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Review

Mangrove ecosystem in Asia: review and synthesis of ecosystem services and economic valuation methods

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Abstract

Mangroves provide multiple ecological and socioeconomic benefits in both terrestrial and aquatic ecosystems; however, little is known about their benefits to humans. This study presents a systematic synthesis of the ecosystem services (ESs) and economic valuation methods (EVMs) of mangrove ecosystems in Asia. A total of 28 studies published from 12 countries encompassing 194 observations were reviewed and included in the analysis using Publish or Perish Software. Results revealed that the majority of the mangrove forests in Asia host the genera *Rhizophora* and *Avicennia* spp. in the largest proportion, indicating that these genera contribute significantly to mangrove ESs. Market price and factor income methods were the most frequently used EVMs with 96 and 66 value estimates, respectively. Provisioning ecosystem services were valued the most often among ESs types. Moreover, regarding the values of specific ESs, the median values of those that belong to regulating ecosystem services were the highest, specifically erosion prevention (5833.22 \$ ha^{-1} year^{-1}) and moderation of extreme events (3633.69 \$ ha^{-1} year^{-1}). Considering contemporary protection and conservation measures, research studies on mangrove ESs and EVMs can be further improved through broader geographic area coverage and improved economic assessment of the rarely studied ESs. Overall, the findings recommend focusing on these gaps, particularly encouraging institutions and policymakers to acknowledge the undervalued ecological and socioeconomic values of mangrove ecosystem services.

Key words: Asia, economic valuation methods, ecosystem services, mangrove ecosystems.
Abbreviations: ECs, ecosystem services; EVM, economic valuation methods..

Introduction

Mangrove ecosystems, which are presently encountering substantial challenges globally, provide a wide range of ecosystem services (ESs) and socioeconomic benefits (FAO 2022; IUCN 2010). These ecosystems have substantial impact on poverty alleviation, food security, empowerment of rural women, regulation of climate patterns, and facilitation of climate change adaption through the utilization of ecosystem-based techniques (Duke et al. 2014; Beck, Lange 2017; UN Environment 2018). However, there is a concerted effort by experts and scientists from the Mangrove Specialist Group to address the worldwide decline of mangrove ecosystems, which is mostly caused by the cumulative effects of human-mediated activities on these ecosystems (Curnick 2019). Despite the numerous research studies conducted on mangrove ecosystems, there remains a significant knowledge gap that necessitates focused investigation, particularly on assessment of the ESs offered by mangroves, as well as the prevailing economic valuation techniques (EVMs) applied to measure their economic value. Documenting the comprehensive understanding of the ESs and EVMs pertaining to mangrove ecosystems plays a pivotal role in informing policy-making procedures and facilitating discussions on mangrove conservation and restoration efforts.

A significant proportion of mangrove species worldwide face the threat of extinction due to various factors, i.e., coastal expansion, agriculture, climate change, and logging (IUCN 2010), which intensifies the need for the conservation and rehabilitation of mangrove ecosystems for ecological and socioeconomic benefits, and requires further attention among experts, scientists, and policy makers (aligned with Sustainable Development Goal, particularly No. 14 – Life Below Water; IUCN 2010). Further, there is a considerably higher average rate of loss from 1996 to 2016 (0.21% per year) for tropical and subtropical mangrove forests globally, requiring immediate attention (GMW 2018; The Nature Conservancy 2018). The observed phenomenon can be attributed to human-mediated activities arising from a lack of prioritization of conservation policies, and a preference for practices like intensive logging, overfishing, and unsustainable management approaches. The assessment of the EVM is a frequently employed method vis-à-vis other management strategies to guide policy procedures and management schemes, as well as to comprehend the significance of the ESs offered by mangrove ecosystems.

Mangrove ecosystems perform critical roles, and directly and indirectly provide various ESs that benefit humans (Cochard 2017). Millions of people worldwide depend on mangrove ecosystems for their means of living and health. Nevertheless, the ESs of aquatic and terrestrial ecosystems are primarily susceptible to various environmental problems (Barbier et al. 2009; Lau et al. 2019). Rising global temperature, rapid population growth, and the ongoing overexploitation of natural resources are wreaking havoc on these ecosystems (George 2018). Continuous decline observed in coastal and estuarine ecosystems, due to human-mediated activities, affects many ESs (Barbier et al. 2011). Mangrove forests are among the incredibly productive ecosystems that provide various ESs to all lifeforms (EcoViva 2016). Mangroves help support other ecosystems, reduce socioeconomic factors, and support livelihoods by the resources it provides to humans (Beck, Lange 2017). These mangroves provide structural support and safeguard the lives of the people living nearby, as they can prevent erosion and can also absorb storm surge impacts (Birch 2020).

Mangrove ecosystems provide a wide array of ESs along with the resources that are necessary for organisms to thrive (Talukdar et al. 2020). These ESs would not exist if there were no organisms that would require them (Haines-Young, Potschin-Young 2018). The natural ecosystem's contribution to these benefits is frequently unsubstantiated and immeasurable (Layke et al. 2019; Martins, Lima 2021). Despite their cultural, ecological, and economic values, mangrove ecosystems and the biodiversity that supports them are still degrading with an enormous loss of functionality (Maynard, Karki 2022). A healthy ecosystem would bring many ESs that make human life possible (FAO 2021). Mangrove forests, which hold great ecological significance, provide ES to many individuals living near the coastal areas; the benefits range from woods and fuel to fish and other food resources (Locatelli et al. 2014). They also provides food security for the local communities, various forest products, support fisheries, protect coastlines, and help improve the quality of water (Duke et al. 2014; UN Environment 2018). They also produce coastal-related jobs through tourism and other types of recreation. Continuous degradation of these mangrove forests may result in a decline of ESs, which may directly affect the organisms that rely on them (Quevedo et al. 2019).

