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Economic Valuation of Ecosystem Services Provided by Forest Ecosystems in Sri Lanka: A Study Based on 2010 Forest Cover Classification and the TEEB Database

by

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A thesis submitted in partial fulfillment of the
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Abstract

Ecosystem service valuation is becoming popular among the economists, ecologists, scientists and policy makers. As a result, various research, publications and programs have arisen and content of literature is developed rapidly. Even though this field of study is developing rapidly, Sri Lankan ecosystems have not yet been valued or evaluated yet in terms of economic returns. Hence, the main purpose of this study is to calculate and define economic value for each forest polygon of 2010 forest cover data base by using the value transferring approach. This data base will be an effective tool to have a fair cost-benefits analyses of development projects which are most likely planned to be implemented on forested landscapes. The value transferring approach was selected for this study considering the free availability of data and expensive and time-consuming nature of primary valuation approaches. This study includes two main analyses: an estimation of total economic value of all ecosystem services provided by forest ecosystems of Sri Lanka and an estimation of economic value of water services provided by the forest ecosystems within the Mahaweli River basin which is known as largest and longest river basin of Sri Lanka. For the first analysis, required reference values of ecosystems services were found from the equivalent biomes of TEEB database. These reference data were processed at three levels and standardized to 2019 US dollar values by following a standard procedure. These processed results regarding water services were used for the second analysis and the watershed boundaries, sub-watershed boundaries, stream network, pour points were created using Arc Map 10.8.1. According to the results of first analysis, the total annual economic value of all considered ecosystem services range from US $ 3.472 billion to US $ 138.818 billion and the estimation can be averaged at US $ 34.5 billion. Results further confirmed that mangrove forests are important and ecologically valuable by reaching to the highest per unit area annual economic value being estimated at US $ 42856 per hectare per year. The water service analysis revealed that the economic value of water services provided by all forest ecosystems within the Mahaweli river basin is US $ 67.9 million. Analysis further indicated that, US $ 11,247,073 worth of water services are produced by the 78,429 ha of forest lands within the Parakrama Samoodraya sub-watershed annually. These results of both analyses are important in future conservation and management decisions making, especially regarding identifying restoration and enrichment priorities, and as a progress monitoring tool.

Executive Summary

Ecosystem Services are defined as the benefits provided by the landscapes, we live in which are closely linked with human well-being. Millennium Ecosystem Assessment has classified ecosystem services into four categories namely provisioning, regulating, cultural, and supporting. However, according to the current context of Sri Lanka, ecosystem services are degraded continuously, and national development projects have been identified as a key driver of deforestation and forest degradation. Quantification and valuation of ecosystem services are becoming popular among economists, ecologists, scientists and policy makers as tools for controlling deforestation. Even though this field of study is developing rapidly in global context, Sri Lankan ecosystems have not yet been valued or evaluated comprehensively in terms of economic returns. Hence, the main purpose of this study is to calculate and define economic value for each forest polygon of 2010 forest cover data base by using the value transferring approach. Other objectives are developing raster maps for each district, identification of information gaps, analyzing the value of water service within the Mahaweli river basin, making the value of ecosystem services more visible and opening a new discussion about ecosystem service values. This study has been designed to find answers for two main research questions.

- What is the annual economic value of all ecosystem services provided by all forest ecosystems in Sri Lanka?
- What is the annual economic value of water services provided by all forest ecosystems located within Mahaweli river basin?

Two analyses were carried out separately for two research questions. The value transferring approach was used for the first analysis. Required reference values of ecosystems services were found from equivalent biomes in the TEEB database. These reference data were processed at three levels and standardized to 2019 US dollar values by following a standard procedure.

These processed results regarding water services were used for the second analysis and the watershed boundaries, sub-watershed boundaries, stream network, pour points were created using Arc Map 10.8.1.

According to the results of first analysis, the total annual economic value of all considered ecosystem services range from US $ 3.472 billion to US $ 138.818 billion and the estimation can be averaged at US $ 34.5 billion (Table 0.1). The Anuradhapura district is recorded as the district having highest economic value of ecosystem services with an estimated value of US $ 4.9 billion.

Table 0.1 Ecosystem service values of different forest types

Forest Type	Unit Value (USD/Ha/Yr)	Total Value (USD/Yr)		
		Average	Min	Max
Low Land Rain	17,723.53	2,424,138,032.23	334,900,921.50	10,577,975,924.98
Moist Monsoon	4,260.24	501,576,059.90	413,443,394.41	984,929,643.36
Montane	17,723.53	793,425,868.17	109,613,830.10	3,462,195,477.38
Sub-montane	17,723.53	513,794,594.71	70,982,048.44	2,241,995,621.13
Dry Monsoon	18,586.14	20,845,967,355.18	1,397,558,577.02	85,088,533,945.28
Riverine Dry	17,057.49	41,369,536.61	11,095,912.54	102,870,233.04
Open and Sparse	18,586.14	7,965,924,786.73	534,052,765.21	32,515,107,122.28
Savanna Forests	2,089.97	142,208,196.43	73,004,209.46	211,274,973.29
Shrubs	2,089.97	625,101,990.42	320,903,279.76	928,697,569.12
Mangrove	42,856.63	693,304,624.05	207,412,285.49	2,705,361,363.55
Total		34,546,811,044.43	3,472,967,223.93	138,818,941,873.40

Mangrove forests show the highest unit value of US $ 42856 because of the value of controlling extreme events and providing nursery services for marine and brackish water species. Furthermore, more information is available with respect to mangrove forests since they contain a considerable number of services which have market values such as fish products. The value of lowland rain forests and dry monsoon forests are also substantially high because of high value of raw material provision service. However this includes the value of timber which cannot be considered in the Sri Lankan context.

The water service analysis revealed that the economic value of water services provided by all forest ecosystems within the Mahaweli river basin is US $ 67.9 million.

Parakrama Samoodra sub-watershed shows the highest water service value of US $ 11.2 million per year because of having the largest extent of forest cover of 78,429 ha. The Kalu ganga sub-watershed shows the highest water service value of US $ 161 per hectare because of the significantly high forest cover percentage of 87%. Furthermore, Kalu ganga sub-watershed comprises substantially diverse forest cover of six forest types including lowland rain forests, montane, and submontane forests which can effectively harvest water from both vertical and horizontal precipitation. Sub-watersheds such as Kothmale, Victoria, Randenigala, and Rantembe, also show significantly high unit values even though the forest cover percentage is significantly low. A possible reason for the high unit value is high extent of montane forest cover of these four sub-watersheds. Furthermore highly diverse forest cover with seven different forest types can be observed. High amounts of shrub forests can be observed in dry zone sub-watersheds such as Minneriya and Kawudulla. Hence there is a possibility of improving the value of water services by enriching those shrub forests to open and sparse forests. Most of the upper catchment sub-watersheds show significantly low percentage of forest cover. Since these sub-watersheds are located within the central highlands, forest cover can be expanded by reforesting more montane forests. These possibilities should be incorporated into national conservation plans and the results could be used to predict the trajectories of enrichment and reforestation programs.

The results of this study can be used both nationally and globally. When considering the national level applicability, cost benefit analyses of development projects, curriculum of forestry cadets, and policy decisions of environmental sensitive area secretariat can be identified as the important places. The most recent global example is the UN decade of restoration, and these results can be used to set economically quantified restoration targets.

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1.0 Introduction

Ecosystems provide a wide range of final and intermediate services that are extremely important to human well-being (Sills et al., 2017; Costanza et al., 1997). These services include the production of goods such as food, life support processes such as water purification, and life-fulfilling conditions such as recreation (Sharp et al., 2018). According to the 2005 Millennium Ecosystem Assessment (MEA), the services provided by an ecosystem are complex and interconnected. Knowing that the services provided by an ecosystem are complex and interconnected, interest in ecosystem services among both research and professional communities has grown rapidly (MEA, 2005). As a result of this increasing interest researchers have found that biological or physical properties and processes of ecosystems are unique and vary according to the ecosystem, habitat, or landscape (Costanza *et al*., 1997). More specifically, ecosystem services are received either directly or indirectly by humans as benefits and those benefits are received at different levels, and in different intensities (Sharp et al., 2018).

Even though the awareness about the importance of ecosystem services to human well-being is growing, the loss of biodiversity and degradation of ecosystems still continue on a considerable scale (www.teebweb.org). Ecosystem services that have been degraded over the past 50 years include water supply, fisheries, waste treatment and detoxification, water purification, natural hazard protection, regulation of air quality, regulation of regional and local climate, regulation of erosion, spiritual fulfillment and aesthetic enjoyment (MEA, 2005). For instance, water supply can be considered as an ecosystem service, and 15-35% of irrigation withdrawals exceed supply rates of water services resulting unsustainable use (MEA, 2005). This unsustainable use is largely the result of population growth and significant changes in sectoral demands. For instance, a statistical analysis of Sri Lanka shows that the industrial water and domestic water usage are increased while the agricultural water demand is decreased (AQUASTAT-FAO). These changes of water demand have shifted Sri Lanka into the vulnerable category defined by UN-Water Category Thresholds.

The problems of management and governance of ecosystem services occur due to not only the poor policy decisions made without analyzing the social surpluses that accrue as a result of the policy decisions described above (Boardman et al., 2018), but also insufficient information and institutional capacities (NCR, 1996; NBSAP, 2017). Unfortunately, information and opportunities to assess the changes in ecosystem services that are bound to human well-being are limited and many of the services are not monitored as well. Specifically, the services related to social, cultural, and economic factors are difficult to estimate (Wallace 2007), since these services are not marketed. Most importantly, the MEA highlights that the degradation of ecosystem services represents the loss of capital assets, and the impact is expected similarly on both poor and wealthy populations. Since many impacts of changes are slow and take considerable time to become apparent, costs and benefits of changes often affect different sets of stakeholders. Furthermore, mitigations or attempts to enhance degraded ecosystem services are often challenging, and continuous degradation of ecosystem services causes significant harm to human well-being (MEA, 2005). Therefore, the importance of ecosystems, as well as the assessment of the resulting impacts of ecosystem service changes (including economic quantification), are important because economic and financial interventions provide powerful tools to regulate the use of ecosystem goods and services (MEA, 2005). Furthermore, Dissanayake and Vidanage (2021) has recommended that the careful use of non-market valuation techniques (i.e. Choice Experiments) could provide useful information for policy making.

The process of ecosystem service quantification started in the 1960s and developed gradually throughout the 20th century (Baggethun et al., 2010). In the 1990s, it was catalyzed by Costanza *et al* (1997), who estimated the world's ecosystem service value to be $33 Trillion/year in 1997. To estimate the value of global ecosystem services, the researchers introduced marine and terrestrial as two main land-use types before synthesizing the values (Costanza *et al*., 1997). The analysis has been further refined and repeated by the same team and has been used to estimate the global ecosystem value again ranging from $16 to $54 trillion/year. In 2014, the estimation was updated again for $125 trillion/year (Costanza *et al*., 2014). At present, federal and state governments in the US and many other nations are using these values in cost benefit analyses of different policy assessments (Sills *et al.*, 2017). For instance, ecosystem service values have been used to calculate the payment for watershed services and to demonstrate that "green infrastructures" or clean and healthy forested landscapes, are more cost effective than "gray infrastructure" water filtration and water treatment plants to clean water (Moore et al., 2012).

Ecosystem services have been classified broadly as final and intermediate (supporting) services based on the nature of how benefits of human wellbeing are received (MEA, 2005; Sharp et al., 2018). Final ecosystems services are known as services which humans directly consume (i.e. provision of raw material such as timber) while the intermediate or supporting services are not directly consumed by humans (i.e. crop pollination service). At the same time, the delineation between intermediate, final services, and benefits is not strict (Fisher and Turner, 2008). For example, timber can be considered as one of the final services if the interest or focus is on timber production, but it can be considered as an intermediate service at the same time if the interest or focus is on the water as a provisioning service or precipitation regime (Fisher and Turner 2008). Because of these challenges in delineation, it is also important to distinguish ecosystem service receivers and types of receivers. Ecosystem service beneficiaries can be divided into two types: Ecosystem service users and Ecosystem service nonusers. These ecosystem services can be either an "ecosystem service production function" or "final ecosystem service" (Holmes *et al.*, 2017). To avoid the error of double counting, the human wellbeing values derived only from final ecosystem services have to be recognized. Also, the human wellbeing derived from benefitting ecosystem services is closely linked with "Revealed Preferences" since it can infer the economic value (Sills *et al.*, 2017).

Despite its importance, this natural capital is poorly understood, scarcely monitored, and in many cases undergoing rapid degradation and depletion due to poor and ineffective decisions. Hence, quantified values of ecosystem services are important to inform policy-level authorities to make effective and efficient decisions to conserve ecosystem services even though the quantification process is challenging. Simplified tools have been developed for ecosystem service quantification and some of them are freely available. To bring an understanding of ecosystem service values into decisions, the authors of the TEEB study (www.teebweb.org) have developed a searchable database with estimates of monetary values of ecosystem services. It contains original values in monetary units organized by ecosystem service and biome (Van der Ploeg et al., 2010) which can be applied to estimate the ecosystem service values of a similar biome. The, TEEB database consists over 1300 different reference values covering substantial area of the world including information of 14 different biomes and 45 different ecosystems.

Although the ecosystems are valued and price tags are defined in many regions of the world, Sri Lankan pristine ecosystems have not yet been comprehensively valued or evaluated in terms of economic returns. A few ecosystem services such as recreation has been valued using the travel cost method in some national parks (Rathnayake & Gunawardena 2011), botanical gardens (Jayarathne & Gunawardena 2004), and zoological gardens (Gunathilake & Vieth 1998). Furthermore, there is evidence of valuing recreation benefits of some urban parks located nearby Colombo (Karunarathne & Gunawardena 2020). Mangrove ecosystems in Sri Lanka has also been valued to a certain extent and these data are available in the TEEB database as well (www.TEEB.lk) but most of these valuations are confined to evaluate the fisheries perspective of Mangrove ecosystems. Even though Sri Lanka is gifted with diversified ecosystems containing remarkable endemism as a tropical island, these valuable ecosystems have not been valued satisfactorily (NCR, 1995). Furthermore, the responsible institutions who manage ecosystem do not maintain a database of unit economic values of the ecosystems which can be a used as a tool of conservation against deforestation.

When considering the deforestation, four deforestation drivers have been identified and they can be listed as 1) encroachments, 2) infrastructure development projects, 3) private agriculture ventures, and 4) localized forest degradation (Fernando et al., 2015). Forest lands are selected for most of the infrastructure development projects such as, irrigation reservoirs, express ways, industrial zone establishments, etc. in order to minimize the compensation costs on lands. Furthermore, most of the cost benefit analyses of above said development projects have allocated zero or a value near zero for forest lands (EIAR-Southern Expressway Stage III) even though the pristine forest ecosystems in Sri Lanka continuously provide valuable services such as provisioning, regulating, cultural, and supporting services. Since these services are not traded in the market, they are not considered or accounted for in policy decisions, especially when there is a conversion of land use from forest utilization to non-forest utilization. Therefore, this invisible nature of ecosystems in decision making can be considered as one of the main courses for ecosystem degradation and deforestation (Dissanayake, 2018). On the other hand, forest officers face difficulties when they are asked to evaluate the damage of forest offenses during court proceedings. At present, forest officers only account for the timber value of a forest offense, even though the value of ecosystem services is irreplaceable. Thus, this study focuses on filling that gap by defining an economic value to the Sri Lankan forest types classified in the 2010 forest cover analysis by using the TEEB database values.

Not only the total value of all ecosystem services, but also the individual value of each ecosystem service is important to analyze because different forest ecosystems have different and unique mechanisms to provide ecosystem services. Recent studies have shown that climate regulation and water regulation are substantially important ecosystem services among others (Balasubramanian, 2019). For Sri Lanka as a nation that has practiced irrigated agriculture as the main livelihood over thousands of years, it is important to analyze the relationship between the forests and water provisioning service.

Paddies as the main crop under irrigated agriculture have been cultivated successfully for years even though long spells of drought have created water scarcity especially within the dry zone.

The bimodal rainfall pattern and the central highlands of Sri Lanka have created three main climatic zones within the island known as the wet zone, dry zone, and intermediate zone. The Southwest monsoon winds bring rain to the wet zone during May to September and the Northeast monsoon winds bring rain to both the wet and dry zones between November and January. This mechanism creates a routine spell of drought within the dry zone from February to November while establishing two main paddy cultivating seasons based on two monsoons. Since the dry zone comprises substantial portion of lands which are significantly productive in terms of paddy cultivation, ancient rulers of Sri Lanka built water storing tanks throughout the dry zone by damming perennial rivers, ensuring the successful paddy cultivation even during the routine spell of drought.

The “Mahaweli” river is known as the longest river in Sri Lanka which starts from central highlands and flows toward the Northeast coast irrigating about 300,000 ha of agricultural lands of dry zone and generating over 54% of the country’s hydropower requirement (Gamage, 1997). A considerable extent of the upper catchment of the Mahaweli river is located within the wet zone and it ensures the continues distribution of water from wet zone to dry zone throughout the year. As a result of that, a number of dams have been built across the different locations of Mahaweli river for various outcomes such as irrigation water storage, hydro electricity production, and drinking water (Weeraratne & Wimalawansa, 2015). However, the productivity of these manmade irrigation structures has been reduced (Paranage, 2019) over the time due to various issues such as change of rainfall pattern and intensity, low water yield, high flow of sediments, and siltation (Amarasekara et al., 2018). Furthermore, the productivity of those reservoirs is crucial in terms of energy requirements, as well as the irrigation requirements since the demand for both energy and irrigation water has increased with increasing population. This uncertainty in the supply of water has been further exacerbated by climate change and changes of forest cover within each sub-watershed of these reservoirs (Amarasekara et al., 2018).

Therefore, it is timely and important to study about the water service provided by forest ecosystems located within Mahaweli river basin. The calculation of economic value of water service provided at each sub-watershed will provide a clear picture of the current status of these forest ecosystems. Further analysis of these water service values, and available forest types will showcase how this water service is transferred to the well being of humans along the Mahaweli river at different reservoirs. Water service values can be used to identify the future restoration requirements, to plan the restoration trajectories, and to set restoration targets.

Hence, the main goal of this project is to define an economic value by using the TEEB database for each forest type described in the 2010 forest cover assessment in Sri Lanka, which will be helpful for fair cost-benefit analysis before finalizing development projects. More specifically the economic value of water service provided by forest ecosystems located within Mahaweli river basin will also be calculated. Furthermore, this proposed mechanism will be a weapon to fight against unplanned infrastructure development proposals proposed by different types of investors. Most importantly, this mechanism will help increase awareness while improving the policies, planning land-use, creating ecosystem service markets, and reducing the inherent bias of valuing forests.

Objectives

- To define economic values of forest types in Sri Lanka by using reference values given in the TEEB database
- To develop a raster map of Sri Lanka indicating district level values of ecosystem services
- To identify the information gaps to evaluate the economic value of forest types
- To demonstrate the distribution of water services within the Mahaweli river basin
- To make an impact on policymakers by showing a monetary value on forest ecosystems, expecting a fair cost-benefit analysis of development projects
- To open up a new discussion among ecologists and economists about the value of Sri Lankan forest types

2.0 Literature Review

This section will cover the technical aspects of ecosystem service valuation. First, the importance of ecosystem service quantification and the difference between quantification and valuation will be introduced. Then four non-market valuation methods will be elaborated while identifying the strengths and weaknesses of each. Modern trends of ecosystem service modelling applications will also be covered as a separate sub section. The next subsection will cover the Sri Lankan context of ecosystem service valuation and quantification. The final section will conclude with a summary about the engagement of ecosystem service valuation in policy making arena in Sri Lanka.

2.1 Quantification and Economic Valuation of Ecosystem Services

A better understanding of what, where, and when services are supplied by a known ecosystem is an integral part of a sound and broad sustainability program or a policy because the amounts of services provided can be monitored and managed (Crossman et al., 2012). Improved quantification methods for ecosystem services are needed to apply the concepts of sustainability in management decisions (de Groot et al., 2010) even though ecosystem service quantification methods are rare (Logsdon and Chaubey 2013). However, Crossman et al (2012) has concluded that ecosystem services can be quantified and mapped. At the same time, the diversity of available mapping methods has been identified as one of the challenges for estimating robust values for ecosystem services. Furthermore, mapping has been recognized as a powerful tool to process complex data and information of ecosystem service quantification estimates done at different spatial and temporal scales (Crossman et al., 2012). While most of the published work on ecosystem services is based on secondary data rather than site specific models or onsite primary valuations (Logsdon and Chaubey 2013), the use of secondary data is cost effective and time saving. Most importantly, assigning some value for ecosystem service is always better than having no value (Moore et al., 2012). Therefore, estimating ecosystem service values using secondary data is a good start for a country or a region where primary valuation capacity is low.

Since ecosystem services are non-marketable, a few methods are available for ecosystem service valuation, called non-market valuation techniques. Non-market valuation techniques are used to estimate the value of a good or service which does not have a market. Hence the value (shadow price) of the non-market good or service is captured indirectly (Boardman et al., 2018; Vegh et al., 2014). Broadly non-market valuation techniques can be classified as Revealed Preference valuation methods and Stated Preference valuation methods. The Revealed Preference methods are based on the actual behaviors that can be observed and this Revealed Preference category includes two types of valuation techniques called Travel Cost method and Price Hedonics method. The Stated Preference method also has two techniques called contingent valuation method and choice experiment method. These techniques estimate the willingness to pay (WTP) of a person (respondent) for the services or goods provided by ecosystems by analyzing the hypothetical choices made by the respondent (Boardman et al., 2018). These valuation techniques are described in more detail in the following section.

Travel Cost Method

Travel cost method is widely used to value the recreational services provide by different entities such as national parks, botanical gardens, urban parks, etc. The cost incurred with travel is used to measure the value under certain assumptions (Vegh et al., 2014). Since this method concerns limited number of variables under substantial number of assumptions, a complete valuation cannot be expected. A value of a particular resource only depends on the cost of travel and the entrance fee is the main assumption use in the travel cost method where, the cost shows a positive relationship with the distance. This relationship provides the basis for estimating a demand curve, and the area under the drawn demand represents the total benefits of the resource. This method is based on market behavior, which is considered as an advantage. On the flip side, a few disadvantages can also be highlighted such as strong assumptions, higher cost for data collection, coverage of only use values, and difficulties to deal with quality changes (Boardman et al., 2018). These non-market valuation methods can be used carefully to reduce the invisible nature of the ecosystem's inherent bias in utilizing forest ecosystems for development projects in policymaking (Dissanayake, 2018).

Price Hedonics Method

The main focus of the price hedonics method is the change in the price of a market good capitalized with a non-market good or service. Changes in housing prices with or without an urban park close by can be considered as a decent example. As in the travel cost method, the same type of demand curve can be considered between the benefits and availability or the closeness of an environmental amenity (non-market good/service).

