Design Engineering Security Implementation Using Penetration Testing

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Indigenous *Pokkali* farming in Kerala: A sustainable Social-Ecological Model

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Abstract

Indigenous farming systems (IFS) are considered as sustainable SES in the world. The IFS refers to a collection of agricultural activities that are grounded on indigenous knowledge, regularly performed in local communities to safeguard the environment and biodiversity, and are vital in ensuring long-term food security and human health (Sharma et al. 2020). The farming of pokkali in the state of Kerala, India, is a classic example of a sustainable social-ecological model. Pokkali farming is an indigenous, eco-friendly, agri-aqua combined cropping system, practiced across the coastal districts – Ernakulam, Alappuzha, and Thrissur - of Kerala which borders the Arabian Sea (Shamna and Vasantha 2017). Through the effective integration of the social, ecological, and economic factors, the pokkali farming system contributes to positive progress in the 2030 Sustainable Development Goals Agenda of the United Nations. The paper describes the social ecological aspects and the sustainabiltiy inplications of the indigenous pokkali cultivation practiced in the Indian state of Kerala

Keywords: Pokkali cultivation, Sustainable development, Indigenous farming system, Social-ecological model, Organic farming, Agri-aqua integration

Introduction

Indigenous Farming Systems (IFS) were developed by local communities in diverse agro-ecological and socio-cultural habitats towards ensuring food security and livelihood stability (FAO 2009). Amidst the growing commercialization in agriculture, indigenous farming practices have survived filling rural landscapes with diversified agrarian systems. In developing countries, 10-15 percent of the cultivated land is occupied by indigenous farming systems which contributes to 30-50 percent of domestic food production. Unique farming

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knowledge and practices are created by the indigenous farmers which are instrumental in adapting the cultivation methods according to the attributes of the local environment. This stands in opposition to modern mono-cultivation systems with unscientific land use and unwise application of agrochemicals resulting in degradation of the natural eco-systems. Indigenous agricultural systems can mitigate the anthropogenic risks on the ecosystem with ecologically sound and financially viable farming practices which contribute to agricultural productivity and sustainability (Mohan et al. 2021).

India's states have developed a varied spectrum of indigenous agriculture methods. Some of the prevalent indigenous farming systems practiced in the Northeast region of India include integrated paddy-fish farming and *jhum* cultivation in Arunachal Pradesh, *jhum* and *bun* farming in Meghalaya, rice-based farming in Tripura, organic farming, and terrace rice cultivation in the river valleys of Sikkim (Giri et al. 2020). Tree-based cultivation practices in central and southern Indian states such as Uttar Pradesh, West Bengal, and Karnataka, as well as animal husbandry, in Uttar Pradesh and Madhya Pradesh (Patel et al. 2020) are also examples of indigenous farming methods in India. The wetland environment is the foundation of the majority of India's indigenous farming practices, particularly in Kerala.

Kerala, which falls in the southernmost part of the country is a coastal state with a shoreline of 580 kilometers(Chandramohanan and Mohanan, 2011). The state of Kerala has about 217 wetland areas, making up a significant percentage of the state's overall land area. The district of Ernakulam contains the largest area of wetlands accounting for 20.26% of the state's total wetlands, followed by Alappuzha (15.8%) and Thrissur (12.99%). The Vembanad – Kole, Ashtamudi, and Sasthamcotta lakes, which are classified in the Ramsar index, are among Kerala's wetlands of international and national significance. The Vembanad Wetlands, with an area of 1521.5 km2 and a volume of 0.55 km3, is the state's largest water body, covering Alappuzha, Kottayam, Ernakulam, and Thrissur districts. This vast hydrological system is made up of coastal lakes, streams, reeds, and mangroves. Most of the indigenous agricultural systems of Kerala are located in proximity of these water bodies (Kokkal et al. 2008).

In Kerala, paddy growing using integrated farming techniques is a common practice (Vijayan, 2016). The majority of Kerala's paddy is grown in coastal marshes and low-lying places like Kuttanad. Low-lying paddy agriculture accounts for thirty-seven percent of the state's total rice production (Chandramohanan and Mohanan, 2011). The coastal intertidal wetlands in Kerala fall among the world's most productive ecosystems and are known for their rich biodiversity (KC et al. 2019). The method of indigenous paddy-shrimp integrated production is exclusively found in the salinity-prone wetlands of the coastal regions of Ernakulam, Alappuzha, Thrissur, and Kannur districts in Kerala and is locally known as "*pokkali/ kaipad/ kaikandam* agriculture" (Nambiar and Raveendran, 2009). Eighty-four percent of the area under indigenous farming systems in Kerala is occupied with *pokkali* fields (Sudhan et al. 2016). These farming systems follow organic methods and hence need only very little external input. In natural field conditions, paddy/shrimp production is generally resistant to pests and diseases and ensures local livelihood and food security. The sustainability of this production system is ensured by the compatibility of various social and ecological factors, stable harvests, desirable soil bio-hydrological conditions, and economic benefits (Sasidharan et al. 2012).

