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The Spatial Patterns of Pluvial Flood Risk, Blue-Green Infrastructure, and Social Vulnerability: A Case Study from Two Alaskan Cities

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Abstract

Flooding is a serious form of natural hazard in Alaska, USA. Two of Alaska's biggest cities, Anchorage and Fairbanks, have experienced flooding of varying magnitude since the cities were first settled in the early 20th century. Although flood mitigation measures such as blue-green infrastructure (BGI) are rising in prominence, the spatial relationship of BGI, urban pluvial flood (UPF) zone, and social vulnerability remains understudied. This study delineates the UPF zone of Anchorage and Fairbanks using the Blue Spot modeling and correlates it with the distribution of BGI at Census Block Group (CBG) scale, focusing on underlying social vulnerability using a set of indicators. Anchorage shows a positive correlation (r = 0.53, p < 0.01) between percentage of UPF area and density of BGF, whereas Fairbanks shows an insignificant negative correlation. In Anchorage, more socially vulnerable CBGs (n = 10) intersect with high blue spot CBGs (n = 33), compared to Fairbanks where those numbers are 1:6. The results indicate that while BGI is equitably and proportionally distributed within the Anchorage UPF zone, the same is not true in Fairbanks, where distribution is equitable, but not proportionate to pluvial flood risk. The study emphasizes that both types of distribution present their unique challenges and opportunities, but the relative absence of BGI increases flood risk for residents. The results are useful for spatial planners to better inform flood mitigation strategies in urban areas, especially to reduce the gap between equitable and proportional distribution of BGI.

Keywords

Urban Flood, Pluvial Flood, Blue-Green Infrastructure, Alaska, GIS

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1 INTRODUCTION

Floods triggered by rainfall referred to as pluvial flooding (Falconer et al. 2009) have increased due to climate change (Dong et al. 2020). On the other hand, rapid urban growth is also intensifying the frequency of flooding in urban areas by reducing green spaces and impeding the flow of water into impervious surfaces (Cutter et al. 2018). Impervious surfaces have a major effect on the hydrological cycle; as evapotranspiration decreases, rainwater surface penetration increases with the amount of runoff peak (La Rosa and Pappalardo 2020; Vamvakeridou-lyroudia et al. 2020). In many parts of the world, including the United States, urban infrastructure is aging and inadequate to alleviate these increases in rainfall and subsequent flooding. For example, the stormwater system in the United States earned a condition status of "D+" according to the American Society of Civil Engineering (ASCE 2017). Current flood management programs have underestimated the impact of urban growth and climate change (i.e., severe and regular flooding triggered by rainfall) on the flood management infrastructure degradation (Amador et al. 2019). To prepare for future climate change, flood risk management strategies need to be appropriately analyzed both for their long-term impacts and capacity to minimize frequent flood occurrences due to unpredictable future amounts of rainfall (Chang et al. 2021a). A well-designed flood-risk management plan would ideally focus on resilience rather than resistance (Liao 2012). While resistance refers to a system's capacity to withstand a disaster, resilience encompasses both resistance and adaptability (Folke 2006; Adger et al. 2005).

In recent decades, rainfall patterns have become increasingly erratic and concentrated within a short period of time, causing pluvial flooding around urban areas, leading to death, property loss, and damage to physical infrastructure (Kunkel et al. 2013; Rosenzweig et al. 2019). Furthermore, extreme rainfall is expected to affect conventional stormwater management procedures, exceeding the current optimal management systems. In severe circumstances, pluvial flooding can destroy urban green runoff (Voskamp and Van de Ven 2015), making presence or absence of green spaces in different neighborhoods an important element in stormwater runoff management. The green spaces mostly affected by flood alteration are parks, public space, green corridors, streets trees, forests in urban areas, vertical roof greenings, and private greens (Gunnell et al. 2019). However, many innovators and sustainability enthusiasts have been increasingly attentive to green space approaches to effectively reduce the impacts of changes in the hydrological cycle especially those caused by urbanization processes (Munyaneza 2014). Urban green space helps to intercept water drops from the canopy and stem area of infiltration to enhance soil and root capacity (Aronson et al. 2017). For this reason, there is a need for urban green space conservation, rehabilitation, and restoration of the degraded spaces to reduce urban flood risks and its effects (Kim et al. 2016). Over the years, urban planning has grown to consider blue and green infrastructure as a combined design for flood management (CNT 2010). Typically, blue infrastructure includes ponds, canals, and wetlands, whereas green infrastructure includes bioswales, trees, parks, and other urban green landscapes that facilitate water flow (Thorne et al. 2015).

In the United States, about 83% of the population lives in urban areas (United Nations 2018). Socio-economic inequities such as gentrification and redlining have resulted in systemic obstacles to urban flood management strategies (NCRC 2020). Years of research in environmental justice has shown that high-polluting forms of land uses, such as hazardous waste sites and power plants, are often sited near marginalized and impoverished neighborhoods (Anguelovski et al. 2016; Mohai et al. 2009; Walker and Bullard 1992). There is also substantial evidence that flood-induced damages and displacements mostly affect low-income population groups (Flyvbjerg et al. 2003; Bararu 2013; Chen et al. 2013; Fahy et al. 2019), especially with the growing number of private property development in vulnerable floodplains. Thus, consideration of social vulnerability is key to understanding potential losses from environmental hazards. Cutter (1996) describes social vulnerability as including "the susceptibility of social groups or society at large to potential losses (structural and nonstructural) from hazard events and disasters". In recent years, indicator-based approaches such as Social Vulnerability Index (SoVI) and Social-Ecological-Technological Systems (SETS)are increasingly being used to assess flood risk (Chang et al. 2021b; Sterzel et al. 2020; Nasiri et al.2019; Müller et al. 2011).

Ongoing research in distribution of urban green spaces indicates that urban green spaces are often not distributed equally (Nesbitt et al. 2019; Immergluck and Balan 2018). In many cases, the access to urban green spaces has shown to be skewed in the favor of those with greater incomes and higher levels of education (Nesbitt et al. 2019). Since studies have also shown that green infrastructure is crucial in combating climate change impacts on the urban environment (Apreda et al. 2019; Oliveira et al. 2011; Rosenzweig et al. 2006) as well as maintaining social and economic wellbeing, it is important to acknowledge the need for equitable distribution of green infrastructure (Baker et al. 2019). Equity, by definition, means a fair and just distribution of resources between or among persons, considering their needs and disadvantages in society (Gooden and Portillo 2010; Rice and Smith 2001).

