

Research Article

Application of the Categorical Change Detection Technique in Investigating the Trends of Urbanization in Wales, Southwest Britain

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Abstract

This study, employing remote sensing and Geographic Information System (GIS) techniques, was carried out using the categorical change detection technique to analyze land use and land cover (LULC) dynamics in Wales, United Kingdom, from the year 1992 to 2019 with a view to understanding the trend of urbanization in the area. Using data from the Global Land Cover 1992 to 2019 image service accessible via ArcGIS Pro 3.0 Living Atlas, with a spatial resolution of 300 meters, the study revealed that grassland, being the predominant land cover in the area, decreased in coverage from 73.98% in 1992 to 72.16% in 2019, cropland decreased from 17.91% to 17.48%, all categories of forest increased from 5.30% to 5.93%, water bodies decreased from 1% to 0.7%, while bare areas remained constant at 0.2% in both years. Results also revealed a significant expansion of urban areas, growing from 1.81% to 3.48% of the land area. The mean percentage change across all counties is approximately 97.29%, indicating substantial urban expansion, while the median percentage change is 68.88%. Counties in South Wales experienced substantial urbanization influenced by coastal proximity, while Western and Northern regions showed significant percentage changes in urban areas but had smaller land area expansions. This research provides insights into the evolving landscape of Wales vital for understanding trends in land use, environmental changes, and urban expansion over this period and contributes valuable insights for sustainable urban planning, environmental preservation, and possible ecological impacts within the study area.

Keywords

Geographic Information System, Global Land Cover, ArcGIS, Urban Expansion, Ecological Impacts, Counties

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1. Introduction

Land has been an indispensable resource for human beings, serving as a source of sustenance, housing, and other fundamental requirements for survival [1]. With increasing demands of modern societies, the use of land has become more complex and diversified resulting in the modification of the global landscape by human activities. Anthropogenic activities have transformed more than half of the Earth's land surface, primarily through the conversion of natural habitats such as forests to agriculture and other uses [2]. This transformation of the global landscape has been an ongoing process for centuries, and its trajectory has been influenced by a multiplicity of factors, such as economic development, population expansion, and urbanization [3]. [4] reported that approximately 60% of global ecosystems have undergone significant alteration by humans, with most of the changes occurring in the past five decades.

Urbanization, a complex and multifaceted process that involves the growth and expansion of urban areas, often driven by economic, social, and demographic factors, is characterized by the transformation of rural landscapes into built-up environments, leading to changes in land use, population density, and infrastructure [5]. Globally, urbanization has been recognized as a significant trend, with more than half of the world's population now living in urban areas; this proportion is expected to increase to 68% by 2050, highlighting the ongoing importance of understanding and managing urbanization [5]. The global significance of urbanization is evident in its wide-ranging impacts on various aspects of human life and the environment. For instance, urbanization has been linked to economic growth and development, as cities often serve as hubs for innovation, trade, and investment [6].

It is known that urbanization impacts the distribution of land cover in any area [7]. It has been one of the most significant drivers of LULC change in Wales, with urban areas expanding into surrounding rural areas. LULC change in Wales is as well driven by economic development, agricultural expansion, and infrastructure development leading to various environmental impacts [8]. Agricultural intensification drives LULC change in Wales, with an increase in the use of fertilizers and pesticides contributing to water pollution and soil degradation [9]. While some studies have documented changes in LULC in Wales (e.g. [10, 11]), the nature and extent of such changes across different regions in Wales remain unclear. Urbanization has significant impacts on the natural and cultural landscape, altering its character and affecting its aesthetic, ecological, and cultural values. This study will seek to address the information gap on the exact extent and pattern of urbanization in Wales, investigate the land cover types which have been most affected by this rapid spread of urbanization.

Pervasive changes in land use and land cover have caused a multitude of impacts on the natural environment, including alteration of hydrological cycles, climate change, amplified

surface erosion, increased water extraction, degradation of soil nutrients, and loss of biodiversity ([12, 13]). Changes in land use and land cover can also have adverse effects on soil and water quality, as well as on the carbon cycle [14]. These changes have significant ecological consequences and may have long-lasting effects on the functioning of ecosystems. According to [15], land use change has been demonstrated to significantly affect regional climate through modifications in land surface albedo, evapotranspiration, and other related factors. Consequently, having knowledge about land use and land cover and understanding the dynamics of urbanization and its consequences, as well as their changing patterns, has become an essential aspect for effective planning of land use and monitoring the trend of urbanization in an area.

The present study endeavors to examine landscape changes in Wales over a span of 27 years, specifically focusing on the phenomenon of urbanization, using remote sensing and GIS techniques. Wales is facing a host of major environmental concerns. One of the significant issues is loss of biodiversity, a major ecological impact, with several species and habitats in decline. The country's natural resources like rivers, woods, and coasts are under pressure, and the loss of green spaces and habitats is a pressing concern. Climate change is another critical issue, with the country experiencing more frequent and severe weather events. Wales is also vulnerable to flooding, particularly in urban areas with consequent impacts on communities and ecosystems. Pollution is also a significant environmental concern in Wales, with issues related to water and air quality. Both rural and urban areas within the country are affected by pollution from several sources including agriculture, transportation, and industrial activities. All these underscore the importance of understanding the urbanization dynamics so as to ensure environmental preservation, sustainable urban planning, and mitigation of possible ecological impacts. Changes in urban areas was investigated for all recognized counties in Wales.

Utilizing change detection techniques on satellite imagery, this study aims to discern shifts in the landscape character of Wales, with particular emphasis on urban development dynamics. The endeavor of change detection analysis entails various challenges, including the acquisition of high-quality remotely sensed imagery, the complexity associated with processing such data, and the impact of noise on satellite imagery, as noted by [16]. This study successfully surmounted the hurdle of data acquisition by leveraging the well-preprocessed categorical data proffered by European Space Agency (ESA) in 2017.

Moreover, the complexity associated with processing landscape changes within the study area was effectively mitigated through the utilization of the change detection wizard tool integrated within ArcGIS Pro 3.0. This study took a different approach to the routine monitoring of time series data used for landscape changes detection; instead, the change detection wiz-

ard in ArcGIS Pro 3.0, which emphasizes real-time monitoring using remotely sensed data and surface dynamics, was employed in estimating and analyzing the changes that took place in Wales over the 27-year period. Having utilized the latest innovations and resources in the field, this study signifies a paradigm shift in landscape character change detection, representing a crucial milestone towards enhanced and expedited monitoring of landscape dynamics.