Origin and history of *pokkali* farming in Kerala

Indigenous paddy and shrimp farming culture was largely practiced in Kerala, in a total area of 25000 hectares (Shyna and Joseph, 2000). *Pokkali* refers to an indigenous salt-resistant paddy variety cultivated in Kerala for the last 3000 years. Currently, it is a certified organic product. The term '*pokkali'* is a combination of two Malayalam words: "*pokkathil*', which means tall, and '*aali',* which implies plentiful growth (Sudhan et al. 2016). According to history, until the fourteenth century, this indigenous paddy type flourished exclusively in the peak areas of the Western Ghats in Kerala's Idukki region. The paddy variety is said to have reached the districts of Thrissur, Ernakulam, and Alleppey during a large flood (Shaji, 2021). Another narrative on *pokkali* paddy is that the Konkani-speaking *Kudumbi* community brought the grain with them when they relocated from Goa to Kerala. *Pokkali* is also grown in Sri Lanka which could have come to the island through Buddhist missionaries. The narratives surrounding *pokkali* are intertwined with the tales of migrations that happened in Kerala (A, 2016). Gradually the rice has become a part of the State's heritage and tradition (KC et al. 2019). The map depicting *pokkali* farming districts in Kerala is given in Figure 1. The area coloured in blue on the map of India represents the physical location of Kerala state, whereas the areas shaded in yellow on the map of Kerala indicate the state's pokkali cultivating districts.

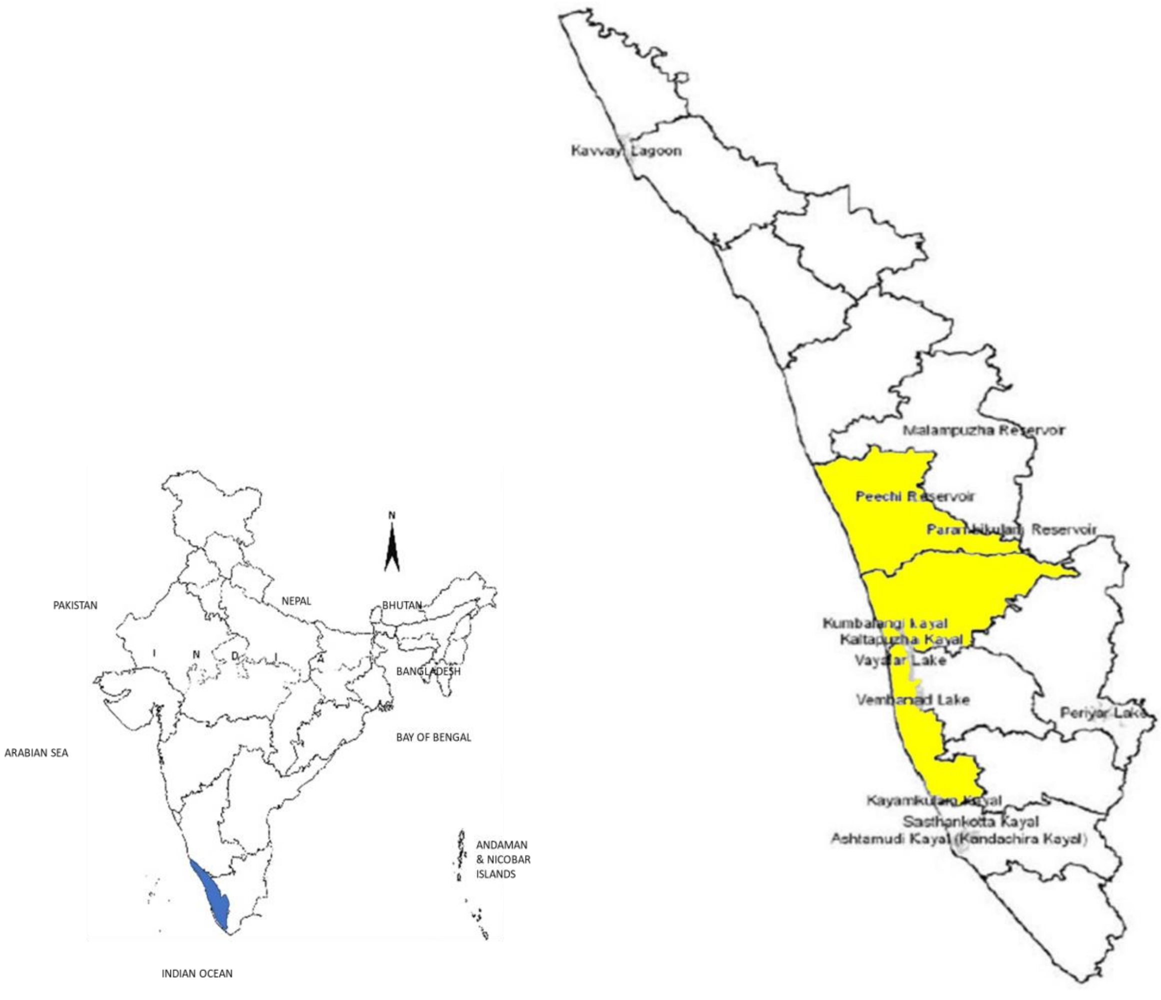

Figure 1. ***Pokkali*** **Cultivating Districts in Kerala (*Source: National Wetland Atlas: Kerala, Government of India, 2010)***

