



Land Use Change and Its Impact on Urban Drainage in Kochi Metropolitan Area

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ABSTRACT

Rapid and largely unregulated urban expansion has transformed the land use and land cover (LULC) profile of the Kochi Metropolitan Area (KMA) over the past two decades, converting wetlands, paddy fields, canal-side buffers, and vegetated open spaces into built-up surfaces. This paper synthesises the published literature on LULC change and its hydrological consequences in Kochi to examine how this transformation has altered the performance of the city's natural and engineered drainage system. Drawing on secondary evidence from remote sensing, GIS-based flood vulnerability studies, and hydrological modelling research conducted in and around Kochi, the review traces the decline of permeable surfaces and water bodies, the corresponding rise in impervious cover and peak stormwater runoff, and the compounding role of clogged and encroached drainage canals. The synthesis indicates that urban green and blue spaces in parts of Kochi fell from roughly half of the study area in the mid-2000s to about a third by 2020, accompanied by a marked rise in composite runoff coefficients and peak discharge for comparable rainfall events. These hydrological shifts, combined with the city's low-lying, tide-influenced topography and increasingly extreme rainfall, have intensified recurrent waterlogging and flood risk. The paper concludes with a discussion of planning and policy measures — including wetland and canal protection, green infrastructure, and

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integration of land use and drainage planning — that could improve the resilience of the KMA's urban drainage system.

1. Introduction

Urbanisation in India has proceeded at a pace that has frequently outstripped the capacity of civic infrastructure to adapt, and nowhere is this mismatch more visible than in the performance of urban drainage systems during the monsoon. As agricultural land, wetlands, and vegetated open space are converted into roads, rooftops, and paved surfaces, the natural hydrological cycle of a city is fundamentally altered: infiltration declines, surface runoff increases, and the timing and volume of stormwater reaching drainage channels intensifies (Pal et al., 2022; Singh et al., 2023). Kochi, the commercial capital of Kerala and the principal urban centre on the state's central coast, illustrates this dynamic with particular clarity. Built on a low-lying deltaic landscape interspersed with backwaters, canals, and reclaimed land, Kochi has historically relied on a dense network of natural and constructed drainage channels to evacuate monsoon rainfall into the Vembanad backwater system (Ahamed & Anilkumar, 2022; Sowmya et al., 2015).

Over the past two to three decades, the Kochi Metropolitan Area (KMA) has experienced sustained population growth, real estate development, and infrastructure expansion, much of it occurring on erstwhile wetlands, paddy fields, and canal buffers (Krishnan & Firoz, 2021; Thekkeyil et al., 2023). This land use transformation has coincided with a marked increase in the frequency of waterlogging and urban flood events in Kochi, most severely during the 2018 Kerala floods but also during more localised and recurrent monsoon flooding in subsequent years (Ahamed & Anilkumar, 2022; George et al., 2025). While rainfall intensity and regional hydrology are important drivers of these events, a growing body of research attributes a substantial share of Kochi's flood vulnerability to changes in land use and the consequent loss of the city's natural capacity to absorb and convey stormwater (Gupta & Nair, 2011; Nagarajan & Basil, 2014).

This paper undertakes a focused synthesis of the available literature on land use change and urban drainage performance in the Kochi Metropolitan Area. The objectives are threefold: first, to trace the documented pattern and magnitude of LULC change in Kochi over recent decades; second, to examine how this change has altered stormwater runoff generation and the loading on the city's drainage infrastructure; and third, to identify the planning and policy responses suggested in the literature for reconciling continued urban growth with drainage resilience. The paper is structured as a literature-based review rather than a primary empirical study, and its conclusions are accordingly drawn from, and bounded by, the findings of the cited secondary sources.

2. Study Area: The Kochi Metropolitan Area

Kochi (also referred to as Cochin) is located on the Malabar Coast of Kerala, in Ernakulam district, between approximately 9°49'N–10°14'N and 76°10'E–76°31'E (George et al., 2025). The city is the most densely populated urban agglomeration in Kerala, with a population density reported at over 6,000 persons per square kilometre, and functions as the state's principal commercial and port hub (George et al., 2025). The terrain is characteristically flat and low-lying, with elevations ranging from less than one metre above mean sea level along the western, coastal fringe to about seven metres above mean sea level toward the eastern edges of the city (Sowmya et al., 2015).

