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Spatio-Temporal Evaluation of Landscape Dynamics in Agro-Ecological Landscape: A Case Study of Onattukara Agro-Ecological Zone, Kerala, India

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ABSTRACT

The modifications in agricultural landscapes by various factors greatly impact the alteration of environmental equilibrium, and a critical assessment is needed to maintain landscape sustainability. The man started innovating farm practices to achieve greater productivity in a shorter period without any concern about future catastrophes. Many landscape indices were developed from 1980 onwards. Their application was eased importantly by the visual aspect and popularity of GIS software and the comparatively low-cost availability of aerial photos and satellite images. Geographically speaking, GIS has played a major part in articulating landscape evaluation using landscape metrics. Landscape metrics help in computing composition and configuration; the two main features of landscape structure. The evolution of computer programs like Fragstats, patch analyst and various plugins in GIS software gave a new face to landscape quantification and change detection analysis. The present study examined the spatiotemporal dynamics of the agricultural landscape in the Onattukara Agro-ecological Zone from 1988 to 2021 employing a set of metrics parameters that are associated closely with agricultural landscape sustainability. Onattukara forms a unique agroecological landscape sprawling over the taluks of Karunagapally in the Kollam district and Karthikappally and Mavelikkara in the Alappuzha districts of Kerala, India. This region is predominantly a sandy tract; famous for the cultivation and production of good-quality sesamum and rice. Now the region become an area of low productivity with many negative factors limiting production. This study established the strong association between agricultural landscape transformation and urbanization using landscape metrics as a major tool.

Keywords Agricultural landscapes, GIS, landscape dynamics, Onattukara AEZ, Sustainability.

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INTRODUCTION

The concept of landscapes represents a relatively new approach that has profound significance in the current urbanization scenario. Landscapes refer to the divide between nature and society which conveys a close interaction of physical features of the human environment with social structures and human thoughts (Selman 2012, Plieninger *et al.* 2015). Landscape metrics are used to explore the landscape structure and the diversity of landscapes and to infer the ecologic routines of the landscape. Using the different indices, we can determine the shape, spatial form of the patches, situation, isolation, and connectivity of the patch types.

The agricultural landscape is the result of interactions between the natural setting in an area and farming activities agricultural landscapes are constituted of three elements: Structure, functions and values. The structure deals with the interaction between man-made objects, landuse patterns and environmental characteristics. Function means the supply of environmental services for society and farmers. The values refer to the economic value that society invests in the agricultural landscapes and the price of preserving the landscape planning by agriculture. Since the natural processes and human activities change over time, the agricultural landscapes are dynamic (Food and Agriculture Organization 2013).

Landscape dynamics refers to every modification that occurs in the basic perceptions of a landscape. Day by day the structure and composition of landscapes are getting altered by different factors which in turn changes the equilibrium state. Landscape metrics tools can be used to easily understand the Spatio-temporal modifications that occurred in a particular landscape. To encompass the composition and configuration of landscape with landscape metrics, different approaches are available.

Remote sensing and Geographic Information Systems have been acknowledged as potent and effectual tools for finding the spatio-temporal dynamics of landscape alterations at several scales (Su *et al* 2011). Landscape metrics are considered an efficient tool to evaluate the transformation of an agricultural landscape.

The agricultural scenario of the Onattukara agricultural landscape is now deteriorating due to agents that induce urbanization. This fertile agricultural zone is now on the verge of collapse. The area under cultivation of both wet and dry land has drastically reduced. Paddy land is kept fallow due to a lack of infrastructural facilities, labor problems, and uncertainty of climatic conditions. The cultivation of other crops like sesamum, vegetables, pulses, tapioca, coconut, and other intercrops is gradually on the decline. Lack of drainage and irrigation facilities, salinity, drought, pest and disease problems, unfavorable market conditions, the massive transition of cultivable land to constructive land connected to conurbation, the abasement of land productiveness and desertion of arable land are the major constraints in this region. The traditional Onattukara farming system associated with the unique landscape entities of '*Kavu*' (Sacred Groves) and '*Kulam*'(Pond) also became rare which represented the typical Onattukara mixed farming system for which the region is famous.