Social-Ecological System dynamics in *pokkali* farming

The *pokkali* wetlands' social and ecological structures operate together to provide a variety of ecosystem services such as habitat provision, seed banks, and nutrient cycling as well as social and recreational opportunities such as farming, fishing, and cattle rearing. Indigenous agroecosystems are often seen as an alternative route to sustainable rural development (Giraldo, 2019) for which the *pokkali* system is a classic example. Though an ideal social-ecological model, *pokkali* farming system is undergoing massive changes in its social and ecological features due to paradigmatic shifts in development policies and practices concerning environmental governance. Wetlands across the globe, including indigenous farming systems like *pokkali*, are subjected to multiple stakeholder conflicts in terms of property ownership and access which may result in adverse consequences for both social and ecosystem health. Because wetland circumstances and social-ecological dynamics are frequently re-engineered to adapt for changes in both technology and societal preferences, wetland conditions and social-ecological dynamics change quickly and clearly (Taylor, 2018). Wetlands are an ideal setting for studying the long-term reworking of society-nature relationships in a region. The conflicting power-relations in indigenous farming systems which engage multiple stakeholders is a reality that demands continuous monitoring and intervention mechanisms. Exploring *pokkali* wetlands through a political-ecological lens sheds light on the dynamics of environmental governance inherent in them, long-term effects of social and environmental shifts, and policy interventions on demand by the system.

Pokkali farming systems – Techniques and strategies

Pokkali cultivation is a comprehensive agricultural practice that promotes the quality of agro-ecosystems, including soil activity and biological diversity. Instead of synthetic components, agronomic, biological, and mechanical approaches are used to satisfy any specific function inside the system. Techniques and strategies utilized to scientifically manage *pokkali* farming system are described in the following sections.

Agri-Aqua integration

Integrated agri-aqua farming is a multi-land use method in food production that incorporates shrimp/fish culture along with other agricultural production systems. The symbiotic nature of paddy and shrimp/fish cultivation is the crux of *pokkali* farming technique (Suchitra and Venugopal 2005; Sreelatha and Shylaraj, 2017). *Pokkali* wetlands lie in coastal belt hence are vulnerable to consistent flooding and saline intrusion. This geographical peculiarity is used to facilitate cultivation practice in *pokkali* farming system. Different varieties of *pokkali* paddy used by native farmers include '*Chettivirippu*', '*Vyttila 1*', and '*Vyttila 2*' (Vijayan 2016). *Pokkali* paddy grows to a height of 4.5 to 6 feet and can keep its grain-bearing head upright above water for up to 10 days during high tide or river flooding, while the plant itself bends over and falls (Manipadma 2017). During the low-saline phase, paddy cultivation is conducted in the *pokkali* tracts, which is substituted with shrimp farming during high-saline phase. Another key element of this farming method is the natural recycling of waste materials (Shaju et al. 2014). For example, the biomass deposits of the paddy crop form the feed base for shrimp and excreta of shrimp/ fish act as fertilizer for paddy. Hence this symbiotic system can be denoted as a "Zero Input" organic farming system (Antony Kuriakose, 2015).

Pokkali farming enhances land-use efficiency while reducing soil degradation. The soil of *pokkali* wetlands is clay-textured with a high water-holding capacity and acidity making the area generally unfit for paddy farming. However, the *pokkali* paddy, which is saline-flood-acidity resistant to a good extent, is suitable for the properties of soil. The unique attribute of this land is that it produces excellent yields in the absence of chemical pesticides or fertilizers (Ranjith, et al. 2018). *Pokkali* paddy has adapted to resist soil acidity and submergence, making it ideal for climate-adaptive agriculture. *Pokkali* paddy's salt tolerance gene, SalTol QTL, could be significant to international rice improvement projects that focus on salinity tolerance. Paddy can also act as a natural biofiltration system, improving the water and soil quality, reducing the danger of disease outbreaks in shrimp or fish crops (30% less risk compared to mono-shrimp) (KC et al. 2019). *Pokkali* lands are also used for cattle grazing, duck rearing, and as a habitat for several organisms (Antony, 2017).

