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(REVIEW ARTICLE)

Assessing social determinants of health using geospatial analytics to reduce disparities and inform targeted interventions

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Abstract

Health inequities persist across populations due to uneven distribution of social determinants of health [SDOH], including income, education, housing quality, environmental exposure, and access to healthcare services. Traditional aggregate-level analyses often mask localized vulnerabilities, limiting the effectiveness of public health interventions. This study examines the application of geospatial analytics to assess SDOH at fine spatial resolutions in order to identify disparity hotspots and inform targeted, equity-oriented interventions. By integrating geospatial data with demographic, socioeconomic, environmental, and health outcome datasets, the approach enables spatial pattern detection, risk stratification, and visualization of complex interactions shaping health outcomes. Geographic information systems [GIS], spatial clustering, and predictive spatial modeling are highlighted as critical tools for uncovering place-based inequities and guiding resource allocation. The paper demonstrates how geospatial analytics can support evidence-based policymaking, improve cross-sector planning, and enhance accountability in public health systems. Furthermore, it discusses ethical considerations, data governance challenges, and the importance of community engagement in geospatial health analyses. The findings underscore the value of spatially informed decision-making in reducing health disparities, optimizing intervention targeting, and advancing health equity, particularly in underserved and marginalized communities. Geospatial assessment of SDOH is positioned as a vital component of modern population health strategies and precision public health frameworks.

Keywords: Social Determinants of Health; Geospatial Analytics; Health Disparities; Geographic Information Systems; Targeted Public Health Interventions; Health Equity

1. Introduction

1.1. Social Determinants of Health and Persistent Disparities

Social determinants of health [SDOH] refer to the non-medical conditions in which individuals are born, grow, live, work, and age, and they play a decisive role in shaping population health outcomes [1]. Extensive evidence demonstrates that factors such as income, education, housing quality, employment conditions, and neighborhood environments account for a substantial proportion of observed health inequities across and within countries [2]. Despite advances in healthcare delivery and biomedical innovation, disparities in morbidity, mortality, and life expectancy persist, particularly among socioeconomically disadvantaged and marginalized populations [3]. These inequities are not

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randomly distributed but instead follow clear social and geographic gradients, reflecting structural and systemic inequalities embedded within societies [4]. Addressing health disparities therefore requires analytical approaches that extend beyond individual-level risk factors to capture the broader social and spatial contexts influencing health outcomes [5].

1.2. Limitations of Traditional Approaches and the Emergence of Geospatial Analytics

Conventional SDOH assessments have largely relied on aggregated national or regional indicators, which can obscure localized patterns of disadvantage and mask intra-community variation [6]. Such non-spatial approaches limit the ability of policymakers and public health practitioners to identify high-risk populations with precision and to design interventions that are responsive to place-specific needs [7]. In response, geospatial analytics has emerged as a critical methodological advancement in population health research, enabling the integration of geographic information systems [GIS] with demographic, socioeconomic, environmental, and health data [8]. By visualizing and analyzing spatial relationships, geospatial tools provide deeper insights into how place-based factors interact to produce health disparities, thereby supporting more targeted, equity-oriented public health strategies.

1.3. Study Aims and Scope

This paper aims to assess the use of geospatial analytics in evaluating social determinants of health to reduce health disparities and inform targeted interventions. It examines conceptual foundations, analytical methods, ethical considerations, and policy implications of spatially informed SDOH analysis, with a focus on translating spatial evidence into actionable public health decision-making.

2. Conceptual Framework: Social Determinants of Health and Place

2.1. Defining Social Determinants of Health

Social determinants of health encompass a broad range of interconnected social, economic, and environmental conditions that shape health risks and outcomes across the life course [7]. Economic stability influences access to nutritious food, safe housing, and healthcare services, while educational attainment affects health literacy, employment opportunities, and long-term wellbeing [8]. Neighborhood and built environments further shape exposure to environmental hazards, transportation options, and opportunities for physical activity [9]. Access to healthcare services and the quality of social and community networks also play critical roles in mediating health outcomes, particularly for vulnerable populations [10]. Understanding SDOH as a multidimensional and interdependent system is essential for capturing their cumulative impact on population health [11].