Since the expansion of urban sprawl accelerates at a greater speed, it is high time to quantify the transformation of agricultural landscapes to maintain sustainability. The present study is carried out to estimate various landscape metrics indices for different periods and to measure the degree of change established by different landscape attributes in the Onattukara Agro-ecological Zone.

MATERIALS AND METHODS

Study area

The Onattukara Agro-ecological Zone (Fig. 1) extends from 8˚ 55' 44" to 9˚ 21' 09" N latitudes and 76˚ 23' 13" E to 76˚ 41' 16" E longitudes. The elevation of the zone is between 0 to 30 meters above mean sea level. It covers an area of 40495 ha and is bounded by Pallipad-Haripad (near Thottapally Pozhi and Kuttanad region) in the North, Neendakara Azhi and Ashtamudi Kayal in the South, midland laterite along Edavanchery, Vattakayal and Kattanam in the East and Lakshadweep Sea in the West. In the olden days, this region was considered as Onam-Oottumkara (meaning 'ushering plenty'). The livelihoods of more than 70% of families in this region depend on agriculture-based activities. The region is famous for the cultivation and production of good quality sesamum and rice; predominantly a sandy tract. The Onattukara agroecological zone experiences a humid tropical climate with tyrannous summers and ample seasonal rainfall. The summer season is marked between March and May. The southwest monsoon follows the summer season and continues till the end of September. The rainfall in December

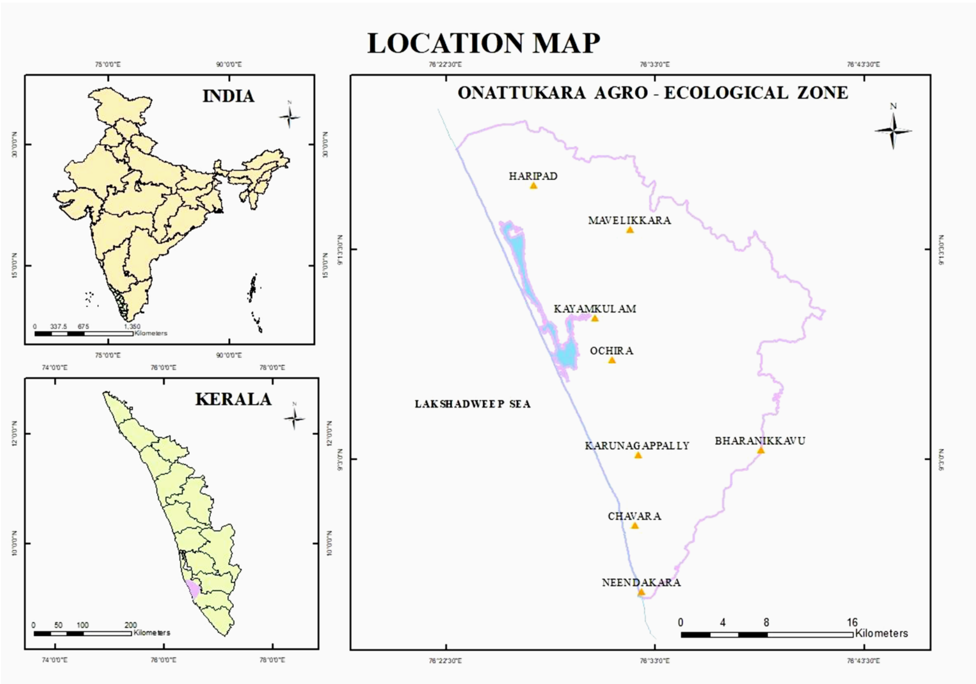

Fig. 1. Study area location map.

is associated with the northeast monsoon season. The average rainfall is 2629 mm, a major share of which is received from the southwest monsoon. The maximum temperature in the region varies from 28˚ C to 32˚ C. The minimum temperature falls in the range of 21˚ C to 28˚ C. Rainwater harvesting and maintenance of the water table in the typical Onattukara sandy soil tract was an added advantage of this typical landscape.

