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THE CONUNDRUM OF THE MODIFIED AREAL UNIT PROBLEM (MAUP) FOR URBAN DECISION-MAKING ACROSS SCALES: A CRITICAL REFLECTION

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Review paper

Abstract: Although the Modified Areal Unit Problem (MAUP) is well-documented in spatial analysis, its effects on urban policy development and decision-making are yet unknown. So, we decided to do this work to critically investigate how MAUP influences urban planning at different levels, impacting analytical results, governance, and spatial policy. The arbitrary division of geographical units still introduces bias and uncertainty in decision-making procedures, even with growing computer capacity and extensive application of urban analytics. By using a semi-structured literature review, we studied current studies on MAUP in urban analytics and planning, therefore highlighting the importance of methodological techniques, difficulties, and mitigating methods. Our results show a fragmented corpus of research where methodological developments usually have no direct relevance for policy-making. We also underline the need for ex-ante and ex-post assessments to evaluate MAUP's influence on urban administration. Additionally, we emphasize the necessity of interdisciplinary collaboration to ensure a more holistic approach. We aim to raise awareness among urban designers, legislators, and researchers by bridging this research gap, thereby supporting more open, strong, and context-sensitive spatial decision-making systems.

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Introduction

The modifiable areal unit problem (MAUP) was formally defined in the 1970s and is known as one of the most stubborn problems for spatial analysis, impacting the results of analytical techniques for urban decision-making (Wong, 2009). The essence of the modifiable areal unit problem is the influence of areal delineation for spatial objects used for analysis where the delineation, and not the studied objects, generates biases whose magnitude is difficult to estimate (Openshaw, 1983). Often, for both primary and secondary data, the areal units are arbitrary and modifiable, which will change the analytical results. A main concern of MAUP is that the results of studies and the communication of results to the public and stakeholders may be based on information that, at worst, has a counter effect.

MAUP is in many ways similar to the statistical fallacy referred to as Simpson's paradox, where the aggregation of ratios into differently sized groups can generate seemingly inverse results from what would be the case if no aggregation was conducted (see also Huff, 1954; Wagner, 1984; Ross, 2004). Simpson's paradox and MAUP are also similar in that the fallacy commonly is the result of a poor understanding of the role of used data, statistical methods, and geography. However, there are cases where the analyst intends to use the fallacies to benefit from the erroneous output. A well-known example is Gerrymandering, referring to specific electoral areal redistricting, where the aggregation of people and electoral areas are based on a concept of changing areal votes to favor a minority over the majority (see, for instance, Vickrey, 1961; Issacharoff, 2002).

Regardless of intent for the areal unit, the delineations serve specific purposes that capture societal functions. However, next to function, ethical considerations and the risk of revealing sensitive information restrict the potential for smaller units' scales and force spatial data to be aggregated into larger units (Östh et al., forthcoming). Therefore, the basis for aggregation is that population size and urban and environmental factors are almost always secondary. This means that features and statistics may be more or less relevant, seen from different societal perspectives. As a consequence, areal analyses will inherit the effects of aggregation. In studies where potentially sensitive demographic data, such as ethnicity, unemployment, poverty, etc., is used, the awareness of the problems and suggestions for mitigating the effects are relatively common. To exemplify, in segregation analyses, there is a substantial body of literature discussing the effects of areal units for the analyses (see, for instance: Wong et al., 1999; Wong, 2003; Östh et al., 2015; Jones et al., 2018; Meister & Niebuhr, 2021; Javanmard et al., 2023), and several methodological approaches for limiting the effects using, for example, bespoke neighborhoods and multi-level approaches (see for instance, Östh et al., 2015; Nelson & Brewer, 2017; Jones et al., 2018), but also in urban planning fields requiring no sensitive demographic data, the problem is realized and discussed, for example, in ecosystem services (Comber & Harris, 2022) or availability to good quality food from a neighborhood perspective (Chen et a., 2022). Most of the above-listed studies depart from analyses with one set or a hierarchical set of geographical units where used data can be assigned to the different units.

However, in urban planning, policy-making and localized decisions often need to be based on data from imperfectly overlapping geographical units. MAUP may have complex and unknown effects in these cases and lead to counter-effective governance. This raises an important question: How is MAUP affecting and mitigated in urban planning, and what are the experiences and workarounds in practice? To improve our understanding, a semi-structured literature review study is conducted, and we aim to systematize and summarize researchers' and practitioners' experiences from MAUP in urban planning.

Although MAUP is a frequently discussed issue in many publications and literature reviews, it has not yet been sufficiently explored in the context of urban decision-making and urban planning. Most studies focus on methodological aspects in the fields of geography, statistics, and spatial analysis, lacking a comprehensive link to practical applications in urban planning and policy-making. This lack of a systematic review of the impact of MAUP on urban decision-making represents a significant research gap that this study seeks to bridge.