Here several assumptions are made such as completeness and accuracy of the information, free choice of consumption or perfect mobility, ability to bundle goods, and homogenous preferences. The connection with the market behavior is considered an advantage, and assumptions about the utility function, the cost of data collection and difficulties in dealing with quality changes are considered disadvantages (Boardman et al., 2018).

Contingent Valuation Method

The contingent valuation method is a simple, flexible non-market valuation method that is widely used in cost-benefit analysis and environment impact assessments and is also known as the most common Stated Preference method (Boardman et al., 2018). Contingent valuation tries to measure the value of a good holistically, for instance, to value the good as a whole, by asking people directly about their willingness to pay. In this method, nothing is revealed about the value of the different attributes that comprise the good. However, the validity and reliability of the results of this method are highly questioned (Carson 1998). For instance, Boardman et al., (2018) has listed six issues bound with the contingent valuation method such as need of specifying a payment vehicle, problem of hypotheticality (problems of understanding, meaning, context, and familiarity), neutrality issue, issues of judgmental biases, more appropriate to assess the willingness to accept (WTA) than willingness to pay (WTP), and possible strategic behaviors of respondents.

Choice Experiment Method

The choice experiment is a survey where the respondents choose one of the choices in a choice set of similar goods or services. Each respondent answers multiple choice questions and asked to select an alternative out of multiple alternatives which are described by attributes. The choice experiment estimates the values of the attributes that make up the good, which distinguishes this survey from the contingent valuation method. Furthermore, choice experiments provide the necessary link between observed consumer behavior and economic theory. The biggest advantage is the low cognitive complexity. It only needs an ordinal judgment by comparing two items (Boardman et al., 2018).

Summary

The use of above-described non-market valuation methods is dependent on the context of the study, since all these methods have unique strengths and weaknesses. The travel cost method is recommended to use in valuation of recreational services and as a supporting tool of management decision making. For instance, the travel cost method can be used to determine the entrance fee of a park. The price hedonic method is useful when an ecosystem service can be bundled with a market good or service. Therefore, this method is considerably popular in the arena of real estate to value their properties including features such as “water fronts, scenic views, forest edges”, etc. which do not have a market price. Contingent valuations are preferred when assessing the whole value of a good or a service while choice experiments are used mostly to value selected attribute of a good or a service. Therefore, the selection of non-market valuation method has to be made according to the valuation requirement, cost, strengths, weaknesses, and the practicality.

2.2 Ecosystem Service Modelling Applications

With the development of interest in ecosystem service estimation, multiple software tools have been developed. Even though mathematical representation of ecosystem services has not yet been deeply explored, these tools can be utilized to study and plan future conservation and management strategies (Villa et al., 2009; Logsdon and Chaubey, 2013). InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), ARIES (ARtificial Intelligence for Environmental Sustainability) and ESII software can be introduced as examples. InVEST is a product of Natural Capita Project (NAT CAP) and it has now been used in over 60 countries as an effective tool in ecosystem service quantification (Sharp et al., 2018). InVEST is designed to facilitate natural resource management and it reflects the changes of benefits received by the people and the changes in the ecosystem. Fourteen final ecosystem services and three supportive services have been identified and modeled in this software. Habitat risk assessment, habitat quality, and pollinator abundance are the three supporting services identified in this software. Both marine and terrestrial services are considered within the 14 final ecosystem services namely: forest carbon edge effect, carbon storage, and sequestration, coastal blue carbon, annual water yield, nutrient delivery ratio, sediment delivery ratio, unobstructed views, recreation and tourism, wave energy production, offshore wind energy production, marine finfish aquaculture production, fisheries, crop production, and seasonal water yield. In addition to these service models, three facilitating tools and four supporting tools are provided. This model has to be fed with raster type images generated through a GIS application. On the other hand, ARIES models ecosystem services by using statistical models and provides a web-based interface (Villa et al., 2009; Vigerstol and Aukema, 2011). ARIES has been developed as an AI-Powered application for natural capital accounting by a collaboration among United Nations Department of Economic and Social Affairs (UNDESA), United Nations Environment Program (UNEP) (aries.integratedmodelling.org). ARIES considers all components within an ecosystem, and then connects those components into a flow network. Then it creates best possible models for each component and interaction and provides detailed assessment of how humans are benefitted from nature (Villa et al., 2009).

2.3 Value or Benefits Transferring

Since primary valuation research is time consuming and expensive, a value transferring approach can be adopt as an effective tool to define ecosystem service values by using reference values calculated globally or regionally for more or less identical ecosystems. This approach of adopting information from one study site for use in another site where valuation data is limited or absent is known as "value transfer" or "benefits transfer". This approach has become more popular because of the low cost incurred with in comparison to other approaches. Furthermore, this method can be applied to summarize the economic value of geographic units. For instance, the value of a particular block or a parcel of land or land use can be defined since the unit values are measured in dollars per hectare per year (Moore et al., 2012).

Not only advantages but a few disadvantages are also bound with this approach. This approach does not consider the spatial arrangement of an ecosystem. Ecosystem services generated from ecosystems do not solely depend on the extent of the ecosystem. A closely connected ecosystem is ecologically more effective and productive than a collection of fragmented patches of a similar ecosystem even though the final extents are similar. Furthermore, the values of ecosystem services are closely linked with their beneficiaries. Since most of these studies are not focused on final ecosystem services, and not having a prescribed set of ecosystem services, the double-counting error could be a possibility (Moore et al., 2012). However, this mechanism will be able to place a dollar value on at least some aspects of ecosystem services which can indirectly preserve the comprehensive ecological value without allowing it to value as zero (Moore et al., 2012).

2.4 Ecosystem Service Valuation and Quantification Attempts in Sri Lanka

The records of ecosystem service quantification and valuation attempts in Sri Lanka are limited (Kotagama et al., 2006; Rathnayake & Gunawardena 2011) even though a substantial number of works have been done in relation to the biological, ecological, management and conservation aspects of Sri Lankan ecosystems. Valuation of recreation services provided by identified forests, valuation of ecosystem services provided by Mangrove forests, cost-benefit analyses, and attempts to introduce economic values to calculate the Green GDP (Gross Domestic Production) can be introduced as most common study areas in current literature on Sri Lankan ecosystem service valuation and quantification. The section synthesizes the findings of some of these published records.

Ecosystem Service Quantification in Sri Lanka and National Conservation Review (NCR)

When considering the quantification attempts, the "National Conservation Review" (NCR) of Sri Lanka, contributes to a considerable portion of published literature especially regarding the soil erosion control, flood hazard control, head water protection, and fog interception. NCR evaluated all-natural forests with respect to the importance of those forests for biodiversity and their value for soil and water conservation (NCR, 1995). This project has been funded by United Nations Development Program (UNDP), and executed by the Forest Department in Sri Lanka with the technical patronage of International Union for Conservation of Nature (IUCN). NCR has identified and defined "consumptive use values" and "productive use values" as "direct values", while "non-consumptive use values", "option values", and "existence values" as "indirect values" of ecosystem services. Furthermore, NCR has listed a few ecosystem services such as water, climate, amenity, timber, medicines, non-timber forest products, aesthetics, research, and education.

Conservation of soil and water as an ecosystem service provided by forests has been assessed in terms of soil erosion, flood hazard, protection of headwaters, and fog interception. The mean annual soil loss of a given forest is estimated under standard conditions such as: slope length; land use; and direction (NCR, 1996). A model developed in UK, which comprises catchment area, stream frequency, and mean annual rainfall, has also been adopted to quantify the flood hazard (NCR, 1996). The assessment of the importance of forests for head water protection is based on: the number of streamlets originating from the forest; the number of river catchments protected by the forests; and the distance from the headwaters stream nearest center of the forest to the outlet (NCR, 1996). A model developed in Hawaii with altitude and area as variables has been used to quantify the volume of fog intercepted by forests located above 1500m of altitude (NCR 1996). NCR has further emphasized results of a field study done at Horton Plains National Park in 1993. According to the field study, a 414mm of fog has been intercepted by the forest canopy during an eight-month period starts from October 1993 (NCR, 1996).

Economic Valuation of Ecosystem Services – Non-Market Valuation Attempts in Sri Lanka

Records of recreation value estimations of several national parks, botanical and zoological gardens, and some UGSs such as "*Diyawanna* park", can be spotted in the literature on valuation of ecosystem services in Sri Lanka (Rathnayake & Gunawardena 2011). The recreation value of *Diyawanna* park has been estimated as LKR 3.8 billion (Marawila & Thibbbotowawa 2010). The annual value of ecosystem services provided by the forest ecosystems (107729 ha) in *Kala Oya* river basin is estimated at 23,500 million Lankan Rupees. Out of that total value 77% represents carbon values (LUPPD, 2020). The recreational value of "Crow Island" urban park has also been estimated through the travel cost approach and the contingent valuation approach. According to the analysis, the annual estimated value of social benefits generated for the park visitors is LKR 495 million (Gunasinghe et al., 2020). When considering the national parks, estimated social benefits provided to visitors by the "*Udawalawa*" national park is LKR 2.2 million (De

Silva & Kotagama 1997), and the recreation value of "*Yala*" national park is estimated at LKR 54.4 million (Marasinghe, 2002). When considering the botanic and zoological gardens, the visitors of "Peradeniya Royal Botanical Garden" have been subjected to travel cost experiments to evaluate the recreation value of the garden (Abeygunawardena & Kodithuwakku 1992). The recreation value of "Hakgala Botanical Garden" is estimated as LKR 221 million (Jayarathne & Gunawardena 2004). Furthermore, the recreation value of "Pinnawala Elephant Orphanage" has been estimated as LKR 12.2 million (Gunathilake & Vieth 1998).

A number of analyses have also been done to evaluate the economic value of recreation services offered by forest ecosystems. For instance, Rathnayake & Gunawardena (2011) estimated the recreation value of Horton plains national park as a decision-making strategy for natural resource management. The travel cost method was used to quantify the economic value of recreation service and data were collected though a questionnaire survey. Results show that the value of recreation service provided by Horton plains national park is LKR 51.68 million per year. It further shows that the increase of entrance fee up to LKR 472.00 may maximize the park revenue by increasing 314%. Similarly, Karunarathne & Gunawardena (2020) have valued the economic value of one of the key Urban Green Space (UGS) located in Colombo Sri Lanka by using the travel cost approach. Authors focused on the recreation value of the UGS, and data were collected through a structured questionnaire. According to the regression analysis, the annual value of recreation services provided by the UGS is estimated at LKR 55.7 billion. Furthermore, the estimated per capita annual consumer surplus of the UGS is LKR 33,250.37. Then the average annual consumer surplus of the UGS was estimated as LKR

55.7 billion and it has been further compared with the present (2020) land value which was LKR 52.6 billion. The comparison confirms that the current land use as a UGS maximizes the social welfare. Authors concluded that economic values of recreation services provided by the UGSs may lead to establish better management and policy decisions.

Sri Lankan wetland ecosystems and mangrove ecosystems have also been estimated for the economic value of their ecosystem services. For instance, Jayasekara and Gunawardena (2020) have estimated the economic value of improvement of water quality of Bolgoda lake in Sri Lanka. The contingent valuation approach was used for the study which is based on the willingness to pay (WTP) concept. According to the results, the estimated annual per hectare value of water quality improvement service provided by Bolgoda lake is LKR 4.4 million. Additionally, authors highlighted the requirement of policies to value and price the natural assets as a measure of controlling degradation. Similarly, Gunawardena and Rowan (2005) conducted an estimation of total economic value (TEV) of “Rekawa” mangrove ecosystem as a part of extended cost-benefit analysis. Approaches such as substitute markets, marginal productivity valuation, preventive expenditures, and contingent valuation were employed to assess the value of environmental goods and services such as firewood collection, lagoon and coastal fisheries, shoreline stabilization and erosion control, and existence and bequest values respectively. According to the analysis, the estimated economic value of ecosystem services given by the Rekawa lagoon is US$ 1088/ha/year. Out of that 70% came from fisheries.

These studies show the extent of the ecosystem service valuation and quantification analyses. Limited number of ecosystem services such as recreation benefits have been selected for those analyses. Furthermore, an inclined preference toward popular national parks, botanical gardens, and urban parks is also observed. However, most of the forest ecosystems out of 1.95 million ha of total forest ecosystems have not been subjected to proper assessment of ecosystem service valuation or quantification, even though the ecological importance of those forests is significant. Furthermore, a widely applicable approach of ecosystem valuation and quantification approach may more useful especially in policy making than small scale scattered assessments.

2.5 Incorporation of Conservation Economics at Policy Level in Sri Lanka

National Biodiversity Strategy and Action Plan (NBSAP) is a requirement specified in Rio-Convention on biological diversity (CBD) in 1992. As a partner country, Sri Lanka prepared the strategies and action plans for two years of inception and ten years of implementation to fulfill the obligations of Rio-Convention in 1996-1998 (NBSAP2016-2022, 2017). However, the fifth national report to CBD confirms that the obligatory targets have not been achieved satisfactorily and lack of financial resources has been identified as the main barrier of showing satisfactory progress. Furthermore, lack of information, human capital, expertise, and inadequate coordination among line agencies have also been identified as other reasons for low progress of achieving CBD targets. To better understand, a gap analysis was performed and following gaps were identified such as: lack of specific emphasis on functional use of economics / valuation of biodiversity; lack of emphasis on influencing individual behavior towards biodiversity conservation through use of economic instruments; and lack of emphasis on generation of finance and allocations of finance for biodiversity conservation (Kotagama et al., 2006). The current NBSAP has seven years of operation period from 2016 to 2022 which provides a strategic approach to ensure the conservation of biodiversity within Sri Lanka while achieving the sustainable development goals (SDG) and Aichi biodiversity targets (NBSAP2016-2022, 2017).

National Research Investment Framework and Action Plan (NRIFAP)

NRIFAP is a five-year plan with USD 99 million worth investment framework. It is supposed to be financed from both domestic and international sources. The NRIFAP identifies 13 Policies and Measures (PAMs) within three key policy areas (1. forest, wildlife and watershed, 2. land use planning, 3. other forested lands) that will be implemented to help achieve Sri Lanka's vision for REDD+ (Reducing Emission from Deforestation and forest Degradation which is a climate change mitigation solution developed for developing countries). These PAMs developed through an extensive process of stake-holder consultation and expert analysis represent the key measures to deliver emission reductions and removals as well as helping to strengthen forest management more broadly within Sri Lanka (NRIFAP, 2017). PAMs 11, 12, and 13 are especially focused on financing ecosystem services since those PAMs considers non-forested lands belong to private or other non-governmental parties. These parties are supposed to be paid with conservation easements for non-converting their forest lands to non-forest utilization. Therefore, economic valuation of these ecosystems must be required to calculate the conservation easement before paying.

These policy analysis reveals that there is a gap of valuing bio diversity and ecosystem services even though it is required. When considering the ecosystem service valuation attempts done so far, the results of these attempts cannot fulfill the requirement of national level database of ecosystem service values which covers all available ecosystems within Sri Lanka. As discussed in the beginning of this section primary ecosystem valuation studies are needed to be multiplied all over Sri Lanka to have a complete database. Next best alternative is to use ecosystem service modelling application such as InVEST or ARIES. But both options are not feasible always since both primary valuation techniques and models are considered expensive and time consuming. Therefore, the best available alternative to build a national level database of ecosystem service values is the value transferring approach which requires a significantly low amount of finance, time and human resources and this study will underpin the basic requirement of national database of ecosystem service values.

3.0 Methodology

Two main analyses were carried out in relation to the ecosystem service valuation. The first analysis was commenced to find out the total economic value of all ecosystem services provided by forest ecosystems of Sri Lanka. The second analysis was done to estimate the economic value of water services provided by the forest ecosystems within the Mahaweli River basin which is the largest and longest river basin in Sri Lanka. Mahaweli river basin attracts especial attention not only because it covers more than 16% of total land extent, but also as the main perennial water source which carries water from wet zone to a considerable portion of dry zone.

3.1 Estimation of Total Economic Value of Sri Lankan Forest Ecosystems

The value transferring approach has been adopted for this estimation. The forest types classified in the 2010 forest cover analysis were used as the forest ecosystems of the analysis. Appropriate reference values of known biomes described in the TEEB database were taken. Aspects of forest cover classifications and the TEEB data base are elaborated on following sections.

Forest Cover Classification

Forest cover data published in 2010 by the Forest Department Sri Lanka were used for the study and all-natural forest types classified under the 2010 forest cover analysis were considered as the basic forest ecosystems (Edirisinghe et al., 2012). The main ten forest types and extents were derived using the attributes of shapefiles of the 2010 forest cover Geo-database. The attribute table of 2010 forest cover shapefile provided the extents of different polygons that have digitized along either natural boundaries or administration boundaries such as district boundaries and divisional secretariat boundaries. Once all the polygons under each forest type were identified, the figures were summed together, and forest extents of each forest type were derived as shown in Table 01.

Table 01: Different Forest types and their extents (Forest Cover Geodatabase, 2010)

Forest Type	**Extent (ha)**
Low land rain forests	136775
Moist monsoon forests	117734
Montane forests	44767
Sub-montane forests	28989
Dry monsoon forests	1121587
Riverine dry forests	2425
Open and sparse forests	428595
Savanna forests	68043
Shrubs	299097
Mangrove	16177
Total Extent	2,264,189

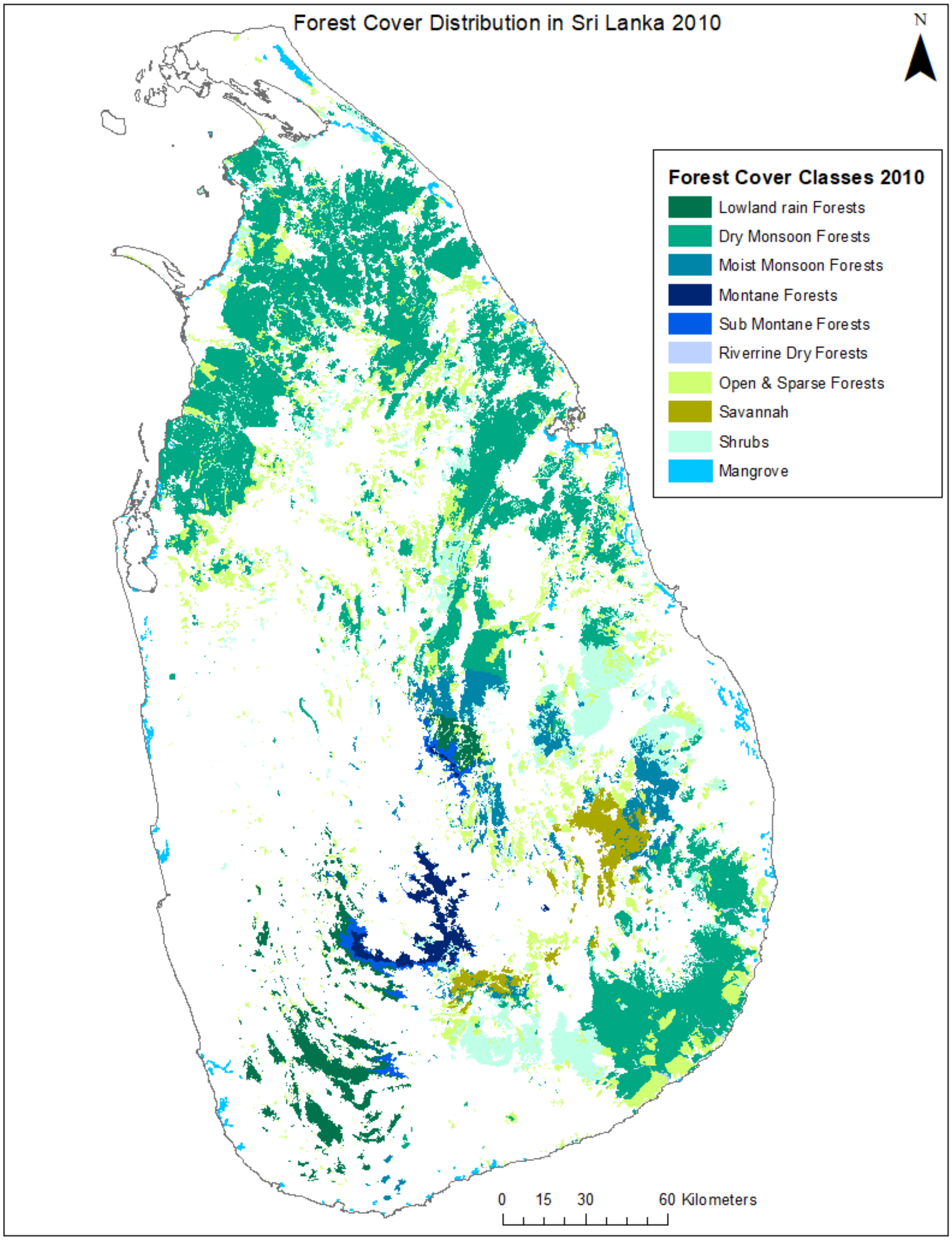

Figure 01. Forest cover classification and distribution of Sri Lanka

TEEB database

To quantify the ecosystem services provided by each ecosystem, the TEEB database was used. The TEEB database includes over a thousand entries under different ecosystem services of different biomes worldwide. Since this study focused on a broader assessment of ecosystem services, a few biomes such as tropical forests, inland wetlands, grasslands, and coastal wetlands were selected. Because Sri Lanka is a tropical island, data related to tropical ecosystems were selected, assuming that these ecosystems are similar to the Sri Lankan ecosystems. Each biome consisted of a set of ecosystems. For instance, the tropical forest biome consisted of three main ecosystems namely; tropical rain forests, tropical dry forests, and tropical forest general. Each ecosystem was classified into different ecosystem services such as climate, erosion, food, gene pool, medical, etc. Each ecosystem service was further classified into different sub-services. For instance, climate ecosystem service was further divided into two sub-services such as carbon sequestration and micro-climate regulation. This sub-service level was the basic data entry level of TEEB database and each sub-service was given informative attributes such as location (Country/region), economic valuation of the sub-service, valuation year, type of value (Annual / Net Present Value), method of valuation, currency unit and the source of information.

Adopting the Ecosystems of TEEB database to Sri Lankan Forest Types

The Sri Lankan forest types shown in Table 01 were not found in the TEEB database. Hence, the most appropriate and comparable ecosystems were selected, out of the given list of ecosystems under a limited number of biomes located close to the equator ensuring the tropical climatic conditions. It was assumed that the services provided by comparable ecosystems are quantitatively and qualitatively similar. The same basis used to determine the 2010 Sri Lankan forest cover classification was used to identify the most appropriate and comparable ecosystems given in the TEEB database. Table 02 shows how the ecosystems given in the TEEB database have been adapted to Sri Lankan forest type classification.