The Onattukara Agro-ecological Zone was delineated from Survey of India Toposheets 58 C/7, 58 C/8, 58 C/11, 58 C/12, and 58 D/9. The history was collected from published literature mentioning the emergence and the downfall of the erstwhile Onattukara kingdom.

The satellite imagery of the zone during different periods was downloaded from USGS Earth Explorer. Landsat 5 TM (Thematic Mapper) images of 1988, Landsat 7 ETM+ (Enhanced Thematic Mapper) images of 2001, and Landsat 8 OLI (Operational Land Imager) images of 2021 (Path/Row-144/054) concerning the study area.

Software and plugins used: Erdas Imagine 2014, Quantum GIS 3.20 (LecoS Plugin), and Fragstats v4.2.

The downloaded images were pre-processed in Erdas Imagine 2014 for better interpretation and then classified into five land-use classes (Agricultural land, Cultivable land, Built-up, Settlement with mixed trees and Waterbody) using the supervised classification technique. The classified images were used as input in the LecoS Plugin in QGIS 3.20 and Fragstats v4.2 software for finding out the indices of landscape metrics at each class level for different years. The indices computed for estimating the degree of transformation are the number of patches, patch density, landscape proportion and total core area. The diversity indices calculated are Shannon's diversity index and Shannon's evenness index.

RESULTS AND DISCUSSION

Landuse documents how people are using the land. It depicts how people use the landscape- whether

Table 1. Area coverage of different landuse classes (1988 - 2021).

Landuse class	The area under each landuse class in different years (in Sq km)		
	1988	2001	2021
Agricultural Land	73.77	68.09	17.32
Cultivable Land	86.64	21.36	4.99
Built-up	21.69	64.44	126.02
Settlement with mixed trees	459.98	489.67	495.97
Waterbody	38.5	37.02	36.28

for conservation, development, or mixed uses. It postulates the alteration and management of the natural environment into built environments like settlements and semi-natural habitats like managed woods, pastures and arable fields. By classifying a particular landscape into different land-use classes, we can analyze the change in the percentage of area under different classes. Here the Satellite imagery of various years of the Onattukara Agro-ecological Zone is classified into five landuse classes: Agricultural land, Cultivable land, Built-up, Settlement with mixed trees and waterbody. After that area coverage under different landuse classes was estimated.

We can see that (Table 1) the entire landscape is in a transforming phase i.e., from an agricultural landscape into a semi-urbanized landscape. The classes which experienced a forceful shift were agricultural land and cultivable land. The effect of urbanization, change in the attitude of farmers, and decline in crop productivity seem to be the major factors pushing the switching of agricultural and cultivable land into other landuse classes. The built-up area coverage increased at a greater pace compared to the different classes. The increasing population and the human need for shelter appear to be the primary elements that boost the extension of the built-up area. Since the study area is an agroecological zone with unique physical and cultural settings, the change-over in landscape patterns alters the ecological balance. The major threat caused by the imbalance is the decline of sesamum cultivation and production in the area. The landuse classes settlement with mixed trees and waterbodies do not show much change during the period between 1988 and 2021.

From the landuse/landcover maps (Figs. 2-4), we can infer the trend in change of different landuse classes which causes a change in landscape patterns

