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Land use dynamics and cropping shifts: Implications for ecosystem services in paddy wetlands of Kuttanad

¹Shraddha Sudhesh, ²Razia Fathima, ³Allan Thomas, ⁴Jayalekshmi G and ⁵Archana Raghavan Sathyan

¹M.Sc. Scholar, Department of Agricultural Extension Education, College of Agriculture, Vellayani, Kerala, India

²Assistant Professor, Central Training Institute, Mannuthy, Kerala, India

³Professor and Head, Department of Agricultural Extension Education, College of Agriculture, Vellayani, Kerala, India

⁴Associate Professor, Programme Coordinator, Krishi Vigyan Kendra, Kottayam, Kerala, India

⁵Assistant Professor, Department of Agricultural Extension Education, College of Agriculture, Vellayani, Kerala, India

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Corresponding Author: Shraddha Sudhesh

Abstract

This study assesses the impact of land-use and cropping pattern changes on ecosystem services in the paddy wetlands of Kuttanad in Kerala, India, during 2024-25, focusing on farmers' perceptions of ecosystem services and the socio-economic factors influencing land-use changes. By using a multistage random sampling technique, a total of 180 farmers were selected from the major rice-growing tracts of Kuttanad, which spreads over the districts of Alappuzha, Kottayam, and Pathanamthitta. Primary data were collected through a structured interview schedule, using a five-point Likert scale to assess the perceived importance of ecosystem services and a five-point continuum to rate the degree of severity of land-use change drivers. Statistics including descriptive method, Spearman's rank correlation, Mann -Whitney U test, and multiple linear regression, were applied to analyse the data thus obtained. The findings show that environmental stressors, particularly declining soil fertility, climate variability, and groundwater depletion due to overuse, are perceived as the most significant drivers of land-use change. Spearman's correlation showed a significant positive relationship between land-use change and regulating services ($r = 0.256$) and supporting services ($r = 0.226$), implying that as land-use change increases, farmers place higher value on ecological functions such as flood regulation, groundwater recharge, and soil fertility. The correlation with provisioning services ($r = 0.089$) and cultural services ($r = -0.049$) was weak and not significant. Mann -Whitney U test results showed significant differences in supporting services between farmers who reported land-use change (mean = 3.18) and those who did not (mean = 2.95). This implies that farmers exposed to land-use change have increased awareness of ecosystem functions such as soil fertility, biodiversity, and water regulation. Income and landholding size were found to be significant predictors of awareness regarding land-use change, with affluent farmers recognizing greater degree of ecological degradation. The study highlights the need for policies integrating land-use planning, paddy land restoration, and farmer participation to sustain both crop productivity and ecosystem services, thereby contributing to a deeper understanding of sustainable wetland management and elucidating how land-use transformation influences the socio-ecological dynamics of this Globally Important Agricultural Heritage System (GIAHS).

Keywords: Land use change, ecosystem services, Kuttanad wetlands, paddy farming, socio-economic factors, regulating services, supporting services

Introduction

Ecosystem services are the numerous benefits that humans derive from natural ecosystems, and it includes provisioning, regulating, supporting, and cultural services that supports ecological stability as well as human well-being (De Groot *et al.*, 2010) ^[1]. These services are widely recognized as the fundamental pillars supporting global social and ecological systems (Gomes *et al.*, 2021) ^[2]. However, in recent decades, unplanned land use changes, intensive farming practices, and climate variations have caused serious damage to natural ecosystems, which has led to a marked decline in the services they offer (Hevia *et al.*, 2017; IPBES, 2019) ^[3, 4]. As per the Millennium Ecosystem Assessment (2005) ^[5], it is found that almost 60 percent of global ecosystem services have been harmed since the mid-

20th century, mainly due to human actions, with Land Use and Land Cover Change (LULCC) being recognised as its single greatest threat (Foley *et al.*, 2005; Zhang *et al.*, 2022) ^[6, 7].