1. Method and data

For this study, a semi-structured literature review was conducted through desk research from January 17, 2025 to February 1, 2025. A semi-systematic literature review aims to expediently assess prior studies that are appropriate to the specific research topic to present a fair assessment of an investigated topic using a rigorous and trustworthy approach (Anthony, 2023). The data collection method was applied through queries, where relevant literature was systematically searched and retrieved using specific keywords and database queries. We used and searched only open-access literature to ensure unrestricted access to scholarly articles, enabling transparency, reproducibility, and inclusivity in our research process. Open-access sources provide cost-free availability to a wide range of high-quality academic works, facilitating a comprehensive and unbiased review of relevant studies without financial or institutional barriers. This approach also aligns with the principles of open science, promoting broader dissemination and accessibility of knowledge.

We conducted our search using the Scopus database with an advanced query, targeting keywords in the abstracts (ABS) of publications. This approach ensured the retrieved articles were directly relevant to the studied topics. Searching in full texts could have resulted in a large number of unrelated results, as individual terms might appear anywhere in an article without directly contributing to its core content. By focusing on abstracts, we aimed to filter out irrelevant studies and identify literature that explicitly engages with our research themes. We included all abstracts from conference papers, books, and journal publications.

Table 1. overviews the search queries used to retrieve literature in the Scopus database. The results show that searches combining multicriteria decision analysis (MCDA) and urban planning yielded various numbers of publications, with some queries having very low return rates (e.g., 0 or 1 result). This fact suggests that the combination of these search terms is not yet sufficiently explored, and therefore, there is room for further research in this area. In contrast, the highest number of publications (354) was obtained for the search "MAUP and Decision-Making in Urban Planning," indicating that this topic is the most researched in the literature among the areas we investigated.

Table 1. Topic search terms

Review topic	Explicit search terms	Scopus results
MCDA, MAUP, and Urban Decision-Making in Analytics and Policies	ABS (("Multicriteria analysis") OR ("MCDA") OR ("Multi Criteria Decision Making") AND ("MAUP") OR ("modified areal unit problem") AND ("urban decision making") OR ("urban analytics") OR ("urban policies"))	0
MCDA and MAUP in Spatial Decision-Making	ABS (("Multicriteria analysis") OR ("MCDA") OR ("Multi Criteria Decision Making") AND ("MAUP") OR ("modified areal unit problem"))	0
MCDA and Spatial Analysis in Urban Planning	ABS (("multicriteria decision analysis" OR "multi-criteria decision making") AND ("urban planning") AND ("spatial analysis"))	1
MCDA in Urban Decision-Making, Analytics, and Policies	ABS (("urban decision making") OR ("urban analytics") OR ("urban policies") AND ("MCDA"))	7
Spatial Scales in Urban Decision-Making and Policies	ABS (("spatial scales") AND ("urban decision making") OR ("urban analytics") OR ("urban policies"))	30

MCDA in Urban Planning and Spatial Analysis	ABS (("multicriteria decision analysis" OR "multi-criteria decision making") AND ("urban planning" OR "spatial analysis"))	150
MAUP and Decision-Making in Urban Planning	ABS (("modified areal unit problem") OR ("MAUP") AND ("urban planning") OR ("urban decision making"))	354

Source: Authors' elaboration 2025

We decided to focus our literature review on the topic "MAUP and Decision-Making in Urban Planning" as it provides the most available resources and represents a more widely discussed issue than other searches in spatial decision-making and urban planning. This selection will allow us understand the existing research gaps better and provide new insights for future research. After retrieving 354 results from the Scopus database, we applied several exclusion criteria to refine our selection.

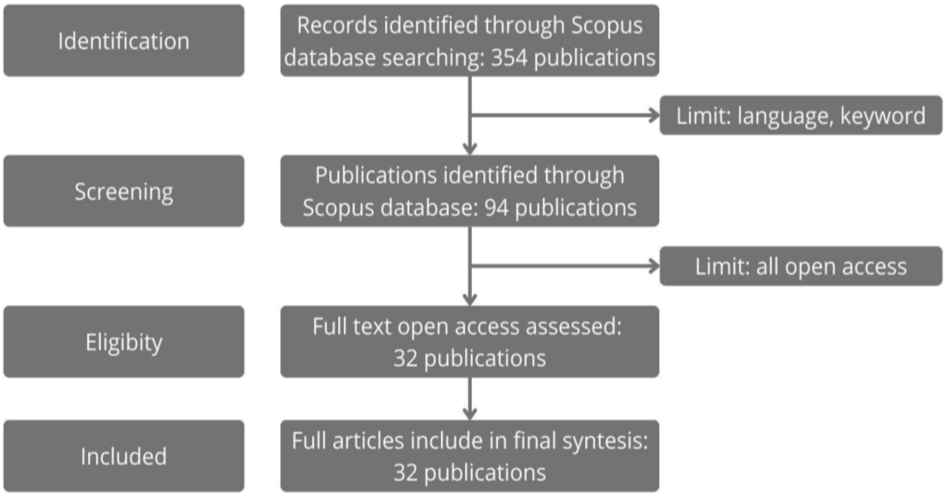
Exclusion based on language: We excluded all publications in a language other than English, leaving us with 336 publications. We excluded all publications in languages other than English to ensure comprehensibility in the review process. English is the predominant language of academic publishing, allowing access to a broad and diverse range of high-quality research. Additionally, this exclusion minimizes the risk of misinterpretation and ensures that all reviewed studies can be accurately analyzed and compared.