The analytical framework adopted in this research operates on a categorical basis, segmenting the landscape character of Wales into eighteen (18) distinct classes. This categorical approach serves to facilitate the identification of specific landscape alterations attributed to urbanization within the United Kingdom's jurisdiction of Wales. Consequently, the study seeks to identify regions within Wales that have transitioned from vegetated to urbanized landscapes within the 1992 to 2019 period. Additionally, this study lays the groundwork for further investigations concerning the causal factors underpinning transformations within distinct counties in Wales.

2. Location and Physiography of the Study Area

Wales, located between approximately 51.2414 °N and

53.4254 °N latitude, and between approximately 2.5441 °W and 5.5254 °W longitude in the western part of the United Kingdom is bordered by England to the east and shares a coastline with the Bristol Channel to the south and the Irish Sea to the north and west. Wales offers a diverse and captivating landscape that combines mountains, coastlines, valleys, and historic landmarks. Its natural beauty includes majestic mountain ranges like Snowdonia and the Brecon Beacons, showcasing peaks, glacial valleys, and cascading waterfalls. The Welsh coastline offers rugged cliffs, sandy beaches, and hidden coves, with areas such as the Pembrokeshire Coast and the Gower Peninsula standing out. Picturesque valleys like the Wye Valley and the Vale of Conwy meander through wooded landscapes and charming villages; while national parks such as Snowdonia and the Brecon Beacons preserve and highlight the country's diverse countryside. Wales's landscape is further enriched by its renowned castles and historic sites, which add a touch of history and charm to the surroundings. The highest peak in Wales is Mount Snowdon, which attracts many hikers and outdoor enthusiasts. The country covers an area of approximately 20,780 square kilometers (8,020 square miles) with population of around three million people. Figure 1 shows the map of Wales.



Figure 1. Map of Wales (Source: [17]).

3. Materials and Methods

This study leveraged data sourced from the global land cover image service, accessible via ArcGIS Living Atlas, with a spatial resolution of 300 meters. The analysis was conducted using ArcGIS Pro 3.0, a valuable tool for assessing spatio-temporal changes. The categorical change detection function within ArcGIS Pro played a pivotal role in the precise

classification of land use and land cover alterations. The methodology employed in this research aligns with prior studies, as exemplified by [18], and [19]. The study initially conducted land cover estimation for Wales in both 1992 and 2019 by utilizing the obtained land cover dataset. Subsequently, a systematic transition matrix was applied to this dataset, facilitating the estimation of areas that underwent varying degrees of landscape.

ArcGIS Pro's change detector wizard was used to gain in-

valuable insights into the transition of various land cover types to urban areas during the specified period, with land areas meticulously measured in square meters. To understand the different types of land cover change in Wales using the change detection wizard in ArcGIS Pro, long-term land cover change from 1992-2019 were analyzed using the acquired land cover datasets. Furthermore, identification of vegetation loss and other land cover changes due to urbanization in 2019 using the imagery dataset were derived by applying the systematic transition matrix on dataset. This helped in estimating areas that have experienced some degree of landscape character change. Thereafter maps and charts were generated to visualize the results.

In carrying out image classification, land cover mapping, and area calculation, feature extraction is followed by collection of training data. Suitable classification algorithm is selected and the classification model is trained using training data. Performance of the model is evaluated using validation data before applying the trained model to the satellite image. Results are then refined and classification accuracy evaluated. This is followed by land cover map production which involves the creation of a thematic map showing the spatial distribution of different land cover types/classes. The overall quality encompassing accuracy and consistency of the final map is then verified. Area calculation follows land cover map production. This involves the use of GIS software to estimate the area of each land cover class by adding the pixels assigned to that class.

While the traditional focus of landscape changes detection has been on monitoring time series data, this study took a different approach. Instead, it employed the change detection wizard in ArcGIS Pro 3.0 to estimate and analyze the changes that have occurred in Wales over a 27-year period. This shift in emphasis reflects a new paradigm in landscape character change detection, which emphasizes real-time monitoring using remotely sensed data and surface dynamics. By utilizing the latest innovations and resources in the field, this research represents a significant step towards more effective and timely monitoring of landscape changes.

The choice of ArcGIS Pro 3.0 as the primary software for this research analysis is based on its robust functionalities in remote sensing and landscape character change detection. The software provides advanced tools and capabilities that enable accurate and efficient analysis of remotely sensed data. The ArcGIS Pro 3.0 is a powerful tool for classifying land use and land cover alterations. It allows users to perform supervised classification which involves training the software to recognize specific land cover classes based on sample data. The software supports advanced classification techniques, such as object-based image analysis and machine learning algorithms which improves the accuracy of land cover classification. ArcGIS Pro 3.0 can be integrated with remote sensing data such as satellite imagery, to analyse land use and land cover changes over time. It provides a range of spatial analysis tools like spatial autocorrelation, and hot spot analysis that can aid

in identifying patterns and trends in LULC changes. The software also allows users to create interactive and dynamic maps that can be utilized in visualizing LULC changes and communicate results to stakeholders. In addition to real-time monitoring using remotely sensed data as against monitoring of time series data used for landscape changes detection by other methods, other advantages this tool hold over other methods include its machine learning algorithms and deep learning models which achieves high accuracy in land cover classification and change detection. It can integrate data from various sources including satellite imagery, aerial photography, and field observations to improve the accuracy of land cover classification and change detection. This tool also provides various change detection analysis techniques including image differencing, image ratioing, and change vector analysis to identify and quantify land cover changes. It also provides data visualization and mapping capabilities, and it is designed to handle large datasets and perform complex analysis quickly and efficiently.