Table 02. How ecosystems given in TEEB database are adopted Sri Lankan forest classification

Forest Type	The comparable ecosystem has given in TEEB database
Low land rain forests	Tropical Rain Forests / Tropical Forest General
Moist monsoon forests	Tropical Rain Forests / Tropical Dry Forests
Montane forests	Tropical Rain Forests / Tropical Forest General
Sub-montane forests	Tropical Rain Forests / Tropical Forest General
Dry monsoon forests	Tropical Dry Forests / Tropical Forest General
Riverine dry forests	Flood Plains / Riparian Buffer
Open and sparse forests	Tropical Dry Forests / Tropical Forest General
Savanna forests	Savannah / Grasslands / Other Grasslands
Shrubs	Savannah / Grasslands / Other Grasslands
Mangrove	Mangrove

Processing of Ecosystem Service Values

The processing of ecosystem service values was performed in three main levels namely, forest type level, ecosystem service level, and ecosystem sub-service level. These three levels are interconnected and filled in descending order. The ecosystem sub-service level was the bottom-most layer of data processing and the final output of sub-services was used in the ecosystem service level which was the second level of data processing. The first and topmost level (forest type level) was fed with the output of the second level of data processing (refer to Appendix 01). Each level of data processing was designed with a separate worksheet in Microsoft Excel. The forest type-level worksheet was designed as a table including ten forest types as rows and extents of each forest type in hectares, the total annual economic value of each forest type in US dollars, and unit economic value of each forest type as columns. This worksheet was named "final evaluation grid". The second level worksheet, named "ecosystem service" database was designed to generate the total economic value of each ecosystem service under each forest type that corresponds to the land extents. The third level was designed with ten separate worksheets for ten forest types and called "ecosystem sub-service". Annual unit area sub-ecosystem service values and net present values (NPVs) of those sub-ecosystem services were fed to these ecosystem sub-service work sheets from the TEEB database.

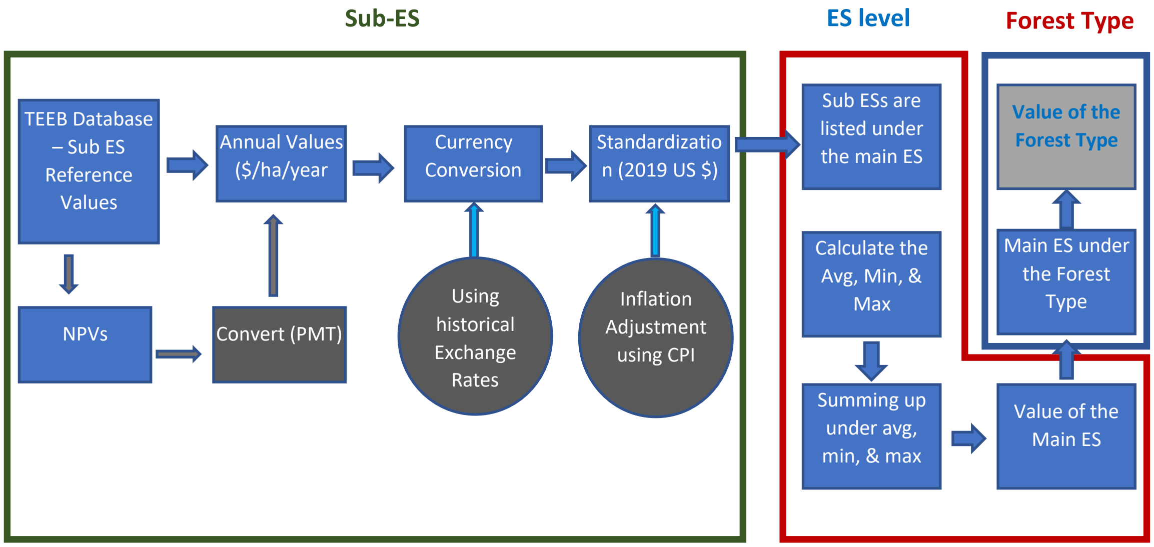

Figure 02. Main steps and three levels of data processing

Sub-service level data processing

The sub-service level data processing can be considered as the base of data processing structure and hierarchy and as well as the most important part of the study. At this level, a separate worksheet was assigned for each forest type and named; sub-service low land rain forest, sub-service moist monsoon forest, sub-service montane forest, sub-service sub-montane forest, sub-service dry monsoon forest, sub-service riverine dry forest, sub-service open and sparse forest, sub-service savannah forest, sub-service shrub forest, and sub-service mangrove forest. Each worksheet was given a considerable number of columns to demonstrate the figures, functions, and equations clearly. First, the ecosystem services were arranged as rows, and then sub-services were placed under corresponding ecosystem services. Then the given ecosystem sub-service values were directly imported from the TEEB database. Since the TEEB database consisted of two main types of values called annual value and net present value different columns were assigned to store the two value types separately. The type of value was also recorded as a separate column. Furthermore, imported values were not standardized and represented different currencies and valuation years. Hence, all the currency units of each sub-service value and valuation year were also recorded as separate columns. Different strategies were used to process and convert these various types of data into a common format. All the values were converted to annual per hectare values by using the PMT function of Microsoft Excel. All different currencies were converted into US Dollars according to the historic exchange rate of a given year of valuation. Then all the values were displayed as values of 2019 after adjusting for inflation. Then average, minimum, and maximum values for each ecosystem sub-service were calculated by using the given Microsoft Excel functions.

Ecosystem sub-service values under each ecosystem service were summed separately and the average, minimum and maximum values for each ecosystem service in US Dollars standardized to 2019 were derived.

Type of value

TEEB data were given in many types of values such as annual value, net present value (NPV), capita /stock value, and etc. Data given as annual values and net present values were picked selectively for this study since defining a per hectare annual value is more useful and easier to understand. However, keeping two types of values was not helpful for further processing and all the net present values were converted to per hectare annual values and placed under the same column where original per hectare annual values were placed and named “unstandardized annual unit values”. Since this conversion required the extent of the study area, discount rate, and time horizon defined for the NPV calculation, those values were also placed in different sub-columns under the main column called "net present values". The PMT function given in Microsoft Excel was used for the conversion and present values were fed as minus values to avoid the negative outputs.

Currency Conversions

Given annual per hectare values and NPVs were in different currency units based on the regions or the countries of the studies. For the easiness of handling, comparing, and further processing, all the values are given in different currencies were converted to equivalents of US Dollars of corresponding valuation year given in the TEEB database.

Annual unit values were converted by using historical exchange rates (ofx.com; fxtop.com) and stored them in a separate column called “exchange rate with respect to year”. Converted values were placed in a separate column called “unstandardized annual unit value” and these were given as US Dollars per Hectare values. Since unstandardized annual unit values were referring to the original valuation years as given in the TEEB database, these values had to be adjusted further.

Standardization and Inflation Adjustment

Inflation adjustment was done by using the average Consumer Price Index (CPI) values (usinflationcalculator.com) where the CPI values are based upon a 1982base of 100. As the first step of inflation adjustment, annual average CPI values were picked and stored in a separate column named "CPI value of corresponding year". Then the annual average CPI value of 2019 was placed in a separate cell below the main table. Then the unstandardized value of each ecosystem subsurface was divided by the CPI value of the corresponding year and then multiplied by the annual average CPI value of 2019. All the inflation-adjusted values were placed again in a separate column called "inflation-adjusted value for 2019". Once all these annual unit values were in similar currency (US Dollars/Ha/Year) and standardized into 2019 by adjusting the inflation, the values were ready to process.

Ecosystem Sub-service Value Calculation

After adjusting all ecosystem sub-service values into a common format, defining sub-services values was started. Since the TEEB database consisted of various values from different studies, there were numbers of observations for a given ecosystem sub-service such as carbon sequestration, bioprospecting, and timber among others. All different values given under each ecosystem sub-service were averaged separately and an average value for each ecosystem sub-service was calculated by using AVEARGEIF functions given in Microsoft Excel. Calculated ecosystem sub-service values were placed again in a separate column. Since the database provided more than one value for a particular sub-service, minimum and maximum values are also important to identify the range. Therefore, recorded minimum values for all different ecosystem sub-services were picked and placed in another separate column. Similarly, maximum values for all different sub-services were picked and stored separately. Hence, the worksheet now consists of average, minimum, and maximum values for each sub-service. Specific minimum and maximum calculating functions were used in order to automate the worksheet. However, the TEEB database does not always include multiple values for one particular sub-service. These sub-services were recorded similar values under all columns named average, minimum, and maximum and used to calculate the ecosystem service values.

Ecosystem Service Value Calculation

Most of the ecosystem services were recorded with multiple attributes or sub-services. For instance, raw materials as an ecosystem service consisted of three sub-services namely; timber, fuelwood, fodder, and other raw. Hence each of these sub-service values was summed together to calculate the ecosystem service value for raw materials. A similar procedure was applied to all other ecosystem services. Average values, minimum values, and maximum values of relevant ecosystem sub-services were summed separately in order to define the average, minimum, and maximum ecosystem service values. There were some ecosystem services consisting of one attribute or sub-service and those sub-service values were directly adopted as ecosystem service values. Bottom level data processing was completed with ecosystem service value calculations and average, minimum, and maximum values of ecosystem services were used as the input of second-level data processing.

Reiteration

This process was reiterated for all forest types in separate worksheets and annual unit values for ecosystem services were calculated separately for each forest type. This was because different forest types of the TEEB database were adopted to match the Sri Lankan forest types ecosystem services and sub-services were not constant.

Ecosystem Service Database

This worksheet was considered the second level of data processing and consisted of the extent of a particular forest type, relevant ecosystem services, annual unit economic values for these ecosystem services, and total ecosystem service value generated from each forest type. Each unit value was multiplied with the extent of relevant forest type and stored in separate columns. Since the unit values were given as average, minimum, and maximum, the total economic value of each ecosystem service of each forest type was also calculated separately. Subtotals of each forest type were calculated by adding the average, minimum, and maximum ecosystem service values separately.

Final Evaluation Grid

The final or the top layer of the data analysis was done by simply adding the subtotals of each forest type calculated at the ecosystem service database. The addition of subtotals of each forest type provided a grand total of economic values of services provided by all Sri Lankan forest types. Furthermore, the average unit value of ecosystem services for each forest type was calculated by dividing the subtotal economic values of each forest type from the corresponding extent.

Updating the attributes of geo-database of 2010 forest cover

Once the unit values of each forest type were derived, the attribute table of the geo database was updated with those unit values by inserting a new column. First, district level forest covers were exported separately and saved as .shp files. Then each polygon of the geodata based on the 2010 forest cover of each district was given a corresponding unit value. Next, the value of ecosystem services of each polygon was calculated by multiplying the extent of the polygon to corresponding unit value and storing them in a separate column. After that, the updated polygon was converted to two raster files, showing both the unit ecosystem service values and total ecosystem service values (Figure 04 and 05). This process was reiterated for all 25 administrative districts and 50 raster maps were prepared altogether. The total value of all ecosystems provided within a particular district was also calculated by using the summary statistics option given in Arc GIS and stored separately (Table 05). Then those district totals were inserted as a new field of the attribute table of district boundary layer and finally the district boundary polygon was converted to a raster displaying total ecosystem services provided by each district (Figure 03).

3.2 Water Service Analysis within Mahaweli River Basin

Water related services provided by forest ecosystems are considered one of the ecosystem services most closely related with the human wellbeing (MEA, 2005). Estimations of water services derived in the previous analysis were used directly for this analysis. River basin determinations, watershed boundary identifications, stream network creations, and all other spatial analyses were performed by using the Arc MAP 10.8.1 package of Arc GIS software.

Mahaweli River Basin

Mahaweli river flows 335 km starting from the central highlands towards the North-East coast through the North-Central and Eastern flat terrain (Withanachchi et al., 2014; Mahaweli.gov.lk). Mahaweli river basin (approximately 1025000 ha) covers about 16% of total Sri Lanka’s land extent. Since the river is naturally arranged to collect water from the wet central highlands and to distribute it over the dry zone of Sri Lanka, this basin acquires a substantial attention as an important valley in terms of agriculture. However, the Mahaweli Development Program (MDP) has also identified the importance of this river basin for hydro electricity production. MDP has confirmed the potential of Mahaweli basin for hydro electricity production at 3800 million kWh while the total hydro-electricity potential of all other rivers in Sri Lanka is estimated at 6300 million kWh (Mahaweli.gov.lk).

Spatial Analysis and Economic Value Estimation of Water Service

Analysis was started with a Digital Elevation Model which covers all parts of Sri Lanka. Sink pixels of DEM were filled by using the spatial analysis tools given in Arc Map 10.8.1. Using the filled DEM, the flow direction raster map was created. Then a flow accumulation raster was created. The river basin raster was also developed, and it was transformed from raster to polygon in order to define the river basin boundaries clearly. Then the Mahaweli river basin was selected and exported as a new layer. This exported polygon was used to clip all other raster maps including DEM, flow direction raster, and flow accumulation raster. Then the flow accumulation raster was exported as a line layer which represented the Mahaweli stream network. Next, the point layers were created for each reservoir located along the Mahaweli river basin. Those points were considered as pour points of the watershed tool and sub watershed raster maps for each pour point was created. Those sub watershed raster maps were transformed to polygon layers to create the sub-watershed boundaries. Then the 2010 forest cover polygons were clipped by using sub-watershed boundaries to create different forest cover layers for all created sub-watersheds. Areas of polygons of clipped forest cover layers were recalculated using the geometry calculator. Then the attribute tables of those clipped forest cover layers were joined with a CSV (Comma Separated Values) table which included all corresponding unit values of ecosystem services provided by different forest types. Next, the field calculator was used to calculate the total economic value of water services provided by each forest cover polygons of each sub-watershed forest cover layers. Finally, forest cover raster maps were created by using the polygon to raster tool depicting the calculated economic values of water services.

4.0 Results

Since this study consists of two main analyses, results of both analyses are presented separately as the two methodologies are described in the previous section. Therefore, results section has two sections: findings of total economic value analysis of Sri Lankan forest ecosystems and the findings of water services analysis within the Mahaweli river basin.

4.1 Findings of Total Economic Value Analysis of Sri Lankan Forest Ecosystems

This study was conducted in three main levels namely: ecosystem sub-service level, ecosystem service level, and finally the main forest type level. The topmost level results are summarized in Table 03. The total economic value of all considered ecosystem services range from US $ 3.472 billion to US $ 138.818 billion and the estimation can be averaged at US $ 34.547 billion. Table 03 also shows ecosystem service values for the unit extent of each forest type. The mangrove forest type holds the highest per unit extent value, estimated at US $ 42,856.63 per year while savannah and shrubs forest types hold the least per unit extent value at US $ 2,089.97 per year. Dry monsoon forests are the most widely distributed forest type, and the total extent of dry monsoon forests is recorded as 1,121,586.7 Ha (Forest cover geodatabase 2010). Showing that the economic values of ecosystem services are positively proportionate to the extent ecosystem, US $ 20.845 billion average value is estimated in front of dry monsoon forests per year. Furthermore, the unit area value of dry monsoon forests is estimated at US $ 18,586.14 per year (Table 03).

Table 03. Summary of total ecosystem service values by forest types

Forest Type	Unit Value (USD/Ha/Yr)	Total Value (USD/Yr)		
		Average	Min	Max
Low Land Rain	17,723.53	2,424,138,032.23	334,900,921.50	10,577,975,924.98
Moist Monsoon	4,260.24	501,576,059.90	413,443,394.41	984,929,643.36
Montane	17,723.53	793,425,868.17	109,613,830.10	3,462,195,477.38
Sub-montane	17,723.53	513,794,594.71	70,982,048.44	2,241,995,621.13
Dry Monsoon	18,586.14	20,845,967,355.18	1,397,558,577.02	85,088,533,945.28
Riverine Dry	17,057.49	41,369,536.61	11,095,912.54	102,870,233.04
Open and Sparse	18,586.14	7,965,924,786.73	534,052,765.21	32,515,107,122.28
Savanna Forests	2,089.97	142,208,196.43	73,004,209.46	211,274,973.29
Shrubs	2,089.97	625,101,990.42	320,903,279.76	928,697,569.12
Mangrove	42,856.63	693,304,624.05	207,412,285.49	2,705,361,363.55
Total		34,546,811,044.43	3,472,967,223.93	138,818,941,873.40

When considering the average unit area, economic values of ecosystem services provided by low land rain forests, including soil erosion control, recreation, and medical services have scored the highest annual values. The total economic value of soil erosion control services provided by low land rain forests in Sri Lanka is estimated at US $ 191million, while recreation and medical services are estimated at US $ 84 million and US $ 77 million, respectively. According to the transferred values, water-related services show US $ 85.96 annual value per hectare while the climate-related services are valued at US $ 16.96 annually per hectare (Refer sub-service low land rain forests of Appendix 01). The total annual economic value of all considered ecosystem services provided by low land rain forests ranges between US $ 334.90 million and 10.57 billion while the average value is estimated at US $ 2.424 billion (Table 03). The unit area annual economic values of lowland rain forests, montane forests, and sub-montane forests are similar since one set of reference values was used for the analysis.

However, to evaluate the ecosystem service values provided by dry monsoon forests and open and sparse forests, another set of reference values were used. According to the calculation (Refer the sub-service_dry monsoon worksheet of Appendix 01), the unit area economic value of raw material provisioning service provided by dry monsoon forests is estimated to be US $ 11,723.73 per annum (Table 04), being the highest unit area value among other services provided by dry monsoon forests. Therefore, the total value of raw material provisioning service is estimated to be US $ 13.1 billion. Climate, medical, food, and soil-related services of dry monsoon forests also show relatively higher economic values with respect to the other services. For instance, the economic value of climate-related services of dry monsoon forests is estimated at US $ 1144.6 million, and the economic value of medical services is estimated at US $ 1219.9 million. The total annual economic value of all considered ecosystem services provided by dry monsoon forests ranges between US $ 1.397 billion and US $ 85.088 billion and it has been averages US $ 20.845 billion (Table 03). The calculated unit area economic values of ecosystem services provided by open and sparse forests are also similar as a result of using the same reference values.

The riverine dry forest type has a limited extent surveyed as 2425 ha. Hence, the calculated total ecosystem service value is a relatively low, ranging between US $ 11.09

million and US $ 102.87 million (Table 03). The estimated average value is US $ 41.37 million. The economic value of waste related services such as waste treatment and water purification is estimated at US $ 10.96 million, but it shows a significant range of values that varies from US $ 1.4 million to US $ 28.9 million. Water services provided by riverine dry forests is also recorded as economically valuable ecosystem service being estimated at 3,318.08 US $/Ha/Year (Table 04). Recreation service and extreme events avoiding service are also recorded as considerably important services and the values have been estimated at 2,004.75 US $/Ha/Year and 1,678.11 US $/Ha/Year respectively (Table 04). The total values of recreation service and extreme event avoiding service are estimated at US $ 4.86 million and US $ 4.07 million respectively.

Results further confirmed that mangrove forests are important and ecologically valuable by reaching the highest per unit area annual economic value in terms of ecosystem services (Refer sub-service_mangrove worksheet of Appendix 01). It is estimated that the economic value of ecosystem services provided by one hectare of mangrove forests for one year is US $ 42856.63. Even though the total extent of mangrove forests is about 16177.3 ha in Sri Lanka, these forests provide valuable ecosystem services worth between US $ 207.4 million and US $ 2705.3 million per year (Table 03). Nursery services provided by the mangrove ecosystem have become the most economically valuable service and the estimated unit area annual value is US $ 10,019.03, while the unit area annual economic value of extreme event controlling service is estimated at US $ 9,138.56 (Table 04). Furthermore, waste, water, food, and gene pool-related services provided by mangrove forests are also estimated over US $ 2,000 per year. In order to assure the continuous and effective services provided by mangrove ecosystems, presence of surrounding mangrove ecosystems is crucial and therefore, composite management of these ecosystems is recommended (Brander et al., 2012).

Table 04. Unit values of different ecosystem services across different forest types

Services	Lowland Rain	Dry monsoon	Riverine	Mangrove	Savannah
Climate	979.56	1,020.56	215.67	789.35	607.86
Erosion	588.09	530.55	109.39	448.88	114.43
Food	377.51	483.83	464.00	2,721.80	51.24
Genetic	889.35	842.16	62.87	2,818.59	0.06
Medical	1004.63	1087.65	38.49	18.97	0.34
Recreation	806.91	546.92	2,004.75	1,148.61	2.13
Extreme Events	36.52	68.27	1,678.11	9,138.56	
Raw Material	9487.44	11,723.73	289.75	1,966.83	
Water	168.20	178.00	3318.08	2,455.27	
Nursery		15.58		10,019.03	

Savannah and Shrub forest types also provide valuable ecosystem services, although the value is not as considerable as other forest types (Refer to Appendix 01). However, the total annual value of ecosystem services provided by shrubs forest type ranges between US $ 320.9 million and US $ 928.7 million. The unit area annual economic values of both shrubs and savannah forest types are similar since one set of reference values was used for the analysis.

The economic values of a few common ecosystem services across different forest types are analyzed and a summary of the analysis is shown in Table 04. Lowland rain forests, dry monsoon forests, riverine dry forests, mangrove forests, and savannah forests were considered with commonly applicable ecosystem services. According to the analysis, dry monsoon forests provide more economically valuable climate services annually, estimated at US $ 1,020.56 per hectare. When considering erosion as an ecosystem service, lowland rain forests play the most important role, and that service has been valued at 1.336.19 US $/Ha/Yr. Mangrove forest's food provisioning service is valued at 2,721.80 US $/Ha/Year. Not only the food provisioning service but also the value of gene pool maintenance, extreme event avoiding service, and nursery service are estimated over other forest types. The value of nursery services provided by mangrove forest is estimated at 10,019.13 US $/Ha/Year while extreme event avoiding service and gene pool maintenance service are valued at 9,138.56 US $/Ha/Year and 2818.59 US $/Ha/Year respectively.