Exclusion based on keywords: We excluded all publications that did not contain the following keywords (Urban Planning (52) Limited to MAUP (24) Limited to Modifiable Areal Unit Problem (20) Limited to Modifiable Areal Unit Problem (MAUP)). After that, we were left with 94 publications. We applied exclusion based on keywords to ensure that only publications directly related to the investigated topic were included in the review. This approach guarantees that the included studies contribute directly to understanding the modifiable areal unit problem within the context of urban planning, thereby enhancing the review's relevance, depth, and quality.

Figure 1. shows a flowchart of the systematic literature review, which was adapted from Prasetiyani et al. (2023). The process of identifying and selecting articles was divided into four phases. To prepare the systematic literature review, we went through a process of filtering the sources.

From the original 354 publications, we finally selected 32 relevant open-access publications using various exclusion criteria, which form the basis of our analysis.

Figure 1. Flowchart of literature review



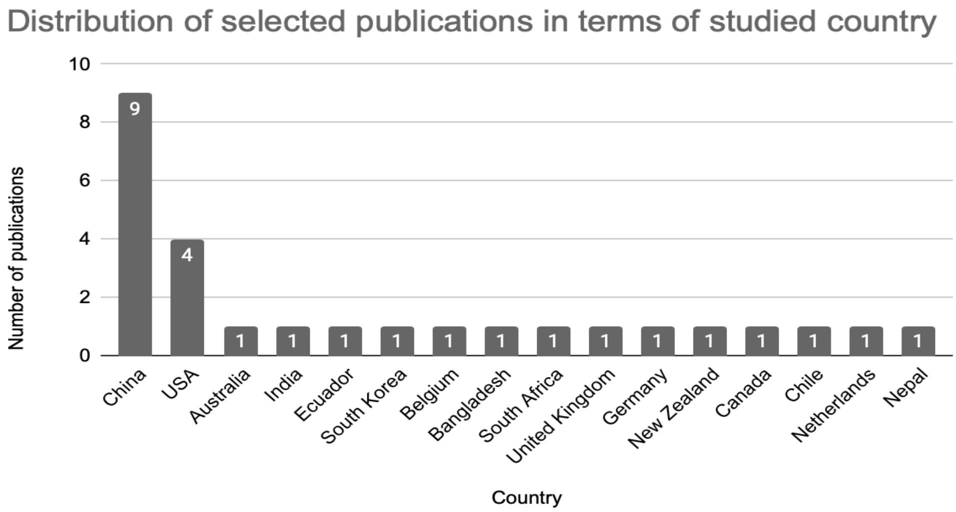
Source: Authors' elaboration adapted from Prasetyani et al., 2023

Focused searches covering the timespan 2017–2024. Between 2017 and 2019, the number of publications was stable, with only one study per year. In 2020, there was a significant increase when six studies were published; this trend continued in 2021 with the same number of publications. The year 2022 saw a slight decrease to 4 publications, but in 2023, the number increased again to 7, representing the highest number in the monitored period. In 2024, the number of publications was slightly lower, namely 6. We can observe that the number of publications is increasing, indicating a growing interest in MAUP issues in the context of modern urban planning and the use of advanced analytical methods.

In addition to temporal evolution, it is also important to analyze the geographical distribution of publications, which shows in which countries the research on this issue has been conducted. Graph 1. shows the number of publications analyzing the issue in each country. Most publications focused on China, with nine studies. China emerges as the dominant location of exploration, corresponding to the trend of rapid urbanization in the country, followed by the USA with four publications. Australia and other countries, such as India, Ecuador, North America, South Korea, Belgium, Bangladesh, South Africa, the United Kingdom, Germany, New Zealand, Canada, Chile, the Netherlands and Nepal, were less studied.

The 32 publications analyzed use various methodological approaches, each offering unique perspectives on the Modifiable Areal Unit Problem (MAUP) in urban planning.