2.2. Spatial Dimensions of Health Inequities

Health inequities are inherently spatial, as social disadvantage and environmental risk factors tend to cluster geographically rather than distribute evenly across populations [12]. Areas characterized by concentrated poverty often experience overlapping burdens of poor housing, environmental pollution, limited healthcare access, and reduced social services, amplifying adverse health outcomes [13]. Urban–rural disparities further illustrate the spatial nature of health inequities, with rural communities frequently facing healthcare workforce shortages and infrastructural barriers, while urban settings exhibit stark intra-urban inequalities at neighborhood level [14]. Spatial analysis enables the identification of these geographic patterns, revealing how place acts as a critical determinant of health risk and resilience [15].

2.3. Linking Place, Policy, and Health Outcomes

Place-based health outcomes are shaped not only by physical environments but also by policy decisions governing land use, transportation, housing, and service provision [16]. Zoning policies, infrastructure investment, and environmental regulations can either mitigate or exacerbate health risks depending on how they are designed and implemented [17]. A conceptual framework that explicitly links SDOH, spatial context, and policy environments provides a foundation for understanding how structural determinants translate into localized health disparities. Geospatial analytics operationalizes this framework by enabling policymakers to visualize policy impacts across space and to align interventions with areas of greatest need.

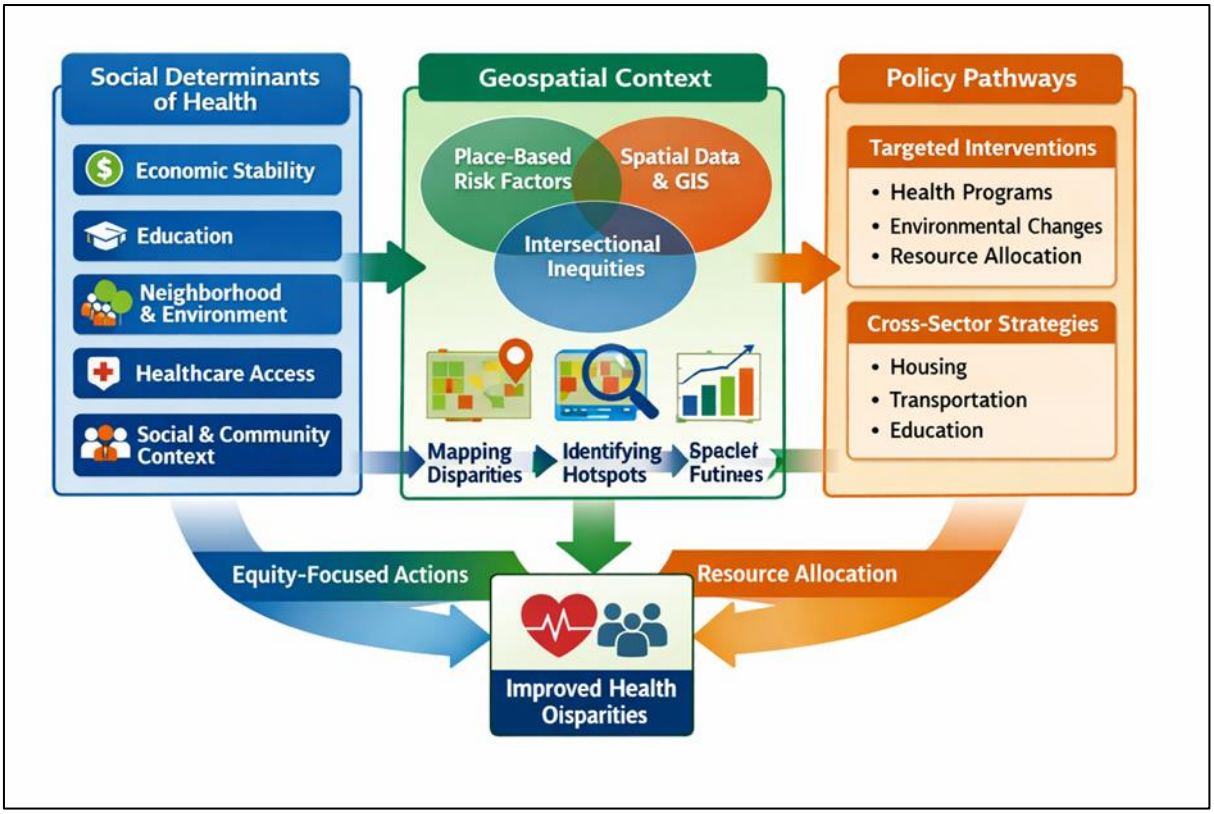

Figure 1 Conceptual framework linking SDOH, place-based factors, and health outcomes

