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Regional: Establishing a Platform for Climate-Resilient and Low-Carbon Urban Development

Baguio City, Philippines: Climate Risk and Vulnerability Assessment

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For ADB and the City Government of Baguio

Asian Development Bank

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Abbreviations

°C	Degree Celsius
ADB	Asian Development Bank
BCEZ	Baguio City Economic Zone
BSTP	Baguio Sewage Treatment Plant
BWD	Baguio Water District
CAP	Climate Adaptation Priorities
CAR	Cordillera Administrative Region
CBD	Central Business District
CCA	Climate Change Adaptation
CDP	Community Development Program
CEI	City Engineering Office
CEO	City Engineering Office
CORDEX	Coordinated Regional Climate Downscaling Experiment
CPDO	City Planning and Development Office
CRVA	Climate Risk and Vulnerability Assessment
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
LDRRMF	Local Disaster Risk Reduction and Management Fund
EFZ	earthquake fault zone
EGIS	E Government Infrastructure Service
GEE	Google Earth Engine
GHG	greenhouse gas
GIS	geographic information system
GSO	General Services Office
GW	global weightage
HEC HMS	Hydrological Engineering Center Hydrological Modeling System
HEC RAS	Hydrological Engineering Center River Analysis System
HM	Hydrodynamic Modeling
HRVA	Hazard Risk and Vulnerability Assessment
ICT	information and communication technology
IPCC	Intergovernmental Panel on Climate Change
LCCAP	Local Climate Change Action Plan
LGU	local government unit
LST	land surface temperature
MHM	multi-hazard map
PAGASA	The Philippine Atmospheric, Geophysical and Astronomical Services Administration
PEZA	Philippine Economic Zone Authority
PSA	Philippine Statistics Authority
RCM	regional climate model

RCP	Representative Concentration Pathway
SEZ	Special Economic Zone
SPADE	Statistical Packet Anomaly Detection Engine
SWMM	Storm Water Management Model
UHI	Urban Heat Island effect
UNDP	United Nations Development Programme
US	United States
USGS	United States Geological Survey
WRI	World Resources Institute

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1. Introduction

1.1 Spatial Climate Risk and Vulnerability Assessment (CRVA) – An Overview

Climate change is one of the key driving forces behind rising natural disasters, which reflects in their increased frequency and severity. The level of the population and assets' exposure to natural hazards denotes the level of risk. An urban **Climate Risk and Vulnerability Assessment (CRVA)** is a fundamental stage in a city's disaster preparedness and management. It aims to develop a detailed understanding of current and future climate-related risks a city is exposed to. While the earlier applied Hazard Risk and Vulnerability Assessment (HRVA) only considered historical climate trends and disasters, a CRVA goes a step ahead and integrates climate change and climate impact forecasts into the analysis.

A CRVA is context-specific and builds the ground for identifying most impactful non-structural and structural interventions to improve the city's resilience and adaptive capacity to climate-related hazards, not only for today, but also for a foreseeable future. Therefore, a CRVA also aims to inform the city's future planning and infrastructure project development

A spatial CRVA, conducted in the frame of the present assessment, is another step ahead at a city level, and is a relatively recent phenomenon. Earlier, either a non-spatial CRVA was conducted over a city or a region, or a spatial CRVA was conducted at a planned project location level. A city level spatial CRVA allows city decision-makers and stakeholders holistically visualize which city areas are affected by each hazard, which areas are most affected by all hazards combined, and which specific social and economic assets are most at risk. In other terms, a spatial CRVA is an essential tool helping decision-makers and stakeholders narrow down to most impactful and cost-effective climate adaptation interventions.

A spatial CRVA has three key stages, and a fourth stage, which the city may implement selectively based on the findings of the first three stages (Figure 1):

1. Hazard risk assessment and mapping
2. Multi-hazard risk assessment and mapping
3. Sectoral disaster risk exposure assessment and mapping
4. Priority assets' disaster risk vulnerability assessment

Once completed, the CRVA allows to develop reality and forecast grounded **Climate Adaptation Priorities (CAP)**, as well as a pipeline of priority climate adaptation projects.

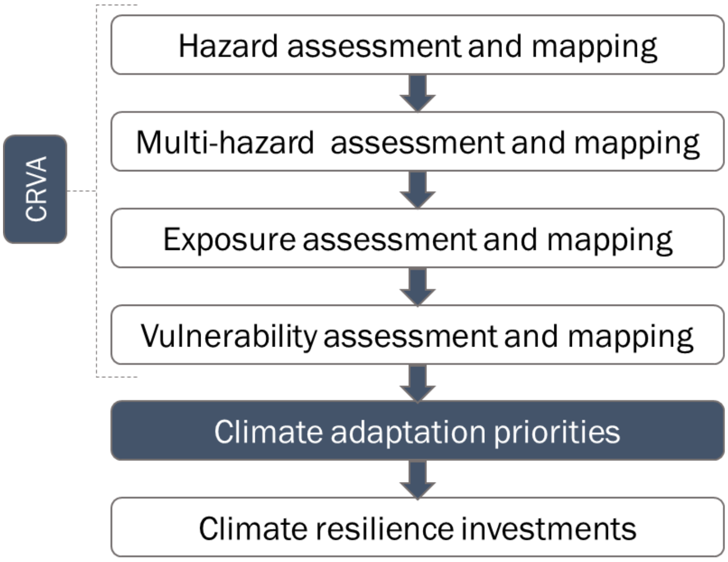


Figure 1: Baguio City assessment steps
Source: Author.

Step 1: Hazard risk assessment and mapping

Hazard and multi-hazard risk assessment and mapping helps understand not only which hazards have affected the city in the past, but also how they are likely to affect the city in the future.

To do so, first, both past records on the past hazards' frequency and intensity, and future climate change projections are utilized to establish a hazard risk matrix. Climate change projections were taken into consideration for the intermediate future period of 2031–2060. The same intermediate future period was taken for the Climate Change Assessment, conducted for Baguio City based on Regional Climate Models (RCM) of the Southeast Asia domain under CORDEX.

Second, hazard-specific risk maps are developed through climate impact modeling of most relevant hazards, or through an alternative methodology most suited to each specific hazard. Hazard-specific risk maps divide the city's surface into zones corresponding to various degrees of each hazard's likelihood (occurrence) and intensity (severity of damages) ranging from low to high or very high. At step 3, these maps allow determining which sectoral assets are exposed to which level of risk.

Step 2: Multi-hazard risk assessment and mapping

A multi-hazard map (MHM) is prepared when a city is exposed to more than one hazard.

An MHM brings together information from all hazard-specific maps, brought together to a common denominator through applying weightages based on each hazard's combined frequency and intensity, and presents a composite picture in a single map. This allows decision-makers to have at-a-glance overview of multi-hazard risk in the city and identify its areas most vulnerable all hazards combined, which facilitates adaptation action prioritization.

Overlaying the MHM with sectoral city assets in step 3 allows to go further in this process by identifying not only which areas are most exposed, but also which assets are most exposed. Depending on the strategic importance and role of each asset, the city is in a position to take more informed action prioritization decisions.

Step 3: Sectoral disaster risk exposure assessment and mapping

In step 3, city's social, economic, and infrastructure assets are mapped. Each map covers a specific assets type. Subsequently, these maps are overlaid with hazard and multi-hazard maps to determine each asset type's level of exposure to hazards and multi-hazards.

The objective is to provide city decision-makers with a practical and data-grounded tool, which showcases at a glance which assets are exposed, and to what extent, which helps them prioritize climate adaptation interventions.

This step may also include a community layer, such as a barangay level layer in Baguio, to help individual barangays or barangay clusters take informed decisions on climate adaptation actions.

Step 4: Priority assets' disaster risk vulnerability assessment

A disaster risk vulnerability assessment adds the sensitivity and the coping capacity dimension to the exposure analysis. *Sensitivity* refers to the degree to which households/communities are affected by exposure to the hazard (Ruijs et al., 2011). *Coping capacity* refers to the ability to cope with the external stress. A number of factors affect the coping capacity, such as level of education, age and gender for social vulnerability, or such as provisions undertaken to mitigate an infrastructure asset exposure for the infrastructure assets (Ruijs et al., 2011).

A disaster risk vulnerability assessment is a preliminary step to a climate adaptation project selection and proposal formulation. Assets identified as both most exposed and most critical for the city's operations under step 3 can be in step 4 assessed for their vulnerability factor to understand whether they are vulnerable and, if so, what the most critical elements making them vulnerable are, which will allow to develop a project proposal addressing these specific vulnerabilities.

Step 4 requires detailed site and asset specific information, which was not possible to collect during the present assessment. While the present CRVA builds the ground to propose key priority action directions, the city may wish to conduct selected vulnerability assessments to determine its most impactful investments and interventions.

Climate adaptation priorities

CRVA outputs coupled with the understanding of the city's key socioeconomic priorities and challenges allow developing integrated climate adaptation priorities (CAP), based on the principle of co-benefits. This principle identifies those interventions which not only help the city and its assets adapt to climate change, but also address several the city's socioeconomic challenges at the same time. This approach is very cost-effective because it optimizes outputs of each single investment.

1.2 Baguio City Profile

1.2.1 Overview

Baguio City is located on the Luzon Island of the Philippines (Figure 2[a]) within the Benguet province of the Cordillera Administrative Region (CAR). It has a territory of 57.5 square kilometers (km^2) and a population of 366,358 people (Census 2020). The city grew in the 20th century as a United States colony. The city attracted by its pleasant temperature contrasting the heat in lowlands, including Manila.

Referred to as the summer capital of the Philippines, Baguio City has a hillside morphology (its elevation ranges between 950 to 1,650 m above the sea level) (Estoque and Murayama, 2013) which, along with a picturesque setting of pine forests, provides a pleasant temperature throughout the year, annually attracting two to three times more tourists than the number of local residents. The number of visitor arrivals in the city has increased from 709,671 in 2006 to 1,294,906 in 2016 (LGU, 2017). Its built-up area significantly increased over the last 20 years. It has a fragmented layout due to steep terrain and green reserves such as parks, wetlands, and forests.

During the early 20th century's initial growth phase, the US Philippine Commission effectively completed crucial infrastructure projects. Rapid further urbanization, followed by the Filipinization, led to an expansion of built-up areas and services. Areas close to main roads observed expansive development, notably along Kennon Road in the south, Marcos Highway in the west, Naguilian Road in the northwest, Ambuklao Road and Halsema Highway in the northeast, Baguio-Bua-Itogon Road in the east, and Loakan Road in the southeast. Transportation networks extended along arteries and roads all converging to the central business district (CBD). The city's accessibility increased when an airport got added.

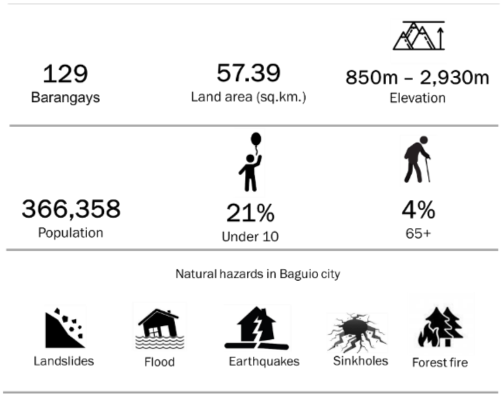


Figure 2: a) Geographical setting of Baguio city, b) Overview
Source: Author

1.2.2 Key Climate Threats

Climate change is leading to intensified typhoons and more summer days in Baguio City. The city's Climate Change Assessment revealed that over 2031–2060 the annual precipitation is likely to increase by 12% (339mm) and 16% (458mm) under RCP 8.5 and RCP 4.5, respectively. The months of August and September are projected to face a maximum increase of 32%–41%. Additionally, August may face a 7% increase in wind speed. A **coincidence between increasing wind speed and precipitation points to an intensification of typhoons.**

Current annual mean and maximum temperatures are also projected to increase by 1.2°C and by 1.6°C under RCP 4.5 and RCP 8.5 respectively, which is a moderate value, but which leads to Baguio passing from an average annual number of summer days of 55 days over 1981–2010 to 170 (RCP 4.5) and 207 (RCP 8.5) over 2031–2060. **These temperature changes will likely be further intensified by the urban heat island (UHI) effect.**

Based on a basin-based hydrological modeling (HEC HMS and HEC RAS) performed over Baguio, the total area exposed to flood of 2, 25, and 50-year return periods (1981–2010) reaches respectively 1.19, 1.45, and 1.49 km^2. For the future (2031–2060), under RCP 4.5, the area exposed to floods for the selected return periods increases by 38%, 36%, and 36% respectively. Under RCP 8.5, it increases by 22%, 27%, and 26%.

1.2.3 Key Natural Hazards

Baguio's geographical location and topography expose the city to many hazards. **The prevalent ones are landslides, floods, earthquakes, forest fires and sinkholes.**

The Philippines archipelago is located right above the equator and lies in the typhoon[1] belt of the Pacific, making Baguio a tropical typhoon-prone city. According to IPCC, storms of greater frequency and intensity are likely to occur over the coming years (IPCC, 2022). Typhoons are not a hazard in themselves, but a phenomenon triggering a series of hydro-geological instability disasters such as **landslides and floods**, which are both the highest risk hazards for the city.

Proximity to forests at the Baguio City boundary and forest patches within the city may cause **forest fire** related damages to the nearby settlements. The city has not witnessed such fire cases, but prolonged dry periods caused by an ongoing temperature and an increase in the number of summer days is likely to cause forest fires and propagate its spread in the future.

Baguio City is exposed to three geological hazards: landslides, earthquakes, and sinkholes. Active extra-territorial seismic fault lines, such as Dig-Dig fault, Tebbo fault and Tuba fault, located at a 40 km, 10 km and 5 km distance respectively from Baguio cause a **category IV earthquake risk** to the city. Additionally, five inactive faults within the city are energy release points during earthquakes, causing intense damage. These are further associated with pronounced surface movements such as landslides and displacements.

Sinkholes are mainly located in the western part of the city, where Kennon and zigzag geological formations prone to sinkholes are located, which limits the city's development opportunities.

Finally, Baguio is witnessing a **UHI,** where the built-up areas' temperatures are higher than in their greener surroundings.

1.2.4 City Assets Overview

1.2.4.1 Social Profile

Demography: The population of Baguio City reached over 366,000 people as per the 2020 census, and projections show that, by 2024, it is expected to reach over 390,000 (Table 1). The city's population has grown from 183,142 in 1990 to 337,800 in 2015. In 2019, 1,550,000 tourist arrivals were recorded (ADB, 2020). In 2019, the city hosted 170,000 students (CHED DepEd School Year, 2018).

As per the 2020 census, the city's demographic structure is characterized by a sex ratio of 104 females to 100 males and 68.7% of the population being under 30. The number of households rose to 78,313 in 2010, which was an increase of 26,011 households compared to the year 2000. The average household size however decreased from 4.3 persons in 2007 to 4.0 persons in 2010.

The above demographic scenario may affect Baguio's climate change vulnerability. An increasing number of residents and tourists is very likely to induce more land use changes, and lead to less permeable versus impervious surfaces due to new residential and tourism needs, new infrastructure and services. This trend may worsen climate risks such as landslides and floods. The

[1] Typhoons are rotating, organized systems of clouds and thunderstorms that originate over tropical or subtropical waters. Once a tropical cyclone reaches maximum sustained winds of 74mph (119km/h) or higher, it is classified as a hurricane, typhoon, or tropical cyclone, depending upon where in the world the storm originates.

very young population of Baguio further points to the need for the city to plan a resilient city for the long run. Finally, it would help if the next census captured the age categories of population by barangay to determine barangays with highest elderly people and children density so that the city gives dedicated attention to safety and evacuation systems for these age categories.

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Projected population (thousands)	337	342	347	352	358	363	370	376	383	390

Table 1: Population data and projections
Source: ESWM Plan (2015-2024)

Ethnically and/or culturally, Baguio is host to native tribes from all over the Cordillera region, including Pangasinenses, Tagalogs, and Kapampangans, as well as a number of foreigners who have chosen to reside in the city. These populations make up the majority of Baguio residents today (ADB, 2021). Linguistically, 50% of the households speak Ilocano as their mother tongue, 23% speak Tagalog and 4% speak Pangasinense. Most of Baguio residents have a fair level of spoken English. Language and dialect diversity is an outcome of extensive migration, which also explains the rapid population expansion (ADB, 2021). It is important to take this population diversity into account when designing climate adaptation awareness campaigns, early warning, and evacuation systems, as well as climate adaptation interventions.

Poverty. Residents below the poverty line are particularly vulnerable to climate change hazards: in periods of stress, when floods or landslides occur, they may be forced to sell off their physical assets such as land, bicycles, and farming tools, thereby undermining the sustainability of their livelihoods. They also tend to live in most vulnerable locations. The poverty incidence in Baguio went up from 2.7 % in 2018 to 3.4 % in 2021, which is slightly above 10,000 people. According to the Philippine Statistics Authority's (PSA), Baguio's poverty threshold went from PHP 12,050 in 2018 to PHP 13,759 in 2021. This is equivalent to a monthly average income of PHP 1,147 to meet basic needs (PSA, 2022), which does not leave room for any extra expenses and hence places such residents in very vulnerable conditions.

Informal settlements. it is difficult to quantify the number of informal settlers in Baguio taking into consideration that a large proportion of residents do not hold a land tenure title and, in a number of cases, their habitats have all basic services facilities. The poverty threshold is hence essentially used to determine most vulnerable populations in the city, which is likely to be underestimating their actual number.

Education. Baguio has a simple literacy rate of 99.6% (ADB, 2021). It is also an educational center of northern Luzon and offers quality education from pre-school to a graduate level, including technical-vocational courses (TESDA, n.d.). As of 2016, the city had 20 universities and colleges, and 32 technical-vocational education and training facilities that offer alternative courses (Table 2). These academic institutions are an asset to the city as they host students from all over the country.

Importantly, these academic institutions are a strong asset which can support the city in strengthening its climate resilience and their involvement in city's assets' vulnerability assessments would be very beneficial. At the same time, the sizable and growing number of students puts additional pressure on Baguio's limited land and resources.

1.2.4.2 Economic Profile

Retail and wholesale. The city's economy is heavily reliant on retail and wholesale business services. Commercial shops, real estate lessee or boarding house operators, services or contractors, eateries and cafés, and wholesalers make up most of the economic activity, accounting for 86% of the total income. In addition to creating jobs, business taxes from such services generate sizable income for the city (LGU , 2012).

Special Economic Zone (SEZ): Operated by the Philippine Economic Zone Authority (PEZA), Baguio's SEZ includes 44 businesses, of which nine are foreign businesses. These businesses are typically textiles, apparels, electronics, or plastic products. Baguio hosts regional headquarters of most export companies in the CAR. The Internal Revenue Allotment collected from national government revenues, tax revenues and non-tax revenues largely based on land area and population, add to the economy of the city. The city is also considered the financial centre of the CAR (LGU , 2012).

Art and Craft: Small and medium-sized handicraft enterprises produce unique and distinctive pottery, clothing, metalwork, woodwork, and other materials. UNESCO recognized Baguio for promoting local handicrafts globally and awarded it a Creative City status. In 2016, the total gross receipts from the 56 establishments directly devoted to crafts and folk art earned almost ₱58 million (LGU , 2012).

Tourism: Baguio is a popular tourist destination in the northern Luzon and is the country's summer capital. Tourism-related services are a major source of income to the city, generated by hotels, restaurants, cafés, tour guides, local transportation, and porters. In 2016, domestic tourists made for 96.05% of the total visitor arrivals, while foreign and overseas visitors comprised 3.92% and 0.03% respectively.

Education hub: A combination of quality institutions and pleasant weather helped Baguio's education sector to economically thrive.

These different economic activities contribute to increasing the city's competitiveness and attractiveness. At the same time, their anticipated growth requires suitable spatial planning and design not reinforce and, consequently, be majorly hit by climate change related natural disasters.

1.2.4.3 Infrastructure Profile

Essential and Residential Buildings

Schools, hospitals, fire stations, police stations and community centers are essential public service buildings. Their number and spread show how well different city areas are covered with services they provide. In Baguio, most of the hospitals are located in the CBD area, while police stations and schools are relatively evenly located across the city. Except for schools, which are geographically well spread across the city, essential buildings are mainly located in the CBD area and in the northern part of Baguio. While these areas have a lower population density, their residents face a higher risk considering that rescue may take longer to be reached.

Uninterrupted functioning of these facilities is crucial for an effective disaster response, quick recovery, and higher city's resilience. Most schools and community centers are designated evacuation shelters while fire and police stations combined are essential rescue service providers within the city.

Vulnerability of essential buildings is hence critical to consider. It encompasses both their location (exposure) and their physical state such as the quality of the building itself, its maintenance, provisions undertaken to disaster proof them (sensitivity and coping capacity).

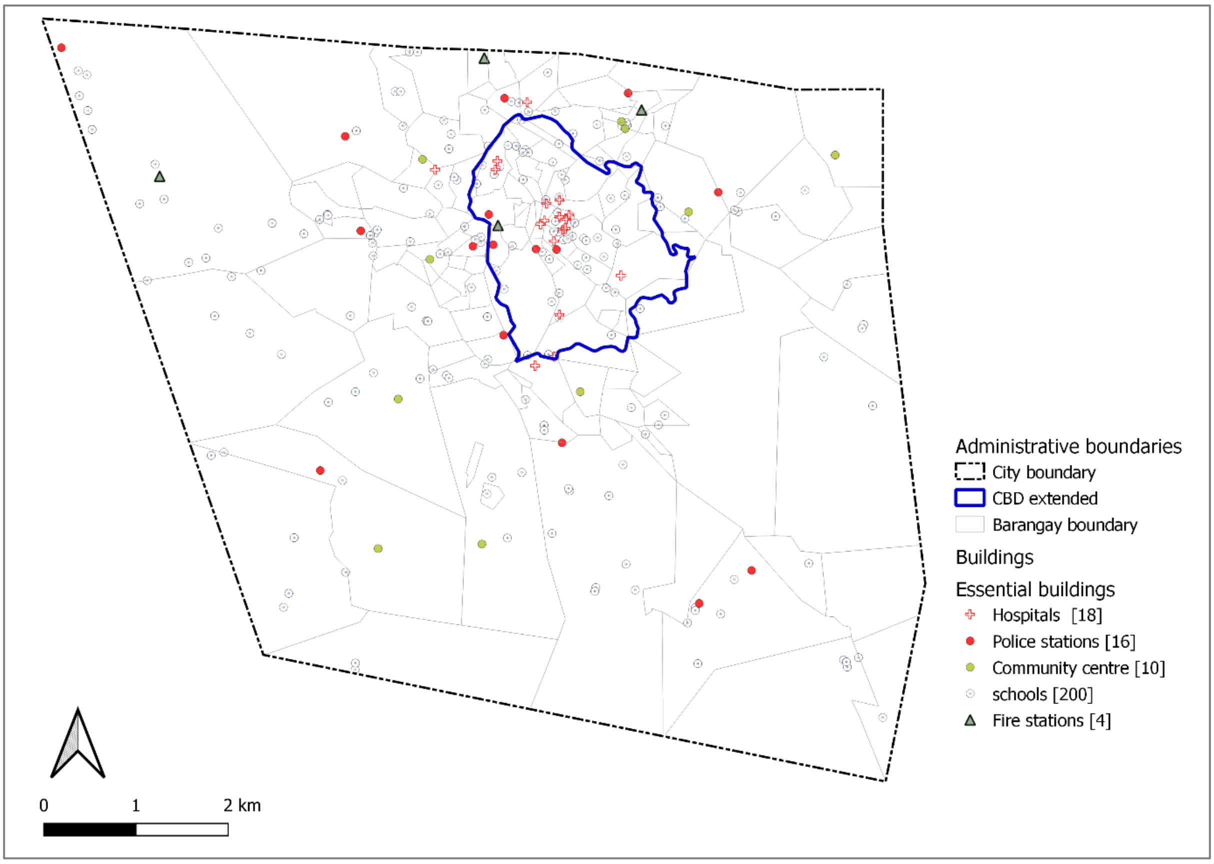


Figure 3: Location of essential buildings
Source: Author

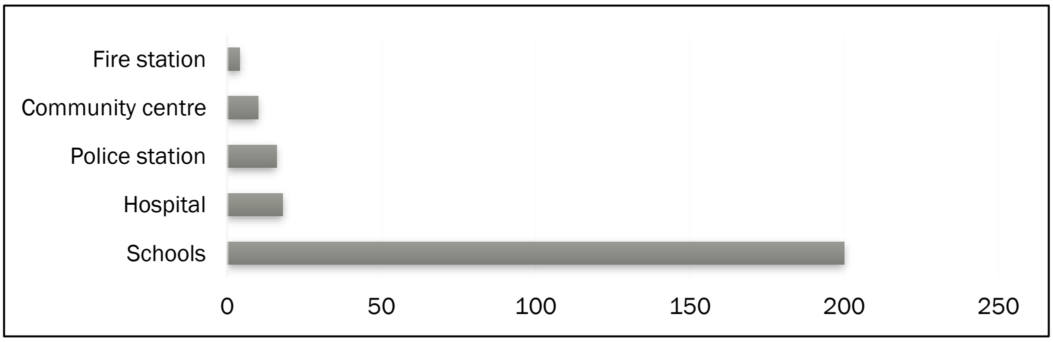


Figure 4: Essential buildings in Baguio
Source: Author

Coming to **materials used for essential and residential buildings**, very little information was available. The population census shows that resistant materials such as bricks or concrete, are used in over half of the existing building stock, and another nearly 30% utilize a mix of the above materials with stone and wood (Table 3). If more detailed information is collected, it will become possible to assess the building stock's resilience to various natural hazards affecting the city.

Construction Materials of the Outer Walls and Highly Urbanized City	Total Occupied Units	Galvanized Iron / Aluminum	Construction Materials of the Roof	
			Tile Concrete / Clay Tile	Half Galvanized Iron & Half Concrete
TOTAL	**76,922**	**67,649**	**5,287**	**3,355**
Concrete / Brick / Stone	45,042	39,299	4,604	933
Wood	3,708	3,442	38	82
Half Concrete / Brick / Stone & Half Wood	18,737	15,855	595	2,213
Galvanized Iron / Aluminum	8,844	8,773	49	126
Bamboo / Sawali / Cogon / Nipa	58	47	-	-
Asbestos	20	16	1	-
Glass	2	2	-	-
Makeshift / Salvaged / Improvised materials	197	123	-	1
Others / Not Reported	109	91	-	-
No Walls	1	1	-	-

Table 2: Construction materials utilized in highly urbanized city areas
Source: NSO: 2010 Census of Population

Tourism-Related Infrastructure and Services in Baguio City

The city's tourism infrastructure comprises of tourism service industry and tourist spots. Service industry includes lodging and eating facilities such as hotels, hostels, cafés, street food and restaurants. Food services are numerous, over 500, while hotels and hostels are mostly located near main roads, typically within a distance of 600m from them (Figure 6). Tourist spots are points of interest for tourists, such as heritage buildings, churches, artists' villages, parks and gardens.

Most of tourism-related services and tourist spots are located in the CBD and around it (Figure 5). Some hotels are also located near the airport area in the Southwest of Baguio. Overall, this creates a disbalanced distribution of tourists over the city or, more specifically, high pressure on the city's center. As a consequence, the center is congested. Going forward, it is important to consider establishing alternative tourism spots and services away from the city center to improve on both the tourist's and the resident's experience.

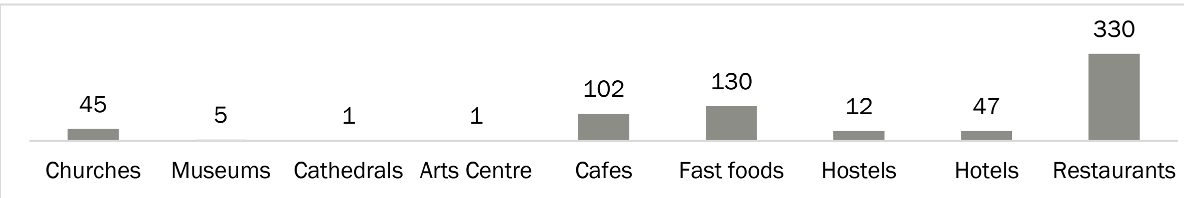


Figure 5: Tourism-related built infrastructure in Baguio
Source: Author

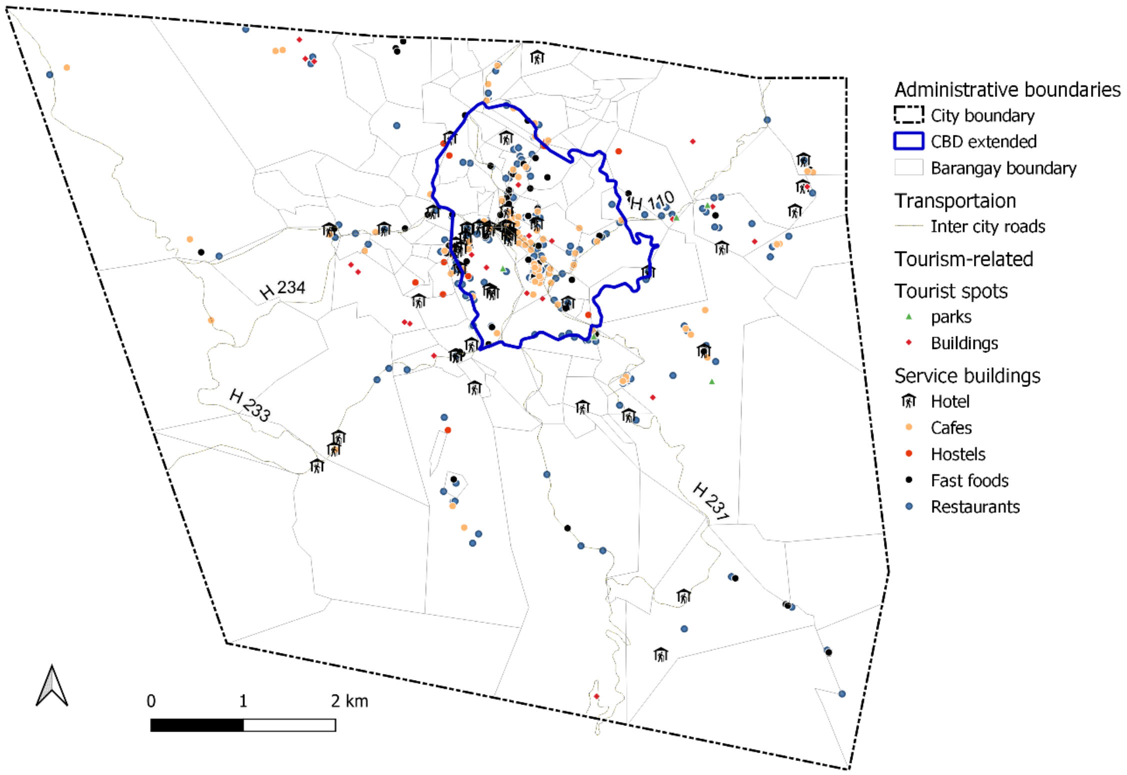


Figure 6: Tourism-related infrastructure in Baguio
Source: Author

Commerce

Baguio's commercial zones are categorized into three types (Figure 7): Commercial 1 (C1-Low Density), Commercial 2 (C2-Medium Density), and Commercial 3 (C3-High Density).

- **Low density commercial:** a major chunk of commercial areas is low density (158.794 hectares) (LGU , 2012).
- **Medium density commercial:** medium density commercial zone (89.468 hectares) developed along the major roads of the city (LGU , 2012).
- **High-density:** High-density commercial zone (21.676 hectares) developed in two parts of the city: Elpidio Quirino Highway and in the Country Club Village (LGU , 2012).