The effects are severe especially in paddy farming systems around the world. While paddy lands are primarily valued for provisioning services like rice production, they also provide a multitude of non-provisioning services, such as groundwater recharge, carbon storage, and flood mitigation (Tsai and Lee, 2023; Dai *et al.*, 2024) ^[8, 9]. When these lands are converted for non-agricultural purposes or a shift occur in its cropping pattern, it significantly alters the ecosystem services they provide. For instance, studies in South Asia shows that conversion of paddy lands for aquaculture reduces regulating services like flood control and nutrient

cycling, even as provisioning services temporarily increase (Islam *et al.*, 2023) ^[10]. Similarly, paddy expansion can improve food supply but result in the reduction of habitat quality and carbon storage (Dai *et al.*, 2024) ^[9]. These findings highlights that land use changes significantly affect the overall stability and ecological equilibrium of paddy ecosystems.

The Kuttanad wetland ecosystem of Kerala, a delta region of about 900 sq.km, represents one of India's most distinctive agro-ecosystems, spanning over the districts of Alappuzha, Pathanamthitta and Kottayam in Kerala. Recognised as a Globally Important Agricultural Heritage System (GIAHS) by FAO, the farming system in this region is an intricate mosaic of fragmented agricultural holdings that comprises of wetlands (used for paddy cultivation and fish farming), garden lands (used for plantation and food crops farming), and water bodies (used for inland fishing and other water body based livelihoods). Kuttanad is the only major rice-growing region situated below mean sea level in the world (Asha *et al.*, 2016; Jayan and Sathyanathan, 2010) ^[11, 12]. The unique paddy lands of this region support multiple ecosystem services. These include provisioning services through rice, fish, and fodder production; regulating services such as flood moderation, sediment retention, and groundwater recharge; supporting services including soil nutrient cycling, biodiversity conservation, and water purification; and cultural services embodied in traditional festivals and collective labour (Ramsar Convention Secretariat, 2016; Rejula *et al.*, 2017) ^[13, 14].

In recent decades, however, Kuttanad has witnessed drastic changes in its land use and cropping pattern driven by socio-economic pressures, and recurrent floods. Extensive conversion of paddy wetlands for housing, aquaculture, and infrastructure has reduced the agricultural area and weakened the flood-buffering capacity of the region (Sreejith, 2013; Sonu and Bhagyanathan, 2022) ^[15, 16]. Land use changes in the upstream of the Meenachil River Basin has heightened downstream flooding, thereby accelerating sediment deposition and waterlogging (Sonu and Bhagyanathan, 2022) ^[16]. Human interventions such as embankments, canal modifications, and drainage restrictions have reduced the soil and water quality, leading to salinity intrusion and declining productivity (Sreeja *et al.*, 2015) ^[17]. Climate variability, increased rainfall intensity, and prolonged inundation have further threatened the sustainability of this sub-sea-level rice farming system (Asha *et al.*, 2016) ^[11]. In addition, labour shortages, high production costs, and the economic attractiveness of non-agricultural activities have led to the abandonment of traditional double-cropping systems in favour of single-season cultivation (Rejula *et al.*, 2017) ^[14]. These shifts have not only reduced food production but also weakened regulating and supporting ecosystem services.

Given this background, understanding the impact of land use and cropping pattern changes on the four domains of ecosystem services namely provisioning, regulating, supporting, and cultural is needed for developing wetland management strategies that are both adaptive and sustainable. The present study therefore aims to analyse the relationship between land use, cropping pattern changes and the ecosystem services of paddy wetlands in Kuttanad, and

to examine the extent to which personal and socio-economic factors influence the extent of land use change. This research is particularly relevant in the context of Kerala's declining paddy area, where more than half of the region's wetland ecosystems have been lost or converted in recent decades (Rejula and Singh, 2015) ^[18]. By integrating perception-based assessment with quantitative analysis, this study advances the understanding of how land-use change shapes the socio-ecological structure of paddy-based ecosystems.

Materials and Methods

Study Area

The study was conducted in the Kuttanad region of Kerala, one of India's most distinctive wetland ecosystems situated below sea level. This area, often called the "rice bowl of Kerala," was purposively selected owing to its predominance in rice cultivation and the extensive ecological and socio-economic transformations it has undergone in recent decades. The region's remarkable agro-ecosystem made it well-suited for studying ecosystem service dynamics.

