CLIMATE-RESILIENT CITIES: TEMPORAL ANALYSIS OF URBAN LAND CHANGES, AND PERCAPITA GREEN SPACES FROM 1993 TO 2023: CASE STUDY OF COLOMBO, SRI LANKA

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Abstract: There is a dearth of research on how urban expansion and the reduction of green cover affect fast-growing cities in the Global South. This study conducted a time series analysis of changes in urban land use and land cover (LULC) in relation to per capita green space (GS) in Colombo, Sri Lanka, over a 30-year period (1993–2023) using Landsat satellite image analysis. It provides an in-depth exploration of the relationship between urban LULC and per capita GS reduction in a rapidly growing city within a tropical context. The study utilized the support vector machine technique for satellite image analysis and categorized five land use types: water bodies, built-up areas, bare lands, trees and shrubs (dense vegetation), and grasslands and lawns (sparse vegetation). The study found a clear decline in GS and an increase in built-up areas in Colombo; however, it also highlighted some positive changes due to the Colombo city remodelling program. Additionally, the study analysed Colombo's position compared to international per capita GS standards and proposed necessary actions for future improvement.

Keywords: *Land-use land cover, Landsat, Green Spaces.*

1. Introduction

Colombo is identified as one of the fastest-growing cities in South Asia. It is also the central economic hub of Sri Lanka and is responsible for more than 80% of the country's industrial output and 50% of GDP. Due to the accelerated urban infrastructure development especially during the post-civil war period, Colombo experienced a plummet in urban green spaces.

The Colombo city area has undergone serious economic, environmental, and social changes during the past three decades due to political and administrative changes, rural-urban migrations, and climate-induced natural disasters, that resulted in significant changes in land use patterns (Senanayake et al., 2013; Wickramasinghe et al., 2016, and Dammalage et al., 2019). Especially during the past civil war period (after 2014), several governments funded city remodelling programs, donor-funded wastewater management projects (grater Colombo wastewater management plan), and Doner-funded development projects (Port City development, kelani valley highway extension) were taken place. Under the city remodelling program, serious land use changes occurred, such as resettling underserved communities in high-rise buildings and clearing up slum areas for real estate development, developing new green spaces (ex: pocket gardens), establishing street tree lines, jogging and walking paths, and modifications to existing green spaces cater to the real estate market (Hettiarachchi, 2014).

The Colombo port city project, funded by the Chinese government had a major impact on the land use pattern of the study area by adding extra land area to the city. After the COVID-19 outbreak and following controversial political decisions country has undergone an economic crisis, and most of these development, and beautification projects had major setbacks. Some projects were permanently or temporally halted, and others were rolled back. It was reported that many resettled underserved communities returned to their previous residential areas, building new slums. Apart from that, the urban population has grown exponentially during the study period, which made Colombo one of the most compact and dense cities in the region.

The objective of this study is to analyze the changes in urban land use and land cover (LULC) in relation to per capita green space (GS) in Colombo, Sri Lanka, over a 30-year period (1993–2023), using satellite image analysis. The study aims to explore the relationship between urban expansion, the reduction of green cover, and the impact of these changes on per capita green space in a rapidly growing tropical city. It also seeks to assess Colombo's alignment with international GS standards and propose actions for future improvement.

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2. Literature review

Climate change (CC) has become the greatest challenge of our era due to its significant, inevitable, and sometimes irreversible impacts on the earth and living beings. Mitigating climate change and adaptation to its unavoidable effects are controversial and being discussed widely. Over half of the world's population now live-in urban areas, and by 2030, one person out of every three will live in a city (United Nations, 2016). These urban residents are highly vulnerable to the CC and its direct and indirect impacts. Thus, building cities resilient to the impacts of CC has become a top priority for local governments and citizens. According to UNISDR and UN-HABITAT, a "resilient city is characterized by its capacity to withstand or absorb the impact of a hazard through resistance or adaptation, which enables it to maintain certain basic functions and structures during a crisis, and bounce back or recover from an event" (UNISDR, 2012b;Soz, 2016).

Since the 1990s, green spaces (GS), i.e., a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in rural and urban settings (European Union, 2013-7), has developed as an alternative and sustainable approach to mitigate flooding hazards in urban areas. (Xiao et al. 2002; Webber 2020; Carter et al. 2017). The importance of urban GS is further highlighted by Food and Agriculture Organization (FAO) who mapped how urban forests advance nine Sustainable Development Goals (SDGs) including no poverty, zero hunger, good health and well-being, and sustainable cities and communities. Over the past century, developing countries have experienced a plummet in green cover due to urban development. In Colombo, a reduction of 13.44% green cover has been observed from 1956 to 2010. (Wickramasinghe et al., 2016). According to Senanayake et al. (2013), the green space percentage of the Colombo Municipal Council (CMC) was 24% in 2013.