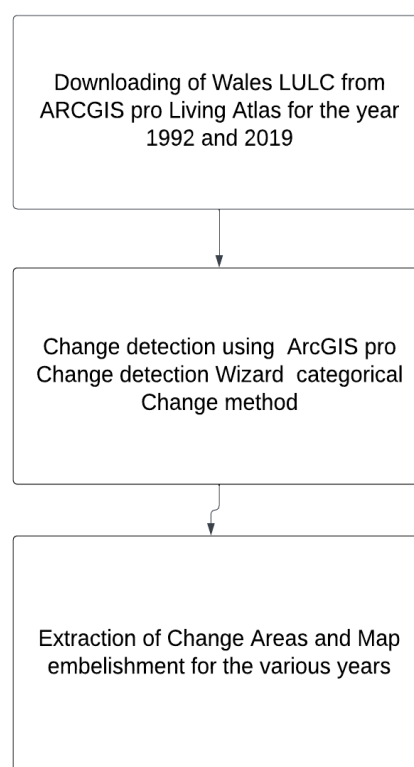


Figure 2. Summarized process flow for the study.

By utilizing ArcGIS Pro 3.0, this study not only presents its findings but also serves as a reference for other researchers to utilize and build upon, leveraging the comprehensive capabilities of the software for their own investigations. The Living Atlas of the ArcGIS Pro 3.0 provides a database of land use and land cover for various countries over the years. This makes it easy to access the data and use the change detection wizard to analyze changes in land use and land cover over a

certain period. This method eliminates the errors from manually downloading and processing landscape data. Figure 2 shows a summarized sequence of steps taken to actualize this study.

4. Results and Discussion

This study classified land cover types into 6 broad groups. These groups are presented in Table 1.

Table 1. Classifications of land cover types within the study area.

Water bodies	Bodies of Water
Forests	Closed to Open Canopy Broad-leaved Deciduous Tree Cover
	Closed to Open Canopy Needle-leaved Deciduous Tree Cover
	Mixed Tree cover
Grasslands	Closed to Open Canopy Needle-leaved Evergreen Tree Cover
	Grassland
	Flooded Shrub or Herbaceous Cover
Croplands	Herbaceous Cropland
	Tree or Shrub Cropland
	Mostly Cropland in a Mosaic with Natural Vegetation

Water bodies	Bodies of Water
	Mostly Herbaceous Cover in a Mosaic with Trees and Shrubs
	Sparse Vegetation
	Mostly Natural Vegetation in a Mosaic with Cropland
	Mostly Trees and Shrubs in a Mosaic with Herbaceous Cover
	Bare Areas
	Consolidated Bare Areas
Barren areas	Unconsolidated Bare Areas
Urban areas	Urban areas

An analysis of the imagery of Wales in 1992 as summarized in the Bar chart of Figure 3 and Table 2 revealed the composition of land cover within the region. Grassland emerged as the predominant land cover, encompassing 74% of the total land area and underscoring the extensive presence of natural or cultivated grassy areas. This was followed closely by cropland, constituting 18% of the land area and signifying substantial agricultural utilization. All categories of forests, collectively comprising 5.3% of the land cover, played a significant ecological role. Urban areas were relatively limited, accounting for just 2% of the total land area, while bare areas and water bodies occupied 0.2% and 1%, respectively.

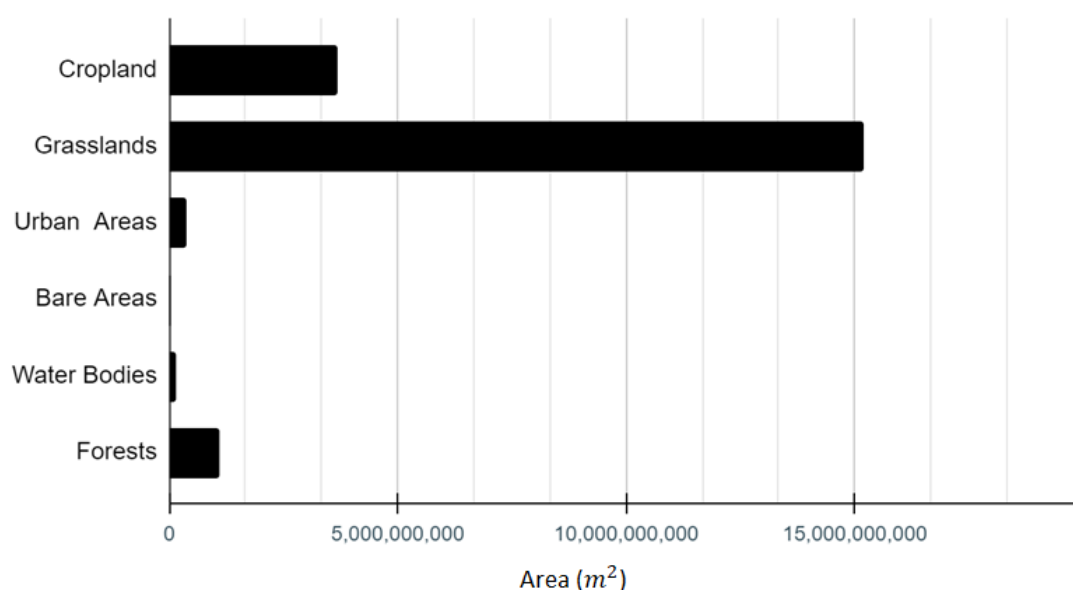


Figure 3. Bar chart showing area covered by each LULC type in 1992.

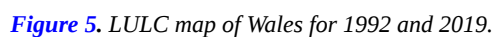
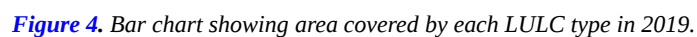


Table 2. Surface area covered by each LULC type in both years.