The main objective of the study is to examine (i) whether Blue-Green Infrastructure (BGI) is equitably and proportionally distributed within the Blue Spot zones within cities in Alaska, and (ii) whether Census Block Groups (CBGs) within the Blue Spot zones are socially vulnerable to pluvial flooding. The proportional distribution aspect in this study refers to BGI spatial distribution in terms of flood risk, while equitable distribution aspect refers to BGI distribution in terms of social vulnerability to flood risk and flooding (Blue Spot areas) combined. Government Reports and City Assessments in Alaska (UAF and USACE 2019; MUNI 2018) have highlighted the issue of pluvial flooding and measures taken, including the development of BGI across the cities, but its distributional pattern has received insufficient coverage. Additionally, the comparison of the major cities in Alaska is also an understudied subject from a pluvial flooding perspective. Our analysis would also help increase the current understanding of the Social-Ecological-Technological-Systems (SETS) flood vulnerability of cities (Chang et al. 2021a; Chang et al. 2021b), and thus offer decision-relevant information for improved policy making to ensure social inclusion and resilience against flood disasters within cities.

This study employed the Blue Spots model (Balstrøm and Crawford 2018), which relies on Geographic Information System (GIS), to map the flood risk areas on the surface. Most of the studies that have analyzed the flood risks and flood management did not employ integrated methods of calculating Blue Spots to model urban Blue-

Green Infrastructure (BGI) and associated social vulnerability indicators (Hosseinzadehtalaei et al. 2020; Berndtsson et al. 2019; Rakib et al. 2017; Zhou et al. 2012). Berndtsson et al. (2019), for example, classified the drivers of urban flood risk into three groups - physical environment, public awareness, and long-term policy changes - to rank risk perception. However, the study does not focus on CBG-scale phenomena and overlooks the flood vulnerability which may or may not exist in every neighborhood. Hosseinzadehtalaei et al. (2020) quantified the future pluvial flood risk in Europe on various scales — continental, regional, and national — using intensity–duration–frequency (IDF) curves. The study provides an extensive understanding of how future flood risk is projected to be in Europe, but quantification of results using the same methods at local scale has not been given. Zhou et al. (2012) provided an insight into understanding the economic assessment of flood adaptation measures within fluvial boundaries, but the framework does not specifically address pluvial flooding, which may occur beyond fluvial flood boundaries.

This paper was structured to offer flood risk analysis and compare their spatial distribution between neighborhoods of Anchorage and Fairbanks; section 1 provides background to various concepts explored in this study, while section 2 presents the study area and context. Section 3 focuses on data and methods, while results in section 4 explore how green infrastructure relate to pluvial flood risk in Alaskan communities. The discussion section i.e., section 5 analyzes the results in the context of research questions and future research scope; section 6 summarizes the study and its findings. The framework (Figure 1) presented in this paper integrates both the problem (pluvial flood risk) and the solution (BGI) into an interconnected process aimed at resolving urban flooding and structural inequalities.

2 STUDY AREA

The study area consists of two major cities in the Alaskan mainland—Anchorage and Fairbanks. The two cities exhibit distinct subarctic characteristics (Table 1). The municipality of Anchorage, which includes the urbanized sections, has nearly 40.5 km^2 of floodplain. Rainfall-induced runoff is a major contributor to urban flooding in the Anchorage municipality, and a strong atmospheric river (AR) called the Pineapple Express—characterized by warm weather and heavy precipitation—caused notable floods in the area during the fall months of 1995, 1997, 2002 and 2005 (MUNI 2018).

Fairbanks experienced heavy rains in the summer of 1967, which caused great damage of more than $80 million in 1967 dollars (NWS 2017). Fairbanks experienced another flood event in 2008 due to excessive precipitation; estimated damage stood at $10 million dollars (NWS 2017). From a demographic perspective, both cities have similar racial composition with a substantial presence of Native American or Alaskan Native population groups (Table 1).

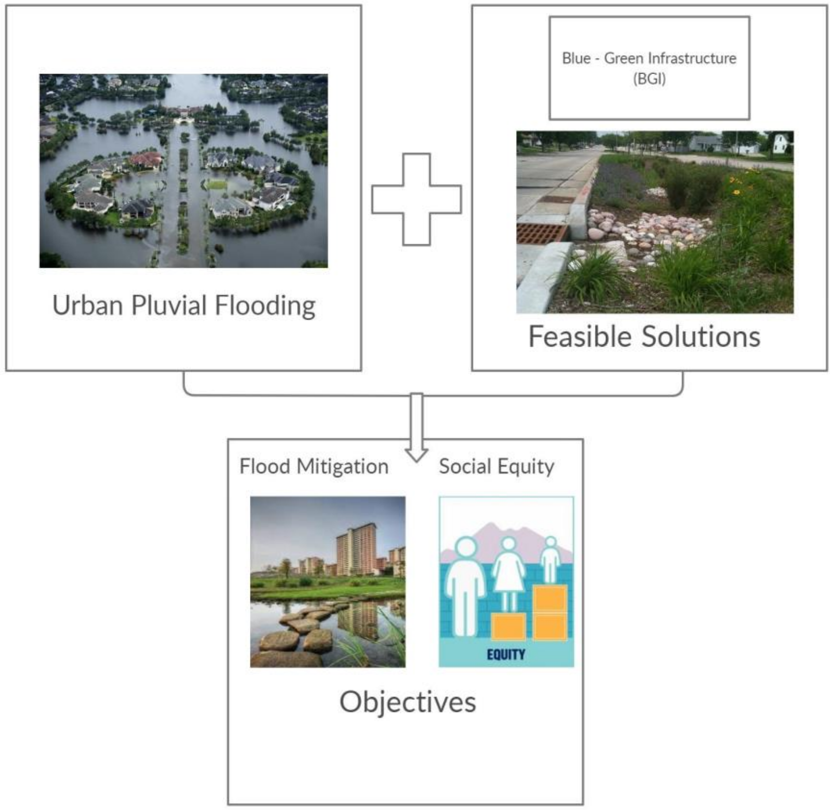

Figure 1. Conceptual Framework describing the integrated objectives of urban pluvial flooding (challenge) and feasible solutions (opportunity).