Distribution of GS across the city plays a vital role in providing its benefits. Yet efforts to strategically integrate different social and ecological benefits into city-wide GS planning have so far been limited. Secondly, it is crucial to identify the relationship between urbanization, and the decline of GS. The next significant research gap is the lack of information for planners and designers to determine an appropriate strategy for GS planning. So far, various attempts have been made to quantify the benefits of green areas in urban contexts and to inform planning processes accordingly. Such attempts have, however, failed to permeate fully into the policy-making system either because they lack transparency in the methodology used or because they are too site- or service-specific (Farrugia, 2013) and there is a clear need for the research community to deliver more practically oriented tools and concepts for doing so.

Cities are already built, and if GS is to be used it is essential to determine the most efficient way of deploying them to achieve optimal benefits. Thus, developing a well-planned GS management strategy that ultimately can mitigate not only urban flooding but also mitigate other CC impacts on urban populations and improving their health and well-being is recognized as one of the most sustainable methods when developing resilient cities. However, at present, the introduction and management of GS are plagued by challenges particular to the local-level contexts, e.g., lack of resources, insufficient or unworkable information on existing GS, high demand for physical space, perceived undesirability and inconveniences of trees, and degraded urban environments. These limitations highlight the importance of a GS deployment strategy that enables robust decision making–mainly by providing an adequate technological and governance tool at the disposal of local governments in their transition towards a more sustainable future. Therefore, it would be worthwhile to explore the potential of emerging technologies and innovative approaches to support sustainable urban GS planning and management and to investigate how successful cases could be replicated in varying locales.

3. Methodology

In this study, we utilized medium-resolution (30 cm resolution) satellite imagery obtained from the United States Geological Survey (USGS). The imagery timeline ranged from 1993 to 2023 and was collected by Landsat 5-8 satellites. We downloaded level 2 products, which have been pre-processed for atmospheric and radiometric corrections. Satellite imagery with minimal cloud cover for each year was chosen to allow for maximum uninterrupted coverage. Further, any clouds or shadows present in the images were masked out using Fmask, following the method used by Basnayake et al. (202a). Table 1 provides comprehensive information regarding the satellite images acquired for each year of the study period, including details on sensors, date, path/row, and percentage of land cloud cover of satellite images.

Table 1 Sensors, Date, Path/ Row, and Land cloud cover of satellite images used for land use land cover analysis

Year	Satellite sensor	Sensor ID	Date	Path/ Row	Land Cloud cover
1993	Landsat 5 Level 2		1993-11-11	141/055	22%
1997	Landsat 5 Level 2	TM	1997-03-11	141/055	4%
2002	Landsat 7 Level 2	ETM	2002-10-27	141/055	15%
2009	Landsat 7 Level 2	ETM	2009-01-15	141/055	15%
2015	Landsat 8 Level 2	OLI-TRIS	2014-12-14	142/55	7.04%
2023	Landsat 8 Level 2	OLI-TRIS	2022-02-04	141/55	15.72%

3.1. STUDY AREA

Colombo City, the commercial, and industrial capital of Sri Lanka, which is responsible for more than 80% of the country's industrial output and 50% of GDP (Pussella et al., 2017). The Colombo Municipal Council (CMC) area is the western part of the Colombo city, authorized under the Colombo Municipal Council. With a 2,324,349 resident population and nearly 100,000 floating population (Census, 2012), Colombo is identified as one of the fastest-growing city in South Asia (World Bank, 2015). The study area maps are presented on figure 1.