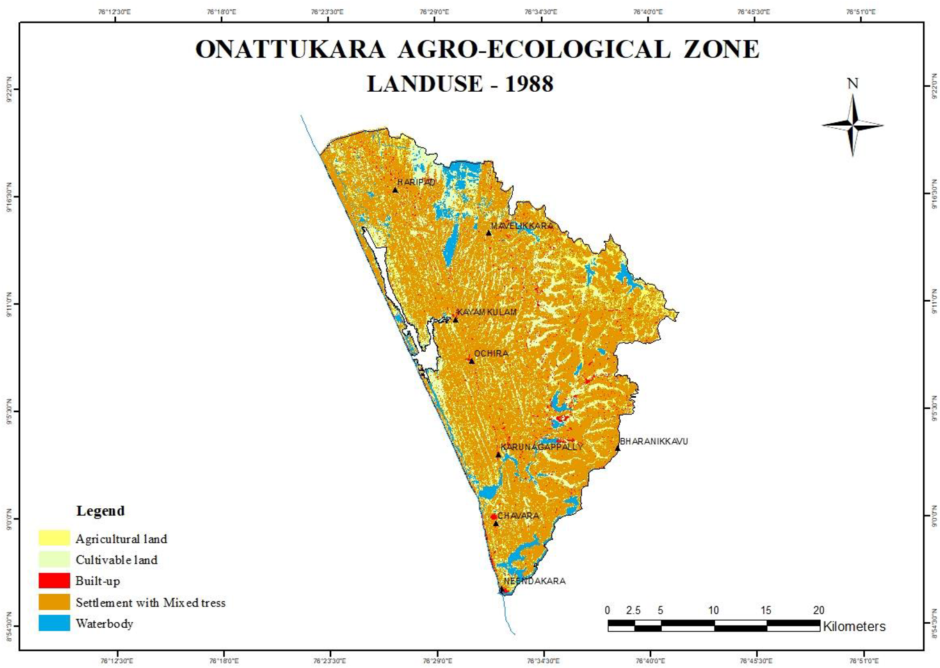

Fig. 2. Landuse map - 1988.

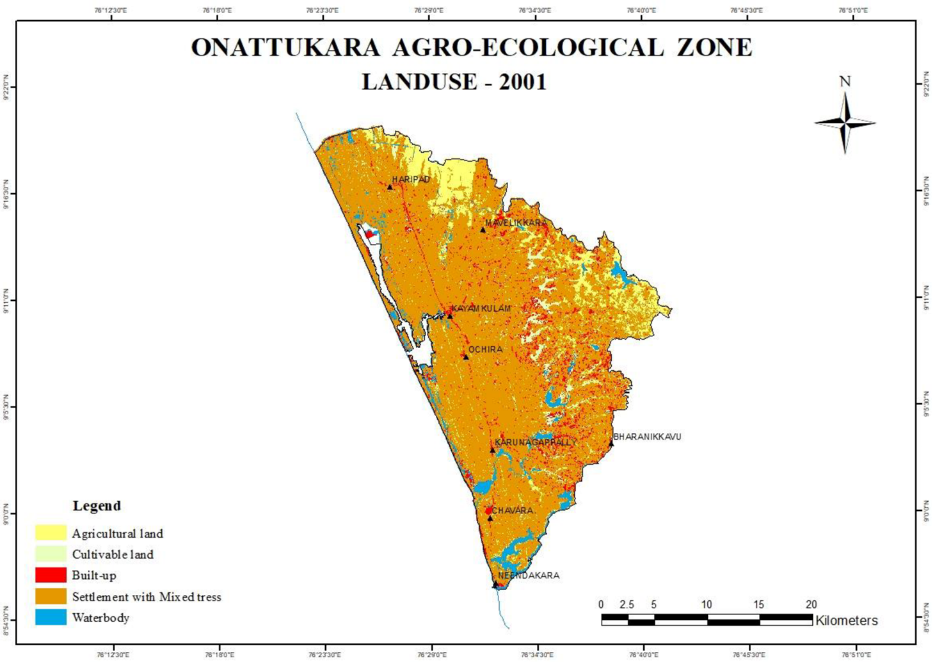

Fig. 3. Landuse map - 2001.