Sampling Procedure

A multistage random sampling technique was used to select the respondents. The rice-growing tracts of Kuttanad fall within three districts: Alappuzha, Kottayam, and Pathanamthitta. From each district, the block panchayat with the largest area under paddy cultivation was purposively selected, namely Ettumanoor (Kottayam district) Champakulam (Alappuzha district) and Thiruvalla (Pathanamthitta district). Two villages, Thiruvarpur and Kumarakom from Ettumanoor, Champakulam and Nedumudy from Champakulam, and Niranam and Peringara from Thiruvalla, were randomly selected. In Kuttanad region farmers follow group farming approach and each paddy farmer group is named as '*padasekharam*'. One padasekharam was selected from each panchayath, and thirty farmers were randomly chosen from each padasekharam for the study with a total of 180 farmers. These farmers primarily depend on paddy land-based resources for their livelihood, making them representative of the Kuttanad agro eco system.

Instrument and Data Collection

Primary data were collected using a structured and pre-tested interview schedule developed through a review of relevant literature, expert consultation, and field validation in the Kuttanad region. The instrument, consisting of both closed- and open-ended questions, was administered through personal interviews to capture information on the extent of land use and cropping pattern changes, farmers' perceptions of ecosystem services, and their personal and socio-economic characteristics. The perceived importance of ecosystem services in paddy wetlands was measured using a five-point Likert scale, wherein respondents rated each service as *Not Important* (0) to *Very Important* (4). This scale was developed by Aswathy Vijayan (2015) ^[19] and modified for the purposes of this study to suit with the regional characteristics of the Kuttanad wetland ecosystem. The ecosystem services were categorized into four domains such as Provisioning, Regulating, Cultural, and Supporting

services as proposed by the Millennium Ecosystem Assessment (2005) [5]. The drivers of land use and cropping pattern change were also rated on a five-point continuum from *Insignificant* (1) to *Severe* (5), encompassing factors such as the prevalence of single cropping, reduced water retention due to urbanization, soil fertility decline, displacement of farming communities, labour shortage from migration, uncertainty due to climate change, tourism-induced land pressure, and groundwater over-extraction. This scale was developed for the study, based on the scale by Hanacek and Rodriguez-Labajos (2018) [20], and modified to suit the ecological setting of the Kuttanad wetland ecosystem. Additionally, a dichotomous question (*Yes/No*) was used to record whether significant land use change had occurred in the respondent's area over the past decade. The personal and socio-economic variables considered for analysis included age, gender, educational level, farming experience, agricultural income, size of operational landholding, years of association with organizations, level of social participation, extension contact, and area under paddy cultivation, which were used to examine their influence on the extent of land use change among farmers.

Statistical Analysis

The collected data were analysed using both descriptive and inferential statistical techniques to assess the extent of land use and cropping pattern changes and their relationship with the ecosystem services of the Kuttanad paddy wetlands. Descriptive statistics such as mean, and standard deviation were used to summarize and describe the magnitude and distribution of the observed variables. The relationship between the extent of land use change and the four domains of ecosystem services, was analysed using Spearman's rank correlation. The Mann-Whitney U test was used to compare the perceptions of ecosystem services between two independent groups of farmers, those who reported land use change and those who did not, to identify any statistically significant differences between the groups. In addition, multiple linear regression analysis was conducted to identify the influence of personal and socio-economic variables such

as age, gender, educational level, farming experience, agricultural income, operational landholding size, years of association with organizations, level of social participation, and extension contact on the extent of land use change. A composite value for Land Use Change (LUC) was derived by averaging farmers' ratings across eight land-use and cropping-pattern drivers. This denotes the perceived intensity of land-use change for each respondent in the Kuttanad region (Swagata Bera, 2024) [22].

Results and Discussion

Perceived severity of LUC drivers (Descriptive Analysis)

For identifying the perceived severity of drivers of LUC, descriptive analysis was done. The results indicates that the highest perceived severity scores (rated on a 5-point scale from *Insignificant* to *Severe*) are increasingly associated with environmental and resource pressures namely uncertainty due to climate change and increased weather extremes ($\mu=4.64$), groundwater over-extraction ($\mu = 4.57$), and the decline in soil fertility ($\mu = 4.45$), followed by increased prevalence of single-crop (puncha) cultivation ($\mu = 3.58$). In contrast, tourism-related land-use shifts ($\mu = 1.62$) and displacement due to urbanization ($\mu = 2.58$) were perceived as relatively less influential.

