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Land Use and Land Cover Change in East Java Indonesia from 1972 to 2021: Learning from Landsat

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This study analyses land use and land cover (LULC) changes during the last five decades (1970–2021) in East Java Province, Indonesia. The changes are analysed by comparing four maps interpreted from Landsat images (MSS 1972, TM 1997, OLI 2013, and OLI 2021). The main research procedures consist of (1) data collection, (2) field survey, (3) image classification, and (4) LULC change interpretation. The classification uses the maximum likelihood algorithm, achieving an overall kappa accuracy of > 75%. The classification produces eight classes, i.e., built-up land (BU), heterogeneous agricultural land (HAL), bare soil (BS), paddy fields (PF), open water (OW), vegetation (VG), shrubland (SH), and wetlands (WL). The analysis shows a significant shift in land use from 1972 to 2021, with HAL declining by 46%, SH by 91%, and BS by 88%. In contrast, PF has increased by 105%, VG (forest and plantation) by 64%, and built-up areas by a remarkable 366%. These changes show a significant shift from dryland agriculture, shrublands, and barren lands to irrigated regions, vegetated areas, and urban growth. Furthermore, there are increases in water bodies due to the construction of several reservoirs to support water availability. In coastal regions, the development of inland aquaculture leads to a proliferation of wetlands (salt evaporation ponds, fish ponds, and rice-fish integrated farming).

Keywords: LULC, change, monitoring, landsat, East Java.

Introduction

The term ‘land use’ refers to humans using the land surface. Typically, land use is defined within an economic context, considering agricultural, residential, commercial, and various purposes. However, the actual utilisation of the land is rarely visible to the naked eye, except under very close inspection. Therefore, the concept of 'land cover' is also considered, encompassing the visible features of the earth's surface, including vegetative cover, both natural and modified by human activity, its structures, transportation and communication, and so forth. Land use and land cover change involves the alteration and transformation of the earth's surface, both in terms of how land is utilised by humans and its physical attributes (Campbell, 2008; Nath et al., 2018; Rash et al., 2023). Land use and land cover change (LULCC) is a dynamic process that profoundly shapes a region's environment, economy, and society (Allan et al., 2022). The dynamic nature of our planet's landscapes, driven by human activities and natural processes, has prompted the need for comprehensive and accurate monitoring tools to understand and manage LULCC. In this context, Landsat imagery has emerged as a powerful and indispensable resource for researchers, policymakers, and land managers (Achmad et al., 2016; Alam et al., 2020).

Landsat, which dates back to the launch of Landsat 1 in 1972, a series of Earth-observing satellites launched by NASA and the U.S. Geological Survey (USGS), has provided over five decades of consistent and high-quality imagery, offering a valuable dataset for studying land use and land cover change (LULCC) on a global scale (Zhu et al., 2019). This helpful resource has empowered researchers to monitor and analyse LULCC with unprecedented accuracy and consistency over an extended period (Cohen and Goward, 2004). The data collected by Landsat satellites offer a unique window into the transformation of the Earth's surface, allowing for the tracking of changes in land use and land cover patterns across diverse landscapes and ecosystems (Piao et al., 2023).

The Landsat data series has been pivotal in monitoring LULCC across various regions and ecosystems. For instance, Landsat imagery has been essential in assessing the impact of urbanisation on land cover transformation, as demonstrated by Almazroui et al. (2017) in Jeddah, where it helped quantify the urban expansion rates. Additionally, Landsat imagery has been explored to assess agricultural shifts. For instance, Hao et al. (2018) harnessed the Landsat series to generate yearly cropland distributions from 2001 to 2016 in Central Asia, underlining its role in agricultural monitoring. Another study by Jamal and Ahmad (2020) utilised Landsat imagery to assess land use and land cover change in Kashmir Valley, providing insights into the impacts of human activities on wetland ecosystems. These examples demonstrate Landsat's significance in showing complex land use and land cover (LULC) patterns and delivering insightful information for sustainable land management and conservation.

Due to human activities, East Java has also experienced dramatic LULCC during the past 50 years. A study by Sujarwo et al. (2022) shows that LULCC impacts the hydrological processes on Brantas watersheds. Studies by Maryantika and Lin (2017) and Sianturi et al. (2019) also shows LULCC on the coastal ecosystems of Sidoarjo and Gresik Regency, East Java, where green space, mangrove forests, and barren lands are converted into farming, industrial, and residential uses due to extensive economic and industrial development. This study attempts to expand the current regional study to encompass the entire East Java Province, as there is a lack of research that studies the prevalence of LULCC more broadly, making it possible to identify more extensive alterations.

This study aims to analyse the LULCC during the last five decades in East Java Province, Indonesia, and to investigate its causes and drivers. East Java is Indonesia's second most populous province after West Java. The 2020 census data shows that the population of East Java Province amounted to 40 million, which increased by 16.97% from 2000 (BPS-Statistics of Jawa Timur Province, 2023). Extensive investigation is required to assess the influence of this enormous population growth on the LULCC profile in East Java Province using the Landsat Series in 1972, 1997, 2014, and 2021.