Graph 1. Distribution of selected publications in terms of a studied country



Source: Authors' elaboration 2025

Bayesian multi-level modeling (Neto-Bradley et al., 2023; Yang et al., 2024) allows spatial data analysis at multiple levels and considers the heterogeneity of different geographical areas. Machine learning, including algorithms such as Extreme Gradient Boosting (XGBoost) (Wang et al., 2024) and Artificial Neural Networks (ANN) (Labib, 2019), has been applied to the prediction and analysis of large datasets related to public transportation environmental factors or urban patterns. Clustering methods, such as clustering ensembles (Li J., & Li C., 2024), allow for better identification of patterns in urban data, especially in analyzing urban form and land use typologies. The GeoDetector tool (Xu et al., 2018) assesses spatial interactions and identifies factors influencing urban development. Spatial risk and distribution analyses, such as Kernel Density Estimation (Lambio et al., 2023), are key in studies related to the COVID-19 pandemic or environmental risks. Geographically weighted regressions (GWR and MGWR) (Wang et al., 2023) provide local regression models that account for geographic variability in data, which is essential in analyses of spatial dependence and urban forms. Geographic information systems (GIS) are commonplace in urban studies. Zhang et al., 2023 use GIS to illustrate principal component analysis output (PCA), and Hazell (2020) uses GIS in multicriteria analysis. In addition, remote sensing analysis (Bhandari & Zhang, 2022) uses satellite imagery to assess land use change and environmental impacts. Modern approaches include open-source software packages for spatial network analysis, such as Python-based network analysis (Simons, 2023). This diversity of methodologies demonstrates the need to use multiple analytical tools in urban planning when investigating this topic. Advanced statistical models, GIS technologies, and machine learning make it possible to identify spatial patterns more accurately, contributing to efficient and sustainable decision-making in urban environments.

The following table contains all the publications investigated. The table lists author/author names, year of publication, author keywords, index keywords, used methodology, and DOI.)

Table 2. Overview of Selected Publications on MAUP in Urban Planning

Author/s	Year	Author Keywords	Index Keywords	Methodology	DOI
Neto-Bradley A.P., Choudhary R., Challenor P.	2023	big data; South Asia; spatial modelling; uncertainty; urban analytics	South Asia; Bayesian analysis; numerical model; residential energy; spatial analysis; spatial distribution; uncertainty analysis; urban development; urban planning	Bayesian multi-level modelling using microsimulation with Markov Chain Monte Carlo (MCMC) sampling	DOI: 10.1177/2399808321107 3140
Wang H., Zhang H., Zhu H., Zhao F., Jiang S., Tang G., Xiong L.	2023	air pollution; geographical boundary model; Regionalization; spatial clustering; spatiotemporal cube	atmospheric pollution; GIS; modeling; multivariate analysis; regionalization; remote sensing; spatiotemporal analysis; urban planning	Bottom-up unsupervised multivariate hierarchical clustering algorithm with spatiotemporal proximity rules	DOI: 10.1080/15481603.2023. 2176704
Kon F., Ferreira É.C., de Souza H.A., Duarte F., Santi P., Ratti C.	2022	Application case study; Bike-sharing; Data science; Mobility; Open source software; Visualization	Abstracting; Data visualization; Decision making; Nonmotorized transportation; Urban planning; Analytical method; Analytical tool; Large amounts of data; Non-motorized modes; Public authorities; Technological advances; Tools and methods; Visualization platforms; Bicycles	Analytical method using origin–destination (OD) data, grid-based aggregation, Python-based open source tool (BikeScience)	DOI: 10.1007/s12469-020-00259-5

Zhang H., Nijhuis S., Newton C.	2023	Blue-health; Digital analytical tools; Mapping application; Multi-scale approaches; Spatial accessibility & visibility; Spatial planning/design	Netherlands; Rotterdam; South Holland; Urban planning; Analytical tool; Blue-health; Digital analytical tool; Mapping applications; Multi-scale approaches; Planning designs; Spatial accessibility & visibility; Spatial planning; Spatial planning/design; Urban environments; accessibility; analytical method; mapping; spatial planning; urban design; urban planning; visibility; Visibility	Digital analytical tools including GIS-based viewshed analysis, isovist analysis, segmentation analysis, eye-tracking analysis	DOI: 10.1016/j.scs.2023.104804
Fernández I.C., Wu J.	2016	Ecological fallacy; Environmental inequity; Environmental justice; MAUP; Spatial inequalities; Urban planning	Chile; Metropolitana; Santiago [Metropolitana]; environmental assessment; environmental justice; environmental risk; policy analysis; spatial distribution; urban planning	Hierarchical multiscale analysis using raster-based approach, Pearson correlation analysis	DOI: 10.1016/j.apgeog.2016.07.012
Hazell E.C.	2020	Ecosystem benefits; Ecosystem services; GIS-MCDA; PCA; Sustainability indicators	Canada; Ontario [Canada]; Toronto; conceptual framework; ecosystem management; ecosystem service; index method; integrated approach; interdisciplinary approach; multicriteria analysis; planning practice; policy making; socioeconomic conditions; stakeholder; urban ecosystem; urban planning; valuation	Principal component analysis (PCA) and GIS-based multicriteria decision analysis (GIS-MCDA)	DOI: 10.3390/su12187589
Cheung K.-S., Sham C.-W., Yiu C.-Y.	2024	Airbnb; hedonic price model; housing density; Modifiable Areal Unit Problem (MAUP); neighbourhood; public housing; urban planning	Costs; Urban growth; Airbnb; Hedonic price model; Housing density; Housing prices; Modifiable areal unit problem; Neighbourhood; Public housing; Quantitative study; Sustainable cities; Urban density; Housing	Block-searching method for customised areal units; hedonic price model	DOI: 10.3390/buildings14061840
Bryant J., Jr., Delamater P.L.	2019	aggregation error; E2SFCA; Floating catchment areas; MAUP; spatial accessibility	accessibility; catchment; error analysis; health services; public transport; recreational facility; spatial analysis	Enhanced two-step floating catchment area (E2SFCA) method	DOI: 10.1080/19475683.2019.1641553