Table 05. District level annual values of ecosystem services provided by the forest ecosystems

District	Total Extent (ha)	FC (ha)	FC (%)	ES Value $ million/year
Ampara	441500	215,536	48.8	2,645
Anuradhapura	717900	292,795	40.8	4,874
Badulla	286100	82,384	28.8	815
Batticaloa	285400	83,983	29.4	1,037
Colombo	69900	2,020	2.9	36
galle	165200	35,697	21.6	636
Gampaha	138700	2,575	1.9	57
Hambanthota	260900	57,894	22.2	1,090
Jaffna	102500	5,780	5.6	153
Kaluthara	159800	17,890	11.2	316
Kandy	194000	41,039	21.2	510
Kegalle	169300	15,756	9.3	274
Kilinochchi	127900	45,607	35.7	769
Kurunegala	481600	28,520	5.9	402
Mannar	199600	134,849	67.6	2,395
Mathale	199300	84,207	42.3	947
Mathara	128300	20,330	15.8	328
Monaragala	563900	294,480	52.2	3,131
Mulathiv	261700	177,668	67.9	3,224
Nuwaraeliya	174100	48,419	27.8	799
Polonnaruwa	329300	151,778	46.1	2,518
Putlam	307200	84,179	27.4	1,612

Rathnapura	327500	79,017	24.1	1,256
Tricomalee	272700	134,961	49.5	2,429
Vavuniya	196700	126,827	64.5	2,291
Total	6561000	2,264,190		34,544

According to the results of district level analysis, Anuradhapura district is recorded with the highest ecosystem service value of US $ 4.8 billion per year while Colombo is recorded as the lowest of US $ 36 million per year (Table 05). Furthermore, Hambanthota, Rathnapura, Moneragala, Ampara, Polonnaruwa, Batticaloa, Trincomalee, Puttalam, Mannar, Vavniya, and Mulathiv districts show annual ecosystem service values over US $ 01 billion. According to the annual ecosystem values calculated as a fraction of district extent, Mullathiv district shows the highest value of US $ 12320.75 per hectare while Gampaha shows the lowest of US $ 413.21 per hectare. In addition to that, Mannar and Vavniya districts show relatively higher district level per hectare values which are over US $ 10000. Kurunegala and Colombo also relatively lower district level per hectare values which are below US $ 1000.00 per hectare. When considering the district level per hectare values of ecosystem services as a fraction of total extent of Sri Lanka, again Anuradhapura District is recorded as the highest with US $ 742.96 per hectare, while Colombo is recorded as the lowest with US $ 5.47 per hectare. District level annual ecosystem service values are displayed in raster map (Figure 03).

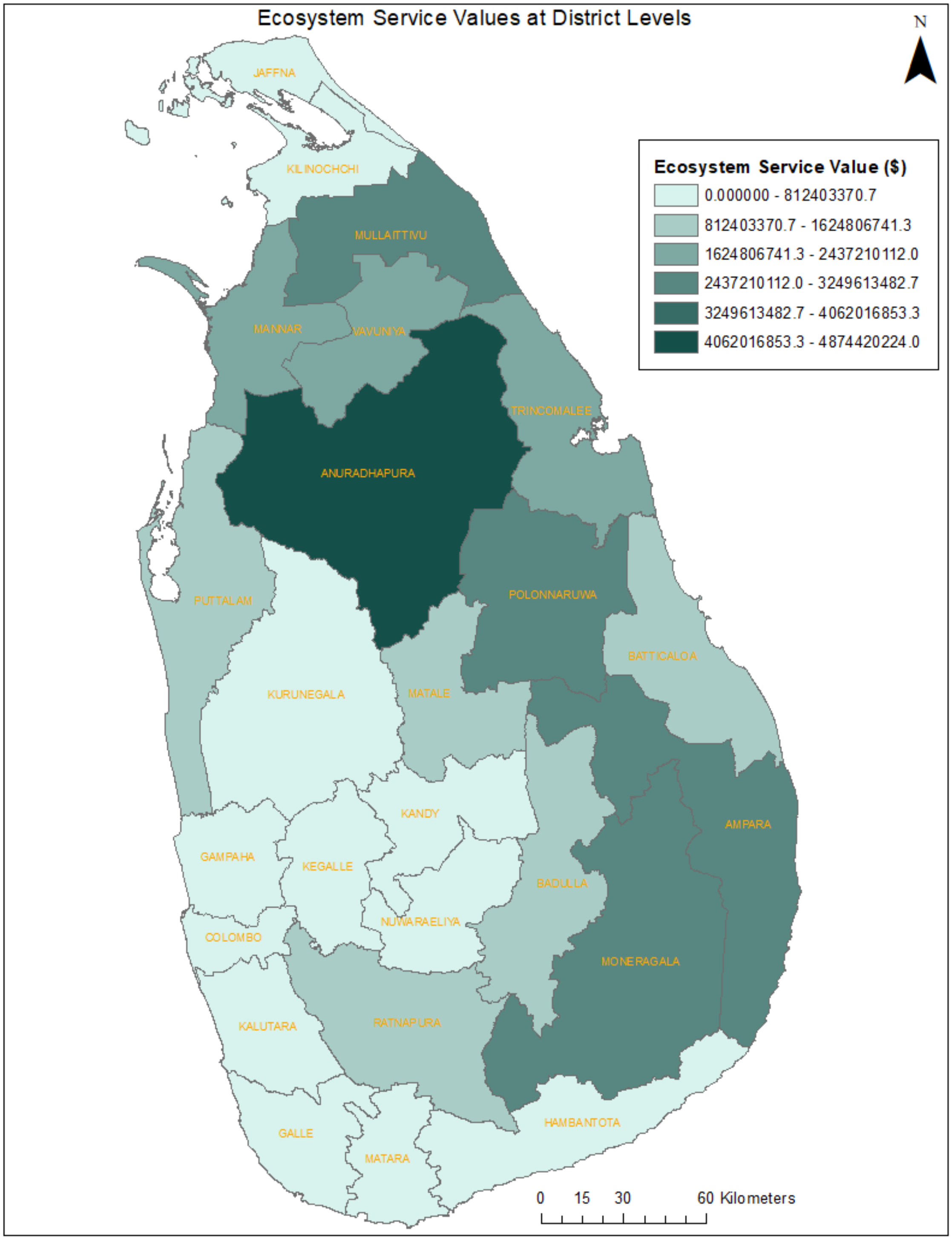

Figure 03. Values of ecosystem services provided by each district of Sri Lanka

Since different geo databases have been developed for each district for the analysis and annual unit values and annual total values of each polygon have been added, two raster maps were developed for each district displaying both the unit annual value of ecosystem services and the total annual value of ecosystem services (Figure 04 and 05). Two raster maps developed for Mathale district are included and rest of the raster maps are attached as an Appendix 02. The stretched color ramps of both maps indicate the economic importance of services provided by forest ecosystems at each polygon level. Dark blue color indicates the higher end of the economic value of ecosystem services while the light green color represents the lower end of the economic value of ecosystem services.

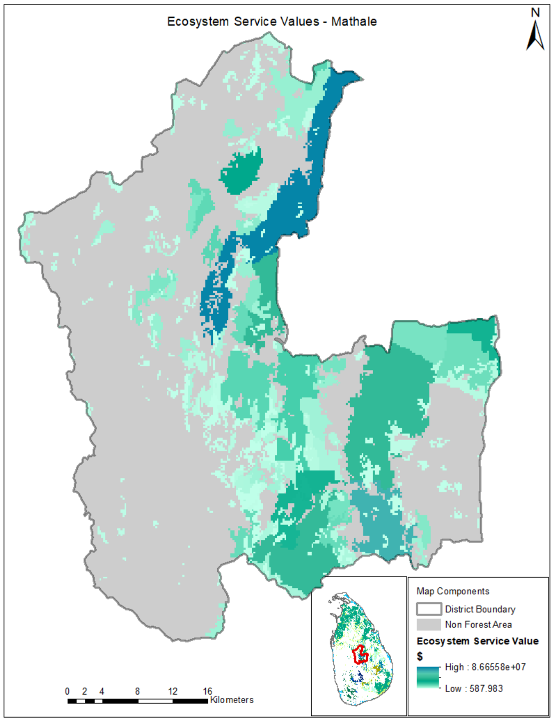

Figure 04. Ecosystem service value of Mathale District forest ecosystems

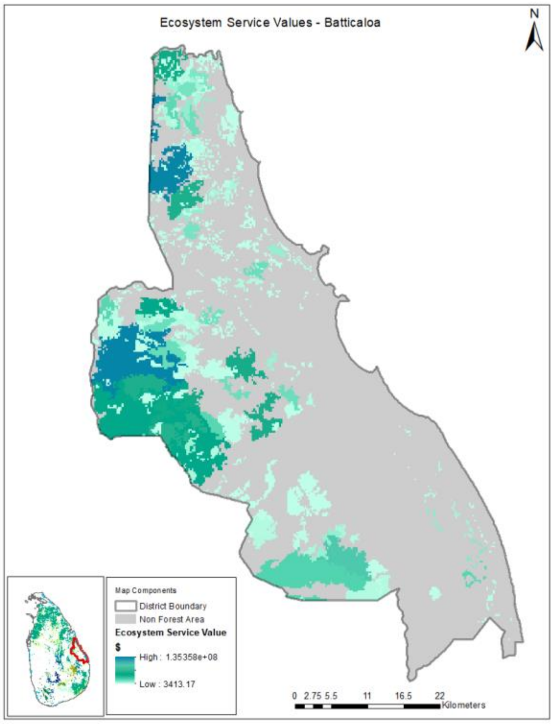

Figure 05. Ecosystem service value of Batticaloa District forest ecosystems

4.2 Findings of Water Services Analysis within the Mahaweli River Basin

Water services analysis was based on the water services value derived in the previous analysis and based on the spatial analysis carried out using Arc Map 10.8.1. This spatial analysis produced the boundary of Mahaweli watershed, stream network of Mahaweli river, terrain, and the forest cover raster maps within Mahaweli watershed (Figure 06). Furthermore, the forest type distribution (Polygon layer) within the Mahaweli watershed (Figure 07), forest cover raster maps within important sub-watersheds of Mahaweli basin (Figure 08), and figures highlight the stream network and forest cover within each sub-watershed (Appendix 03) were also created.

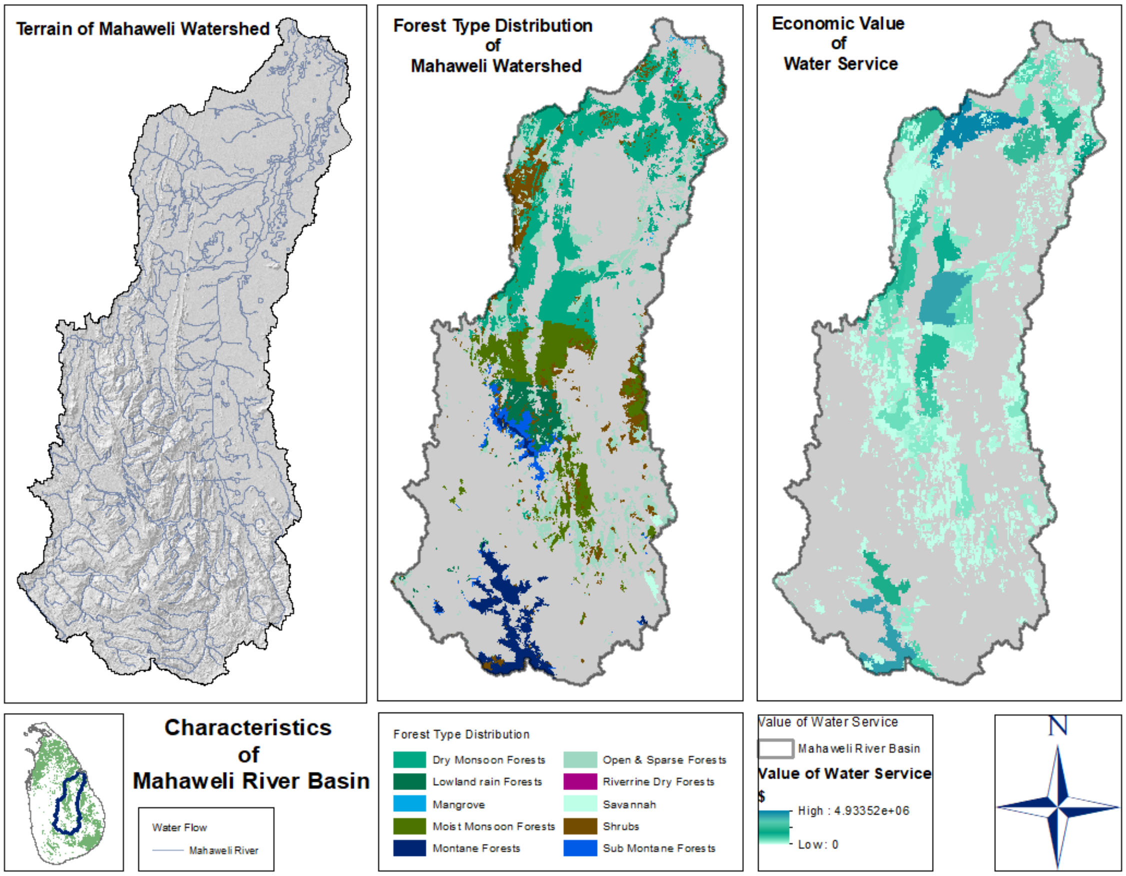

Figure 06. Stream network, terrain, forest types and value of water services of forests within Mahaweli watershed

When considering the results of forest cover analysis within the sub-watersheds, the highest forest cover percentage of 87% is recorded within the sub-watershed of the Kaluganga reservoir. On the other hand, the sub watershed of the reservoirs such as Victoria, Randenigala, and Rantembe, which have been in relatively higher elevations are recorded among the lowest percentages of forest cover (Table 06, and Figure 08). Forest cover percentages of the Vicoria, Randenigala, and Rantembe sub-watersheds are 16%, 19%, and 19% respectively, while the forest cover percentages of the Parakrama samoodraya, Minneriya, and Kawudulla sub-watersheds are 49%, 74%, and 76% respectively (Table 06). The sub-watershed of Rantembe reservoir is recorded as the largest sub watershed with 311,941 ha while the sub watershed of Kaluganga reservoir is recorded as the smallest sub-watershed with 11,501 ha (Table 06).

The economic value of water services provided by all forest ecosystems within the Mahaweli river basin is estimated at US $ 67.9 million. The sub-watershed of the Parakrama samoodraya reservoir is recorded as the most important sub-watershed in terms of the economic value of water services provided by the forest ecosystems. According to the results, US $ 11,247,073 worth of water services are produced by the 78,429 ha of forest lands within the Parakrama Samoodraya sub-watershed annually (Table 06). However, the unit values among the results confirms that the sub-watershed of Kaluganga reservoir has the highest unit value of US $ 161 per ha per year (Table 06).

Table 06. Values of water services, forest cover percentages, and Extents of sub-watersheds

Sub-watershed	Extent (ha)	Forest Cover (ha)	Forest Cover as a percentage	Value of Water Services ($)	Unit Value of Water Services ($/Ha/Year)
Kothmale	57231	19249	33.6	3030051.00	157.00
Victoria	190269	30547	16	4806358.00	157.00
Randenigala	235247	44947	19	6838894.00	152.00
Rantembe	311941	58896	19	8828749.00	150.00
Loggal oya	26993	5307	20	590981.00	111.00
Kalu ganga	11501	10054	87	1615587.00	161.00
Mora: Kanda	77876	23170	30	2846308.00	123.00
P.Samoodraya	158832	78429	49	11247073.00	143.00

Minneriya	21265	15772	74	1821505.00	115.00
Kawudulla	38305	28977	76	3972004.00	137.00

Results of the forest type distribution analysis shows all classified forest types in 2010 forest cover are available within the 1025730 ha of Mahaweli watershed. It includes mangroves from coastal ecosystems to montane forest ecosystems located only above 1500m mean sea level (Figure 07). Forest cover analysis within the sub-watersheds still shows substantial diversity among the forest types and especially the sub-watersheds of Victoria, Randenigala, Rantembe, Moragahakanda, and Parakrama Samoodraya reservoirs are comprised with seven distinctive forest types namely dry monsoon, low land rain, moist monsoon, montane, open and sparse, shrubs, and sub montane (Table 07). The total economic value of water services provided by each forest polygon located within identified sub-watersheds are calculated and depicted as a raster map including the sub-watershed boundaries and the pour points (Figure 07).

Table 07. Extents and unit value water services of different forest types located within identified sub-watersheds

watershed	Dry Monsoon	Lowland rain	Moist monsoon	Montane	Open & Sparse	Shrubs	Sub montane	Savana
Kothmale		269		16938	251	1273	519	
Victoria	78	1302	869	19721	2642	1952	3981	
Randenigala	333	1312	5304	22929	7945	2921	4201	
Rantembe	333	1316	8481	29275	11204	3981	4303	
Loggal oya			387	207	2623	606	87	1395
Kalu ganga		6643	68	263	538	498	2044	
Moragahakanda	2410	2330	11022	154	3452	1526	2276	
P. Samoodraya	27039	10871	21513	417	10092	4177	4320	
Minneriya	6908				3049	5815		
Kawudulla	13073				8420	7425		

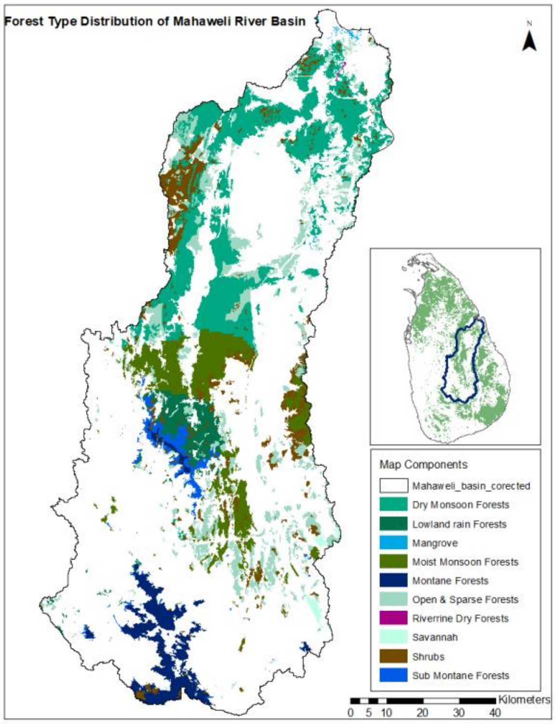

Figure 07. Forest type distribution of Mahaweli River Basin

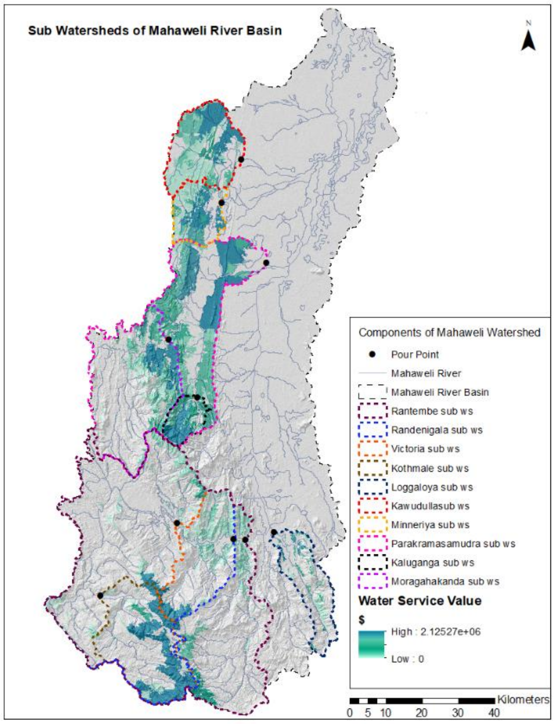

Figure 08. Pour points, sub watershed boundaries, and value of water services of each sub watersheds

5.0 Discussion

Quantification and valuation of ecosystem services have emerged as an effective conservation tool over the last few years (Verweij et al., 2009). Primary valuation researches are the best approach to value and quantify the ecosystem services if the budget is not limited (Moore et al., 2012). However, value transfer can also be used as a strategy to value ecosystem goods and services because it is always better than assigning zero economic value (Moore et al., 2012). The TEEB (The Economics of Ecosystems and Biodiversity) database consists of 1310 original ecosystem service values as data points from 290 case study locations and 267 publications, which can be used for value transferring (Van der Ploeg et al., 2010). Van der Ploeg et al (2010) have further emphasized that information about the monetary importance of ecosystem services is a powerful and essential tool to make more accurate and balanced decisions regarding trade-offs involved in land use planning and management. Since not enough primary level studies have been carried out to investigate the ecosystem services within Sri Lanka, we used the above mentioned the TEEB database information as reference values to determine the economic value of ecosystem services provided by different forest types of Sri Lanka. Since many ecosystem services are not yet understood and valued comprehensively (Moore et al., 2012) the figures estimated in this study are possible underestimations.

5.1 Comparison of Ecosystem Service Values of Sri Lanka with GDP and Global Ecosystem Service Values

The estimated average annual value of ecosystem services provided by all forest ecosystems in Sri Lanka is US $ 34.5 billion while the estimated Gross National Production (GNP) of Sri Lanka for the year 2019 is US $ 81.6 billion (Central bank annual report, 2019). The maximum annual value of estimated ecosystem services being US $ 138.8 billion, exceeds the national GNP by a considerable lead. The economic value of global ecosystem services was originally estimated US $ 33 trillion per year while the estimated global GNP (Gross National Production) is US $ 18 trillion at the time (Costanza *et al*., 1997). The global ecosystem service assessment since been revised upward and the annual economic value of global ecosystem services was estimated at US $ 46 trillion in 2007 and US $ 125 trillion in 2011 (Costanza *et al.*, 2014). Furthermore, a loss of ecosystem services from 1997 to 2011 has ranged between US $ 4.3 trillion and US $ 20.2 trillion due to land-use changes, deforestation, and forest degradation. Contrastingly, the above said global assessments have included even marine ecosystem services which have contributed about 63% of the total value of 1995 estimation (Costanza *et al*., 1997). Even though there are a reasonable number of natural aquatic ecosystems such as wetlands, streams, lagoons, estuaries, etc., which provide valuable services, this study only considered the terrestrial forest ecosystems. Hence, the values of services provided by those non-forested and non-terrestrial ecosystems are excluded from this estimation. It reflects that the value estimated for forest ecosystems of Sri Lanka is comparable to some extent with the value estimated for global ecosystems since the value of terrestrial ecosystems can be estimated around US $ 12 trillion (37% of US $ 33 trillion). Furthermore, revising this valuation and analysis of ecosystem service losses will be a good indicator of the healthiness of ecosystems.

The final estimation of the total value of considered all ecosystem services provided by all ten forest types of Sri Lanka ranges between US $ 3.47 billion and US $ 138.8 billion. Ecosystem service values are derived by adding up the relevant sub-service values described under a corresponding ecosystem service. If the database consists of more than one value from different studies for one ecosystem sub-service, the simple arithmetic average, minimum and maximum values are recorded separately. Furthermore, these values are processed separately when generating ecosystem service values. Therefore, each ecosystem service, which has been estimated in this study consist of an average value, a minimum value, and as well as a maximum value. This difference between the minimum and maximum values generates a considerable range of values of total ecosystem services. If the number of reference values can be increased, some of this variation can be minimized since some uncertainties may describe by other variables (Costanza *et al.*, 2014). Similar type of assessments done in global context have also delivered the results as a range from minimum to maximum (Costanza *et al.*, 1997; Costanza *et al.*, 2014).