Table 1. Anchorage and Fairbanks physical and social characteristics.

City	Anchorage	Fairbanks
Climate (Koppen)	Subarctic (Dfc)	Subarctic (Dfc)
Latitude	61^0 N	65^0 N
Elevation Mean Sea Level (Meters)	31	136
Population (2010)	293,310	31,760
% White Population	63%	65.7%
% Racial Minority Population (Significant)	Native 8%, Asian 8%, Black 6%	Native 10%, Black, 9%, Asian 4%,
BGI Density (Km^2)	64	160
Major Flood Years and causes AR* = Atmospheric River	1995 - Fall Rainstorm (AR) 1997 - Rain and Snowmelt (AR) 2002 - Fall Rainstorm (AR) 2005 - Fall Rainstorm (AR)	1967 - Summer Rainstorm 2008 - Summer Rainstorm

The experience of floods over several decades has made the city of Anchorage require a Flood Hazard Permit prior to construction of all new buildings (MUNI 2018).

The buildings are required to be at least one foot above the elevation of the 100-year flood. In Fairbanks, the city has institutionalized structural and non-structural Best Management Practices (BMPs). Structural BMPs include erosion control, sediment control, velocity control, and treatment practices, while non-structural BMPs include project design, housekeeping, and phasing. Although many of the efforts of both cities go towards fluvial flood mitigation, pluvial flooding remains a major policy concern for urban planners and residents.

Due to climate change, Alaska has warmed by about 2.5°F (1.4°C) since the 1970s, compared to about 1.5° F (0.8° C) for the contiguous US as a whole (Stewart el al. 2017). Further, by the middle of the 21st century, average annual precipitation is expected to rise by 10 % or more across all of Alaska under a higher emission pathway (NASEM 2019; Stewart et al. 2017). The floods associated with this climate change scenario could adversely impact high population centers. The floods associated with this climate change scenario could adversely impact high population centers, such as Anchorage and Fairbanks (Figure 2). These cities could face loss of life, damages to property, infrastructure, livelihoods as well as disruption of essential services due to flood impacts.

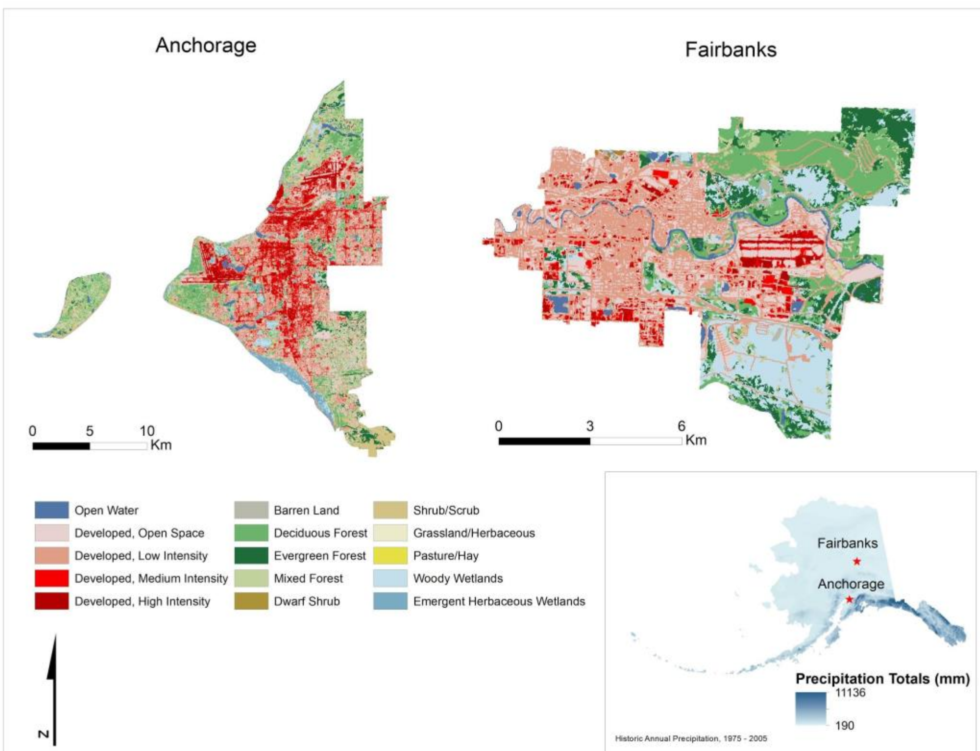

Figure 2. Land cover classes in Anchorage and Fairbanks, Alaska.

As a response to climate change, cities in Alaska have begun to implement Blue-Green space in most of their streets (UAF and USACE 2019). The green infrastructure performance and maintenance are limited in scope when comparing the relationship between green spaces and flood mitigation in Alaska. BGI contributes to more benefits than negative effects, such as mitigation of pluvial floods, promotion of urban cooling, conservation of biodiversity and boosting urban agriculture (Voskamp and Van de Ven 2015). Therefore, BGI should integrate urban landscapes that give multiple benefits and minimize the amount of land required (Dawson et al. 2020; Krivtsov et al. 2020). In the context of social vulnerability to flood exposure, the integration of BGI in Alaskan cities remains largely understudied; an integrated model with various aspects and patterns of reducing the extent of damage is needed. However, the urban planning system would require integrating social, environmental, technical, institutional, and legal aspects, as well as economic benefits (Lindberg et al. 2016); therefore, understanding the social vulnerability of Alaska's major cities is critical for mitigating urban floods through the development of an integrated urban green space.

3. DATA AND METHODS

3.1 Data Collection

We collected data from three major sources: US Geological Survey (USGS), US Census Bureau, and City GIS Department (Table 2). Digital Elevation Model (DEM) data of 5-meter resolution is available in the USGS catalog for Alaska. The US Census Bureau publishes American Community Survey (ACS) on its website, which is also easily accessible. We used 2010 ACS data because some of the variable data for Alaska is incomplete for later years. Municipality of Anchorage hosts an open GIS data portal, which carries an extensive set of spatial data in a well-organized manner. Fairbanks-area GIS data is available for educational use on request.

Table 2. Elevation, sociodemographic and BGI data used for analysis.