Class Name	1992		2019	
	Area (m ²)	% of Total	Area (m ²)	% of Total
Cropland	3,678,447,980	18%	3,646,482,806	17.5%
Grasslands	15,193,564,377	74.0%	15,055,238,451	72.2%
Urban Areas	372,308,905	2%	726,622,564	3.5%
Bare Areas	48,532,348	0.2%	48,330,352	0.2%
Water Bodies	154,830,440	1%	147,527,088	0.7%
Forests	1,089,353,343	5.3%	1,238,146,576	5.9%

In 2019, Wales witnessed notable changes in its land cover composition when compared to the data from 1992, as summarized in the Bar chart of [Figure 4](#). The dominant feature of both years remained grasslands, but there was a slight decrease in its coverage, declining from 73.98% in 1992 to 72.16% in 2019. Cropland maintained a significant presence in 2019, comprising 17.48% of the land area, similar to its 17.91% share in 1992 and indicating a consistent focus on agriculture. Urban and built-up areas, however, saw an increase from 1.81% in 1992 to 3.48% in 2019, reflecting a growth in urbanization and infrastructure development over the years. Forests continued to play a vital ecological role, accounting for 5.30% in 1992 and 5.93% in 2019 and underscoring their persistent significance. These shifts in land cover data between 1992 and 2019 provide insights into the evolving landscape of Wales vital for understanding trends in land use, environmental changes, and urban expansion over this period. [Figure 5](#) shows the LULC map of Wales for 1992 and 2019.

Between 1992 and 2019, Wales underwent significant changes in its land cover, with some of the most remarkable shifts occurring in urban areas, which expanded dramatically from 372,308,905 to 726,622,564 square meters, marking an extraordinary increase of 354,313,659 square meters or 95.17%. This monumental growth underscores a substantial urbanization trend over these years, reflecting increased infrastructure development and urban expansion.

Two other prominent changes were observed. Water bodies experienced a notable decrease, shrinking from 154,830,440 to 147,527,088 square meters showing a decline of 7,303,352 square meters or 4.72%. Similarly, forests also saw significant alterations, increasing from 1,089,353,343 to 1,238,146,576 square meters, indicating a substantial growth of 148,793,233 square meters or 13.66%.

While urban areas expanded dramatically, the decrease in water bodies and the increase in forests are pivotal in understanding the evolving landscape of Wales during this period, reflecting shifts in land use, urbanization, and environmental changes. These changes are summarized and visualized in [Table 3](#) and [Figure 6](#). Delving deeper into the intricacies of

urbanization and meticulously measuring the changes in urban areas by county offers an insightful narrative of the evolving landscape within Wales during the study timeframe spanning 1992 to 2019. The mean percentage change across all counties is approximately 97.29%. This indicates that, on average, urban areas in these counties expanded significantly, with a substantial 97.29% increase over the 27-year period. This remarkable growth suggests a noteworthy shift in land use patterns, likely driven by factors such as population growth, economic development, and urbanization.

The median percentage change, which is 68.88%, provides a more typical perspective. For the median county, urban areas expanded by approximately 68.88% during the study period. This median value indicates that, for a typical county, urban areas grew by nearly 69%, showcasing the range of urbanization experiences within Wales.

In assessing the dynamics of urbanization in various Welsh counties during the period from 1992 to 2019, two critical factors emerge as key indicators: percentage change and land area change. Notably, counties such as Ceredigion and Carmarthenshire experienced a remarkable surge in urbanization, marked by staggering percentage increases of 207% and 166%, respectively. These figures signify that these regions have seen more than a doubling of their urban areas over the studied timeframe. Such substantial changes could be attributed to a combination of factors, including robust economic development and population growth.

When examining the shift in land area, specific counties stand out prominently. Cardiff, the capital city of Wales, exhibited a significant expansion of its urban footprint, with an increase of approximately 18.97 million square meters. This expansion carries significant implications, highlighting Cardiff's growing stature as a vital hub for economic and social activities. Pembrokeshire and Caerphilly also experienced notable growth in their urban areas, with land area increments of around 24.53 million square meters and 21.38 million square meters, respectively. These transformations suggest heightened urban development and substantial infrastructure projects within these counties. Moreover, Rhondda,

Cynon, Taff, nestled in the South Wales Valleys, experienced one of the most substantial land area increases, tallying around 25.04 million square meters. This underscores a pronounced shift towards urbanization within this particular region, further accentuating the diverse urbanization patterns across Welsh counties during this period.

On the other hand, several counties demonstrated a more measured trajectory of urbanization. Counties such as Denbighshire and Conwy exhibited urban area growth rates of 68%, while Flintshire and Wrexham experienced expansions of 63% and 64%, respectively. These locales showcased steady urban development, potentially influenced by multifaceted factors including economic activities, infrastructure advancements, and demographic dynamics. Cardiff, being the capital city, warrants particular attention. While its 36% growth rate may appear moderate when compared to certain counties, it translated into a substantial increase in urban area, adding 18,965,904 square meters. This phenomenon emphasizes Cardiff's pivotal role as an economic and cultural nucleus, continually attracting both residents and businesses over the years.

Counties situated in South Wales, such as Caerphilly,

Blaenau Gwent, Rhondda, Cynon, and Taff, underwent substantial urbanization. This phenomenon could be attributed to their proximity to major urban centers and economic opportunities. Counties located in the Western and Northern regions, like Ceredigion and Gwynedd, also experienced significant percentage changes in urban areas but had smaller land area expansions. This suggests that while these regions underwent urbanization, the scale of this transformation was more modest, likely due to the preservation of rural and scenic landscapes. In contrast, counties in more rural settings have experienced more measured urban expansions. The data underscores the diverse trends in urbanization that have unfolded across Welsh counties. Some, particularly those in the southern part of the country with coastal access, have witnessed rapid growth in their urban areas which aligns with the global trend of urbanization near coastlines. In contrast, counties in more rural settings, often with picturesque coastal regions, have experienced more measured urban expansions. Table 4 illustrates the significant changes in urban areas across various Welsh counties from 1992 to 2019. Figure 7 shows the LULC change areas in Wales from 1992 to 2019.