Lambio C., Schmitz T., Elson R., Butler J., Roth A., Feller S., Savaskan N., Lakes T.	2023	COVID-19; infectious disease; kernel density; modifiable areal unit problem; point data; spatial relative risk	Berlin; COVID-19; Geography; Humans; Risk; Spatial Analysis; Berlin; Germany; COVID-19; epidemiology; health risk; infectious disease; risk factor; spatial analysis; spatial distribution; access to information; adolescent; adult; aged; Article; child; controlled study; coronavirus disease 2019; disease transmission; exploratory research; Germany; health status; human; infection rate; kernel method; middle aged; pilot study; risk assessment; risk factor; social status; spatial analysis; statistical analysis; urban area; coronavirus disease 2019; geography; risk; spatial analysis	Kernel density estimation for spatial relative risk analysis	DOI: 10.3390 /ijerph2 0105830
Li J., Li C.	2024	China; Clustering analysis; Clustering ensembles; Urban form; Urban land use	China; Guangdong; Guangzhou; algorithm; land use planning; regulatory framework; three-dimensional modeling; typology; urban area; urban planning	Clustering ensembles using multiple clustering algorithms on 3D building data	DOI: 10.1016 /j.landus epol.202 4.10716 6
Wang Z., Liu S., Lian H., Chen X.	2024	built environment; explainable machine learning; Extreme Gradient Boosting (XGBoost); land use; Modifiable Areal Unit Problem (MAUP); Public Transportation Index	Beijing [Beijing (ADS)]; Beijing [China]; China; land use; machine learning; nonlinearity; public transport; travel behavior	Extreme Gradient Boosting (XGBoost) for nonlinear analysis with 7D built environment dimensions	DOI: 10.3390 /land130 81302

Labib S.M.	2019	Artificial neural network (ANN); Green infrastructure; Green space; Machine learning; Urban land use	England; Manchester [England]; United Kingdom; Computation theory; Inference engines; Land use; Learning systems; Machine learning; Neural networks; Soft computing; Fuzzy inference systems; Green infrastructure; Green spaces; Multi Criteria Analysis; Predictive capacity; Site transformations; Statistical modelling; Urban land use; artificial neural network; atmospheric pollution; greenspace; land use; machine learning; urban planning; Fuzzy inference	Artificial neural network (ANN) and adaptive network-based fuzzy inference system (ANFIS)	DOI: 10.1016 /j.envsof t.2019.0 5.006
Wang S., Cai W., Sun Q.C., Martin C., Tewari S., Hurley J., Amati M., Duckham M., Choy S.	2023	Australia; Ethnic diversity; Ethnic settlement; Migrants; Minority population; Multiculturalism; Neighbourhood features	Australia; ethnic minority; landscape change; migrants experience; multiculturalism; neighborhood; policy making; spatiotemporal analysis; urban planning	Shannon's diversity index applied to census data (2001-2021); machine learning for modeling relationships	DOI: 10.1016 /j.apgeo g.2023.1 03114
Wang Z., Gong X., Zhang Y., Liu S., Chen N.	2023	built environment; elasticity; modifiable areal unit problem; multi-scale geographically weighted regression; ride-hailing	Chengdu; China; Sichuan; environmental factor; heterogeneity; numerical model; regression analysis; scale effect; urban renewal	Multi-scale geographically weighted elasticity regression (MGWER) with OLS for spatial unit selection	DOI: 10.3390 /su1506 4966
Cabrera-Barona P., Wei C., Hagenlocher M.	2016	Automatic zoning procedure; Census areas; Deprivation; Health; MAUP; Quality of life	Ecuador; Pichincha; Quito; accessibility; census; health care; quality of life; social policy; urban area	Weighted deprivation index using census data and automatic zoning procedure (AZP)	DOI: 10.1016 /j.apgeo g.2016.0 2.009
Lloyd C.D., Bhatti S., McLennan D., Noble M., Mans G.	2021	census; grids; inequalities; scale; South Africa	Cape Town; South Africa; Western Cape; neighbourhood; spatiotemporal analysis; unemployment; urban area; urban planning; urban policy; urban population	Area-to-point kriging of census data (2001 and 2011) with Small Area Layers, Spot Building Count, and Open Street Map data	DOI: 10.1111 /geoj.12 400
Ma J., Shen Z., Xie Y., Liang P., Yu B., Chen L.	2022	metro station; node-place model; Tianfu new area; TOD; urban planning	None	Extended Node-Place-System (NPS) model using GIS-based multi-sourced data analysis	DOI: 10.3389 /fenvs.2 022.990 416