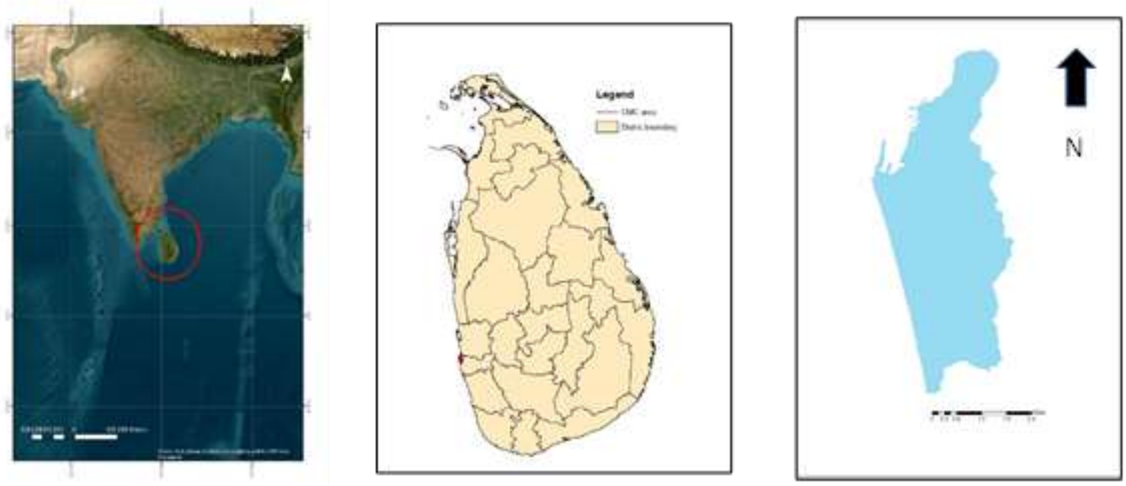

Figure 1, Study area (*Source: Author*)

3.1.1 Land-use Land-cover change detection

Five land use and land cover classes were identified in the study area: built-up areas, water bodies, bare lands, lawns and grasslands (sparse vegetation), and trees and shrubs (dense vegetation). We selected the highest possible number of training samples for each class based on the consistency and distribution of the satellite images. Land use and land cover classification was performed using the support vector machine technique. In this supervised classification method, each image pixel is assigned to the category most similar to its spectral signature, corresponding to recognized land cover types. The classification was implemented using the ArcGIS 10.8 software package. Accuracy assessment was conducted by selecting 100 random spatial points for each satellite image. For historical datasets, Google Earth images (from 1993 to 2023) and past land use maps available on the Google Earth platform were used for accuracy assessment. To ensure consistency, the classified images were resampled to a spatial resolution of 30 meters by 30 meters.

3.1.2 Per capita green spaces

The percentage of green space (GS) relative to the total extent of an urban area can be used to assess the environmental sustainability of a city (Chiesura, 2004). Various organizations have established standards to determine a city's ecological sustainability, such as the per capita GS requirements set by the World Health Organisation (WHO) and the United Nations (UN). The WHO recommends a minimum per capita GS of 9 square meters for a sustainable urban life, while the UN standard is 30 square meters. The per capita GS for Colombo city was calculated each year using population data and these per capita green space requirements.

4. Results and Discussion

The LULC maps were prepared using Landsat satellite images and accuracy assessment was carried out.

4.1. ACCURACY ASSESSMENT OF LULC MAPS

Table 2 presents the accuracy assessment results for the prepared land use and land cover (LULC) maps, while Figure 2 displays the LULC maps for 1993, 1997, 2002, 2009, 2015, and 2023. The study identified five categories of land use: water bodies, built-up areas, bare lands, trees and shrubs, and grasslands and lawns. Water bodies, built-up areas, and bare lands were categorized as non-green spaces, whereas trees and shrubs (dense vegetation) and grasslands and lawns (sparse vegetation) were categorized as green spaces. User accuracy, producer accuracy, and kappa coefficient values were assessed for all land use categories. Table 2 shows that user accuracy, producer accuracy, and kappa coefficient values are close to 1, indicating that the maps are sufficiently accurate for further analysis. The total land area is 37.29 km^2; however, additional land areas, such as Colombo Port City, were excluded from the study.

With the economic development of the country, there has been a significant development of infrastructure in Colombo city. As such, the LULC of the city has changed drastically. Most of the green areas were converted to developable (vacant) land plots, and later in to built-up areas. It is clearly visible that urbanisation caused significant deterioration of urban greenery in Colombo. Further, during the period of 1997-2002 there is clearly visible changes in the land use pattern of CMC area, with a hype of built-up areas, and which scarified cities greenery.