Water management

The integrated paddy/shrimp farming system employed in *pokkali* field depends profoundly on proper water management. Since the fields are mostly below sea level, water is drawn by gravity flow from the neighboring canal system and used for irrigation (Suchitra and Venugopal, 2005). To reduce risk of flash floods and preserve soil and agricultural health, '*thoompu*', or sluice gates, are used. After passing through a feeder canal, the saltwater arrives into the fields during cultivation. The sluice gate attached about thirty centimeters from the field area facilitates transport of water into the ground. In the course of high flows, water is pumped into the fields and then it is sieved across velon nets and split bamboo traps to remove the crop-destroying species such as fish, shrimp, and carnivores (Joy, 2019). Another sluice opening is operated during low tides to divert water from the culture area to the feeder channel for exchange, desalination, and discharge of water. Wooden shutters are installed on the sluice gate's entry and exit mouths to control the water flow (Shyna and Joseph, 2000). The *Thanneermukkom* saltwater barrier also keeps brackish water out, making paddy cultivation easier in the post-monsoon season. The fields are permitted to have a free exchange of water throughout the transient period (Shaju et al. 2014).

Organic weed and pest management

Since *pokkali* cultivation is a type of organic agriculture, the fields are home to a variety of aquatic and semi-aquatic pests and weeds (Sreelatha and Shylaraj, 2017). Three pests *Thanduthurappanpuzhu (Scirpophaga incertulas)*, *Chazhi (Mupli beetle)*, and *Ela churuttipuzhu (Cnaphalocrocis medinalis)* cause around 20 to 25% damage to the crops (Joy, 2019). Paddy cultivation in *pokkali* fields is hampered by weeds also. Fourteen aquatic weed species were discovered in *pokkali* fields (Deepa, 2014) in which the floating migratory weeds such as water hyacinth *(Eichornia crassippes)*, water moss *(Salvinia auriculata)*, and more recently, duckweeds *(Lemna minor)* cause severe disturbance to *pokkali* cultivation. Unwanted plants and weeds are removed either before or after the seedlings are transplanted. Weed removal is performed only once during the cultivation process, and it is mostly done by female labourers (Vijayan, 2016). Weed control is also accomplished by raising water levels and allowing free flow of brackish water into and out of the field. These weeds, as well as the flora and fauna, decay and contribute to soil fertility during high salinity phase. A non-native seasonal bird known as *Nelli kozhi (Purple moorhen*) seen in *pokkali* fields from January to September, causes crop damage to *pokkali* fields (Sreelatha and Shylaraj, 2017). Long strings attached to empty polyethylene bags are kept around the field to keep birds away (Joy, 2019). These bags flutter in wind, making a noise that scares away birds. Bird scares are also used to keep the crop safe from predators. However, since the pest and disease occurrence in these fields is below the threshold level, only a small amount of organic manuring or plant defense is used. Chemicals are not used in these fields due to the potential harm they can cause to paddy and shrimp (Antony 2015). The low frequency of pests and illnesses can also be attributed to the presence of natural enemies and predators.

Application of indigenous knowledge

The indigenous wisdom associated with *pokkali* cultivation contributes significantly to the food security and ecological protection of agro zones. The soil classification system adopted by *pokkali* farmers contributes to the prevention of soil erosion and improvement of land quality and nutrient recycling in *pokkali* fields. This method has evolved from the indigenous knowledge base of the local farmers. The indigenous method of regulating flow of water via sluice gates helps for effective water management in the *pokkali* tracts. The efficient management of natural resources and planned allocation of skilled human labour in the *pokkali* fields lead to local environmental conservation and rural poverty alleviation (Manipadma 2017). In the long run, the application of the indigenous knowledge base of the community in the agricultural systems results in climate change mitigation and control of natural disasters (Joshy, 2018).

Institutional management in *pokkali* cultivation

The Department of Agriculture of the Government of Kerala had launched the *padasekharam* (polder) strategy in the 1980s, to improve paddy output through joint administration of farming methods and community participation. '*Padashekharam'* refers to the collection of several small fields into a viable field, to conduct farming. Dewatering, bund construction, and decision-making are all carried out in each *Padasekharam* under the supervision of a *Padasekharam committee* set up by the farmers. Farmers, on the other hand, are responsible for the actual planting here (Srinath et al. 2000). The cost-effective use of agricultural machinery for tillage, transplanting, harvesting, and threshing is made possible by the community farming system of cultivation used in *pokkali* lands. The fields, on the other hand, are almost always susceptible to flooding. As a result, indigenous pumps are used to dewater the fields into nearby water canals (Joy, 2019). Each "*Paadasekharam*" has one to six similar pumps to handle the levels of water throughout the cultivation process.

Following paddy harvest, the fields are leased to shrimp farmers for five months beginning in November and ending in mid-April, the following year. To get a license for shrimp cultivation, the people have to register with the Kerala Government's Department of Fisheries. The tenure of the lease depends upon the productivity of the fields, location, and vicinity of the water sources. The head of the group who brings agricultural labourers for farming practice takes the shrimp or fish caught in the sluice gate, as labour fee. During the six months, the aquaculture is on a profitmaking basis and the workers can catch the fish only at the expiration of the tenure period (Antony 2015).