Fotheringham A.S., Sachdeva M.	2022	Local modeling; MAUP; Multiscale geographically weighted regression; Replicability; Spatial context; Spatial process scale	None	Theoretical analysis of local modeling using multiscale geographically weighted regression (MGWR) and spatial filtering	DOI: 10.1016/j.spasta.2022.100601
Xu Q., Zheng X., Zhang C.	2018	Driving forces; GeoDetector model; Interactions; Spatial analysis; Urban expansion	Beijing [China]; China; heterogeneity; model; quantitative analysis; spatial analysis; spatiotemporal analysis; statistical analysis; urban development; urban economy; urban growth; urban planning; urban sprawl	GeoDetector spatial statistical method with remote sensing and GIS data	DOI: 10.3390/su10051630
Wolf L.J., Fox S., Harris R., Johnston R., Jones K., Manley D., Tranos E., Wang W.W.	2021	causality; data science; inclusiveness; modifiable areal unit problem; open science; quantitative geography; replication; spatial dependence	conceptual framework; historical perspective; human geography; quantitative analysis; social structure; spatial analysis	Review and conceptual analysis of quantitative geography methods and challenges, including MAUP, spatial dependence, and open science	DOI: 10.1177/0309132520924722
Bajracharya P., Sultana S.	2020	Bangladesh; Google Earth Engine; Urban growth; Urbanization; Zipf's law	Bangladesh; Chittagong [Bangladesh]; Dhaka [Bangladesh]; land cover; range expansion; size distribution; urban area; urban development; urban planning	Rank-size distribution analysis using Zipf's law; data from Google Earth Engine land cover classification and population census (1990–2019)	DOI: 10.3390/su12114643
Jones J., Peeters D., Thomas I.	2017	Brussels; LUTI models; MAUP; Policy evaluation	Land use; Brussels; Business-as-usual; Land use and transports; MAUP; Policy evaluation; Scale effects; Study areas; Sustainability indicators; Cost benefit analysis	UrbanSim (+MATsim) LUTI model with four levels of Basic Spatial Units (BSUs) for Brussels, using cost-benefit analysis and sustainability indicators	DOI: 10.18757/ejtir.2017.17.1.3182
Gupta J., Long A., Xu C.K., Tang T., Shekhar S.	2021	Accountability; and Transparency; Fairness; Public policy; Spatial data science; Urban Planning	Partitions (building); Surveys; Transparency; Dissimilarity index; Income inequality; Mathematical proof; Policy decisions; Social scientists; Space partitioning; Spatial dimension; Spatial partitioning; Population statistics	Mathematical analysis and case studies on Gini index, income quintile share ratio (IQSR), and index of dissimilarity with census data	DOI: 10.1145/3469830.3470898

Hwang C.S., Hong S.-Y., Hwang T., Yang B.	2020	Census output areas; GIS; National statistics; Urban planning	census; economic activity; estimation method; homogeneity; population size; socioeconomic conditions; statistical analysis; urban planning; urban system; workplace	Algorithmic aggregation of economic zones using population, workplaces, and worker data with matrix systems	DOI: 10.3390 /su1214 5640
Zhang Y., Mavoa S., Zhao J., Raphael D., Smith M.	2020	Adolescent; Green space; Mental well-being; Urban planning	Adolescent; Cohort Studies; Cross-Sectional Studies; Humans; Longitudinal Studies; Mental Health; Parks, Recreational; adolescence; greenspace; literature review; mental health; perception; urban planning; adolescent; adolescent behavior; city planning; depression; distress syndrome; environment; environmental exposure; green space; human; major clinical study; mental health; mood; psychological well-being; Review; stress; systematic review; adolescent; cohort analysis; cross-sectional study; longitudinal study; mental health; recreational park	Systematic review using PRISMA guidelines, synthesis of 14 observational studies (cross-sectional, experimental, longitudinal)	DOI: 10.3390 /ijerph1 7186640
Simons G.	2023	Computation; data science; geographical information systems; land-use analysis; morphometrics; network analysis; spatial analysis; urban analytics; urban morphology; urban planning; urbanism	data management; GIS; land use; morphometry; network analysis; pedestrian; software; spatial analysis; urban morphology; urban planning	Computational package using Python (Numba, NetworkX, GeoPandas) for network-based urban analysis at pedestrian scale	DOI: 10.1177 /239980 8322113 3827
Jiang M., Wu Y., Chang Z., Shi K.	2021	Modifiable areal unit problem; Multiscale analysis; PM2.5 concentration; Spatial heterogeneity; Urban forms	Air Pollutants; Air Pollution; China; Cities; Environmental Monitoring; Particulate Matter; China; air quality; atmospheric pollution; concentration (composition); hierarchical system; numerical model; particulate matter; remote sensing; satellite data; sustainable development; article; China; city; land use; particulate matter 2.5; remote sensing; air pollutant; air pollution; China; environmental monitoring; particulate matter	Hierarchical multiscale analysis using remote sensing, land-use data, and panel data models	DOI: 10.3390 /ijerph1 8073785