Table 2 Accuracy Assessment 2022 LULC map

Year	User Accuracy	Producer Accuracy	Kappa coefficient
1993	0.77	0.91	0.81
1997	0.81	0.94	0.88
2002	0.82	0.93	0.86
2009	0.78	0.91	0.82
2015	0.93	0.80	0.85
2023	0.92	0.90	0.81

4.2. LAND USE LAND COVER CHANGES

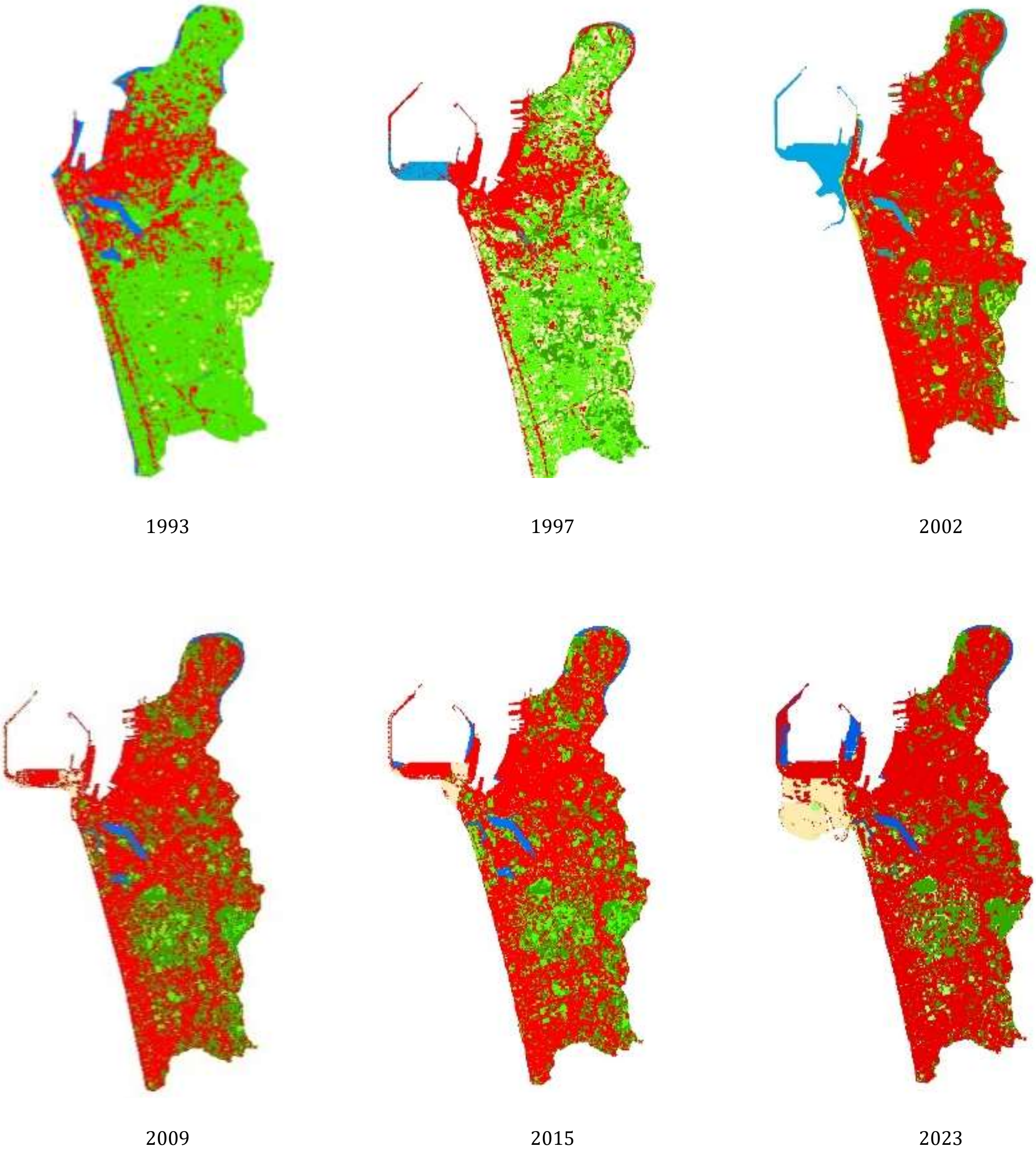

Figure 2, Temporal changes of LULC in CMC area (*Source: Author*)

Following table 3 present the area extent of different land use types, from 1993 to 2023, as a percentage of the total CMC area 37.27 km^2. Figure 3 clearly shows a gradual increase in built-up areas and a decrease in urban green areas. However, a slight increase in green areas is observable in 2015 compared to 2009. This increase can be attributed to the city remodelling program undertaken during that period.