The government provides many assistance programs for *pokkali* farmers. Since the cultivation of *pokkali* is fully reliant on monsoons and tidal fluctuations, changes in rainfall and climatic conditions would have an impact on the crop, and a bad monsoon will result in crop failure. In these circumstances, the government provides subsidies, crop failure compensation, etc for supporting the farmers. The "*Pokkali* Land Development Agency (PLDA)" was established by the government in 1996 to promote paddy farming in *pokkali* wetlands. To encourage community engagement, the local government, in partnership with "*Pokkali* Land Development Authority (PLDA)", is designing plans to promote the traditional, organic form of paddy production in the district. The Central Marine Fisheries Research Institute's "*Krishi Vigyan Kendra"* (Ernakulam) has introduced machinery appropriate for *pokkali* wetlands and provides training to women through a partnership with *Kudumbashree* programme (ibid). Cooperative societies serve the agricultural and allied sectors in the most productive way possible by offering sufficient, low-cost, and timely inputs and credit (Joy, 2019). A group of farmers and activists from Ernakulam and Alappuzha districts have joined together to revive *pokkali* farming fields under the banner of "*pokkali* S*amrakshana Samithi"* (*pokkali* conservation agitation committee). The PSS takes uncultivated *pokkali* lands for lease and conducts farming by making finance through informal '*pokkali* bonds' (Antony 2015).

The social relevance of *pokkali* farming

Wetlands are referred to as "biological supermarkets" on occasion. Wetlands provide a variety of benefits to society, including rural livelihood, food security, water security, and recreational activities. The different societal values of the *pokkali* farming system are listed below.

Rural Livelihood

The *pokkali* wetlands in Kerala act as a direct and indirect source of livelihood for the local community. Farming, fishing, tourism, coir retting, shrimp/ crab farming, and cattle fodder collection are major livelihood activities related to *pokkali* wetlands (Ranga, 2006). The method of alternate harvesting paddy and shrimp provides farmers with consistent labour and money throughout the year. *Pokkali* farming requires 207 human labour-days per hectare, with 84 men and 123 women contributing to the labour force. Seasonal labour requirements for shrimp farming are projected to be 246 per hectare, with 181 men and 65 women forming the labour force (Shyna and Joseph, 2000). Since women with traditional farming skills are the primary agricultural labourers in *pokkali* fields, the farming method promotes women's empowerment in the area by allowing them to be financially self-sufficient (Antony, 2017). The tourist industry is recent to this area, but it has provided job possibilities for residents and also acts as a significant source of money for the state (Rajan et al. 2008).

Food Security

Pokkali cultivation is both a concept and farming practice aimed at producing food that is healthy and free of contaminants that could affect human health. *Pokkali* fields are the primary source of nutrition to which the rural communities have access. The unique pattern of production ensures availability of *pokkali* rice and fish for the natives (Antony, 2017). The *'kanji'* (rice gruel) prepared from *pokkali* rice is quite popular among the residents of this region. *Pokkali* rice is well-known for its flavour and is found in rice flour, rice bran, rice flakes, and a variety of local breakfast items. The medicinal value of *pokkali* rice is scientifically proven in a study undertaken at the Rice Research Station in Ernakulam. The study revealed that the *pokkali* varieties are very rich in antioxidants like *oryzanol, tocopherol*, and *tocotrienol* (Sreelatha and Shylaraj, 2017). These levels are significantly greater than those seen in *njavara*, a popular variety of medicinal rice available in Kerala. Since *pokkali* rice is high in amylase, it is suitable for diabetic patients too.

The availability of fish/shrimp varieties from the *pokkali* fields provides the local community with sufficient food sources as well as a variety of by-products. In these fields, high-value shrimp species like *naran (Penaeus indicus) and kara chemmen (Penaeus monodon), poovalan*, or *thelly (Metapenaeus dobsoni), choodan (Metapenaeus monocero)* are numerous (Ranga, 2006). The main fish varieties found in *pokkali* wetlands are *kolaan (Hyporhamphus limbatus), manja para (Caranx carangus), mangrove jack (Lutjanus argentimaculatus), nachara (Scatophagus argus), kanambu (Mugil cephalus)*, and *milkfish (Chanos chanos)* (Deepa, 2014). In the same land, several *pokkali* farmers grow tiger shrimp and crabs alongside native shrimp types (Ranjith, et al. 2018), all of which contribute to the local food security in the region.