Zhou X., Sun C., Niu X., Shi C.	2022	Big data; Commuting distance; Jobs–housing balance; Modifiable areal unit problem; Multi scale	None	Combination of cellphone location big data and traditional survey data for multi-scale analysis	DOI: 10.1016/j.tbs.2021.11.001
Deng H., Liu K., Feng J.	2024	Built Environment (BE); Modifiable Areal Unit Problem (MAUP); Optimal Parameters-based Geographic Detector (OPGD); scale effect; urban vitality	Autocorrelation; Surface measurement; Urban growth; Zoning; Build environment; Built environment; Environment factors; Geographics; Modifiable areal unit problem; Optimal parameter; Optimal parameter-based geographic detector; Q-values; Scale effects; Urban vitality; Decision making	Optimal Parameters-based Geographic Detector (OPGD) model with spatial autocorrelation analysis	DOI: 10.1080/10095020.2024.2336593
Feng Q., Gauthier P.	2021	Climate change; Energy consumption; Greenhouse gas emission; Land use; Physical planning; Urban form; Urban sprawl; Urban transportation	Energy utilization; Land use; Urban growth; Urban transportation; Combined effect; Critical review; Environmental costs; Fossil energy consumption; Land cover; Number of factors; Physical planning; Urban sprawl; climate change; emission inventory; energy use; greenhouse gas; land cover; land use planning; literature review; transportation planning; urban planning; urban sprawl; urban transport; Climate change	Critical literature review of 220 studies from 1979-2018 using ISI Web of Science	DOI: 10.3390/atmos12050547
Bhandari S., Zhang C.	2022	developing country; index; Land Surface Temperature; MAUP; remote sensing; rooftop greenery; urbanization	Bagmati; Kathmandu; Nepal; atmospheric pollution; developing world; greenspace; heat island; metropolitan area; remote sensing; surface temperature; urbanization	Composite priority index using remote sensing (Landsat 8), QGIS, and OpenQuake; analysis at administrative ward and fishnet levels	DOI: 10.3390/land11112074
Yang Y., Wu Y., Yuan M.	2024	Bayesian network; MAUP; place–event relationships; POIs; social events	None	Bayesian Network model integrating POI data (SafeGraph), sociodemographic data (ACS), and spatial clustering (Moran's I)	DOI: 10.3390/ijgi13030081

Source: Authors' elaboration 2025

2. Conclusion and critical reflection

Let us remind you that we departed from the fragmented body of literature on the relationship between modified areal unit problems (MAUP) and urban decision-making. This resulted in providing a semi-structured literature review to better understand how MAUP is affecting and mitigating urban planning in research and practice.

Our semi-structured literature review examined the role of the MAUP in urban decision-making and urban planning. The findings indicate a growing interest among authors in this issue, especially after 2020 when the number of publications on this topic had an increasing trend. From the perspective of Geographical Distribution, we can observe that the dominant country is China, where nine studies have been conducted so far, followed by the USA with four publications. From a methodological perspective, the literature review reveals various analytical techniques used to solve MAUP. In the literature review, we can observe that different authors used, for example, Bayesian multi-level modeling, Hierarchical multiscale analysis (using a raster-based approach/ or using remote sensing, land-use data, and panel data models), or Principal component analysis (PCA) and GIS-based multicriteria decision analysis (GIS-MCDA) and many others. The literature review suggests that a wide range of tools and methods can be applied to the MAUP in urban decision-making and urban planning.

However, several challenges and research gaps remain. A key issue is that MAUP becomes particularly problematic when urban planning decisions rely on data from imperfectly overlapping geographic units, leading to incorrect urban planning decisions. Although various methodological approaches have been proposed, there is no generally accepted solution to mitigate MAUP, so case-specific techniques need to be used. Furthermore, the practical implications of MAUP in urban governance and policy-making are still under-explored, highlighting the need for further research into how spatial biases influence decisions in the real world. However, strategies to mitigate MAUP have also emerged, including tailored neighborhood modeling, multiscale analysis, and spatial disaggregation techniques that help minimize the effects of MAUP in decision-making processes.