5.2 Comparison of Unit Area Ecosystem Service Values of Different Forest Types

Unit annual values represent the economic value of ecosystem services provided by one hectare of each forest type per year. Therefore, these unit values can be used as indicators of the economic values of each forest type. However, low land rain forests, montane forests, and sub-montane forests show the relatively lower and similar unit value which is

US $ 17723 because the same reference values given in the TEEB database were used for these calculations (Table 03). Furthermore, the unit value of dry monsoon forest type and open and sparse forest type shows similar figures. Savannah forest type and shrub forest type are having the same values due to the usage of similar reference values as similar to the above two cases. Therefore, comparing the unit values within similar categories is not meaningful. However, the unit values can be compared by considering the reference values used for the analysis. Furthermore, these forest ecosystems can be classified broadly considering the climatic regions. For instance, low land rain forests, montane forests and sub montane forests can be considered as wet zone forests and both dry monsoon forests and open and sparse forests can be considered as dry zone forests while moist monsoon forests are considered as intermediate zone forests. Based on that broad classification, the value of ecosystems services provided by wet, dry and intermediate forests can be introduced as US $ 17723, 18586, and 4260 respectively.

Mangrove forest type and riverine dry forest types have been assigned unique reference values and independent comparisons among them are meaningful. According to the statistics of the geo database the highest annual unit economic value has been assigned to mangrove forest type which is the US $ 42856 (Table 03). Possible reasons behind this high value are; being a specific ecosystem which combines terrestrial, brackish and marine ecosystems; specific ecosystem services provide such as nursery, storm protection, blue carbon, etc.; high information availability since mangroves are related with several other industries such as fisheries, aquaculture, salt, and tourism industries (Gammage, 1997). This study considered about 137 data entries from a number of studies and publications given in TEEB database. Furthermore, Table 04 shows a comparison of economic unit values of ecosystem services across different forest types. Hence, it again shows the considerable high values for nursery, extreme events, foods, gene pool, and water-related services provided by mangrove forest type compared to the other forest types.

5.3 Under Valuation and Data Deficiency

While the mangrove forests lead the way in terms of unit annual ecosystem values, savanna and shrub forest types show significantly lower unit annual ecosystem service values (Table 03). Forests categorized under savanna or shrubs have most likely been disturbed naturally or anthropologically. Hence, those ecosystems do not contain the typical ecological components or relationships as in a tropical ecosystem. This poor composition of components and interactions might be the reason for being undervalued. Low land rain forests, montane forests, and sub-montane forests are valued at US $ 17723. These forest types have scored similar values because of the usage of similar reference values. However, the calculated unit annual values are considerably lower when compared to the value of dry monsoon forests, which is US $ 18,586. This difference may be the result of using two different sets of reference values. Contrastingly, in species composition of wet zone forests substantially leads the way ahead of all other forest types indicating the rich biodiversity and higher importance in terms of ecosystem services (NCR, 1995). However, the unit annual ecosystem values of dry monsoon forests and riverine dry forests (US $ 17,057.49), were calculated using completely different sets of reference values. The possible reason for being valued at the lower end for moist monsoon forests could be the lower availability of reference information. For the valuation of dry monsoon forests, about 180 data entries, 35 sub-services, and 19 services were considered while about 30 data entries, 18 sub-services, and 11 services were only available and considered for the valuation of moist monsoon forests. Hence, moist monsoon forests were considerably undervalued. Since lowland rain forests and montane forests are technically different from each other in many aspects, more literature has to be found or primary valuation studies have to be conducted on valuation of these forest types, as well as the moist monsoon forests.

When considering the calculated unit value assigned for climate ecosystem service provided by low land rain forests, it shows relatively low figures compared to the dry monsoon forests even though tropical forests are considered an important part of climate regulation (Verweij *et al.,* 2009). Contrastingly, according to Table 04, the value assigned for climate services provided by dry monsoon forest is US $ 1020.56 which is the highest value and is greater than the value of lowland rain forests. Verweij et al. (2009) further highlight the importance of rain forests for climate regulation quoting Filho (2006) who emphasizes that the necessity of 70% of forest cover of amazon landscape to maintain the forest-dependent rainfall regime. This implies that importance of rain forests in terms of providing climate related ecosystem services may not be accounted for in these calculations. Therefore, the value assigned for climate services provided by low land rain forests is a possible undervaluation.

Not only the climate ecosystem service, but also other ecosystem services such as water and extreme events are also undervalued per the used reference values because water cycling as water-related supporting service is one of the main features of tropical rain forest landscapes (Verweij *et al.*, 2009). Additionally, as Verweij et al. (2009) highlighted, regulation of runoff, sediment control, and regulation of flooding are the important hydrological services provided by tropical natural forest landscapes. Furthermore, services like fog interception (horizontal precipitation) are not valued or considered because of the unavailability of reference values with respect to the tropical forest biome, even though the fog interception service is not significant at elevations below 1100m (NCR, 1996). Therefore, low land rainforests are undervalued for a certain level and those gaps of literature have to be filled.

Dry monsoon forest type shows the second-highest unit value which is US $ 18,586.14. Ecosystem service values of tropical general and tropical dry forest ecosystems given in the TEEB database are adopted to calculate the ecosystem values of dry monsoon forests. Therefore, we found a considerable amount of data entries with a considerable amount of ecosystem services and sub-services. Since the value of an ecosystem service is calculated by summing up the relevant sub-services of a given ecosystem service, the estimated value tends to be high when the considered number of sub-services are higher. Similarly, riverine dry forest type was calculated by using the values of flood plain and riparian buffer ecosystems which consist of a considerable amount of ecosystem services and sub-services.

Savannah and shrubs forest types show relatively lower economic values. Even though it is classified as savannah, the corresponding Sri Lankan forest type does not match the international classification criteria of savannah ecosystems. Shrub forests are mainly the distributed forests in the dry zone of Sri Lanka and savannah and grasslands are the most suitable ecosystems given in the TEEB database.

This study used 2010 forest cover statistics and 2015 forest cover data have been published very recently. Hence, there is an opportunity to reiterate this process and analyze the loss or gain of ecosystem service values. However, with the development of geo information science (GIS), different technologies have been used for different forest cover assessments and therefore, it would not be accurate to compare the differences. At the same time, the revenue collected for the government by the Sri Lanka Forest Department for the year 2019 is about US $ 10.32 million (Forest Department Admin Report, 2019). This estimation is only a gross estimation of revenues earned through various services such as, timber, NTFPs, and other forest products such as sand, gravel and metal. A deep analysis of these revenues would also be helpful to assess ecosystem service values which are being already marketed.

5.4 Ecosystem Service Values at Administrative District Level

According to the analysis carried out to calculate the district level annual values of ecosystem services provided by forests located within a particular district, the Anuradhapura district is recorded as the highest with US $ 4.8 billion. On the other hand, the Colombo district is recorded as the lowest with US $ 35.9 million. Reasons behind these valuation differences are, Anuradhapura has the highest extent of forests while the Colombo district has the lowest extent of forests. Furthermore, most of the forests located within the Anuradhapura administration boundary are classified as dry monsoon forests which are priced at US $ 18586 per hectare per year in terms of ecosystem services provided. This unit annual value only second to the value of the services provided by mangrove forest ecosystems. When considering the other districts which are valued over a one billion US dollar benchmark, it is clear, that all those districts are in dry zone except the Rathnapura district. Rathnapura district is also relatively larger in extent and harbors a substantial number of forest ecosystems. Most importantly, part of the Rathnapura administrative district represents the dry zone too. Generally, dry zone areas are larger in extent, sparsely populated, and densely forested. Therefore, the dry zone districts show substantially higher values for the ecosystem services provided by the forests.

When considering the district level total annual values of ecosystem services provided by forests as a fraction of the extent of corresponding district (district ES value divided by the extent of district), the Mulathiv district is recorded highest with US $ 12,319 per hectare. With no surprise, the Mannar and Vavniya districts are also recorded significantly higher fraction values because the 30-year war avoided converting those forest lands to non-forests land utilization. Therefore, those districts still carry significantly higher forest cover percentage compared to the southern regions. Meanwhile the Gampaha district shows the lowest annual fraction value of US $ 411 per hectare. Furthermore, other wet zone districts such as Colombo, Kaluthara, Kegalle. Mathara, Galle, and Kandy show relatively low annual fraction values for ecosystem services because those districts contain significantly lower forest cover percentage. The Kurunegala district is also recorded with a relatively lower value due to the higher amount of non-forest land utilizations. Even though Jaffna is a dry zone district, it is also densely populated with significant number of agricultural lands. Therefore, the annual fraction value of Jaffna is recorded low. When considering the district level total annual values of ecosystem services provided by forests as a fraction of total extent of Sri Lanka, the Anuradhapura district is again recorded as the highest. Similarly, other dry zone districts which have considerable forest cover percentage are also recorded with relatively higher values. Following the same pattern Colombo, Gampaha and other densely populated districts are recorded with lower values because of the same reasons discussed above.

5.5 Economic Value of Water Services within the Mahaweli River Basin

Water as an important service provided by forest ecosystems has been a focus for numerous quantification and valuation attempts over the years (NCR, 1995). According to the literature, changes of land use does not have an effect on rainfall and on water yield (Bruijnzeel, 1986; Meher, 1988; & Pereira, 1989). When it comes to the tropical forest land use, the canopy of the tropical forest intercepts about 20% of rainfall. Furthermore, when confined into the wet zone of Sri Lanka, about 30% of rainfall is intercepted by the forest canopy and released back to the atmosphere (Ponnadurai et al., 1977). A recent water yield modelling study executed in Himachal Pradesh shows an inversely proportionate relationship between forest cover and water yield. Water yield modelling has been done by using the RIOS (Resource Investment Optimization System) and InVEST software and it confirms the significant impact of forest cover and related management interventions in terms of sediment retention (Vogl et al., 2016). NCR has quoted a study done by Hibbert in 1967 who claimed that the reduction of forest cover increases the water yield and establishment of forest cover decreases the water yield.

However, the role of forests of Sri Lanka with respect to the water service is contrasted according to the NCR, because 75% of annual rainfall receives within about two to three weeks, especially in the dry zone. Therefore, Sri Lankan forests do a significantly important role of holding the water received as high intense precipitation and release it slowly. Therefore, the NCR confirms that Sri Lankan forests are substantially important in increasing the water yield, especially during the dry season. Furthermore, Vincent et al., (2015) has introduced significant and robust evidence for reduced water treatment costs by protecting both virgin and plantation forests. Additionally, montane forests intercept horizontal precipitation from clouds or fogs in between 7% -18% where the proportion of vertical precipitation (rainfall), intercepted by montane forests is estimated at 5% of closed moist tropical forests (Bruijzneel, 1986). A similar type of study done in Sri Lanka suggests that the montane forests contribute for 17% of additional rainfall through intercepting horizontal precipitation (Mowjood & Gunawardena, 1992).

Therefore, the results of water services obtained within the Mahaweli river basin are important because a considerable portion of the Mahaweli river basin lies within the dry zone of Sri Lanka. More specifically, the sub-watersheds of Kawudulla, Minneriya, Loggal oya and substantial extents of Parakrama Samoodraya and Moragahakanda sub-watersheds represent the dry zone. Hence, as described in the previous paragraph, Sri Lankan tropical forests in dry zone areas are substantially responsible for increasing the productive use of yielded water. Furthermore, the results shown in Table 07, Figure 07 and Figure 08 confirm that the Mahaweli river basin and its sub-watersheds hold a significant extent of montane (29899 ha) and sub montane (8710 ha) forests which can contribute an additional 18% of volume for the water yield apart from rainfall. When considering the forest cover percentages shown in Table 06, Victoria, Randenigala, Rantembe, Loggal-oya, and Moragahakanda show substantially low values. At the same time, all those sub-watersheds represent the high altitudes greater than 1500m above mean sea level. Therefore, it suggests the potential expansion of montane forests across all the sub-watersheds mentioned above, which will increase the economic return of investment significantly. This will be a significantly effective range which should be considered in future restoration plans. Furthermore, the figures shown in Table 06, indicates that there is an opportunity for enriching relatively unproductive ecosystems such as shrubs and transforming these ecosystems into higher value forest categories.

Relatively low percentages of forest cover especially among the sub-watersheds located in higher altitudes, may need a thorough analysis since the potential of soil erosion is considered high in those areas. A study carried out in *Kalu Ganga* river basin (Another major river located out of the *Mahaweli* river basin) has concluded that the higher percentage of forest cover may significantly lower the soil erosion (Panditharathne, 2019). Furthermore, Vogl et al., (2016) have confirmed that there is a significant impact of forest ecosystems on sediment retention. Since the reservoirs such as Kothmale, Victoria, Randenigala, and Rantembe contribute 507MW of hydroelectricity for the national electricity grid, the water capacity without sediments is crucial. According to Withanachchi et al., (2014) there is a substantial failure in MDP regarding water, climate, food, and energy provisions. Therefore, the volume of sediments plays a key role in both water and energy sector. Even though this study does not focus on soil erosion services within the Mahaweli river basin, it is highly recommended to consider the both services together.

When considering the economic value of water services provided by forest ecosystems within the Mahaweli river basin, the sub-watershed of Parakrama Samoodraya shows the highest value of US $ 11247073.00. The reason for this significantly higher figure is the forest extent (78429 ha) located within the sub-watershed, which is the highest, among others. Another reason is the rich and diversified forest type distribution within the sub-watershed. For instance, it includes, montane forests, monsoon forests, lowland rain forests, sub montane forests, and open and sparse forests. When considering the unit value of water services provided by different sub-watersheds, Kalu Ganga sub-watershed is recorded as the highest at US $ 161. The most prominent reason for the highest unit value is the substantially higher forest cover which is 87%. Furthermore, the Kalu Ganga sub-watershed inhabits significant ecosystems of low land rain forests, montane forests, and sub montane forests. Therefore, maintaining the existing forest cover and composition is the best strategy to maintain the effective flow of ecosystem services from the Kalu ganga sub-watershed.

5.6 Incorporation of Results into National Programs

Cost Benefit Analyses of national development projects can be considered one of the most appropriate tools where these results can be applied effectively. CBAs have become an obligatory component of Environmental Impact Assessments (EIA) after the enactment of National Environmental Act in 1980 (Gunawardena 2013). As a result, EIAs of major development projects often include a CBA to reflect the costs and benefits of each alternative. Development projects which propose a forest land as the project site could calculate the total economic value of ecosystem services which are supposed to be lost by using this updated geo database. All previous CBAs of EIAs in Sri Lanka have considered only the timber value and the land value of forests when calculating the costs which have resulted considerable undervaluation. However, these results including the geo database need to be shared among all stake-holder organizations that represent the Technical Evaluation Committee (TEC) of corresponding EIAs. Furthermore, increasing awareness among forest conservation officers regarding economic valuation of ecosystems services and interpretation of these results is crucial. Not only the awareness but also the policy framework is required, which could enforce and motivate the use of these results in CBAs.

Capacity building of all stake-holders in governmental and non-governmental conservation institutes, and local communities has been identified and described deeply in the operational manual prepared for identification, planning, management, and monitoring and evaluation of environmentally sensitive areas (ESAs) in Sri Lanka. The main purpose of the manual is to support all stake holders including local communities to plan and manage their ESAs (Jansen, 2020). A more comprehensive and integrated approach is aimed for the planning and management of ESAs which functions as a bottom-up planning and decision-making process. The manual has further recommended three administrative levels, different actors at each level, and actor specific training contents by considering the level specific capacity gaps (Jansen, 2020). Therefore, Forests Department officers who serve at different levels should be trained about economic valuation of ecosystem services. The curriculum of the forestry college is one of the best places where this knowledge can be inserted and effective dissemination can be expected since all fresh forestry cadets are supposed complete the full syllabus. Not only the capacity building but also the incorporation of these results into management decisions is crucial. Therefore, these results will be shared through updated geo database with all the other leading conservation-oriented institutes such as, Ministry of Environment, Department of Wildlife Conservation, Coast Conservation Department, Central Environment Authority, and newly established Environmentally Sensitive Areas Secretariat. The key expectation of sharing these data is to incorporate them into policy and management decisions. Furthermore, project proponents are also expected to use these results in their CBAs and EIAs. The use of results will enhance the effectiveness of TEC discussions since the losses and gains of ecosystem services can be quantified economically.

5.7 Incorporation of Results into Global Trends and Programs

Applicability of these results with global trends is also important since ecosystem services and their changes act on global and regional scales when considering the spatial scales. Leading global environmental organizations introduce different programs from time to time with one common goal. Unconditional commitment to achieving these global conservation goals is much needed from responsible nations. Therefore, the effective use of budget allocations from these global programs is vital because the prioritization of tasks based on the requirement, outcome, and available human and financial capital are the key reasons behind successful goal achievements. The data and information presented in this study are required to prioritize management activities and to identify the gaps.

The United Nations Environmental Program (UNEP), and Food and Agriculture Organization (FAO) has declared a decade (2021 - 2030) for ecosystem restoration. The theme and the common goal of the program is "prevent, halt and reverse the degradation of ecosystems worldwide" (UNEP/FAO fact sheet, 2020). The program is mainly focused on achieving sustainable goals on climate change, poverty, food security, water and biodiversity conservation. According to the fact sheet of the program, 350 million hectares of degraded landscapes are expected to be restored by 2030 and are expected to subsequently generate ecosystem services worth US $ 9 trillion. This is where the results of this study can be applied the program of decade of restoration. Based on the results of this study, a national level goal can be defined for Sri Lanka with exact dollar values. Furthermore, any landscape within Sri Lanka can be analyzed in the same way as the sub-watershed analysis and the restoration needs can be identified in terms of economic value of ecosystem services expected after the restoration. For instance, upper sub-watersheds such as Kothmale, Victoria, Randenigala, and Rantembe are recorded with substantially low forest cover percentages. Forest cover and forest type analysis show that there is a possibility of expanding the forest cover and restoring the degraded shrub forests. When considering the unit values of ecosystem services and the geography of the sub-watershed, montane forests comprise a crucial role in terms of providing ecosystem services. Therefore, these types of sub-watershed analyses can be done in other important river basins and similar results can be found. Therefore, the results of this study are very important to set national level restoration targets with respect to the decade of restoration program. Furthermore, the gaps identified in this study can be used to prioritize the research needs with respect to the economic valuation of ecosystem services and to plan more primary valuation studies on forest types which currently show a deficiency of information. Furthermore, the sub-watershed analysis shows the possibilities of enriching forest areas into more economically important forest types. Hence, based on the unit value of the current forest type and the unit value of the predicted forest type, the economic value of increased ecosystem services can be estimated. For instance, a patch of shrub or savanna forest can be enriched to a rain forest, dry monsoon forest or a montane forest which can serve more effectively. Thus, the results of this study can be applied in global programs as a supporting tool for planning, setting targets, and monitoring.

5.8 Limitations and Suggestions for Future Research

This study addressed the gap of not having a database of ecosystem service values for Sri Lankan forest ecosystems. It further updated the attribute table of 2010 forest cover geo database opening up new opportunities for further analyses and mapping activities. Furthermore, the geo database will provide an economic value for all ecosystem services provided by any forest ecosystem polygon classified under the 2010 forest cover analysis. Even though this study has provided useful findings regarding valuation of ecosystem services of Sri Lankan forest ecosystems, some limitations still prevail, since the study was based on a few assumptions. Principally, due to the lack of availability of data within the TEEB database which are identical to the Sri Lankan forest ecosystems, the ecologically most analogous forest ecosystem values had to be adopted assuming that Sri Lankan and analogous forest ecosystems are identical. This limitation should be addressed through finding more and more primary values from ecologically related ecosystems. This assessment could be further specified by finding and adding more reference values to areas like fog interception in montane ecosystems and water services in low land rain forests where data are insufficient. Other limitations and suggestions for future research are described below.

Annual values are used directly after adjusting the currency and inflation but some of the data were given as net present values (NPV) define for a certain period of time under a defined discount rate. TEEB database does not provide time horizon, discount rates, and extent of the study. Therefore, to find out time horizon and discount rates and some data about extents, each publication was referred by following the full citation given in the TEEB database. Since some components of NPV calculations were not clear enough, those values were dropped from the database. Similarly, there were a few numbers of annual values without the extent of the considered ecosystem. Therefore, those data were also dropped from the calculations.

Historical exchange rates were also used (ofx.com/fxtop.com) according to the valuation year and currency mentioned in the TEEB database. Then the values were standardized by using the consumer price index (CPI) values (usinflationcalculator.com). However, there are other ways of value standardization. Some TEEB values have been already standardized to 2007 values by using the general standardization technique. According to the general standardization technique, first, all the values should be converted back to the original currency of the corresponding location. Then those values have to be adjusted by using corresponding GDP deflators of relevant economies. Finally, the inflation-adjusted values are converted to international dollars by using purchasing power parity (PPP) conversion factors. The advantage of using a general standardization technique is, it considers the purchasing power parity prevailing among different countries (Van der Ploeg et al., 2010). Hence, by following the above steps described under general standardization technique, the results of this study could be further adjusted according to the purchasing power parities of original study locations and would provide more accurate values at the end.

Ecosystem services are closely linked with human well-being (Millennium Ecosystem Assessment, 2005) and ecosystems are now being defined in terms of the values of the benefits received by humans as the end part of the chain to avoid the double-counting error (Sills *et al.*, 2017). Therefore, ecosystems in close proximity to a large group of human beneficiaries should yield a larger amount of ecosystem services except for the ecosystem services like carbon storage and sequestration (Moore et al., 2012). Since this study has not considered the proximity of beneficiaries to the ecosystem, the above relationship is not reflected. Hence, it is recommended to use the population statistics of surrounding settlements as an attribute of ecosystem service value. An important index called “Wilderness Index” has been described by Jayasuriya et al., (2006) by quoting International Union for conservation Nature (IUCN) and World Conservation Monitoring Center (WCMC). This index describes the extent which nature is changed because of anthropogenic involvements. Remoteness from settlements, and aesthetic naturalness are used as the indicators of wilderness index. Therefore, this index can be used as a proxy of proximity to a human settlement. Another index called “Viability Index” has also been introduced and mapped by Jayasuriya et al (2006) which can be used to estimate the proximity to human settlements since the viability is a function of the condition, size, shape, and isolation factors.

Value transferring is not a perfect method to value the ecosystem services, primary ecosystem service valuation researches are the best approach if the budget is disregarded. On the other hand, most of the information found in the literature is derived from the studies driven by economists and not ecologists. Therefore, most of the studies are skewed towards analyses of recreation, aesthetic and other cultural services even though they are more quantifiable and utility-based. However, value transfer can still be useful and considerable as a decision support tool since it provides a low-cost and understandable way of summarizing complex information about larger ecosystems, but these calculations should not be used for decision making about individual pieces of land (Moore et al., 2012). More accurate valuation could be conducted through applications such as InVEST and ARIES, since Sri Lankan ecosystems are unique and have a higher degree of endemism, being an island.