3. Geospatial Analytics Methods for Sdoh Assessment

3.1. Data Sources and Integration

Robust geospatial assessment of social determinants of health [SDOH] relies on the integration of diverse data sources capturing social, economic, environmental, and health dimensions at appropriate spatial scales [16]. Commonly used datasets include population census data, administrative health records, education and employment statistics, housing registries, and environmental monitoring data such as air quality and land use indicators [17]. These datasets vary substantially in temporal frequency, geographic resolution, and data quality, creating challenges for meaningful spatial integration [18]. Harmonization processes, including geocoding, spatial interpolation, and boundary alignment, are therefore essential to ensure consistency across datasets [19]. Decisions regarding spatial resolution, such as neighborhood, census tract, or postal code level, significantly influence the sensitivity of analyses and the visibility of localized disparities [20]. Inadequate resolution can obscure micro-level vulnerabilities, while overly granular data may raise privacy and governance concerns [21].

3.2. Geographic Information Systems [GIS] in Public Health

Geographic information systems [GIS] provide the foundational platform for visualising and analysing spatial distributions of SDOH and health outcomes [22]. Through thematic mapping, GIS enables the overlay of multiple determinants such as poverty rates, housing conditions, and healthcare accessibility onto geographic space, revealing spatial correlations that are not apparent in tabular data [16]. GIS tools also support proximity analysis, service catchment mapping, and accessibility modelling, which are particularly valuable for evaluating inequities in healthcare and social service provision [17]. By transforming complex datasets into intuitive spatial representations, GIS enhances decision-makers' capacity to identify priority areas and communicate evidence to stakeholders across sectors [23].

3.3. Spatial Statistical Techniques

Beyond visualization, spatial statistical methods allow for rigorous quantification of geographic patterns in health inequities [18]. Hotspot analysis is commonly used to identify statistically significant clusters of high or low values for specific SDOH indicators or health outcomes, supporting the detection of concentrated disadvantage [19]. Measures of spatial autocorrelation assess whether observed patterns are randomly distributed or spatially dependent, providing

insight into structural drivers of inequity [20]. Cluster detection techniques further enable differentiation between isolated high-risk areas and broader regional trends, informing the scale at which interventions should be designed [21]. These methods strengthen causal inference by accounting for spatial dependence that traditional statistical approaches often overlook [24].

3.4. Predictive and Exploratory Spatial Models

Predictive spatial models extend descriptive analyses by estimating future risk distributions based on existing SDOH patterns [22]. Risk mapping techniques combine multiple determinants to identify areas with elevated probability of adverse health outcomes, enabling proactive intervention planning [23]. Vulnerability indices aggregate social, economic, and environmental indicators into composite scores that facilitate comparison across geographic units [24]. While such models enhance targeting efficiency, their validity depends on transparent variable selection, appropriate weighting, and sensitivity testing to avoid reinforcing existing biases [16].

Table 1 Common Social Determinants of Health (SDOH) Indicators and Corresponding Geospatial Data Sources

SDOH Domain	Indicator	Description	Common Geospatial Data Sources
Economic Stability	Household income	Median or per-capita income levels	Census Bureau (ACS), World Bank Subnational Data
	Poverty rate	Percentage of population below poverty threshold	Census Bureau (ACS), DHS Spatial Data
	Employment status	Unemployment and labor participation rates	Bureau of Labor Statistics, ILOSTAT
Education Access and Quality	Educational attainment	Highest level of education completed	Census Bureau (ACS), UNESCO Institute for Statistics
	School accessibility	Distance to primary and secondary schools	OpenStreetMap, Ministry of Education GIS portals
Healthcare Access and Quality	Health facility density	Number of clinics/hospitals per population	WHO Service Availability Mapping, OpenStreetMap
	Insurance coverage	Percentage of insured population	Census Bureau (ACS), National Health Surveys
Neighbourhood and Built Environment	Housing quality	Overcrowding, housing age, structural condition	Census Bureau (ACS), UN-Habitat
	Transportation access	Proximity to public transit networks	OpenStreetMap, Local Transport Authorities
	Environmental exposure	Air pollution, flood risk, heat vulnerability	EPA EJSCREEN, NASA Earth Data
Social and Community Context	Population density	Concentration of residents per area	Census Bureau, World Pop
	Marginalization index	Composite measures of social exclusion	CDC Social Vulnerability Index (SVI)
	Crime rates	Incidence of violent and property crime	Local Police GIS, UNODC
Food and Nutrition Access	Food desert status	Distance to affordable healthy food outlets	USDA Food Access Research Atlas
	Market accessibility	Proximity to food markets or vendors	OpenStreetMap, FAO Geonet work
Geographic Accessibility	Rural–urban classification	Settlement type and remoteness	Census Urban–Rural Classifications, GHS-SMOD
	Travel time to services	Time to nearest healthcare or service node	WHO AccessMod, Google Open Data