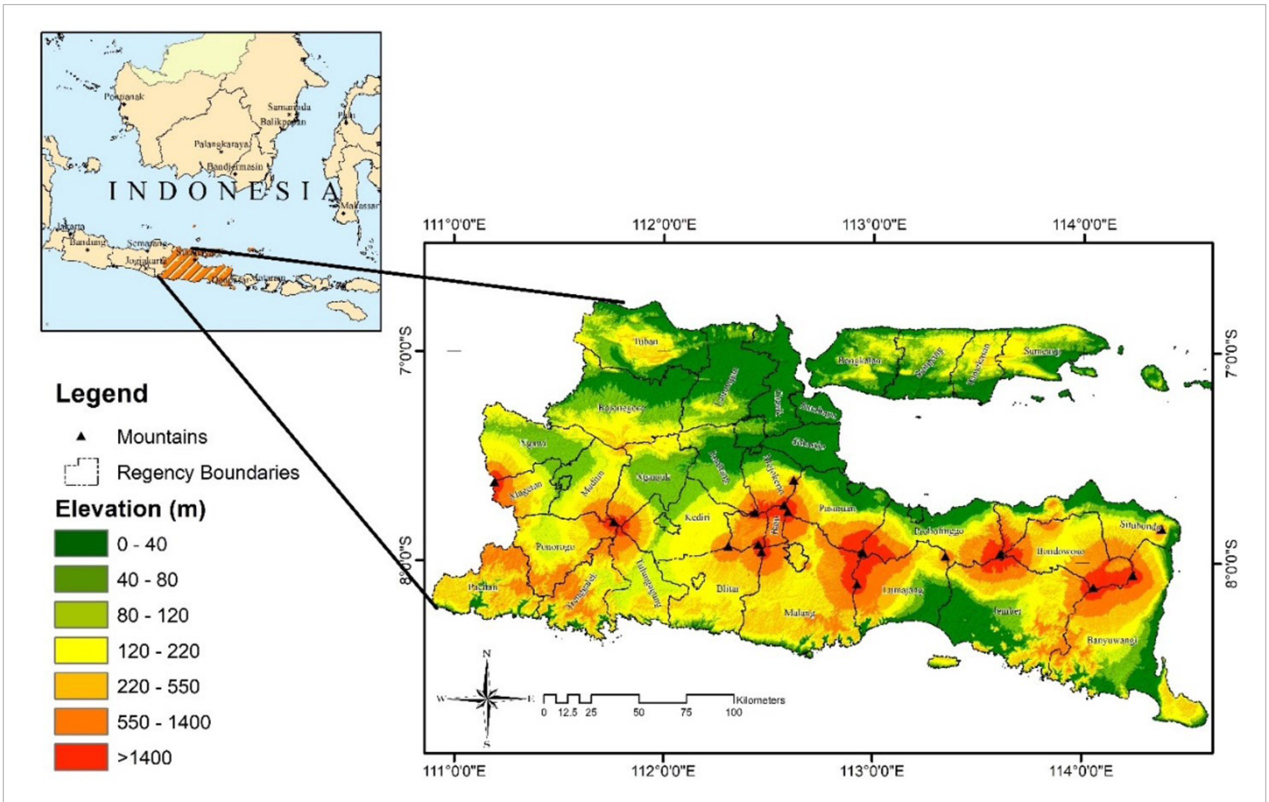
Methods

Study area

The study was conducted in the East Java province, Indonesia (*Fig. 1*), covering an area of 47 075.35 km^2. According to the BPS-Statistics of Jawa Timur Province (2022), this region experiences a tropical climate with hot and wet seasons, with an average temperature of 27.1°C and average precipitation of 210.5 mm/month. Based on 30-m digital elevation model data from the Shuttle Radar Topography Mission (NASA, 2013), the elevation ranges from 2 to 3669 meters above sea level.

East Java has many active volcanoes on its surface due to its location just above the Alpide belt. Mount Semeru, the highest summit on the Island of Java, is

Fig. 1. *Study area*



one of them. East Java is a very fertile region that is well suited for varied agricultural cultivation due to these rows of volcanoes (Israel, 2010; Qi, 2017). According to BPS-Statistics Indonesia (2022) survey data for 2022, East Java produces the most rice in Indonesia, with a harvested area of about 16 932.11 km^2. Compared to 2018 data, this number has dropped by 3.3%; compared to 2015 data, it has plummeted by 21.3% (BPS-Statistics Indonesia, 2015).