Development of new commercial areas determines new resident and city visitors' flows, which can increase the city's exposure to climate hazards in some parts of the city if increasing impervious surfaces and constructions in landslide and flood-prone areas. risk. It is hence critical to identify less hazard prone areas when expanding commercial outreach in the city.

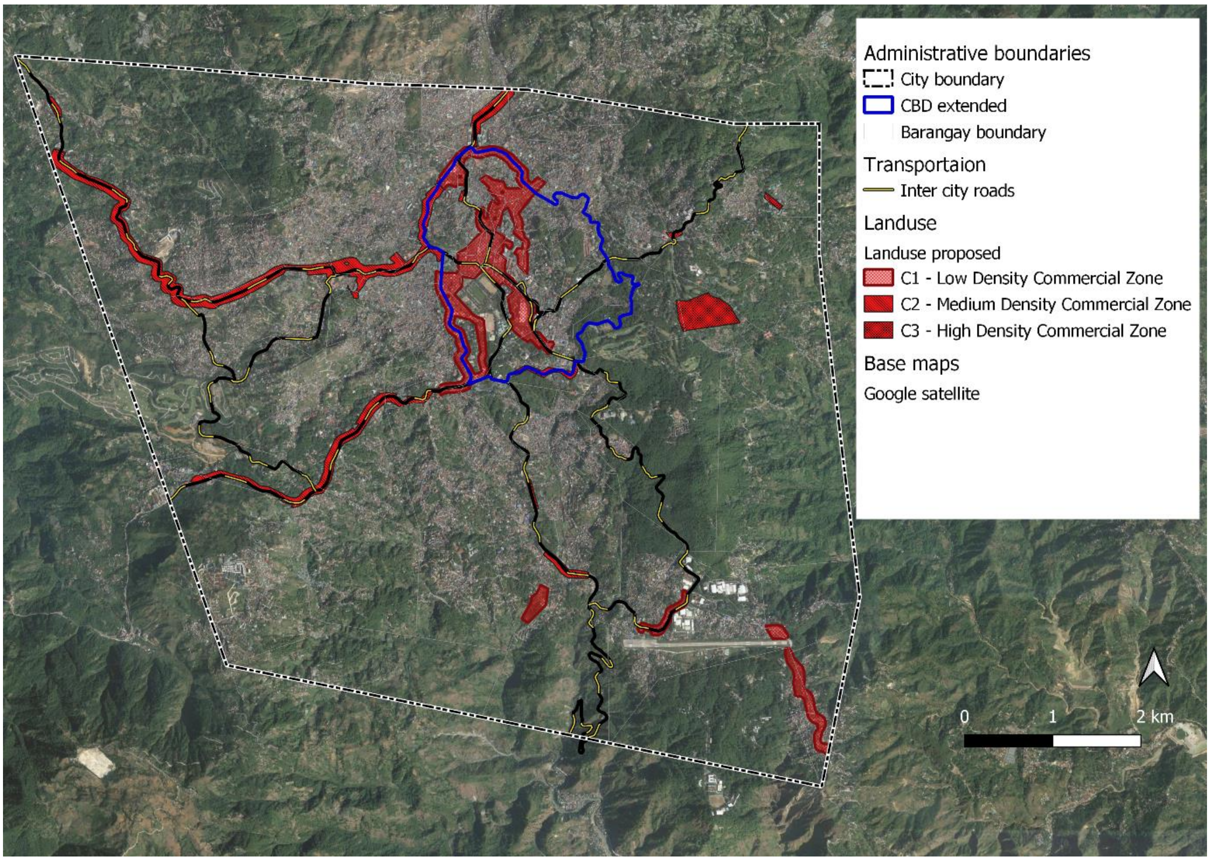


Figure 7: Low, medium and high-density commercial zones in Baguio
Source: Author

Transportation

As of today, Baguio can only be reached by road. There is no railway network in Baguio and the airport is at present not functional for commercial purposes. Roads are hence the lifeline of the city with major roads being:

- Highway 54 – Elpidio Quirino highway in the Northwest and Kennon Road in the south
- Highway 204 – Magsaysay Avenue in the north
- Highway 208 – Marcos highway in the west
- Highway 110 in the northeast

Intercity roads are arteries of life facilitating goods supply and export, intercity mobility, and tourism. As such, these roads need to be disaster proofed not only inside the city, but equally at the approach of the city.

According to the Carbon Footprint Assessment conducted for Baguio City, the transport sector has emerged as the second most GHG emitting sector. Over 2012-2016, the number of cars registered in Baguio increased by 7% (Table 3). A high dependence on private vehicles and jeepneys, coupled with a large number of trucks crossing the city on a daily basis to supply goods between the northern and the southern part of Luzon island, as well as with the road structure converging to the city center generated high congestion and air pollution in the city.

TYPE	2012	2013	2014	2015	2016
CARS	6,874	6,151	6,681	6,867	6,762
UTILITY VEHICLE	21,197	20,460	14,390	18,593	20,527
SPORTS UV	2,801	2,593	4,288	3,805	4,535
TRUCKS	2,142	1,976	1,715	1,502	1,668
BUSES	131	171	119	129	118
MOTORCYCLE	4,790	5,321	4,965	5,613	6,938
TRAILERS	64	56	68	76	94
TOTAL	**37,999**	**36,728**	**35,321**	**36,585**	**40,642**

Table 3: Transportation in Baguio
Source: Department of Transportation - CAR

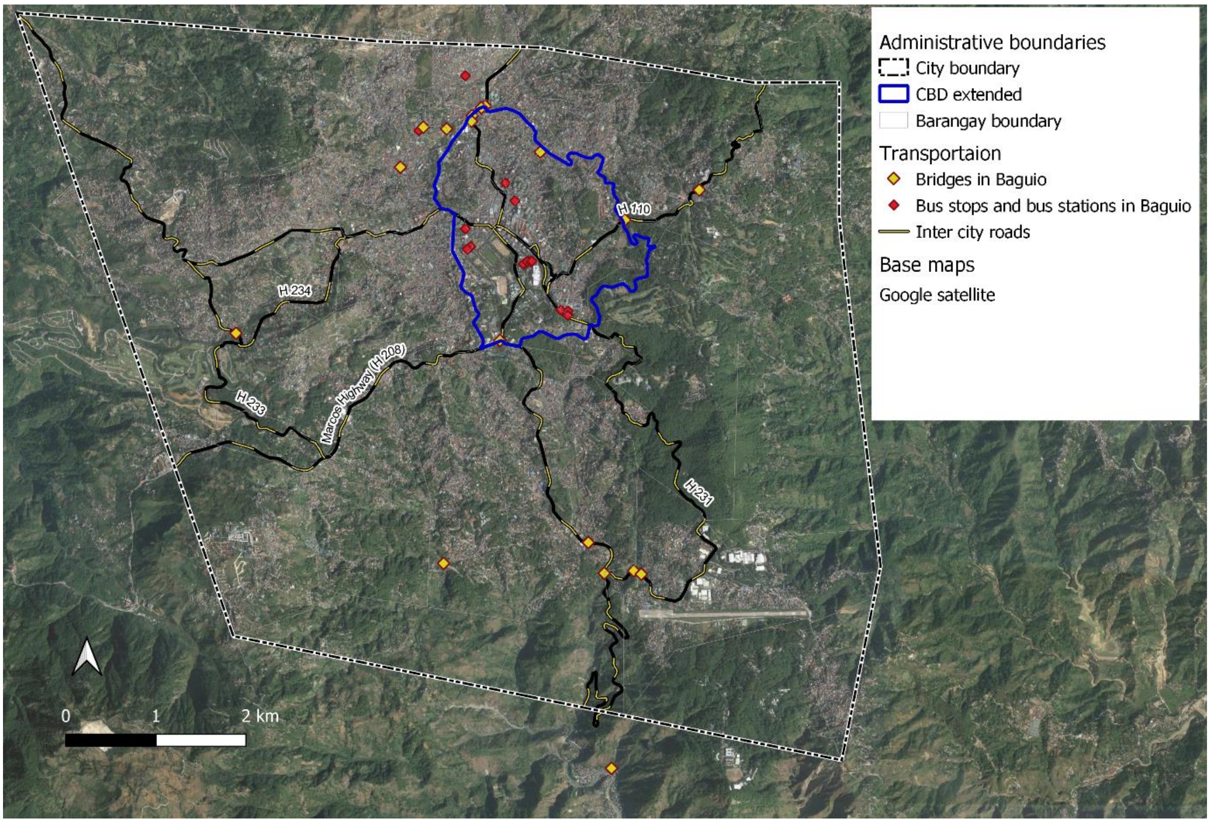


Figure 8: Transportation related infrastructure in Baguio
Source: Author

Water Supply and Waste Management

Baguio is heavily dependent on ground water for its water supply: 94% of water is supplied by deep wells. Baguio Water District (BWD) and City Environment and Parks Management Office, Wastewater, Water and Ambient Air Monitoring division, administer water supply and wastewater in barangays. The city has over 600 legal public and private deep wells, but water storage capacity is limited.

Baguio's rugged topography makes water distribution difficult and cost-intensive. In addition, acquisition of new drilling spots has become very challenging for the BWD due to most authorized areas belonging to private owners and a number of other areas falling into unsuitable sinkhole-prone soil type area or into protected areas. On the other hand, private deep wells drilling remains uncontrolled.

As a result, Baguio does not benefit from a 24/7 water supply, but faces an intermittent supply. Residents commonly use water storage containers, in which mosquito breeding is frequent, which generates a health concern. Water supply quantity is under threat in the long run considering the steady population growth coupled with no measures to replenish the ground water table undertaken at scale. Water supply quality equally needs to be closely monitored. Ground water contamination is likely to be taking place through insufficient sewerage volume treatment, septic tanks' sewerage occasionally released into rivers during heavy rains as well as through sinkholes and deep wells.

Baguio City has two rainwater harvesting facilities located in Santo Thomas and Buses barangays. Both are used as water reservoirs. They play a particularly important role during water stress periods such as a high tourist inflow. tourist season when the demand supply due to higher numbers of city users. This step in the right direction needs to be followed by more steps which help the city close the loop of the annual water cycle, in which ground water table would be replenished with bigger quantity and better quality of water during the rainy season. This requires an integrated approach to the flood and water supply challenge.

Drainage and Sewage Management

Drainage. An analysis of flood instances for 2015–2021, based on data provided by the municipality and digitized in GIS, showed that a number of flood locations lie outside watersheds. This leads to concluding that the primary cause of these flood instances is expanded built-up areas, which disrupted the natural drainage pattern of the city, coupled with an artificial drainage system insufficient to cover for the city's needs. Drainage channels' functionality also gets affected by clogging.

Sewage. One single sewage treatment plant – Balili Sewage Treatment Plant (BSTP) – services Baguio City. Out of 128 barangays of Baguio City, 50 barangays are fully connected to the BSTW and 15 barangays are partially connected to the BSTP as of December 2013 (WAMD, 2015). Nearly 69 km of network cover the CBD area and are connected to the BSTP, which has a capacity of 8,600 cubic meters (m^3)/day (ADB, 2021). Of the rest of the barangays, 53 use individual septic tanks, and 12 use community septic tanks. Hence, **only half of the barangays are serviced by the Baguio City treatment plant.** As per the report on Baguio's sanitation infrastructure situation by the EGIS group, nearly 20 private sewage treatment plants are also available in the city (EGIS, 2021). These 20 private sewage treatment plants are industrial treatment plants and are not considered in this assessment.

As per the ADB/EGIS report on Baguio City Sanitation Improvement Project, Volume 3, Sanitation (EGIS, 2021), 10% of wastewater is captured by the sewer lines, 88% goes to private and community septic tanks and 2% is open discharge. As per this report, only 22% of the total wastewater ends up being safely managed while the rest of it may be discharged into water bodies without any treatment.

Indicator	2012	2013	2014	2015	2016
HH with access to improved/ safe water supply	98.48	81.5	93.02	93.8	98.84
HH with Sanitary toilet facilities	98.99	99.04	95.77	97.98	96.89
HH with satisfactory disposal of solid waste	…	…	96.00	98.60	97.20
HH with complete basic sanitation facilities	…	…	95.38	97.98	97.00

Table 4: Water supply and waste management in Baguio
Source: Health Services Office

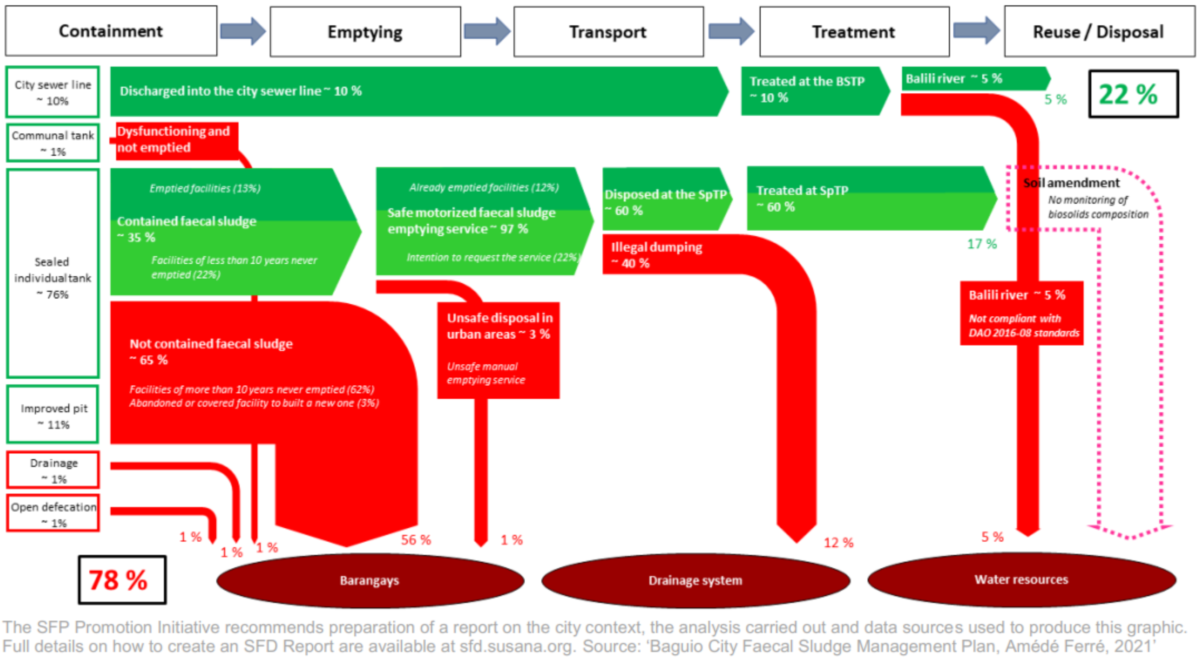


Figure 9: Baguio City wastewater flow diagram
Source: (EGIS, 2021)

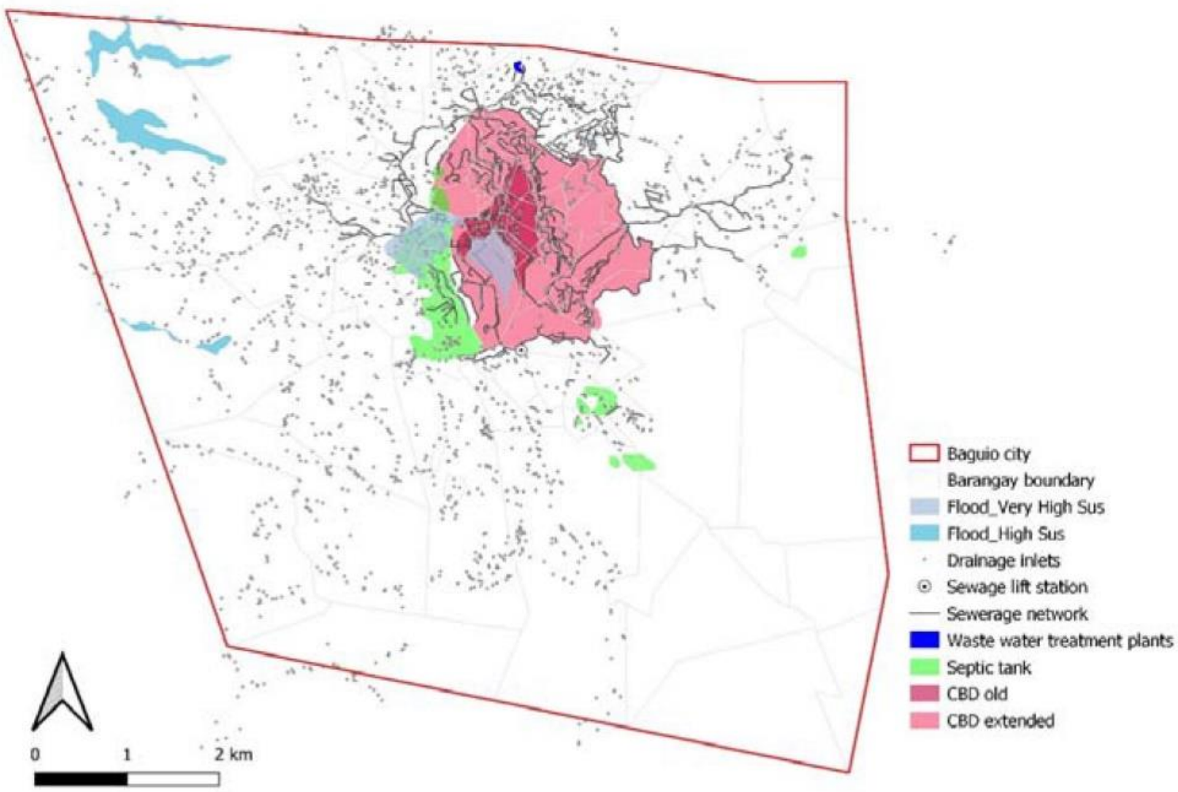


Figure 10: Drainage and sewerage systems and their exposure to floods in Baguio
Source: Author.

Solid Waste

The total solid waste generated by Baguio was of 455,900 kilograms (kg)/day in 2020. This converts to 1.25 kg per capita considering that the population census registered 363,883 citizens in 2020 (Table 6). This per capita value is 1,2 times the national average. Considering that in the period 2020-2024 the population is projected to grow by 7,34% and that the generated solid waste is expected to increase by 11,36 kg/day, it is critical to put an efficient waste reduction, management, and disposal system in place.

Baguio's solid waste, generated and collected inside the city, is disposed of outside the municipal boundaries in Capas, Tarlac. Over the years, the waste was disposed of in different landfills:

- The Irisan dumpsite is almost 60 years old and was used by Baguio City until 2011, when it collapsed, leading to life losses and pollution of the local environment.
- The incident led Baguio to switch to the Metro Clark waste management site in Capas, Tarlac.
- Metro Clark waste landfill was used from 2011 to 2018 and the Urdaneta landfill was used from 2019 to 2020.

The City General Services Office (GSO) indicated that a portion of solid waste generated by residents is managed by the residences themselves and that informal areas occasionally practice waste dumping into the city's rivers and canals.

Waste Generation Projection of Baguio City, 2015-2024

Planning Period	PCG (kg/day)	Projected Population	Projected Waste Generation (Kg/day)
2020	1.2529	363,883	455,900.01
2021	1.2704	367,771	467,219.53
2022	1.2771	376,538	480,865.93
2023	1.2886	383,390	494,038.94
024	1.2997	390,610	507,693.14

Source: ESWM Plan (2015-2024)

Table 5: Waste generation projection of Baguio (2015-2024)
Source: ESWM Plan (2015-2024)

Energy

The city's power is supplied by Benguet Electric Cooperative (Beneco), which is a power distribution cooperative entity. Electricity is generated away from the city at Sual and Ambuklao by National Power Corporation, which is 100% produced from coal. The total power used by Baguio City in 2018 was nearly 356,410,000 kWh. The electricity demand is increasing due to commercial, demographic and tourism growth and the annual energy consumption for Baguio is equal to 319.2 x 10^6 kWh

Many essential urban services, such as water, street lighting, communications, and information and communication technology (ICT), depend on the energy distribution network's continuity. It is hence of prime importance to ensure their resilience to natural hazards. The present report does not cover the power distribution's network exposure assessment due to a lack of data on this network. The municipality may choose to overlay this network with the hazard risk maps when data become available to devise a sectoral resilience plan.

1.2.4.4 Heritage and Culture

Baguio City is rich in cultural events throughout the year, particularly during the dry season. Many festivities and celebrations in the city are held near the Burnham Park area, including the Session Road and the Baguio Convention Center. Baguio City also hosts a large number of heritage buildings (Figure 12).

Arts festivals and crafts. Baguio hosts a major arts festival in November and December. It originated in 1989 with the vision to make Baguio a premier art and artistic destination. It features visual arts (photography, film, video, sculpture and art installations); performing arts (modern dances drama, music, poetry reading) and ethnic arts. Tam-Awan Village is a living artists' colony that attracts many visitors. Arko Ni Apo is another artists' residence in the vicinity of Tam-Awan Village. A 3 km long woodcarver's village along the Asin Road is a working hub for woodcarvers.

Fil-Am Golf Tournament is held from November to December in the Camp John Hay golf courses. It hosts thousands of golfers from the country and the United States.

Built-heritage. Most famous heritage buildings in Baguio are the Mansion built in 1908, Our Lady of Lourdes Grotto, Our Lady of Atonement Cathedral, Bell Church, and Bell House – Camp John Hay. Among these, the most prominent ones are the Our Lady of Lourdes Grotto for its religious significance, tranquility and for the locals' belief of healing touch; and the Bell Church for its religious significance, architectural appeal and for observing the hungry ghost festival.

All these events and cultural places may be considered as particularly susceptible to human and asset damage because the buildings may not incorporate disaster proof features, and because both the buildings and the events attract a large amount of visitors, which exposes a large number of people in case of a disaster occurrence. It is hence essential to elaborate disaster safety measures specific to these spaces.

Figure 11: Tourism-related built infrastructure in Baguio
Source: Author

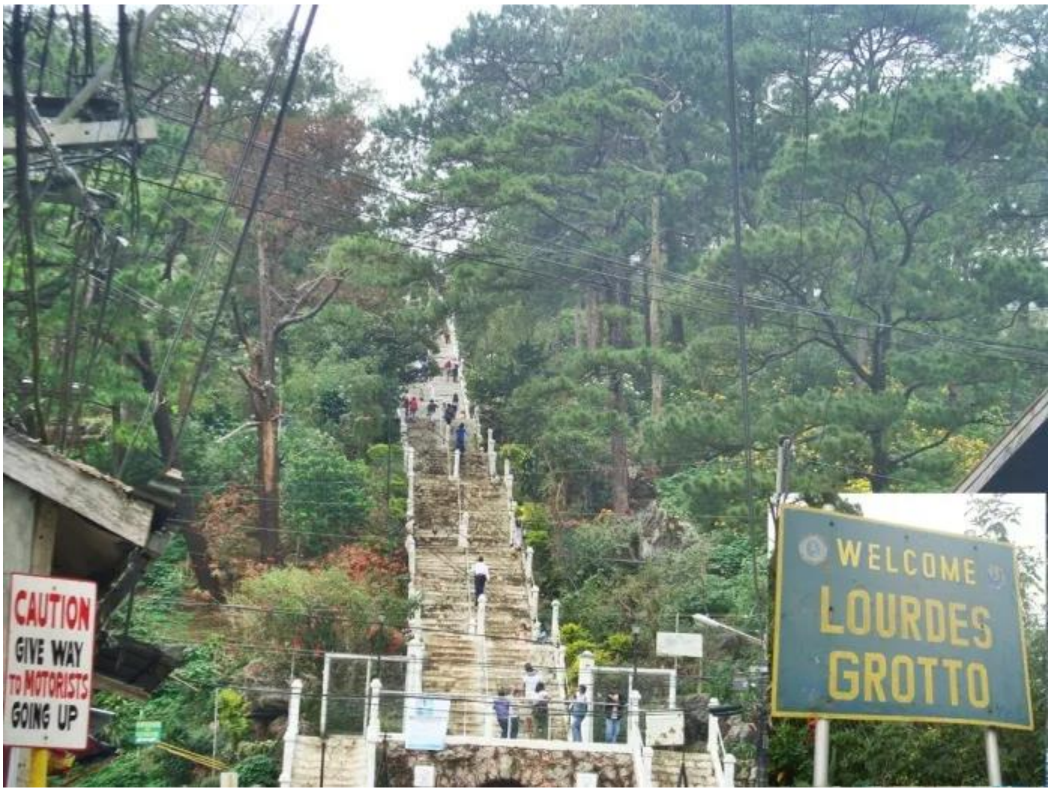


Figure 12: Tourist spot: Our Lady of Lourdes Grotto
Source: Internet

1.2.4.4 Land Use Profile

Before urbanization, Baguio was a grazing land for cattle and horses, and hosted coffee plantations. According to the city's latest available land use map, the city's forest reserves and watersheds cover a total of 521.23 ha corresponding to the 30.43% of the total territory. However, settlers have partially encroached on several of these natural ecosystems. Residential land use covers 69% of the city's territory, transport infrastructure and industrial land uses cover 6% and 2.8% respectively. Over 24% of the total surface of Baguio City is characterized by high-density residential and commercial areas (Table 6).

Land Use	Existing Land Area (Hectares)	Percent
R1 - Low Density Residential Zone	1,395.21	24.27
R2 - Medium Density Residential Zone	610.26	10.61
R3 - High Density Residential Zone	1,234.44	21.47
C1 - Low Density Commercial Zone	147.62	2.57
C2 - Medium Density Commercial Zone	96.62	1.68
C3 - High Density Commercial Zone	72.89	1.27
a. Camp John Hay-Planned Unit Development Zone (Special Tourism Economic Zone)	301.86	5.25
b. Camp John Hay-Watershed / Protected Forest Zone (Reservation)	323.55	5.63
Planned Unit Development Zone	57.89	1.01
General Institutional Zone	213.05	3.71
Parks and Recreation Zone	81.32	1.41
Watershed/Protected Forest Zone	240.37	4.18
Vacant Forested Areas	591.84	10.29
Slaughterhouse Zone	2.70	0.05
Cemeteries/Memorial Parks Zone	13.88	0.24
Airport Zone	32.16	0.56
Utilities Zone	9.85	0.17
Special Use (Bureau of Plant Industry)	8.98	0.16
Special Use (Bureau of Animal Industry)	104.35	1.81
Roads/Roads right-of-way	210.16	3.66
Total	**5,749.00**	**100.00**

Table 6: Baguio's land use in 2015
Source: CPDO

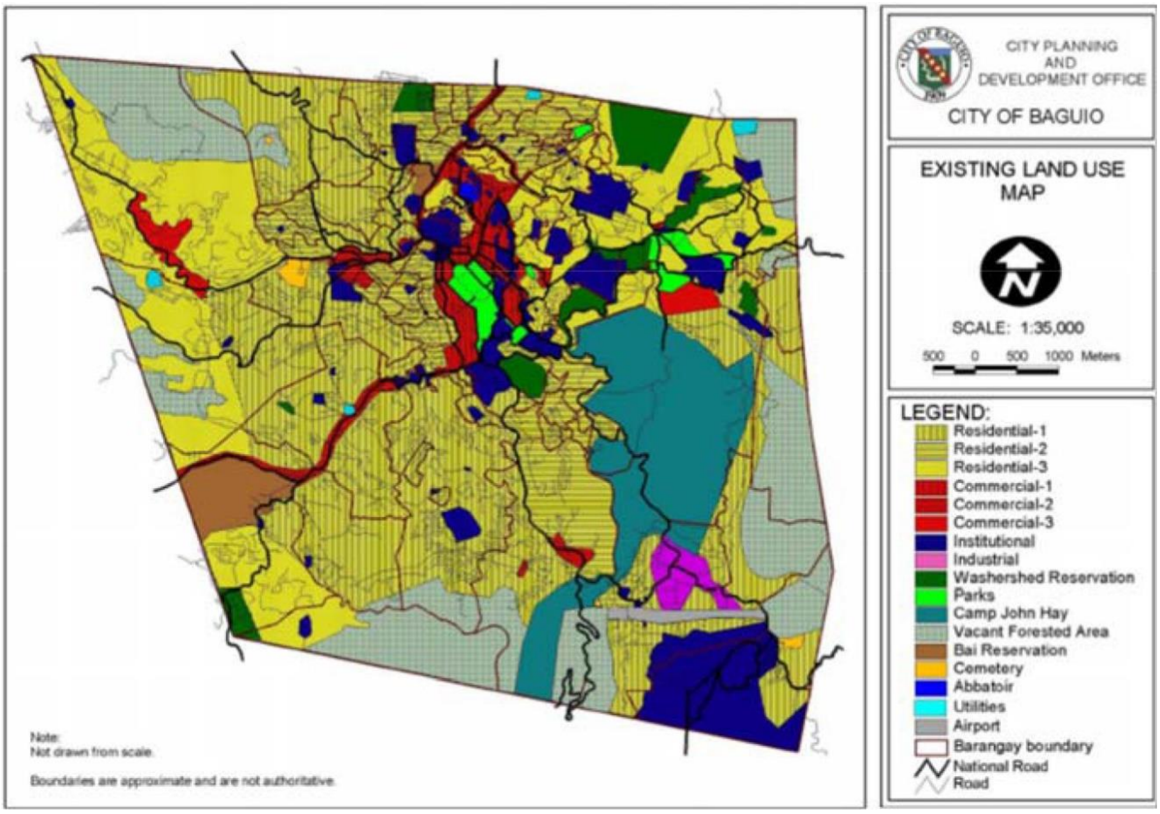


Figure 13: Existing land uses in Baguio
Source: Comprehensive land-use plan 2013-2023, Baguio city

2. Methodology

Chapter 2 on Methodology presents steps used to obtain results presented in Chapters 3 and 4. The presented methodology was developed based on UNICITI's methodology in progress elaborated through research and its testing on pilot cities, and further refined under the ADB Climate Resilient and Low Carbon Cities Platform. It consists in four steps:

1. Hazard risk assessment and mapping
2. Multi-hazard risk assessment and mapping
3. Sectoral exposure assessment and mapping
4. Sectoral vulnerability assessment and mapping

A methodology on assessing the UHI effect was added to this chapter. It is not directly part of the steps above since UHI falls under the category of a fully man-made hazard rather than into a category of a natural hazard. It could hence not be methodologically included into the multi-hazard risk assessment, but remained a separate assessment.

To effectively support the city in its action taking, the CRVA needs to be followed by CAP and by a project pipeline of climate resilient investments.

Step 1: Hazard Risk Assessment and Mapping Methodology

A climate change sensitive **hazard risk assessment** identifies prevalent hazards in the city through past records and looks into how future climate change is likely to influence the frequency and intensity, or severity, of damages related to each hazard. Frequency and intensity are determined spatially through criteria specific to each hazard.

Steps in hazard assessment:

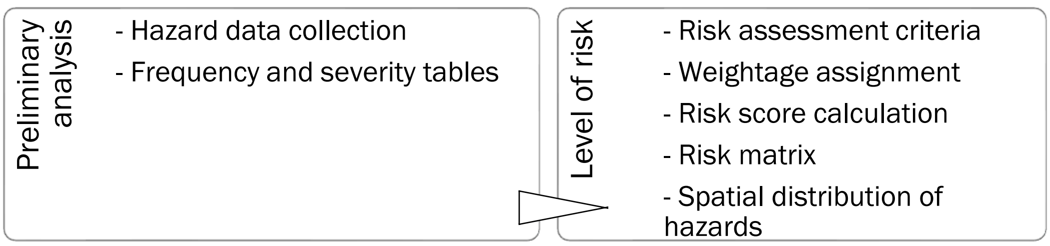


Figure 14: Steps in hazard assessment
Source: Author

1.1 Determine Hazards Prevalent in the City through Preliminary Data Analysis

Preliminary analysis gathered information on the types of hazards in Baguio by extracting data from latest ADB and Baguio Local Government Unit (LGU) documents, CCA results, academic literature and, primarily, from newspaper reports from 1990 to 2022. This time frame was not rigid, however the availability of online news reports reduced significantly around and before 1990. Hazard-specific tabular recordings, separately shared with the city, systematized data documentation. Table 7 provides a sample of a frequency and severity table.