4. Identifying Disparities and Vulnerable Populations

4.1. Spatial Patterns of Health Inequities

Geospatial analyses consistently demonstrate that health inequities are spatially patterned, reflecting the geographic concentration of social and environmental disadvantage [23]. Communities experiencing poverty often face coexisting risks, including substandard housing, environmental pollution, limited transportation, and reduced access to healthcare services [24]. These overlapping risk factors contribute to disproportionate burdens of chronic disease, poor mental health, and premature mortality [25]. Spatial pattern analysis reveals how structural inequalities manifest geographically, highlighting the role of historical segregation, urban planning decisions, and unequal resource distribution in shaping health outcomes [26].

4.2. Disparity Hotspots and Risk Stratification

Identifying disparity hotspots is a central application of geospatial SDOH analysis [27]. By combining spatial clustering techniques with multidimensional indicators, researchers can delineate high-need geographic zones where adverse social conditions and poor health outcomes converge [23]. Risk stratification based on spatial evidence enables public health agencies to priorities interventions, allocate resources more equitably, and tailor strategies to local contexts [28]. This approach shifts public health planning from uniform, population-wide interventions toward targeted, place-based action that aligns with equity objectives [29].

4.3. Intersectionality and Compound Disadvantage

Spatial inequities are often intensified by intersectionality, where multiple axes of disadvantage such as socioeconomic status, race, environmental exposure, and geographic isolation interact within the same communities [30]. Geospatial analytics allows for the simultaneous examination of these intersecting factors, revealing how compound disadvantage amplifies health risk beyond the impact of individual determinants [24]. Mapping intersectional vulnerabilities supports more nuanced understanding of inequity and helps prevent oversimplified policy responses that fail to address structural complexity [25]. Incorporating intersectionality into spatial analyses is therefore essential for designing interventions that are both effective and socially just [27].