This study used multitemporal Landsat Data Series as the primary input, i.e., Landsat 1 MSS, Landsat 5 ETM, and Landsat 8 OLI/TIRS. The imageries were generated on the Google Earth Engine (GEE) code editor platform. Google Earth Engine is a cloud-based platform that allows users to easily access high-performance computing resources for processing large geographic datasets (Gorelick et al., 2017), such as East Java Province satellite imagery. The image collections were filtered based on minimum cloud cover with the help of the cloud mask function to eliminate areas that are covered by cloud (Basheer et al., 2022). Additionally, the gathered images were aggregated using median techniques to fill in the gaps in the hazy pixels. *Table 1* shows the metadata related to the imageries used in the study.

Input data

The image data utilised in this study (*Table 1*) is mainly Tier 1 Surface Reflectance that has been atmospherically and geometrically corrected (USGS, 2019). Due to existing constraints, Landsat-1 imagery uses Tier 2 DN values. Geometric and atmospheric modifications are thus required for this data to improve the quality. QGIS software is used for both rectification processes. The DOS algorithm is utilised in the atmospheric correction process to minimise the impacts of atmospheric disturbances on the images (Chavez, 1988). Meanwhile, the ground control points used for geometric correction are acquired from existing corrected Landsat images and aided with a 25 000-scale Indonesian Earth Map (*Rupa Bumi*) retrieved from Indonesian Geospatial Information Agency portal web. All images in this study were georeferenced using the UTM WGS84 Zone 49S projection system.

Table 1. *Raw metadata*

Satellite	Acquisition	Data type	Composite
Landsat 1 MSS	01/08/1972 - 31/12/1972	Collection 1 Tier 2 DN Values	Green, Red, NIR 1 – 2
Landsat 5 ETM	01/01/1997 - 31/12/1997	Collection 1 Tier 1 SR	Blue, Green, Red, NIR, SWIR 1 – 2
Landsat 8 OLI	01/01/2013 - 31/12/2014	Collection 1 Tier 1 SR	Blue, Green, Red, NIR, SWIR 1 – 2
Landsat 8 OLI	01/01/2020 - 31/07/2021	Collection 1 Tier 1 SR	Blue, Green, Red, NIR, SWIR 1 – 2

Table 2. *LULC classes description*

Classes	Description
Built-up area (BU)	BU represents all artificial or human-made objects within the study area, including buildings, settlements, paved surfaces, etc.
Heterogeneous agricultural land (HAL)	HAL comprises all agricultural areas featuring diverse non-paddy cultivation, dryland farming, seasonal crops or secondary food commodities (known as *palawija* in Indonesia), i.e., corn, sugarcane, soybean, and cassava (Squires and Tabor, 1991).
Bare soil (BS)	Bare soil (BS) refers to areas devoid of significant vegetation, often covered with sand or rock. Sandy terrain is commonly found along coastlines, while rocky landscapes are predominant in mining and mountainous regions.
Paddy field (PF)	Arable agricultural land is predominantly used for growing rice crops.
Open water (OW)	OW represents land features that are submerged under deep water, such as lakes, rivers, and reservoirs.
Vegetation (VG)	VG represents all non-agricultural areas occupied by woody perennial plants, dense tropical forests, mixed forests, and plantations.
Shrubland (SH)	SH covers all surface features, including grass, bush, arid landscapes with sparse/less vegetation, and vacant farmland.
Wetland (WL)	WL represents surface features characterised by shallow water, inundated areas, or ponds, often utilised for various purposes such as fish, shrimp, and salt farming. Wetlands are commonly found along seashores and predominate the northern section of the main island of East Java.

This region's primary land cover profile is represented by eight land cover classes (*Table 2*), derived based on the researcher's understanding of the study area, field surveys, and the interpretation of available Landsat images. Each picture period uses 500 ground-truth points for data processing, with 80% of the points utilised for training samples and the remaining 20% for accuracy assessment. Google Earth Pro includes additional ground-truth points for the present era (2020–2021) in difficult-to-access regions, e.g., top of mountains, dense forests, and remote areas. This study also used historical photos from Google Earth to acquire ground-truth locations from 1972 to 2014.

The corrected images were then classified with the MultiSpec© software version 2020.09.09 using the supervised maximum likelihood classifier (MLC) method. MultiSpec© is a freeware image data analysis programme created for interactively analysing Earth's observational multispectral and hyperspectral image data from aerial and spaceborne devices (Biehl and Landgrebe, 2002). This programme can also calculate the kappa and overall accuracy of the classified images. However, we repeated accuracy testing in QGIS using the AcAtaMa plugin (Llano, 2019). This accuracy test will also generate overall and kappa accuracy results from classified images. The stratified random sampling-area based proportion approach created the accuracy test distribution points, which resulted in more exact and representative accuracy numbers (Carrão et al., 2007). However, before entering the accuracy testing procedure, the classified images are post-processed using the majority filter and sieve tools to decrease noise and the influence of salt and paper or image spots (Kelly et al., 2011).