The KMA's drainage geography is dominated by a network of natural canals that historically connected the city's interior to the Vembanad backwater system, supplemented by tidal influence from the Arabian Sea. These secondary canals, together with adjoining wetlands and low-lying paddy tracts, functioned as natural detention and conveyance systems for monsoon runoff (Ahamed & Anilkumar, 2022; George et al., 2025). The city receives an average annual rainfall in the range of 3,000 millimetres, concentrated heavily in the southwest and northeast monsoon seasons, and has recorded increasingly extreme rainfall years — for instance, an annual total of over 3,600 millimetres in 2021, roughly 23 percent above the long-term average (Abdul Salam et al., 2024). This combination of low elevation, tidal backwater influence, and monsoon rainfall extremes makes the KMA structurally predisposed to waterlogging whenever its drainage capacity is compromised.

3. Literature Review

3.1 Land Use Change and Urban Hydrology: Conceptual Background

The relationship between land use change and urban hydrology is well established in the international literature. As pervious, vegetated surfaces are replaced with impervious cover such as rooftops, pavements, and roads, the infiltration capacity of the landscape declines while the volume and velocity of surface runoff rise correspondingly (Pal et al., 2022). Impervious surfaces are generally defined as natural or artificial materials that prevent the infiltration of water into the underlying soil, and their proportion within a catchment is one of the strongest predictors of peak runoff and flood response (Pal et al., 2022; Singh et al., 2023). Reviews of urban land use change and sewer system performance across diverse global contexts confirm that expanding impervious cover places systemic stress on drainage networks through hydraulic overload, more frequent combined sewer overflows, and a general reduction in the return-period capacity for which older drainage systems were originally designed. These reviews also note that nature-based and



decentralised stormwater interventions, such as green roofs and clustered green infrastructure, can meaningfully offset these effects where they are implemented at sufficient scale.

Land use land cover (LULC) analysis using satellite remote sensing and GIS has become the standard methodological approach for quantifying this transformation, allowing researchers to compare classified land cover at different time points and derive change matrices showing gains and losses across categories such as built-up area, vegetation, water bodies, and agricultural land (Krishnan & Firoz, 2021). Such approaches have been widely applied across Indian cities, consistently finding substantial increases in built-up area and corresponding declines in vegetation, cropland, and water-body cover as cities urbanise.

3.2 Land Use Change Trends in the Kochi Metropolitan Area

Several studies document the scale of LULC transformation within Kochi. Krishnan and Firoz (2021), examining Ernakulam district, found that land use and land cover change over recent decades has measurably degraded the environmental quality of the region, linking the loss of vegetated and wetland cover to declining ecosystem function. Thekkeyil et al. (2023) similarly report land use intensification in Kochi, noting a pattern in which urban land use is approaching saturation within the city core even as conversion pressure extends outward into peripheral and previously rural tracts. Devi and Nair (2021) documented the effects of this urbanisation on the shallow coastal aquifer underlying Cochin, an indication that land use change in Kochi has hydrological consequences that extend below as well as above the ground surface.

The most direct evidence of the magnitude of change comes from watershed-scale LULC classification within Kochi city. George et al. (2025) classified land cover for a study watershed within the KMA for 2005 and 2020 using object-based image analysis, and reported that urban green space and tree-clad cover declined from approximately 50 percent of the study area in 2005 to about 36 percent by 2020, while high-density residential land use rose from roughly 21 percent to 31 percent and apartment cover more than quadrupled over the same period. Water-body cover within the same watershed fell from around 3 percent to under 1 percent. Projections based on Cellular Automata-Markov modelling in the same study suggested a further decline of green space to around 34 percent by 2035 if prevailing development trends continue unchecked. These findings are broadly consistent with the wider literature on Kerala, where satellite-based classification using Landsat imagery from 1990 to 2020 has shown substantial urban expansion accompanied by loss of agricultural and water-body cover across the state.

3.3 Land Use Change and Drainage or Flood Outcomes in Kochi

A parallel body of research links this land use transformation directly to drainage performance and flood risk in Kochi. Nagarajan and Basil (2014) used remote sensing and GIS-based runoff modelling to examine the effect of land use change on runoff within the Cochin Corporation area, providing one of the earliest quantitative demonstrations that urban expansion in the city was measurably increasing surface runoff generation. Sowmya et al. (2015) produced an urban flood vulnerability zoning of Cochin City using remote sensing and GIS, identifying that the areas of very high and high flood vulnerability together comprised close to a tenth of the city's total area, with drainage-channel blockage and proximity to tidally influenced coastal waters identified as major contributing factors.

Ahamed and Anilkumar (2022) undertook a land-use-based study of urban flood management in Kochi under a changing climate, situating the city's flood risk within the broader context of national urban flood governance and highlighting the need for land use regulation as part of flood risk management. Abdul Salam et al. (2024) applied a GIS-based multi-criteria zonation tool to Kochi Municipal Corporation, finding that wards with low vegetation and water indices, gentle slope, high built-up density, and high population density consistently emerged as flood risk hotspots, and that wards located close to water bodies were disproportionately classified in the very-high-risk category.