	Frequency of hazard				Severity of the impact							Other		
Date	Location	No. of barangays affected	Names of barangay affected	Comments that will help to determine the severity of damage	No. of people injured	Number of deaths	Damage to critical infrastructure (Y/N)	Type of the infrastructure that was damaged	People transferred to evacuation center (Y/N)	Evacuation center information	Comments that will help to determine the severity of damage	Cause of hazard	Comments	Sources
2015	Baguio city	14	Irisan, City Camp Central, Lower Rock Quarry, Pinget, Bakakeng Central, Dontogan, Sto. Tomas Proper, Asin, Dominican Mirador, Lourdes Subd. Ext., San Roque Village, Middle	The identified sinkhole areas are in grave danger during typhoons	0	0	Y	Residential (boarding house)	Y	NA	Pre-emptive evacuation in case of landslides advised by mayor.	Sinkholes occuring in limestone, sandstone and quartzite terrains.		https://www.pressreader.com/philippines/manila-bulletin/20150614/281517929747506
2015	Itogon, Benguet	1	NA	Atleast 500 houses at riak	0	0	Y	Residential (boarding house)	Y	The affected families were moved to evacuation centers that were set up for typhoon survivors	78 families were left homeless after a sinkhole opened up in Batuang Road in Virac, Itogon, in Benguet	Typhoon Lando	A 150 m wide sinkhole was created	https://www.manilatimes.net/2015/10/23/todays-headline-photos/top-stories/sinkhole-swallows-
2009	Crystal Cave	1	NA	50 buildings in Crystal Cave were deemed to be endangered because they either stood on or near sinkholes.	0	0	Y		N	Reports indicate that the government officials were unwilling to relocate 50 endangered	Cracks seen in periphery of building.			https://www.manilatimes.net/2015/10/23/todays-headline-photos/top-stories/sinkhole-swallows-
1996	Crystal Cave	1	NA	NA	0	0	Y		N	NA				https://www.pressreader.com/philippines/philippine-daily-inquirer-1109/20100604/283433

Table 7: Screenshot of sinkholes' frequency and severity table
Source: Author

1.2 Determine Levels of Risk at a City Scale

1.2.1 Risk Assessment Criteria and Weightage

Establishing frequency and severity assessment criteria was essential to determine **the risk levels** of each natural hazard. Criteria were developed considering the specific context and data collected on Baguio City. However, once completed, these criteria were also found to be applicable to cities in general. Maintaining similar criteria across cities of a country allows to first compare baseline scenarios objectively and, second, to monitor their respective evolution, which can fruitfully inform climate and disaster sensitive urban policies at the national level.

Frequency was sub-categorized into historical evidence and climate change, where the former indicates each hazard occurrence frequency in the past, and the latter indicates how climate change is likely to affect it based on obtained climate change projections. The influence of climate change on frequency was categorized into an immediate future (by 2030), an intermediate future (by 2060) and a remote future (by 2100). Integrating climate change is critical because it is likely to heavily affect most hazards. Hazards likely to not get affected or lightly get affected in the near to intermediate future, such as earthquakes, show evidence of getting affected in the remote future. Other hazards, such as forest fires, are not adequately represented through the historical evidence and climate change is likely to affect their frequency significantly in the near to intermediate future.

Severity of damages was assessed under 3 sub-categories: fatalities, infrastructure damage and climate change impact. The first two were determined from historical evidence, and climate change's influence on the severity of damages could be assessed by the likelihood or not of increasing the level of severity.

Value assignment. Frequency and severity indicators were assigned a numeric value following natural ordering. For instance, a hazard's occurrence on an annual basis was assigned the highest value, followed by several times in a decade, once in a decade and once in 50 years, respectively. Similarly, the number of deaths exceeding 10 during a disaster event was assigned a higher value. Value assignment allowed creating a quantitative comparison and ranking.

Weightage assignment. Equal weights method was employed to compute frequency and severity indices (Table 8). It conferred equal importance to all sub-categories within a category and all the indicators within a sub-category. See Table 8 for clarity.

Category	Sub-category	Weight (w_1)	Indicator	Assigned Value (v)	Weight (w_2)	Weighted value ($v_w = w_2 \times v$)	Score ($w_1 \times v_w$)	
Frequency of hazard occurrence (f)	Historic evidence (a)	0.5	Likely to occur annually	4	0.25	1.00	$a = w_1 \times v_w$	$f = a + b$
			Likely to occur several times per decade	3	0.25	0.75		
			Likely to occur once a decade	2	0.25	0.50		
			Likely to occur once in 50 years or more	1	0.25	0.25		
	Climate change assessment (b)	0.5	Likely to increase by 2030 (immediate)	3	0.33	0.99	$b = w_1 \times v_w$	
			Likely to increase by 2060 (short-term)	2	0.33	0.66		
			Likely to increase by 2100 (long-term)	1	0.33	0.33		
Severity of damages (s)	Fatalities (a)	0.33	Death ≥10	3	0.33	0.99	$a = w_1 \times v_w$	$s = a + b + c$
			Death <10	2	0.33	0.66		
			Injuries or health hazards	1	0.33	0.33		
	Infrastructure damages (b)	0.33	Damage to infrastructure or disruption of services	2	0.5	1.00	$b = w_1 \times v_w$	
			Other damages	1	0.5	0.50		
	Climate change impact (c)	0.33	Damages will increase	1	1	1.00	$c = w_1 \times v_w$	

Table 8: Criteria for calculating frequency and severity values
Source: Author

1.2.2 Risk Score and Matrix

A **risk score** is the level of risk calculated by multiplying the hazard frequency value by the hazard severity value. Risk scores facilitate the ranking of different hazards and allow decision-makers to identify which risks should be addressed as a priority. The following formula was used for **risk score calculation**:

$$Risk\ score = Frequency\ of\ hazard\ occurance * Severity\ of\ damages\ caused$$

where,

$$Frequency\ of\ hazard\ occurance = frequency\ based\ on\ historic\ evidence + frequency\ based\ on\ climate\ change$$

$$Severity\ of\ damages\ caused = fatalities + infrastructure\ damages + climate\ change\ impact$$

A **risk matrix** is a common way to visualize and compare hazard risk scores based on each hazard's frequency and severity. The frequency and severity values, each having 10 entries ranging from 0.1 to 1.0, form the two axes of the 10x10 matrix. A unique risk score is reflected in each cell of the resulting 100-celled matrix (Table 9). Risk scores range from 0.01 (lowest risk possible) to 1.00 (highest risk possible). By dividing 100 risk scores into 3 nearly equal parts, 3 thresholds were defined to determine the hazard risk level (Table 10).

		Severity									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Frequency	0.1	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
	0.2	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
	0.3	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.30
	0.4	0.04	0.08	0.12	0.16	0.20	0.24	0.28	0.32	0.36	0.40
	0.5	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
	0.6	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.60
	0.7	0.07	0.14	0.21	0.28	0.35	0.42	0.49	0.56	0.63	0.70
	0.8	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80
	0.9	0.09	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.81	0.90
	1	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00

Table 9: A 10x10 frequency and severity risk matrix
Source: Author

Risk level	Risk score	Description
High	> 0.35	The event is likely to occur annually or multiple times in a decade; loss of human lives and infrastructure damages very likely to occur
Medium	≤ 0.35 and > 0.15	Either the event is rare, but damages are high; or the event is frequent, but the damages are low
Low	≤ 0.15	The event is very rare, loss of life is nil, and no damage to important infrastructure is likely to occur

Table 10: Threshold values of risk scores to determine the hazard risk level
Source: Author

1.2.3 Spatial Distribution of Risk Levels Hazards

Not all parts of a city are equally exposed to each hazard. Once the risk score matrix exercise yields the list of potential disasters in an area, the next step is to develop hazard-specific maps. Maps were prepared for hazards falling into high and medium risk categories. Hazard maps highlight the level of risk different parts of the city are exposed to.

Separate maps were prepared for each hazard based on different criteria. These criteria depended upon the nature of each hazard. For instance, these were location of inactive fault lines for earthquakes, steepness of slopes for landslides, or distance from rivers and catchment size for flooding. By setting threshold values, spatial distribution of hazards can be categorized as low, moderate, high, or very high. Specific criteria utilized for hazard maps are shared in Table 11, and further detailed in Chapter 3. To generate maps, different levels of risk were represented by different colors in GIS.

Hazard maps are sourced and prepared based on the following criteria:

Hazard maps	Source	Criteria for hazard map development
Landslides	– Landslide-prone areas map provided by EGIS/SPADE	
Forest fire	– Forest map provided by Ramboll – Forest fire hazard map prepared by UNICITI based on geoprocessing on GIS	– Classification of forests into two categories: urban forests and peripheral forests – 100 m buffer from forest boundaries – 560 m buffer from forest boundaries
Sinkholes	– Location map of sinkholes, Ramboll – Geological map of Baguio, SPADE	– Locations of actual sinkholes in Baguio are overlayed with geological formation layers
Floods	– Flood-prone areas map prepared by UNICITI	– Hydrological modeling on HEC HMS and HEC RAS
UHI	– Prepared by UNICITI	– LST analysis on GIS using the Landsat imagery
Earthquakes	– Prepared by UNICITI – Faultline by SPADE – Seismic zone map of the Philippines	– Based on seismic zone map of the Philippines

Table 11: Hazard-specific criteria utilized to prepare hazard maps
Source: Author

Step 2: Multi-Hazard Risk Assessment and Mapping Methodology

Hazard-specific maps help prepare hazard-specific resilience strategies. A multi-hazard map (MHM) helps develop holistic resilience planning. It gathers information from all hazard-specific maps and presents a composite picture in a single map. It is a tool which does not replace but is complementary to individual hazard maps to help prioritize interventions in decision-making. When overlapped with sectoral assets maps, MHM reveals exposure to risk levels all hazards combined.

All hazards are not equally harmful to different city areas. To develop an MHM, it is hence important to assign adequate weightage to each hazard. An MHM requires calculating the weighted sum of individual hazard risk levels to generate the composite map.

Multi-hazard mapping is based on the following formula:

$$Weighted\ sum = (W1 * Hazard1) + (W2 * Hazard2) + (W3 * Hazard3) \ldots. + (Wn * Hazard\ n)$$

The weighted overlay adds all the raster layer values of each hazard to generate an **MHM.** The multi-hazard mapping method is summarized in Figure 15.

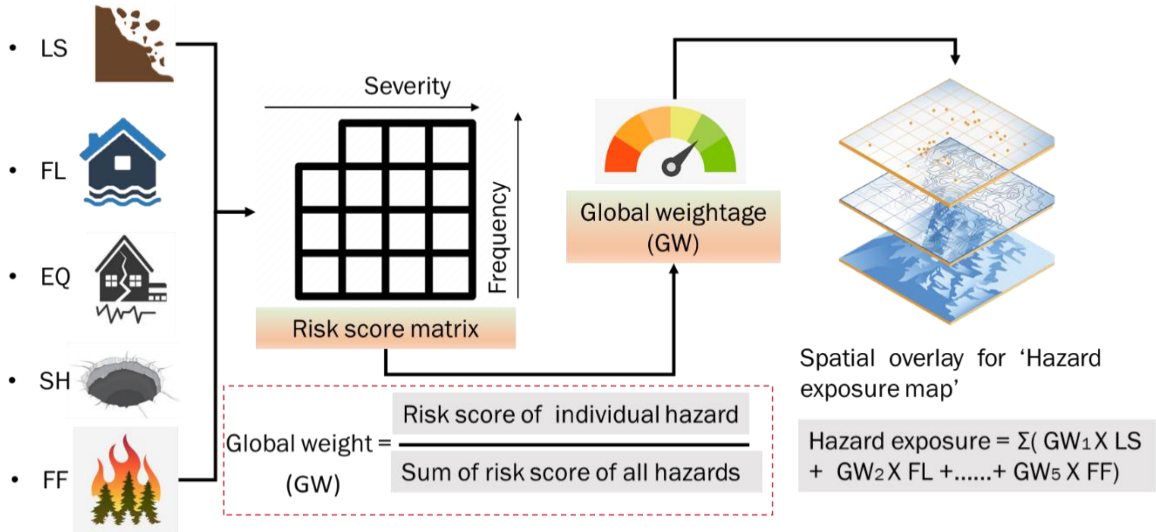


Figure 15: Multi-hazard mapping methodology
Source: Author

Individual hazard layers included into the multi-hazard assessment included landslides, floods, earthquakes, sinkholes, and forest fires. The risk score for each hazard was developed using the frequency and severity scores of each hazard. The multi-hazard assessment used global weights derived from individual hazards' risk scores. **Global weightage (GW)** is a normalized value obtained from summing up individual risk scores.

To identify Baguio's multi-hazard exposure, the following steps were followed:

1. The risk score of each individual hazard was divided by the sum of risk scores of all hazards to derive the global weight of each individual hazard;

2. Each individual hazard layer was ranked based on whether it is low, medium, high or very high exposure. Ranks consisted of numerical scores;

3. Ranks were added as a new attribute table within vector layers of each hazard. Earthquake was ranked as three as the entire city falls into a high-risk zone;

Landslide exposure	Rank	Flood				Forest fire exposure	Ranks	Sinkholes exposure	Ranks
		Buffer (meters)	Ranks	Return period (years)	Ranks				
Very High	4	150	3	2	3	High	3	High	3
High	3	100	2	25	2	Medium	2	Medium	2
Medium	2	50	1	50	1	Low	1	Low	1
Low	1								

Table 12: Hazard exposure and ranking
Source: Author

4. Individual hazard layers were converted from vector to raster based on their ranks. Raster maps were used for weighted overlay analysis;

5. Each raster hazard layer was multiplied by **respective GW** to reflect its relative risk/ impact on the city. For instance, the landslides layer has a higher risk score than the floods layer for Baguio;
6. All hazard layers were brought to one to obtain the multi-hazard exposure map (Figure 15).

Weighted sum = (W1 X Landslide) + (W2 X Floods (buffer+ return period)) + (W3 X Earthquake) + (W4 X Forestfire) + (W5+ Sinkholes) – eq1

Weighted overlay added all the raster layer values for landslides, floods, earthquakes, sinkholes, and forest fires to generate a **multi-hazard exposure map.**

Step 3: Sectoral Disaster Risk Exposure Assessment and Mapping Methodology

An asset's exposure to a hazard signifies that the asset is located in a disaster risk area. Exposure is essentially defined by the location and the level of risk. Spatially, when a map of a set of sectoral assets is overlaid with a hazard risk exposure map, stakeholders may visualize which assets are exposed to which category of risk (low, medium, high or very high).

The present assessment screened three categories of sectors, namely physical infrastructure sector, social sector, and economic sector. Existing and planned land use sector could and should also be screened when updated land use maps become available. Table 13 presents assets each of these categories covers. Most of the listed sub-categories have been covered in the present assessment, except for those for which data was not available and could not be identified. Sector-wise data was obtained from online statistics, digitization of data provided by the city, digitization of remote sensing and open street maps, Google Earth and other geoprocessing tools, ADB SPADE database, as well as selected data digitized by EGIS and Ramboll in the frame of ADB work with Baguio City.

Sectors to be covered by a disaster risk vulnerability assessment

Physical infrastructure	Data requirement

Critical infrastructure	• Hospitals • Schools • Fire stations • Police stations • Community centers • Evacuation centers
Transportation	• Road (national, state, local) • Road density • Bridges • Bus stops • Airport
Water management and supply	• Water supply outlets by barangay • Water transmission network • Deep well locations • Catchment boundary • Waterways + buffers • River
Sewage and drainage	• Wastewater treatment plants • Existing drainage network • Drainage inlets • Sewerage network • Existing sewage treatment plant • Sceptic tanks
Solid waste management	• Landfill/dumpsite • Solid waste treatment plants • Designated garbage pickup points
Energy	• Energy transmission and distribution lines • Street light locations • Powe house location • Dams / reservoirs
ICT	• Telecommunication network • Post offices

Social sector	
Demography	• Population density • Population • Female population • Age distribution • Median income • Gender • Level of education • Employment status • Type of occupation
Housing	• Building typology (G, G+1, G+2, G+3, etc.) • Building construction material • Household size • Housing quality (structure condition) • Type of lighting used (electricity, kerosene, LPG, Oil etc.) • Source of drinking water • Informal settlements

Economic sector	
Tourism	• Tourist spots • Hotels • Hostels • Restaurants • Cafés • Fast food
Heritage and culture	• Historical/heritage buildings • Cultural activity centers • Arts and crafts locations • Outdoor cultural and sports festivals
Commercial	• Commercial zones • CBD – old and planned extension
Industrial	• Special economic zone • Industries

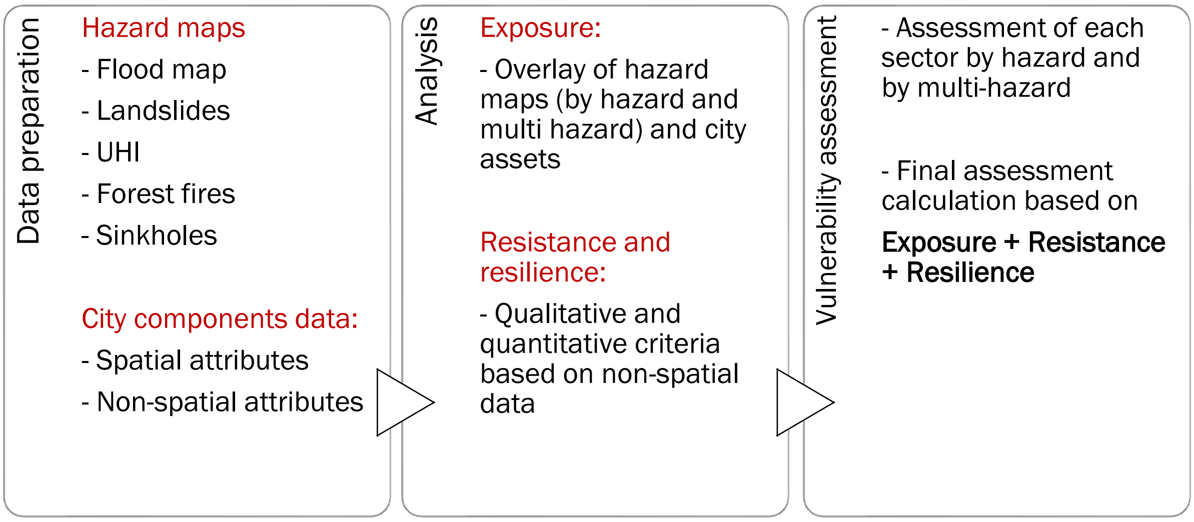
Land use	Data requirement
Land use	• Building footprint • Built-up extent • Land use existing • Land use proposed • Developable area • Forest area • Wetlands + buffers • Watercourse (Tributary/Rivers/Stream/Canal) • City parks

Table 13: Sectors and sub-sectors a CRVA should aim covering, within the scope of available data
Source: Author

Step 4: Priority Assets' Disaster Risk Vulnerability Assessment Methodology

A disaster risk vulnerability assessment identifies the degree of people's and assets' vulnerability to natural hazards. **Vulnerability is a function of intangible aspects and non-spatial qualities of people and assets located under a hazard exposure zone.** Vulnerability equals to exposure plus coping capacity, which includes resistance and resilience qualities. Resistance refers to measures integrated into an asset to prevent, avoid, or reduce losses. Resilience refers to the ability to recover a prior-to-disaster state or to achieve a desired post-disaster state.

Steps in Vulnerability Assessment



To determining the coping capacity of a population or of an asset, non-spatial quantitative and qualitative information about it is required. Assets and population located in a very high or high hazard exposure zone are not necessarily at very high or high risk. Their vulnerability depends not only on their location, but also on other social, economic, structural, and non-structural factors. For example, a locality where the population is majority composed of highly educated and technology savvy youth will be in a much better position to receive early warning and evacuate during a disaster compared to a locality where the elderly constitute the majority of the population and where awareness of disaster effects is lower. Similarly, a road located in a high to a very high landslide and flood exposure zone may not necessarily be highly vulnerable if engineering provisions such as slope stabilization and an increased drainage capacity have been integrated into its construction.

Step 4 requires detailed site and asset specific information, which was not possible to collect during the present assessment. While the present CRVA builds the ground to propose key priority action directions, the city may wish to conduct selected vulnerability assessments to determine its most impactful investments and interventions.

Urban Heat Island Assessment Methodology

Heat islands are areas which record higher temperatures compared to other neighboring areas. Often observed in urban areas, and therefore termed as UHI effect, heat islands usually take places at constructed and paved surfaces such as buildings, roads or parking lots. They tend to absorb and re-emit solar heat more than natural landscapes such as waterbodies and green areas. Areas with a higher concentration of paved surfaces and lack of greenery hence become islands of higher temperature compared to their surroundings. UHI may generate very negative impacts, such as severely affecting sensitive population categories' health or significantly increasing usage of indoor air conditioning.

The UHI assessment of Baguio City was developed by considering changes in land surface temperature (LST). To derive LST, an annual median approach was implemented for 2 years at a 20 year interval—2001 and 2021—at three different types of location: densely built-up (CBD), forest area and neighboring rural area. UHI was then assessed through an analysis the changes in LST in between these three area types over 2001 and 2021.

Land Surface Temperature and Annual Median Approach

Assessing UHI requires comparing temperature of areas with different layouts. Most often, the city's meteorological stations are not located in all representative areas. Satellite data is hence a common source to assess UHI. **LST** is a helpful instrument to assess urban micro-climates, estimating high-resolution evapotranspiration for the management of water resources, and assessing vegetation stress. Among various remotely sensed data sources which provide LST related data, Landsat series provide high spatial resolution observations in the thermal infrared (~100 m) and are available over 38 years with relatively high resolution (30 m) (Ermida, et al., 2020).

The **annual median approach** was selected following a number of studies, which used annual median temperature and achieved accurate results (Ranagalage et al., 2020). For example, Ranagalage analyzed annual median temperature from years 1996, 2009 and 2019. His study also evaluated the correlation between LST and land use. For the selected years, 4 classes of land use were analyzed: water, green, impervious and other areas. The increase in temperature was directly proportional to an increase of impervious area and inversely proportional to an increase of green area.

UHI Baguio data was prepared using the Google Earth Engine (GEE) platform. The source code used for LST derivation from Landsat images was detailed in GEE Open-Source Code for Land Surface Temperature Estimation from the Landsat Series (Ermida, et al., 2020). To obtain LST from Landsat image collections for a particular year, image collections were filtered with cloud cover of below 10%. The annual median of filtered images was taken for each given year. The median methodology took the median value of pixels available in the year from the filtered image having <10% cloud. A total of 15 images from Landsat8 (2021) and three images from Landsat7 (2001) were used in the study.

Selection of Built-Up, Green, and Neighboring Rural Areas

To identify temperature differences between densely built-up versus green and rural areas, one most representative sample was selected for each area type:

The buffer selection for this land use zone was based on building footprint density and forest in Baguio.

- CBD was selected as a densely built-up and populated urban area;
- Forest area located 4 km away from CBD, in the southeast, was selected as a representative green area of the city;
- Rural area with a low building density and population density was selected 12 km away from the CBD, on its western side.

Coordinates of densely built-up, green, and rural areas are detailed in table 14 and circular 600 m buffers around these points are showcased in Figure 16.

Land use zone	Coordinate (°)	
	lon	lat
Densely built-up area	120.60	16.42
Rural area	120.58	16.39
Green area	120.62	16.39

Table 14: Coordinates of land use zones utilized to create buffer layer
Source: Author

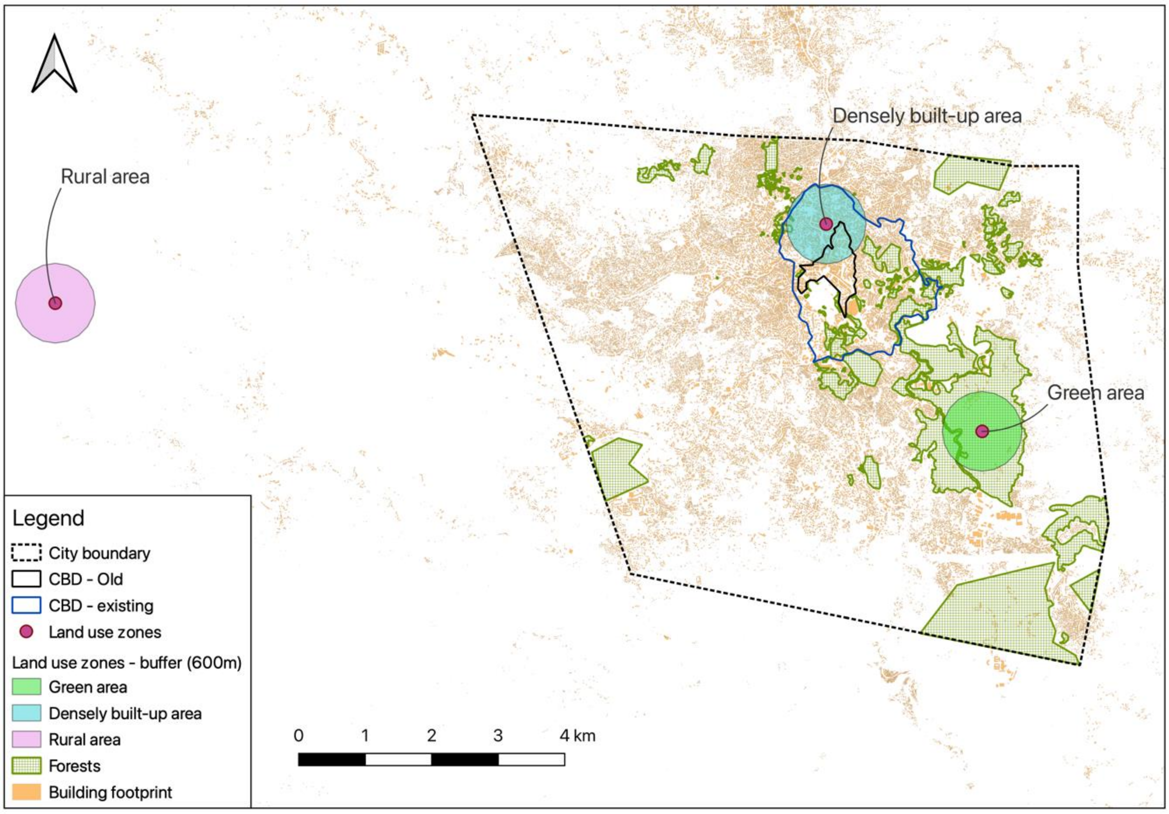


Figure 16: Building footprint, Central Business District (CBD), land use zones with its corresponding buffer in the city
Source: Author

Statistics including min, mean, max and standard deviation of LST were calculated over the buffer zones of the three area types for 2001 and 2021 to evaluate annual median LST changes of these areas, between themselves and over time.

LST and Observed Temperature Total Values

Mean daily air temperature from a meteorological station located in the city (Baguio City Benguet) and LST from Landsat 8 show different total values. LST indicated a higher temperature compared to observation in the range of 5 to 15^{0}C. The author of the GEE code for LST retrieval stated that LST is likely to overestimate/underestimate temperature for different regions (Ermida, et al., 2020). The fact that LST does not match observed values does not invalidate LST data for the following reasons:

- Air temperature was measured at 2 m above the ground while the LST measures temperature at the ground surface;
- Gauged temperature is the mean daily value. LST from Landsats 8, on the other hand, was sensed at a particular place and date. Most images used in the study area were recorded around 1-2 p.m. for days corresponding to data acquisition dates.

A comparative analysis of both temperature measurements was conducted for the time period of 13 June 2013—27 December 2015 (Figure 17). It confirmed that both the methods recorded the same temperature trend, which validated the fact that LST series could be reliable used to assess UHI in Baguio.

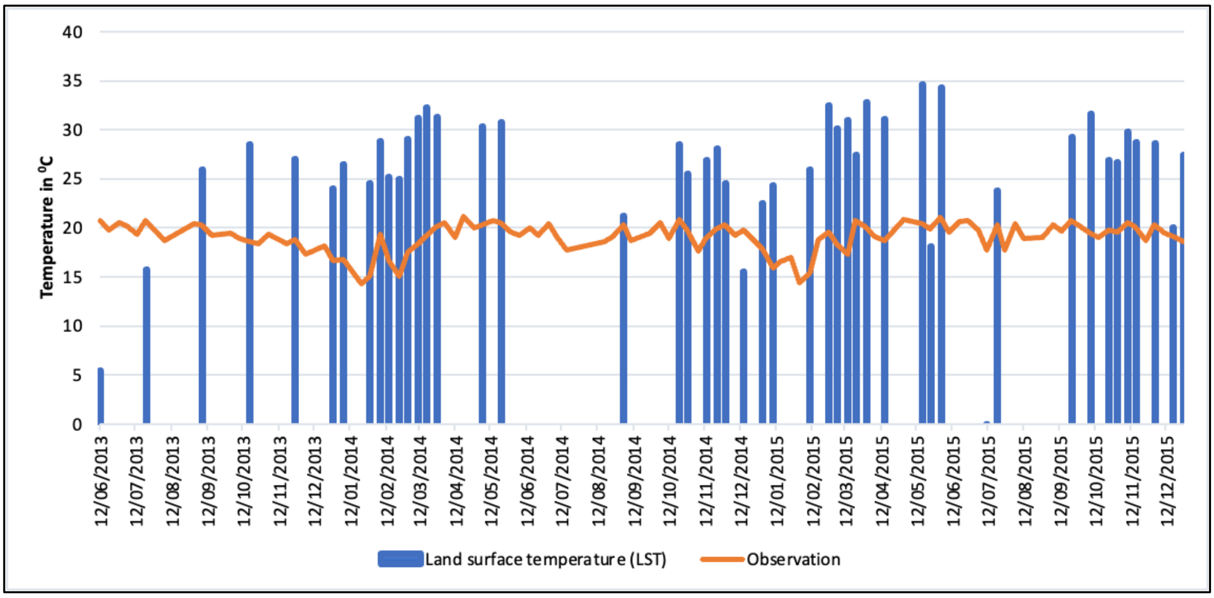


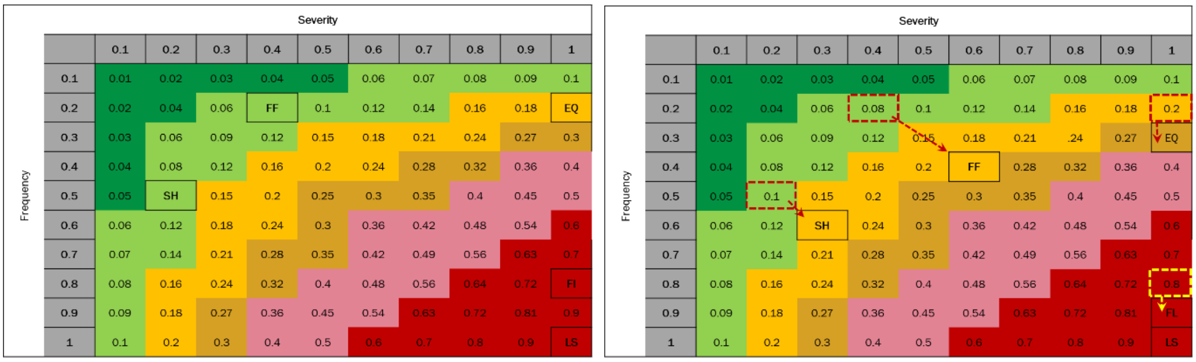
Figure 17: Comparison of LST with air temperature (13.06.2013-27.12.2015)
Source: Author

3. Sectoral Disaster Risk Exposure Assessment and Mapping

The hazard risk assessment matrix identified that most impactful natural hazards for Baguio City over the intermediate future are the following, in a decreasing order: landslides (very high risk), floods (very high risk), earthquakes (moderate risk), sinkholes (moderate risk) and forest fires (moderate risk). Hence, the exposure analysis is focused on the above five hazards. The UHI effect has been assessed separately since it is essentially a man-made phenomenon and cannot be integrated into the hazard risk matrix.