Results and Discussion

Classification results

Kappa and overall accuracy of classified 1972–2021 images show values ranging from 75.94 to 95.18% (*Table 3*). The lowest kappa and overall accuracy were obtained in the 1972 image. The low accuracy value is due to the Landsat 1 MSS image specification, which is lower than Landsat 5 and 8 with a spatial resolution of 60 meters and four spectral bands, making this image classification quite complicated (Phiri and Morgenroth, 2017). However, from the obtained accuracy value, the classified Landsat 1 imagery can still be calculated and reaches a substantial agreement (61–80%). Whereas in classified Landsat 5 and 8 images, the accuracy values obtained reach an 'almost perfect agreement' which ranges from 81 to 99% (Bogoliubova and Tymków, 2014).

The individual producer's and user's accuracy for each class is mostly more significant than 80%. Therefore, we can state that the classified images meet the standard classification processes (Foody, 2008). The lowest producer (PA) and user (UA) accuracy values are BS (60.64%) and SH (58.18%) in Landsat 1 imagery. These two classes are land cover types that are difficult to classify because they have similar colour characteristic profiles and mixed locations. In general, three land cover classes have difficulties in their classification, namely BU, BS and SH. Many of these land cover types in East Java are mixed, fragmented, and predominantly in smaller areas (Suprajaka, 2009). So, classifying this land cover becomes challenging with the existing Landsat resolution (30–60 m).

Table 3. *Accuracy assessment results of classified images*

Class	1972		1997		2013		2021	
	PA	UA	PA	UA	PA	UA	PA	UA
PUA	80.65	64.66	96.77	90	71.58	88.31	79.37	86.96
HAL	76.56	90.21	95.26	95.77	90.65	88.11	95.65	81.48
BS	60.64	62.64	77.78	95.45	90	100	89.47	77.27
PF	85.08	83.24	100	91.28	88.69	79.41	96.52	90.77
OWB	100	100	100	96.67	100	100	75.86	73.33
VG	92.13	96.14	92.5	100	87.79	91.85	89.95	95.77
SH	73.28	58.18	75.86	95.65	76.62	71.08	85.42	93.18
WL	100	91.67	97.3	100	91.67	100	78.26	100
Over. acc.	79.82		95.18		84.82		88.27	
Kappa	75.94		94.09		81.14		85.73	

Overall LULC changes

Fig. 2 shows the LULC classification of four classified images. The overall coverage and percentage of each class are summarised in *Table 4*. The eight main classes (*Table 2*) were classified, and the total area obtained in each period is 47 045.35 km^2. In general, dryland (HAL and SH) dominated the regional studies in the first periods (1972), while in the following periods, this dominance was replaced by PF. In *Fig. 2*, the changes in land cover were determined using the 'From-To' criteria, which identifies transitions between different land cover types. Meanwhile, *Fig. 3* and *Table 5–7* display these detected changes along with the transformation matrix.

The Landsat MSS 1972 classified images show that most LULC classes in this period were HAL, VG, and SH, respectively. HAL covers an area of about 15 932.66 km^2 (33.85% of the total area), while VG and SH cover 19.53% and 16.99% of the whole area. Rice is the primary food for 95% of Indonesians, and most rice is grown in paddy fields on Java Island (Widiatmaka et al., 2016). East Java is also known as a national food barn, with Indonesia's largest harvested areas, productivity,