These findings suggest that farmers are greater aware of environmental stressors that directly affect their production capacity. They perceive biophysical and agronomic pressures (soil fertility loss, water extraction, and changing climatic risk) as the greatest immediate threats to paddy production, which clearly shows an increasing recognition of hydrological instability in the Kuttanad wetlands, consistent with earlier reports (Asha *et al.*, 2016) [11]. The predominance of single-cropping system in paddy lands indicates a structural change in the agricultural calendar of Kuttanad, primarily influenced by economic and labour constraints, which aligns with earlier findings in this regard (Rejula *et al.*, 2017) [14]. The low mean value for tourism-related land conversion implies that although tourism development exists in Kuttanad, its perceived threat to paddy land remains secondary to climatic and soil-related drivers.

Table 1: Descriptive statistics on the perceived severity of drivers influencing land-use and cropping pattern changes in the Kuttanad paddy wetlands (1=*Insignificant* to 5=*Severe*)

Statement	Mean (μ)	SD	Dominant category based on percentage of severity
The cultivation of paddy in single crop (puncha) is becoming more prevalent instead of double cropping (virippu-puncha)	3.58	1.61	Major-Severe
The reduced water retention capacity of paddy wetlands due to urbanization has increased flood risks.	3.30	1.19	Major
The decline in soil fertility due to excessive chemical use has reduced paddy yields over time.	4.45	0.72	Severe
The displacement of farming communities due to urban expansion has disrupted agricultural continuity.	2.58	1.06	Minor-Moderate
Labour shortages due to migration have increased dependence on hired mechanized farming services	3.02	1.23	Moderate
Perceived climate change and increased weather extremes have made paddy farming more uncertain.	4.64	0.48	Severe
Expanding tourism in wetland areas has shifted land use priorities, affecting farming livelihoods	1.62	0.69	Insignificant
The thrust for intensified production and "more crop per drop" strategies has led to over-extraction of groundwater resources.	4.57	0.65	Severe

Socio-economic factors influencing perceived LUC

The results of multiple linear regression model ($R^2 = 0.073$;

Adj. $R^2 = 0.024$) accounted for nearly 7.3 percent of the variation, indicating that land-use perception is largely

influenced by broader environmental processes rather than socio-economic factors. Among the predictors, income ($\beta = 0.162$, $p = 0.009$) and landholding area ($\beta = -0.123$, $p = 0.002$) were found to be significant. Higher-income farmers reported greater awareness of land-use change, possibly because of better information access and greater dependence on agricultural income. However, farmers with larger landholdings perceived lower intensity of land-use change, possibly due to the increased economic stability of larger

farms, which can better manage labour shortages or yield reductions, thus minimising the perceived impact. Other variables such as age, education, gender, and social participation showed no significant effect. Similar results were reported by Islam *et al.* (2023) ^[10] that small holders as well as high income farmers are more likely to perceive ecosystem deterioration, possibly due to dependence on intensive production systems.

Table 2: Multiple linear regression analysis showing the influence of socio-economic factors on the extent of LUC among Kuttanad farmers

Variable	Estimate (β)	Std. Error	t value	p-value
Intercept	2.862	0.497	5.757	0.000
Age	0.035	0.070	0.494	0.622
Gender	0.071	0.078	0.907	0.365
Education	0.012	0.030	0.406	0.685
Farm experience	-0.046	0.061	-0.748	0.456
Income	0.162**	0.062	2.625	0.009
Years of association	0.142	0.146	0.969	0.334
Social participation	-0.022	0.041	-0.540	0.590
Extension contact	0.074	0.077	0.965	0.336
Area	-0.123**	0.039	-3.127	0.002

** Significant at 0.01 level

Impact of LUC drivers on Ecosystem Services

The Spearman correlation results (Table 3) reveal that the LUC composite value had a significant positive relationship with regulating services ($r = 0.256$, $p = 0.001$) and supporting services ($r = 0.226$, $p = 0.002$). This implies that as perceived land-use change increases, farmers place higher value on ecological functions such as flood regulation, groundwater recharge, and soil fertility. The

correlation with provisioning services ($r = 0.089$) and cultural services ($r = -0.049$) was weak and not significant. These results agree with findings by Dai *et al.* (2024) ^[9] and Li *et al.* (2024) ^[21], who reported that intensifying land use enhances the recognition of ecological support functions, especially when provisioning outputs decline. Moreover, farmer value the regulating and supporting roles of wetlands more when they experience LUC in their ecosystem.