Data	Digital Elevation Model (DEM)	American Community Survey (ACS)	Blue-Green Infrastructure Layer
Year(s)	2015	2010 (5 Year Estimates)	2010 – 2015
Type(s)	Raster	Survey	Vector
Variable(s)	5-Meter	Population Population Density % Single Largest Minority Group % Renters % Poverty % College and Advanced Degree Holders	Basic Storm Infrastructure (drains, inlets, etc.) * Green Facilities (Rain Gardens, Bioswales, etc.) Parks Wetlands Ponds and Lakes
Purpose	Derive Blue Spots using surface elevation variation	Calculate Social Vulnerability	Combine and Calculate BGI Density
Source	US Geological Survey (USGS)	US Census Bureau	City GIS Department

*Gray infrastructure count incorporated to provide comprehensive picture as typically Green Infrastructure and Blue Infrastructure incorporate some element of Gray Infrastructure in cities in the form of drainage outlets, catch basins, and pipes; general manholes excluded.

3.2 Methods

To delineate a pluvial flood zone, we used the Balstrøm method for identifying networks of depressions in the topography of the study areas, known as conducting Blue Spot modeling (Balstrøm et al. 2018). This method delineates flood sensitive areas, where the likelihood of flooding is relatively high and where its consequences on populations are significant (Climate-ADAPT 2015). Through the Blue Spot analysis with the 5-meter DEM data, we identified low-lying areas in the landscape (census block groups). The low-lying areas are possibly pluvial flood zones under 10-year return period storm conditions, for which stormwater management infrastructure is typically designed. We processed the DEM in ArcGIS 10.7 (ESRI 2019) model builder to identify the bluespot areas of at least 5 cm (0.05 meter) depth within the city. The processing included running ArcGIS tool *fill* twice, followed by *con*, and *raster to polygon* to extract the output.

We then summarized the area of the pluvial floodplain (Blue Spots) by the unique census identifier known as GEOID and divided it by the total area of GEOID (of each CBG). Next, we multiplied the result by 100 to derive the total % of Blue Spot area per CBG. Also, we created a BGI layer by combining parks and wetlands layers. For additional precision, we added the stormwater infrastructure layer. We then summarized the combined BGI layer at CBG-scale and divided by the total area (Km^2) of each CBG to obtain the density of BGI. We used demography data from the American Community Survey (Census) five-year estimates in 2010 to determine social implications of the results (Rufat et al. 2015; Cutter and Finch 2008). All three data, Blue Spots, BGI, and social vulnerability indicators, were summarized using the following formula (Eq. 1):

$$V_i = \frac{X_i - X_{imin}}{X_{imax} - X_{imin}} \quad (1)$$

where V_i = normalized value of indicator X_i, X_{imin}, and X_{imax} represent the minimum and maximum values of a specific indicator i, respectively.

First, using normalized values of % Blue Spots and Density of BGI, all the Blue Spots and BGS were sorted in a descending order. Top 25% CBGs were identified for each variable and labeled as High Blue Spots and High BGI, respectively. The remaining CBGs that do not fall into these two groups (the remaining 75% each) were labeled as Low Blue Spots and Low BGI, respectively. By combining these top quartiles and the remaining three quartiles, four new classes of CBGs were created (Table 3).

Table 3. Classification of CBGs based on the combination of Blue Sport and BGI density.

		Blue Spot (%)	
		Top quartile	Remaining quartiles
BGI density	Top quartile	High Blue Spot, High BGI	Low Blue Spot, High BGI
	Remaining quartiles	High Blue Spot, Low BGI	Low Blue Spot, Low BGI

Second, social flood vulnerability was calculated using a set of indicators (Chang et al. 2021b; Cutter et al. 2003) to identify the underlying social vulnerability patterns (Table 4). Each indicator was normalized on a scale of 0-1 using the minimum-maximum rescaling formula described above. The social vulnerability of a CBG is the sum of all the normalized social indicators for the CBG.

Table 4. Social vulnerability indicators relationship to pluvial flood vulnerability.

Indicator	**Hypothesized relation**	**Justification**	**Reference**
Population SV1	+	More people living in a place, more people are exposed to floods	Cutter 2016, Rufat et al. 2015
Population Density SV2	+	High Population Density makes a place more vulnerable	Cutter 2016, Khan 2012, Tate et al. 2011
Racial Minority Group (Significant) SV3	+	Minorities form disadvantaged groups socially and economically, so they are more vulnerable	Anguelovski et al. 2016; Schmidtlein et al. 2011
Educational Attainment SV4	-	Higher education (Bachelor's or higher) is associated with better standards of living and safety, making them less vulnerable	Munyai et al. 2019
Renters SV5	+	Renters have less flexibility and financial independence during flood events, making them more vulnerable	Rufat et al. 2015
Poverty Based on Income SV6	+	Poor people are less mobile; more likely to be homeless, and more exposed to floods	Nesbitt et al. 2019; Schmidtlein et al. 2011

(SV1N+SV2N+SV3N+SV4N+SV5N+SV6N) = Social Vulnerability

For indicators that are inversely related to pluvial flood vulnerability, the formula shown below was used for standardization (e.g., higher % educated population reduces vulnerability; Eq. 2). For top quartile Blue Spots that intersected with top quartile BGI, we interpreted those CBGs as having *proportionate distribution* to flood risk, whereas top quartile Blue Spots that fall in socially vulnerable CBGs and share top quartile BGI were interpreted as having *equitable distribution*.

$$V_i = \frac{X_{imax} - X_i}{X_{imax} - X_{imin}} \quad (2)$$

4. RESULTS

The Blue Spots in Anchorage range from 0 - 60 %, with an average of 5 %. The BGI density in Anchorage is 64/Km^2. In Anchorage, high % Blue Spots are located in the northeast, west, and central neighborhoods (Figure 3).