The economic value of *pokkali* cultivation

By producing resources, facilitating recreational activities, and offering several additional services such as pollution management and flood protection, the *pokkali* farming system delivers a substantial contribution to the local and national economies. Integrated paddy-shrimp farming is a highly cost-effective technique in farming. According to the studies, the net return for *pokkali* paddy farming alone is Rs 62,864 (712 €) per hectare. However, it is compensated by farming shrimp in the following season, which yields a net return of roughly Rs. 3,43,879 (3782€) for one hectare of shrimp. The overall cost of cultivation for the complete production process is Rs. 2,39,505 (2634€), with a gross profit of Rs. 5,20,521 (5725€) (Karunakaran et al. 2019). Another study conducted in the Eranakulam district in 2019 found that the rotational production of *pokkali* rice-shrimp generates a net income of Rs 5.21 lakhs (5889.40 €) per year. Though paddy causes a loss of around Rs. 63000 (712.15€) in this system, it is counterbalanced by Shrimp culture. Subsequently, the integrated cultivation generates a gross return of 2.81 (3176.43€) lakhs per year with an input-output ratio of 2.17, signifying that for every rupee invested in the system, a gross return of Rs. 1.17 could be reached, indicating the system's economic possibilities (Ranjith, et al. 2018).

In addition, indigenous paddy-shrimp farming generated 20 percent more net revenue than conventional paddy production. On a larger scale, intensive management with time-bound care could increase the profit from the system. The *pokkali* paddy varieties VTL-3, VTL-4, and VTL-5 have been discovered to have a yield potential of 3500 kg/Ha to 4000 kg /Ha (Joy, 2019), resulting in a greater economic output. Being a 100 percent organic product, there is plenty of room in the national and worldwide markets for *pokkali* rice and other value-added products. *Pokkali* rice is processed into value-added products, such as rice powder, which is utilized in a variety of regional dishes. The *pokkali* rice and shrimp have significant export opportunities in global markets, which could lead to a higher income generation (Srinath et al. 2000). The *pokkali* farming model is beneficial to tourism business as well (Priyadershini, 2020). The Blue Yonder, for example, is a socially responsible tourism programme that collaborates with local farmers to promote *pokkali* regions as tourist destinations for those interested in learning about the unique agriculture, thereby providing a substantial source of revenue (Shaji, 2021)

Ecological relevance of *pokkali* fields

Pokkali wetlands are part of the Vembanad *Kole* wetlands, India's largest tropical estuary, which has been designated as a Ramsar site. *Pokkali* wetlands are multi-functional habitats that sustain a diverse range of biodiversity and hydrology. The key ecological services provided by *pokkali* farming system are detailed in the following paragraphs.

Water security and flood control

The *pokkali* wetlands play a crucial role in ensuring water security in the coastal districts of Central Kerala (Shaji, 2021). Indigenous *pokkali* farmers have created numerous water gathering structures and sources to ensure water availability in the tracts and domestic uses. Further, *pokkali* wetlands are surrounded by freshwater sources like Periyar, Muvattupuzha river, and Chalakudy rivers and backwater bodies like Kodungallor *Kaya*l, Varapuzha *Kayal,* and Vembanad *Kayal.* All through the monsoon season, these rivers overflow, causing severe flooding in low-lying regions along the banks (Antony 2015). By retaining a considerable amount of water, *pokkali* wetlands prevent flooding and waterlogging. Similarly, during storms and when water levels are high, these fields hold water which they slowly discharge when the water table is low. In this sense, *pokkali* wetlands prevent flooding/waterlogging and have an impact on ground-surface water recharge and discharge (Rajan, et al. 2008).

Pokkali wetlands also improve the water quality of nearby rivers and streams, acting as water filters. When water hits a wetland, it slows down and travels around wetland vegetation (Joy, 2019). Huge amounts of suspended debris sink to the bottom of the wetland. Excess nutrients in the water from fertilizers, manures, leaking septic tanks, and municipal sewage which can induce algal development and are hazardous to aquatic life, are absorbed by plant roots and microorganisms on a plant stem, and the soil in the fields (Abraham, 2004). Cropping in *pokkali* fields is also important because it allows precipitation to penetrate the subsoil (Priyadershini, 2020). The proximity of several freshwater sources also lowers the salinity level in *pokkali* fields.

Biodiversity

By sustaining a large concentration of aquatic fauna, mammals, native and migratory bird species, permanent resident amphibians, reptiles, and extra insect species, the *pokkali* wetlands help to preserve biodiversity. These fields are a viable environment with species diversity due to the shifting physico-chemical parameters of water. The *pokkali* wetland region preserves a total of 77 species of terrestrial plants, about 50 different fish species, and 119 species of birds (Mumthaz & john 2017). A critically endangered fish species, *Ham-Buch (Pisodonophis boro*), has been discovered in the *pokkali* wetland habitat. Three endemic species namely *sun Catfish (Horabagrus brachysoma), Malabar pufferfish (Tetraodon travancoricus), and Oolari (Amblypharyngodon melettinus),* and five exotic species namely *Gambezi (Gambusia affinis), Catla (Catla Catla), Common carp (Cyprinus carpio), Tilapia (Oreochromis mossambicus),* and *Rohu (Labeo rohita)* were recorded from the wetlands (Deepa 2014). *Purple Moorhen* uses mangrove allies found in these wetlands as significant nesting material. The mangrove roots provide cover, breeding grounds, and nurseries for a variety of fish and shellfish.