Comparative analysis of hazard risk matrix with and without a climate change component led to the following conclusions (Table 15):

- Landslides and floods remain predominant hazards in Baguio, and are getting further exacerbated by climate change;
- Sinkholes and forest fires are shifting from low to moderate risk zone under the climate change effect;
- Earthquakes pose a moderate risk. They have the lowest frequency among all hazards and climate change may influence them only in the long-term future. However, severity of damages related to them is very high and puts the entire city's territory under risk.



	With climate change components			Without climate change components		
Hazard	Frequency (f)	Severity (s)	Risk score (f x s)	Frequency (f)	Severity (s)	Risk score (f x s)
Landslides	1.00	0.98	0.98	1.00	1.00	1.00
Floods	0.87	0.99	0.86	0.75	1.00	0.75
Earthquakes	0.29	0.99	0.29	0.25	1.00	0.25
Sinkholes	0.58	0.50	0.29	0.50	0.25	0.13
Forest fires	0.46	0.60	0.28	0.25	0.42	0.11

Table 15: Comparison of hazard risk scores without (left) and with (right) climate change component
Source: Author

Exposure assessment was conducted by overlaying hazard maps, which include the climate change component, with city assets' maps. The present chapter shows outputs and learnings from the exposure analysis.

3.1 Landslides

Risk level	High	Risk score	0.98
Impact of climate change:			
Increase in frequency	↑	Increase in intensity	↑

3.1 Overview

Landslides are the downward and outward movement of slope-forming materials such as soil, rocks, artificial fill, or a combination of these. Landslides are common in mountainous areas and have the potential to cause severe damage depending on the frequency and magnitude of the event. UNISDR categorized landslides as a geohazard (UNDRR, 2020). Geohazards have a geophysical origin.

Due to Baguio's hilly terrain combined with intense rainfalls, rainfall-induced landslides are the first most frequent and intense hazard in the city. Baguio faces both minor scale and severe landslide incidences. From 2009 to 2021, the city faced nine disastrous landslide events causing heavy damage. Eight of these events took away human lives; 4 of them led to 10 deaths; all 9 events damaged roads, disrupted electricity and water supply services. four landslide events led to moving people to evacuation centers.

3.1.1 Landslide Triggering Factors

Landslides are a gravity-driven phenomenon, but various dynamic factors serve as triggers:

- **Pore saturation.** Water from rainfalls, lakes or river banks, or groundwater changes saturates the pore spaces in the soil and exerts outward pressure that pushes the grains away from each other, causing slope failure.
- **Erosion.** Waterbodies such as rivers, glaciers and waves erode the slopes, increasing the slope angles and decreasing the slope stability.
- **Ground shaking** stresses act as a trigger for landslides. Natural ground shaking factors are earthquakes and volcanic activities, while anthropogenic factors are blasting and mining.
- **Atmospheric temperature** increase can conduce desiccation cracks which trigger slope failure during the wet season.
- **Infrastructure development** such as roads, rails, mines, and other manufactured structures involve cutting and overweighing slopes. Both factors disturb slopes' natural equilibrium, which may cause slope failure after a trigger.

Landslide Triggering Factors in Baguio:

In Baguio, natural landslide triggers are predominantly heavy precipitation and seismic fault lines.

Monsoon and typhoons. Baguio experiences southwest monsoons (June to November) with tropical cyclones. In addition, the city receives typhoon-led intense rainfalls every year. About 20 typhoons visit the Philippines archipelago in a year, which brings heavy rainfall, causing massive earth slides, mudslides, and debris flows.

Tectonic instability. Baguio City falls under a seismic zone IV and has five inactive fault lines: Loakan fault, Bued River fault, Burnham fault, San Vicente fault and Mirador fault. Thus, the ground near the fault lines is weak with cracks and is prone to weathering and erosion. Ground shaking from earthquakes triggers landslides.

Topography and terrain. Baguio is an origin of four major drainage systems namely Balili river, Ambalanga river, Bued River, Galiano river and its associated streams. The seepage of these streams into the cracks of the rocks can moist the terrain which can also leads to erosion.

Soil types exposed to erosion. The major soil types of Baguio are Kennon formation, Klondyke formation and zigzag formation in which Kennon formation and zigzag formation are more exposed to landslides since they are composed of easily weathered components. Landslide very high and high-risk areas are located in Kennon formation and zigzag formation areas:

Deforestation. Removal of indigenous vegetation for construction and agriculture can also trigger landslides in steep slopes. According to the Global Forest Watch, from 2001 to 2021, Baguio City lost 40 hectares of relative tree cover. Forest fires may further exacerbate this trend.

Construction on the slopes. Population increase and urbanization led to more constructions on slopes, especially low-income residential areas. Construction and excavation on slopes may weaken the ground and cause landslides. According to the 2010 data, 73% of residential areas were situated in the high landslide risk prone areas.

3.1.2 Climate Change Impact on Landslide Hazard's Frequency and Intensity

The projected increase in the number of days with heavy and extreme rainfalls is likely to increase landslides over 2031—2060. In addition, climate change-induced temperatures increase is likely to exacerbate slope instability by enhancing the thermal breakdown of rocks.

3.1.3 Landslide Hazard Assessment

Landslides

Category	Sub-category	Weight (w_1)	Indicator	Assigned Value (v)	Weight (w_2)	Weighted value ($v_w = w_2 \times v$)	($w_1 \times v_w$)	Score
Frequency of hazard occurrence (f)	Historic evidence (a)	0.5	Likely to occur annually	4	0.25	1.00	0.50	1.00
			Likely to occur several times per decade	3	0.25	0.75		
			Likely to occur once a decade	2	0.25	0.50		
			Likely to occur once in 50 years or more	1	0.25	0.25		
	Climate change assessment (b)	0.5	Likely to increase by 2030 (immediate)	3	0.33	0.99	0.50	
			Likely to increase by 2060 (short-term)	2	0.33	0.66		
			Likely to increase by 2100 (long-term)	1	0.33	0.33		
Severity of damages (s)	Fatalities (a)	0.33	Death ≥10	3	0.33	0.99	0.33	0.99
			Death <10	2	0.33	0.66		
			Injuries or health hazards	1	0.33	0.33		
	Infrastructure damages (b)	0.33	Damage to infrastructure or disruption of services	2	0.5	1.00	0.33	
			Other damages	1	0.5	0.50		
	Climate change impact (c)	0.33	Damages will increase	1	1	1.00	0.33	
							Risk score	0.98

Table 16: Risk score calculation for landslide hazard
Source: Author

In the hazard risk matrix, landslide hazard emerged as the most severe natural hazard affecting Baguio. Overall, it scored 0.98 on a scale of 0.01 to 1.00, where the frequency of landslide occurrence was 1.0, and the severity of associated damages was 0.99 (Table 16).

3.2 Landslide Sectoral Exposure Assessment

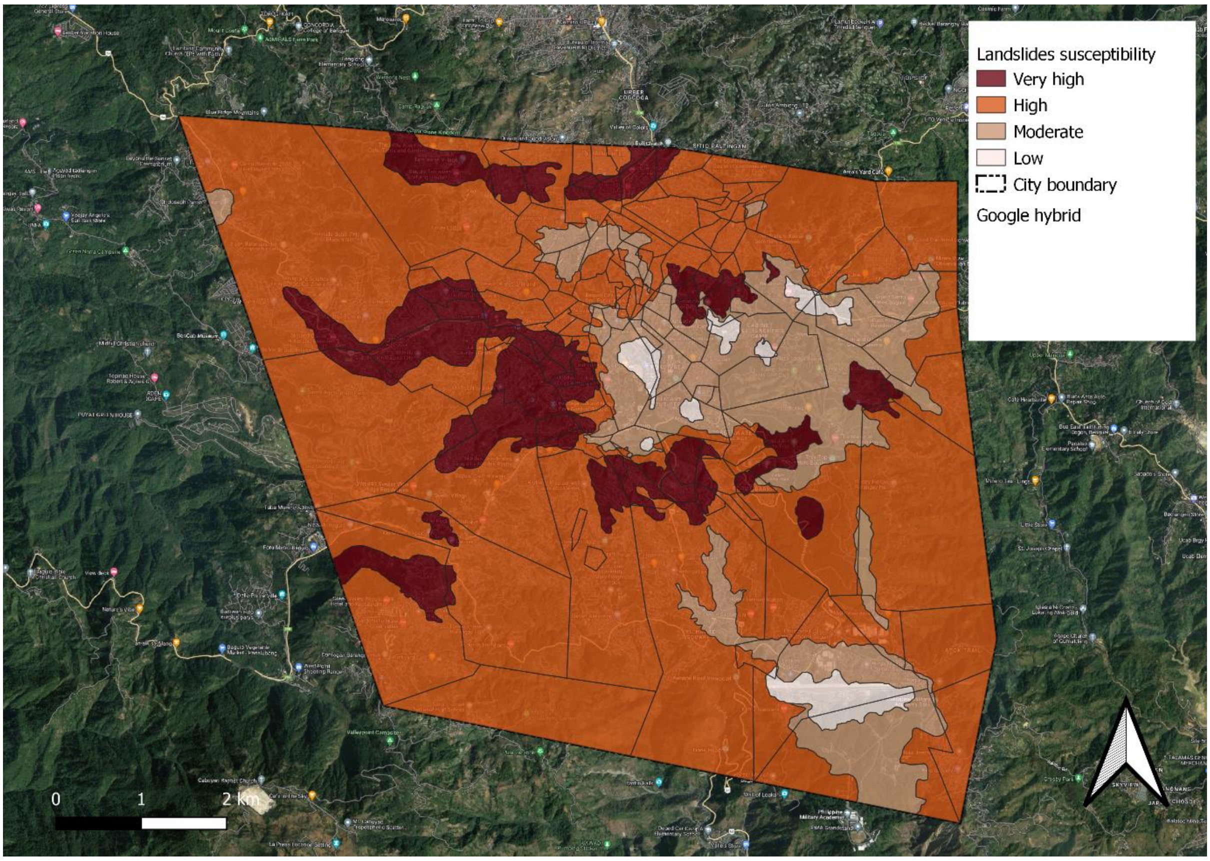


Figure 18: Landslides exposure map of Baguio
Source: SPADE

Over 80% of the city's surface is highly prone to landslides: 7.18 km² (13%) fall into a very high exposure zone and 39.8 km² (69%) into a high exposure zone. The rest of the city falls into either a moderate or a low exposure zone (Figure 18). Landslides risks hence guide and determine a large amount of processes and activities in the city. In particular, mobility and habitats need to be organized in such a way that they are not sizably damaged by landslides, today or in the future. Most of the city's territories planned for new development fall into a high or a very high-risk zone, which means that a detailed landslide resilience plan needs to be finalized before this development takes place.

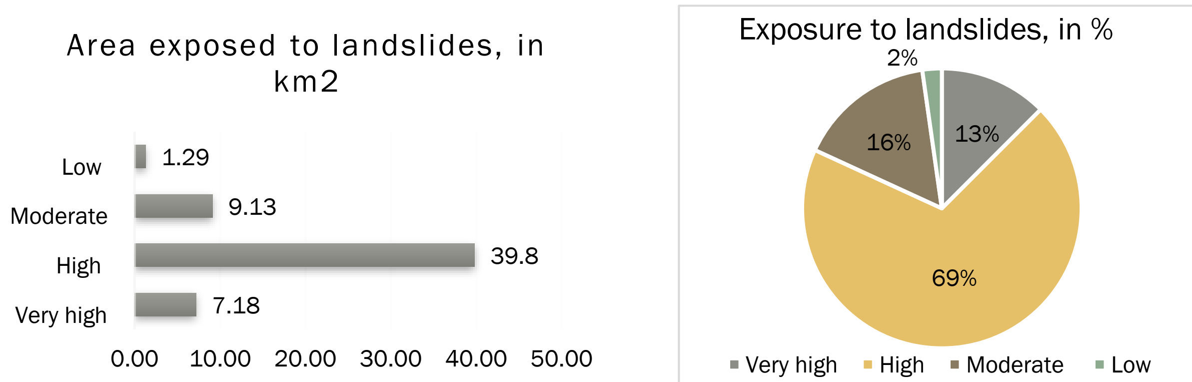


Figure 19: a)Area exposed to landslides, in km²; b) Exposure to landslides
Source: Author

3.2.1 Infrastructure Sector's Exposure to Landslides

a. Essential buildings, ICT, and Energy

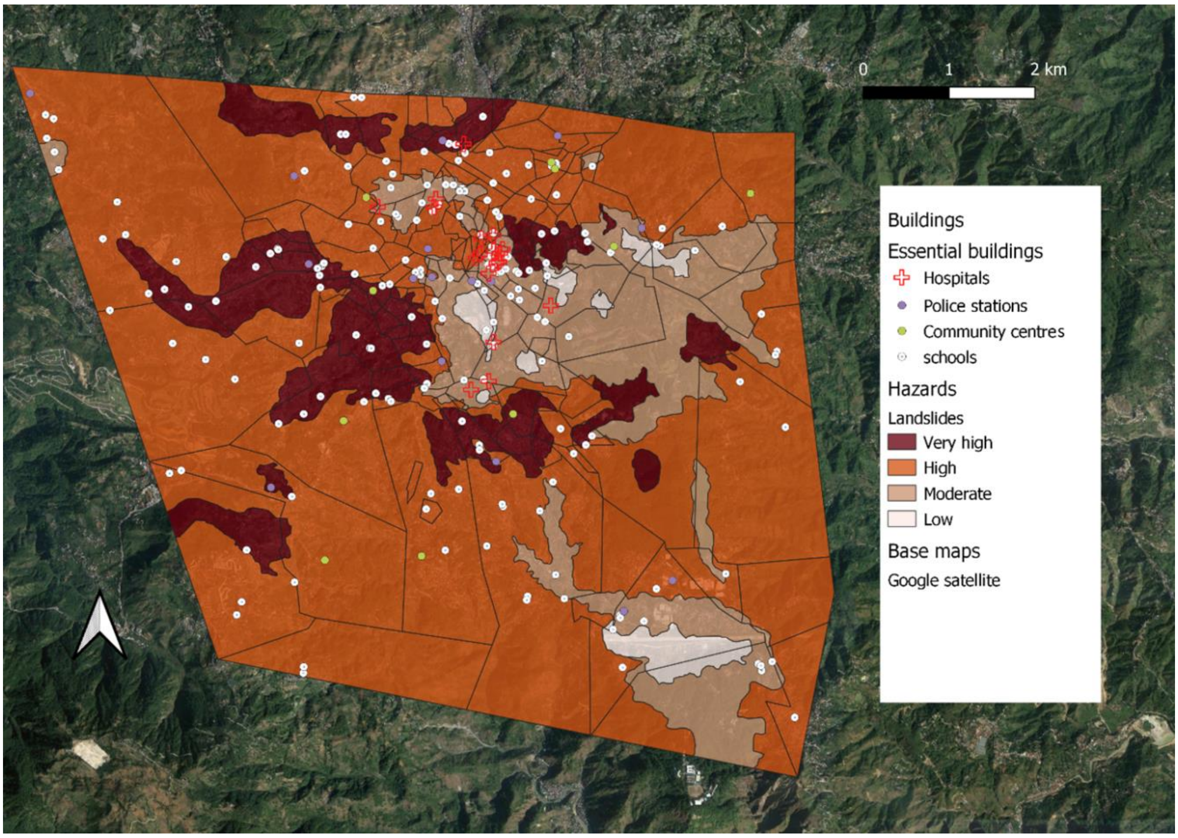


Figure 20: Overlay of landslides exposure and essential buildings
Source: Author

Densest city areas, such as the CBD, sit in a moderate and a low exposure zones. Consequently, a reasonable amount of essential infrastructure is relatively safe from landslides. For example, almost all **hospitals** are in a moderate and a low exposure area. However, **schools** are spread across the city and lie in a high and a very high exposure zone. Incidentally, they also serve as evacuation centers, which calls for effective measures protecting them from landslide damages.

In addition, even when landslides occur in areas away from main settlements, they can disrupt the functioning of the city. For example, damages to **electricity poles, telephone towers, overhead and underground wires** can prove highly detrimental to early warning systems, rescue operations, industries, and economic activities. They can also impact livelihoods for a long period of time.

b. Transportation

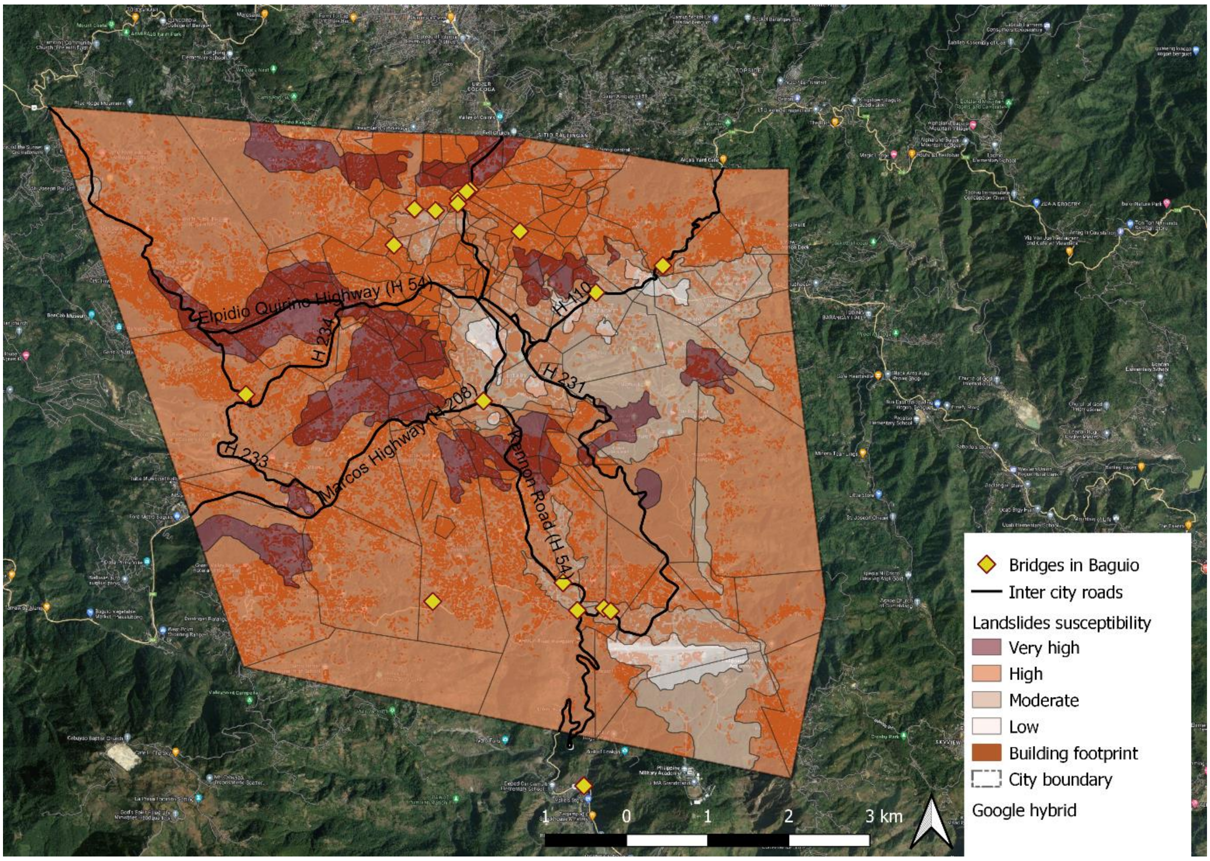


Figure 21: Overlay of landslides exposure and transportation sector
Source: Author

Roads are the lifeline of Baguio City in the absence of railway network and no airport services. There are multiple ways to access the city by road, which connect it to other municipalities of the Luzon island:

- Highway 54: Kennon Road in the south, which is the main road connecting the city to Manila, and Elpidio Quirino Highway in the northwest;
- Highway 204: Magsaysay Avenue in the north;
- Highway 208: Marcos highway in the west;
- Highway 110: in the northeast.

To maintain the city's vital passenger, goods and services internal and external connectivity, all the city's roads need to have resilience to landslides. However, intercity roads should be seen as a priority for the following reasons:

- In the event of a disaster, the functionality of intercity roads facilitates external support, such as provision of rescue and relief forces, of food and other essential supplies. They also allow transporting injured people to hospitals mostly located in the city center.
- The city imports and exports a large number of goods such as agricultural produce or industrial equipment. Disruption of timely delivery may generate shortages within the city or disrupt business activity of Baguio suppliers.
- Tourism is a major economic factor, and these roads ensure tourist connectivity of the city.

Assessing the city's intracity roads exposure to landslides more in detail, we notice that a 3.6 km stretch of Elpidio Quirino Highway falls under a very high landslide exposure zone. Including small stretches of other highways, a total length of 15 km highways lies in a very high landslide exposure zone (Table 17).

Bridges majorly lie in a high exposure area. Resilience of these bridges, primarily in the intercity highways, is a foremost priority.

Name of the highway	Length (km)	Connects to (city)	Exposure
Elpidio Quirino Highway (H-54)	3.6	Sablan	Very high
	2.3		High
Magsaysay Avenue H 204)	0.765	La Trinidad	Very high
	1.19		High
Marcos Highway (H 208)	1.25	Pugo	Very high
	3.3		High
	0.65		Moderate
Kennon Road (H 54)	0.822	Tuba	Very high
	5		High
	1.13		Moderate
	0.75		Low
H 233	0.13	Connects Elpidio Quirino Highway and Marcos Highway	Very high
	2.8	Connects Elpidio Quirino Highway and Marcos Highway (Asin road)	High
H 234	0.185		Very high
	1.8		High
H 231	0.786	Connects Magsaysay Avenue (H 204) and H 110 with Kennon Road (H 54)	Very high
	3.28		High
	4		Moderate
	0.11		Low
H 110	1.95	Bokod	High
	2.1		Moderate
	0.64		Low

Table 17: Highways' exposure to landslides
Source: Author

c. Water Supply and Wastewater Management

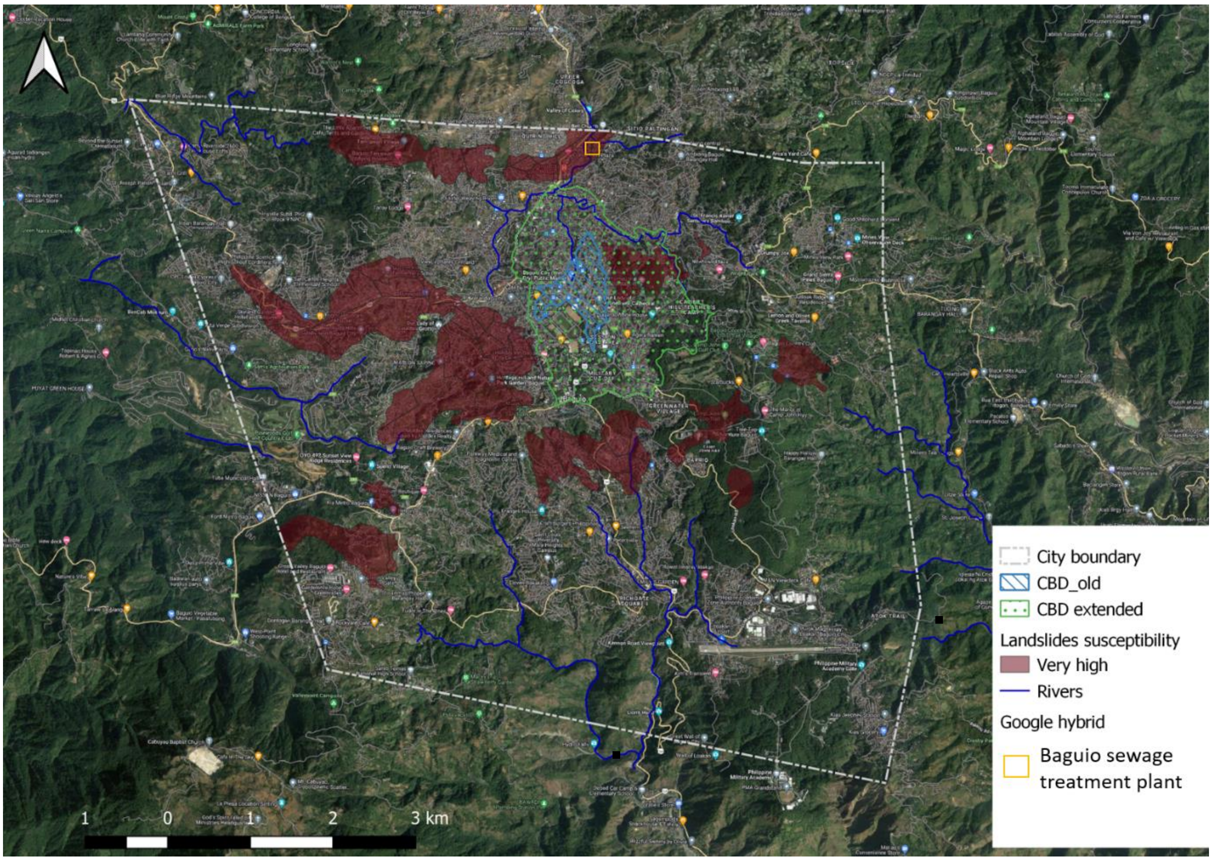


Figure 22: Location of BSTP in very high landside exposure zone
Source: Author

Baguio's water supply is over 90% dependent on underground water. According to the ICF report, sewage is predominantly managed through septic tanks (ICF, 2016). Many barangays have individual septic tanks, while some have communal septic tanks. Only parts of CBD, which is in the Balili river catchment, have a connection to a sewerage network. Served by the BSTP, this network processes 8,600 cum/day.

Deep wells and septic tanks in landslide-prone areas may develop cracks or, in an extreme cases, get filled with debris. Leakage from deep wells and septic tanks can cause future landslides. Leakages in sinkhole-prone areas can trigger sinkhole formation. Leakages in septic tanks may contaminate the groundwater, which would be particularly problematic for Baguio considering that ground water is not treated beyond chlorination.

The **BSTP,** located in the North of the city, lies in a very high landslide exposure zone (Figure 22), however a close inspection of the terrain shows that the BSTP itself lies on a flat terrain.

Landslides often break **water pipes.** The city's water pipes network may get affected by landslides and disrupt water service in very high and high exposure areas.

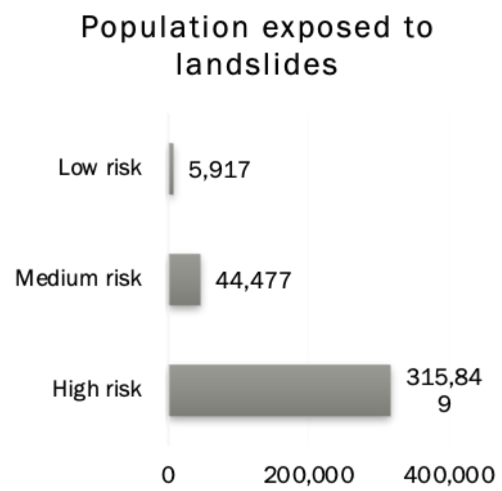
d. Solid Waste Management

Landslides have a direct repercussion on the solid waste management sector when the landfill site gets affected. In 2011, Baguio City faced a disaster when the garbage load and rainwater collapsed a retaining wall causing garbage flow from the Irisan landfill (Figure 23). Today, this former landfill has been converted into an eco-parc and there are no landfill sites within the city's boundaries.

Figure 23: Garbage flow in Baguio after rainfall collapsed landfill site
Source: Petley, 2011

3.2.2 Social Sector's Exposure to Landslides

Population exposed to landslides



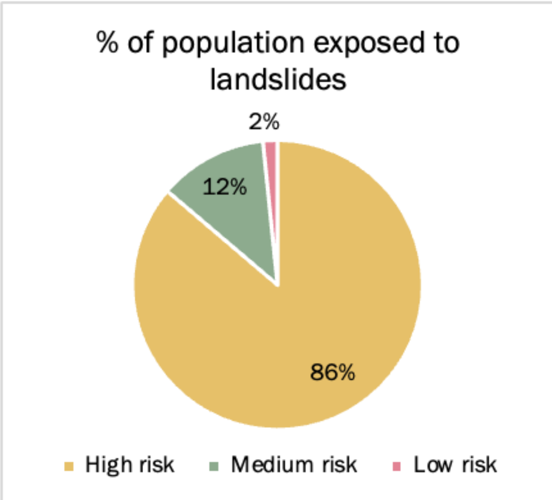


Figure 24: Population exposed to landslides
Source: Author

As per the population repartition according to the Census 2021, nearly 86% of the population is very highly or highly exposed to landslides. The moderate risk areas, spanning 9 km², include barangays located in the eastern part of Baguio City. These areas shelter 12% of the population.

Majority of Informal settlements in Baguio are situated in high-risk areas and are prone to landslides. Informal settlements in Camp 7 fall under a moderate risk zone, Country Club Village falls under a very high-risk zone, Dagsian falls under a moderate to a high-risk zone, Greenwater village and Happy Hollow fall under a high-risk zone, Liwanag-Loakan, Macroville and South Drive fall under a moderate risk zone. In addition, the location of these informal settlements is distant from essential facilities such as hospitals, police stations and fire stations, making it difficult for residents to evacuate in the event of a natural disaster.

3.2.3 Economic Sector's Exposure to Landslides

a. Tourism, Heritage, and Cultural Assets

Most of the tourist spots and services are located in barangays with the highest exposure to landslides. For example, this is the case for the Mirador Heritage and Eco Park, Maryknoll Ecological Sanctuary, Heritage Hill and Nature Park Garden, Tam-Awan Village, Igorot Stone Kingdom and The Cathedral Church. Many prime hotels such as Le Château, Diplomat Hotel, Bitaga Transient, Cooyeesan Hotel Plaza, and Skyland Garden Hotel and Resort also lie in very high landslide exposure. A damage of these prime properties may affect the high-income segment tourism, and hence exponentially reflect on the city's economic growth and livelihoods.

Baguio City is known for its cultural events, fairs and festivals, held throughout the year. A number of them are located in a a very high exposure zone. This is the case of **Tam-Awan Village,** a living artists' colony that attracts many visitors. Such an exposure may compromise the community's perennity. **Arko Ni Apo**, another residence in the vicinity of the Tam-Awan Village and a 3 km long woodcarver's village along the Asin Road also lie in a very high exposure zone.

Other cultural activities have a less exposed location. Many festivities and celebrations are hosted near Burnham Park area, including on the Session Road and in the Baguio Convention Center, which lie in moderate and low exposure zones. Both golf courses and the Golf Club are also located in the moderate to low exposure zones (Figure 25). In the Camp John Hay golf courses, thousands of golfers from the country and the United States come to attend the **Fil-Am Golf Tournament** held from November to December.