Fig. 2. *Classified images*

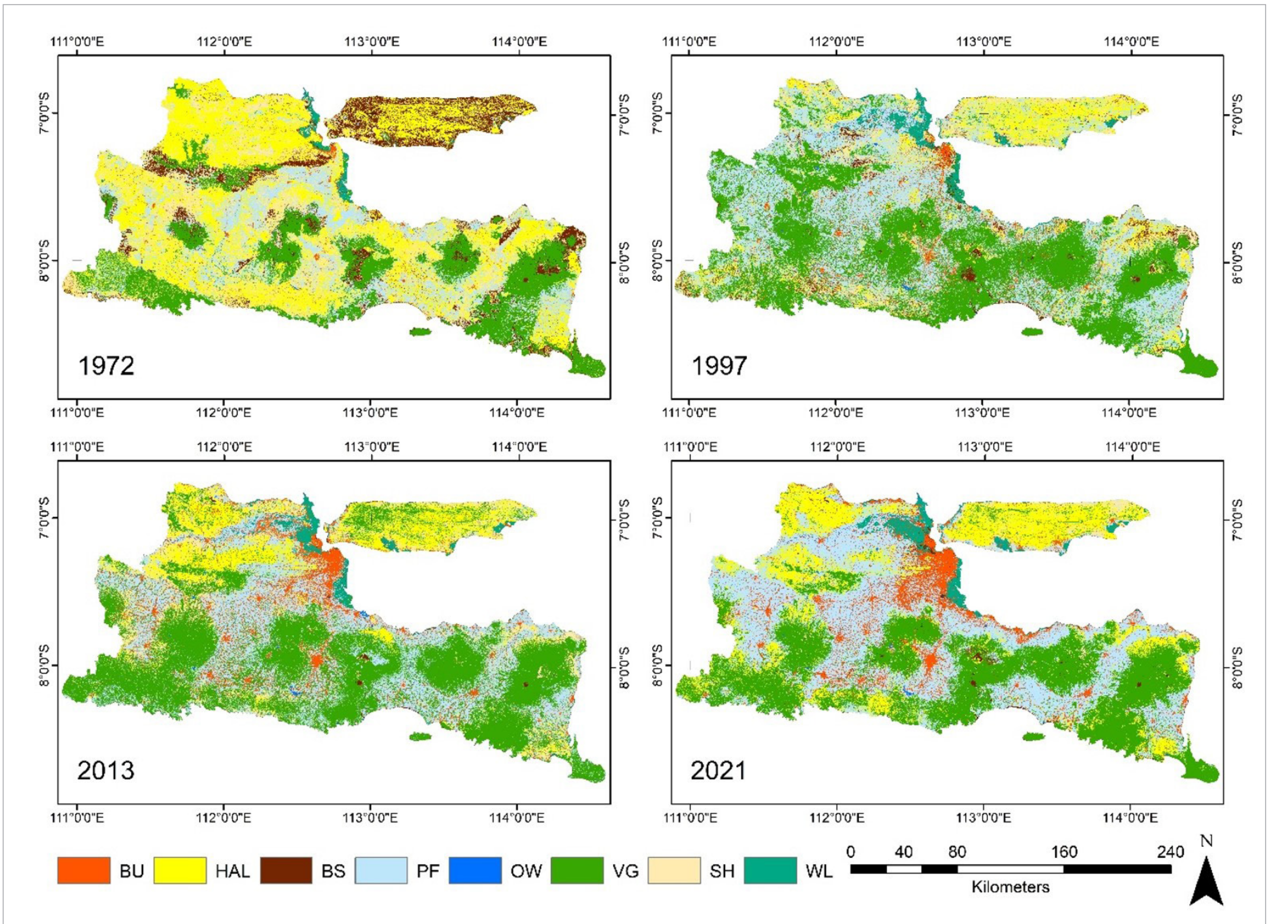


Table 4. *LULC area*

Classes	Landsat 72		Landsat 97		Landsat 13		Landsat 21	
	km²	%	km²	%	km²	%	km²	%
BU	939.90	2.00	1954.36	4.15	3734.10	7.93	4387.29	9.32
HAL	15 932.67	33.85	5557.63	11.81	5802.89	12.33	8530.25	18.12
BS	4445.59	9.44	1492.36	3.17	183.97	0.39	496.42	1.05
PF	8026.60	17.05	17 369.30	36.90	12 549.78	26.66	16 490.24	35.03
OW	41.56	0.09	77.01	0.16	160.77	0.34	184.76	0.39
VG	9194.88	19.53	17 219.75	36.58	19 425.35	41.26	15 158.83	32.20
SH	7997.54	16.99	2369.42	5.03	4328.01	9.19	694.37	1.48
WL	496.61	1.05	1035.52	2.20	890.48	1.89	1133.18	2.41
Total	47 075.35	100.00	47 075.35	100.00	47 075.35	100.00	47 075.35	100.00