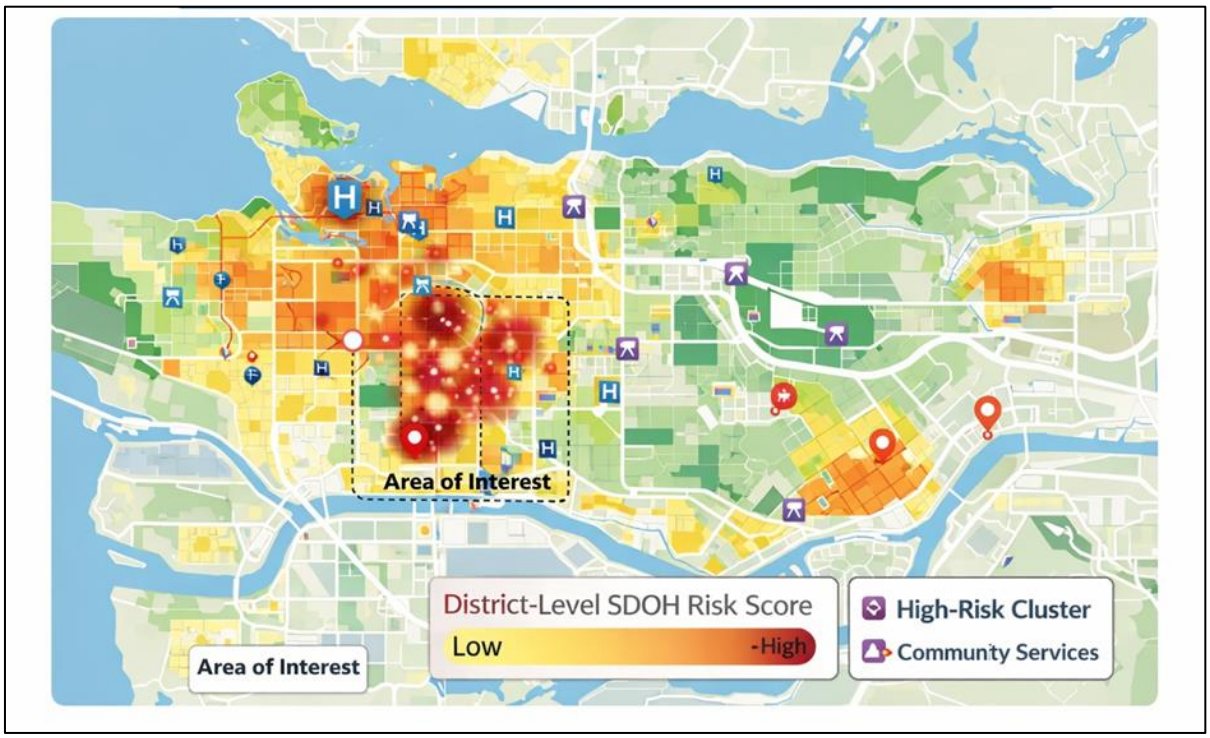

Figure 2 Geospatial disparity hotspot map illustrating clustered SDOH risks [22]

5. Informing Targeted Interventions and Resource Allocation

5.1. Translating Spatial Insights into Action

Geospatial analysis of social determinants of health [SDOH] provides actionable intelligence by transforming abstract patterns of disadvantage into clearly defined geographic priorities for intervention [29]. Spatial visualizations such as risk maps and hotspot analyses allow policymakers to move from descriptive awareness of inequities toward evidence-based decision-making grounded in place [30]. By identifying where adverse social conditions and poor health outcomes converge, geospatial tools support the alignment of policy responses with localized needs rather than broad population averages [31]. This translation from maps to policy decisions enhances accountability by enabling decision-makers to justify interventions based on transparent spatial evidence and measurable equity gaps [32]. When embedded into planning cycles, geospatial insights facilitate iterative monitoring, allowing interventions to be refined as spatial conditions evolve over time [33].

5.2. Targeted Public Health Interventions

Targeted public health interventions informed by geospatial analytics focus on addressing community-specific drivers of health inequity rather than relying on uniform approaches [34]. Community-level prevention strategies may include geographically targeted screening programmers, health promotion initiatives tailored to local risk profiles, and environmental interventions aimed at reducing exposure to spatially concentrated hazards [29]. Place-based service delivery models, such as mobile clinics or decentralized social services, leverage spatial accessibility analysis to reduce barriers faced by underserved populations [30]. By situating interventions within high-need areas, geospatially informed strategies increase efficiency, improve reach, and enhance the likelihood of measurable impact on health outcomes [35]. These approaches also support intersectoral collaboration by aligning health interventions with housing, transport, and environmental policies operating within the same geographic contexts [36].

5.3. Optimizing Resource Distribution

Equity-driven resource allocation is a central objective of spatial SDOH analysis, particularly in settings with constrained public health budgets [31]. Geospatial methods enable the prioritization of healthcare infrastructure, workforce deployment, and social services based on demonstrated need rather than political or historical allocation patterns [32]. By quantifying spatial inequities, decision-makers can redirect resources toward communities experiencing disproportionate burden, thereby reducing inefficiencies associated with over-servicing low-need areas [33]. Resource optimization informed by spatial evidence also supports performance evaluation, as changes in geographic patterns of health outcomes can be tracked following targeted investments [34]. This spatially responsive allocation framework strengthens the capacity of health systems to advance equity while maintaining fiscal sustainability [36].

Table 2 Equity outcomes

Geospatial Insight Identified	Type of Intervention	Target Population / Area	Mechanism of Action	Expected Equity Outcome
Spatial clustering of low primary care access	Deployment of mobile health clinics	Underserved urban neighbourhoods and remote rural areas	Uses proximity and accessibility mapping to locate services closer to high-need populations	Reduced geographic barriers to care and improved service utilisation
Concentrated poverty and high chronic disease prevalence	Targeted community-based screening programmes	Socioeconomically disadvantaged census tracts	Spatial risk stratification guides prioritisation of screening locations	Earlier disease detection and reduced outcome disparities
High exposure to environmental hazards [e.g. air pollution]	Environmental risk mitigation and regulatory enforcement	Industrial-adjacent or high-traffic residential zones	Overlay of health outcomes with environmental exposure data	Reduced environmental health burden in vulnerable communities