When considering the uses and applications of defined ecosystem services, level of precision, spatial scale, and appropriateness of values have to be considered (Costanza *et al.*, 2014). For instance, regional to global level total or macro aggregates values or information with low precision can be used for awareness-raising activities while regional level values derived from land use changing scenarios with low to medium precision are required for actions like urban and regional land use planning. Similarly, regional to global level total values by business, product, or activity, and their changes with medium to high precision are required for actions like full cost accounting. In light of these suggestions, future research should be planned and executed according to the span of decision context such as global level, regional level or land use level.

6.0 Conclusion

The study is directed according to six specific objectives. The first objective was to define economic values to each available forest type within Sri Lanka and then to calculate the total economic value of all forest ecosystems. Based on the results of the analysis, an average value of all ecosystem services provided by all forest ecosystems of Sri Lanka is estimated at US $ 34.5 billion per year as specified in the first objective. Furthermore, ecosystem service unit values of classified forest types are also estimated and out of all forest types mangrove forest type is recorded with the highest unit value of US $ 42,856 per hectare per year. As directed by the second specific objective, raster maps were created at the district level depicting both the unit and total values of ecosystem services provided by forest ecosystems within each administrative district. This analysis concludes that Anuradhapura District holds the highest ecosystem service value among others. Since the unit ecosystem service values are included in forest cover geodatabase, this analysis can be further deepened to identify the distribution of forest types within the any district to identify the restoration priorities in terms of economic benefits. When considering the information gaps as specified in the third objective, reference values were not found for forest types such as low land rain forests, montane forests, sub montane forests, moist monsoon forests, and open and sparse forests. These gaps should be considered when prioritizing future research in order to define more accurate price tag on these forest types. On the other hand, a considerable number of reference values are available for forest types such as dry monsoon forests, riverine dry forests, and mangrove forests. The fourth objective directed the study towards more specific attribute of total ecosystem service value within a selected river basin called

Mahaweli basin. This specific analysis focused on water services provided by the forest ecosystems located within Mahaweli basin and the results concluded Parakrama Samoodra sub-watershed as the most economically valuable sub-watershed being estimated at US $ 11247073.00. Ten important sub-watersheds were identified and the extent of forest cover and the distribution of forest types within the sub-watershed were further identified as important determinants of ecosystem service values within a watershed. This water service analysis opens up new tools to identify the catchment restoration and enrichment plans and activities. As highlighted in the fifth and sixth objectives, this analysis provides basic information required for a fair cost benefit analysis and initiates a new dialog among ecologists, economists, and other practitioners which may helpful in building a favorable impression among policy makers. Finally, these results are expected to be used in conservation and land use management related decision making to identify the priorities, to set targets, to monitor and evaluate the progress, and to analyze the costs and benefits effectively. Furthermore, watershed analysis can be replicated and extended to other important watersheds also. Initiating a discussion among the stakeholders may also be helpful to enhance the awareness of economic value of ecosystem services provided by Sri Lankan forest ecosystems.

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Appendix 01

Forest Type	Possible Application from TEEB	Ecosystem Services	Extent (Ha)	Unit Value (USD/Ha/Yr)			Raw Total (USD/Yr)		
				Average	Min	Max	Average	Min	Max
low land rain forests	Tropical Rain Forests / Tropical Forest Genral	Air Quality	136775.10	283.46	12.50	554.41	38,769,709.77	1,709,441.87	75,829,977.67
		Bio Control		11.45	11.45	11.45	1,565,888.86	1,565,888.86	1,565,888.86
		Climate		979.56	296.31	2746.95	133,979,416.89	40,527,327.46	375,714,369.33
		Cultural Service		9.78	9.78	9.78	1,337,892.91	1,337,892.91	1,337,892.91
		Energy		630.12	0.02	1260.22	86,184,606.73	2,185.47	172,367,027.98
		Erosion		588.09	4.13	2930.91	80,436,714.99	564,421.25	400,875,859.97
		Extreme Events		61.54	20.70	150.99	8,417,298.07	2,831,890.79	20,652,143.62
		Food		377.51	24.57	2193.01	51,633,640.17	3,360,762.21	299,949,613.16
		Genepool		408.30	0.10	6351.73	55,845,558.10	13,302.86	868,758,055.67
		Genetic		481.05	10.11	2165.36	65,796,325.46	1,382,115.09	296,167,518.98
		Medical		1004.63	1.10	4789.47	137,407,943.35	149,902.81	655,079,783.24
		Nursery		15.58	15.58	15.58	2,130,601.06	2,130,601.06	2,130,601.06
		Pollination		79.37	12.01	178.65	10,856,191.85	1,642,442.88	24,434,499.03
		Rawmaterial		9487.44	118.26	46762.03	1,297,646,072.23	16,174,529.24	6,395,881,805.91
		Recreation		806.91	10.81	3255.23	110,364,939.00	1,477,995.47	445,234,016.54
		Soil Fertility		640.88	628.18	648.73	87,655,761.27	85,919,877.66	88,730,512.33
		Waste		441.57	9.73	1526.55	60,396,397.80	1,330,342.61	208,794,238.30
		Water		147.01	13.16	506.90	20,106,741.19	1,800,205.10	69,330,840.78
		Water Flow		21.19	1.99	32.42	2,898,865.12	272,328.50	4,433,812.21
		Various		1248.09	1248.09	1248.09	170,707,467.42	170,707,467.42	170,707,467.42
Sub Total							2,424,138,032.23	334,900,921.50	10,577,975,924.98
moist monsoon forests	Tropical Rain Forests / Tropical Dry Forests	Climate	117734.1	16.96	16.96	16.96	1,997,233.06	1,997,287.41	1,997,287.41
		Erosion		1,336.19	1,336.19	1,336.19	157,314,704.55	157,315,127.08	157,315,127.08
		Extreme Events		36.52	13.98	59.05	4,299,066.16	1,646,498.35	6,951,633.97
		Food		34.33	25.14	57.80	4,042,279.09	2,959,835.27	6,805,030.98
		Genepool		169.40	4.62	645.82	19,944,623.73	544,067.57	76,035,036.46
		Medical		542.83	1.23	4,115.41	63,909,470.16	144,812.94	484,524,092.48
		Rawmaterial		181.58	171.10	192.05	21,377,993.83	20,144,709.56	22,610,378.76
		Recreation		590.87	590.87	590.87	69,565,464.19	69,565,464.19	69,565,464.19
		Water		53.54	53.54	53.54	6,303,573.96	6,303,573.96	6,303,573.96
		Water Flow		32.42	32.42	32.42	3,816,563.76	3,816,563.76	3,816,563.76

		Various		17.52	17.52	17.52	2,062,478.41	2,062,701.43	2,062,701.43
		Polination		1,248.09	1,248.09	1,248.09	146,942,609.00	146,942,752.87	146,942,752.87
Sub Total							501,576,059.90	413,443,394.41	984,929,643.36
montane forests	Tropical Rain Forests / Tropical Forest Genral	Air Quality	44766.8	283.46	12.50	554.41	12,689,413.81	559,504.19	24,819,323.43
		Bio Control		11.45	11.45	11.45	512,518.97	512,518.97	512,518.97
		Climate		979.56	296.31	2,746.95	43,851,766.59	13,264,686.06	122,972,164.00
		Cultural Service		9.78	9.78	9.78	437,895.38	437,895.38	437,895.38
		Energy		630.12	0.02	1,260.22	28,208,416.97	715.31	56,416,118.64
		Erosion		588.09	4.13	2,930.91	26,327,118.99	184,736.35	131,207,576.88
		Extreme Events		61.54	20.70	150.99	2,755,000.72	926,884.27	6,759,493.38
		Food		377.51	24.57	2,193.01	16,899,807.37	1,099,985.08	98,174,187.72
		Genepool		408.30	0.10	6,351.73	18,278,377.65	4,354.06	284,346,479.20
		Genetic		481.05	10.11	2,165.36	21,535,286.34	452,369.40	96,936,299.73
		Medical		1,004.63	1.10	4,789.47	44,973,931.06	49,063.53	214,409,096.69
		Nursery		15.58	15.58	15.58	697,350.55	697,350.55	697,350.55
		Pollination		79.37	12.01	178.65	3,553,256.18	537,575.27	7,997,466.87
		Rawmaterial		9,487.44	118.26	46,762.03	424,722,498.37	5,293,960.05	2,093,386,600.55
		Recreation		806.91	10.81	3,255.23	36,122,694.49	483,751.27	145,726,101.98
		Soil Fertility		640.88	628.18	648.73	28,689,929.19	28,121,770.55	29,041,697.64
		Waste		441.57	9.73	1,526.55	19,767,877.79	435,424.15	68,338,827.08
		Water		147.01	13.16	506.90	6,580,981.93	589,211.21	22,692,141.21
		Water Flow		21.19	1.99	32.42	948,805.12	89,133.73	1,451,196.78
		Various		1,248.09	1,248.09	1,248.09	55,872,940.71	55,872,940.71	55,872,940.71
Sub Total							793,425,868.17	109,613,830.10	3,462,195,477.38
submontane forests	Tropical Rain Forests / Tropical Forest Genral	Air Quality	28989.4	283.46	12.50	554.41	8,217,216.62	362,315.17	16,072,118.06
		Bio Control		11.45	11.45	11.45	331,889.20	331,889.20	331,889.20
		Climate		979.56	296.31	2746.95	28,396,856.65	8,589,742.63	79,632,434.11
		Cultural Service		9.78	9.78	9.78	283,565.60	283,565.60	283,565.60
		Energy		630.12	0.02	1260.22	18,266,775.45	463.21	36,533,087.68
		Erosion		588.09	4.13	2930.91	17,048,513.26	119,628.74	84,965,396.88
		Extreme Events		61.54	20.70	150.99	1,784,041.25	600,217.55	4,377,209.39
		Food		377.51	24.57	2193.01	10,943,718.91	712,311.53	63,574,139.71
		Genepool		408.30	0.10	6351.73	11,836,432.38	2,819.53	184,132,746.23
		Genetic		481.05	10.11	2165.36	13,945,491.52	292,938.46	62,772,527.12

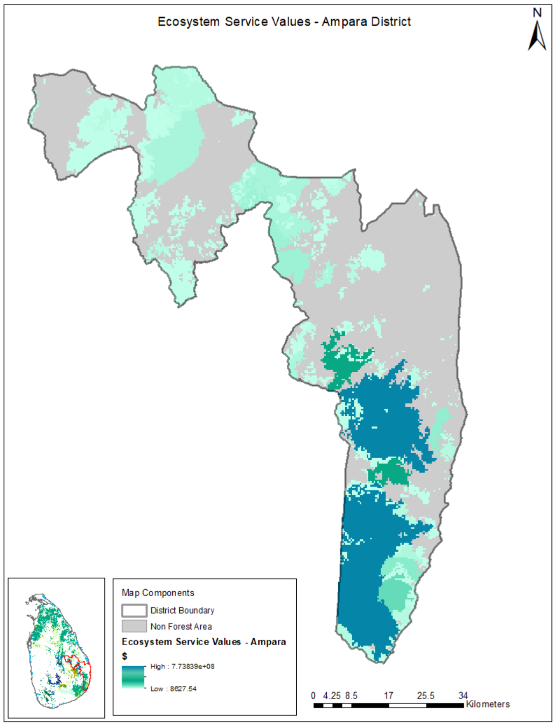
		Medical		1004.63	1.10	4789.47	29,123,530.77	31,771.81	138,843,765.19
		Nursery		15.58	15.58	15.58	451,579.61	451,579.61	451,579.61
		Pollination		79.37	12.01	178.65	2,300,963.32	348,114.78	5,178,877.34
		Rawmaterial		9487.44	118.26	46762.03	275,035,302.82	3,428,181.72	1,355,603,293.47
		Recreation		806.91	10.81	3255.23	23,391,782.29	313,260.25	94,367,081.43
		Soil Fertility		640.88	628.18	648.73	18,578,585.77	18,210,666.28	18,806,378.60
		Waste		441.57	9.73	1526.55	12,800,980.11	281,965.31	44,253,812.95
		Water		147.01	13.16	506.90	4,261,611.67	381,552.39	14,694,629.91
		Water Flow		21.19	1.99	32.42	614,412.71	57,719.86	939,743.83
		Various		1248.09	1248.09	1248.09	36,181,344.82	36,181,344.82	36,181,344.82
Sub Total							513,794,594.71	70,982,048.44	2,241,995,621.13
dry monsoon forests	Tropical Dry Forests / Tropical Forest General	Air Quality	1121586.7	283.46	12.50	554.41	317,920,373.22	14,017,809.26	621,822,937.18
		Bio control		11.45	11.45	11.45	12,840,642.19	12,840,642.19	12,840,642.19
		Climate		1,020.56	283.69	2,734.33	1,144,643,998.52	318,179,328.73	3,066,788,747.98
		Cultural Service		9.78	9.78	9.78	10,971,023.92	10,971,023.92	10,971,023.92
		Energy		630.12	0.02	1,260.22	706,733,233.23	17,921.34	1,413,448,545.12
		Erosion		530.55	4.13	2,930.91	595,056,939.92	4,628,381.67	3,287,272,558.33
		Extreme Events		68.27	26.59	147.76	76,568,109.15	29,822,564.61	165,723,342.67
		Food		483.83	0.51	3,161.79	542,653,750.28	567,761.16	3,546,216,068.61
		Genepool		361.11	0.10	6,351.73	405,021,726.09	109,086.44	7,124,012,197.81
		Genetic		481.05	10.11	2,165.36	539,544,723.72	11,333,655.77	2,428,640,521.98
		Medical		1,087.65	1.10	4,169.07	1,219,897,923.81	1,229,236.85	4,675,974,714.49
		Nursery		15.58	15.58	15.58	17,471,409.68	17,471,409.68	17,471,409.68
		Polination		116.59	72.44	196.17	130,766,403.22	81,246,178.88	220,016,483.05
		Raw Material		11,723.73	134.22	46,762.03	13,149,176,767.94	150,536,931.64	52,447,674,820.08
		Recreation		546.92	10.81	2,682.48	613,413,490.84	12,119,896.57	3,008,638,627.88
		Soil Fertility		640.88	628.18	648.73	718,797,032.67	704,562,395.13	727,610,233.98
		TEV		380.88	9.73	1,526.55	427,189,028.89	10,909,109.76	1,712,159,893.98
		Water flow		178.16	13.16	506.90	199,822,885.83	14,762,088.25	568,528,547.38
		Waste		15.58	1.99	29.18	17,477,892.06	2,233,155.16	32,722,628.95
Sub Total							20,845,967,355.18	1,397,558,577.02	85,088,533,945.28
riverine dry forests	Flood Plains / Riparian Buffer	Bio Control	2425.3	19.48	19.48	19.48	47,235.54	47,235.54	47,235.54
		Climate		215.67	215.67	215.67	523,061.06	523,061.06	523,061.06
		Erosion		109.39	109.39	109.39	265,297.22	265,297.22	265,297.22

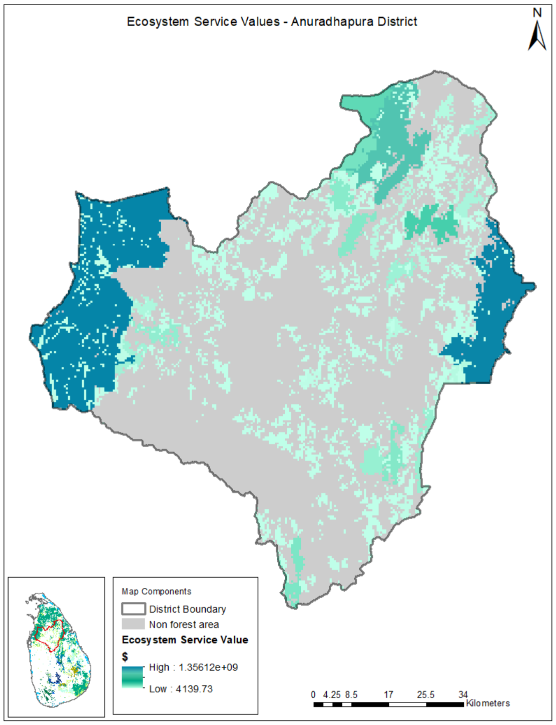
		Extreme Events		1,678.11	317.93	3,038.29	4,069,916.40	771,075.82	7,368,756.98
		Food		464.00	88.84	945.21	1,125,335.47	215,461.63	2,292,423.61
		Genepool		48.67	0.19	182.65	118,043.11	460.22	442,984.86
		Genetic		14.20	14.20	14.20	34,432.99	34,432.99	34,432.99
		Inspiration		733.38	733.38	733.38	1,778,675.42	1,778,675.42	1,778,675.42
		Medical		38.49	0.36	113.86	93,345.01	873.57	276,133.37
		Pollination		21.17	21.17	21.17	51,335.70	51,335.70	51,335.70
		Provisionning Services		91.53	46.71	136.35	221,997.41	113,294.03	330,700.80
		Raw Materials		289.75	157.57	421.00	702,720.64	382,144.88	1,021,045.37
		Recretion		2,004.75	506.86	5,078.50	4,862,127.40	1,229,295.96	12,316,880.66
		Soil Fertility		357.83	357.83	357.83	867,853.70	867,853.70	867,853.70
		TEV		3,094.10	9.73	11,313.06	7,504,131.76	23,600.33	27,437,562.22
		Various		24.13	24.13	24.13	58,512.81	58,512.81	58,512.81
		Waste		4,521.23	617.77	11,933.07	10,965,348.13	1,498,283.17	28,941,267.69
		Water		2,051.44	53.69	6,478.07	4,975,363.24	130,214.89	15,711,269.44
		Water Flows		1,266.64	1,266.64	1,266.64	3,071,979.62	3,071,979.62	3,071,979.62
		Cultural Services		13.53	13.53	13.53	32,823.98	32,823.98	32,823.98
Sub Total							41,369,536.61	11,095,912.54	102,870,233.04
open and sparse forests	Tropical Forest General	Air Quality	428594.9	283.46	12.50	554.41	121,487,755.31	5,356,662.62	237,618,847.99
		Bio Control		11.45	11.45	11.45	4,906,828.65	4,906,828.65	4,906,828.65
		Climate		1,020.56	283.69	2,734.33	437,405,846.63	121,586,710.67	1,171,920,117.06
		Cultural Service		9.78	9.78	9.78	4,192,386.46	4,192,386.46	4,192,386.46
		Energy		630.12	0.02	1,260.22	270,065,844.60	6,848.33	540,124,840.86
		Erosion		530.55	4.13	2,930.91	227,390,686.48	1,768,655.76	1,256,174,180.21
		Extreme Events		68.27	26.59	147.76	29,259,174.60	11,396,175.70	63,328,300.42
		Food		483.83	0.51	3,161.79	207,365,716.65	216,960.08	1,355,124,950.49
		Genepool		361.11	0.10	6,351.73	154,772,026.26	41,685.49	2,722,317,673.27
		Genetic		481.05	10.11	2,165.36	206,177,656.09	4,330,959.93	928,062,843.16
		Medical		1,087.65	1.10	4,169.07	466,162,828.66	469,731.54	1,786,842,617.84
		Nursery		15.58	15.58	15.58	6,676,396.11	6,676,396.11	6,676,396.11
		Pollination		116.59	72.44	196.17	49,970,112.44	31,046,817.79	84,075,482.13
		Raw Material		11,723.73	134.22	46,762.03	5,024,729,788.56	57,525,076.89	20,041,969,064.67
		Recreation		546.92	10.81	2,682.48	234,405,323.96	4,631,408.22	1,149,699,057.46
		Soil Fertility		640.88	628.18	648.73	274,675,816.27	269,236,296.48	278,043,628.26
		Waste		380.88	9.73	1,526.55	163,242,876.47	4,168,727.04	654,272,200.75

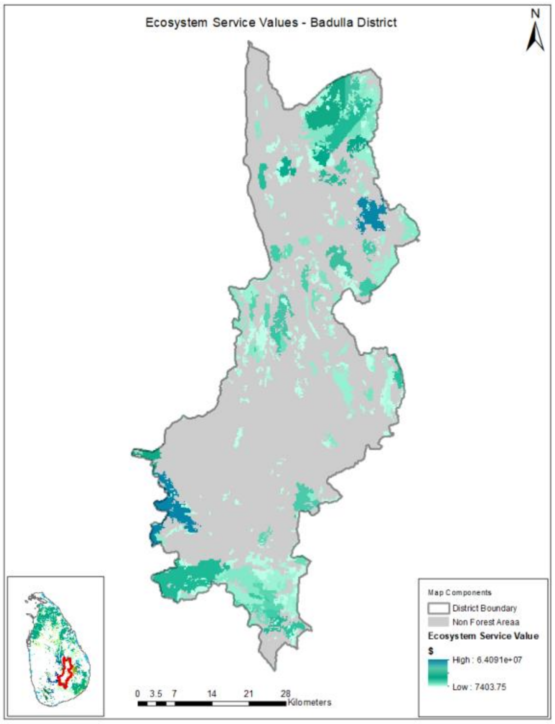
		Water		178.16	13.16	506.90	76,358,849.27	5,641,075.93	217,253,321.49
		Water Flows		15.58	1.99	29.18	6,678,873.24	853,361.50	12,504,384.98
Sub Total							7,965,924,786.73	534,052,765.21	32,515,107,122.28
savanna forests	Savannah / Grasslans / Other Grassland	Food	68043.3	51.24	4.09	98.40	3,486,695.94	278,025.15	6,695,366.73
		Medical		0.34	0.34	0.34	22,829.06	22,829.06	22,829.06
		Genepool		0.04	0.01	0.06	2,701.20	982.26	4,420.15
		Recreation		2.13	2.13	2.13	144,992.99	144,992.99	144,992.99
		Aesthetic		44.68	44.68	44.68	3,040,199.54	3,040,199.54	3,040,199.54
		Climate		607.86	603.81	615.08	41,360,803.09	41,085,285.06	41,852,227.55
		Erosion		114.43	46.64	182.22	7,786,329.64	3,173,695.67	12,398,963.61
		Genetic		0.02	0.02	0.02	1,239.53	1,239.53	1,239.53
		Provisionning Services		873.67	1.64	1,745.69	59,447,165.73	111,707.49	118,782,623.97
		TEV		395.56	369.55	416.38	26,915,239.70	25,145,252.71	28,332,110.15
Sub Total							142,208,196.43	73,004,209.46	211,274,973.29
shrubs	Savannah / Grasslans / Other Grassland	Food	299096.7	51.24	4.09	98.40	15,326,406.11	1,222,110.10	29,430,702.11
		Medical		0.34	0.34	0.34	100,349.30	100,349.30	100,349.30
		Genepool		0.04	0.01	0.06	11,873.63	4,317.68	19,429.57
		Recreation		2.13	2.13	2.13	637,343.06	637,343.06	637,343.06
		Aesthetic		44.68	44.68	44.68	13,363,749.98	13,363,749.98	13,363,749.98
		Climate		607.86	603.81	615.08	181,808,932.15	180,597,842.55	183,969,077.77
		Erosion		114.43	46.64	182.22	34,226,228.01	13,950,556.50	54,501,899.52
		Genetic		0.02	0.02	0.02	5,448.60	5,448.60	5,448.60
		Provisionning Services		873.67	1.64	1,745.69	261,310,828.47	491,030.61	522,130,626.34
		TEV		395.56	369.55	416.38	118,310,831.11	110,530,531.39	124,538,942.86
Sub Total							625,101,990.42	320,903,279.76	928,697,569.12
mangrove	Mangrove	Air Quality	16177.3	285.13	285.13	285.13	4,612,706.06	4,612,706.06	4,612,706.06
		Climate		789.35	2.84	2,708.73	12,769,485.99	45,979.32	43,819,913.45
		Erosion		448.88	119.27	1,054.00	7,261,674.58	1,929,460.13	17,050,824.97
		Extreme Events		9,138.56	4,659.35	21,615.45	147,837,201.55	75,375,742.08	349,679,686.33
		Food		2,721.80	634.01	11,849.34	44,031,453.14	10,256,582.98	191,690,363.17
		Genepool		2,818.59	4.24	11,509.17	45,597,171.64	68,535.27	186,187,274.28
		Medical		18.97	2.77	42.99	306,890.37	44,889.72	695,491.47
		Nursery		10,019.03	174.58	74,569.20	162,080,853.49	2,824,225.39	1,206,328,325.45
		Provisionning Services		1,863.19	236.52	3,489.85	30,141,337.21	3,826,311.98	56,456,362.44
		Raw Materials		1,966.83	27.72	14,172.33	31,818,079.39	448,370.09	229,270,104.82
		Recreation		1,148.61	47.70	1,911.17	18,581,489.06	771,686.47	30,917,591.82