Heritage buildings are not only crucial for the tourism sector but also essential for maintaining the unique visual identity of the city. Among most famous of these buildings, **Our Lady of Lourdes Grotto and Bell Church lie in a very high exposure zone.** The former is of high religious significance and receives a large number of visitors despite a strenuous 250 steps ascend. The latter has religious significance, architectural appeal and is famous for observing the Hungry Ghost Festival. Protecting heritage buildings from disaster related damages is a high priority for Baguio.

b. Commercial Assets and Industrial Assets

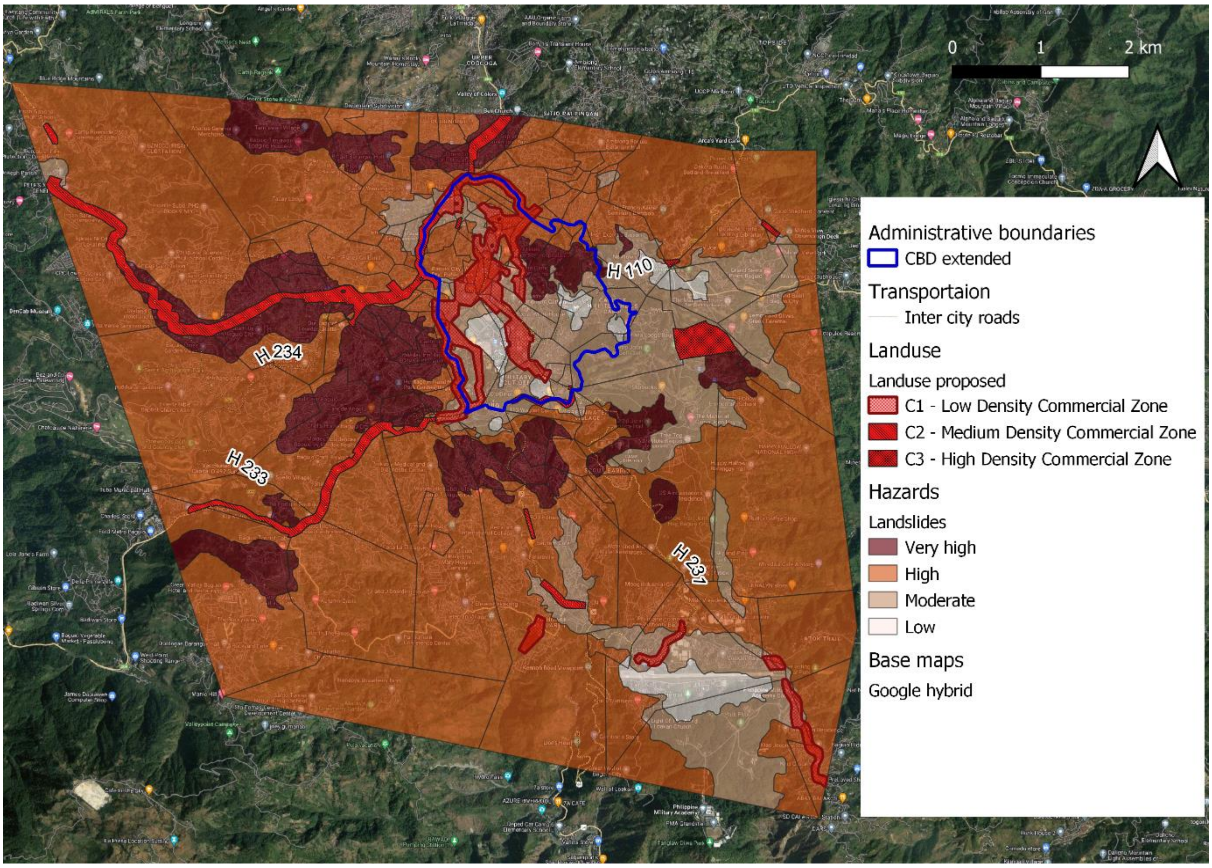


Figure 25: Commercial zones and CBD's exposure to landslides
Source: Author

A large portion of commercial areas has low density (158.794 hectares) and lies in the CBD, which is a moderately exposed zone. The **medium density commercial zone** (89.468 hectares) developed along major roads of the city. Partly lying along the Elpidio Quirino Highway, Magsaysay highway, Kennon Road and Marcus highway, it sits in a very high exposure zone. **High-density** commercial zone (21.676 hectares) developed over two parts of the city: Elpidio Quirino Highway and in the Country Club Village. Both these areas are in a very high landslide exposure zone.

From the above observations, the commercial zone in the CBD area is less prone to the impact of landslides. However, the medium and high-density commercial zones along the roads are highly exposed to landslides. City landslides resilience plan needs to focus on these areas.

Nearly 64% of the industrial area falls under a high-risk zone and the remaining part of it falls under a moderate risk zone. Considering the economic role the industrial sector plays for the city, it is critical to analyze its vulnerability to landslides and, where need may be, landslide proof or relocate the vulnerable industrial assets.

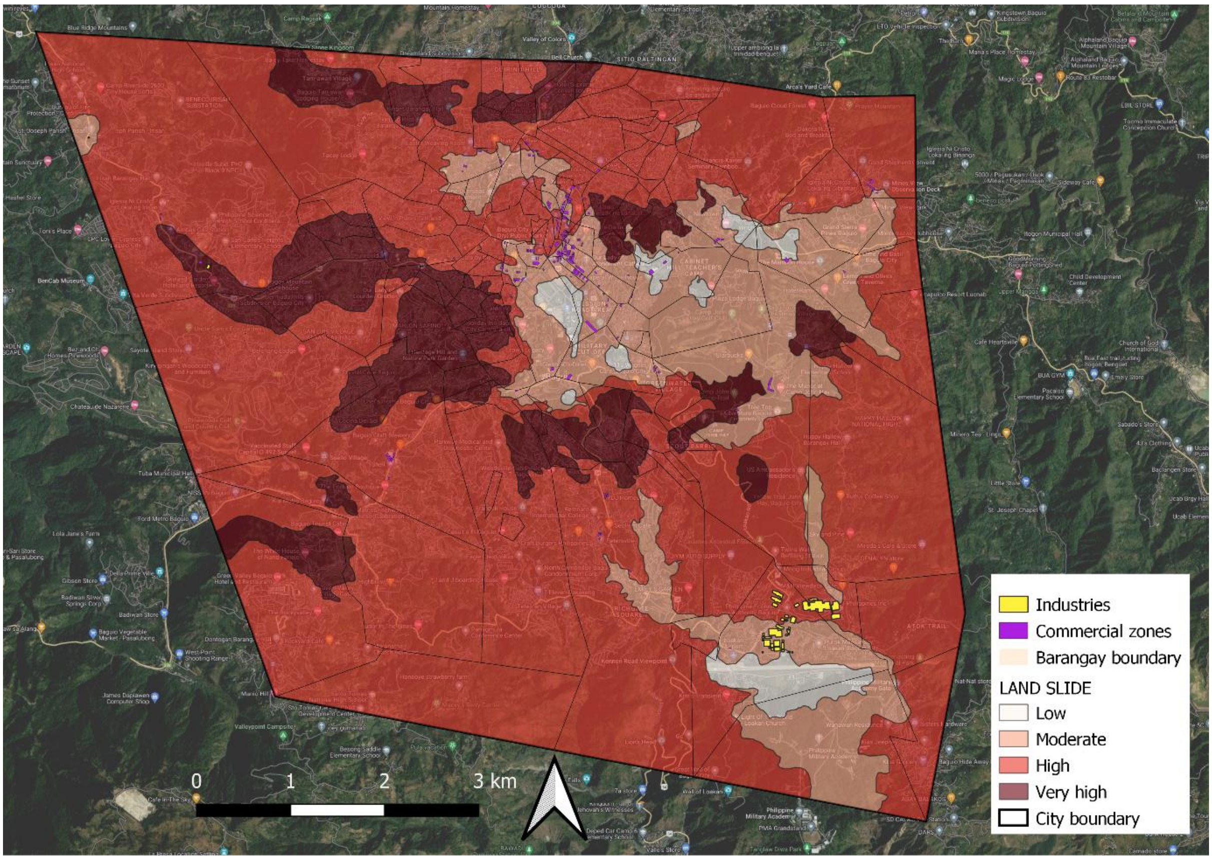


Figure 26: Industrial zones and commercial zones' exposure to landslides
Source: Author

3.3 Conclusion

The city originally developed on a stable hill section (CBD area), less prone to landslide events. However, newer urban developments happened and are happening in highly landslide-prone areas. A number of critical transportation axes, as well as city's tourism spots and city's unique cultural and natural assets are highly exposed to landslides. This may result in increased vulnerability of the residents: rescue and evacuation difficulties, disruption of goods and services supply, disruption of exports, or a drop in tourism affecting local livelihoods are some of the examples. The combination of these factors coupled with the likelihood of landslides increasing in frequency and intensity over 2031-2060 due to climate change calls for a preventive resilience action plan. Steps to ensure that the informal sector is protected and has access to information and rescue resources are also critically important.

3.2 Floods

Risk level	High	Risk score	0.86
Impact of climate change:			
Increase in frequency	↑	Increase in intensity	↑

3.2.1. Overview

Floods have the second most severe effect on the city after landslides. The hazard risk matrix gave floods a score of 0.86 on a scale of 0 to 1. Based on basin-based hydrological modeling (HEC HMS and HEC RAS) applied to Baguio, the total area exposed to flood of 2, 25, and 50-year return periods (1981-2010) reaches 1.21 km^2, 1.45 km^2, and 1.49 km^2 (Figure 27). Over the intermediate future (2031-2060), under RCP 4.5, the area exposed to flood for the selected return periods is likely to increase by 38, 36, and 36%. respectively under RCP 8.5, it is likely to increase by 22, 27, and 26% respectively.

However, this analysis does not reflect exposure to urban flooding, related to the city's natural and artificial drainage channels, which drain rainfall flows. An analysis of flood instances for the period 2015-2021, based on data provided by the municipality and digitized in GIS, showed that a number of flood locations lie outside watersheds. This leads to concluding that the primary cause of these flood instances is expanded built-up areas, which disrupted the natural drainage pattern of the city, coupled with an artificial drainage system insufficient to cover for the city's needs. The city would hence highly benefit from running an urban hydraulic and hydrodynamic modeling, such as the Storm Water Management Model (SWMM), once required data has been collected, to better understand its present and projected flood patterns.

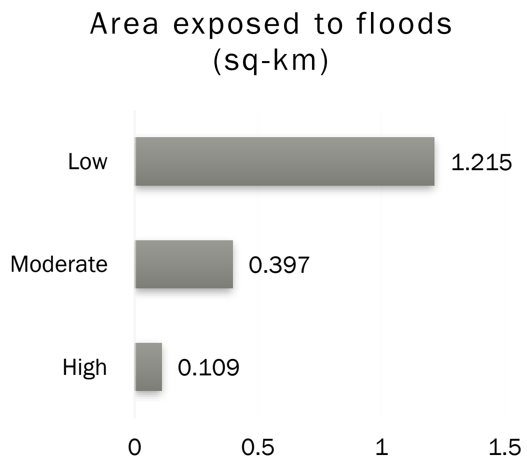
As per basin-based hydrological modeling (HEC HMS and HEC RAS):

- 2.6 % of the city has low flood exposure
- 0.52 % has moderate flood exposure
- 0.01 % has high flood exposure

However, taking into consideration proximity to flood incidences:

- 25.2% of the city has high exposure
- 23.2% has moderate exposure
- 19.6 % has low exposure

Floods also act as a **triggering factor to landslides**, enhancing the overall Baguio's exposure to these two natural hazards combined. Four primary rivers (Balili, Bued, Galiano, and Ambalanga) flowing through the city cause scouring effects on the slopes, making them unstable during peak flows.



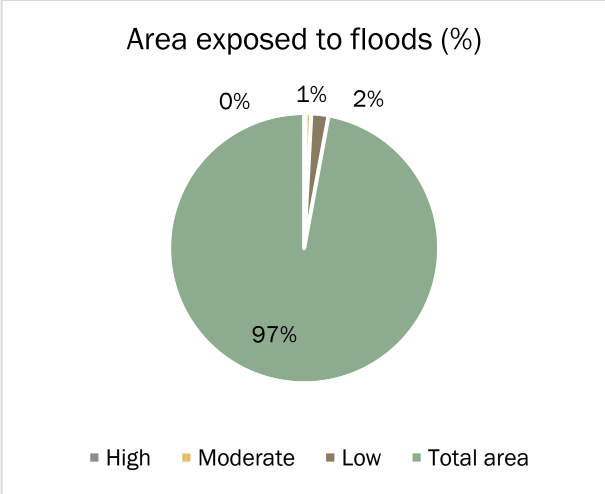


Figure 27: Area exposed to floods, in sq.km.
Source: Author

3.2.1.1 Flood Triggering Factors

Several factors make the city prone to the flood hazard:

- **Rainfall and typhoons.** The city receives the highest annual precipitation in the Philippines, triggering peak flows into rivers and causing floods. Flood inducing rainfalls mostly occur during monsoons, however peak flows are also associated with heavy rainfalls during typhoons. The city lies in the **typhoon belt** and receives an average of five tropical cyclones a year. Typhoon Pepeng brought an intense rainfall (over 1,000 mm at various locations), causing 97 landslides and 41 flood events (World Bank,2011; 2020 (Paringit, 2020). It reported 62 cyclone-induced flood incidents between 2015 to 2021.

- **Rapid and unregulated urban development.** Flood exposure gets further enhanced with encroachments into flood plains and land use change from green ecosystems into impervious open or built-up spaces, both triggered by a rapid, and at times unregulated, urban development. Impervious layers obstruct the water flow, decrease the percolation rate and lead to large runoff generation causing prolonged inundation of low-lying areas.

- **Insufficient drainage system.** A number of natural drainage channels have been disrupted by urban development, and artificial drainage does not fully cover the city's drainage needs. Drainage channels' functionality gets affected by clogging. As a result, flooding in city's low-lying areas is usually short-lived; however, when unusual amounts of precipitation associated with typhoons occur, the inundation period gets extended.

- **Elevation (DEM) and slope**, Baguio lies within the Cordillera Central Mountain range, and has an elevation varying between 900 to 1,600 meters. Lower elevation regions are relatively more exposed to inundation than those located on higher terrains. Similarly, gentle slopes have high exposure to flooding due to the scope of water retention in the flatter terrain between ridges.

3.2.1.2 Climate Change Impact on Flood Hazard's Frequency and Intensity

The following section includes the evaluation of climate change impact on rainfall. The changing rainfall trend has been used to develop a basin-based hydrodynamic model. The model identifies the area exposed to rainfall-induced floods in Baguio.

a. Climate Change Impact on Future Rainfall

As per the hydraulic and hydrodynamic analysis, the rapidly changing climate will result in a noticeable **rainfall increase** in Baguio over the intermediate future period 2031-2060 compared to the baseline period 1981–2010. Climate modeling was performed with RCM and bias-corrected. For this purpose, future daily rainfall data (under RCP scenarios 4.5 and 8.5) was generated from an ensemble of RCM and bias-corrected through the delta bias correction method based on observed rainfall data—Baguio meteorological station, which was provided by Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The outputs differ from the CCA report, which utilized AgERA5 reanalysis data for the baseline period since data from PAGASA was not yet shared with the ADB team back then.

The applied climate modeling identified that, while the city received an average annual rainfall of 3,875 mm between 1981–2010, it is likely to rise by as much as 21% under RCP 4.5 and 26% under RCP 8.5 scenarios (Table 18) over 2031—2060.

	Baseline (1981-2010)	RCP 4.5	Change	RCP 8.5	Change
Annual rainfall, mm	3,875	4,697	833 (21%)	4,895	1,019 (26%)
Wet season, mm	3,564	4,336	771(22%)	4,506	942 (26%)

Table 18: Changes in rainfall, Baguio
Source: Author

In addition to an increasing annual rainfall trend, the **monsoon (May to October) trend is projected to increase** compared to its historical in terms of timespan, frequency, and intensity:

- Over 1981—2010, the monsoon season registered a maximum multi-year mean monthly precipitation level of 933 mm in July and 788 mm in August. However, the highest precipitation increase for 2031—2060 is projected to happen in October and November, by 61% and 124% under RCP 4.5 and by 66% and 99% under RCP 8.5 respectively, which is a noticeable increase. Conversely, a significant decline in precipitation is projected for January and February, by 16% and 48% under RCP 4.5 and by 24% and 51% under RCP 8.5 respectively.

- The rainfall peak is projected to remain in August, although it will face a **significant interannual variability** ranging between 288 mm and 2,240 mm under RCP 4.5, and 315 mm and 2,502 mm under RCP 8.5. Precipitation variability was also high during the reference period, but the selected future period will face higher extremes.

- The annual number of days with heavy precipitation (R10mm) is projected to increase by 5 days under RCP 4.5 and 6 days under RCP 8.5. However, the days with very heavy precipitation (R20mm) are projected to increase by 5 days under RCP 4.5 and 6 days under RCP 8.5. The increase in days with extreme precipitation will rise by 4 days under both RCPs.

- As heavy rainfalls are one of the key flood triggers in Baguio, the changing trend in the number of rainy days will be a critical point in disaster-resilient planning. The projected increase of 39% and 112% in an annual maximum 1-day precipitation under scenarios RCP 4.5 and RCP 8.5, respectively, shall enhance the threat of **flash floods** in the city.

b. Climate Change Impact on the Frequency and Intensity of Baguio Floods

UNICITI conducted basin-based hydraulic and hydrodynamic modeling (HEC HMS and HEC RAS) to assess the projected impact of climate change on the riverine flood hazard in Baguio. This flood risk was assessed for the intermediate future period of 2031-2060 compared to the historical period of 1981–2010.

Using bias-corrected rainfall as input in HEC HMS, discharge was simulated at six different watersheds (North HM, South HM, East HM, West1st HM, West2nd HM, and West 3rd HM) identified taking into consideration the city's natural topography and hydrologic properties. Based on the outputs of the modeled discharge, HEC RAS model was applied to simulate 2D flood depth.

HEC RAS 2D performs well for riverine floods. Baguio City is highly urbanized, which disturbed natural water flow in many locations. HEC RAS is not designed to simulate urban floods, which includes parameters such as built-up areas, flood plain encroachments, as well as detailed artificial and natural drainage information. UNICITI team attempted running an urban model—the SWMM—however the drainage data provided by the municipality did now allow running SWMM model with valuable outputs.

Considering that the HEC RAS model did not capture urban floods, the present analysis combines outputs of HEC RAS with mapped flood instances documented by the municipality (Figure 28). While the latter does not include climate change and is based on historical 2015—2021 data, it shows where urban floods are taking place and where they are likely to intensity if measures are not taken.

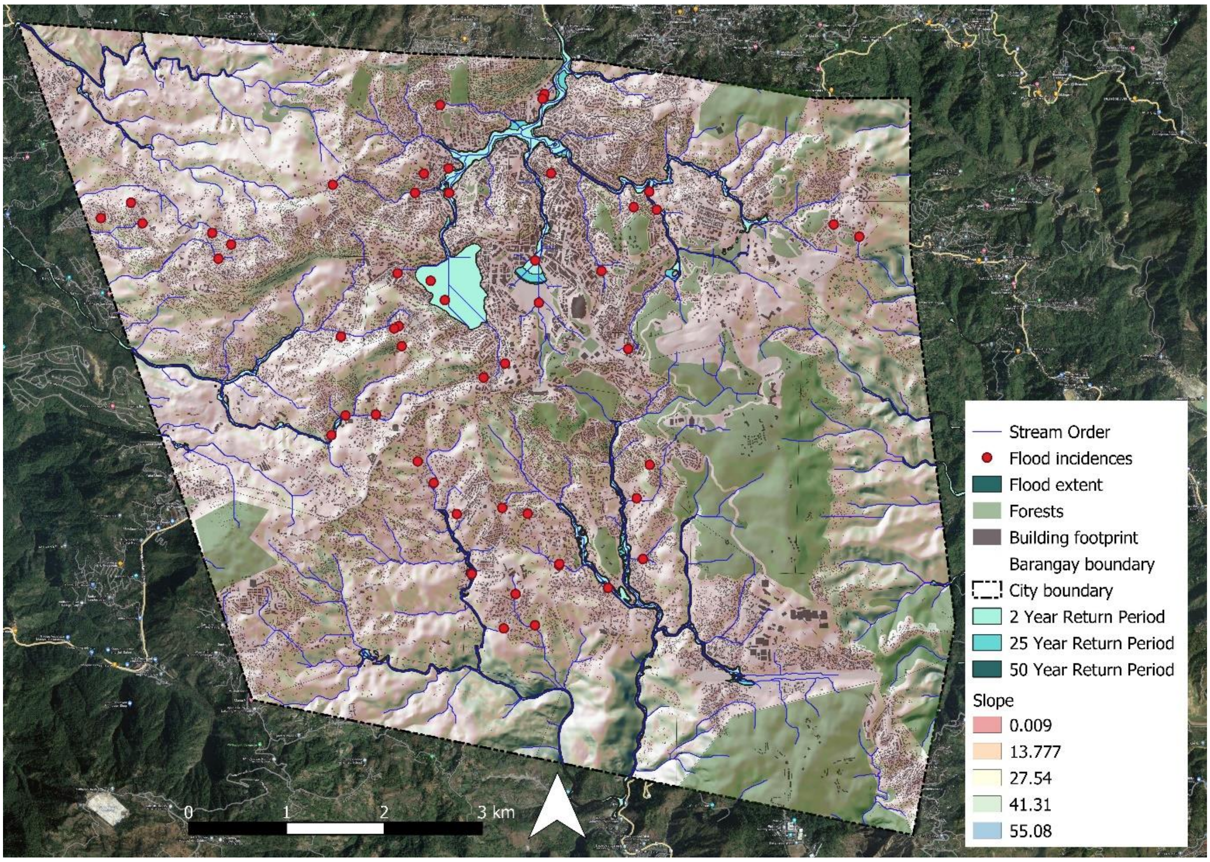


Figure 28: Flood return period and past flood incidents map of C
Source: Author

The HEC RAS model identifies flood exposure as 2, 25, and 50-year return periods. Higher return periods are related to infrequent flood events, hence the population and the authorities are usually less prepared to handle or accommodate this situation. The flood exposure therefore increases with the longer flood return periods. The present assessment covered three return periods 2-year, 25-

year and 5—year. The spatial extent of each given return period utilized in the resent report was obtained by merging spatial extents of both the RCP scenarios. The GIS project shared with the municipality allows looking at each RCP map separately.

Simulated flood extents increase from the historical to the future period in all the six catchments. The total flood area (sum of all watersheds) increases by 36 to 38% under RCP 4.5 and by 22 to 27% under RCP 8.5, respectively for 2, 25 and 50-year return periods. Under RCP 4.5, the highest increase occurs in the south watershed, followed by the North, West 2nd, East, West 3rd and West 1st. The flood extent for the south watershed in projected to increase by 77 to 81%; North by 32 to 38%, and West 2nd by 17 to 25%. The smallest increase is projected to occur in West 3rd, by 6 to 12%. The areas that have high increment in flood extent are exposed to higher flood risk.

Return period in years	Period	Flooded area in km² and changes of the flooded area in % for the given catchment						
		East HM	North HM	South HM	West 1st HM	West 2nd HM	West 3rd HM	Total
2	Historical (km²)	0.163	0.590	0.241	0.074	0.109	0.014	1.191
	RCP 4.5 (km²)	0.175	0.813	0.437	0.079	0.128	0.015	1.647
	RCP 8.5 (km²)	0.169	0.810	0.256	0.077	0.128	0.015	1.455
	RCP 4.5 (%)	7	38	81	7	17	7	38
	RCP 8.5 (%)	4	37	6	4	17	7	22
25	Historical (km²)	0.197	0.735	0.286	0.087	0.131	0.017	1.453
	RCP 4.5 (km²)	0.218	0.976	0.509	0.097	0.164	0.018	1.982
	RCP 8.5 (km²)	0.219	0.996	0.338	0.104	0.164	0.019	1.840
	RCP 4.5 (%)	11	33	78	11	25	6	36
	RCP 8.5 (%)	11	36	18	20	25	12	27
50	Historical (km²)	0.202	0.758	0.296	0.090	0.135	0.017	1.498
	RCP 4.5 (km²)	0.227	1.000	0.524	0.101	0.171	0.019	2.042
	RCP 8.5 (km²)	0.227	1.022	0.347	0.108	0.171	0.019	1.894
	RCP 4.5 (%)	12	32	77	12	27	12	36
	RCP 8.5 (%)	12	35	17	20	27	12	26

Table 19: Catchment-wise flood extent for 2, 25, and 50-year return period
Source: Author

The urban flood instances were georeferenced by the UNICITI team based on the list of flood instances occurred in 2015, 2016, 2018, 2019, 2020, and 2021 shared by the municipality. Buffers of 50, 100 and 150m from past flood incidents were taken into account to analyze the exposure of infrastructure based on proximity (John-Nwagwu, Edith, & Hassan, 2014).

By combining flood buffers and 50-year return periods (under RCP 4.5 scenario), 8.3% of total Baguio City surface is involved (it corresponds to 4,766.000 sqm) and this data needs to be linked to the location of the different categories of services and infrastructure to understand the exposure level of the different urban sectors.

Natural drainage or the stream order was extracted using the Digital Elevation Model (DEM). A large number of buildings and essential infrastructure lie within the proximity of these flood-prone areas (29). The city hence requires interventions to protect these areas from floods.

Considering the limitation of basin-based hydrodynamic modeling for Baguio City as explained above, this section utilizes a mix of HEC RAS outcomes and of 2015-2021 flood instances observed by the city.

3.2.1.3 Flood Hazard Assessment

Floods

Category	Sub-category	Weight (w_1)	Indicator	Assigned Value (v)	Weight (w_2)	Weighted value ($v_w = w_2 \times v$)	($w_1 \times v_w$)	Score
Frequency of hazard occurrence (f)	Historic evidence (a)	0.5	Likely to occur annually	4	0.25	1.00		
			Likely to occur several times per decade	3	0.25	0.75	0.38	
			Likely to occur once a decade	2	0.25	0.50		
			Likely to occur once in 50 years or more	1	0.25	0.25		0.87
	Climate change assessment (b)	0.5	Likely to increase by 2030 (immediate)	3	0.33	0.99	0.50	
			Likely to increase by 2060 (short-term)	2	0.33	0.66		
			Likely to increase by 2100 (long-term)	1	0.33	0.33		
Severity of damages (s)	Fatalities (a)	0.33	Death ≥10	3	0.33	0.99	0.33	
			Death <10	2	0.33	0.66		
			Injuries or health hazards	1	0.33	0.33		
	Infrastructure damages (b)	0.33	Damage to infrastructure or disruption of services	2	0.5	1.00	0.33	0.987
			Other damages	1	0.5	0.50		
	Climate change impact (c)	0.33	Damages will increase	1	1	1.00	0.33	
							Risk score	0.858

Table 20: Risk score calculation for flood hazard
Source: Author

In the hazard risk matrix, flood hazard emerged as another most severe natural hazard affecting Baguio. Overall, it scored 0.86 on a scale of 0.01 to 1.00, where the frequency of flood occurrence was 0.87, and the severity of associated damages was 0.99 (Table 20).

3.2.2 Flood Sectoral Exposure Assessment

The CBD concentrates major economic and business-related activities, and is expected to face the highest flood exposure under climate change scenarios RCP 4.5 and 8.5 as per the HEC HMS / HEC RAS outputs, which is likely to have a higher impact of the CBD activities over 2031—2060 compared to today. Strategic flood prevention efforts are primarily required in this city area.

3.2.2.1 Infrastructure Sector Exposure to Floods

a. Essential Buildings

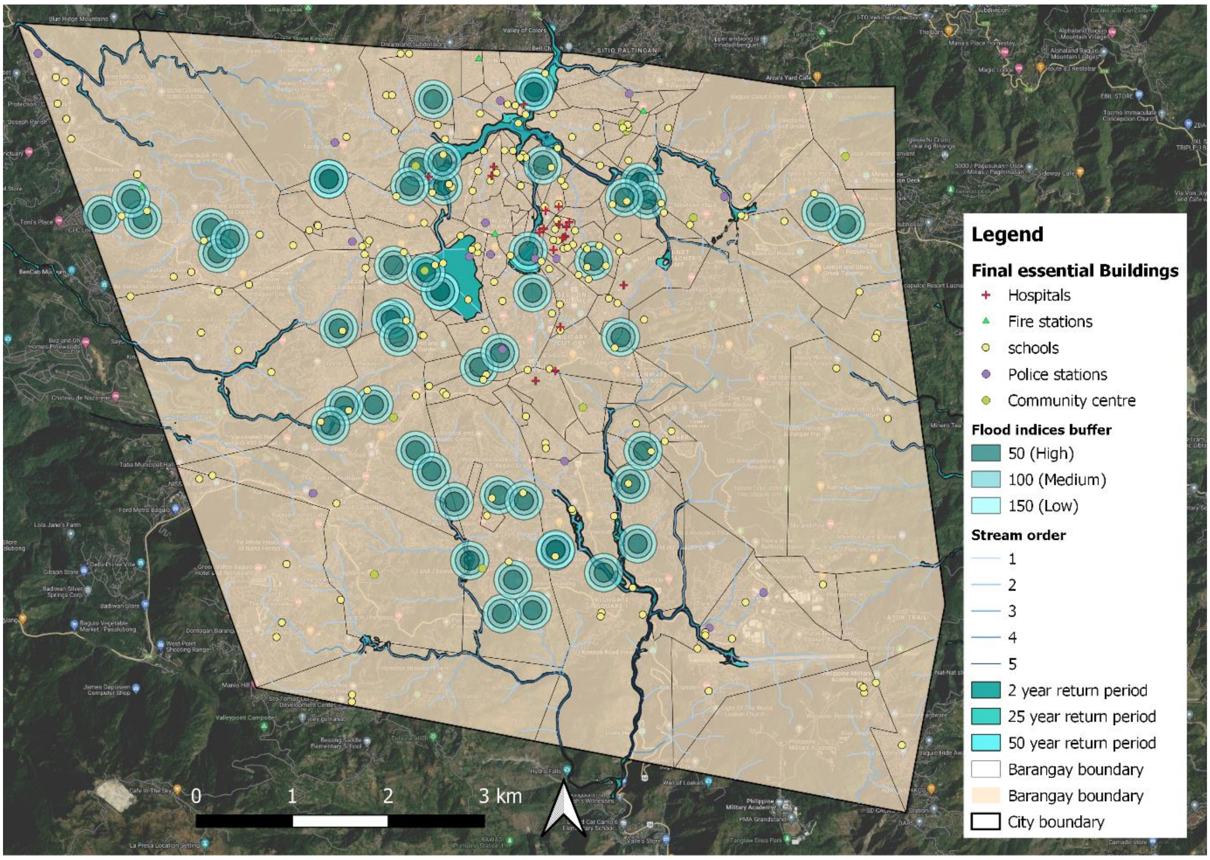


Figure 29: Flood extent and location of essential buildings in Baguio
Source: Author

Essential buildings include community centers, hospitals, schools, fire stations, police stations, and rescue stations. Figure 8 showcases the location of these buildings in the backdrop of the flood extent map, past flood incidences, and the natural drainage pattern of Baguio. Two key learnings derive from this overlay:

- City's hospitals are concentrated in the flood-prone CBD area, which is potentially affecting their accessibility during floods. Hospitals may also find it challenging to provide regular treatments due to increased patient admissions and failure of related infrastructure such as power supply, solid waste management, and road infrastructure (Pant, Thacker, Alderson, & Barr, 2018).
- A number of schools are located in the flood instances buffer areas in the west of the city. Since these are urban floods, it is essential to look into stormwater draining solutions in these areas to avoid future water logging and a consequential malfunctioning of the exposed schools. In addition to material damage, a study demonstrated that flooding in schools may result in in school dropout and absenteeism (Munsaka & Mutasa, 2020).
- In addition, a number of academic buildings, such as Christian Legacy Academy, Casiciaco Recoletos Seminary, Living Epistle Christian Academy, or San Pablo major Seminary have been affected by flooding as per the records. Baguio being a renowned educational center, a large number of students reside in the city and a number of student hostels are located within the exposed CBD area.

b. Transportation

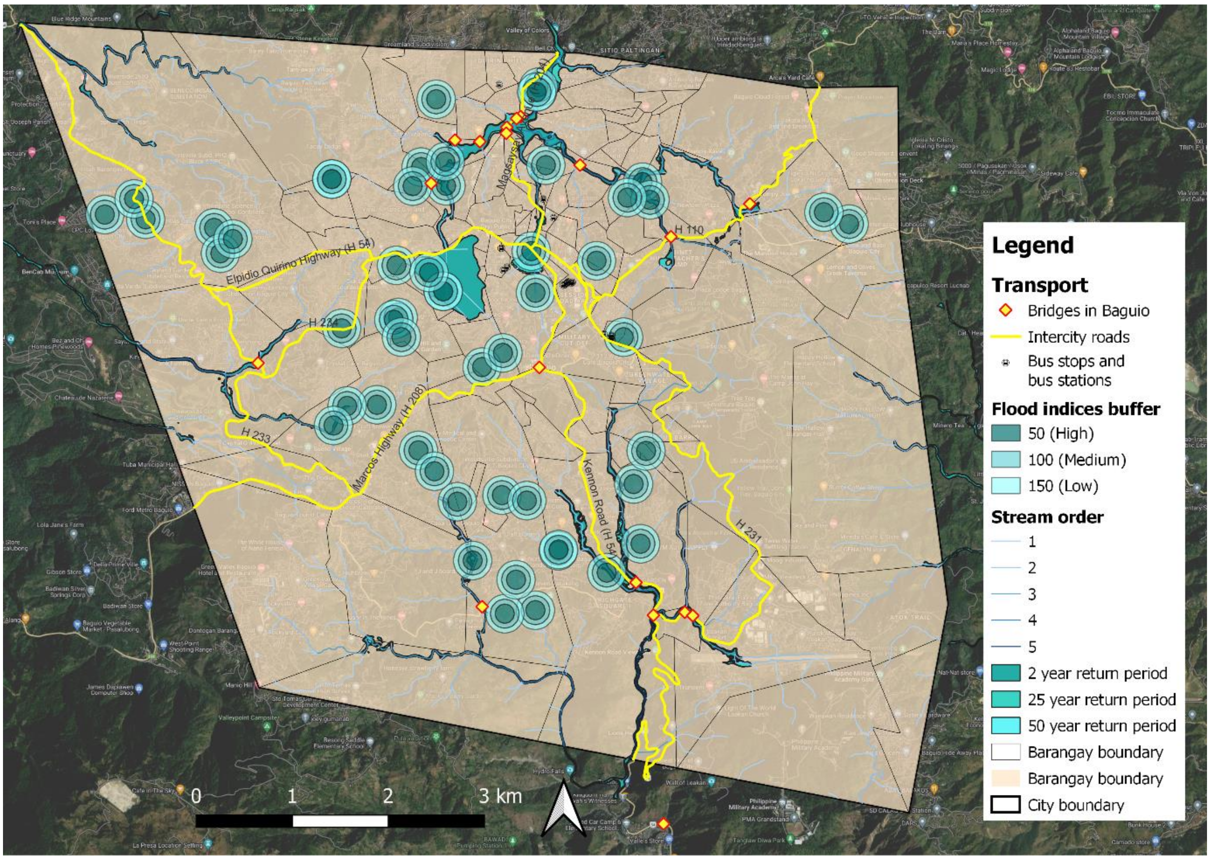


Figure 30: Transportation sector's exposure to floods
Source: Author

A number of intercity road axes cross Baguio and play a key role in maintaining tourism as well as in provisioning goods to the city and to cities north of Baguio. Highway 54 (in northwest), 204 (in north), 208 (in west), and 110 (in northeast) are primary connections for intercity movements. The **intersection point between Elpidio Quirino Highway, H110, and H231** (from Figure 30) lies within in 2-year flood return period, hence will have frequent exposure to flooding.