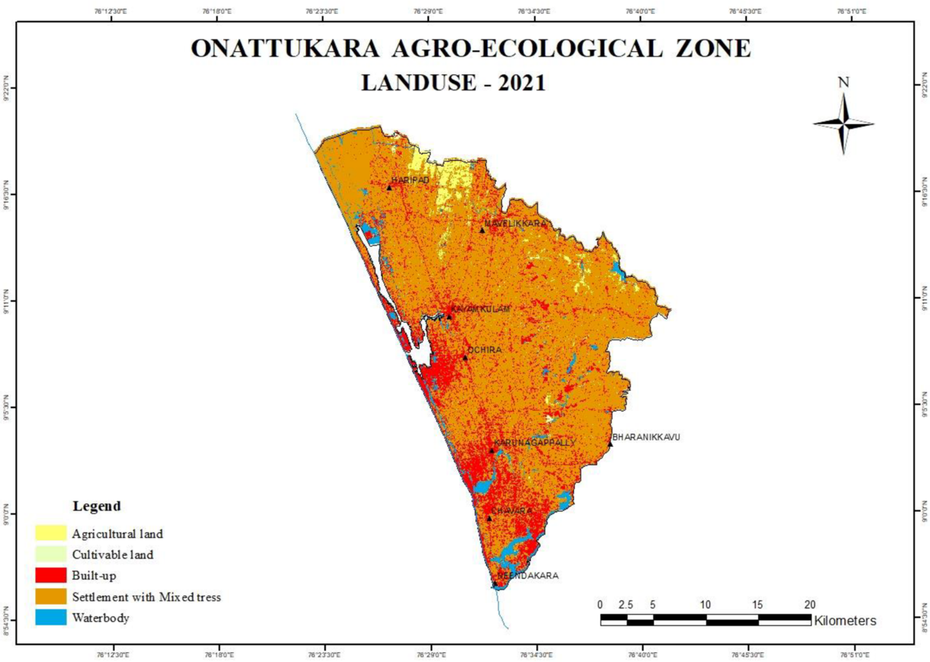

Fig. 4. Landuse map - 2021.

of the zone. In 1988, the majority of the study area was comprised of agricultural and cultivable land; mainly in the eastern and north-eastern portions of the zone. The built-up was seen in patches around the major junctions.

In 2001, we can see that the built-up started sprouting around the major junctions and along the roads. The cultivable land was converted to settlement with mixed trees due to the increase in settlements. The agricultural land was left as fallow land which in turn were sites for built-up.

In 2021, the agricultural land can be seen only in patches in the northern part of the zone. All other areas of the zone witnessed a heavy intrusion of built-up especially in the southern and south-western portions. The major junctions like Chavara, Oachira, Karunagappally, and Kayamkulam were fully consumed by the built-up.

By using landscape metrics we can evaluate the spatial arrangement of different land-use classes. The classified image is then used as input in Fragstats software to find out the different metrics indices to find out the transformation of the agrarian landscape into a semi-urbanized one. From the classified images of the years 1988, 2001, and 2021 we get clear information that the agricultural zone is in the transition stage. The huge effect of urbanization speeds up the conversion of cultivable and agricultural land which in turn changes the entire zone's ecological equilibrium.

Number of patches: Patches are the cardinal units for computing landscape metrics (McGarigal *et al.* 2012). The number of patches refers to the total number of patches of an individual class occupied within a landscape matrix. If the number of patch values increases, it implies that fragmentation increases in the region under study. If the value of the number of patches decreases, it means that fragmentation decreases in the region.

Table 2. Number of patches.

Class	1988	2001	2021
Agricultural land	26044	7864	1039
Cultivable land	8547	4649	2694
Built-up	6126	9145	16011
Settlement with mixed trees	1694	1191	1632
Waterbody	1180	1009	1140

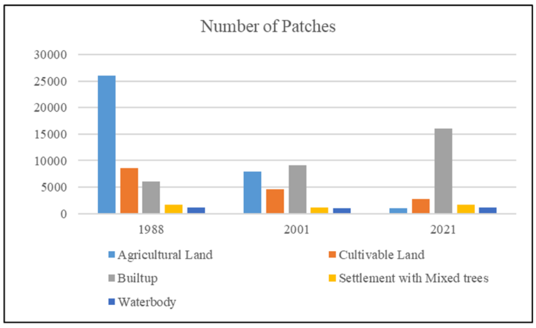

Fig. 5. Change in the number of patches from 1988 - 2021.

$$\text{Number of patches} = n_i$$

The number of patch indexes is calculated using the LecoS plugin in QGIS software. We can find that the classes (Table 2 and Fig. 5) agricultural land, and built-up show high variation in the number of patches from the year 1988 to 2021. The number of patches in the class agricultural land dipped alarmingly after 1988 which points out that there occurred a high downfall in fragmentation. The other notable class which shows positive progression in the number of patches is built-up. It indicates that the fragmentation of the built-up area increased from 1988 to 2021. The number of patches for the class cultivable land also reduced after 1988 which shows low fragmentation. The remaining class values show a slight progression in the number of patches from 1988 to 2021 points a slender rise in fragmentation.