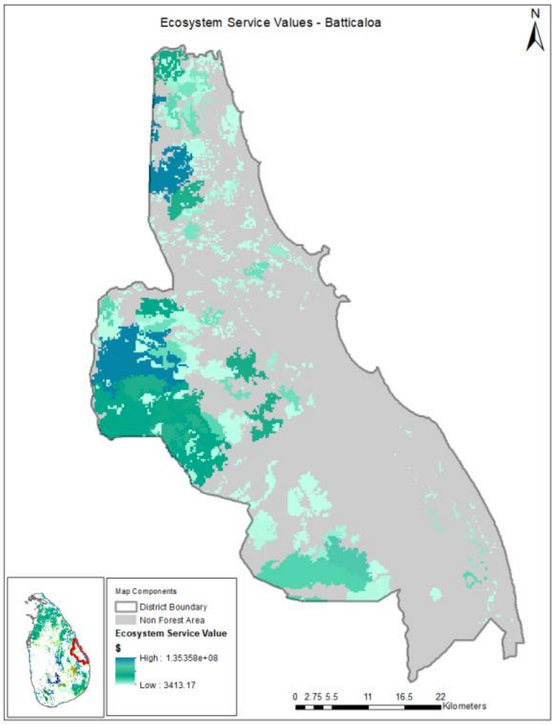
		Soil Fertility		270.87	270.87	270.87	4,381,885.46	4,381,885.46	4,381,885.46
		TEV		5,711.24	868.96	17,929.77	92,392,390.31	14,057,392.01	290,055,340.76
		Various		320.51	152.16	488.86	5,184,956.06	2,461,468.78	7,908,443.33
		Waste		2,879.80	2,879.80	2,879.80	46,587,378.26	46,587,378.26	46,587,378.26
		Water		2,455.27	2,455.27	2,455.27	39,719,671.46	39,719,671.46	39,719,671.46
Sub Total							693,304,624.05	207,412,285.49	2,705,361,363.55
Grand Total			2264189.60				34,546,811,044.43	3,472,967,223.93	138,818,941,873.40

Appendix 02 – District Level Ecosystem Service Raster Maps

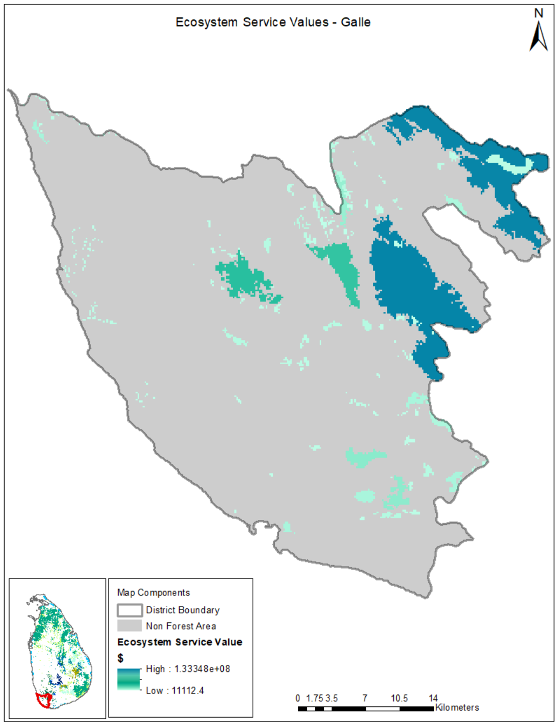


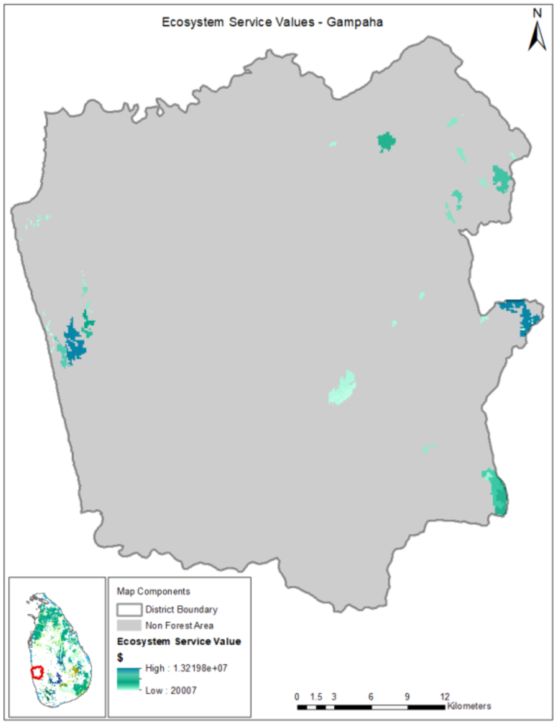


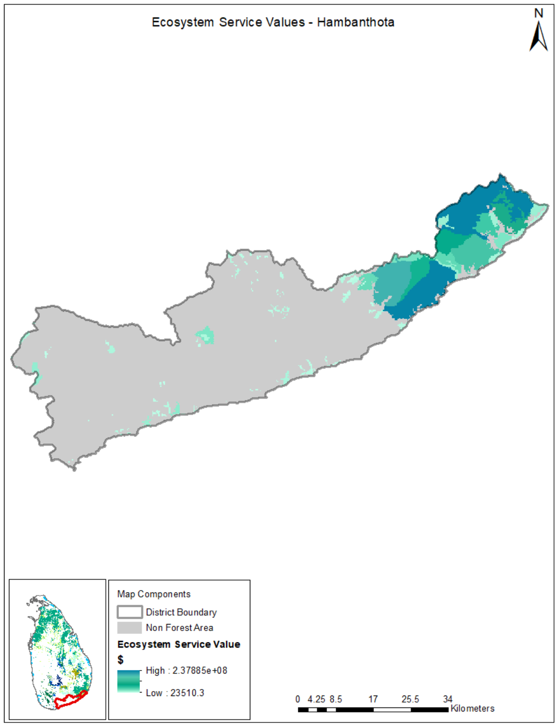




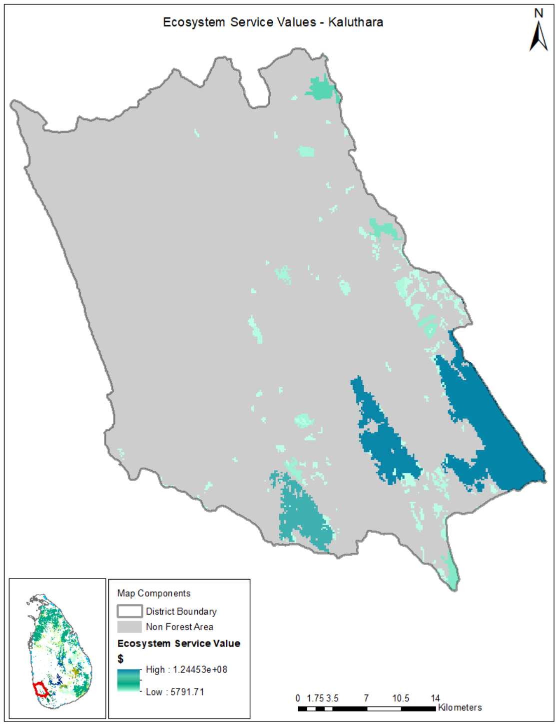

Ecosystem Service Values - Colombo
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 2.21014e+07
Low : 15367.6
0 1.5 3 6 9 12
Kilometers


Ecosystem Service Values - Galle
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 1.33348e+08
Low : 11112.4
0 1.75 3.5 7 10.5 14
Kilometers

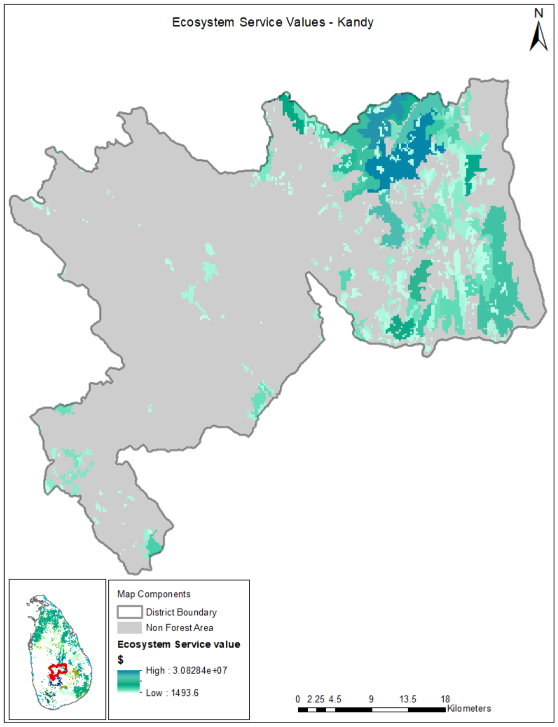

Ecosystem Service Values - Gampaha
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 1.32198e+07
Low : 20007
0 1.5 3 6 9 12
Kilometers


Ecosystem Service Values - Hambanthota
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 2.37885e+08
Low : 23510.3
0 4.25 8.5 17 25.5 34
Kilometers

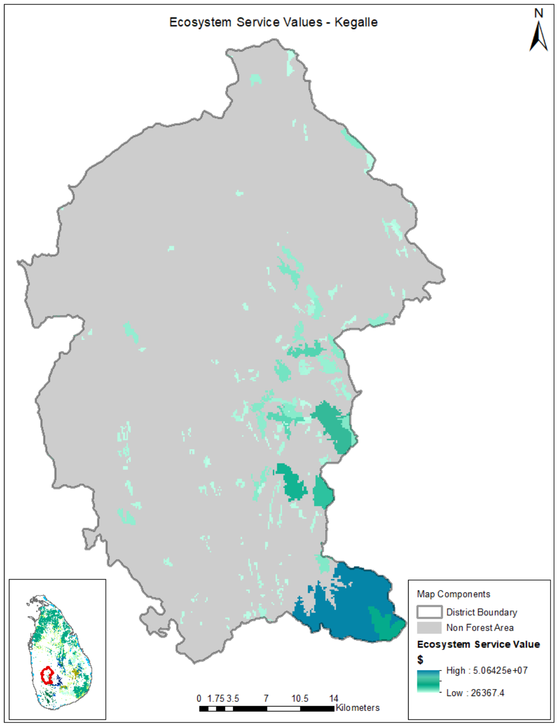
Ecosystem Service Values - Jaffna



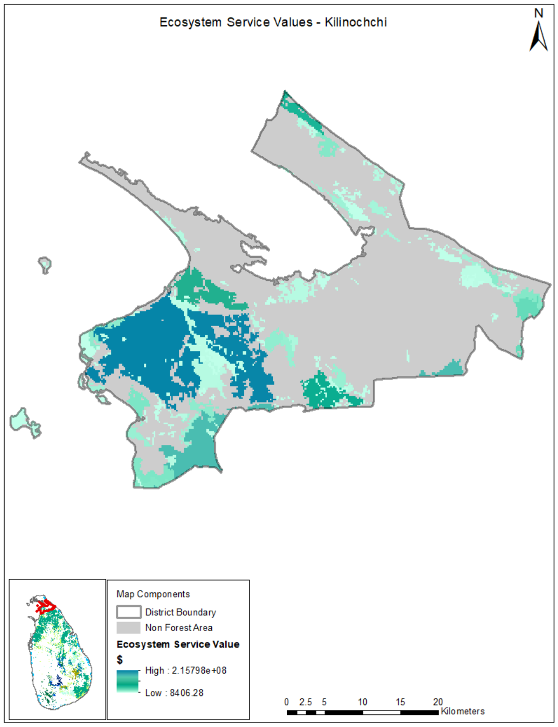
Ecosystem Service Values - Kaluthara

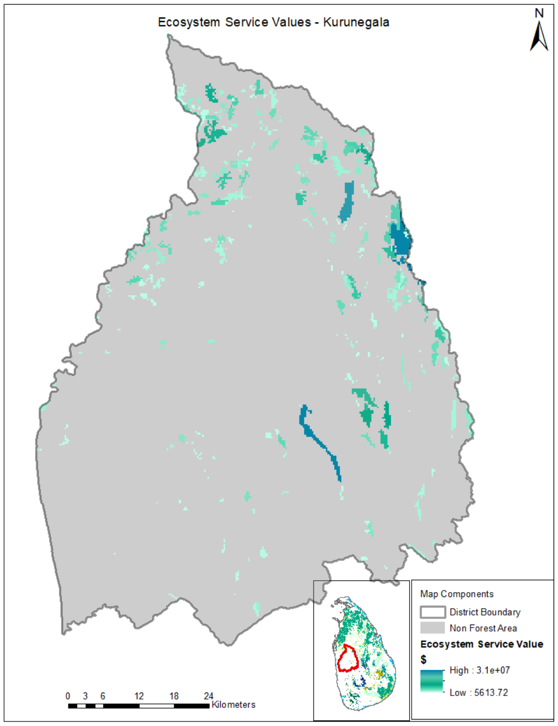


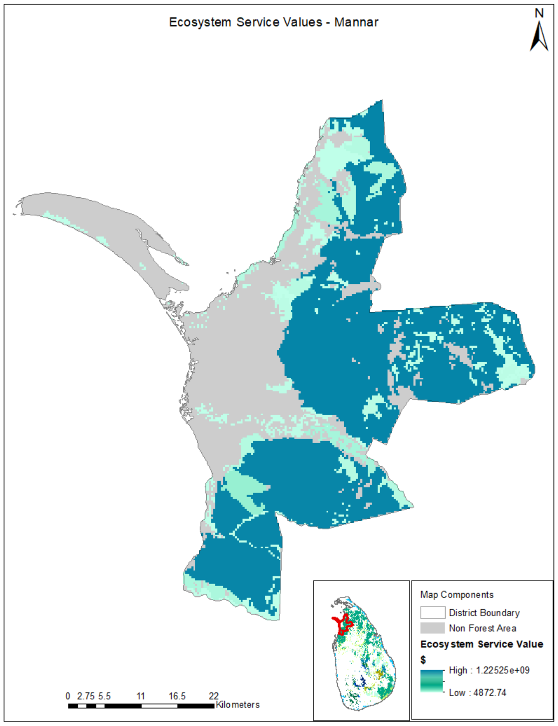
Ecosystem Service Values - Kandy

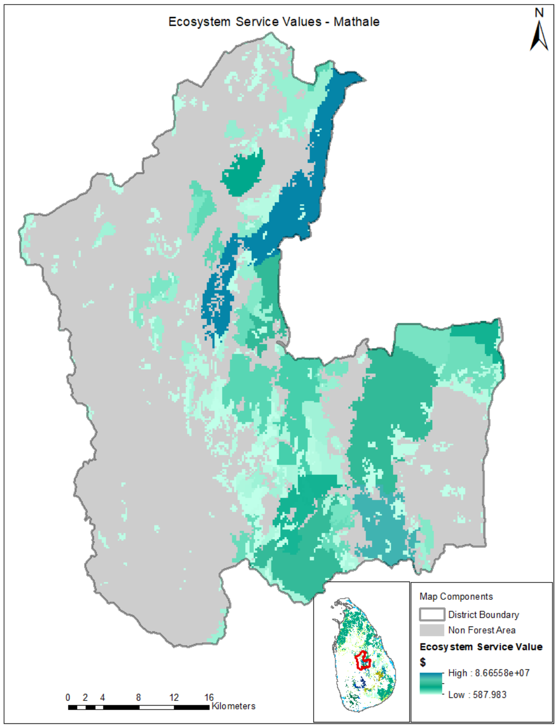


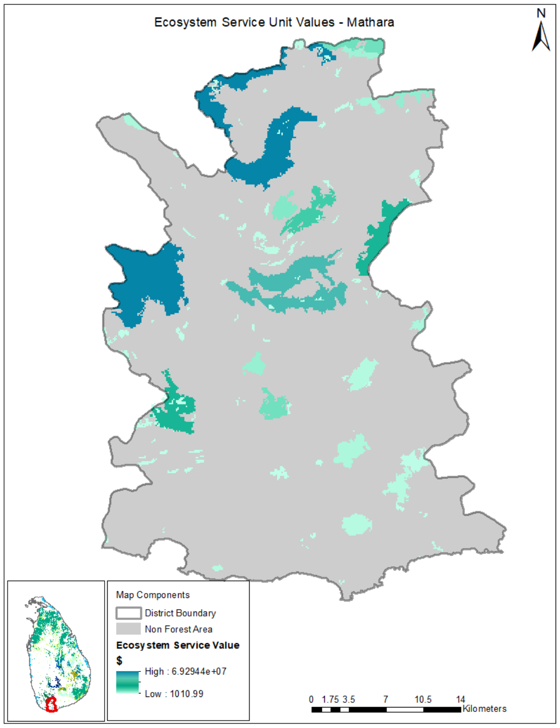
Ecosystem Service Values - Kegalle

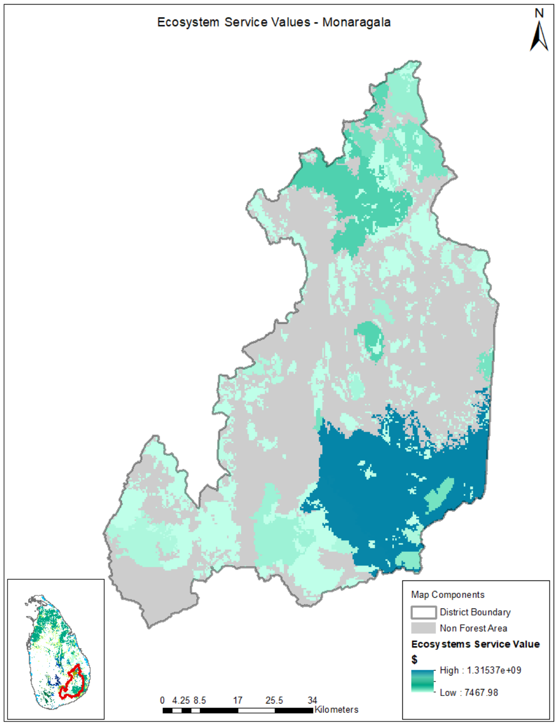

Ecosystem Service Values - Kilinochchi
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 2.15798e+08
Low : 8406.28
0 2.5 5 10 15 20
Kilometers

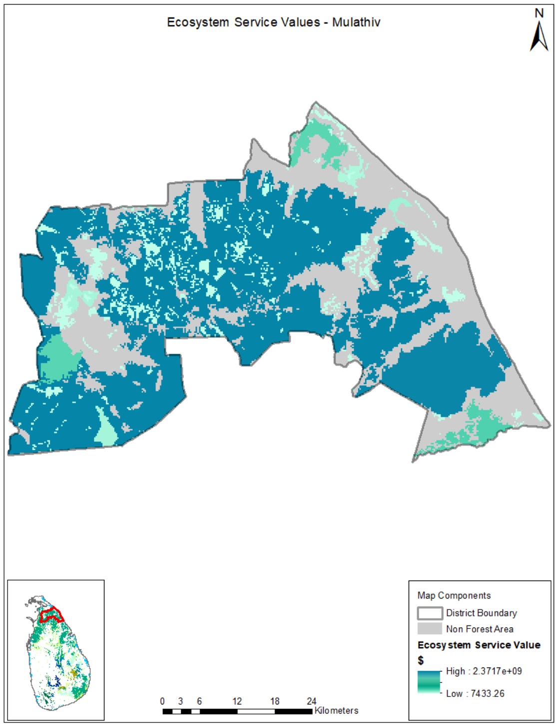

Ecosystem Service Values - Kurunegala
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 3.1e+07
Low : 5613.72
0 3 6 12 18 24
Kilometers

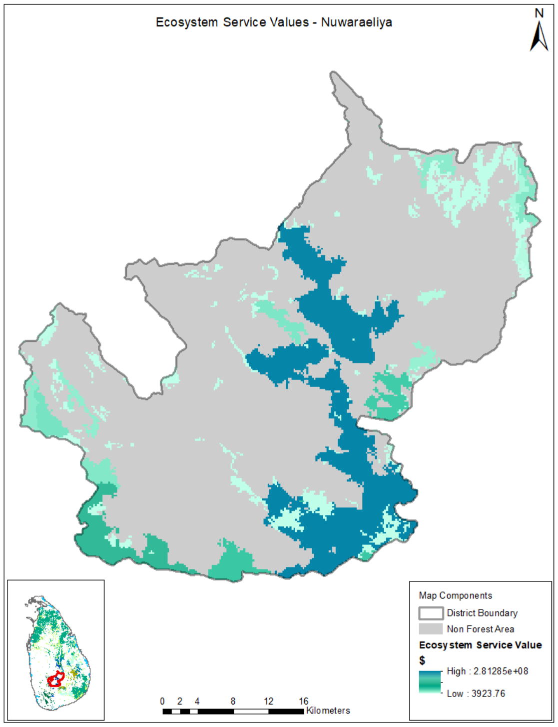

Ecosystem Service Values - Mannar
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 1.22525e+09
Low : 4872.74
0 2.75 5.5 11 16.5 22
Kilometers