The insufficiency of information on mangrove forests and the inaccessibility of literature for researchers limit the understanding of their importance. Notwithstanding, a bias might occur in the global understanding of mangrove ecosystems, which could limit cooperative research on this topic among scientists around the world. To document the study on this worldwide significant topic, a search approach using a systematic review was utilized to overcome most of these limitations. Comparing and integrating the results of a literature search with those in other databases may complete the picture on this topic while also presenting a greater understanding of the global nature of coastal ecosystems in general (Rizal, Sahidin 2018). Summarizing what is documented in the current literature on the ESs and the most common EVMs of mangrove forests may serve as a benchmark study for future research. Conducting a systematic review is an exhaustive and thorough process for collecting, analyzing, and synthesizing all relevant data on a certain research question or topic. It is a crucial and essential tool for researchers, decision-makers, and professionals who are interested in mangrove ESs and EVMs research, since it provides an unbiased and reliable assessment of an existing body of information on a particular subject (TEEB 2012). It also highlights knowledge gaps and offers guidance on decision-making processes regarding mangrove management and conservation. Overall, it helps to ensure that decisions are based on the best information available and that research efforts are concentrated on areas requiring more study.

Hence, we conducted a systematic review to document, collate, analyze, and synthesize published literature about the ESs of mangrove ecosystems and the most common EVMs employed in determining the values of mangrove forests in Asian coastal communities. The objectives of this study were to: (a) identify the baseline information on the study characteristics (e.g., year of publication, value year used, country of the study site, geographic area of the study site, and the genera of mangrove species identified); (b) calculate the frequency of EVMs used in existing valuation studies in Asia; (c) classify the EVM estimates of mangrove ESs in Asia by service types (e.g., provisioning services, regulating services, supporting services, and cultural services; and (d) determine the EVM estimates of the species ESs in Asia according to TEEB classification (i.e., food, raw materials, erosion prevention, etc.). These objectives are important in understanding the value of mangrove based ESs in coastal communities and the relevance of the EVMs in mangrove forest conservation and prioritization, determining what information is missing from previous valuation research studies to address conservation and prioritization of mangrove forests efficiently, and finally, resolving the overall basis for mangrove management and rehabilitation in Asia.

Materials and methods

Exemption from the ethical review

The study was granted exemption from ethical review by the Cebu Normal University Ethics Research Board (CNU-ERB) on September 29, 2022 (CNU-REC Code: 127/2022-08), since it had minimum risk and did not involve human subjects.

Systematic literature search

We systematically searched peer-reviewed literature using Harzing's Publish or Perish 7 program (https://harzing.com/resources/publish-or-perish). A cross-reference was done to look for relevant papers in the electronic databases, institutional resources, and government websites such as Elsevier Scopus (https://scopus.com), ISI Web of Science Core Collection, Google Scholar, and Semantic Scholar. These data sources were chosen to cover a variety of publication styles, including academic journals, literature reviews, thesis and dissertations, and systematic reviews, to limit the possibility of publication bias. The cross-reference investigated online databases with the use of Boolean Operators (AND and OR operators) to narrow and limit the search to the desired pool of literature (Hollier 2020).

Search strategy development and implementation and inclusion and exclusion criteria

We used the search terms "mangrove [title], valuation AND ecosystem services", "mangrove AND valuation [title], valuation AND ecosystem services OR Asia", and "mangrove valuation ecosystem services". Other than the online databases, a repository site, the Ecosystem Services Valuation Database (https://www.esvd.net/), was utilized to collect studies focused on the valuation of ecosystems. Studies included were those that contained data on the baseline information of mangrove ecosystems (e.g., mangrove species, geographical area of study site, and country of study site). Studies containing data on the EVMs of mangrove ESs and information on the valuation method used were included. For results with overlapping cohorts, the study with the more complete data was included. Published non-English studies with an English abstract were included provided that the abstract contained sufficient information for the systematic review. Studies without full-text availability or abstract-only papers were excluded from this review. Studies considered as systematic reviews, meta- analysis, and bibliometric reviews were excluded as well. The identification of studies for inclusion in the review was conducted with the use of guidelines set by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Page 2021). The collected literature from the databases (Elsevier Scopus, Semantic Scholar, Google Scholar) underwent title and abstract screening, as well as eligibility screening.

Relevance assessment, data extraction and bias assessment

Peer-reviewed publications were screened using Rayyan (https://www.rayyan.ai/) – a free web-based program that processes title and abstract screenings through semi-automation (Ouzanni 2016). The program features a blind screening mode, wherein decisions of the reviewers are not visible to others, thereby reducing potential biases in study selection. Risk of Bias in Temporal Trends for Ecological Studies (ROBITT), a tool developed and designed specifically to assess the risk of bias in systematic reviews, was used for this review (Whiting 2016). Risk of biases were rated by two independent reviewers using Google Sheets, wherein the reviewers worked on separate worksheets. A full-text screening was conducted for studies included in the final selection, and qualitative and quantitative data were extracted to compare valuation studies done in mangroves. For each study, publication year, baseline information of mangrove ecosystems (e.g., mangrove species, geographical area of the study site, and country of study site), valuation methods and valuation estimates were extracted. The value estimates were standardized using common spatiotemporal unit and currency value, as US$ per hectare per year.

Data analysis

A general descriptive analysis was followed to analyze the collated data, summarizing key points. Included studies were arranged chronologically according to the year of publication. The frequency of studies published per year was determined. Baseline information of the mangrove ecosystems such as geographical location was also identified to determine the frequency of studies being published per country in Asia. Geographical areas of the mangrove ecosystem, in terms of hectares, were also obtained to assess the scope of the mangrove ecosystem's goods and services within the studied region. Mangrove species identified were also examined within the included studies. Mentioned mangrove species were grouped and classified according to their genus, e.g., *Rhizophora mucronata* and *Rhizophora apiculata* were grouped in *Rhizophora* spp. Furthermore, valuation methods were identified accordingly from each peer-reviewed article to determine the most and least frequently used valuation methods; similarly, various estimated ES were organized from the final pool of collated literature. Moreover, the values of these ES were tabulated to provide an overview on the estimated values of ESs in Asia.