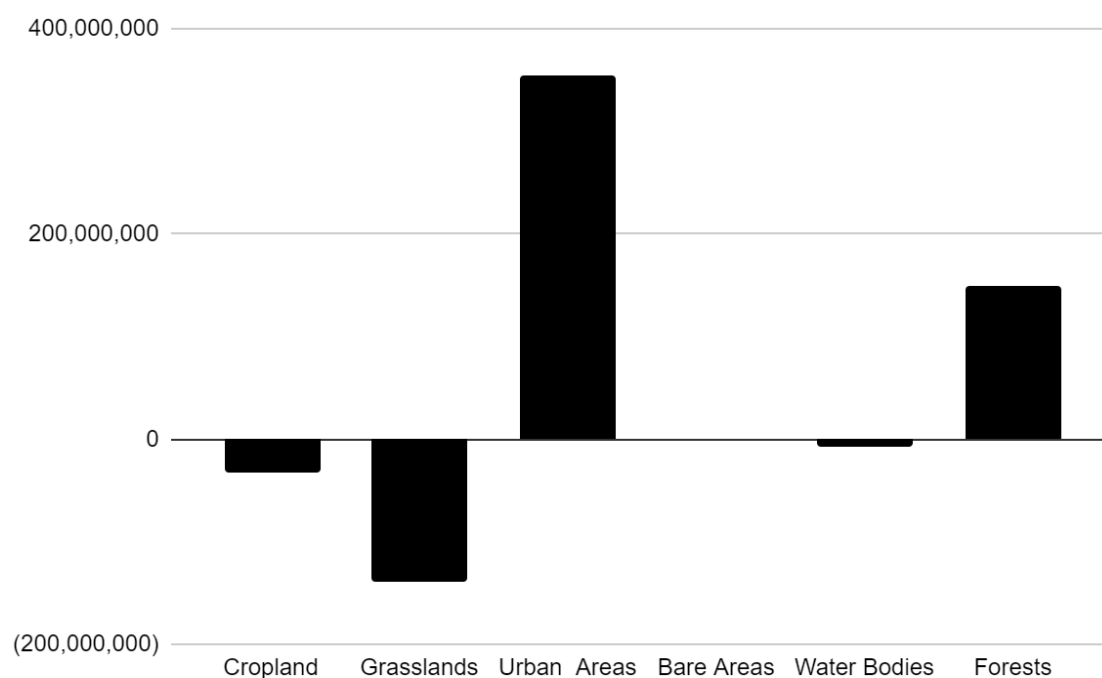


Figure 6. 1992 - 2019 Change analysis for LULC groups.

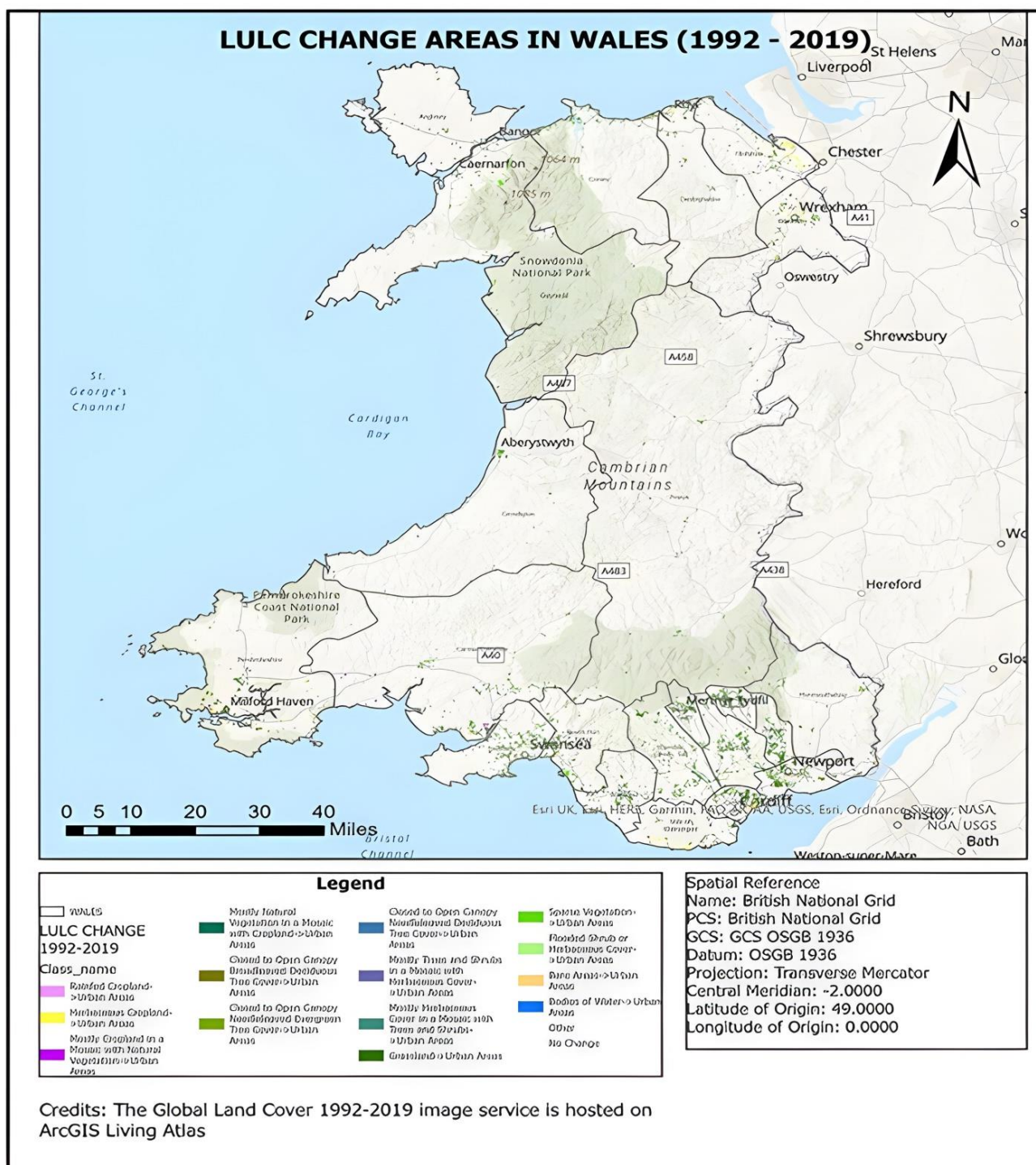


Figure 7. LULC change areas in Wales (1992 to 2019).

Table 3. 1992 - 2019 Change analysis for LULC groups.

Class Name	Land Area (m ²)			
	1992	2019	Change	Percentage change
Cropland	3,678,447,980.46	3,646,482,806.41	-31,965,174.05	-0.87%
Grasslands	15,193,564,376.90	15,055,238,450.60	-138,325,926.30	-0.91%

Class Name	Land Area (m ²)			
	1992	2019	Change	Percentage change
Urban Areas	372,308,905.13	726,622,564.00	354,313,658.87	95.17%
Bare Areas	48,532,347.88	48,330,352.02	-201,995.86	-0.42%
Water Bodies	154,830,440.46	147,527,088.00	-7,303,352.46	-4.72%
Forests	1,089,353,342.65	1,238,146,576.00	148,793,233.35	13.66%

Table 4. Changes in Urban Areas by County in Wales (1992-2019).