Table 3: Spearman's correlation between LUC composite values and different domains of ecosystem services in the Kuttanad paddy wetlands

Variable	Provisioning (PS)	Regulating (RS)	Cultural (CS)	Supporting (SS)
Correlation (r)	0.089	0.256**	-0.049	0.226**
p-value	0.237	0.001	0.515	0.002

** Significant at 0.01 level

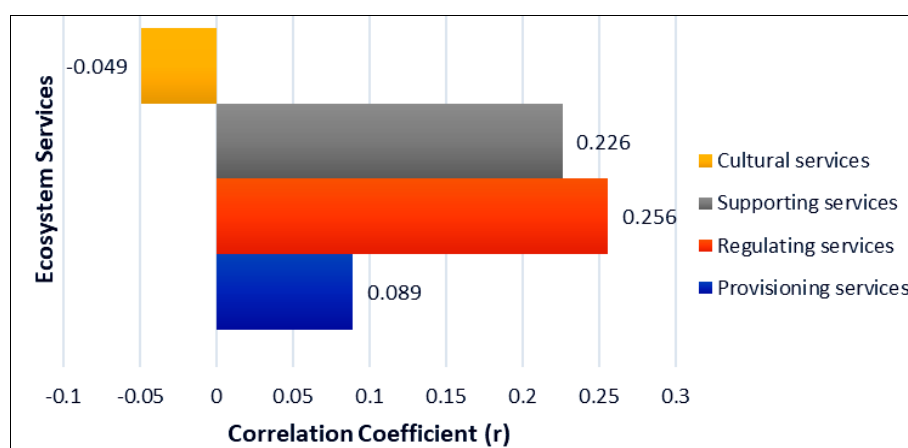


Fig 1: Spearman's correlation coefficients showing the relationship between LUC composite values and four domains of ecosystem services in the Kuttanad wetlands.

Spatial variation in the relationship between Land Use Changes (LUC) and Ecosystem Services

With a view to assess the regional differences in the relationship between LUC and perceived ecosystem service dimensions, district-wise Spearman's rank correlation

analyses were performed. The results highlight how local factors- such as flood proneness, intensity of land conversion, and management practices- shape stakeholder perceptions of ecosystem change.

Table 4: District-wise Spearman's correlation between LUC and ecosystem service domains in the Kuttanad paddy wetlands

District	Provisioning Services (PS)	Regulating Services (RS)	Cultural Services (CS)	Supporting Services (SS)
Kottayam	-0.238 (p= 0.067)	- 0.137(p=0.298)	-0.265*(p= 0.041)	-0.133(p= 0.312)
Alappuzha	0.200 (p= 0.126)	0.161 (p= 0.219)	0.181(p= 0.165)	0.122(p= 0.355)
Pathanamthitta	-0.043(p = 0.747)	0.309* (p= 0.016)	-0.202(p= 0.121)	0.144(p= 0.273)

* Significant at 0.05 level (two-tailed)

In Kottayam, a significant negative correlation was observed between LUC and cultural services ($r = -0.265$, $p < 0.05$), while relationships with other service dimensions were weak and statistically non-significant. This suggests that in areas of Kottayam where land conversions are prominent, communities perceive a decline in cultural and aesthetic values linked to traditional ways of farming. The region's transition from paddy land-based livelihoods to increased use of lands for construction purposes and plantations may have adversely affected the cultural identities and shared affiliation of the area, a trend similarly reported by Das *et al.* (2022) ^[23] in peri-urban landscapes undergoing agricultural decline.