The most detailed hydrological evidence comes from George et al. (2025), who modelled peak stormwater runoff for the same Kochi watershed under baseline (2020), past (2005), and projected severe (2035) land use scenarios using the rational method. The composite runoff coefficient for the watershed rose from 0.320 under the 2005 land use pattern to 0.407 under the 2020 pattern, and was projected to reach 0.414 under the 2035 severe-growth scenario. For a three-hour rainfall event with a two-year return period, this translated into an increase in peak runoff from about 6.15 cubic metres per second under the past land use scenario to 7.82 cubic metres per second under the 2020 baseline — an increase of approximately 27 percent attributable to land use change alone, with a further rise to about 7.93 cubic metres per second, or 29 percent above the past scenario, projected under continued unregulated growth. The same study found that a land-use scenario incorporating green infrastructure guidelines could reduce peak runoff by around 16 to 18 percent relative to the baseline and severe scenarios respectively, underscoring that the relationship between land use and drainage loading in Kochi is not fixed but responsive to planning intervention.

These city-specific findings echo broader assessments of urban flooding in India. Gupta and Nair (2011) compared urban flood risk management challenges in Bangalore and Chennai, concluding that land use change, wetland degradation, and inadequate drainage infrastructure were common drivers of urban flood

vulnerability across major Indian metropolitan areas. Pal et al. (2022) similarly found that the interaction of climate change and changing land use patterns is increasing the susceptibility of Indian cities to future flooding. A recent systematic review of urban pluvial flooding in India identified inadequate or encroached drainage systems, alongside rapid and often unplanned land use change, as recurring causal themes across the national literature (Singh et al., 2023).

3.4 The Compounding Role of the 2018 Kerala Floods

The catastrophic 2018 Kerala floods brought national attention to the relationship between land use change and flood vulnerability across the state, including in Kochi. A critical review of post-2018 flood risk assessment research in Kerala found that anthropogenic factors — including wetland encroachment, sand mining, and inadequate urban drainage — were consistently identified across the literature as having worsened the impact of the floods, alongside the localised heavy rainfall and regional hydrology that triggered the event (Singh et al., 2025). The same review noted that urban flooding arising from poor land use planning remains an identified gap requiring further research attention within the state. More broadly, commentary on Kerala's land use history has observed that the state has lost a substantial share of its historic paddy field area and wetland extent over the past five decades, reducing the natural water-storage capacity of its landscapes and altering the volume and timing of runoff reaching rivers and urban drainage systems during heavy rainfall.

4. Methodology

This paper adopts a narrative literature review and synthesis methodology rather than primary field investigation. Peer-reviewed journal articles, edited book chapters, and conference proceedings addressing land use change, urban flooding, stormwater runoff, and drainage performance in the Kochi Metropolitan Area and comparable Indian urban contexts were identified through targeted searches of academic databases and publisher platforms. Priority was given to studies employing remote sensing and GIS-based land use classification, hydrological or hydraulic runoff modelling, and flood vulnerability zonation, as these methods provide the most direct and quantifiable evidence of the relationship between land use change and drainage outcomes. Findings from the identified studies were then thematically organised around (a) the documented pattern and magnitude of LULC change in Kochi, (b) the hydrological and drainage consequences of this change, and (c) the planning and policy responses proposed in the literature. Because the paper synthesises secondary evidence, its findings are necessarily bounded by the spatial and temporal scope, methods, and assumptions of the underlying studies cited, and no new primary field data, satellite classification, or hydrological modelling was undertaken as part of this review.

5. Findings and Discussion

5.1 *The Scale and Direction of Land Use Change*

Taken together, the reviewed literature points to a consistent and unambiguous direction of land use change within the Kochi Metropolitan Area: a sustained decline in vegetated, wetland, and water-body cover accompanied by a corresponding rise in built-up and impervious surface. The watershed-level evidence reported by George et al. (2025) — a fall in green and tree-clad cover from around half to roughly a third of the study area within fifteen years, alongside a near-total loss of water-body cover — is corroborated at the district scale by Krishnan and Firoz (2021) and at the city scale by Thekkeyil et al. (2023). This pattern is consistent with land use change trajectories documented elsewhere in urbanising coastal Kerala and in other rapidly growing Indian cities, where built-up expansion has occurred disproportionately at the expense of agricultural land, open space, and wetlands rather than through the redevelopment of already built surfaces.