County	Class Name	Land Area (m ²)			
		1992	2019	Change	% Change
Anglesey	Urban Areas	6208120	9936580	3728460	60.06%
Blaenau Gwent	Urban Areas	7295350	16788200	9492850	130.12%
Bridgend	Urban Areas	21480100	36076100	14596000	68%
Caerphilly	Urban Areas	20773000	42152900	21379900	103%
Cardiff	Urban Areas	52610800	71576704	18965904	36%
Carmarthenshire	Urban Areas	14814900	39370700	24555800	166%
Ceredigion	Urban Areas	2777510	8513180	5735670	207%
Conwy	Urban Areas	15577100	26306800	10729700	69%
Denbighshire	Urban Areas	12654900	21289400	8634500	68%
Flintshire	Urban Areas	25881300	42202000	16320700	63%
Gwynedd	Urban Areas	14081200	27108000	13026800	93%
Merthyr Tydfil	Urban Areas	6376670	14548200	8171530	128%
Monmouthshire	Urban Areas	7615610	16476500	8860890	116%
Neath Port Talbot	Urban Areas	28539400	44030100	15490700	54%
Newport	Urban Areas	29408000	48792000	19384000	66%
Pembrokeshire	Urban Areas	12021000	36550800	24529800	204%
Powys	Urban Areas	7956770	18330300	10373530	130%
Rhondda, Cynon, Taff	Urban Areas	27238700	52275000	25036300	92%
Swansea	Urban Areas	34517900	57208000	22690100	66%
Vale of Glamorgan	Urban Areas	22635400	36347400	13712000	61%
Wrexham	Urban Areas	19413400	31760700	12347300	64%

This analysis underscores how previously distinct land cover classes have evolved into urban zones. Notably, cropland, with a substantial land area of 70,171,410 square meters, has undergone conversion into urban areas, signaling the transformation of agricultural regions into urban spaces, potentially driven by urbanization trends stemming from

population growth and economic shifts. Similarly, the vast grasslands, occupying a significant 235,862,492 square meters, have transitioned into urban areas, underscoring the encroachment of urban development on natural or cultivated grassy areas. The conversion of bare areas (12,365,006 square meters) and water bodies (4,204,102 square meters) into ur-

ban zones indicates significant changes in the landscape, potentially affecting local ecosystems and hydrology. Additionally, the shift of forested land (4,513,227 square meters) into urban areas highlights the complex challenge of balancing urban growth with environmental conservation, especially in regions where forests contribute to biodiversity and ecological stability. Table 5 presents the land cover classes that transitioned into urban areas, indicating their respective land areas converted to urban use.

4.1. LULC Change in Select Counties

4.1.1. Cardiff

Over the period from 1992 to 2019, Cardiff County underwent a profound transformation in its land cover composition, with a notable emphasis on the substantial 36% increase in urban areas. This remarkable growth underscores Cardiff's burgeoning role as the capital city and a vibrant economic nucleus, drawing residents and businesses alike. Simultaneously, the 30% reduction in grasslands reflects the encroachment of urban development upon natural or cultivated grassy areas, with potential implications for local ecosystems. These interconnected changes in land cover emphasize the intricate dynamics influencing Cardiff County's landscape evolution. The 38% decrease in water bodies underscores alterations in hydrological features, typically associated with urbanization-induced modifications to natural watercourses, potentially affecting local water resources and ecosystems. Lastly, the 22% reduction in forested land serves as a stark reminder of the intricate challenge of balancing burgeoning urban growth with the imperatives of environmental conservation, particularly in regions where forests serve as bastions of biodiversity, carbon sequestration, and

ecological resilience. Table 6 and Figure 8 provide a summary of land cover changes in Cardiff County (1992-2019).

Table 5. Land Cover Classes Converted to Urban Areas (1992-2019).

Previous class name	New class name	Land area (m^2)
Cropland	Urban Areas	70,171,410
Grasslands	Urban Areas	235,862,492
Bare Areas	Urban Areas	12,365,006
Water Bodies	Urban Areas	4,204,102
Forests	Urban Areas	4,513,227

Table 6. Land Cover Changes in Cardiff County (1992-2019).

Class Name	Land area (m^2)		
	1992	2019	% change
Cropland	14,678,642	9,370,303	-36%
Grasslands	38,533,475	27,015,051	-30%
Urban Areas	52,610,800	71,576,704	36%
Bare Areas	2,765,220	1,096,420	-60%
Water Bodies	773,059	477,966	-38%
Forests	1,419,554	1,107,443	-22%

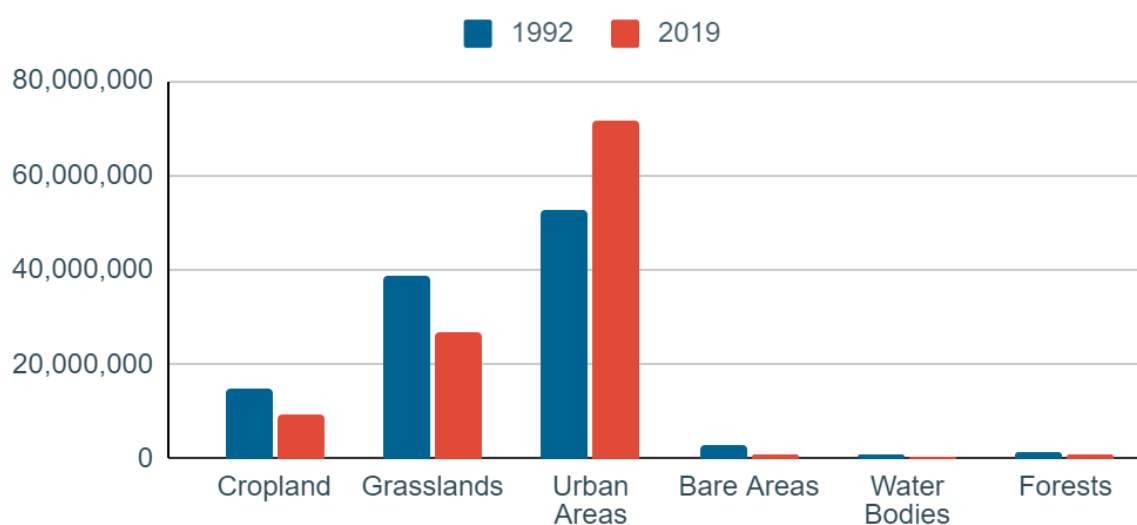


Figure 8. Land Cover Changes in Cardiff County for 1992 to 2019.