Climate adaptability

Methods that bind the potential of the environment to bring adaptation assistance are broadly known as ecosystem-based adaptation (Bourne et al. 2016). An indigenous farming system is widely considered as an ecosystem-based adaptive strategy towards addressing climate change. The paddy-shrimp farming in *pokkali* fields reduces the environmental impact of farming. This cultivation differs greatly from conventional paddy farming. Unlike the conventional paddy system, the water gets tide-fed into and out of the fields at high and low tides. The continuous water exchange during the production cycle retains adequate oxygen in the fields and maintains an oxidized state rather than a reduced state thereby contributing to an adverse condition for methane production, as it happens in typical wetland paddy environments. Hence methane gas emissions from *pokkali* fields are less, reducing the contribution of Green House Gas emissions from the region (Ranjith et al. 2018).

The saline tolerance capacity makes *pokkali*, a climate-savvy system during floods too. According to studies, the *Pokkali* rice plant can resist salinity levels of 6 to 8 grams of salt per 1,000 grams of water (Manipadma, 2017). The researchers from the International Rice Research Institute are actively working on producing new paddy varieties from the climate-adaptive *Pokkali* seeds for extending the cultivation across India's coastal districts (Thomas, 2019).

Evolving challenges to *pokkali* farming system

Wetlands are disappearing at alarming rates around the world, despite the valuable ecological services and products they provide due to several anthropogenic activities. The growing risks of environmental change have made wetlands more vulnerable, worsening the living conditions of people who depend on these wetlands. Currently, the *pokkali* wetlands are at various tipping points, which refers to a situation in which an ecosystem gradually shifts to a new state over a period of time (Prusty et al. 2017). The major challenges to *pokkali* farming system include alienation of land for commercial and infrastructure development, real estate development, pollution from industries, waste dumping and reclamation of wetlands, and a shift towards shrimp monoculture (Sudhan et al. 2016).

Since the 1960s, *pokkali* farming has been steadily declining in the State. According to the *Pokkali* Land Development Agency, the total area under *pokkali* cultivation had shrunk from 25000 Ha (Sreelatha and Shylaraj, 2017), a few decades back, to a mere 8500 Ha. Of this, only 5500 Ha are being used currently for farming. *Pokkali* paddy farming field covers 574 hectares in Thrissur, 1371 hectares in Alappuzha, and 3555 hectares in Ernakulam districts, respectively (Antony 2015). *Pokkali* fields are being converted for infrastructure development which includes roads, bridges, residential areas, or commercial activities (Vijayan, 2016). The real estate boom has resulted in the reclamation and drainage of vast tracts of *pokkali* lands in the region.

Development often necessitates relocation while also jeopardizing environmental quality (Joy, 2013). The Vallarpadam Container Transshipment Terminal and the auxiliary road and rail projects in Ernakulam have also irreversibly harmed the *pokkali* farming system in the region. As a result of this project, vast areas of *pokkali* lands underwent reclamation and conversion. Unscientific road planning, dumping of construction wastes, reclamation for rehabilitation, and real estate development contribute to wetland conversion in a short period (Chitra, 2013). A considerable number of families who are dependent on *pokkali* fields for their livelihood were also got displaced (Joy, 2019).

The majority of the *pokkali* tracts, which are close to the Vembanad backwaters, are heavily contaminated by indiscriminate effluent discharge from industries. For example, studies reveal that the Vembanad Lake, which is located along the Periyar River's Eloor-Edayar industrial belt, is a dumping ground for heavy metals such as arsenic, cobalt, cadmium, mercury, nickel, and others (Joshy, 2018). Also, explicit and covert dumping of solid wastes, unscientific and indiscriminate application of agrochemicals, and oil discharge from overboard engines of vessels have all aggravated the degradation of *pokkali* wetlands. Pesticides are sprayed by the contractors in shrimp farms on the day of harvesting to ensure stunning of shrimp to increase their catch (Prusty et al. 2017). This makes *in-situ* conservation of salinity-tolerant indigenous paddy varieties and cultivation practices difficult. In recent years, the large net returns from Monoaqua-cultivation in pokkali lands have gained appeal, but in the long run, it is destructive to the area's social-ecological system. Due to the conflict of interest between rice farmers and the aquaculture lobby, unproductive measures have been implemented. To prepare the fields, salty water must be pumped out, but breaches in the outer bunds occasionally occur, sparking concerns of sabotage (Pillai, 2016).