Table 3I Different land use areas as a percentage of total study areas in different years

Year	Water bodies	Built up area	Bare lands	Trees and Shrubs	Grasslands and lawns
1993	9.29	10.71	8.51	54.15	17.33
1997	2.24	24.14	2.95	49.63	21.04
2002	1.78	63.32	2.02	26.35	6.52
2009	2.36	67.61	1.81	14.59	13.62
2015	3.05	67.68	5.27	17.01	6.99
2023	2.8	72.44	5.21	14.27	5.28

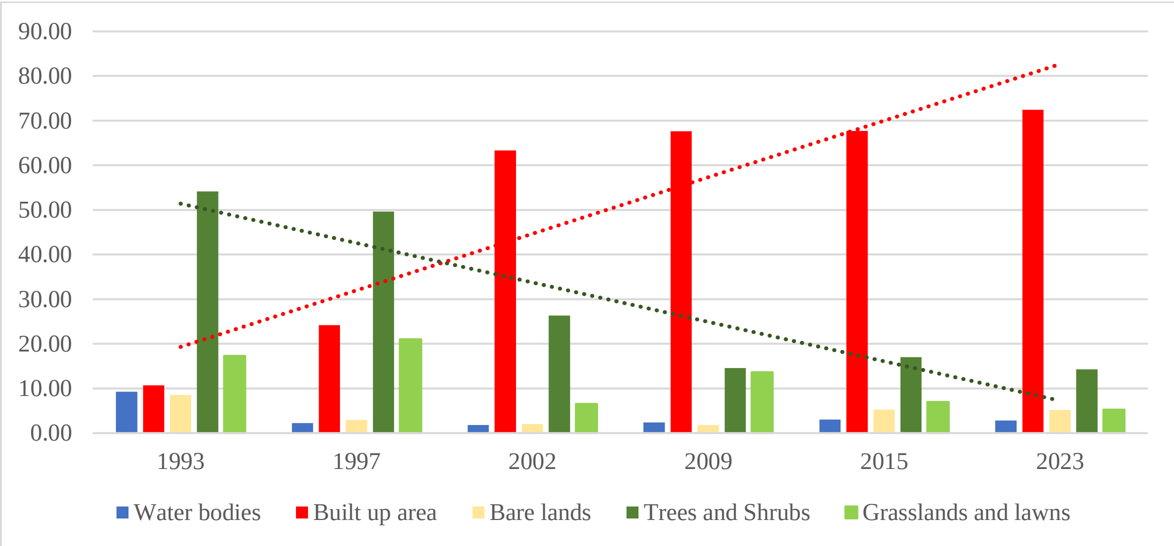

Figure 3, Temporal changes of LULC in CMC area (*Source: Author*)

4.3 PER-CAPITA GREEN SPACE ANALYSIS

The temporal analysis of per capita GS is presented in Table 4. Both trees and shrubs, and grasslands and lawns are considered as GS. The data clearly show that per capita GS is significantly decreasing over time. Although the amount of per capita GS remains above the WHO standard of 9 m^2, it is significantly below the UN minimum standard of 30 m^2. Given the exponential increase in population and urban development, it is critical to take action to prevent the city from facing an ecological disaster. Furthermore, with the growing urban population, the pressure and ecological demand on existing GS are very high, which could potentially lead to ecological collapse if not addressed.

Table 4: Per capita green spaces in Colombo Municipal Council Area

Year	Total green (km^2)	Total green (m^2)	Population size	Per capita GS
1993	26.65	26654892.00	622,894	42.79
1997	26.35	26352843.00	634,816	41.51
2002	12.26	12257223.00	638,910	19.18
2009	10.52	10519509.00	582,025	18.07
2015	8.95	8949600.00	581,107	15.40
2023	7.29	7290195.00	632,543	11.53

Figure 4 indicates the percentage changes in different land use types in the CMC area over the past 30 years. It shows that the area of water bodies decreased during the first decade, increased in the second decade, and then decreased again in the last decade. In contrast, built-up areas have significantly increased over time. Bare lands initially showed an increasing trend, but the extent of bare lands decreased between 2009 and 2015. However, there was an increase in bare land extent again between 2015 and 2023.

For trees and shrubs, there was a significant reduction in area from 1993-1997, 1997-2002, and 2002-2009. However, the area of trees and shrubs increased during 2009-2015, only to decrease again between 2015 and 2023. Regarding grasslands and lawns, the area initially increased but saw a significant decrease between 1997 and 2002. From 2015 onwards, the area of grasslands and lawns has been significantly decreasing.