Fig. 3. *Land use change detection map from 1972 to 2021*

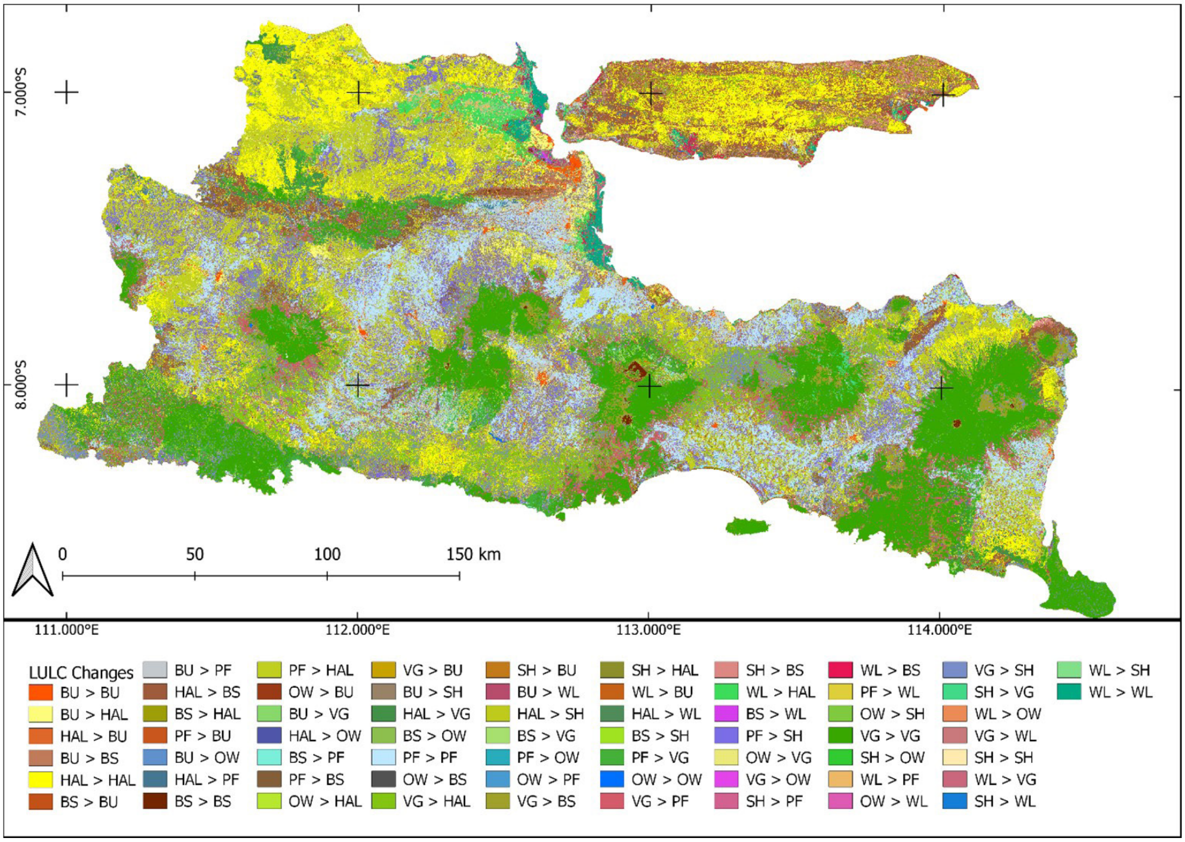


Table 5. *1972–1997 conversion matrix*

Class	1997								Total
1972	BU	HAL	BS	PF	OW	VG	SH	WL	
BU	939.90	0	0	0	0	0	0	0	939.90
HAL	342.23	3029.72	548.43	7142.86	31.70	3456.87	1052.55	328.30	15 932.67
BS	81.35	1065.33	319.30	1219.22	8.45	1030.30	624.15	97.50	4445.59
PF	233.22	430.44	98.33	4318.91	2.15	2789.88	101.39	52.28	8026.60
OW	0.36	1.07	4.21	4.02	13.96	2.40	0.41	15.13	41.56
VG	62.58	324.30	157.21	1291.68	0.75	7201.33	104.44	52.59	9194.88
SH	283.00	701.17	334.77	3361.87	7.49	2718.37	483.05	107.82	7997.54
WL	11.72	5.59	30.12	30.74	12.50	20.60	3.43	381.91	496.61
Total	1954.36	5557.63	1492.36	17 369.30	77.01	17 219.75	2369.42	1035.52	47 075.35

Table 6. *1997–2013 conversion matrix*

Class	2013								Total
1997	BU	HAL	BS	PF	OW	VG	SH	WL	
BU	1089.97	98.51	7.09	313.35	4.30	274.89	158.95	7.30	1954.36
HAL	486.01	1993.85	10.73	957.19	3.24	1252.63	845.83	8.14	5557.63
BS	233.88	143.87	72.47	302.43	12.11	447.41	216.09	64.10	1492.36
PF	1153.48	2091.18	28.13	7718.62	24.59	4625.21	1618.43	109.66	17 369.30
OW	2.73	3.66	1.05	3.05	62.67	1.11	0.74	2.00	77.01
VG	438.45	706.56	12.08	2779.98	4.12	12 312.49	953.88	12.18	17 219.75
SH	260.79	758.56	9.94	332.94	2.12	471.29	527.07	6.71	2369.42
WL	68.78	6.70	42.49	142.23	47.61	40.32	7.01	680.38	1035.52
Total	3734.10	5802.89	183.97	12 549.78	160.77	19 425.35	4328.01	890.48	47 075.35

Table 7. *2013–2021 conversion matrix*

Class	2021								Total
2013	BU	HAL	BS	PF	OW	VG	SH	WL	
BU	2383.07	196.61	81.60	806.03	11.39	158.63	13.93	82.84	3734.10
HAL	332.93	3209.89	53.61	1690.21	12.75	167.78	318.43	17.28	5802.89
BS	16.70	17.05	76.46	24.12	7.08	9.81	1.89	30.86	183.97
PF	918.00	740.59	106.86	8667.47	28.30	1845.22	52.05	191.30	12 549.78
OW	6.43	0.95	8.89	32.61	89.58	3.33	0.08	18.90	160.77
VG	324.01	2743.42	80.66	3629.64	17.44	12 454.88	143.04	32.27	19 425.35
SH	365.92	1621.09	46.47	1595.13	5.87	516.54	164.91	12.09	4328.01
WL	40.23	0.64	41.87	45.04	12.36	2.65	0.04	747.65	890.48
Total	4387.29	8530.25	496.42	16 490.24	184.76	15 158.83	694.37	1133.18	47 075.35

and rice production (BPS-Statistics Indonesia, 2021). However, during this period, drought occurred, causing the paddy planting area to decrease. As a substitute, farmers have switched to planting corn and various other crops as a substitute for rice; these substitutes only require a little water to cultivate (Hardjosoekarto, 1982; Abisono, 2002). Furthermore, due to the drought, many agricultural areas lie fallow or are not farmed; therefore, the site of SH is relatively broader than PF.