4.1.2. Wrexham

In Wrexham County from 1992 to 2019, urban areas saw a significant 64% increase, reflecting urbanization trends driven by population growth and economic activities. Concurrently, cropland and grasslands both decreased by 2%, aligning with regional shifts towards urban land use. Notably, bare areas were completely eliminated, suggesting land repurposing efforts; forests declined by 11%, highlighting the challenge of preserving ecosystems amidst urbanization. These changes emphasize the need for effective urban planning and land management to balance urban growth with environmental sustainability in Wrexham County. This is summarized in Table 7 and Figure 9.

4.1.3. Swansea

The most notable transformation in Swansea County over the period from 1992 to 2019 is the substantial growth of urban areas by 66%, indicating significant urban development within the county. This surge in urbanization is a central theme in the land cover changes observed, reflecting evolving demographic and economic dynamics. Alongside this urban expansion, cropland and grasslands experienced modest declines of 2% and 8%, respectively, while bare areas and water bodies decreased by 12% and 23%, suggesting repurposing of land for urban use and potential changes in water management practices. Notably, the forested areas, while showing a slight 1% decrease, remained relatively stable, emphasizing the county's commitment to preserving green spaces amidst urban growth. Swansea County's land cover changes underscore the dynamic interplay between urban expansion and the preservation of natural features, shedding light on the evolving character of the region and the need for careful urban planning and environmental conservation efforts. This is shown in Table 8

and Figure 10.

Table 7. Land Cover Changes in Wrexham County (1992-2019).

Class Name	Land area (m ²)		
	1992	2019	% change
Cropland	133,579,320	130,296,845	-2%
Grasslands	488,638,084	481,298,832	-2%
Urban Areas	19,413,400	31,760,700	64%
Bare Areas	247,300	0	-100%
Forests	8,732,430	7,777,620	-11%

Table 8. Land Cover Changes in Swansea County (1992-2019).

Class Name	Land area (m ²)		
	1992	2019	% change
Cropland	58,817,600	57,478,833	-2%
Grasslands	258,637,410	238,934,720	-8%
Urban Areas	34,517,900	57,208,000	66%
Bare Areas	11,361,146	9,982,499	-12%
Water Bodies	3,190,930	2,452,500	-23%
Forests	9,401,810	9,275,750	-1%

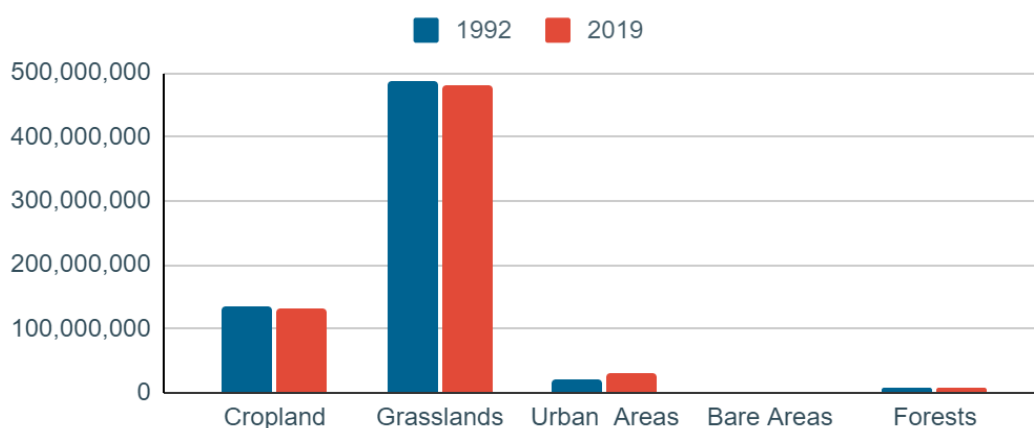


Figure 9. Land Cover Changes in Wrexham County (1992-2019).

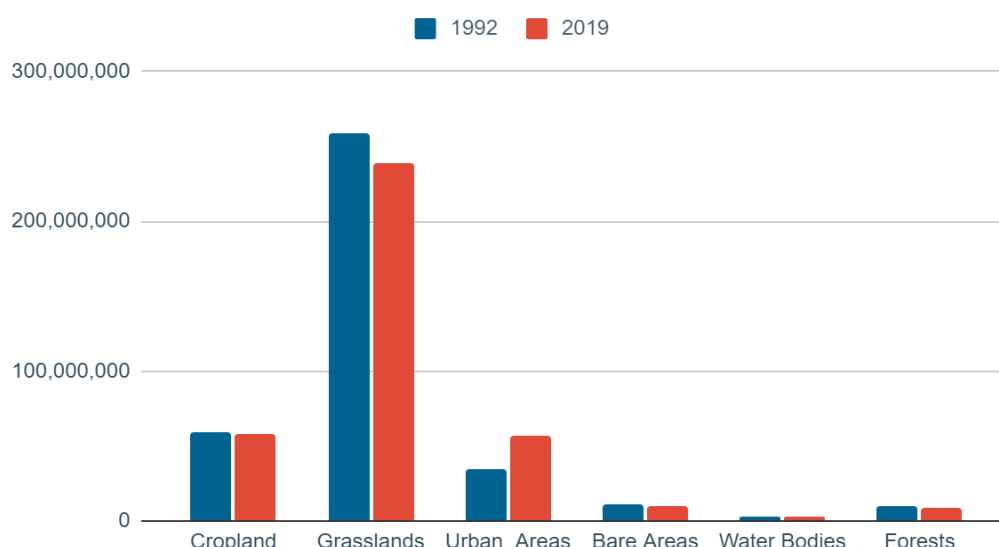


Figure 10. Land Cover Changes in Swansea County (1992-2019).