Results

Literature search

A total of 817 EVM and ESs studies were obtained from search databases and engines; 97% of the reviewed studies (*n* = 789) were considered ineligible or unavailable, hence, eliminated from the study (Fig. 1). Most of the data was obtained from Semantic Scholar (*n* = 500), followed by Google Scholar (*n* = 141), and finally Elsevier Scopus (*n* = 90). Furthermore, duplicate records (*n* = 113) were eliminated from the databases, leaving a remaining count of 86 registers that underwent the further screening process. The literature analysis identified a total of 28 articles that were published between 1996 and 2020. The primary objective of these studies was to assess and quantify the economic values associated with ESs offered by mangroves across different Asian countries.

Risk of bias assessment

The ROBITT bias contrast tool was used to set up transparency of evidence synthesis, results, and findings. During the full-text screening stage, all 28 studies were reviewed individually by each of two reviewers, who employed a comprehensive evaluation approach that encompassed three distinct domains: (a) the geographical domain, (b) the environmental domain, and the (c) taxonomic domain (Fig. 2). In addition, the reviewers also considered potential biases, which were further addressed using guiding questions provided in the assessment. The second reviewer conducted an evaluation of the same studies that were previously analyzed using the same tool for assessing bias in records. The reviewer also documented any study that was excluded or not fully covered, along with justifications (Fig. 2).

Qualification as a risk bias assessment reviewer in research frequently necessitates a robust foundation in the given study topic, such as Biology and Environmental Science, together with a thorough understanding of relevant standards and frameworks for analyzing bias in research (Page 2021). Both reviewers of this work possessed the necessary expertise in their respective fields. The reviewers demonstrated both autonomous and collaborative qualities in their assessment of research bias. As presented in Fig. 2 and 3, most of the research under consideration exhibited a low risk of bias across all domains. Nevertheless, the study conducted by Chow (2015) received a high-risk rating from the second reviewer in relation to environmental domains, taxonomic domains, and other potential biases. In contrast, the first reviewer assessed the study as having a low risk of bias in the taxonomic domain, while the risk of bias in the environmental domain and other potential biases remained unclear. The utilization of contrasting assessments aids in the establishment of the transparency of findings derived from the synthesis of evidence. However, the study was included despite its significant risk of bias, which was only assessed in three out of the eight ratings conducted by the two reviewers.

Study characteristics

EVM and ESs studies included in this analysis were sourced from a total of 12 Asian countries (Fig. 4). Most of these studies were published in India (*n* = 5), followed by Indonesia (*n* = 4) and the Philippines (*n* = 3). The remaining countries, namely Bangladesh, Sri Lanka, Thailand, Vietnam, China, Cambodia, Malaysia, Myanmar, and Pakistan, each contributed one or two studies to the dataset. In terms of geographical distribution, a total of 12 publications originated from the South Asian region,

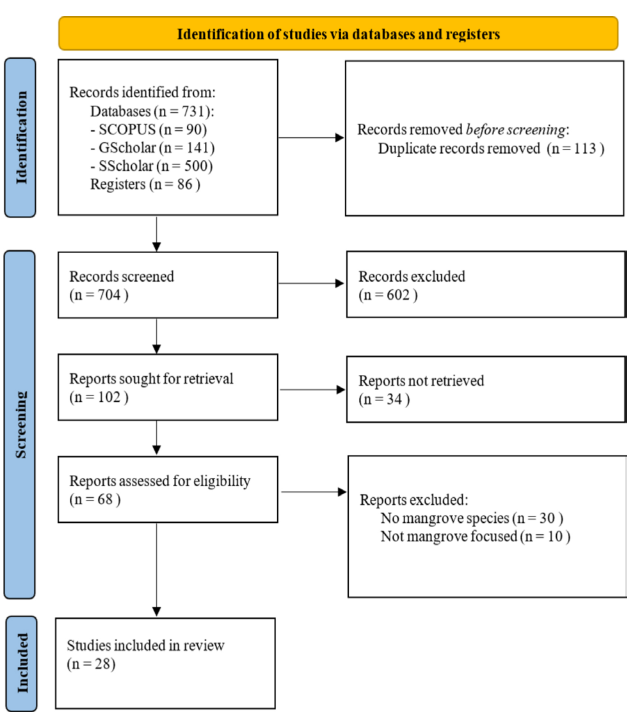

Fig. 1. PRISMA flow diagram for the identification of studies for inclusion in the systematic review.

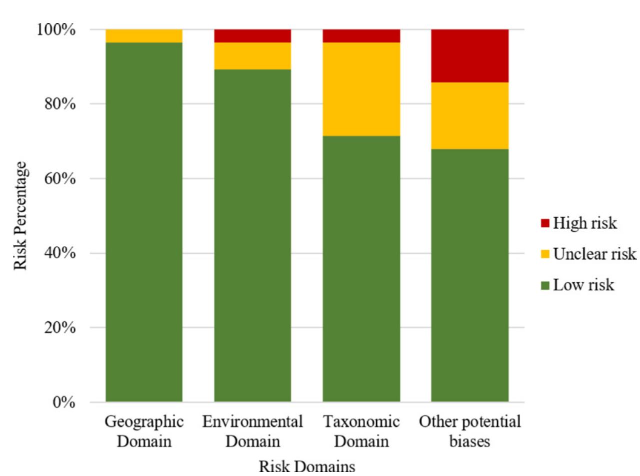

Fig. 2. Result summary of the risk of bias in temporal trends for ecological studies or ROBITT tool.