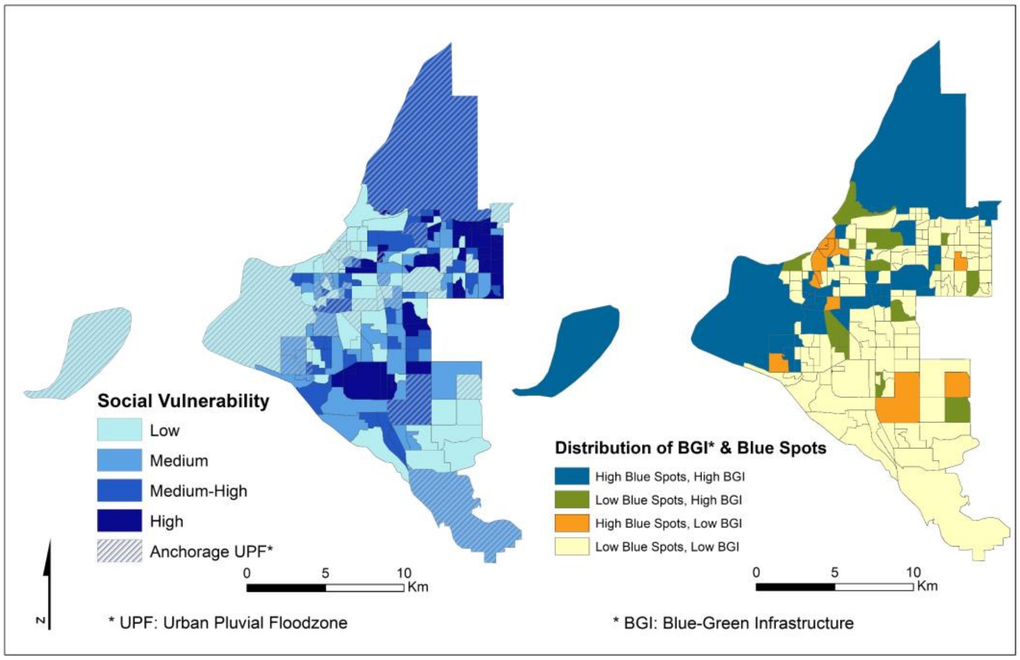

Figure 3. Anchorage social vulnerability, Blue Spot and BGI distribution map.

Neighborhoods such as Russian Jack Spring and Spenard have both high % Blue Spots and high density of BGI. Other neighborhoods such as Fairview and Taku/Campbell have high density of BGI, but low % Blue Spots. The neighborhoods with low density of BGI, but high % Blue Spots are primarily South Addition and Downtown Anchorage. In Anchorage, overall, Blue Spots and BGI show positive correlation (r = 0.53, p < 0.01). The neighborhoods with high social vulnerability, among others, are Downtown Anchorage, Fairview, Government Hill, Mountain View, North Star, Russian Jack Park, and Spenard (Figure 4).

In Anchorage, 55 % of CBGs (33 of 59 significant CBGs) show high Blue Spots and high BGI and 20 % of CBGs (12 of 59 significant CBGs) show high Blue Spots and low BGI. The remaining 25 % of CBGs (14 of 59) display low Blue Spots and high BGI. In Anchorage, 10 socially vulnerable CBGs intersect with high Blue Spots and high BGI CBGS (Table 5), whereas no socially vulnerable CBGs directly intersect with high Blue Spots and low BGI CBGs (n = 12), and two socially vulnerable CBGs intersect with low Blue Spots and high BGI CBGs (n = 14).

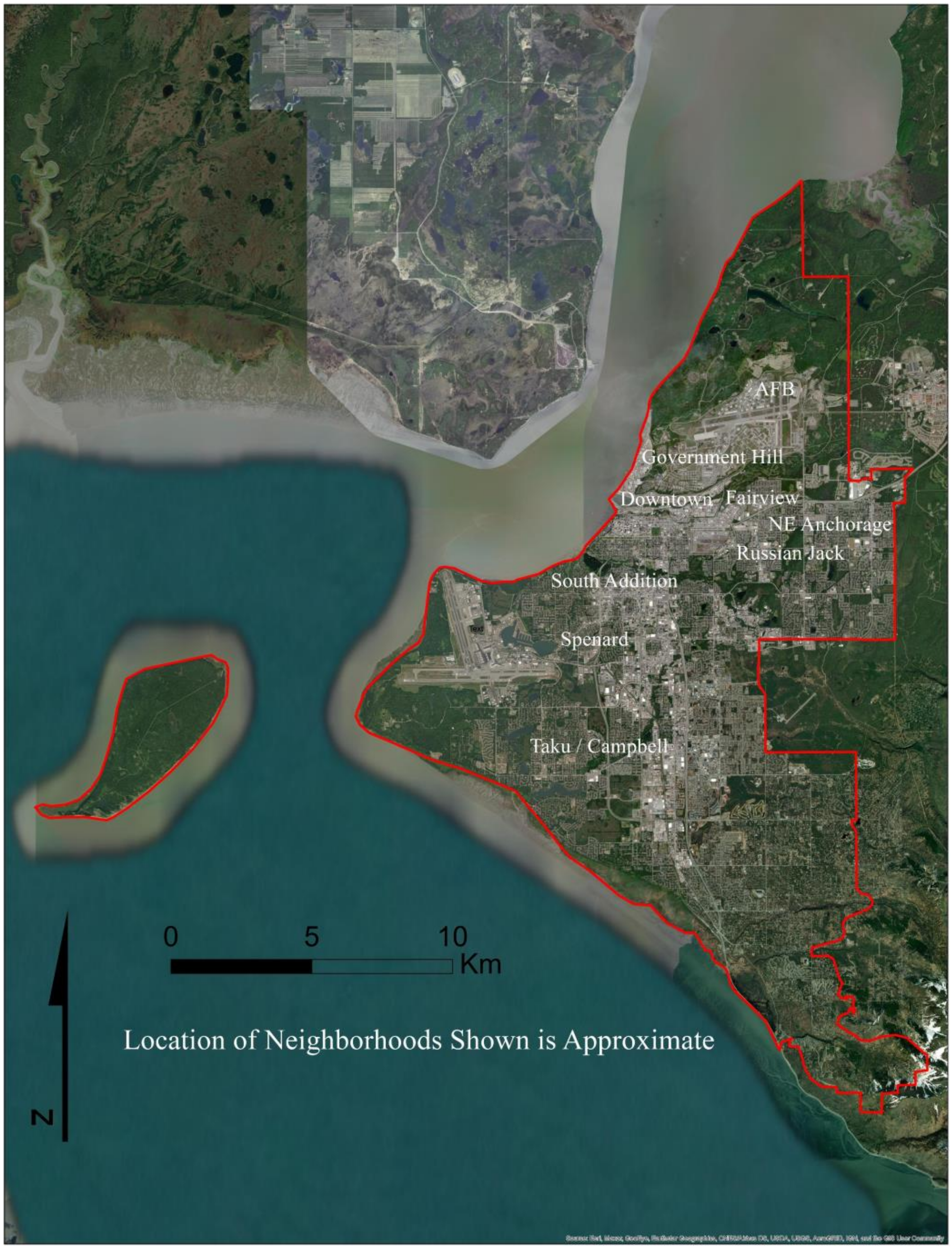

Figure 4. Neighborhoods of Anchorage, Alaska.