Finally, our findings highlight that while methodological innovations have improved spatial analysis, urban contexts' lack of standardization and diversity poses ongoing challenges. Future research should focus on developing standardized frameworks to address MAUP, exploring real-world policy applications to assess their impact on governance, and further integrating big data, AI, and spatial analytics into urban planning. By addressing these issues, the field can move toward more accurate, transparent, and efficient spatial decision-making despite the inherent challenges of MAUP.

Our findings demonstrate the growing importance of MAUP in urban decision-making, emphasizing its influence on analytical outcomes, policy recommendations, and spatial transformations. As urban planning increasingly relies on big data and computational analytics, the risk of biased results grows.

In urban planning, informed decision-making has become popular in recent years. It is conducted mainly by using analytical approaches for cities – from the perspective of a factual reality – for information and consensus building among stakeholders. This approach is supported by the ever-increasing computational power for processing big data across urban scales with increasing complexity (De Roo et al., 2020). Thus, the challenge of MAUP becomes even more prominent, and we have to raise awareness among decision-makers and urban planning practitioners about the strong relationship between areal delineation and analytical results. The decision-making chain reaction of this is impacting policy recommendations and further multi-scale governance. Policies are path-dependent over time, and their spatial outcomes are often hard to reverse (Hidayati et al., 2019, 2021). Obtaining biased results can greatly affect outcomes in ways that counter the intention (Östh et al., forthcoming) and, in the worst case, a misplaced decision that is also evident in obtained policies.

How MAUP influences urban decision-making and policies can be understood in practice through an ex-ante and ex-post-evaluation of areas where urban analytics for informing policies was applied. Urban analytics for scenario building, decision-making, and further policy recommendation belong to the ex-ante-evaluation, which is meant to predict the impact of a policy and provides intended and unintended information for different scenarios (UNCTAD, 2016). In contrast, an ex-post-evaluation is defined as a "summative evaluation conducted after the completion of policy interventions to demonstrate the achievements of policy objectives, policy impacts and results to stakeholder and general public, increase the policy transparency and to learn how to do policy better in the future." (European Network for Rural Development, accessed 19/02/2025).

Therefore, both *ex-ante* and *ex-post* evaluations play a crucial role in the assessment of the level of effectiveness of policies through their spatial outcomes. Urban policy recommendations departing from urban analytics are inherently linked through a causal relationship between MAUP and urban decision making: Areal delineation influencing urban analytical results influencing policy recommendations influencing spatial outcomes.

Thus, we are asked to create awareness among stakeholders, urban practitioners, and policymakers about the impact of MAUP on urban decision-makers and its chain effects on the establishment and manifestation of the built environment.

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UTICAJ PROBLEMA MODIFIKOVANIH PROSTORNIH JEDINICA (MAUP) NA URBANO ODLUČIVANJE: KRITIČKA REFLEKSIJA

Apstrakt: Iako je problem modifikovanih prostrnih jedinica (MAUP) dobro dokumentovan u prostornoj analizi, njegovi efekti na razvoj urbane politike i donošenje odluka su još uvek nepoznati. Stoga smo odlučili da uradimo ovaj posao kako bismo kritički istražili kako MAUP utiče na urbano planiranje na različitim nivoima na analitičke rezultate, upravljanje i prostornu politiku. Proizvoljna podela geografskih jedinica i dalje unosi pristrasnost i neizvesnost u postupcima donošenja odluka, čak i uz rastući računarski kapacitet i široku primenu urbane analitike. Koristeći polustrukturirani pregled literature, proučavali smo aktuelne studije o MAUP-u u urbanoj analitici i planiranju, naglašavajući važnost metodoloških tehnika, poteškoća i metoda ublažavanja. Naši rezultati pokazuju fragmentiran korpus istraživanja gde metodološki razvoj obično nema direktnu relevantnost za kreiranje politike. Takođe, naglašavamo potrebu za ex-ante i ex-post procenama kako bi se procenio uticaj MAUP-a na urbanu administraciju. Pored toga, naglašavamo neophodnost interdisciplinarne saradnje kako bismo osigurali holističkiji pristup. Cilj nam je da podignemo svest među urbanim dizajnerima, zakonodavcima i istraživačima, tako što ćemo premostiti ovaj istraživački jaz, podržavajući, na taj način, otvorenije, snažnije, kontekstualno osetljive sisteme prostornog odlučivanja.

Ključne reči: Problem modifikovanih prostornih jedinica, MAUP, urbana analitika, urbano odlučivanje, urbane politike, prostorna analiza.

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