Study	Reviewer #1: **Geographic** Domain	Reviewer #1: **Environmental** Domain	Reviewer #1: **Taxonomic** Domain	Reviewer #1: Other potential biases	Reviewer #2: **Geographic** Domain	Reviewer #2: **Environmental** Domain	Reviewer #2: **Taxonomic** Domain	Reviewer #2: Other potential biases
Janssen and Padilla, 1996	+	+	+	?	+	+	+	+
Bann, 2003	+	+	+	+	+	+	+	+
Badola and Hussain, 2003	+	+	+	+	+	+	+	+
IUCN - Sri Lanka, 2003	+	?	?	?	+	+	+	?
Walton et al., 2006	+	+	+	?	+	+	+	+
Ranasinghe and Kallesoe, 2006	+	+	+	?	+	+	+	+
Baig and Iftikhar, 2006	+	+	+	+	+	+	+	+
Sathirathai and Barbier, 2007	+	+	+	+	+	+	+	+
Hussain and Badola, 2008	+	+	+	?	+	+	+	?
Muraleedharan et al., 2009	+	+	+	-	+	+	+	-
Janekarnkij, 2010	+	+	+	?	+	+	+	?
Hussain and Badola, 2010	+	+	+	+	+	+	+	+
Adhikari et al., 2010	+	+	+	+	+	+	+	+
Viswanathan et al., 2011	+	+	?	+	+	+	?	?
Tantu et al., 2012	+	+	?	?	+	+	?	-
Shuib et al., 2012	?	+	+	?	+	+	+	+
Kuenzer et al., 2013	+	+	+	?	+	+	+	+
Uddin et al., 2013	+	+	?	+	+	+	?	+
Fan et al., 2013	+	?	?	-	+	-	?	-
Carandang et al., 2013	+	+	+	+	+	+	+	+
Vo et al., 2015	+	+	?	+	+	+	?	+
Malik et al., 2015	+	+	+	+	+	+	+	+
Hema and Devi, 2015	+	+	+	?	+	+	+	?
Chow, 2015	+	?	+	?	+	-	-	-
Susilo et al., 2017	+	+	+	+	+	+	+	+
Damastuti and de Groot, 2017	+	+	+	?	+	+	+	+
Lahjie et al., 2019	+	+	+	+	+	+	+	+
Phan et al., 2020	+	+	?	?	+	+	+	+

Fig. 3. Risk of bias assessment rating of independent reviewers.

encompassing nations such as India, Pakistan, Sri Lanka, and Bangladesh. Additionally, 15 studies that were examined were attributed to the Southeast Asian countries. Notably, only one study was identified from the East Asian countries – specifically China.

Regarding publication year, the earliest literature was published in 1996; the most recent being in 2020. The years 2013 and 2015 had a total of four publications, while the years 2003, 2006, and 2010 each had three publications. In contrast, the years 2012 and 2017 provided two publications each. Furthermore, the years 1996, 2007, 2008, 2009, 2011, 2019, and 2020 each provided one publication. Value years refer to specific time periods during which economic valuations of ESs was determined. Hence, most of the studies commonly employed values that were published prior to the year of publication (Table 1). On average, there was a time lag of 2.25 years between the publication year and the value year. Within the set of studies under examination, a total of six studies employed data sourced from the year 2012.

Fig. 5 provides the area in ha of the mangrove sites that were examined. Among these sites, Bangladesh has the largest area at 606 872 ha, followed by Vietnam with 335 085 ha, India with 90 648 ha, Malaysia with 52 318 ha, Cambodia with 48 000 ha, Indonesia with 32 857 ha, Thailand with 31 911 ha, the Philippines with 17 199 ha, Pakistan with 6863 ha, Myanmar with 2441 ha, and Sri Lanka with 589 ha. The study conducted solely inside the

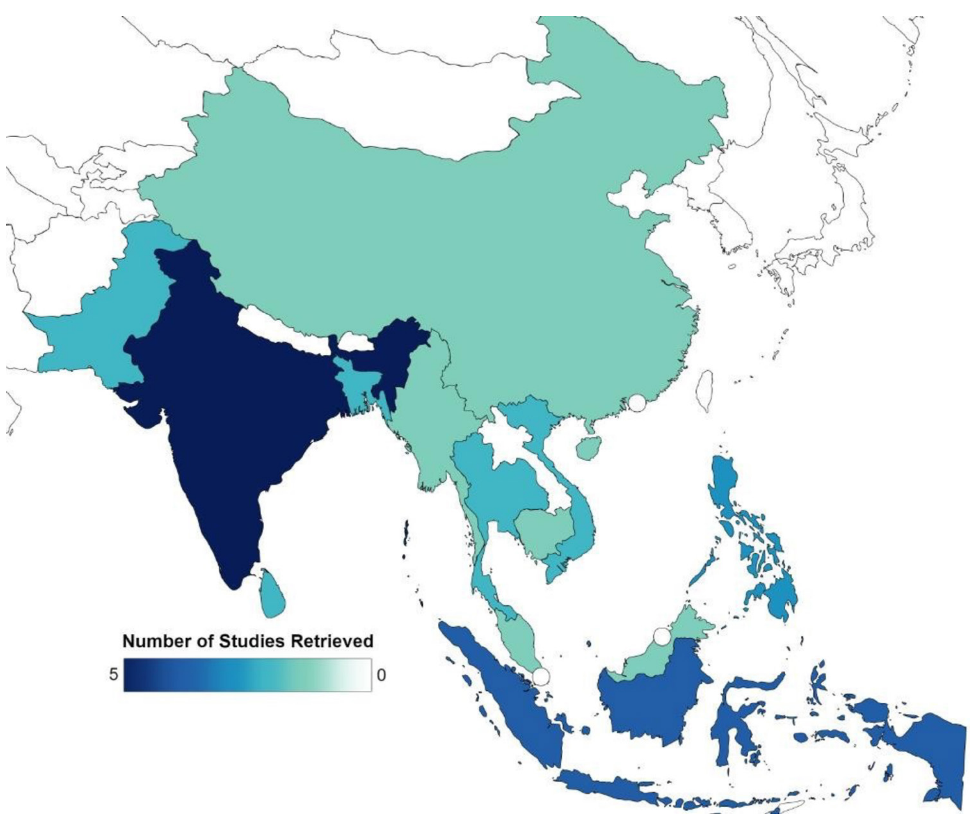

Fig. 4. Density map representation on the number of valuation studies reviewed from each Asian country.