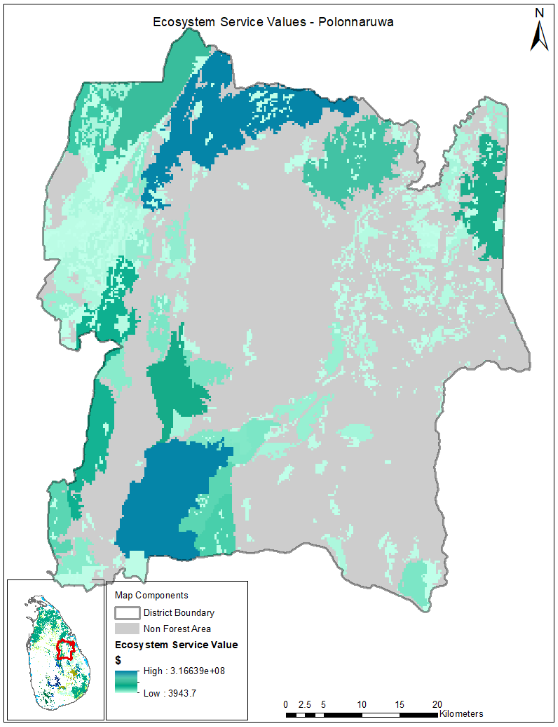

Ecosystem Service Values - Mathale
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 8.66558e+07
Low : 587.983
0 2 4 8 12 16
Kilometers

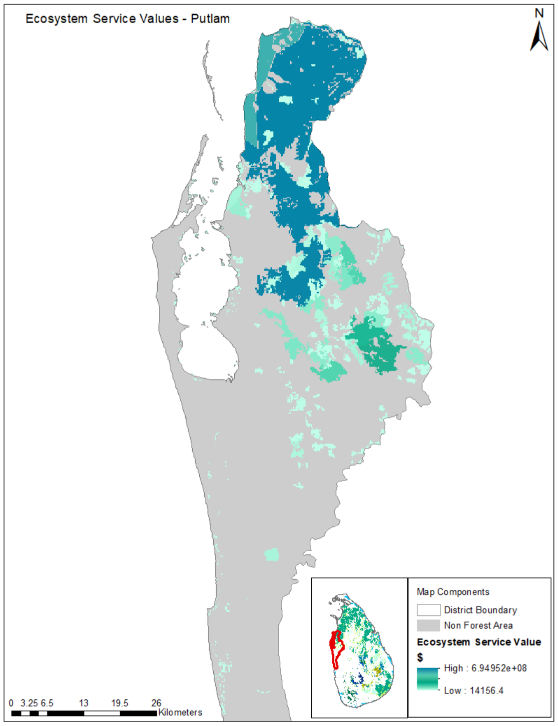

Ecosystem Service Unit Values - Mathara
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 6.92944e+07
Low : 1010.99
0 1.75 3.5 7 10.5 14
Kilometers

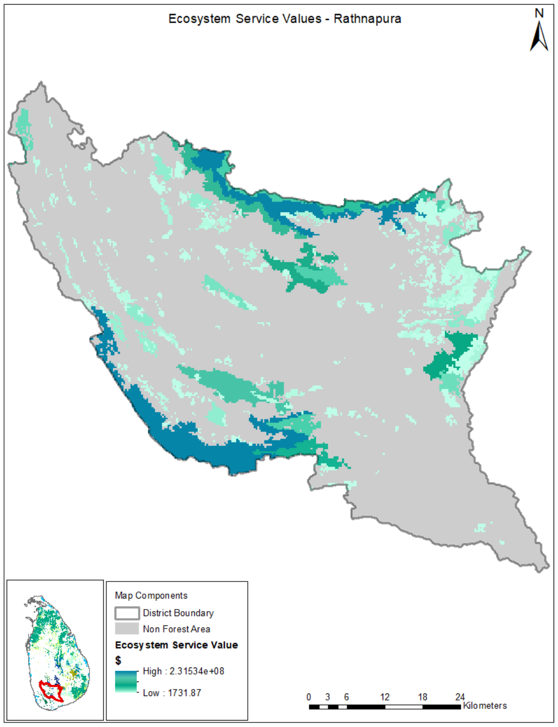

Ecosystem Service Values - Monaragala
N
Map Components
District Boundary
Non Forest Area
Ecosystems Service Value
$
High : 1.31537e+09
Low : 7467.98
0 4.25 8.5 17 25.5 34
Kilometers

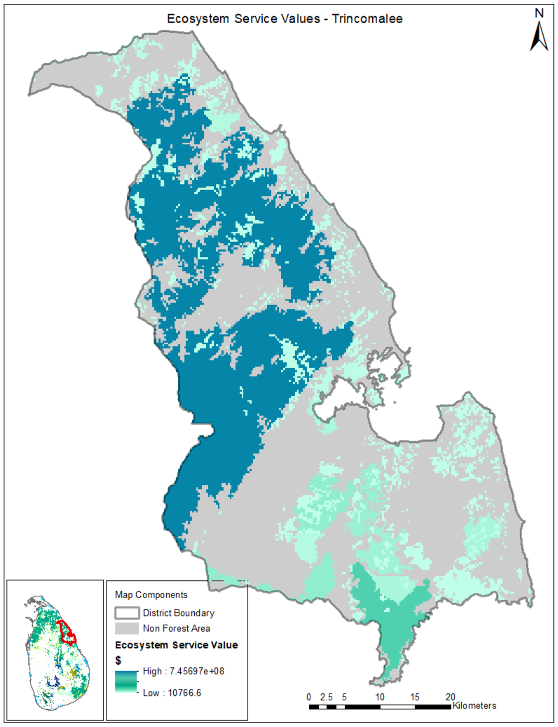

Ecosystem Service Values - Mulathiv
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 2.3717e+09
Low : 7433.26
0 3 6 12 18 24
Kilometers

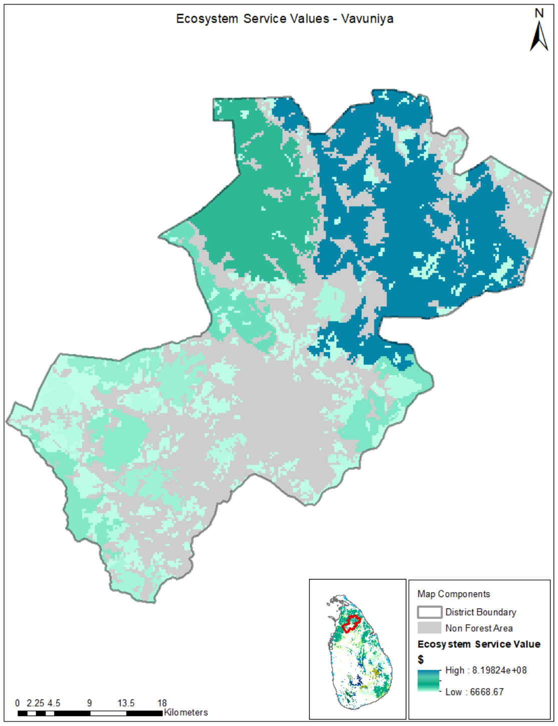

Ecosystem Service Values - Nuwaraeliya
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 2.81285e+08
Low : 3923.76
0 2 4 8 12 16
Kilometers


Ecosystem Service Values - Polonnaruwa
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 3.16639e+08
Low : 3943.7
0 2.5 5 10 15 20
Kilometers

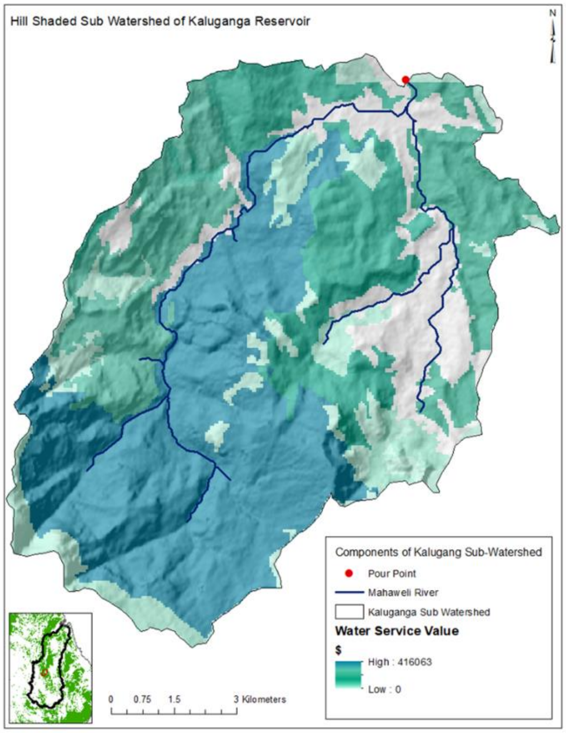

Ecosystem Service Values - Putlam
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 6.94952e+08
Low : 14156.4
0 3.25 6.5 13 19.5 26
Kilometers

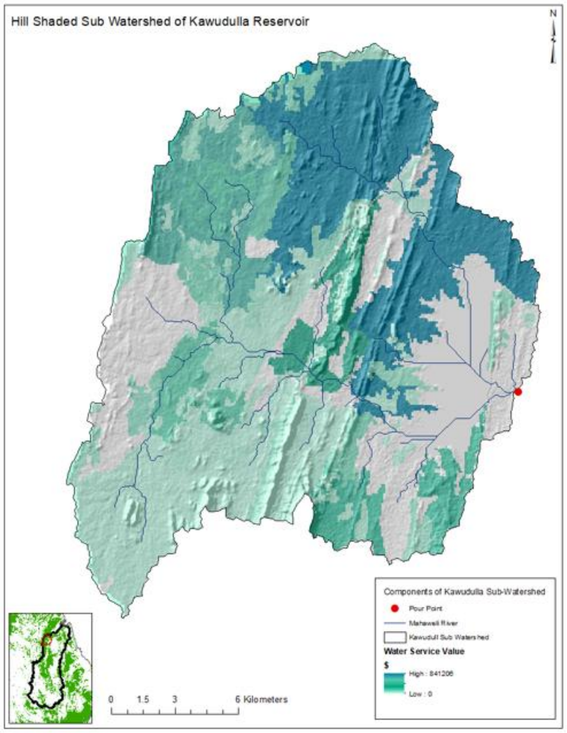

Ecosystem Service Values - Rathnapura
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 2.31534e+08
Low : 1731.87
0 3 6 12 18 24
Kilometers

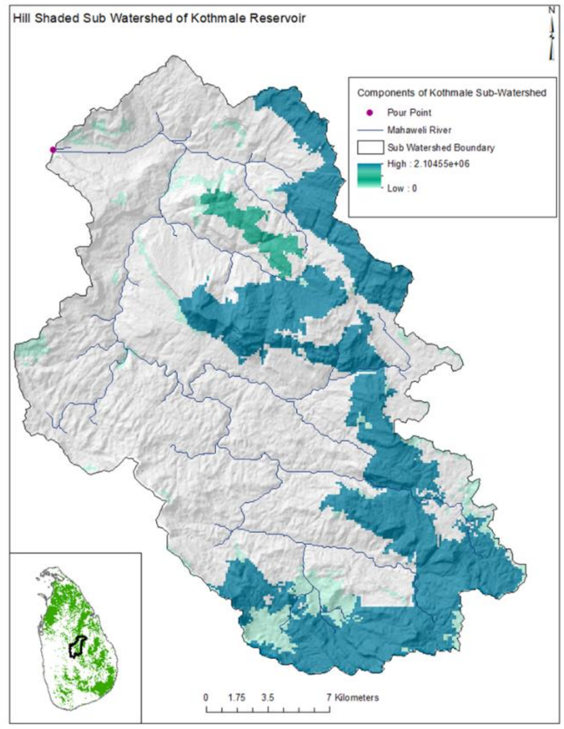

Ecosystem Service Values - Trincomalee
N
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 7.45697e+08
Low : 10766.6
0 2.5 5 10 15 20
Kilometers

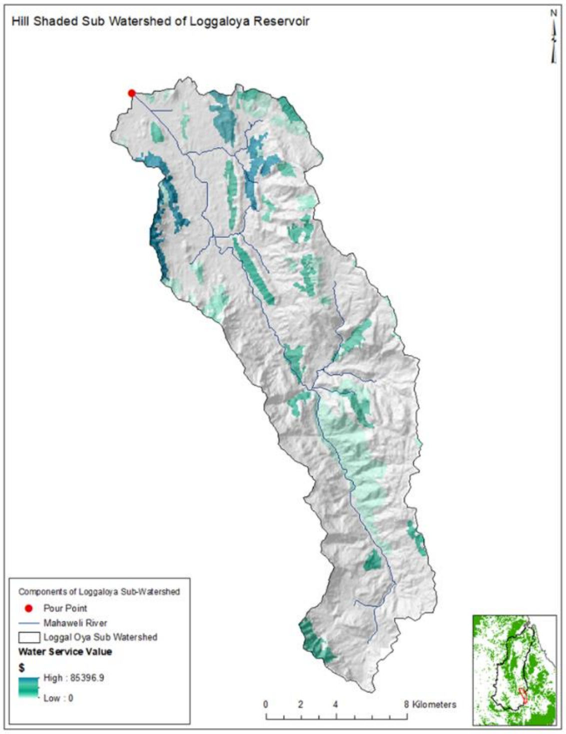

Ecosystem Service Values - Vavuniya
N
0 2.25 4.5 9 13.5 18
Kilometers
Map Components
District Boundary
Non Forest Area
Ecosystem Service Value
$
High : 8.19824e+08
Low : 6668.67

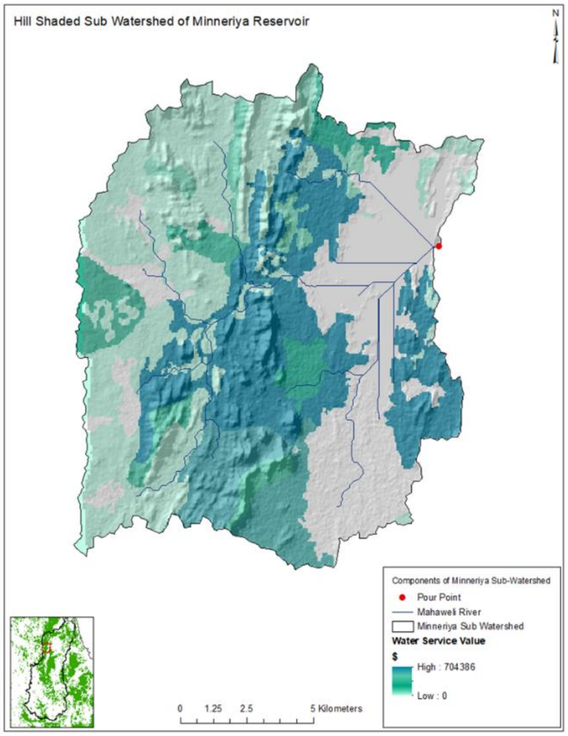
Appendix 03 – Water Service Value Raster Maps of Sub-Watersheds

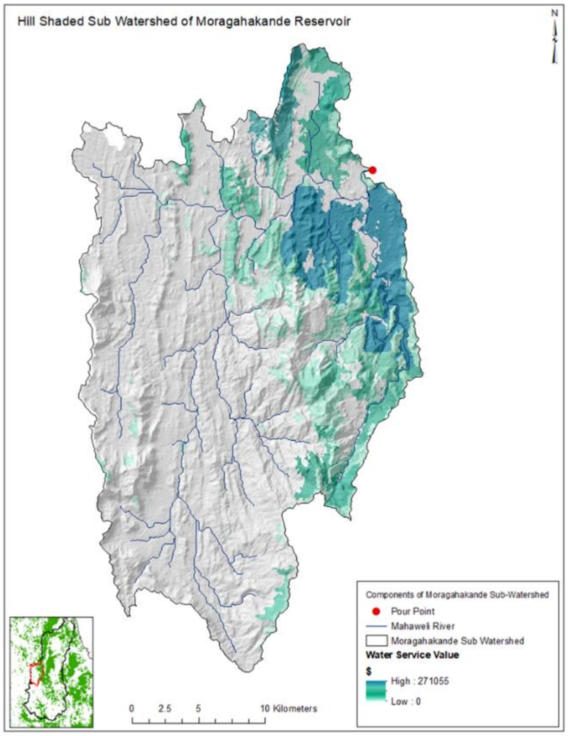


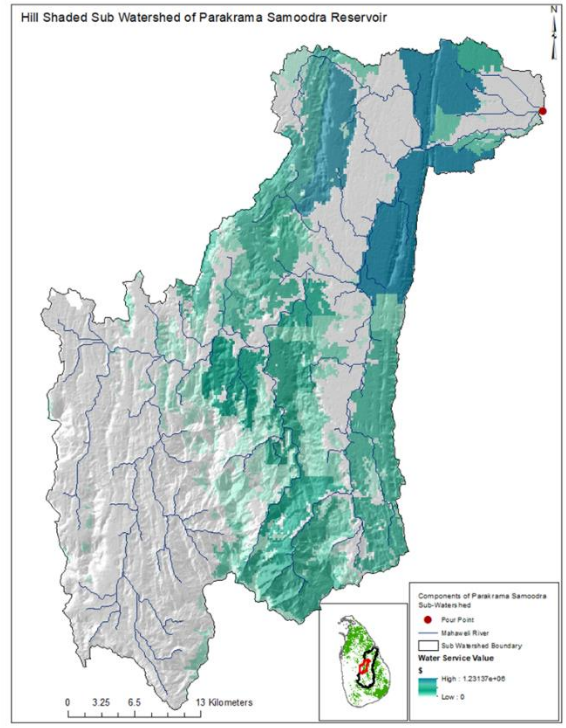


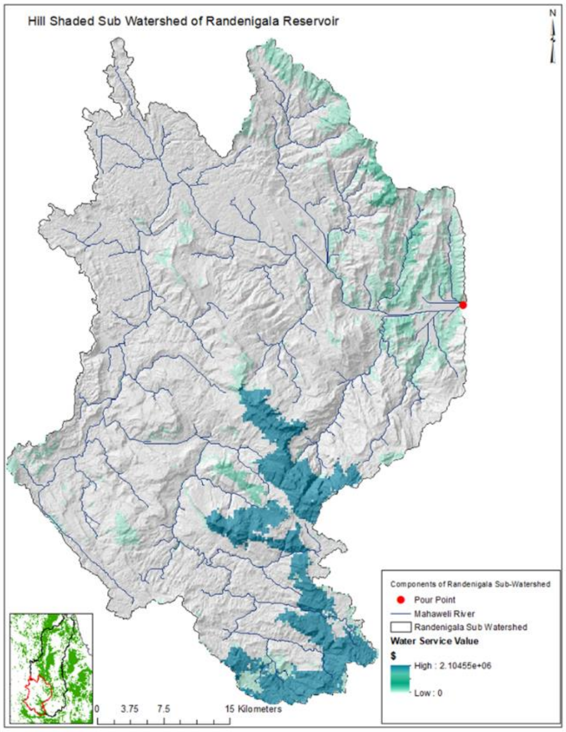


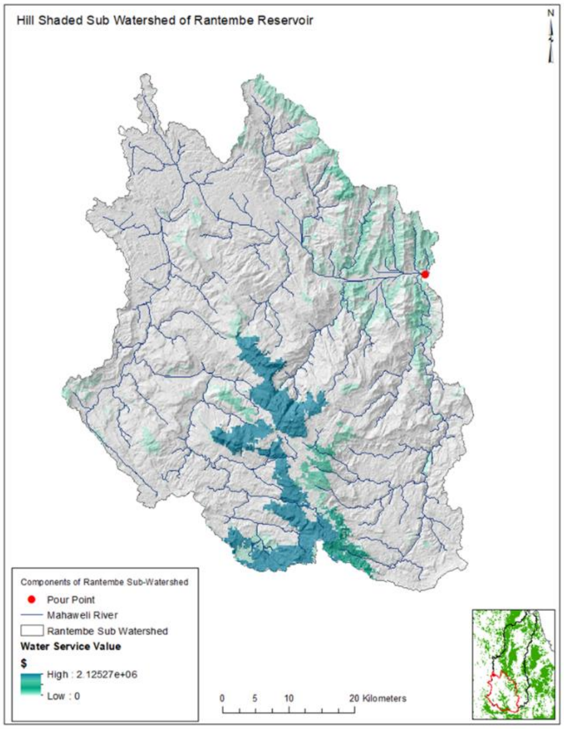


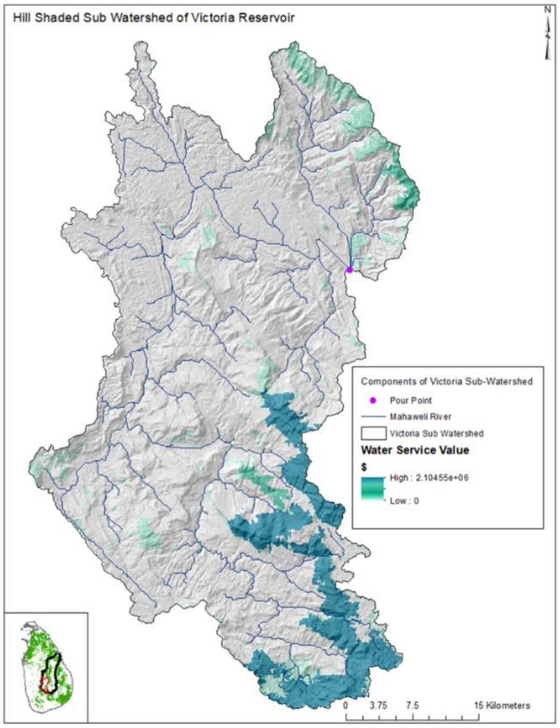

Hill Shaded Sub Watershed of Minneriya Reservoir


Hill Shaded Sub Watershed of Moragahakande Reservoir


Hill Shaded Sub Watershed of Parakrama Samoodra Reservoir


Hill Shaded Sub Watershed of Randenigala Reservoir


Hill Shaded Sub Watershed of Rantembe Reservoir
N
Components of Rantembe Sub-Watershed
Pour Point
Mahaweli River
Rantembe Sub Watershed
Water Service Value
$
High : 2.12527e+06
Low : 0
0 5 10 20 Kilometers


Hill Shaded Sub Watershed of Victoria Reservoir
N
Components of Victoria Sub-Watershed
Pour Point
Mahaweli River
Victoria Sub Watershed
Water Service Value
$
High : 2.10455e+06
Low : 0
0 3.75 7.5 15 Kilometers