Several **bridges** are located at critical junctions that facilitate intercity movements: Asin Road Bridge, Magsaysay West Flyover, Manuel Roxas Bridge, and Rimando Bridge. Their flood exposure may hamper the tourist movement between Baguio and Manila as well as other cities located North of Baguio. Bridges are also critical for evacuation and rescue missions in case of emergency. Exposure of these critical junctions may jeopardize safety during hazards. (Helderop & Grubesic, 2019)

Several intracity roads also lie within the exposed to floods zone. Most exposed intracity roads lie in barangays Alfonso Tabora Asin road, Bakakeng Central, Cabinet Hill, Camp 7, Camp Allen, Camp Filipino, City Camp Central, Country Club Village, Cresencia Village, Dominican Hill Mirador, Dontogan, Happy Hollow, Holy Ghost Extension, Irisan, Kangitingan, Liwanag-Loakan, Loakan Proper, Magsaysay lower, Padre Zamora, Rock Quarry Middle, Rock Quarry Upper and Teodora Alonzo.

As the city continues its socioeconomic growth, roads need to be preventively secured from future floods over 2031—2060 to secure an uninterrupted city functioning.

c. Water Supply and Management

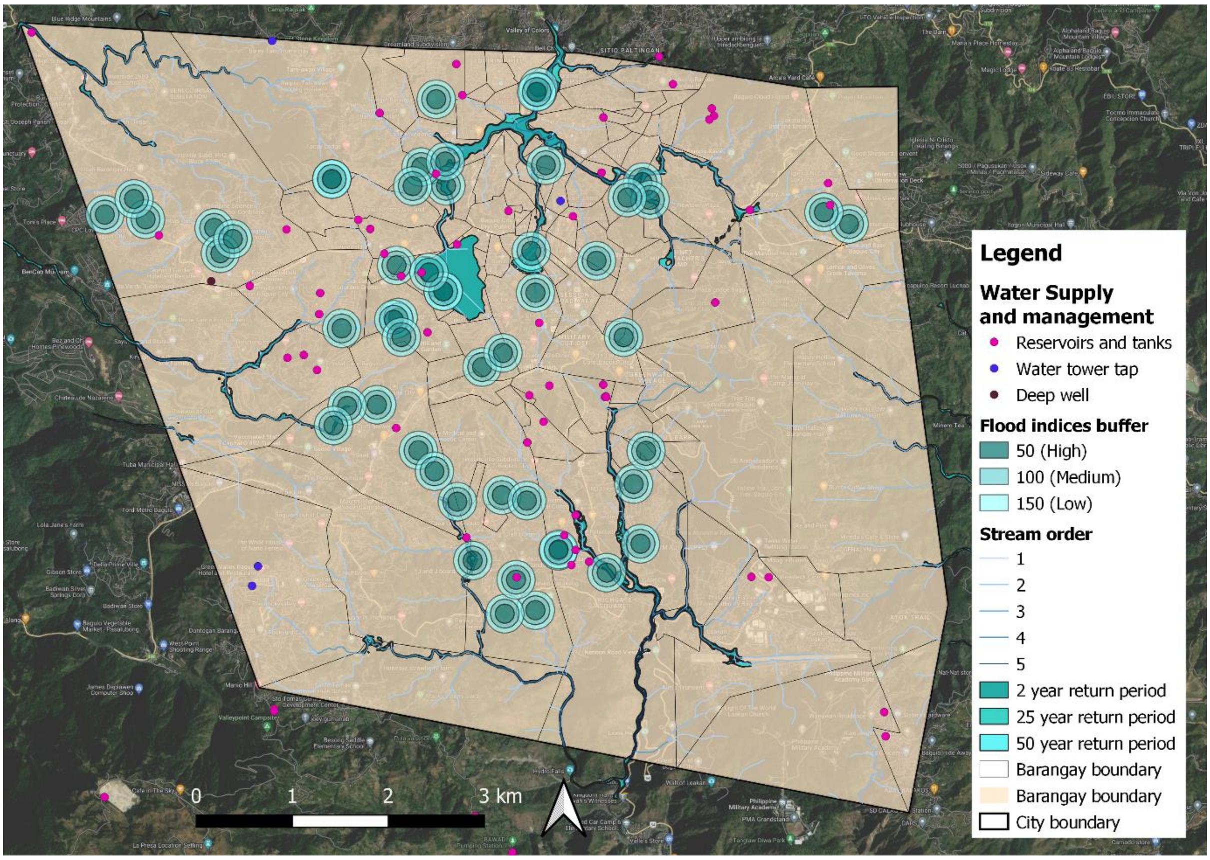


Figure 31: Water supply and management's sector exposure to floods
Source: Author

Groundwater meets over 90% of the city's water demand. BWD manages water supply in 125 barangays out of 129. Protecting deep wells from damages related to natural disasters, including floods, is hence crucial for maintaining an operational water supply in the city.

Nearly 22 reservoirs and tanks are located within an average distance of 300 m from past flood incidents (Figure 31). The proximity of water sources to flood water is alarming as it increases the chance of potable water sources contamination with microorganisms, chemicals, and organic substances that can cause serious health issues (Sun, et al., 2016) (Arrighi, Tarani, Vicario, & Castelli, 2017). Flood water damages the water supply infrastructure due to siltation, corrosion, and blockages, which may result in insufficient supply of safe drinking water in the city.

d. Wastewater Management (Drainage and Sewage)

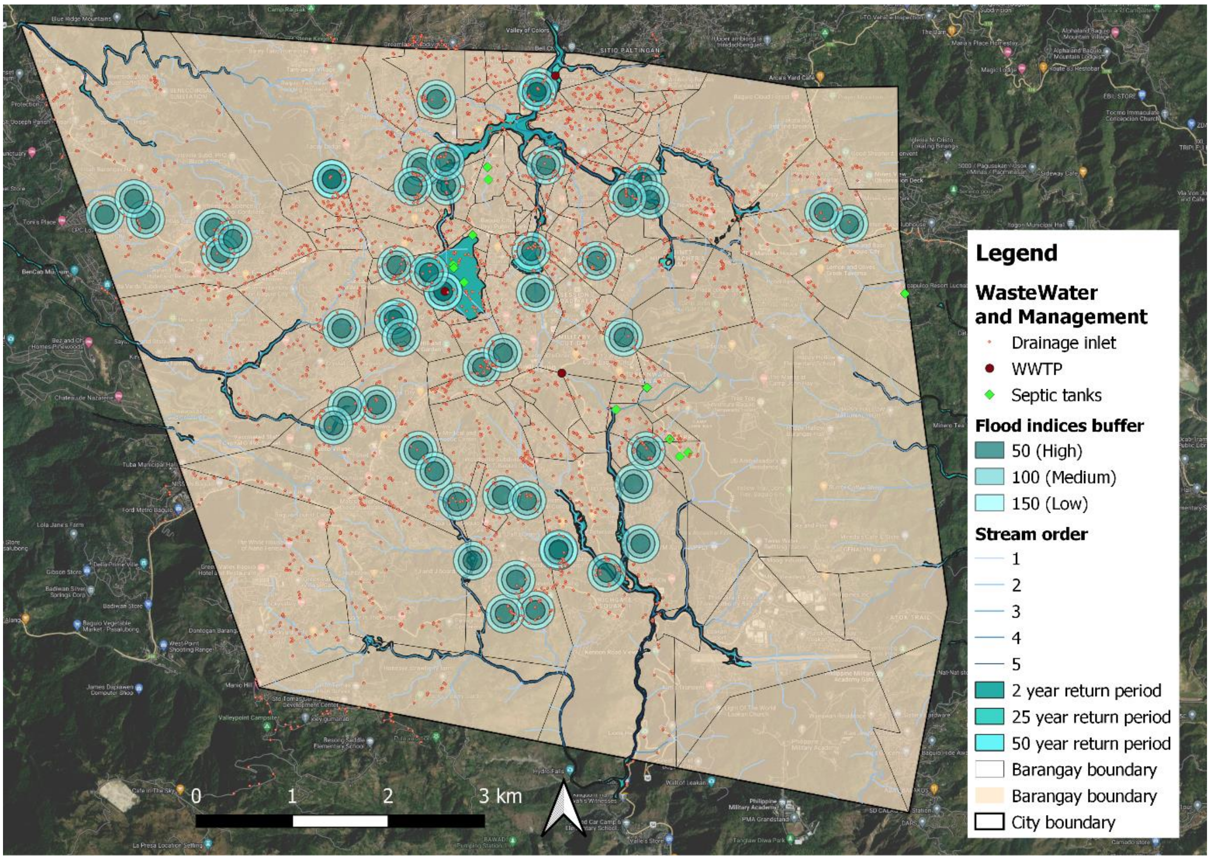


Figure 32: Flood exposure of wastewater management sector, Baguio
Source: Author

Baguio has nearly 2,500 drainage inlets, however the location of flooding incidents points to an insufficient artificial drainage capacity to timely offload stormwater and avoid flooding. This capacity is further reduced by siltation and blockages due to the movement of debris during floods. This can cause prolonged water logging, mosquito breeding, and the spread of vector-borne diseases.

Sewage treatment facilities have a noticeable exposure to floods. Five out of eight septic tank locations coincide with the 2-year flood extent boundary. Two of the three wastewater treatment plants (WWTP) coincide with the flood extent. Floods rarely damage septic tank since they are located below the ground and are completely covered. However, flood water can cause blocking due to silts that may cause gray water to overflow in the areas around the tank (Albertin, 2018).STPs face a high exposure since they are commonly located near a waterbody. The rise in runoff due to increased rainfall intensity and imperviousness in Baguio can hence affect the STP efficiency (Zouboulis & Athanasia, 2014).

e. Solid Waste Management

Baguio City currently has no operational landfill within its boundaries. In relation to floods, two matters need to be monitored:

- Solid waste clogging natural and artificial drains makes the drainage system less efficient at times of heavy rainfalls because it slows down the water runoff. This matter was particularly identified as an issue in low-lying informal settlements;
- Rainfall-induced landslides cause solid waste such as debris and tree trunks to flow into drainage inlets and clog them up, which causes flash floods.

Effective solid waste management in the above two areas will improve the existing drainage system's efficiency.

3.2.2.2 Social Sector Exposure to Floods

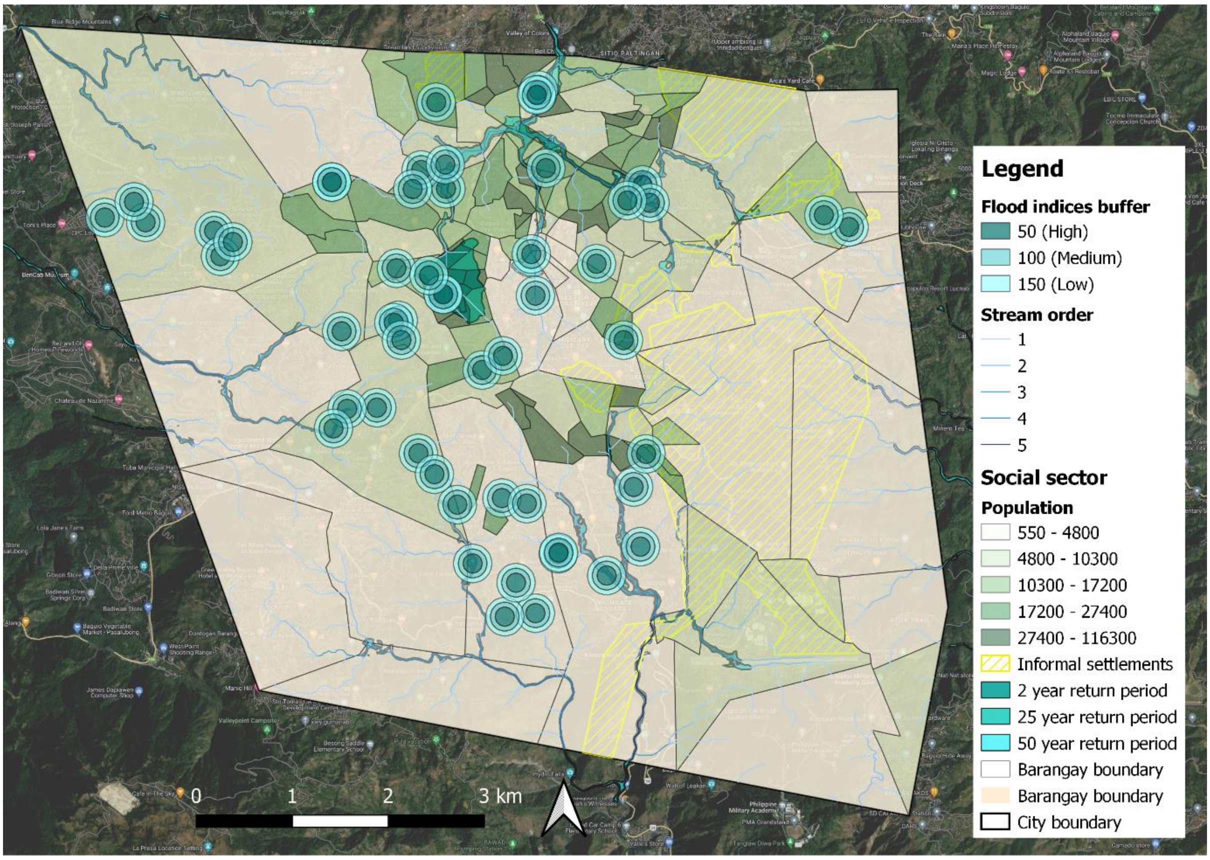


Figure 33: Population's exposure to floods
Source: Author

Over 44% of Baguio's population faces exposure to frequently occurring floods (Figure 33). Sanitary Camp South is the highest densely populated barangay prone to a 50-year return period flood. It is followed by other barangays such as Alfonso Tabora, Brookside, City Camp Proper, Gabriela Silang, Holy Ghost Extension, Kayang Extension, Poliwes, New Lucban Quirino Hill, and Rock Quarry Upper, with densities of more than 30,000 people per km^2 and high flood exposure.

Camp 7 barangay has 4% of the territory subject to a 2-year return period flood, 2% to 25-year, and 1% to 50–year return periods. However, the population density being as low as 670 people per km^2 reduces the overall human exposure of the barangay. Similar is the case of Happy Homes, Irisan and Malcolm Square-Perfecto.

City Camp Central and Palma Urbano have the highest exposure in terms of surface: they are entirely located within a 2-year flood return period, which means they are facing frequent floods and will be facing more frequent ones over 2031—2060. They are followed by MRR- Queen of Peace, Lourdes Subdivision (Extension and Lower), City Camp Proper, with flood-prone areas varying between 50%and 95%.

Informal settlements have been growing in Camp 7, Country Club Village, Dagsian (Upper-Lower) Greenwater village, Happy Hollow, Liwanag-Loakan, Macroville and South Drive (Figure 34). The total area under informal settlements, as per available data, comprises 14% of the Baguio City. These settlements lack basic municipal services such as water and sanitation infrastructure (ADB, 2021). This situation can have a detrimental effect on the health of residents during floods. The city plans to develop resilient and sustainable communities and is currently finalizing the Luna Terraces project, which will offer 260 affordable residential units (PIA, 2022).

3.2.2.3 Economic Sector Exposure to Floods

Natural hazards such as floods have both a direct and an indirect impact on a city. The economic sector often faces an indirect impact, such as a reduced tourism activity until a direct impact of floods is addressed, or a slowdown in commerce and industrial services due to a disruption of regular traffic. These impacts are looked at in the present section.

a. Tourism

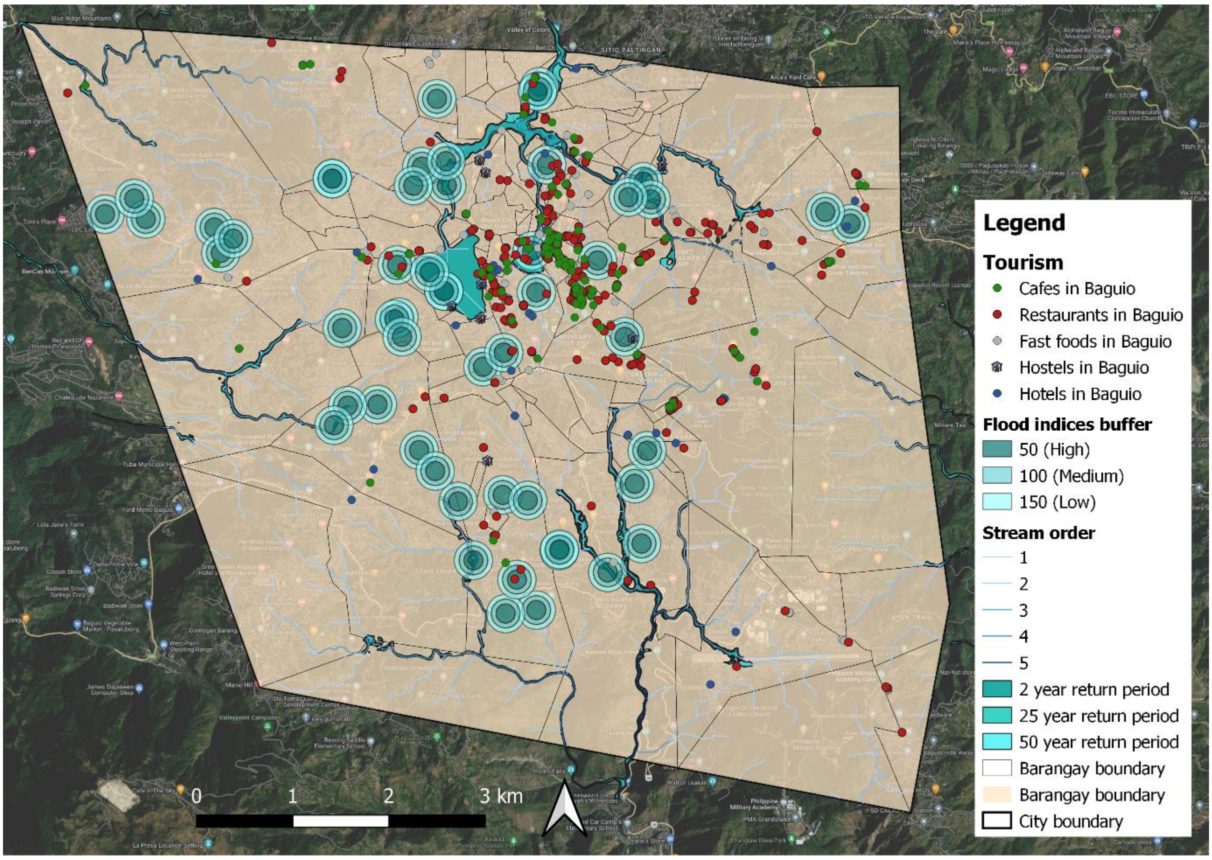


Figure 34: Flood exposure of economic sector of Baguio
Source: Author

Baguio is a summer capital of the Philippines for its scenic beauty and thermal comfort. The CBD area hosts the highest concentration of tourism-related infrastructure. Since the CBD is a highly exposed to floods area, 30 out of the city's 37 hotels are within an average of 200m to flood instances. Almost all the fast food centers are also located within an average distance of 200m to frequently flooded areas. Restaurants such as Bulaluhan, Beggang, Bonabil Diner, Café Veniz, Don Henricos, Food N' Spice, Gereck's Eatery, Hap Chan, Kashmiri Biryani Café, Lyn's Transient House, New Ganza Restaurant, St. Martin's Breadhouse, 45 Restaurant, coincide with the location of a 2-year flood extent and past flood occurrences in Baguio. Porch Lechon and Batchoy Hans face a high flood exposure due to their proximity to the Bued River. The area is known for boating and other recreational activities.

b. Heritage and Culture

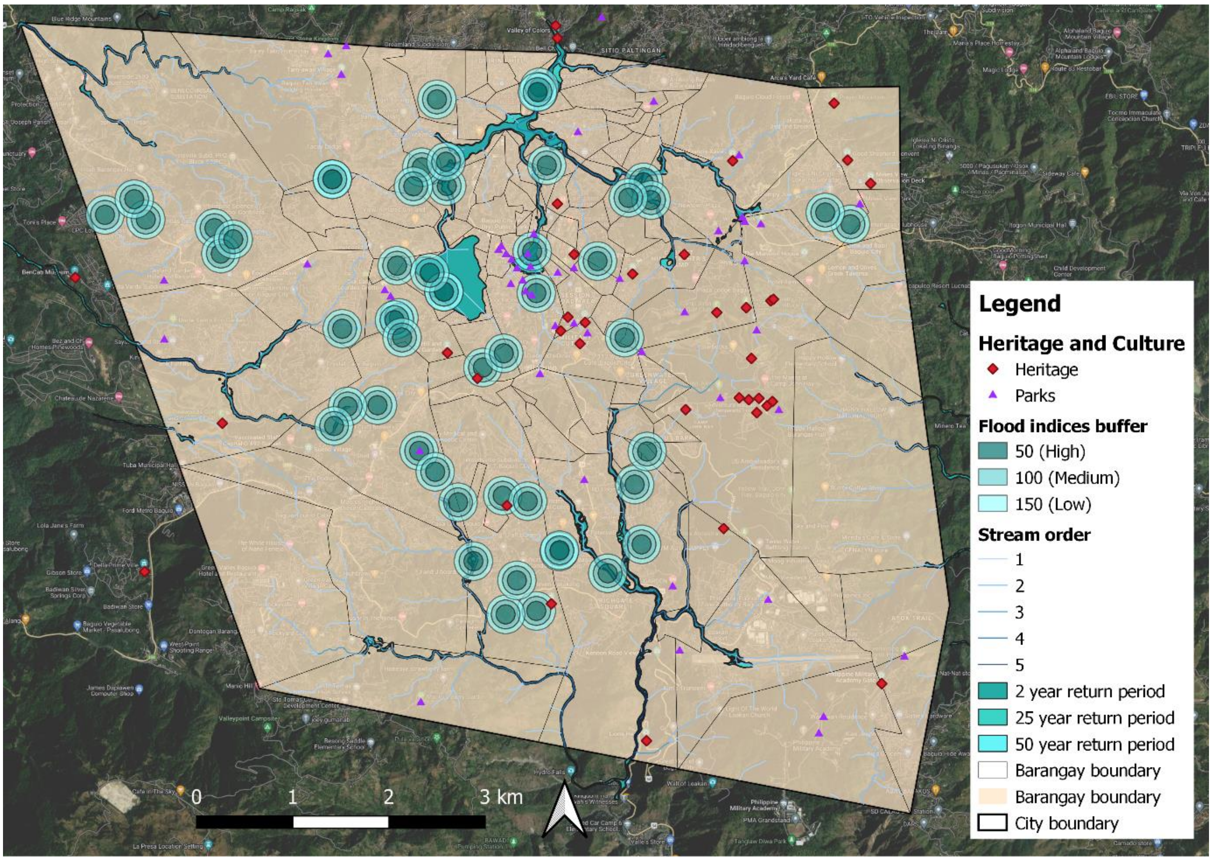


Figure 35: Flood exposure of heritage and culture sector, Baguio
Source: Author

Figure 36: Burnham Park; Burnham Park during cyclone Manghur (left to right)
Source: (Cruz, NA), (Magalong, NA)

Burnham Park a center of festivities and celebrations in Baguio City (Estoque & Murayama, 2013). It is also one of the primary tourist attractions. The park coincides with all flood return periods: 2, 25 and 50-year (Figure 36). Similarly, the adjacent spaces near the park such as Baguio City market mini garden, Eco Park, Heritage Park, Maple tree park, Rigel's park, Sunshine park, Igorot garden either coincide with or are within an average proximity of 150m to frequently flooded areas. The presence of open spaces such as parks however reduces the overall flood exposure by increasing the percolation time for the excess runoff (Kim, Dong-Kun, & Sung, 2016).

Heritage areas such as Frageli house, Lion's head, Museo Kordilyera, Sky Ranch, SLU museum, Tetep-an Village and Teachers' Camp museum also lie within the flood exposure area. Heritage buildings and parks cumulatively add value to the tourism experience of Baguio, which may be threatened due to rising flood exposure in the city.

c. Commercial Assets

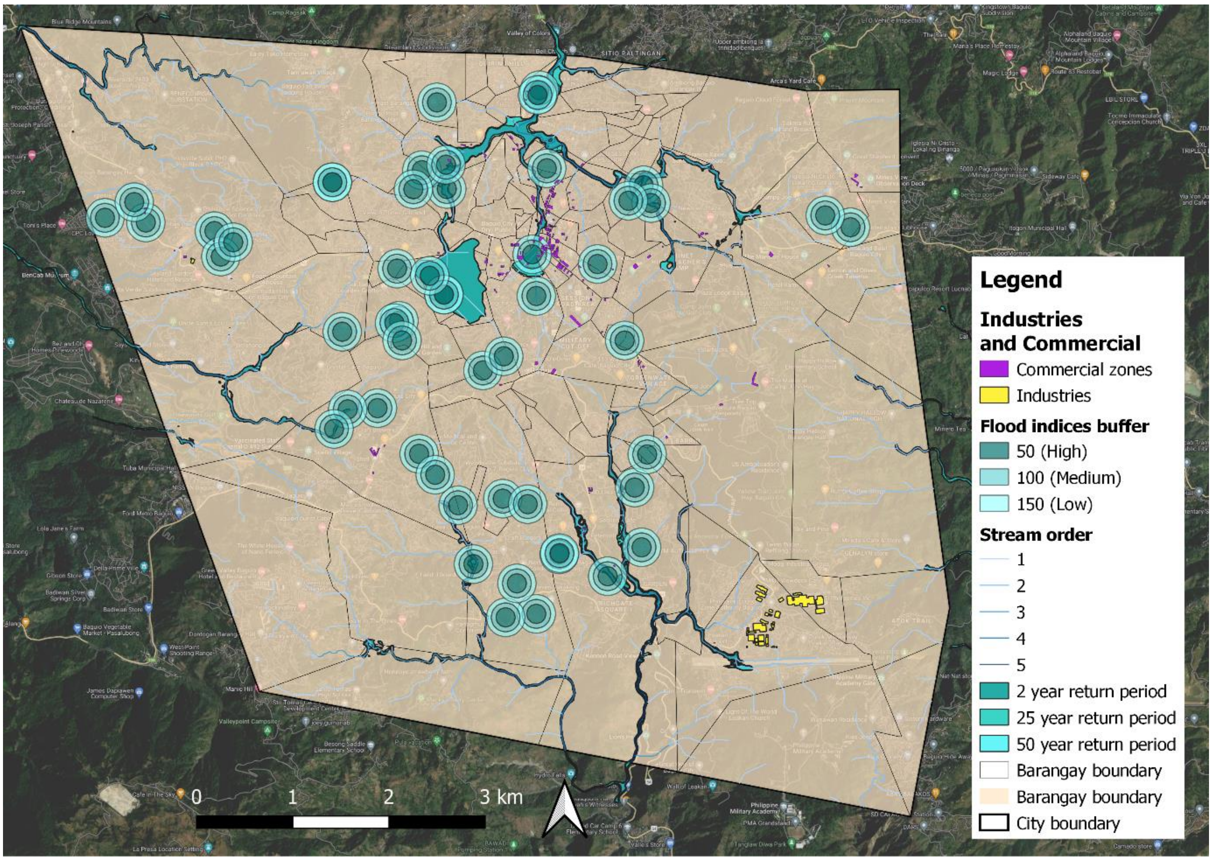


Figure 37: Exposure of Industrial and commercial sector Baguio
Source: Author

The majority of commercial establishments are located within a 100m distance to flood-exposed areas (Figure 37). A large section of the city's economy (over 85%) depends on these services. Hence, flood impact on these areas can detrimentally hamper these businesses by damaging equipment and belongings (Wedawatta, Ingirige, & Proverbs, 2014).

d. Industrial Assets

The industrial area of Baguio is an SEZ. It is located within 100m of flood-prone areas in the Southeast part of the city. While no exposure is foreseen based on historical or projected hydrological modeling outputs, it may occur in the future if the drainage system is not adapted to increasing city's activities and needs, which may slow down the city's economic growth (Sarmiento, 2007).