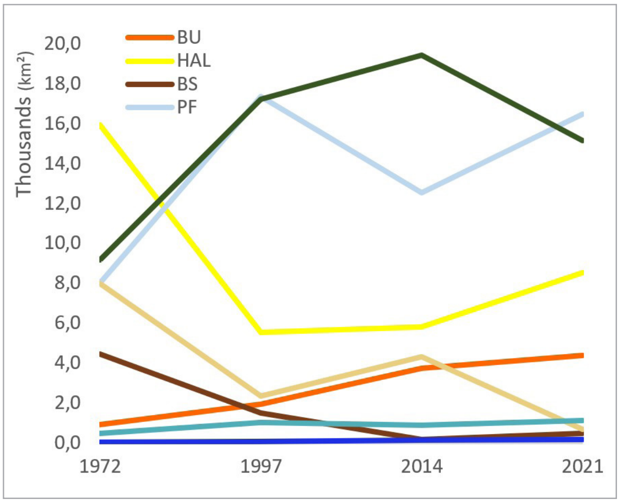
The PF area significantly increased by 116.4% in the subsequent period (Landsat ETM 1997). This growth was marked by the development of BU (107.93%), OW (85.30%), VG (87.28%), and WL (108.52%). Meanwhile, the areas of HAL, BS, and SH witnessed decreases of 65.12%, 66.43%, and 70.37%, respectively. After the 1972 drought, vegetation and agricultural conditions have expanded due to the conversion of dry-barren lands back onto fertile soil. The conversion matrix in *Table 5* reveals that 7142.86 km^2 of HAL and 3361.87 km^2 of SH were changed to PF, while 3456.87 km^2 of HAL and 2718.37 km^2 of SH were converted to VG. Meanwhile, in BU, the high population growth rate of 1.2% per year between 1972 and 1997 increased the need for housing and other urban facilities. The other LULC classes, namely HAL, PF, and SH, were mainly transformed into BU to meet this demand. WL and OW also experienced an increase during this period due to the development of existing salt ponds, inland aquaculture, such as fish or shrimp ponds, and rice-fish integrated farming fields, which are mainly in the northern coastal area of East Java (BPS-Statistics of Jawa Timur Province, 2000).

From 1997 to 2014, the region significantly increased in built-up area (BU), totalling 1779.75 km^2. Following the economic crisis that struck Indonesia in mid-1997, industrial expansion accelerated. Census statistics show an increase of 921 primary and medium industries from 1997. Furthermore, there was a 5.6 million rise in population, necessitating the establishment of built-up regions and related supporting infrastructure (BPS-Statistics of Jawa Timur Province, 1998, 2015). Another land cover that experienced expansion was OW of 108.77%. This expansion is the impact of the Indonesian government's programme to maintain water security and availability through the construction of dams, reservoirs and retention ponds in several areas, including those in East Java, for example, the Bajulmati, Bendo, Kedungbrubus and Gonggang Reservoirs which were constructed between 2005 and 2014 (Febrianto, 2014).

In 2021, the trend of increasing BU area continued. An expansion of 653.18 km^2 was recorded from 2014 to 2021. Significant population growth occurred during 2014–2021periods (± 5.8% annually). Statistical data show an increase in population from 38.6 million to 40.9 million. Research by Fakhruddin and Gultom (2021) also mentions that the construction of the Trans Java Toll Road, which began in 2015, has contributed to the increase in built-up areas. Agricultural land also experienced quite a significant expansion in this period; it was recorded that HAL and PF increased by 2727.36 and 3940.45 km^2. As a consequence, VG and SH were decreased (*Fig. 4*).

Aside from BU, BS had a considerable growth (169.84%). The conversion of VG, SH, and WL land increased the rise in the area. Image analysis also revealed that the site was fallow, dry, or vacant agricultural land; hence, it was classified as BS. Aside from that, some wetlands (WL) are also drying up (not filled with water). As a result, it appears in the classification results as empty land (BS). Mount Semeru also experienced a massive eruption, affecting and converting various SH and VG regions to BS (Detikcom, 2021).

Fig. 4. *LULC trends*



Over the last five decades, East Java has experienced significant LULC changes primarily driven by population growth, urbanisation, and economic development. These changes have inevitably posed various environmental challenges in the region.

1 Impact on coastal ecosystems. The expansion of fish, shrimp, and salt farming, particularly along the northern coast of East Java, has reduced natural wetlands, mainly mangroves. Mangroves play a crucial role in protecting coastlines from erosion, maintaining coastal water quality, and supporting marine life. The conversion of mangrove wetlands into fish ponds and built-up areas has altered coastal ecosystems in regions such as Sidoarjo and Gresik, resulting in increased tidal flooding and erosion (Habib and Yudhistira, 2022; Rino and Arifin, 2023).