Patch density: It is an 'Aggregation metric' which describes the atomization of the landscape (http://www.umass.edu/). Patch density often serves as an indicator of the spatial heterogeneousness of a particular landscape mosaic. If the density of patches is greater, then the landscape has a finer grain which means that the spatial heterogeneity takes place at a finer resolution (McGarigal *et al.* 2012). When the landscape gets patchier, patch density increases and reaches its maximum if every cell is a different patch (http://www.umass.edu/).

$$\text{Patch density} = N/A * 10000 * 100$$

Where, N equals the number of patches and A equals the total landscape area in square meters (http://www.

Table 3. Patch density.

Class	1988	2001	2021
Agricultural land	3.8446	1.162	1.5301
Cultivable land	1.2617	6.8698	3.9675
Built-up	9.0433	1.3513	2.3579
Settlement with mixed trees	2.5007	1.7599	2.4034
Waterbody	1.7419	1.491	1.6789

umass.edu/).

Patch density metrics of the Onattukara AEZ are calculated using the LecoS plugin in QGIS software. The patch density of agricultural land is decreasing from 1988 to 2021 (Table 3 and Fig. 6) which means that the homogeneity of that class increases. While looking for cultivable land, we can see that the patch density values have ups and downs in different periods which implies that the heterogeneity is affected by land-use changes. Considering the class built-up, patch density decreases because of the development of urban fringes around the core areas. In the case of settlement with mixed trees, there is not much variation during the period which implies that the homogeneity of that class is not altered by external factors. The patch density of the class waterbody receded from 1988 to 2021 and the major reason behind this is urbanization.

Landscape proportion: It measures the symmetrical abundance of different patch types in a particular landscape. It is used in many ecological applications since it measures landscape composition. It is a relative proportion and the most appropriate measure to assess landscape composition than the total class area for equating landscapes of altering sizes (McGarigal *et al.* 2012). Landscape proportion nears zero when the specific patch type gets more and more rarer. Landscape proportion equals a hundred when the total landscape is covered by a single patch.

$$\text{Pland} = P_I \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$$

Where, P_i = proportion of the landscape occupied by patch type (class) i, a_{ij} = area (m^2) of patch ij, and A

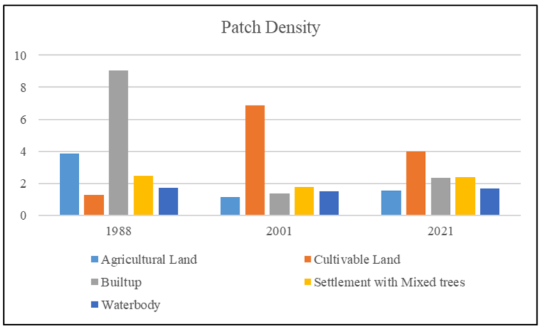

Fig. 6. Change in patch density from 1988 - 2021.

A = Total landscape area (m^2).

The landscape proportion metric of the Onattukara region is calculated using FRAGSTATS v4 software. During the period 1988 to 2021(Table 4 and Fig.7), we can find that the land-use class which shows a reasonable change is built up, which implies that the percentage of patches of this class displays a slight increase. Even though the value is small, the impact is higher. The class of agricultural land shows a decrease in proportion compared to other classes during the period. From this, it is evident that the agri-

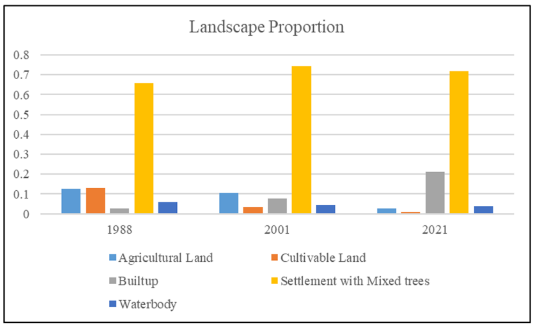

Fig. 7. Change in landscape proportion from 1988 - 2021.