Table 1. Valuation approaches and methods in ecosystem services valuation (EVMs). Sources: Hussen 2000; Louviere et al. 2001; Woodward 2001; de Groot et al. 2002; Liiri et al. 2002; Patterson 2002; Wilson, Howarth 2002; Hensher et al. 2005; Kahn 2005; Philip, MacMillan 2005; Brander et al. 2006; Hackett 2006; Street, Burgess 2007; Spash 2008; Kaval 2010; Anderson 2019; Sacramento, Geges 2019

Type	Method	Example
Market	Market price	The value ecosystems have for trade such as 'goods' e.g., production functions. regulation inactions. and some information functions (e.g., recreational) Example: The value of catch by comparing fish prices from zones with and without mangrove
Cost-based	Avoided cost	The value of climate regulation services can be derived from the estimated damage of longer and extreme droughts
	Replacement cost	The value of the worms that provide nutrients for the soil can be estimated from the cost of obtaining synthetic fertilizers
	Mitigation / restoration costs	Cost of environmental damage repair caused by M/T Solar 1 Guimaras Oil Spill in 2006
	Production function / factor income	How improvements in water quality increase industrial yield and thereby incomes of fishermen. and how bees pollinate the flowers of agricultural crops, thus increase yield, quality, and commercial value of many crops
Revealed preference	Hedonic pricing	To determine the value of basing a beach as a view in front of a house. A researcher could compare the house prices from the one overlooking the beach to those that are a block away
	Travel cost method	Cost of travel to a lake for camping and fishing. Extra money and time would people have to spend while travelling on gas/petrol, camping fees, food and fishing equipment rent
Simulated	Contingent valuation method	It is often the only method to estimate non-use values. For example, the amount a group of fishermen are willing-to-pay to fish in an area, only if guaranteed to catch at least five loads of fish within the site
	Choice modeling	It is applicable though different methods (e.g., choice experiments, contingent ranking, contingent rating. pair comparison) Example of choice experiments alternatives are percentage of harvested trees or species diversity. dollar value and annual tax fees rates
	Group valuation	It addresses revealed preference methods' drawbacks during a survey. as well as the lack of knowledge coming from the respondent about what they are supposed to give values to

confines of a three-hectare mangrove area, was carried out by researchers affiliated with China.

Mangrove species richness

Rhizophora spp. and *Avicennia* spp. were the most frequently identified mangrove species within the study sites from the reviewed literature, and were found in 25 and 20 studies, respectively (Fig. 6). This was followed by *Sonneratia* spp. (n = 15), *Ceriops* spp. (n = 12), *Bruguiera* spp. (n = 10), *Heritiera* spp. (n = 10), *Nypa* sp. (n = 7), *Excoecaria* sp. (n = 6), *Xylocarpus* spp. (n = 6), *Lumnitzera* spp. (n = 5), *Phoenix* sp. (n = 4), *Aegiceras* sp. (n = 3), *Acanthus* sp. (n = 2), and *Kandelia* spp. (n = 2). Other mangrove species (e.g., *Pongamia* sp., *Madhuanchar* sp., *Gohira* sp., *Eriochloa* sp., *Dolichandrone* sp., *Diospyros* sp., *Derris* sp., *Cynometra* sp., *Cerbera* sp., *Aegialitis* sp., *Acrostichum* spp., and *Acanyus* sp.) were only mentioned once in the 28 reviewed studies. When categorized on region, it was found that most of the mangroves identified within the South Asian region were *Avicennia* spp. (n = 8), followed by genera *Sonneratia* spp. (n = 7), *Heritiera* spp. (n = 7), *Rhizophora* spp. (n = 6), and *Ceriops* spp. (n = 6). *Bruguiera* sp., *Excoecaria* sp., *Xylocarpus* sp., *Nypa* sp., *Aegiceras* sp., *Lumnitzera* sp., *Phoenix* sp., *Acanthus* sp., and *Kandelia* spp. were all mentioned only once among South Asian studies. Species of the genus *Rhizophora* were the most mentioned mangrove genera within the Southeast Asian region. This was followed by *Avicennia* spp. (n = 11), *Sonneratia* spp. (n = 8), *Ceriops* spp.

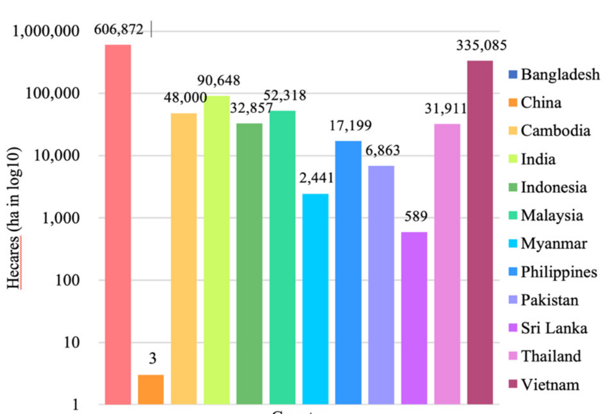

Fig. 5. Total hectarage of studied mangrove sites in each Asian country.

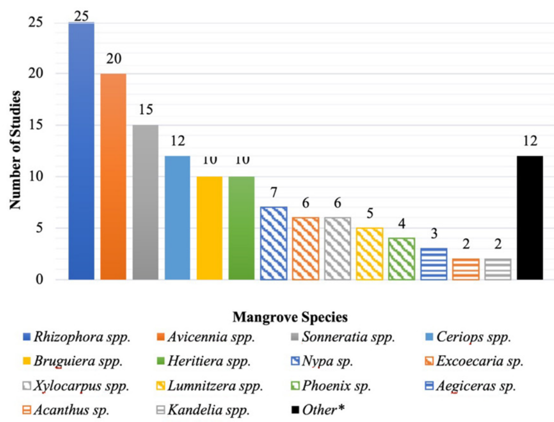

Fig. 6. Frequency of mangrove genera identified and mentioned by reviewed studies. *Other species: *Pongamia, Madhuanchar, Gohira, Eriochloa, Dolichandrone, Diospyrus, Derris, Cynometra, Cerbera, Aegialitis, Acrostichum, Acanyus.*

(*n* = 6), *Nypa* sp. (*n* = 6), *Bruguiera* spp. (*n* = 5), *Lumnitzera* spp. (*n* = 4), *Xylocarpus* spp. (*n* = 4), *Excoecaria* sp. (*n* = 3), *Phoenix* sp. (*n* = 3), *Heritiera* spp. (*n* = 3) and *Aegiceras* sp. (*n* = 1). Only one study was reviewed from the East Asian region, specifically from China. The species *Avicennia* spp., *Bruguiera* spp., and *Kandelia* spp. each accounted for one-third of the total identified mangrove species in East Asia.