The Blue Spots in Fairbanks range from 0 - 84 %, with an average of 35 %. Fairbanks boasts an impressive BGI of 160/Km^2. In Fairbanks, socially vulnerable neighborhoods generally have low % Blue Spots with low BGI for the top quartile (Figure 5).

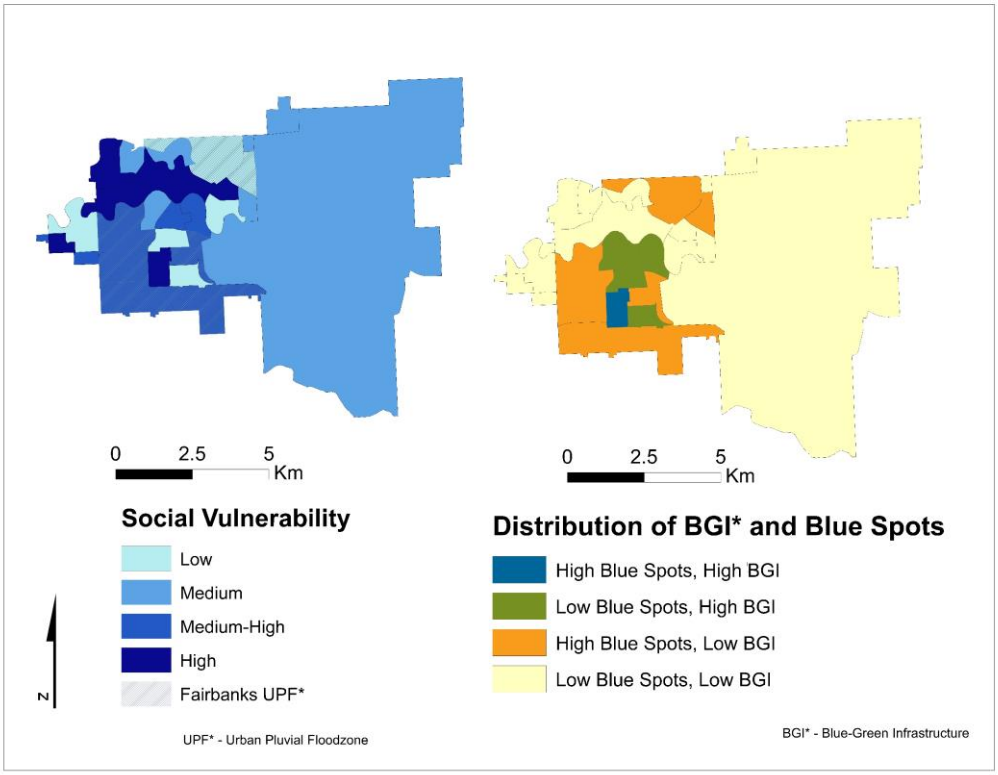

Figure 5. Fairbanks Blue Spots – BGI distribution map.

Fairbanks has only one CBG where a high density of BGI intersects with high % Blue Spots. Other neighborhoods have low % Blue Spots and low concentration of BGI. In Fairbanks, Blue Spots and BGI show negative correlation (r = –0.021). We note some of the neighborhoods with high social vulnerability, among others, are Aurora / Totem Park, South Van Horn and Tovey Dr / Birch Ln (Figure 6). Low social vulnerability is found in neighborhoods such as Hamilton, Richardson Hwy / Old Richardson Hwy, and Lemeta. In Fairbanks, 9 % of CBGs (1 of 11 significant CBGs) show high Blue Spots and high BGI, about 45 % of CBGs (5 of 11 significant CBGs) show high Blue Spots and low BGI (Table 5). The remaining CBGs (5 of 11 significant CBGs) show low Blue Spots and high BGI. In Fairbanks, one socially vulnerable CBGs intersects with high Blue Spots and high BGI CBGS (n = 1), whereas no socially vulnerable CBGs directly intersect with either high Blue Spots and low BGI CBGs (n = 5) or with low Blue Spots and high BGI CBGs (n = 5).