Labour scarcity in *pokkali* fields has evolved as a major issue over the years. In a 2019 study among150 *pokkali* farmers in Ernakulam district, 85 percent of the farmers said that the lack of farm labour was the most significant barrier to the farming system's continuation (Ranjith et al.2018). The availability of alternative employment opportunities and high earnings in the nearby urban areas attract people more to it. Another factor for the workforce scarcity in the region is the local youth's predilection for white-collar occupation. The youth workforce is deterred from farming by non-agricultural employment options and the possibility of labour migration to other areas of the state, country, and abroad. Furthermore, other crops such as rubber, banana, coconut, cocoa, and others have proven to be less labour-intensive and yield larger earnings than *pokkali* which also resulted in the decline of the farming system (Ranga, 2006). The conversion of *pokkali* paddy fields ultimately resulted in the loss of employment of female labourers who are traditional farmhands (Shyna and Joseph, 2000).

Conclusion

Kerala's traditional *pokkali* agricultural system is a highly sustainable farming approach. The different strategies and techniques employed in this cultivation contribute to the area's and stakeholders' environmental, social, and economic well-being. However, the socio-ecological significance of this farming system is still unidentified. Countless anthropogenic interventions and natural disasters lead to the decline of this sustainable cultivation system. Strong policy measures and comprehensive research are necessary to conserve the *pokkali* cultivation and achieving the SDGs through it.

Economic, institutional, social, and environmental sustainability are four equally essential components of sustainable development. Hence a development intervention strategy that is inclusive of all forms of sustainability is mandatory. The indigenous *pokkali* cultivation method is a model for long-term sustainability in socio-cultural, economic, and ecological realms. The *pokkali* farming system which generates local livelihood lowers input costs for small farmers, and raises income by offering premium prices for goods, is a key anti-poverty strategy, ensuring the attainment of United Nations SDG1; poverty alleviation. Similarly, effective implementation of agri-aqua integration in farming can ensure water and food security for the local community in the region which in turn, supports to ensure food security and nutrition implied in SDG 2. SDG 5 will not be met unless women empowerment and gender equality are ensured. This is ensured by the farming system, which employs women as the main agricultural labourers (Rajan et al. 2008).

The *pokkali* farming system performs functions such as soil fertility protection, carbon dioxide storage, fossil fuel reduction, water conservation, flood control, landscape, and biodiversity preservation, etc which contribute to environmental sustainability and climate change reduction. By following an organic model of agriculture based on ecological cycles and natural resources, the farming approach decreases the environmental impact of food production while keeping non-renewable resources to a minimum (Sasidharan et al. 2012). These characteristics help to accomplish SDGs 6, 7, and 8, which are sustainable water resource management, affordable, sustainable, and modern energy, and inclusive and sustainable economic growth, respectively. The high export potential of *pokkali* farming products aids in the inflow of foreign currency into the country, resulting in reduced inequality in the country and the realization of SDG 10 (Karunakaran et al. 2019). The rotational farming strategy used in *pokkali* fields allows waste material recycling without hurting the environment or water while also renewing soil life for long-term usage. These qualities underscore the relevance of *pokkali* farming in accomplishing SDGs 12, 13, and 14. SDG 15 is concerned with the preservation of land life. *Pokkali* wetlands are vital to the survival of life on Earth because of the incredible variety and environmental services they provide. As a result, wetland conservation initiatives help to achieve SDG 15 in a holistic way (Ranga, 2006).

In this context, effective policy formation is critical to safeguarding the *pokkali* socio-ecological system. In addition to the social and ecological relevance to local development, the conservation of the *pokkali* farming system which falls in Vembanad wetlands, a Ramsar site, is significant to international and national wetland conservation and development. Interventions for the protection of indigenous farming systems entail a process of ongoing communication with policymakers at various levels, from local self-government to central government. Inherent conflicts in *pokkali* farming system which involves land ownership, seasonality in farming, water management for paddy and shrimp, marketing, and labour issues need to be addressed through grassroots level institutional strengthening and proactive interventions from state actors in the sectors of wetland conservation, water resources development, agriculture, and fisheries development.

A detailed inventory of wetland systems including *pokkali* lands needs to be developed towards ensuring wetland conservation in the state. Since the situation necessitates a bottom-up strategy for development, the state's ecologically sustainable "post-growth" development must be monitored through the strengthening of traditional communities or resource-dependent people and their indigenous knowledge systems. Farmers and local people should be made aware of the importance of preserving the ecological uniqueness of *pokkali* wetlands for mitigating the risks of climate change and consequent disasters. It is also critical to conduct periodic research covering indigenous farming practices, community livelihoods, local biodiversity, traditional water conservation practices, and developmental dilemmas in the region through interdisciplinary teams and participatory processes to produce practice-based evidence that can inform state policy. *Pokkali* farming system has proven itself to be an ideal social-ecological model ensuring socio-economic and ecological sustainability, but at present, stands affected due to the absence of participatory and environment-sensitive decision making in mainstream development processes. Facilitating the emergence of a strong environmental governance mechanism, which critically acknowledges the dynamic social and ecological exchanges in an indigenous farming system, and which attempts to translate the knowledge to policy and practice, can effectively redesign development practices towards the sustainability of *pokkali* farming.

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