Ecosystem services valuation

The reviewed studies reported 194 individual ESs value estimates (Table 2). A total of 156 value estimates were for Provisioning Ecosystem Services, making it the predominant ecosystem service category. Under Provisioning Ecosystem Services, Food and Raw Materials were the most frequently valued by studies, while Water and Medicinal Resources were the least valued. This was followed by Regulating Ecosystem Services and Cultural Ecosystem Services with 22 and 13 value estimates, respectively. Supporting Ecosystem Services was the least valued, with only three estimates for the ecosystem service – maintenance of life cycles. Regarding the frequency of valuation methods used, Market Price and Factor Income valuation methods were the most frequently used, in 96 and 66 value estimates, respectively (Table 3). Travel Cost, on the other hand, was the least used valuation method.

When value estimates are categorized according to their ESs types, Provisioning Ecosystem Services and Regulating Ecosystem Services were valued more on average than Supporting Ecosystem Services and Cultural Ecosystem Services (Fig. 7). Provisioning Ecosystem Services were, on average, valued at 7258.01 $, Regulating Ecosystem Services at 6580.35 $, while Supporting Ecosystem Services and Cultural Ecosystem Services were valued well below 2000 $, at 1350.14 and 1371.87 $, respectively.

A different picture was obtained when values are categorized according to their specific ESs (Fig. 8). Erosion prevention of Regulating Ecosystem Services was valued the highest at 15 522.13 $, followed by food (Provisioning Ecosystem Services, 14 201.65 $). Water (Provisioning Ecosystem Services, 27.94 $) and existence/bequest values (Cultural Ecosystem Services, 28.19 $) were the least valued ES. However, the data differed for specific ES when median values were used. Regulating Ecosystem Services such as Erosion Prevention (5833.22 $) and Moderation of Extreme Events (3633.69 $) were the highest valued ES. Provisioning Ecosystem Services, particularly, Water (27.94 $) and Cultural Ecosystem Services, mainly regarding Existence/Bequest Values (28.31 $), were still the least valued ES (Fig. 9).

Table 2. Summary table on the year of publication and value year utilized by studies.

Source	Year published	Value year
Janssen, Padilla	1996	1995
Bann	2003	1996
Badola, Hussain	2003	2002
IUCN - Sri Lanka	2003	2003
Walton et al.	2006	2004
Ranasinghe, Kallesoe	2006	2005
Baig, Iftikhar	2006	2006
Sathirathai, Barbier	2007	2001
Hussain, Badola	2008	2007
Muraleedharan et al.	2009	2004
Janekarnkij	2010	2003
Hussain, Badola	2010	2007
Adhikari et al.	2010	2005
Viswanathan et al.	2011	2010
Tantu et al.	2012	2012
Shuib et al.	2012	2012
Kuenzer et al.	2013	2011
Uddin et al.	2013	2012
Fan et al.	2013	2012
Carandang et al.	2013	2009
Vo et al.	2015	2010
Malik et al.	2015	2015
Hema, Devi	2015	2012
Chow	2015	2012
Susilo et al.	2017	2016
Damastuti, de Groot	2017	2017
Lahjie et al.	2019	2018
Phan et al.	2020	2020

Discussion

The economic valuation of mangrove ecosystems varies among countries based on the interaction of institutional, social, and economic factors (Pham et al. 2021; Bhukta, Bhukta, 2022; Bimrah et al. 2022; Raihan 2023). This review investigated and analyzed a selection of publications on the economic valuation of mangrove ecosystems, where in all the reviewed studies, the economic value of the Asian

Table 3. Valuation methods used for ESs. Valuation methods: CV, Contingent Valuation; DC, Damage Cost; FI, Factor Income; GV, Gross Value; MP, Market Price; RC, Replacement Cos; TC, Travel Cost; VT, Value Transfer. **f, number of estimates/observations.

Ecosystem services	CV	DC	FI	GV	MP	RC	TC	VT	*f*
A. Provisioning									156
Food			34	3	42				79
Medicinal resources								1	1
Raw materials			21	7	38				66
Water					1				1
Other			8		1				9
B. Regulating									22
Climate regulation					4			1	5
Erosion prevention	1	3			1	3		1	9
Maintenance of soil fertility					1	2			3
Moderation of extreme events		1			2	1		1	5
C. Supporting									3
Maintenance of life cycles			1		2				3
D. Cultural									13
Existence, bequest values	2				1			1	4
Opportunities for recreation and tourism	1		2		3		2		8
Other	1								1
Total	**5**	**4**	**66**	**10**	**96**	**6**	**2**	**5**	**194**

mangrove ecosystem was emphasized, as millions of people depend on its ecological services. Since crucial strategic decisions regarding the present and future have been made, historical information from these publications from 1996 to 2020 was compiled. With this information, scientists can monitor the value of mangrove ecosystems over time, and people can identify improvement areas and predict future trends in mangrove preservation.