Limited access to healthy food outlets	Place-based nutrition and food access interventions	Identified food deserts	Spatial analysis of food retail distribution informs intervention siting	Improved dietary options and reduced nutrition-related inequities
High maternal and child health risk clusters	Decentralised maternal and child health services	High-risk neighbourhoods	GIS-guided placement of outreach and support services	Improved maternal and child health outcomes
Poor public transport connectivity to healthcare facilities	Transport policy and service planning	Peripheral urban and rural communities	Accessibility modelling identifies transport gaps	Enhanced healthcare access and reduced missed appointments
Overlapping social vulnerability indicators	Integrated multi-sector intervention packages	Communities with compound disadvantage	Spatial integration of health, housing, and social data	Holistic reduction of cumulative health risks
Uneven allocation of healthcare resources	Equity-driven reallocation of funding and workforce	Regions with documented service shortfalls	Spatial evidence supports needs-based redistribution	More equitable health system performance across regions

6. Governance, Ethics, And Data Considerations

6.1. Data Governance and Privacy

The use of geospatial data in SDOH analysis raises significant governance and privacy considerations due to the sensitive nature of location-linked health and social information [35]. Fine-grained spatial data can increase the risk of individual or community re-identification, particularly when multiple datasets are combined [36]. Robust data governance frameworks are therefore essential to ensure secure data storage, controlled access, and responsible data sharing across institutions [37]. Clear protocols governing data ownership, consent, and use limitations help maintain public trust while enabling the analytical integration necessary for spatial health research [38]. Balancing data utility with privacy protection is a critical prerequisite for sustainable geospatial SDOH initiatives [39].

6.2. Ethical Risks in Spatial Health Analysis

Ethical risks associated with spatial health analysis extend beyond data privacy to include the potential stigmatization of communities identified as high-risk or disadvantaged [40]. Public dissemination of maps highlighting concentrated vulnerability may inadvertently reinforce negative stereotypes or influence investment decisions in ways that disadvantage already marginalized areas [35]. Algorithmic bias represents an additional concern, as predictive spatial models may perpetuate structural inequities if underlying data reflect historical discrimination or uneven service provision [36]. Ethical spatial analysis therefore requires careful interpretation, contextualisation, and safeguards to prevent misuse or oversimplification of findings [37].

6.3. Community Engagement and Participatory Mapping

Meaningful community engagement is essential for ensuring that geospatial SDOH analyses are both ethically sound and socially legitimate [38]. Participatory mapping approaches involve community members in defining relevant indicators, interpreting spatial findings, and co-designing interventions, thereby enhancing contextual accuracy and local ownership [39]. Inclusive and transparent spatial decision-making processes help mitigate ethical risks by ensuring that affected populations have a voice in how data are used and represented [40]. Embedding participatory principles within geospatial governance frameworks strengthens the responsiveness and equity orientation of spatially informed public health action [41].

