indexed in six databases reveal that research on this subject spans Asia, Europe, America, and Africa. The data come from different sources which contain spatial information combined with field research activities. The research area size, usually in the form of river flow, does not always correspond to the detail of the data. The smaller area has implications for LULC types, but the involvement of RES can provide an upscaling and simplification of geospatial information. The landscape for RES research is divided into 3-18 types of LULC. This information was obtained through several analyses such as supervised, unsupervised, and vectorized-analyzed data. It is important for researchers to give more attention to spatial resolution, both using primary or secondary data for landscape analysis. Landscape classification should be more diverse for small areas, especially if the research uses high or very high-resolution spatial data sources. Meanwhile, RES data raises many parameters that are adjusted to the ecosystem service types. Previous research showed that nutrient regulation and water quality could reveal changes in RES due to landscape dynamics. RES related to water balance has been disclosed to contain parameters related to runoff and recharge-discharge. This review revealed that natural landscapes provide more benefits to ecosystem services than anthropogenic landscapes. The presence of forests and grasslands can contribute positively to RES. Changes in forest and grassland for at least three years have significantly affected RES deterioration. However, it can also contain research on biodiversity, provisioning, and cultural services. The interaction between landscape and RES is revealed through quantitative approaches such as inferential statistics and modeling. Regression, correlation, variance analysis, probability and scenario as well as modeling are options to quantify these interactions as long as data meet the scientific criteria. Choosing an analysis model to reveal the interaction between these variables must comply with the sampling and data characteristics. Choosing the inferential statistical methods, either parametric or non-parametric should be appropriate for similar studies in the future to get more rigorous information on relationship between these variables. This review gained information about landscape and RES, which makes future research convenient, especially in selecting these parameters, data acquisition, and analytical methods. Researchers need to determine the observation interval based on dynamics in the study area and other geographical conditions. However, researchers should be emphasized the time interval for each observation, either in its season or year. Moreover, this literature review is valuable information for all stakeholders to manage landscapes through formal regulation and action. Landscape dynamics and RES are two interrelated phenomena, this study can inspire researchers, governments, communities, and environmentalists to take real action in environmental management for present and future generations based on data evidence. Landscape management needs attention to its function, even its allocation in spatial and regional terms is still important.

AUTHOR CONTRIBUTIONS

M. Dede performed the conceptualizing the draft, literature review, experimental design, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. S. Sunardi performed the conceptualizing the draft, compiled the data, and revising the final manuscript version. K.C. Lam performed the conceptualizing the draft, literature review and manuscript preparation, and review the whole manuscript. S. Withaningsih performed the literature review, prepared the manuscript text, revising the final manuscript version, remained experiments.

ACKNOWLEDGEMENT

Authors are thankful for the financial support provided by Universitas Padjadjaran through 'Beasiswa Program Doktoral Padjadjaran' [2203/UN6.3.1/PT.00/2022] and 'Hibah Publikasi Ilmiah Bereputasi' year 2022. Special thanks to Millary Agung Widiawaty (CIGESS), Heni Susiati (BRIN) and Arif Ismail (UPI) as interlocutors. Authors also thank to the independent reviewers who provided valuable recommendations.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

ABBREVIATIONS

%	Percent
AIC	Akaike Information Criterion
ANOVA	Analysis of variance
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BOD	Biochemical oxygen demand
BRIN	Badan Riset and Inovasi Nasional
C	Carbon
CIGESS	Cakrabuana Institute for Geoinformation, Environment and Social Studies
COD	Chemical oxygen demand
DOAJ	Directory of Open Access Journals
ESA	European Space Agency
Fig.	Figure
Garuda	Garba Rujukan Digital
GLMs	Generalized linear models
GWR	Geographical weighted regression
Km	Kilometer
km^2	Square kilometer
LLM	Linear mixed model
LULC	Land use and land cover
M	Meter
MA	Millennium Ecosystem Assessment
MDGs	Millennium Development Goals
MDPI	Multidisciplinary Digital Publishing Institute
MLR	Multiple linear regression
MODIS	Moderate-Resolution Imaging Spectroradiometer
N	Nitrate
OLS	Ordinary least square
P	Phosphate
PCA	Principal component analysis
PERMANOVA	Permutational multivariate analysis of variance
pH	Potential hydrogen
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PTN-BH	Perguruan Tinggi Negeri Berbadan Hukum (Indonesian State Universities with Legal Entities)
R2	r-squared or coefficient of determination
REDD	Reducing Emissions from Deforestation and Forest Degradation
RES	River ecosystem services
SDGs	Sustainable development goals
SLR	Systematic Literature Review
SLR	Simple linear regression
UPI	Universitas Pendidikan Indonesia
US	United States of America
USD	United States Dollar
USLE	Universal soil loss equation
TSS	Total suspended solids
VIIRS	Visible Infrared Imaging Radiometer Suite
WOS	Web of Science

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HOW TO CITE THIS ARTICLE

Dede, M.; Sunardi, S.; Lam, K.C.; Withaningsih, S., (2023). Relationship between landscape and river ecosystem services. Global J. Environ. Sci. Manage., 9(3): 637-652.

DOI: 10.22035/gjesm.2023.03.18

URL: https://www.gjesm.net/article_699772.html