Rhizophora and *Avicennia* were the genera of mangroves that were most frequently mentioned in the reviewed literature. *Rhizophora* was identified in Southeast Asia and South Asia studies reviewed. *Rhizophora*, in comparison to the other genera mentioned in the reviewed studies, is highly tolerant of severe intertidal zones with high salinity and is found along the coasts of tropical and subtropical regions. Genus *Avicennia* was identified in all three regions, including East Asia. This genus is also found in intertidal estuaries along the tropical and subtropical coasts of the globe. This genus, like *Rhizophora*, exhibits high salt tolerance and can thrive in saline environments (Flores-Verdugo et al. 2013; Curnick et al. 2019). These genera provide a shelter and breeding site for a broad range of fauna like fish, crustaceans, mollusks, crabs, and other invertebrates. These genera also yield a variety of products, including charcoal, fuel, timber, wood, and other construction materials (Harini 2019; Getzner, Islam 2020). These mangrove species also have significant recreational and economic value. The thematic study conducted as part of the FAO-UN (2007) global forest resources assessment revealed that Asia possesses a mangrove area exceeding 5.8 million ha. This figure represents approximately 38% of the total mangrove area worldwide, the highest proportion among all continents. Approximately 21% of the total mangrove area in Asia has been analyzed in the publications compiled for this study, totaling approximately 1.2 million ha. There were insufficient entries of data collected on the distribution of mangroves in East Asia, as only one study, published in China, identified the species present in the mangrove ecosystem region. This prevented the researchers from undertaking relevant analyses regarding the evaluation of mangroves in all East Asian regions.

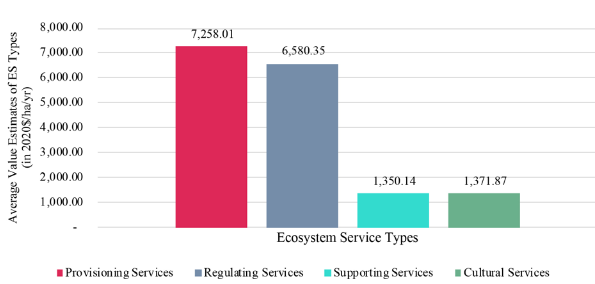

Fig. 7. Average value estimates (in 2020 \$ ha^{-1} $year^{-1}$) of ecosystem service types.

In this assessment, the Market Price method was most frequently employed. In the study of Harini et al. (2019), this method of valuing ecosystem products was deemed to be the most realistic and straightforward. In addition, Himes-Cornell et al. (2018) described the Market Price method as both practical and inexpensive in their review. According to a separate study by Kaval (2010), there have been growing concerns about modifying and adapting traditional, market-based environmental valuation

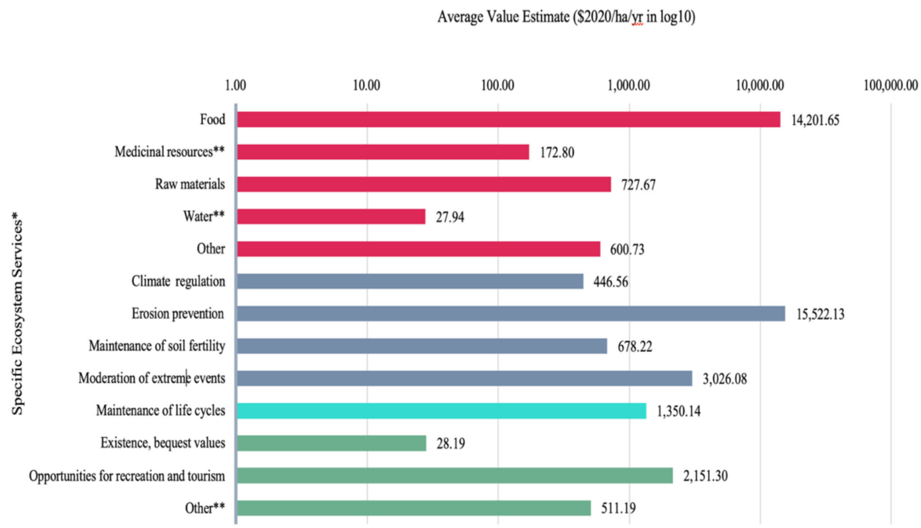

Fig. 8. Average value estimates (in 2020$/hectares/year) of specific ecosystem services. *Colored according to ES Type: maroon bars, Provisioning Ecosystem Services; slate Gray bars, Regulating Ecosystem Services; teal bars, Supporting Ecosystem Services; green bars, Cultural Ecosystem Services. **Values depicted are of only one estimate.

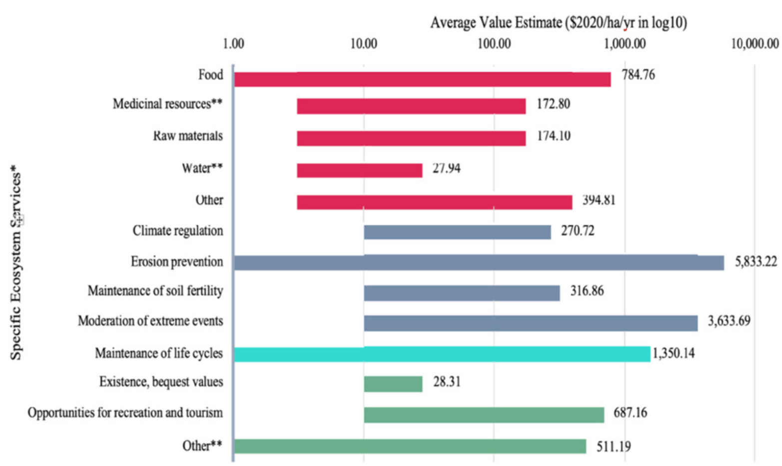

Fig. 9. Median value estimates (in 2020$/ hectares/year) of specific ecosystem services. *Colored according to ES Type: maroon bars, Provisioning Ecosystem Services; slate Gray bars, Regulating Ecosystem Services; teal bars, Supporting Ecosystem Services; green bars, Cultural Ecosystem Services. **Values depicted are of only one estimate.

approaches to better deal with the real-world field and management conditions in developing countries, especially considering time, data, skill, and financial constraints. This valuation method reflects the marginal product cost and preference price. It computes the economic value of ESs, and products bought and sold on the market. Moreover, the information obtained through this method is a reliable indicator of the ESs value. The Travel Cost method was the least utilized of all the valuation approaches mentioned in the studies. Since it necessitates collaboration, this strategy has a limited range of applications (Kumar 2012). This is also because Cultural ecosystem services are difficult to value since they are the non-material benefits people receive from ecosystems and interactions with various environmental species (Van Oudenhoven et al. 2012). Vo et al. (2015) evaluated the recreation services of mangrove forests in Bohol and Palawan based on the estimated average travel costs incurred by visitors.