In Alappuzha, all correlation coefficients were positive though statistically insignificant, indicating that land use changes were perceived to have a mild, non-harmful effect on all ecosystem service dimensions. This may be because, the region, also known as 'Venice of the East', has been heavily altered over times, by creating polders and interconnected canals for specific uses like farming and tourism, and this existing system of canals, bunds, and water control systems may help sustain environmental balance even when land use patterns shift slightly.

In Pathanamthitta, a significant positive correlation was found between LUC and regulating services ($r = 0.309$, $p < 0.05$), while the relationships with provisioning, supporting, and cultural services were weak. The sample panchayaths from Pathanamthitta namely Niranam and Peringara, being located in flood-prone lowlands, frequently experience

water inundation during the monsoon. Here, the continued threat of floods forces people to value and prioritize nature's flood defense services more highly, even while the land is changing. Respondents appeared to associate land use modifications - such as building embankments, improving drainage, or adjusting crop varieties - with better control over floods and direction of water flow. Hence, they seem to perceive LUC as an important factor influencing the ability of the environment to regulate natural processes.

Perceived impacts of LUC on Ecosystem Services in Kuttanad: Comparison between farmers reporting and not reporting LUC

A Mann-Whitney U test was used to compare ecosystem service perceptions between farmers reporting land-use change and those who did not (Table 5). Only supporting services showed a statistically significant difference ($p = 0.007$). Farmers who experienced land-use change reported higher mean supporting service scores (mean = 3.18) than those who did not (mean = 2.95). This suggests that exposure to land conversion and degradation enhances awareness of functions such as soil fertility, biodiversity, and water regulation. The result supports findings from Islam *et al.* (2023) ^[10], who reported that farmers exposed to ecological stress tend to value environmental support systems more. The non-significant differences for provisioning, regulating, and cultural services indicate that production-related and cultural perceptions are less sensitive to land-use change in the short term.

Table 5: Mann-Whitney U test comparing farmers' perceptions of ecosystem service domains between those reporting and not reporting LUC in the Kuttanad paddy wetlands

Ecosystem Service	U value	p-value	Mean (Yes)	Mean (No)	Significance
Provisioning (PS)	1733.0	0.751	2.65	2.65	NS
Regulating (RS)	1584.0	0.337	2.68	2.83	NS
Cultural (CS)	1407.0	0.085	2.21	2.43	NS
Supporting (SS)	1186.5	0.007	3.18	2.95	Significant

Conclusion

The Kuttanad paddy wetlands, a unique below-sea-level farming system in Kerala, are experiencing rapid ecological transformations due to changing land-use and cropping patterns. The findings of this study emphasize that environmental stressors such as declining soil fertility, groundwater depletion, and increasing climate variability as the key drivers of these changes. The gradual transition from traditional double-cropping systems (Virippu-Puncha) to single-season cultivation, along with the widespread conversion of paddy lands for non-agricultural purposes, has negatively affected the ecological equilibrium of the region. As these pressures intensify, farmers increasingly recognize the importance of regulating and supporting services offered by ecosystem, including flood regulation, soil fertility maintenance, and biodiversity conservation, which are imperative for sustaining both livelihoods and the wetland

ecosystem. The increased awareness among farmers who have directly experienced land-use change reflects an emerging realization of ecological degradation and the greater need to conserve wetland resources for long-term sustainability.

The study reinforces the necessity of policies that integrate land-use planning, wetland restoration, and farmer participation to sustain both productivity and ecosystem services in Kuttanad. Strengthening wetland governance through community-based land-use planning, effective enforcement of paddy and wetland conservation acts, and incentives for resource-efficient paddy cultivation are important steps toward preserving ecosystem integrity. Policies should also focus on promoting climate-resilient farming practices, water and soil conservation, and diversification of income sources to reduce the vulnerability of small and marginal farmers. Enhanced institutional

support through agricultural extension, capacity building, and payment mechanisms for ecosystem services can further empower farmers to adopt environmentally sustainable practices. A coordinated, multi-stakeholder approach involving farmers, policymakers, researchers, and local self-governments is essential to restore the ecological stability of Kuttanad while ensuring the socio-economic security of its wetland-dependent communities.

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