Table 4. Landscape proportion (in %).

Class	1988	2001	2021
Agricultural land	0.1258	0.1049	0.0259
Cultivable land	0.1291	0.0329	0.0085
Built-up	0.0265	0.0764	0.2096
Settlement with mixed trees	0.6587	0.7419	0.7175
Waterbody	0.0597	0.0438	0.0383

cultural land is converted into built-up areas. The class cultivable land's proportion also decreased during this period, and it signals the transition of arable land to non-agricultural land. The other classes (Settlement with mixed trees and Waterbody) did not alter much during this period; the proportion remained more or less the same.

Total core area: Generally, the core area index evaluates the share of the patch that is constituted of the core area. It can be calculated at the patch level and can be summed up at the class/landscape level. Total core area refers to the amount of core areas of all patches present in a landscape (http://www.umass.edu). It characterizes the shapes of all patch areas and patches in the landscape concurrently. The total core area index refers to the ratio of core area in the entire landscape. When no patches in the landscape contain core then the index equals zero and if the relative proportion of core area in the landscape increases, the index approaches one (http://geography.middlebury.edu/). When patch areas increase and patch shapes are simplified, the core area index increases without limit. It equals zero when every cell in every patch is an edge (http://www.umass.edu).

$$TCA = \sum_{j=1}^{n} a_{ij}^{core} * \left(\frac{1}{1000}\right)$$

The total core area metric for the Onattukara AEZ is computed using FRAGSTATS v4 software. We can find that the land-use class (Table 5 and Fig. 8) that shows constant change is the settlement with mixed trees. It implies that the core area of the entire landscape is mainly occupied by settlements with mixed trees from the period 1988 to 2021. The other class which improved its area coverage in the core area is built up, induced by rapid urbanization. The share of

Table 5. Total core area (in hectares).

Class	1988	2001	2021
Agricultural land	3052800	26121600	7230600
Cultivable land	17994600	4239900	328500
Built-up	1138500	4270500	29283300
Settlement with mixed trees	188480700	319590900	256894200
Waterbody	20291400	13157100	10900800

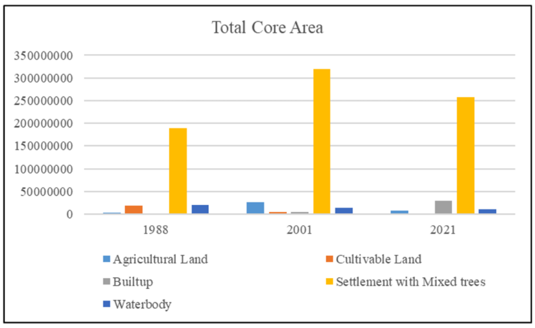

Fig. 8. Change in total core area from 1988 - 2021.

agricultural land and cultivable land in the core area gradually decreased during the period, which shows the transition of the agricultural land to other uses.

Shannon's diversity index (SHDI): SHDI is a 'Diversity metric', used in ecological studies, which considers both the number of classes and the teemingness of each class (http://www.umass.edu). It is a common diversity measure used in community ecology, employed here in landscapes. The normalized value of this diversity index ranges from zero to one. When the land cover types present have equal proportions then the index value tends to be one. A lower SHDI value means that the landscape is prevailed by a single land cover type (Ramezani, H. 2012). In other words, the particular landscape has less variety. If the landscape contains only one patch, then the SHDI value equals zero which means that there is no diverseness. As the number of different patch types increases, then SHDI also increases and the relative distribution of area among patch types becomes more precise.

$$SHDI = -\sum_{j=1}^{m} (P_i * \ln P_i)$$

Where P_i equals the proportion of the landscape occupied by patch type (class) i.

Table 6. Shannon's diversity index (SHDI).