The predominant ESs in this study were the Provisioning Ecosystem Services. These are the tangible assets or goods that people obtain from the ecosystem. These are limited and sustainable resources that can be consumed, allocated, and marketed directly. In this review, the Provisioning Ecosystem Services commonly valued were food, medicinal resources, raw materials such as wood production, water, etc. This is significant because people rely on these services for their livelihood, as the reviewed literature mentioned. The least valued ESs were the Supporting Ecosystem Services, with only three estimates for the ESs maintenance of life cycles (Folkersen 2018). These ESs are indirect services, and the methods for gathering the necessary data frequently vary. The most difficult challenge in valuing these ESs is assigning a monetary value to services that provide no direct or indirect economic advantages and are conceptual rather than physical (Liekens et al. 2013). They have fewer tangible benefits and are more difficult to quantify. In the study of Bimrah et al. (2022), supporting services were more emphasized in management initiatives, most likely due to a need for more knowledge about their economic advantages.

Results regarding average economic values of ESs types were found to be in congruence with the findings of Okumu et al. (2017), where Provisioning Ecosystem Services had the highest average economic value. Within Regulating Ecosystem Services, natural hazard prevention (i.e., erosion prevention and moderation of extreme events) were valued the highest as well. The total value of estimated valuations were in the range of 0.08 \$ ha^{-1} $year^{-1}$ to 333 739.53 \$ ha^{-1} $year^{-1}$, with a median value of 332.6 \$ ha^{-1} $year^{-1}$, and a mean value of 6682.95 \$ ha^{-1} $year^{-1}$. Median values as opposed to mean values are less affected by outliers within the data. Noticeably, the large difference between the mean and median values of the data indeed indicates that the data on ESs valuation is skewed. Similar skewness was also observed in the study of Salem (2012), where mean values of the economic valuations were observed to be greater than the median values. Similarly, in this review, food and erosion prevention had median values of around 700 and 5000 $, respectively; compared with mean values over 10 000 $.

Summary and perspectives

Overall, this systematic review highlights the importance of the economic valuation of mangrove ecosystems and its variation across different countries in Asia. The majority of the reviewed publications from 1996 up to 2020 provided historical data that can be used for critical strategic decisions concerning the present and future. Additionally, the economic valuation of mangroves depended on the interaction between social, economic, and institutional forces, varying from country to country. The reviewed literature focused on the economic valuation of mangrove ecosystems in Asia, with *Rhizophora* and *Avicennia* being the most common mangrove genera mentioned. These mangrove genera provide shelter and breeding sites for a wide range of fauna, as well as an array of products like charcoal, fuel, timber, wood, and other building materials, with great recreational and commercial importance. The publications compiled for this study covered a combined area of roughly 1.2 million hectares, which accounted for around 21% of the entire mangrove area in Asia. The Market Price method was the most used valuation method in the reviewed studies. The predominant estimated ESs values were for Provisioning Ecosystem Services, which are the tangible assets or goods that people obtain from the ecosystem, such as food, medicinal resources, raw materials, and water. The least valued ecosystem service was Supporting Ecosystem Services, which has fewer tangible benefits and is more difficult to quantify. The total value estimates ranged from 0.08 to 333 739.53 \$ ha^{-1} $year^{-1}$, with a median value of 332.69 \$ ha^{-1} $year^{-1}$ and a mean value of 6682.95 \$ ha^{-1} $year^{-1}$. The data on ESs valuation is skewed, with mean values being greater than median values. Overall, this review provides valuable insights into the economic valuation of mangrove ecosystems and highlights the need for more research in the East Asian regions to improve mangrove preservation strategies.

Ideally, EVMs of mangroves is a complex issue that depends on a variety of social, economic, and institutional factors that vary across different countries. Nevertheless, there is an increasing recognition of the various products and services provided by mangrove ecosystems, particularly in Asian countries, where they play a crucial role in providing ESs. However, despite their economic and ecological significance, mangroves in Asia continue to face numerous threats, including coastal development, aquaculture, and overexploitation of resources (Abdullah et al. 2020). Loss of mangrove ecosystems and their associated services can have severe consequences for local communities and the environment; consequently, there is a need for policymakers and stakeholders to recognize the economic value of mangrove ESs and incorporate this into decision-making processes. EVMs of mangroves is essential for policy and decision-making processes. It provides a strong case for the conservation and restoration of mangrove forests in Asia. Nevertheless, valuation alone is not enough to ensure the long-term sustainability of these ecosystems. The implementation of effective management and governance strategies is crucial to ensure that the benefits provided by mangrove forests are sustained for future generations. Mangrove ESs helps raise awareness among policymakers and stakeholders about the importance of mangrove ecosystems, provides a basis for making informed decisions regarding their conservation and management, and affords a strong economic case for conservation and restoration. Yet, effective management and governance strategies are also necessary to ensure the long-term sustainability of these ecosystems.

Finally, research on valuation methods have advanced greatly over the years, which has resulted in a wider coverage of literature, but more work needs to be done in improving the implementation of these methods especially in terms of where and how. Indirect use values and non-use values for the ESs provided by mangroves are still poorly understood. It is recommended that future valuation studies concentrate on extending the range of ESs that are valued beyond those that are easily valued such as market price. This may include provision of support, which are the least valued ESs. It was also shown that the literature lacks enough relevant, primary valuation estimates, which may be a risk of bias because these may miss reflecting current ESs values. We recommend the development of additional and more relevant valuation methods to adequately account for such a situation. Additionally, it is recommended to examine the ESs valuation based on method; to determine which method yields higher values for different specific ESs. Another crucial recommendation would be to consider determining for whom the ESs are focused, specifically whether they be for the local community or for the other sectors of the population, in all the publications collated.

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