5.2 *Hydrological Consequences for Urban Drainage*

The reviewed hydrological studies indicate that this land use transformation has translated directly into greater stormwater loading on Kochi's drainage system. The rise in composite runoff coefficient documented by George et al. (2025), and the associated 27 to 29 percent increase in modelled peak runoff for a given rainfall event between the 2005 and 2020–2035 land use scenarios, demonstrates that a substantial share of the increase in flood risk in Kochi over this period can be attributed to land use change independent of any change in rainfall intensity. This finding aligns with the broader hydrological literature, which consistently shows that impervious surface expansion is among the strongest predictors of increased peak discharge and reduced catchment response time in urbanising watersheds (Pal et al., 2022).

This hydrological loading interacts with two structural vulnerabilities specific to Kochi's physical setting. First, the city's low-lying and largely flat topography, with much of the urban core close to mean sea level, limits the gravitational head available to convey stormwater to outfalls, making the system highly sensitive to any reduction in channel capacity (Sowmya et al., 2015). Second, tidal influence from the Arabian Sea periodically restricts outflow from the city's canal network, compounding the effect of increased inflow volumes during high-tide conditions (Sowmya et al., 2015; Ahamed & Anilkumar, 2022). Where these physical constraints combine with drainage channels that have been narrowed, silted, or encroached upon as a direct consequence of land use conversion along canal buffers, the capacity of the system to evacuate stormwater is doubly compromised — a dynamic explicitly identified in the flood vulnerability zoning of

Cochin City conducted by Sowmya et al. (2015) and in ward-level flood risk hotspot analysis reported by Abdul Salam et al. (2024).

5.3 Compounding and Interacting Factors

Land use change does not act on Kochi's drainage system in isolation. The reviewed literature identifies several interacting factors that amplify its hydrological effects. Rainfall extremes have themselves intensified in recent years, with the 2021 monsoon season in the Kochi region recording precipitation roughly 23 percent above the long-term average (Abdul Salam et al., 2024), meaning that the drainage system is simultaneously absorbing higher rainfall intensities and a reduced capacity to convey them. Encroachment and inadequate maintenance of the canal network — including silt accumulation and waste dumping identified as ongoing problems in several studies (George et al., 2025) — further erode the conveyance capacity that remains after land use conversion. At the district and state scale, the post-2018 flood literature situates Kochi's drainage vulnerability within a wider pattern of wetland loss, paddy field conversion, and unplanned settlement that has reduced Kerala's natural flood-buffering capacity as a whole (Singh et al., 2025).

5.4 Planning and Policy Implications

The reviewed studies converge on several planning and policy directions for improving drainage resilience in the KMA. First, several authors emphasise the protection and, where feasible, restoration of remaining wetlands, canals, and water bodies as functional components of the urban drainage system rather than incidental open space, given their demonstrated role in flood buffering (Ahamed & Anilkumar, 2022; Sowmya et al., 2015). Second, the modelled green infrastructure scenario reported by George et al. (2025) — which reduced peak runoff by 16 to 18 percent relative to baseline and projected severe-growth scenarios respectively — provides direct evidence that targeted green infrastructure requirements, such as minimum vegetated or permeable area ratios in new residential and vacant-land development, can meaningfully offset the hydrological effects of continued urban growth. Third, the ward-level flood risk hotspot mapping conducted by Abdul Salam et al. (2024) suggests that drainage investment and land use regulation could be more effectively targeted if calibrated to spatially explicit flood risk zonation rather than applied uniformly across the city. Finally, the post-2018 flood literature underscores the value of integrating land use planning and drainage engineering functions, which in many Indian cities, including Kochi, have historically been administered separately, resulting in development approvals that do not adequately account for downstream drainage capacity (Gupta & Nair, 2011; Singh et al., 2025).

6. Conclusion

The literature reviewed in this paper presents a consistent picture of the relationship between land use change and urban drainage performance in the Kochi Metropolitan Area. Over the past two decades, Kochi has experienced a substantial and well-documented decline in vegetated, wetland, and water-body cover, matched by a corresponding rise in built-up and impervious surface. This transformation has measurably increased stormwater runoff generation, with modelled peak discharge for comparable rainfall events rising by roughly a quarter to a third between land use conditions prevailing in the mid-2000s and those observed by 2020, and further increases projected if current development trends continue. These hydrological changes interact with Kochi's low-lying, tide-influenced topography and with the ongoing degradation of its canal network to produce the recurrent waterlogging and flood events that have characterised the city in recent years, most severely during the 2018 Kerala floods. At the same time, the evidence reviewed here indicates that this trajectory is not inevitable: modelled green infrastructure and land use planning interventions demonstrate a meaningful capacity to reduce peak runoff and, by extension, drainage loading, even under continued urban growth. Future research would benefit from more granular, city-wide hydrological modelling that links ward-level land use projections to drainage network capacity, together with longitudinal monitoring of canal encroachment and wetland loss, to support the kind of integrated land use and drainage planning that the reviewed literature identifies as central to improving the resilience of the Kochi Metropolitan Area.

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