3.2.3 Conclusion

The city is anticipated to face an over 20% precipitation increase over 2031—2060, with an enhanced and prolonged rainy season. This means that both riverine and urban floods are likely to become more frequent and more intense, which will both affect areas already under the flood exposure more intensely and affect currently safe areas. To prevent these effects, it is equally important to revive the city's rivers and natural canals and to optimize as well as expand the city's artificial drainage system. Coupled with generating more permeable surfaces across the city, these interventions will help improve the water runoff during heavy rainfalls.

3.3 Earthquakes

Risk level	Moderate	Risk score	0.29
Impact of climate change:			
Increase in frequency	⬆	Increase in intensity	⬆

3.3.1 Overview

Earthquakes are commonly defined as the shaking of earth caused by waves moving on and below the earth's surface, and generating surface faulting, tremors vibration, liquefaction, landslides, aftershocks and/or tsunamis (WHO). They constitute another important geophysical risk for the city in addition to landslides. The National Structural Code of the Philippines (edition of 2010) placed Baguio City in the high-risk seismic zone. Indeed, over the 20th century, Baguio witnessed three devastating earthquakes and several minor tremors. The most devastating earthquake occurred on 16 July 1990, when a 7.7-magnitude quake damaged 28 buildings. Due to a lack of full preparedness, the event forced people to take shelter in parks, streets, and other open areas with no sanitary provisions.

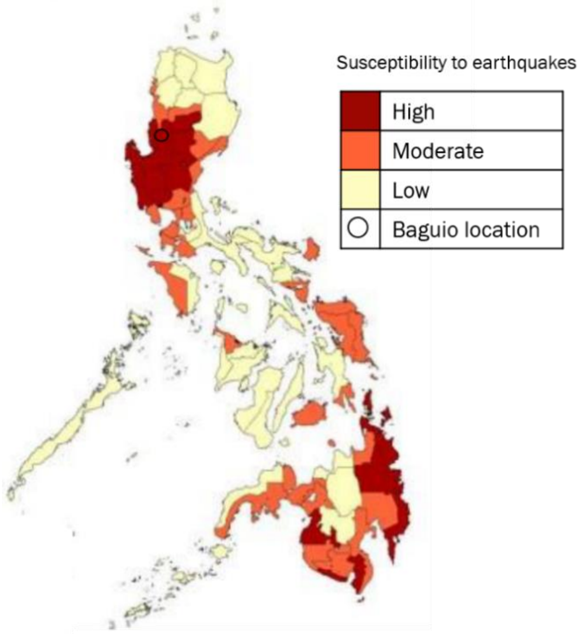


Figure 38: Earthquake exposure map, the Philippines
Source: National Structural Code of the Philippines

3.3.1.1 Earthquake Triggering Factors

Earthquakes may be of either a tectonic or a volcanic origin. A movement of seismic plates causes a tectonic earthquake and a movement of magma causes a volcanic earthquake. Baguio's earthquakes are tectonic, which causes ground shaking when the sides of two fault lines slip against each other. A fault is a fracture between two rocks allowing their relative movement.

The city has five fault lines within its boundary: Bued River fault Burnham fault, Loakan fault, Mirador fault, and San Vicente fault. A fault line is a fracture or discontinuity in the earth's surface, along which movement and displacement takes place. Faults in Baguio are not active, which means that they do not cause earthquakes in the city. However, these fault lines are the weak points from where energy releases during earthquakes. They are also associated with pronounced surface movements, such as landslides and displacements of earth.

Figure 39 shows active faults in the Cordillera region. Baguio's earthquakes are caused by three extra-territorial fault lines:

- The Dig-Dig fault passes at a distance of 40 km to the east of Baguio,
- The Tebbo fault in the southeast at a distance of 10 km, and
- The Tuba fault is at a distance of 5 km in the northwest.

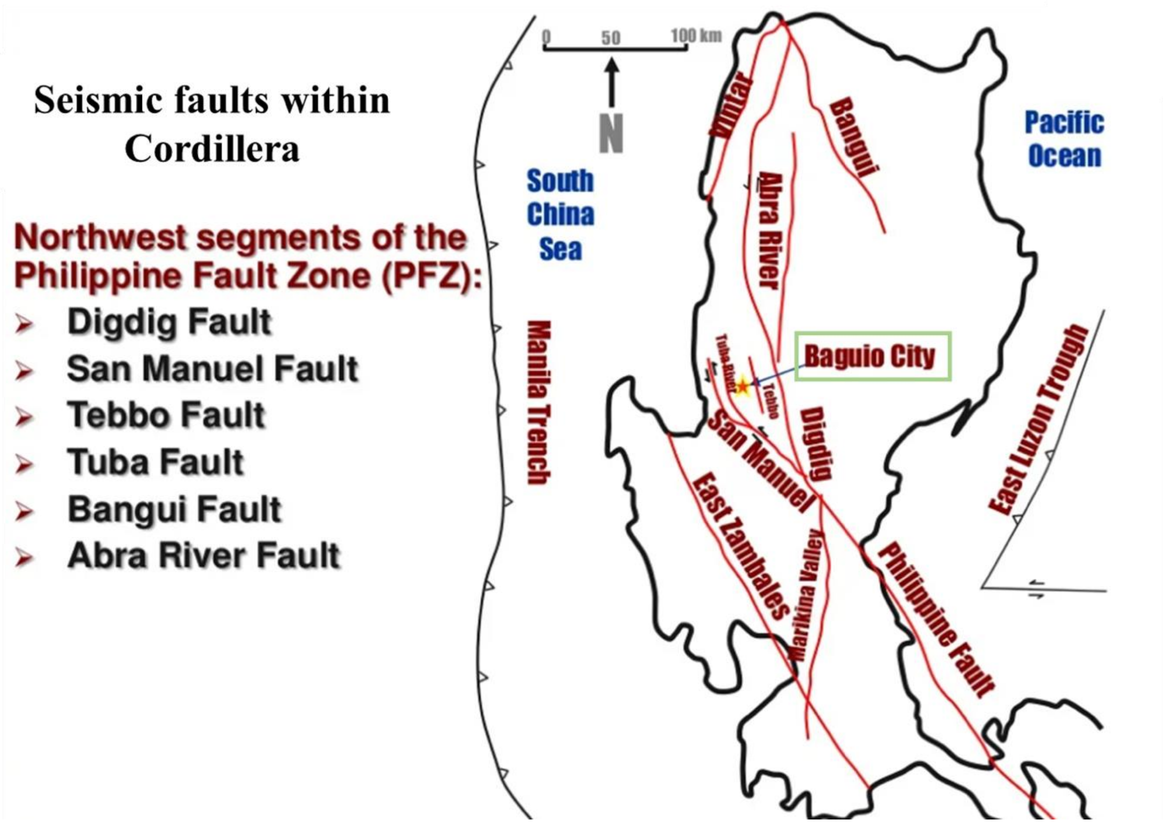


Figure 39: Active seismic fault lines in the Cordillera region, in close proximity to Baguio
Source: Phivolcs

Lateral shifting of these fault lines caused three major earthquakes in 1937, 1973 and 1975. Furthermore, the Philippine fault zone induced a devastating earthquake in 1990. The fault lines nearby and within the city make Baguio classified in the seismic zone IV which, by international standards, is equivalent to a high-risk zone.

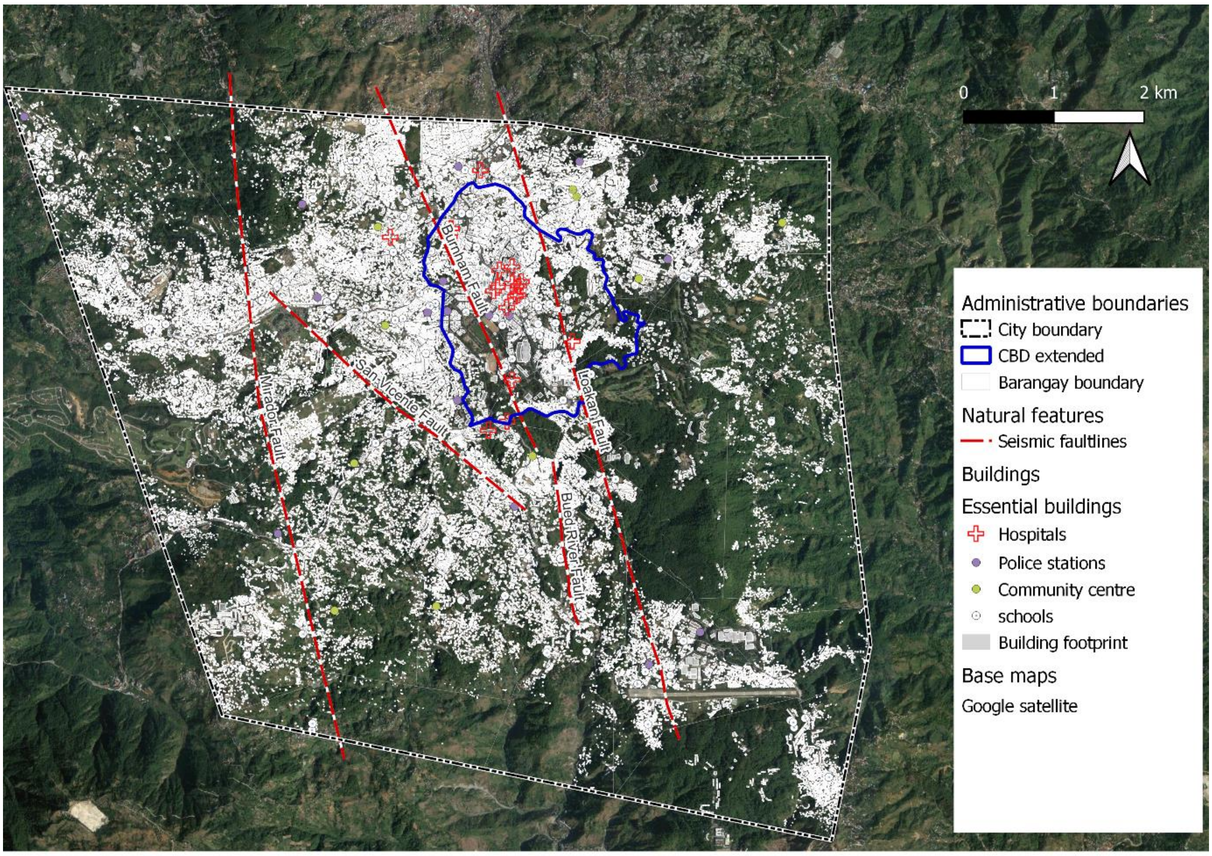


Figure 40: Exposure of essential buildings od Baguio
Source: SPADE

Baguio's topographic profile exacerbates the impact of earthquakes on the city. Over 50% of the terrain has a moderate to a steep slope. The ground shaking may trigger the downward movement of the earth and cause additional damage. Furthermore, the Kennon and zigzag formations constituting nearly half of the city's surface are porous in nature and can result in liquefaction, a process that causes soil to behave as a liquid more than as a solid during an earthquake.

3.3.1.2 Climate Change Impacts on Earthquake Hazard's Frequency and Intensity

The relationship between climate change and earthquakes is widely argued and is yet not conclusive. As a result, many CRVA studies excluded earthquakes. Nonetheless, climate change is most likely to affect the movement of the seismic plates in a long-term future, if not in the near or intermediate future. Therefore, the present CRVA report factors in the devastating nature of earthquakes in formulating a holistic action plan for the city.

Various climate change-induced phenomena that may impact earthquake activities, for example:

- Rising seas are raising the water table in many places of the world, which can translate into an increased tendency for liquefaction during earthquakes;

- The retreat of a glacier can reduce stress loads on the Earth's crust underneath, impacting the movement of subsurface magma. A recent study in the journal *Geology* on volcanic activity in Iceland between 4,500 and 5,500 years ago, when the Earth was much cooler than today, found a link between deglaciation and increased volcanic activity.

3.3.1.3 Earthquake Hazard Assessment

Earthquakes								
Category	Sub-category	Weight (w_1)	Indicator	Assigned Value (v)	Weight (w_2)	Weighted value ($v_w = w_2 \times v$)	Score ($w_1 \times v_w$)	
Frequency of hazard occurrence (f)	Historic evidence (a)	0.5	Likely to occur annually	4	0.25	1.00		0.29
			Likely to occur several times per decade	3	0.25	0.75		
			Likely to occur once a decade	2	0.25	0.50		
			Likely to occur once in 50 years or more	1	0.25	0.25	0.13	
	Climate change assessment (b)	0.5	Likely to increase by 2030 (immediate)	3	0.33	0.99		
			Likely to increase by 2060 (short-term)	2	0.33	0.66		
			Likely to increase by 2100 (long-term)	1	0.33	0.33	0.17	
Severity of damages (s)	Fatalities (a)	0.33	Death ≥10	3	0.33	0.99	0.33	0.99
			Death <10	2	0.33	0.66		
			Injuries or health hazards	1	0.33	0.33		
	Infrastructure damages (b)	0.33	Damage to infrastructure or disruption of services	2	0.5	1.00	0.33	
			Other damages	1	0.5	0.50		
	Climate change impact (c)	0.33	Damages will increase	1	1	1.00	0.33	
							Risk score	0.29

Table 21: Earthquakes risk score calculation
Source: Author

In the hazard risk matrix, earthquake hazard emerged as a moderate risk natural hazard affecting Baguio. Overall, it scored 0.29 on a scale of 0.01 to 1.00, where the frequency of earthquake occurrence was 0.29, and the severity of associated damages was 0.99 (Table 21).

3.3.2 Earthquake Sectoral Exposure Assessment

The Alquist-Priolo Earthquake Fault Zoning Act suggests a regulatory buffer zone within a distance (150—200m) of the highest impact from the active fault lines, known as Earthquake Fault Zones (EFZ). A number of studies conducted an EFZ-based analysis of Baguio City. However, considering that Baguio's fault lines are inactive, this analysis seemed to amplify their negative impacts and distract the focus from the rest of the city. The present CRVA hence considered the entire city equally prone to the earthquake hazard and requiring citywide resiliency.

Earthquakes may trigger landslides. However, this section excluded mapping their impact on the steep slopes to prevent duplicity with the landslide hazard mapping, which was one of the components included into the landslide hazard risk map development. Similarly, liquefaction received no added weightage since the section on sinkhole exposure included this geological aspect into the sinkhole hazard risk map development. **It is also important to highlight that slope failure or liquefaction triggered by an earthquake requires targeted landslides' and sinkholes' resilience building rather than resilience building against ground shaking alone.** Therefore, the study did not consider earthquake-induced secondary hazards.

Earthquakes are historically not a frequent hazard, and their frequency is also not likely to increase in the short term or immediate future. However, severity of damages caused by earthquakes is very high. Due to their devastating nature, earthquakes keep a moderate level of risk status with and without climate change assessment despite their low frequency.

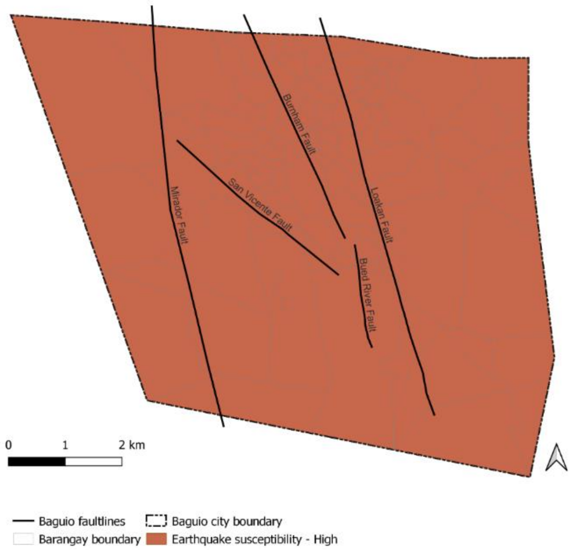
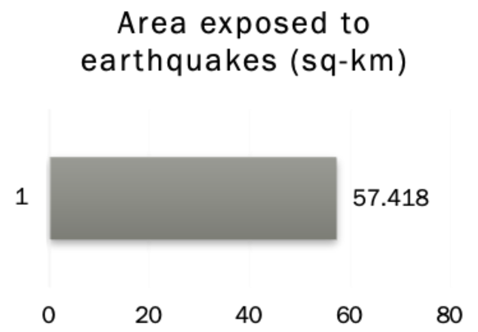


Figure 41: Earthquake exposure map of Baguio
Source: Author



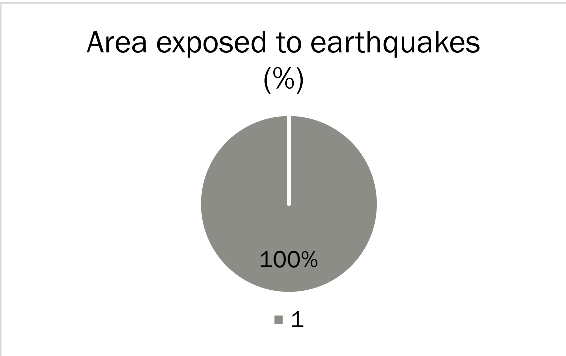


Figure 42: Area exposed to earthquakes, in sq.km.
Source: Author

3.3.2.1 Infrastructure Sector's Exposure to Earthquakes

a. Essential Buildings

All fault lines in Baguio pass through the built-up area in the city, exposing its entire infrastructure to earthquakes. Essential buildings require priority resilience measures against earthquakes, in particular schools, hospitals, and fire stations.

Schools are critical assets in two respects when considering the earthquake disaster:

- If an earthquake occurs during school hours, most children of the city may get severely affected;
- Schools often have a combination of large open playgrounds and of basic facilities (water, sanitation). As such, they often serve as emergency shelters during earthquakes.

Schools should therefore undergo priority retrofitting to build resilience against earthquakes.

Hospitals are essential during response and recovery phase and must continue uninterrupted functionality during earthquake disasters. Damages from the Luzon earthquake in 1990 caused shifting of patients from a damaged hospital to the makeshift tents. It is, therefore, important for the city to prepare for such possible incidences in the future.

Fire stations equally require priority earthquake resilience measures. An earthquake may trigger a gas leakage, an electrical short-circuiting, or other serious incidences specific to a fire station, causing a fire breakout, which need to be prevented.

b. Transportation

Transportation networks are not only a significant supply network for the city but are also vital lifelines for the supply of basic needs and emergency services during disasters.

Bridges which do not have in-built earthquake resilience measures would weaken a large part of the transportation system irrespective of the robustness of the road network. Thus, the city may want to prioritize inspecting existing bridges and perform necessary retrofitting. For precautionary reasons, new bridges should be preferably constructed 150 m away from the fault lines, regardless of their inactive status.

Roads: Earthquakes may cause ground failure and/or ground cracks, which may tilt, wear and tear highways and roads when the ground stretches or flows (U.S. Department of Commerce , 1994). Elpidio Quirino Highway (H-54) crosses the Mirandor fault and San Vicente fault in high-risk conditions. This is due to the weak Kennon (limestone) formation at a steep slope of 41% and 35% at the points of crossing over the fault lines. The route of the Kennon Road goes between waterways and fault lines of the Bued River fault, San Vicente fault and Burnham fault in the North. The presence of waterbodies and fault lines throughout the route can induce vibrations and liquefaction, making the Kennon Road highly vulnerable to earthquakes. Magsaysay avenue (H-204) is also at high risk due to its proximity to waterbodies between the Burnham fault and Loakan fault. Provisions to increase key road networks' resilience to earthquakes, in particular roads leading to evacuation and shelter areas, be they permanent or temporary, can also be seen as a priority intervention.

Air travel is proven to provide relief during the rescue and response phase. Opening the Loakan airport for commercial flights would facilitate the response to an earthquake or a landslide-induced damage when road connectivity is affected.

The Loakan fault passes through the airport runway. Considering the high importance of the airport infrastructure in the absence of a railway network, earthquake resilience measures should be taken for this critical asset.

Figure 43: Loakan fault passing through the airport runway
Source: Author

c. Water Supply and Management

Ground shaking can severely damage the waterpipe network in the city and disrupt water supply, including to emergency services such as hospitals and evacuation centers. Water supply in Baguio is majorly dependent upon underground water. The BWD manages a number of deep wells, and another large number of deep wells operate illegally. Earthquakes may generate cracks in them and contaminate the groundwater. They may also dry up the wells by changing the course of groundwater.

d. Wastewater Management (Sewage and Drainage)

The failure of the wastewater system during an earthquake may affect human health through contaminating potable water sources. The BSTP is situated near the Loakan fault, at a distance of 130 m.

e. Solid Waste Management

Earthquakes can generate a massive volume of debris, requiring heavy post-disaster management. Additionally, earthquake tremors may trigger the sliding of garbage from landfill sites. Although the Irisan former landfill is currently an ecopark, it may be beneficial to conduct an analysis on whether any garbage buried in it before 2011 may still be released in case of a high magnitude earthquake and, if so, what would be the anticipated consequences and, if required, what preventive measures may need to be undertaken.

f. Energy and Information and Communication Technology

Electrical facilities and systems have significant seismic risk due to ground shaking and failure, including liquefaction and lateral spreading. Seismically vulnerable facilities include substations and transmission in the City Engineering Office (CEI) Hubs as well as facilities outside of the CEI Hubs, including substations. distribution and transmission lines (Earling - Risk Transfer Platform, 2022).

ICT is an important sector in the disaster risk and management for the rescue, relief and warning systems. A high intensity earthquake can collapse an ICT infrastructure: cables may break, towers may topple, power sources (and the backups) may fail, and people operating the system may become in operational (Zuhyle, 2013). Communication towers installed of on top of a building are likely to be more affected by an earthquake than towers installed on the ground. Towers installed on the ground act as cantilever trusses designed to carry wind and seismic loads. When installed on a building roof top, the stiffness and quality of both the tower and the building will change and may result in partial damage or complete collapse if proper testing is not done. (Archana Dongre, Govardhan Polepally, 2016).

3.3.2.2 Social Sector Exposure to Earthquakes

The earthquake hazard coefficient in urban centers is more complex and riskier than in rural areas due to higher density and a higher built-up ratio (Peyman Yariyan, 2020). On the one hand, tall buildings are more capable of withstanding earthquake shocks due to flexibility. However, they may cause pounding damage. On the other hand, short buildings are stiffer and can withstand more damage. Thus, the city should ensure that constructions adhere to earthquake-safe construction standards. Retrofitting measures should be carried out for the existing buildings, such as jacketing or bracings.

3.3.2.3 Economic Sector Exposure to Earthquakes

Two out of five fault lines are crossing the extended CBD. The highly dense nature of the CBD in terms of population, commercial activities and tourism activities raises concerns over the safety of this infrastructure.

a. Tourism, Heritage, and Culture

Heritage and cultural buildings play a key role not only in Baguio's tourism activities, but also in conferring it its unique character and visual identity. Their resilience to earthquakes is of a prime importance to the city. An assessment would need to be conducted to understand these buildings' resilience to earthquakes so that adequate measures may be applied. Hospitality assets such as cafés, fast food outlets, restaurants, hostels, and hotels enhance tourism-related economy and also need to be earthquake proofed in priority.

b. Commercial Assets

Engineers Hill Satellite Market of Engineers Hill barangay is located at 100 m from the Loakan fault line. An earthquake can cause a decrease in sales, clients, loss of market assets and damage to the physical infrastructure of the market (David Smith, 2020).

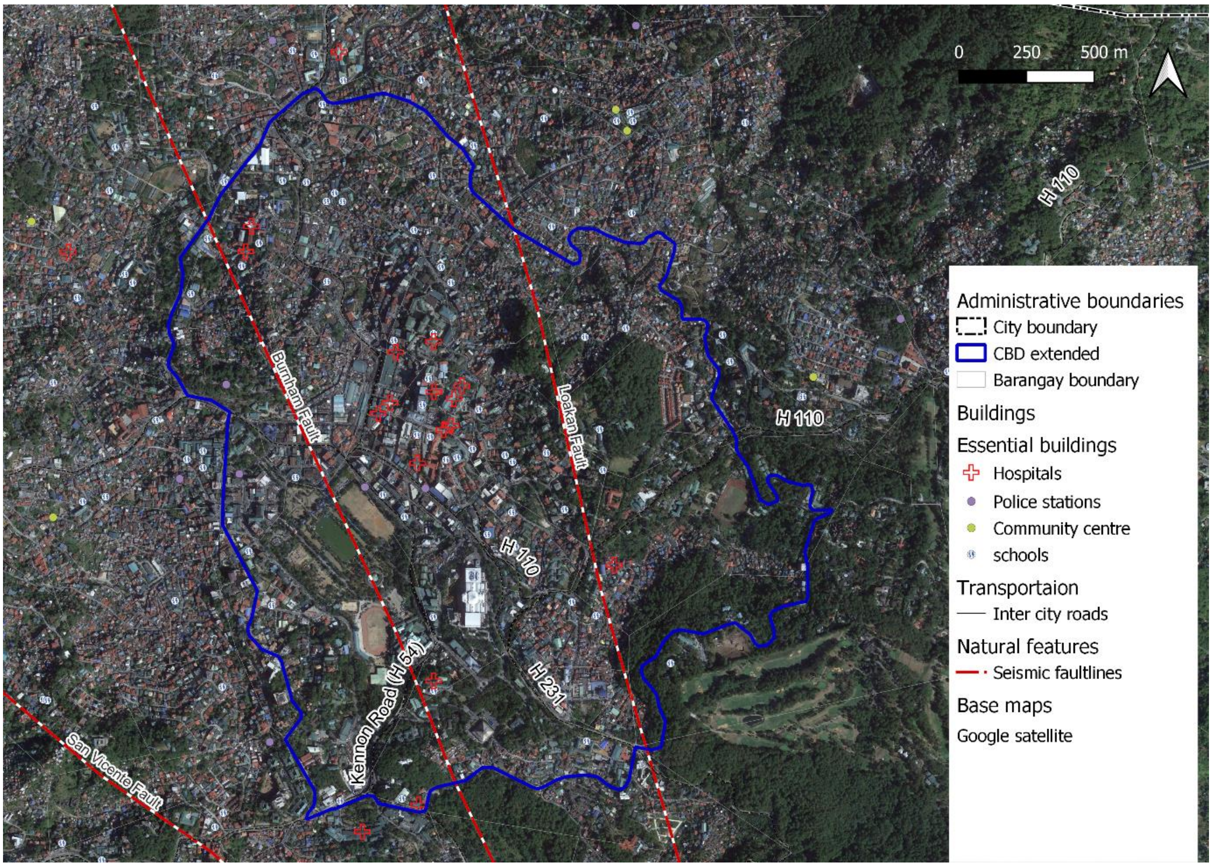


Figure 44: 2 out of 5 lines crossing the extended CBD
Source: Author

c. Industrial Assets

A part of the industrial area in the Loakan Proper barangay falls within a 200 m zone of the Loakan fault. The impact of an earthquake can cause severe damage to industrial facilities. It may lead to structural failure with a potential for fire and for the release of toxic substances, contaminating the groundwater and the air (Anne Kiremidjian, 1985). Delayed resumption in the function will negatively impact people's livelihood.

3.3.3 Earthquake Vulnerability Assessment

Although the seismic zoning of the Philippines places Baguio in the risk category IV acknowledging the city’s high exposure to earthquakes, the city's vulnerability depends upon various structural and non-structural measures implemented in the past. The following questions may help determine the city’s level of vulnerability:

1. Do evacuation centers, hospitals and other critical buildings follow earthquake-safe construction codes? Safety and robustness of such buildings ensure the functioning of services in the event of a disaster.

2. Are there retrofitting provisions for historical buildings and other buildings of special value to the city? Loss of such buildings reduces the touristic footfall and associated economy and generates an irreparable damage to the city’s visual identity.

3. Are there retrofitting provisions for hotels, hostels, and other lodging facilities? Delayed recovery of such infrastructure delays the resumption of the tourism sector. Speedy recovery after damages is crucial for the livelihood of tourists' dependent population. It includes local transportation drivers, porters, tour guides, café and street food workers. A quick resumption of livelihood activities facilitates early departure from refugee camps and reduces financial burden on the local government.

Baguio is host to many **engineering universities**, which can support the city in enhancing earthquake resilience. In collaboration with the civil engineering and similar departments, the city can conduct rapid visual surveys and detailed inspections to prepare a database of existing built infrastructure's vulnerability to earthquakes. Such a database will establish criteria and facilitate vulnerability assessments as well as progress monitoring in the future. Social sciences departments can contribute with instruments on assessing social vulnerability.

3.3.4 Conclusion

As the complex built-up infrastructures in urban areas increase the likelihood of earthquake damages, earthquake preparedness and resilience are critical for Baguio City. Long gaps between two consecutive earthquake incidences of the order of one or more decades through the 20th century are de facto a major limiting factor for this preparedness. People tend to forget the atrocities of an earthquake from one generation to another. The responsibility to continue preparedness activities generally lies on the generation that has never witnessed an earthquake. Therefore, it is particularly challenging to maintain the required level of earthquake preparedness.

Earthquake memorial museums or relic parks are crucial to keeping ties with past earthquakes. These can also be awareness and education centres, as well as tourist visits spots as a secondary purpose. The city can draw learnings from Japan on successfully creating such memorials.

Figure 45: Hyatt hotel damage after the Luzon earthquake of 1990
Source: Author

3.4 Sinkholes

Risk level	Moderate	Risk score	0.29
Impact of climate change:			
Increase in frequency		Increase in intensity	

3.4.1 Overview

Sinkholes are another Baguio's geophysical challenge in addition to landslides and earthquakes. A number of Baguio's areas are prone to sinkholes, which limits development opportunities and poses a continuous threat on the people residing in them.

Sinkholes are depressions or holes in the ground surface caused by erosion of underlying soil triggered by a movement of the groundwater. If left open, sinkholes get filled with water and further aggravate the situation: by taking in more water, they keep growing and trigger the appearance of more sinkholes nearby.

Thirteen barangays in Baguio have sinkholes (Table 22). Since 1991, 6 sinkhole formation incidences have occurred in the city. No deaths or injuries were reported, but damages to infrastructure took place: collapse of boarding houses; collapse of a bus terminal, or a collapse of a lodging facility.

Name of barangay	Number of sinkholes
Middle Quezon Hill Subdivisi	16
Quezon Hill, Upper	12
Victoria Village	4
Dominican Hill-Mirador	13
Quezon Hill Proper	6
Dontogan	41
Asin Road	18
Irisan	26
Pinsao Pilot Project	1
Fairview Village	1
Bakakeng Central	3
San Luis Village	1
Pinsao Proper	2
Total	142

Name of barangay	Number of sinkholes
Middle Quezon Hill Subdivisi	16
Quezon Hill, Upper	12
Victoria Village	4
Dominican Hill-Mirador	13
Quezon Hill Proper	6
Dontogan	41
Asin Road	18
Irisan	26
Pinsao Pilot Project	1
Fairview Village	1
Bakakeng Central	3
San Luis Village	1
Pinsao Proper	2
Total	142

Table 22: Barangay-wise location of sinkholes in Baguio
Source: Author

3.4.1.1 Sinkhole Triggering Factors

Sinkholes naturally appear in limestone, sandstone, and quartzite geological conditions. These water-soluble minerals get eroded due to changing underground hydrological conditions. Lowering of groundwater levels leave voids, which collapse when they fail to support the ground weight above.