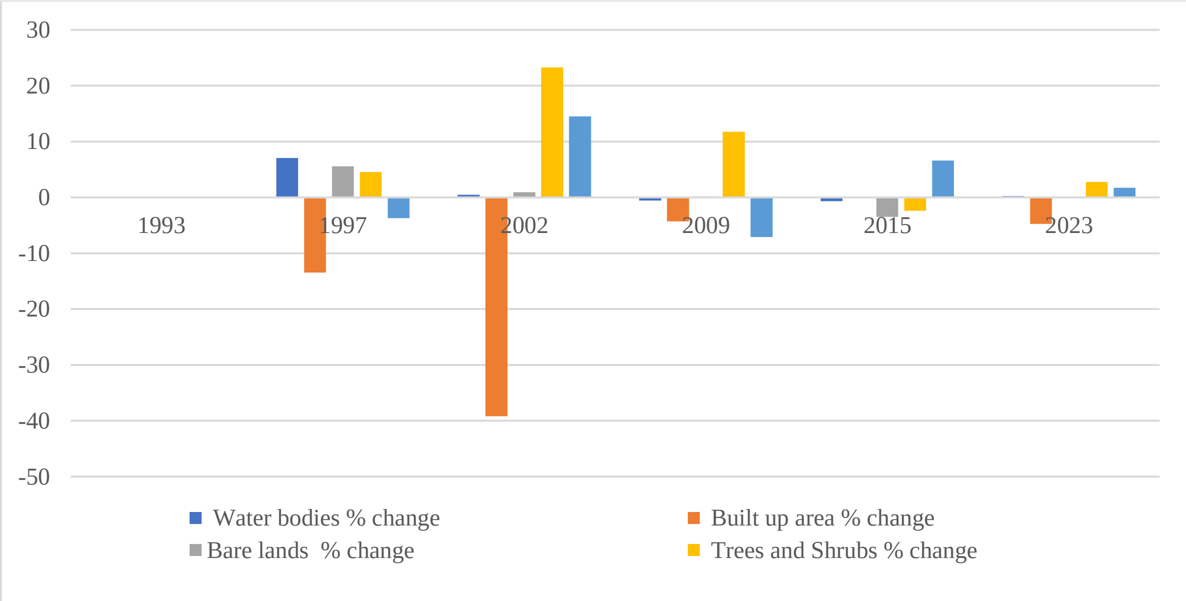

Figure 4, Percentage difference of LULC in CMC area (Source: Author)

5. Conclusion: Does Colombo have enough per capita GS?

Rapid urbanization in Sri Lanka has led to a reduction in urban green spaces and their degradation due to unplanned changes in LULC. Between 1993 and 2023, these changes resulted in the loss of over 60% of urban greenery. The consequences of this destruction are evident in altered hydrological processes and the spatial and temporal redistribution of moisture.

In LULC classification, water bodies, buildings, and bare lands were categorised as non-urban green spaces (non-UGs), while urban trees and shrubs, lawns, and grass were classified as urban green spaces (UGs). The results clearly indicate that per capita green space (GS) is significantly decreasing over time. Although the per capita GS in 2023 is 11.53 m^2, which is higher than the WHO minimum standard of 9 m^2, it is still much lower than the UN minimum standard of 30 m^2. In 2017, Li & Pussella conducted a study titled “Is Colombo City, Sri Lanka Secured for Urban Green Space Standards?” According to their study, the per capita GS in the Colombo Municipal Council (CMC) area in 2015 was 7.16 m^2, which is below the WHO standard. They used the NDVI mapping technique for urban GS mapping, whereas this study employed the Support Vector Machine technique, which is novel and widely accepted in the research community.

It was observed that there was an increase in green areas and water bodies in the study area between 2009 and 2015. This can be attributed to city remodelling programs undertaken after the civil war period in Sri Lanka. During these remodelling programs, some built-up areas, such as slums, were cleared to make way for green spaces, including jogging paths and recreational areas. Additionally, some deteriorated water bodies were rehabilitated, leading to an increase in water body areas during this period. However, these improvements were reversed after 2015, as evidenced by the trends observed from 2015 to 2023. It can be concluded that the per capita GS requirement in Colombo meets the WHO standard but falls short of the UN standard. More importantly, this amount is decreasing rapidly. If this trend continues, per capita GS levels could fall well below WHO standards. Therefore, strategic and rapid planning is essential to maintain GS in the Colombo Municipal Council (CMC) area and ensure the continued provision of urban ecosystem services.

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