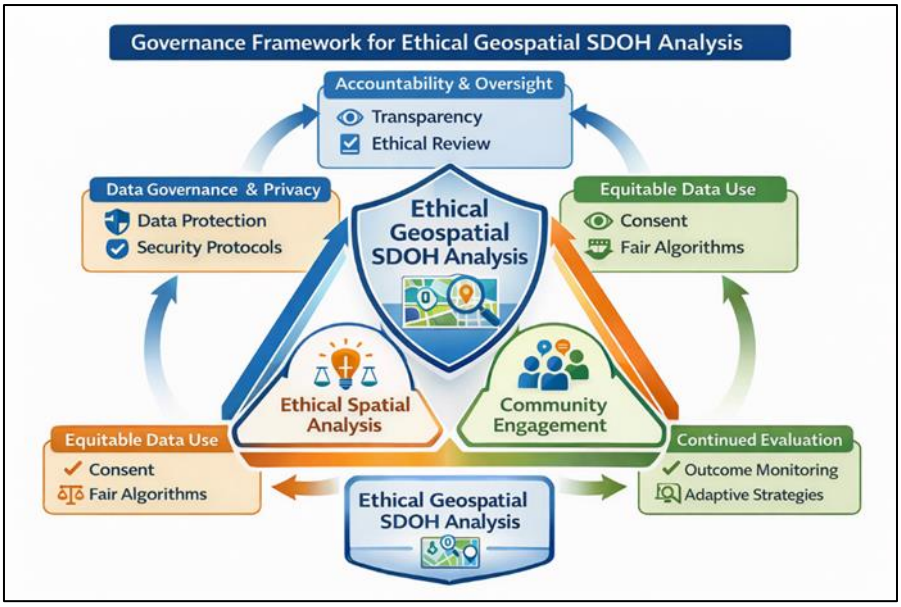

Figure 3 Governance and ethical safeguards for geospatial SDOH analytics

7. Policy Implications and Future Directions

7.1. Integrating Geospatial SDOH Analytics into Health Systems Planning

Integrating geospatial analytics into routine health systems planning enables policymakers to move from reactive service provision toward proactive, equity-oriented decision-making [40]. Spatial assessment of social determinants of health [SDOH] supports needs-based planning by identifying geographic mismatches between population health needs and existing service capacity [41]. When embedded within health information systems, geospatial tools can inform facility siting, workforce deployment, and prioritization of preventive services [42]. This integration enhances strategic planning by allowing health authorities to anticipate emerging disparities and adapt interventions dynamically in response to changing social and environmental conditions [43]. Institutionalizing spatial analytics within planning frameworks is therefore critical for translating evidence into sustained health system improvements [44].

7.2. Cross-Sector Collaboration for Addressing Place-Based Determinants

Effective action on SDOH requires coordinated policy responses across sectors such as health, housing, transportation, education, and environmental management [40]. Geospatial analytics provides a shared evidentiary platform that enables these sectors to align objectives around common geographic priorities [41]. Spatial data integration facilitates identification of co-located risks, such as poor housing quality, limited transport access, and environmental exposure, which no single sector can address in isolation [42]. Cross-sector collaboration supported by geospatial evidence improves policy coherence, reduces duplication of efforts, and strengthens the overall impact of interventions on population health equity [45].

7.3. Scaling Geospatial Tools for National and Regional Equity Strategies

Scaling geospatial SDOH analytics from local pilots to national and regional strategies is essential for achieving systemic reductions in health disparities [43]. Standardized indicators, interoperable data infrastructures, and shared analytical frameworks support comparability across jurisdictions while allowing contextual adaptation [44]. National-level adoption of spatial equity metrics enables governments to monitor progress, benchmark performance, and direct investments toward persistently underserved areas [45]. However, scaling efforts must be accompanied by investments in technical capacity, workforce training, and governance structures to ensure sustainable and ethical use of spatial data [41].

7.4. Role in Precision Public Health and Health Systems Strengthening

Geospatial analytics plays a foundational role in advancing precision public health by enabling interventions to be tailored to the specific needs of populations defined by place as well as demographic characteristics [42]. Spatially informed strategies enhance the efficiency and effectiveness of public health actions by targeting resources where they

are most likely to yield equity gains [43]. Over time, the integration of geospatial SDOH analysis strengthens health systems by improving responsiveness, accountability, and resilience, particularly in the face of social, environmental, and epidemiological change [44]. As such, geospatial analytics represents a critical enabler of health systems strengthening and long-term equity-focused reform [45].

8. Conclusion

This paper has examined the role of geospatial analytics in assessing social determinants of health and addressing persistent health disparities. By situating health outcomes within their social and geographic contexts, geospatial approaches reveal patterns of inequity that are often obscured by aggregate analyses. The integration of spatial data with socioeconomic, environmental, and health indicators enables more precise identification of vulnerable populations and supports targeted, place-based interventions.

Geospatial analytics adds significant value to SDOH assessment by enhancing visibility of localized disadvantage, improving resource allocation, and strengthening accountability in public health decision-making. When applied responsibly, spatial tools facilitate cross-sector collaboration and inform policies that address the structural drivers of inequity rather than their downstream consequences alone.

Ultimately, advancing equity-driven, place-based public health action requires sustained investment in geospatial capacity, ethical governance, and community engagement. As health systems increasingly confront complex social and environmental challenges, geospatially informed approaches will remain essential for translating evidence into effective, inclusive, and resilient public health strategies. Commission on Social Determinants of Health, World Health Organization. Closing the gap in a generation: health equity through action on the social determinants of health. Final report of the Commission on Social Determinants of Health.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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