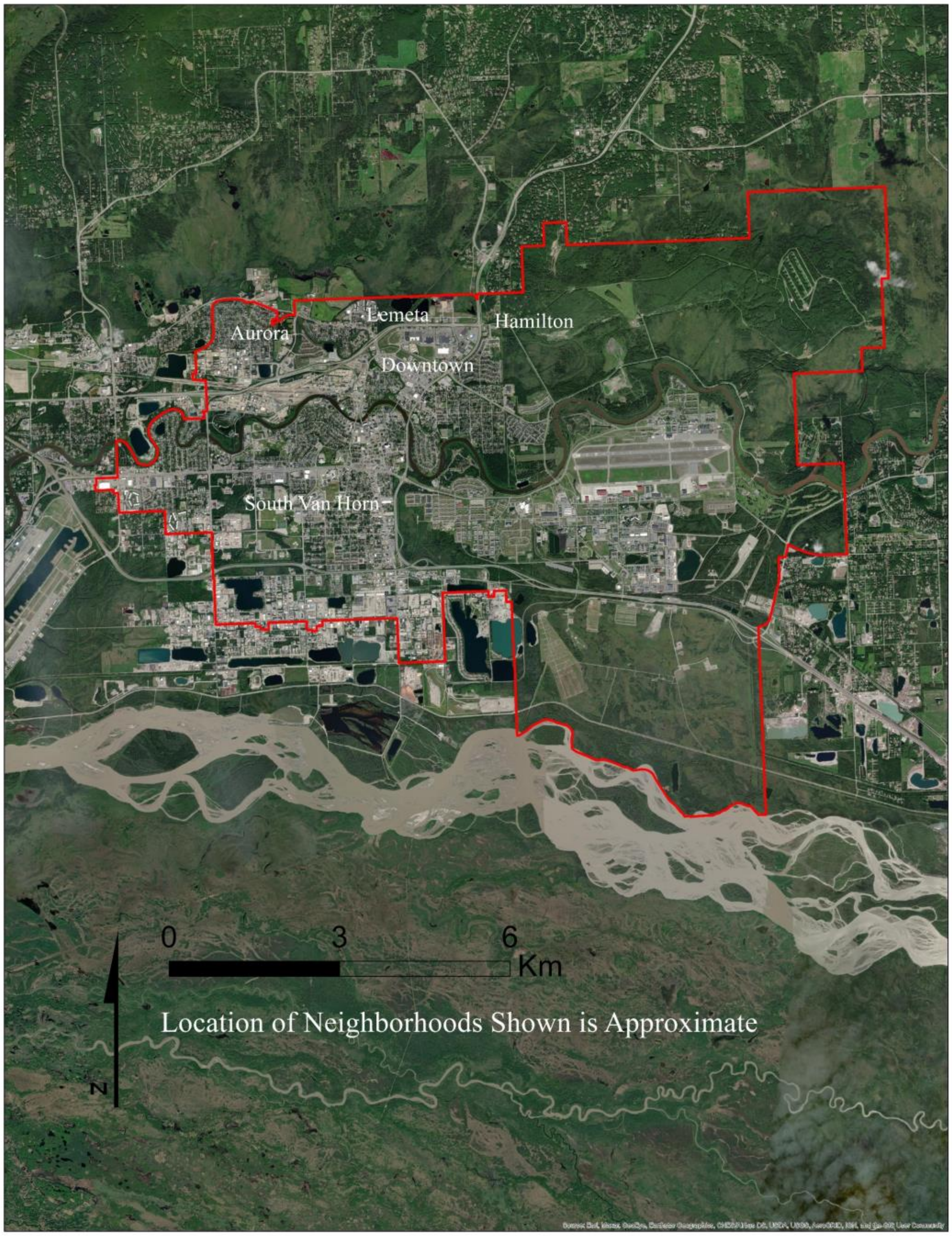

Figure 6. Neighborhoods of Fairbanks, Alaska.

Table 5. Classification of social vulnerability and its overlap with Blue Spots and BGI.

City	**Classification of Social Vulnerability (SoV)**	**Number of CBGs**	**Number of CBGs that intersect with High Blue Spots and Low BGI**	**Number of CBGs that intersect with High BGI and Low Blue Spots**	**Number of CBGs that intersect with High Blue Spots and High BGI**	**Number of CBGs that that intersect with Low Blue Spots and Low BGI**
Anchorage (*n* = 187)	High SoV	43	0	3	10	30
	Medium-High SoV	31	0	1	5	25
	Medium SoV	35	0	2	7	26
	Low SoV	78	12	8	11	47
Fairbanks (*n* = 23)	High SoV	6	0	1	1	4
	Medium-High SoV	6	2	2	0	2
	Medium SoV	6	0	1	0	5
	Low SoV	5	2	2	1	0

5. DISCUSSION

5.1. Equitable and Proportional Distribution: Challenges and Opportunities

The Anchorage spatial analysis results suggest that (i) BGI is relatively proportional to pluvial flood risk, and (ii) BGI is equitably present from a pluvial flood risk perspective in that no socially vulnerable hotspot CBG (top quartile CBG) lacks adequate BGI (top quartile BGI) protection. Several natural disasters such as blizzards, earthquakes, floods, and wildfires have affected downtown Anchorage and its surrounding neighborhoods over the past several decades. Because the majority of Anchorage municipality, outside of the core urban neighborhoods, is largely forested terrain, historically there has been very little green space in the city. Anchorage City Stormwater Manual and state government recommendations show extensive research into how BGI is distributed in the city, with emphasis on past flood experiences. Although no specific research into pluvial flood vulnerability is available now, these policies are a result of decades of observation of increasing flood trends in Anchorage neighborhoods, (Anchorage Watershed Management Services 2019), suggesting that social learning might have played a role in reducing flood risk in the city (Chang et al. 2021a) and improving BGI coverage.

The Fairbanks spatial analysis results suggest that (i) BGI is relatively not disproportional to pluvial flood risk, but (ii) BGI is equitably present from a pluvial flood risk perspective, in that no socially vulnerable hotspot CBG (top quartile CBG) lacks adequate BGI (top quartile BGI) protection. Fairbanks historically benefited from nearby mining and oil activity. Fairbanks' economy grew as a result, and it is reflected in its image as a much safer university town (The National Campus Safety Summit 2020). These factors may have contributed to the overall low level of social vulnerability and the equitable distribution of BGI. The disproportional BGI distribution may have resulted from Fairbanks' city area being much smaller (85 km^2), compared to the Anchorage city area (287 km^2). The flood mitigation efforts have shown to face proportional distribution challenges in a smaller geographic area (Liu and Jensen 2018). Because of their limited geographic area, smaller cities often find it difficult to find the balance between basic infrastructure and sufficient BGI. With a framework like the one described here; it is still possible to achieve balance.

It is worth noting that the intervention, i.e., BGI, does not completely prevent storm runoff on the surface in all zones during rainfall events. Therefore, a neighborhood's capacity to store and convey storm runoff requires more intervention than that of either proportional or equitable distribution of BGI; however, the expansion and conservation of green urban spaces has potential benefits for livability and social wellbeing (Moudrak et al. 2018; Jennings et al. 2016; Foster et al. 2011; Donovan and Butry 2010). Green spaces are not only economical but also an environmentally friendly approach to address storm runoff and pluvial flooding. Enhanced understanding of ecosystem services and the benefits they generate across diverse urban landscapes could therefore help to inform flood-related policy and decision making.