4.2. Impacts of Urbanization on the Ecology of Wales

It is important to state that substantial urbanization in any particular area impacts on or threatens the biodiversity and ecology of that area [20]. This investigation into land cover changes in Wales between 1992 and 2019 revealed a significant increase in urbanization, characterized by the expansion of built-up areas and infrastructure development. This transformation has undoubtedly impacted the local ecology, necessitating an examination of the ecological implications.

Having recorded significant urbanization between 1992 and 2019, there must be accompanying loss of habitat, fragmentation, and isolation which must have affected biodiversity within the study area. There will be an increase, due to emissions growth, in the generation of air pollutants [21], water and soil pollutants which often accompany urbanization. These pollutants have the capacity to harm ecosystems and human health. With the observed urban expansion within Wales, essential ecosystem services, including water cycling, soil formation, and nutrient cycling, will be disrupted. In addition, and according to [22], through increased energy consumption, greenhouse gas emissions, and urban heat island effects, there will be increased contribution to climate change within the study area.

The increased urbanization in Wales likely led to habitat destruction and fragmentation. According to [23], loss of habitat is the greatest threat to biodiversity. Loss of habitat impacts biodiversity in ways that lead to the eventual extinction of species that depend on that habitat. Remaining habitats may become isolated leading to fragmentation of population, reduced gene flow, and increased vulnerability to extinction. Nutrient cycling, pollination, seed dispersal, and other important ecosystem processes can be disrupted as a result of

loss of habitat. It can lead to reduced provision of ecosystem services, such as clean air and water, soil formation, and regulation of climate. It can also result in changes in species composition due to the fact that some species are more tolerant of habitat loss than others. The resilience of ecosystems to climate change can be reduced; this can make them more vulnerable to severe weather events and varying environmental conditions. It can also have negative impacts on the wellbeing of humans including decreased access to clean water and air, reduced food security, and loss of cultural and recreational opportunities.

The expansion of urban areas in Wales likely resulted in increased pollution, including water pollution. Increased urbanization can have negative consequences on water quality [24]. Storm water runoff can carry pollutants into waterways due to increased presence of impervious surfaces like pavements and buildings. Urban centers generate pollutants from industrial processes, vehicle emissions, and waste disposal and these can contaminate waterways. There can also be increased wastewater generation in urban areas from industrial, domestic, and commercial activities, and these can overload wastewater treatment systems leading to water pollution. Natural water flow patterns can also be altered by urbanization and this can result in changes in sedimentation [25], erosion, and deposition which can impact water quality. Urbanization can destroy natural buffers like wetlands and floodplains that can filter out pollutants and sediments from waterways. There can also be an elevated risk of waterborne diseases including cholera and typhoid fever as a result contaminated water sources and inadequate sanitation infrastructure.

There will most likely be increased contribution to carbon emissions as a result of increased urbanization in the study area. Urban areas are responsible for a significant proportion of global GHG (Greenhouse Gas) emissions [26], due mainly

to fossil fuel combustion, industrial processes and waste management. Urban areas are a significant source of Carbon dioxide emissions as a result of energy consumption, transportation, and industrial activities. Also, a disproportionate amount of energy is consumed in urban areas due mainly to heating, cooling, lighting, and transportation.

5. Conclusion

From 1992 to 2019, Wales experienced a significant increase in urban and built-up areas, marking a substantial shift in its land cover composition. Urban areas expanded dramatically, increasing from 1.81% of the land area in 1992 to 3.48% in 2019 showcasing significant urbanization and infrastructure development. While grasslands remained dominant, their share slightly decreased from 73.98% in 1992 to 72.16% in 2019. Cropland maintained a consistent presence at 17.48% of the land area in 2019, similar to 1992. Additionally, forests played a vital ecological role, with their share increasing from 5.30% in 1992 to 5.93% in 2019.

Analyzing urbanization dynamics in Welsh counties from 1992 to 2019 reveals a significant transformation in land use. The mean percentage change of approximately 97.29% across all counties indicates substantial urban expansion during this 27-year period, reflecting shifts in population, economic development, and urbanization. The median percentage change of 68.88% provides a typical perspective, highlighting that, for the median county, urban areas grew by nearly 69%, illustrating the range of urbanization experiences.

The analysis reveals how distinct land cover classes have transformed into urban zones. Cropland and grasslands, covering vast areas, transitioned into urban areas, signifying the conversion of agricultural regions into urban spaces. The conversion of bare areas and water bodies into urban zones indicates changes in the landscape with potential ecological implications. In addition, the shift of forested land into urban areas highlights the challenge of balancing urban growth with environmental conservation, especially in regions where forests contribute to biodiversity and ecological stability.

The research underscores the diverse trends in urbanization across Welsh counties, with varying degrees of change in land area and percentage change. These trends, influenced by factors like economic development and population growth, provide valuable insights for sustainable urban planning, equitable resource allocation, and the preservation of each county's unique character. Moreover, considering coastal perspectives highlights the importance of environmental preservation in regions with picturesque coastal landscapes. This research contributes to a comprehensive understanding of land use dynamics and urbanization in Wales, informing future development strategies.

Urbanization has far-reaching and devastating impacts on ecology and these include habitat destruction and fragmentation, loss of biodiversity and disruption of ecosystem, increased pollution and decreased air and water quality, urban

heat island effect and climate change, and disruption of natural processes and ecosystem services. These impacts can have severe consequences for both rural and urban ecosystems, ultimately affecting human health, wellbeing, and quality of life.

The outcome of this study has provided valuable insights for forest managers and policymakers, highlighting the importance of preserving and conserving the vegetation that appears to be diminishing in Wales, United Kingdom. The findings will inform strategic decision-making processes and guide initiatives aimed at maintaining and protecting the natural landscape within the region.

Abbreviations

GIS	Geographic Information System
LULC	Land Use and Land Cover
ESA	European Space Agency
GHG	Greenhouse Gas

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Ethics Approval

The paper reflects the authors' research and analysis completely and truthfully.

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The datasets utilized for this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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