2 Impact on hydrological processes and water quality. LULC transformation, particularly the increase in built-up and agricultural land, has impacted the region's hydrological processes and water quality. These changes have led to increased peak discharge and surface runoff, as well as to decreased base flow, thereby increasing the occurrence of floods and landslides, sedimentation in reservoirs/dams, and drought risk (Pribadi et al., 2020; Putri et al., 2021). Astuti (2017) even reported that flood and landslide incidences doubled during 2012–2017 in the Brantas River basin. In addition to the hydrological processes, water quality degradation is an issue that needs further observation due to associated risks. The development of settlements, industry, and agriculture can potentially increase pollutants

(Novita et al., 2020; Pradana et al., 2020). Further research is needed to discuss the impact of LULC changes on water quality in East Java.

3 Impact of urbanisation. Rapid urbanisation, indicated by the significant increase in built-up areas over the last five decades, particularly in central urban areas such as Surabaya and Malang, has driven the growth of urban sprawl in surrounding areas. Urban sprawl is the uncontrolled and unplanned expansion of urban areas into surrounding rural lands (Setyawati et al., 2022). This growth converts barren land, agricultural fields, and vegetation into residential and urban facilities, resulting in unstructured urban planning. Besides spatial issues, urban sprawl also causes various social problems and disparities (Siswanto et al., 2014; Wagistina et al., 2017; Wagistina and Antariksa, 2019).

4 Impact of agricultural intensification. The shift from heterogeneous dry land agriculture (HAL) to irrigated paddy fields has successfully increased rice production in Indonesia but has also heightened disease risk, reduced soil nutrients (land quality degradation), and caused pollution due to excessive fertiliser use. Additionally, this intensification has driven land clearing by converting forests and plantation land (deforestation), particularly in vegetated areas around mountains, such as in Jember (Mandala et al., 2024). This intensification has also accelerated soil erosion in these areas (Andriyani et al., 2019; Taslim et al., 2019).

Conclusions

This research concludes that there have been drastic changes in LULC in the East Java Province region over the last five decades (1972–2021). The most significant transformation occurs mainly in barren and dry agricultural lands, which are then transformed into irrigated agricultural land, plantations, settlements, and other urban areas. The analysis shows massive decreases in three classes, HAL, SH and BS, amounting to –7402.42 km², –7303.17 km², and –3949.17 km², respectively. Meanwhile, the most considerable additions were in the PF, VG and BU classes, amounting to 8463.64 km², 5963.95 km² and 3447.39 km², respectively. The significant increase in population is estimated to be the main factor in this development, where the need for housing, food (especially rice), household needs, employment opportunities and other human needs increases. Meanwhile, in OW and WL, the addition was 143.20 km² and 636.58 km², respectively, due to the construction of various water storage reservoirs and the development of inland fisheries cultivation centres in coastal areas.

Good spatial planning is crucial to managing sustainable urban growth in facing these changes. Collaboration between local governments, communities and the private sector is needed to accommodate urban needs while balancing environmental and social aspects. Coordinated and sustained efforts are necessary to ensure that urban growth benefits society while minimising its negative impacts on the environment and quality of life. From the results of this research, several strategies can be implemented by the relevant parties to mitigate the negative impacts of the emerging environmental issues, including:

1 Coastal ecosystem restoration. This can be achieved by promoting and implementing mangrove restoration projects in coastal areas and establishing protected areas for the remaining mangrove forests. Additionally, environmentally friendly aquaculture practices should be promoted to avoid damaging existing mangrove ecosystems.

2 Reforestation. This is one of the activities widely carried out by various stakeholders to restore critical lands in East Java as a mitigation measure for existing hydrogeological disasters. Furthermore, watershed management needs to be improved. The planning of watershed management in Indonesia is based on the Ministry of Forestry Regulation (2013) No P.60/Menhut-II/2013 on the procedures for the preparation and determination of watershed management plans. This regulation encompasses various tasks for stakeholders, from planning, implementation, and monitoring and evaluation stages. Monitoring and evaluation are conducted to measure watershed management and assess the improvements or degradation experienced. However, research by Basuki et al. (2022) mentions that the results of monitoring and evaluation have not been widely applied to improve existing management plans.

3 Urban planning improvement. This must be done to address the existing urbanisation issues. Urban growth issues need to be further regulated so that the growth of new urban areas can be more controlled. Some approaches, such as vertical housing integrated with public transportation, can be further studied in existing urban planning to make land use more efficient (Prahastuti and Defiana, 2017; Krisnaputri et al., 2023).

4 Soil conservation implementation. This involves encouraging crop rotation and agroforestry practices in existing agriculture to maintain soil health and reduce disease pressure. Additionally, organic farming practices should be more widely promoted to reduce chemical input, increase soil biological activity, and improve soil structure (Salaheen and Biswas, 2019; Durrer et al., 2021).

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