5.2 Social Vulnerability Context in Spatial Planning

In Anchorage, socially vulnerable areas have a higher proportion of Blue Spots, suggesting that socially vulnerable groups tend to live around flood risk zones (Kawasaki et al. 2020; Frank 2020). The frequent floods often keep the affluent home buyers away, likely contributing to underdevelopment of such neighborhoods. Anchorage ranked average on a list of cities with gentrified neighborhoods (Guerrieri et al. 2013), and there is evidence to suggest that gentrification impacts both homeowners and renters but threatens renters with displacement more often than homeowners (Martin and Beck 2016). In Anchorage, we observed that the percentage of renters is high in certain neighborhoods, but there is no concrete evidence to suggest that these neighborhoods have already undergone gentrification. The overall social vulnerability pattern in Anchorage, however, tends to be embedded in concerns unique to Anchorage because of chronic challenges such as homelessness, mental illness, crime, and drug abuse happening in certain neighborhoods (Dobbyn 2020). Over time, this contributes to a phenomenon comparable to Broken Windows Theory, which suggests that visible signs of disorder in a neighborhood encourages further disorder (Kelling 2020).

In Fairbanks, however, the top socially vulnerable populations do not directly intersect with top flood-risk CBGs; the middle and lower socially vulnerable populations do. BGI is equitably distributed here but is not proportional to flood risk. Hence, the social characteristics of neighborhoods exposed to flooding need to be considered in flood management planning (Kok et al. 2014). Such considerations may reduce gaps in equitable and proportional distribution of BGI. Today, a growing number of researchers are embracing the idea that there are important links between social equity and economic growth (Fitzgibbons and Mitchell 2020; Benner and Pastor 2016). In cities like Salt Lake City and San Antonio, a deliberate consensus-oriented regional planning process has contributed to a long and sustained record of both above average employment growth and improvement in social equity (Benner and Pastor 2016).

5.3 Multidimensional Spatial Planning of BGI as a priority

The study demonstrates that success of BGI acting as a pluvial flood management strategy requires more than instituting urban policies. A multidimensional approach, which involves understanding social vulnerability with inputs from stakeholders such as industry experts, public advocacy groups, and the general public, may be necessary in urban spatial planning to focus on areas of high Blue Spots and low BGI (Woltjer 2005). The social variations within this wide spectrum opens numerous opportunities for urban planners to improve their spatial planning priorities. Some CBGs with low Blue Spots containing high BGI further underline the fact that situating BGI is often done for reasons other than flood mitigation alone. The critical analysis of such policies facilitates the implementation of flood management strategies for all social, economic, and environmental prosperity in flood catchment areas (La Rosa and Pappalardo 2020), which benefit the city's flood management (Ferrati et al. 2005). Exploring the multidimensional nature of urban spatial distribution of BGI helps to yield a better understanding of the local factors that drive or shape pluvial flood vulnerability. The successful implementation of BGI implementation is likely to occur when partnering with interdisciplinary scientists and local community members. Thus, multidimensional spatial planning directly involving all stakeholders is a priority that will gradually impact community livelihoods against pluvial flood damage.

5.4 Study Implications and Future Research

This study reveals the importance of geographical context for long term priorities of policymakers and planners in flood resilience planning. In addition, this research also highlights the considerations of state and federal agencies. Thus, it is important to acknowledge that cities will always differ from each other in how policies are implemented, even within the same state. This is a subsequent research direction that can be pursued to analyze how local/regional/federal decision-making impacts social vulnerability in urban pluvial floodplains. Future researchers may benefit from analyzing BGI distribution patterns from other cities to better understand flood management practices and priorities that reduce both flood risk and social vulnerability. Other research scope exists in reviewing how cities of different sizes (by area and population) present different or similar results in how their UPF zones intersect with BGI and socially vulnerable areas. Future research should explore how spatial planning impacts cities to have varied distribution patterns of social vulnerability and BGI according to their history, geography, and policy goals.

5.5 Limitations

The study uses the Blue Spot model, which has certain inherent limitations. First, the model is indicative in nature and helps researchers identify areas of flood risk. The results should be interpreted with caution and after considering the surface characteristics such as pre-existing infrastructure to mitigate risk and the natural absorptive capacity of the land. The model is not a replacement for professional hydrologic studies, especially because the model uses only one type of data i.e., high-resolution digital elevation model, along with a city boundary for reference. The model does not consider data about the sewer system or any other underground or surface drainage channels (Hansson et al. 2010). Second, the BGI data used in this study assumes optimal performance of infrastructure. It does not consider real world issues like poor maintenance, lack of access for water flow, and the presence of other natural vulnerabilities such as fluvial flooding, extreme cold, and thawing permafrost, which may significantly impact the performance of BGI (Semadeni-Davies 2004). Finally, we acknowledge that there are different indicators of social vulnerability, as there are different ways of calculating the same issues, which may yield slightly or vastly different results. For example, crime rate, homelessness, tax assessed value, and language proficiency may also be useful indicators in the context of this study.

6. CONCLUSION

This study examined the relationship between pluvial flood exposure and the distribution of BGI (BGI) in Alaska at CBG scale. We used a Blue Spot model to analyze the areas of flood risk in Anchorage and Fairbanks. Further, we measured social vulnerability using a set of indicators to capture the underlying socioeconomics as they relate to pluvial flooding. Our results highlight that the urban distribution of BGI can be equitable, proportionate, or both. BGI is distributed equitably and proportionately in Anchorage, while it is only distributed equitably, not proportionally in Fairbanks. A just resilient city would ensure both types of distribution to mitigate the effects of pluvial flooding as well as improve socioeconomic conditions, guaranteeing environmental equity. Hence, the employed Blue Spot analysis can help to strengthen the planning activities within urban centers. The BGI with well-designed and managed grey infrastructure is likely to ensure urban management that contributes to social development, economic prosperity, environmental integrity, and community resilience. The green space's role is not limited to planning cities but extends to ecological production and benefits such as wildlife conservation and aesthetic beauty for landscape orientation.

This study's outcome provides an approach that obtains a diverse quality framework that integrates vulnerabilities of flood risk and feasible solutions for meeting practical objectives of communities, urban planners, and policymakers. This study's conclusions provide better information and management for city practitioners and policymakers in Alaska, and other parts of the United States where pluvial flooding risk may exist. Drawing on the results of these studies, we recommend that better planning and resource allocation in cities with green spaces would help to foster sustainability by reducing economic loss and social inequities, while ensuring protection and integrity of the environment. The study emphasizes considering any local social factors and variations for equitable and proportionate distribution of BGI.

Conflict of Interest

The authors declare they have no conflict of interest.

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