Year	Shannon's Diversity index
1988	1.1643
2001	1.0912
2021	1.0574

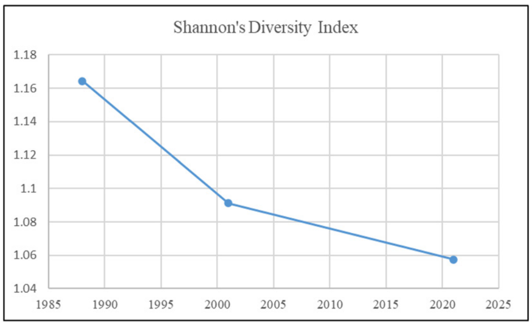

Fig. 9. SHDI.

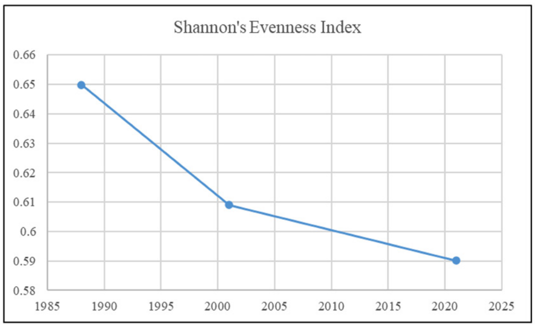

Fig. 10. SHEI.

SHDI for the Onattukara region is computed using FRAGSTATS v4 software. We can see that from 1973 to 2021(Table 6 and Fig. 9), the diversity of the landscape has fallen at a normal rate. It implies that the ratio of different patch types is becoming more in equitable and the entire landscape has started losing its diverse nature.

Shannon's evenness index (SHEI): Generally, evenness measures the other aspects of diversity within the landscape. Shannon's evenness index does not suffer from the limitation of shannon's diversity index concerning interpretability (McGarigal *et al.* 2012, Ramezani 2012). If the landscape contains only one patch, then SHEI equals zero. When the distribution of area among the different patch types becomes increasingly odd, then SHEI approaches zero (McGarigal *et al.* 2012, Ramezani 2012). When the distribution of area among patch types is perfectly divided, then SHEI equals One.

$$SHEI = \frac{-\sum_{i=1}^{m} (Pi * \ln Pi)}{\ln m}$$

Where, Pi equals the proportion of the landscape occupied by patch type (class) I, m equals the number of patch types (classes) present in the landscape, excluding the landscape border if present (http://www.umass.edu).

Table 7. Shannon's evenness index (SHEI).

Year	Shannon's evenness index
1988	0.6498
2001	0.6090
2021	0.5901

SHEI for the Onattukara AEZ is computed using FRAGSTATS v4 software. We can see that the SHEI value started decreasing during the period 1988 to 2021(Table 7 and Fig.10). It shows that the entire landscape is in the transition stage from being equally distributed to becoming dominated by a single class (Settlement with mixed trees).

CONCLUSION

This study assessed the rate and trend in the change of agricultural landscape in the Onattukara Agro-ecological Zone from 1988 to 2021. Speaking about the methods used in this paper gives a clear and comprehensive idea about the analysis of landscape transformation. Landscape metrics prove to be assistive in developing the geographic framework of agricultural landscape dynamics induced by human acts (Su *et al.* 2011). The landscape metrics used in the study unveil the major movements of agricultural landscape transformations and will regain the actions targeting the preservation of agricultural landscapes (Su *et al.* 2011). The change in values of different indices indicates that the Onattukara landscape is in the transitional stage from an agrarian to an urbanized landscape. This study gives an immediate call for initiating steps to preserve the uniqueness and sustainability of the Onattukara landscape. The conversion of this landscape into an urbanized one brings many negative impacts on the ecological dynamism present in the zone. Both the biotic and abiotic uniqueness in the zone may disappear by the encroachment of the built-up area. So, the present study gives a wake-up call for preserving the sustainable nature of the zone. The modern-day world is testifying to the hauling effect of urbanization in every nook and corner of land-use patterns; the practical application of landscape metrics will help in the research of the transformation of landscapes.

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