It causes sudden appearance of sinkholes. Sinkholes can be triggered by depleting groundwater, introducing more water, seasonal changes in groundwater table, droughts, and heavy rainfalls.

In Baguio, sinkholes essentially get formed in its Kennon and zigzag formations (Figure 46). Baguio City may consider conducting new development activities with extreme care in these areas because sinkholes get triggered due to anthropogenic activities such as:

- Disturbance of the soil: digging through soil layers, soil removal, drilling
- Point-source of water: leaking water/sewer pipes, injection of water
- Concentration of water flow: stormwater drains, swales, etc.
- Heavy loads on the surface: structures, equipment
- Decline of water levels: groundwater pumping (wells, quarries, mines)

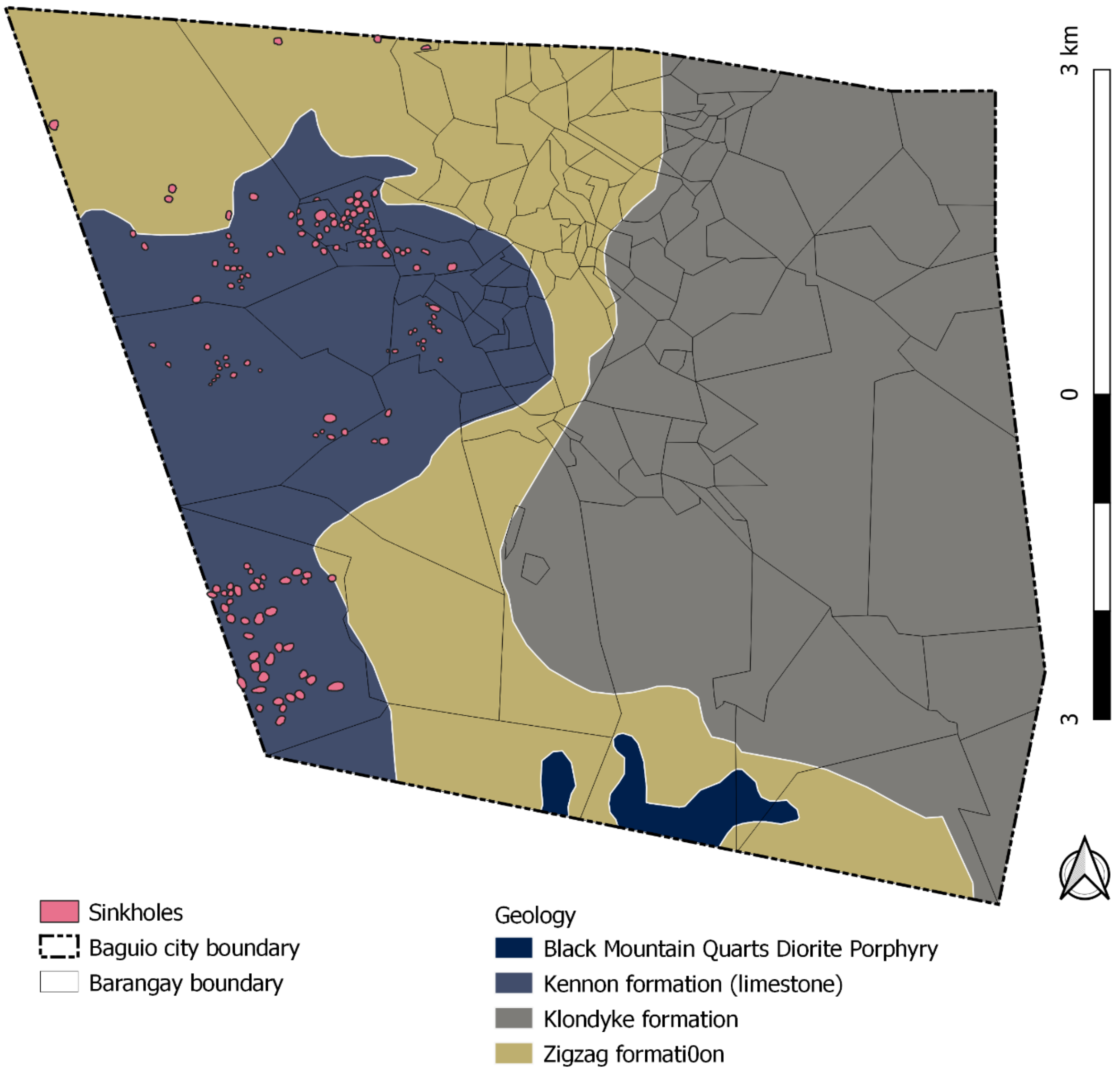


Figure 46: Baguio's geological formations and the actual location of sinkholes
Source: SPADE

3.4.1.2 Climate Change Impact on Sinkhole Hazard's Frequency and Intensity

The probability of sinkhole appearance is more likely to enhance in the future because of both an increase in precipitation and an increase in temperature. Rising temperatures will change the natural hydrological processes and enhance limestone dissolution, leading to soil failure and increased sinkhole appearances. A study in Florida concluded that with every 0.1°C rise in global temperature, the number of sinkholes would increase by 1%—3%. The latest IPCC 2022 report predicts a global temperature increase equal to 1.5°C by 2040. It is difficult to downscale this global scenario at the Baguio level; however, more sinkholes will inevitably appear in the city.

3.4.1.3 Sinkhole Hazard Assessment and Mapping

Sinkholes

Category	Sub-category	Weight (w_1)	Indicator	Assigned Value (v)	Weight (w_2)	Weighted value ($v_w = w_2 \times v$)	($w_1 \times v_w$)	Score
Frequency of hazard occurrence (f)	Historic evidence (a)	0.5	Likely to occur annually	4	0.25	1.00		0.58
			Likely to occur several times per decade	3	0.25	0.75		
			Likely to occur once a decade	2	0.25	0.50	0.25	
			Likely to occur once in 50 years or more	1	0.25	0.25		
	Climate change assessment (b)	0.5	Likely to increase by 2030 (immediate)	3	0.33	0.99		
			Likely to increase by 2060 (short-term)	2	0.33	0.66	0.33	
			Likely to increase by 2100 (long-term)	1	0.33	0.33		
Severity of damages (s)	Fatalities (a)	0.33	Death ≥10	3	0.33	0.99		0.50
			Death <10	2	0.33	0.66		
			Injuries or health hazards	1	0.33	0.33		
	Infrastructure damages (b)	0.33	Damage to infrastructure or disruption of services	2	0.5	1.00		
			Other damages	1	0.5	0.50	0.17	
	Climate change impact	0.33	Damages will increase	1	1	1.00	0.33	
							Risk score	0.29

Table 23: Risk score calculation of sinkholes hazard
Source: Author

In the hazard risk matrix, sinkholes hazard emerged as a moderate risk level natural hazard affecting Baguio. Overall, it scored 0.29 on a scale of 0.01 to 1.00, where the frequency of sinkholes occurrence was 0.58, and the severity of associated damages was 0.50 (Table 23).

3.4.1.4 Sinkhole Mapping

Baguio's sinkhole exposure map was developed based on two factors: type of geological formations and location of actual sinkholes. The level of exposure to sinkholes was ranked as high, medium, and low. Parts of Baguio lying in Kennon formation (limestone) and having more sinkholes have hence been classified as a high exposure zone, parts with zigzag formation and a lesser number of sinkholes as a medium exposure zone, and the remaining geological formations with no sinkhole occurrence as a low exposure zone (Table 24).

Level of exposure	Criteria	Corresponding geological formations
High	Geological formations with the highest number of sinkholes	- Kennon formation (limestone)
Medium	Geological formations with sparse sinkholes	- Zigzag formation
Low	Geological formations with no sinkholes	- Black mountain quarts diorite porphyry - Klondyke formation

Table 24: Criteria for preparing sinkholes exposure map
Source: Author

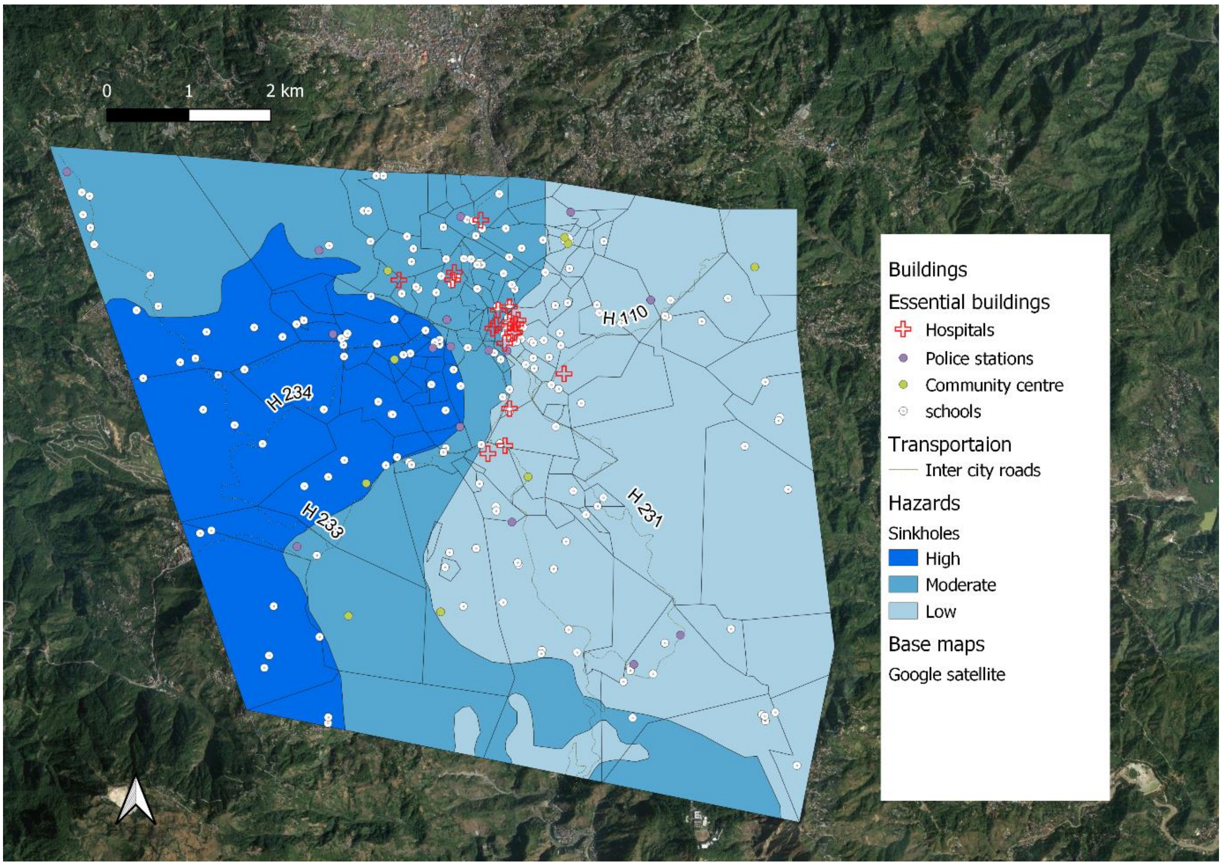


Figure 47: Sinkhole exposure map of Baguio
Source: Author

3.4.2 Sinkhole Sectoral Exposure Assessment

The sinkhole exposure map suggests that more than 50% of the city is prone to sinkhole formations. The percentage of the built-up area under the high exposure zone is 26%, the area under moderate exposure is 30.8 % and the low exposure area consists of 43 % built-up. Dontogan barangay consists of the maximum number of sinkholes in the city, followed by Irisan. Bakakeng Centra, Dominican Hill-Mirador, San Luis Village, Quezon Hill Proper, Victoria Village, Middle Quezon Hill Subdivision(Quezon Hill Middle), Fairview Village, Pinsao Pilot Project, Quezon Hill, Upper, Pinsao Proper and Asin Road are other barangayslying with the high exposure zone. Sectoral exposure is discussed in the following subsections.

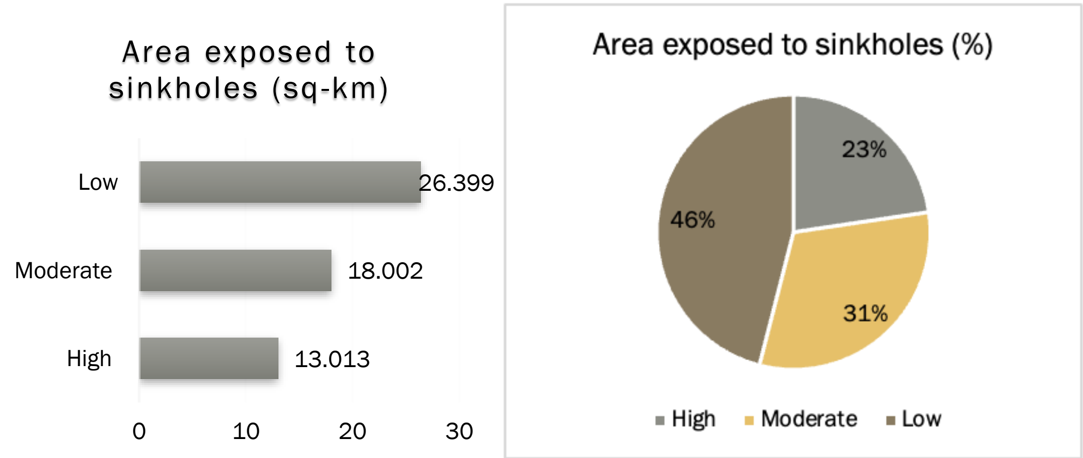


Figure 48: Area exposed to sinkholes, in sq.km.
Source: Author

Over 50% of the city is prone to sinkholes:

144 sinkholes in Baguio City

- 23% or 13 km^2 of the city area is highly exposed
- 31% or 18 km^2 of the city area is moderately exposed
-

13 barangays are prone to sinkholes

Dontogan has the highest number of sinkholes (41)

3.4.2.1. Infrastructure Sector's Exposure to Sinkholes

a. Essential Buildings, Transportation, Tourism, Energy and Information and Communication Technology Sectors

Uncertainty on where in the highly exposed areas sinkholes could appear prevents tactical resilience planning. The safest strategy to prevent potential damages to declare these areas highly sensitive and unfit for development. However, it is hardly possible for rapidly growing Baguio, where infrastructure has already expanded to sensitive areas.

As per available data, 25,826 buildings or 26% of total city's buildings are situated in the sinkhole-prone barangays. Similarly, 22% of the total built-up area of Baguio City is situated in the sinkhole-prone barangays.

In terms of essential buildings, 57 schools (28.5% of all city's schools) are situated in the high-risk zone, out of which three are located in the barangay Middle Quezon Hill Subdivision, having the highest density of sinkholes. In addition, three police stations and one community center are located in this zone. **There is no hospital in any of the sinkhole-prone barangays.**

In tourism-related infrastructure, 5% or 29 assets are located in high exposure areas, which calls for continuous groundwater levels monitoring under heritage buildings crucial for tourism and the city's identity.

Service infrastructure such as telephone towers, pipelines, roads or electrical substations in the high sinkhole exposure zone runs the risk of disruption, which may lead to subsequent disruption of services and loss of life.

Establishing sinkhole monitoring facilities may help Baguio prevent sinkhole-related damages and life losses. These facilities may take care of ground surveying, groundwater monitoring, and sinkhole deformation monitoring using techniques such as ground penetrating radar.

b. Water Supply and Wastewater Management

Baguio requires an integrated approach to water supply and wastewater management to prevent sinkholes formation. Baguio's water supply is heavily dependent on underground wells, most of which are illegal and off the record. Groundwater depletion can lead to sinkholes formation, which can be prevented if water table levels are maintained.

Inconsistent seepage of rainfall runoff can also disturb underground geology by triggering the excessive dissolution of limestone. An unmanaged outfall of stormwater drains in the sinkholes can increase their size overtime. Sinkholes can also become a source of groundwater contamination because surface runoff at outfall is contaminated with urban pollutants.

Through monitoring groundwater levels, the sinkhole-prone barangays need to have a controlled wastewater discharge and potable water extraction. This set up calls for a coordination between the water supply and the wastewater management municipal entities.

Sinkhole-prone barangays should not have an extensive amount of permeable pavements, rain gardens, or other stormwater management measures that facilitate groundwater recharge. To reduce surface runoff, these barangays can promote alternative solutions such as green roofs, vertical gardens and similar measures that withhold stormwater but do not recharge groundwater.

c. Solid Waste Management

Sinkholes are natural pits in the ground, which makes them exposed to garbage disposal. Site visits confirmed this is occasionally taking place. However, **sinkholes are sensitive areas easily leading to groundwater contamination.** Measures to prevent garbage dumping into sinkholes are essential.

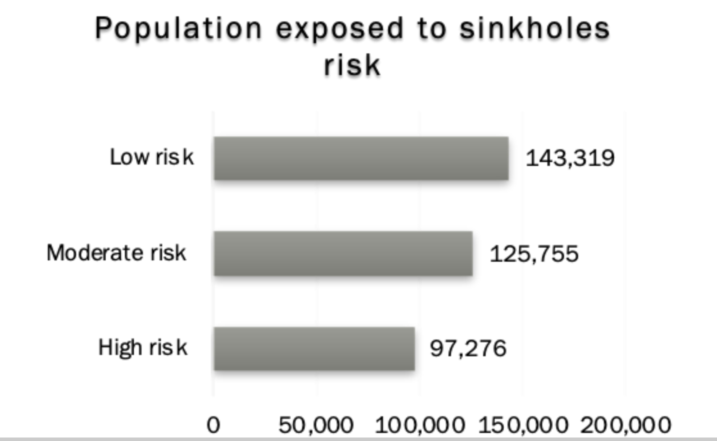
3.4.2.2 Social Sector Exposure to Sinkholes

About 60% of Baguio's population is residing in sinkhole-prone areas where 27% is in the limestone formation, and hence at high risk. However, circulating information on how to observe the signs of a sinkhole appearance among local residents can facilitate timely evacuation and reduce the risk of sinkhole-related life losses. These signs include:

- Sudden drop in a well water level
- Appearance of cracks on roads
- Appearance of circular shaped ponds or puddles
- Sinking of buildings' foundations
- Sudden wilting of vegetation (as sinkhole draws away essential water)
- Appearance of circular ground cracks

If detected in advance, the ground collapse can also be prevented by engineered solutions.

Population Exposed to Sinkholes



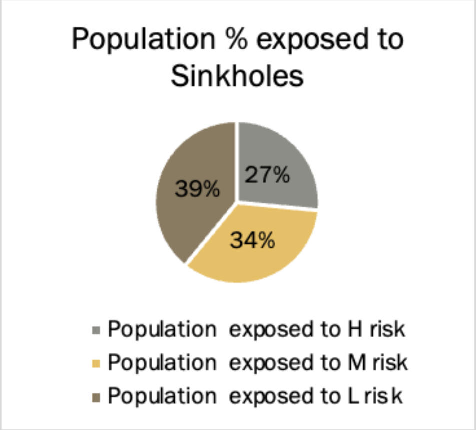


Figure 49: Population exposed to sinkholes risk
Source: Author

3.4.2.3 Economic Sector's Exposure to Sinkholes

a. Commercial Assets

The city area highly exposed to sinkholes is primarily residential. The CBD is safely located away from the highly prone sinkhole area. However, the newly developing commercial area along the highway Elpidio Quirino Highway (H-54) has grown in the highly sinkhole-prone area.

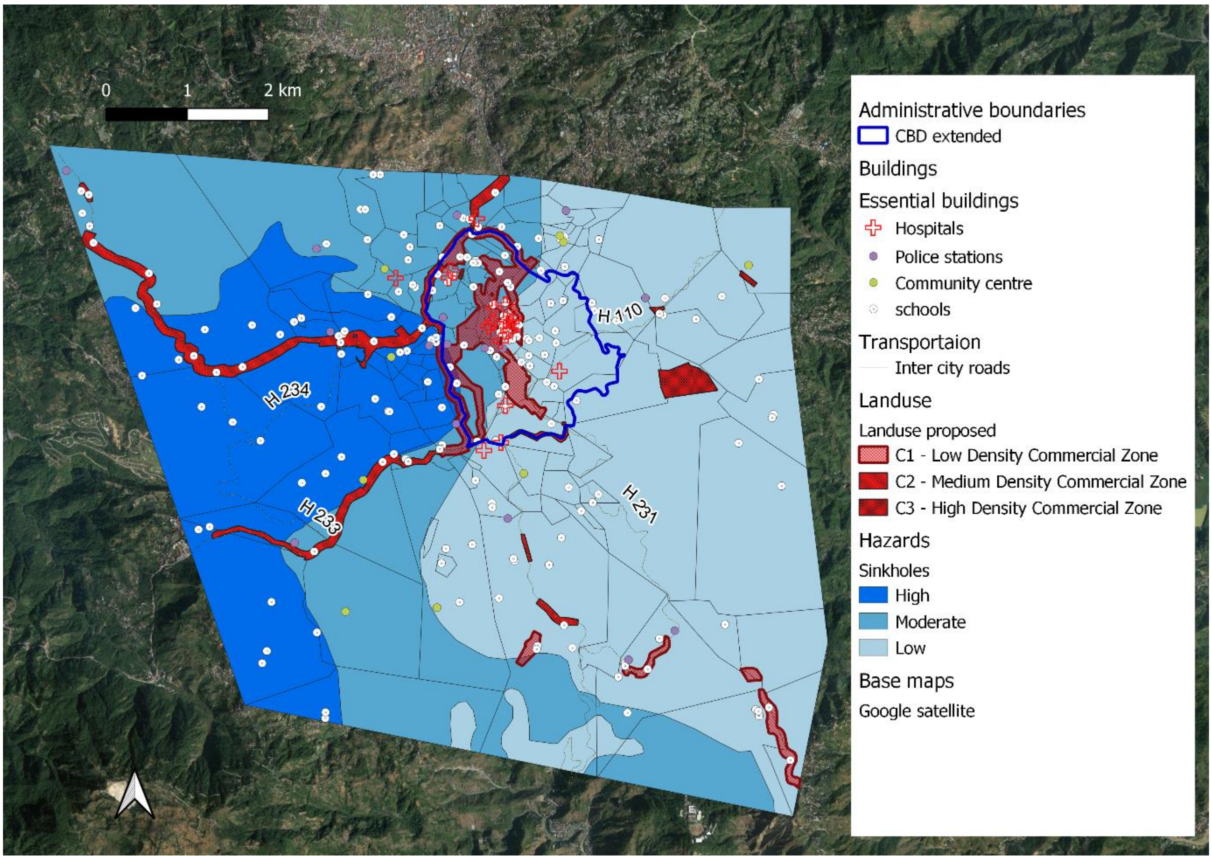


Figure 50: Exposure of essential buildings and proposed commercial zones
Source: Author

3.4.3 Conclusion

Sinkholes hazard is a development limiting factor for Baguio which renders most of the city's western part unfit for significant development activities. In the Comprehensive Development Plan 2018–2022, a project Protection and Rehabilitation of Sinkholes/Natural Drain in Barangay Crystal Cave and Other Identified as Sinkholes was proposed under the Department of Environment and Natural Resources (DENR) and the City Engineering Office (CEO). A similar project on Rehabilitation of Sinkholes at Various Locations (fencing, declogging, riprap, canal) is also proposed under (DRRMF).

Strategies under both the projects are limited to protecting existing sinkholes, but are not extending to preventing new sinkhole formations. Based on the above analysis, the city will advance its resilience by undertaking the following sinkhole disaster preparedness activities:

- Monitoring of groundwater levels
- Early forecast of sinkholes through radar and other scientific technologies
- Integrated wastewater and water supply management
- Capacity building of locals to observe the warily signs of sinkholes.

3.5 Forest Fires

Risk level	Moderate	Risk score	0.27
Impact of climate change:			
Increase in frequency	↑	Increase in intensity	↑

3.5.1 Overview

Global warming tends to generate a vicious cycle, in which rising temperatures lead to fire related forest cover loss which, in turn, further contributes to rising temperatures (Phillips, 2021). Over the last decade, Baguio City reported 2 incidents of forest fires. The first incident occurred in February 2020 in South Drive barangay and the fire was doused in 8 days. It damaged the forest, but did not generate other damages. The second incident, occurred in 2022, damaged tree plantations under the Expanded National Greening Program and natural pine forests. The southeasterly wind conditions facilitated the spread of the fire, extending it to some portions of the land characterized by the presence of dry shrubs, which is easily flammable. In February 2019, pine forests in the neighboring city of Itogon were on fire. Five people died in the incident, and 90 families were affected.

The hazard risk matrix based on frequency and severity of past incidents attributes Baguio's forest fires hazard an overall score of 0.28. Both frequency and severity lie in the medium risk category as an average throughout the city. However, 24% of the city's surface lies in the high-risk category (Figure 51). In addition, forest cover is an essential feature of Baguio City: it maintains a pleasant temperature and biodiversity, and constitutes a major tourism attraction. The city's hilly terrain makes it difficult for fire tenders to douse a forest fire. Hence, mitigating soring heat should be an strategy included in Baguio's Local Climate Change Action Plan (LCCAP) to reduce forest fire occurrence.

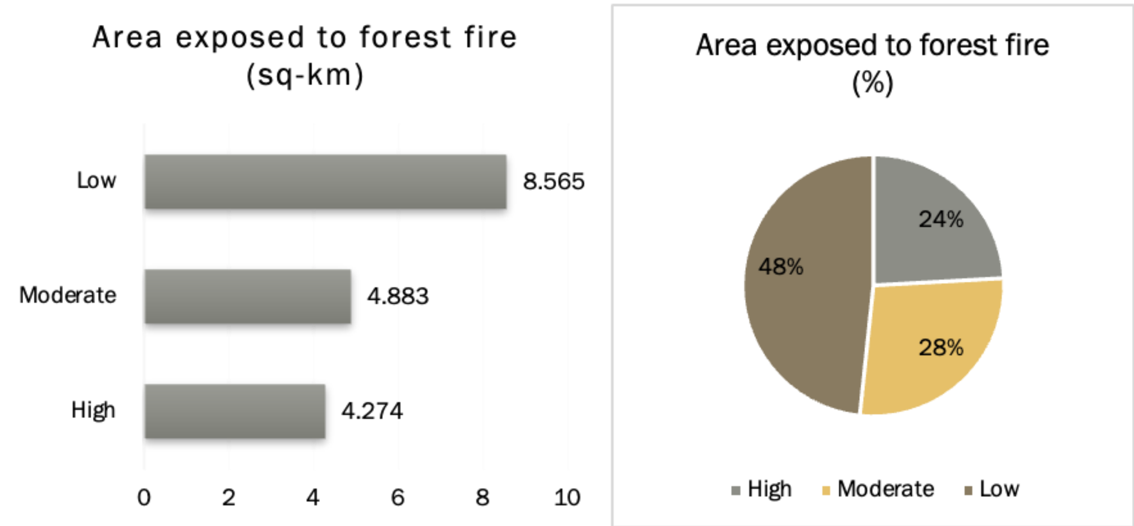


Figure 51: Area exposed to forest fire, in sq.km.
Source: Author

3.5.1.1 Forest Fire Triggering Factors

The city experienced recent incidents of forest fires in the dryer months. The rising temperature, dry weather, loss of soil moisture and wind from the northeast have been observed to aggravate forest fire in Baguio.

Today, forest covers 8.7 km^2 or 20% of the total area. Baguio's forest major plantation is **pine trees, which are highly flammable**. Pine forests are majorly located at the periphery of the city. They are directly connected to an extensive pine forest of the Benguet province in the southwestern part of the city. Such continuous forest patches have a higher forest fire risk because of their sheer size and continuity.

Less reporting of such incidents in the past suggests that forest fires are a new phenomenon in Baguio. Any fire incidence in the peripheral forest is likely to have a sizable negative impact on Baguio. However, forest fires are yet to be acknowledged as a considerable threat to forest cover in the near future under the influence of climate change.

3.5.1.2 Climate change impact on forest fire hazard's frequency and intensity

Figure 52: Forest fire in Benguet; forest fire in South Drive, Baguio (left to right)
Source: Lupad, 2022

As per the Climate Change Assessment conducted by ADB in 2021, Baguio will experience a significant rise in the number of summer days. Over 1981–2010, the number of days with the maximum daily temperature above 25°C varied from 30 to 115 days a year, with an average of 55 days a year. In the intermediate future period 2031-2060, **the annual number of summer days is projected to vary from 91 to 232 days, with an average of 170** days under RCP 4.5; and from 97 to 304 days with an average of 207 days under RCP 8.5, considered to be the most plausible scenario as of today. This is a **significant increase compared to the reference period**. An increased temperature leads to dryer vegetation and a reduction of soil moisture. Both factors facilitate forest fire propagation.

3.5.1.3 Forest Fire Hazard Assessment

Forest fires

Category	Sub-category	Weight (w_1)	Indicator	Assigned Value (v)	Weight (w_2)	Weighted value ($v_w = w_2 \times v$)	Score ($w_1 \times v_w$)	
Frequency of hazard occurrence (f)	Historic evidence (a)	0.5	Likely to occur annually	4	0.25	1.00		
			Likely to occur several times per decade	3	0.25	0.75		
			Likely to occur once a decade	2	0.25	0.50		
			Likely to occur once in 50 years or more	1	0.25	0.25	0.13	0.46
	Climate change assessment (b)	0.5	Likely to increase by 2030 (immediate)	3	0.33	0.99		
			Likely to increase by 2060 (short-term)	2	0.33	0.66	0.33	
			Likely to increase by 2100 (long-term)	1	0.33	0.33		
Severity of damages (s)	Fatalities (a)	0.33	Death ≥10	3	0.33	0.99		
			Death <10	2	0.33	0.66		
			Injuries or health hazards	1	0.33	0.33	0.11	
	Infrastructure damages (b)	0.33	Damage to infrastructure or disruption of services	2	0.5	1.00		0.60
			Other damages	1	0.5	0.50	0.17	
	Climate change impact (c)	0.33	Damages will increase	1	1	1.00	0.33	
							Risk score	0.27

Table 25: Risk score calculation of forest fire
Source: Author

In the hazard risk matrix, forest fires hazard emerged as medium risk level hazard affecting Baguio. Overall, it scored 0.27 on a scale of 0.01 to 1.00, where the frequency of sinkholes forest fires occurrence was 0.46, and the severity of associated damages was 0.60 (Table 25).

3.5.1.4 Forest Fire Hazard Mapping

Forest fire exposure of Baguio was determined using a forest-urban interface approach. A forest-urban interface consists in considering buffers at various distances from the forest boundary to determine respective degrees of the hazard effect. Table 26 lists the buffers criteria adopted for Baguio City.

Level of exposure	Criteria	Description
High	Areas belonging to peripheral forests and a 100 m buffer from its boundary	Barangays lying next to the peripheral forests are highly exposed to forest fire. Chances of forest fires are higher in these forests considering their connectivity with forest lands of the Benguet province.
Moderate	Areas belonging to urban forests and a 100 m buffer from its boundary	Barangays in the vicinity of urban forests have a medium forest fire risk because the isolated nature of such forests reduces the chances of forest fires.
Low	Areas within a 560m buffer from the forest boundaries	Here, the nature of consequences is mainly health and breathing-related complications. Forest fire particles are spotted up to a distance of 560 m (Pereira, J. C., Pereira, J., Leite, A. L., & Albuquerque, D. (2015).

Table 26: Criteria for preparing the forest fire hazard map
Source: Author

3.5.2 Forest Fire Sector Exposure Assessment

4.5.2.1 Infrastructure Sector's Exposure to Forest Fire

a. Essential Buildings

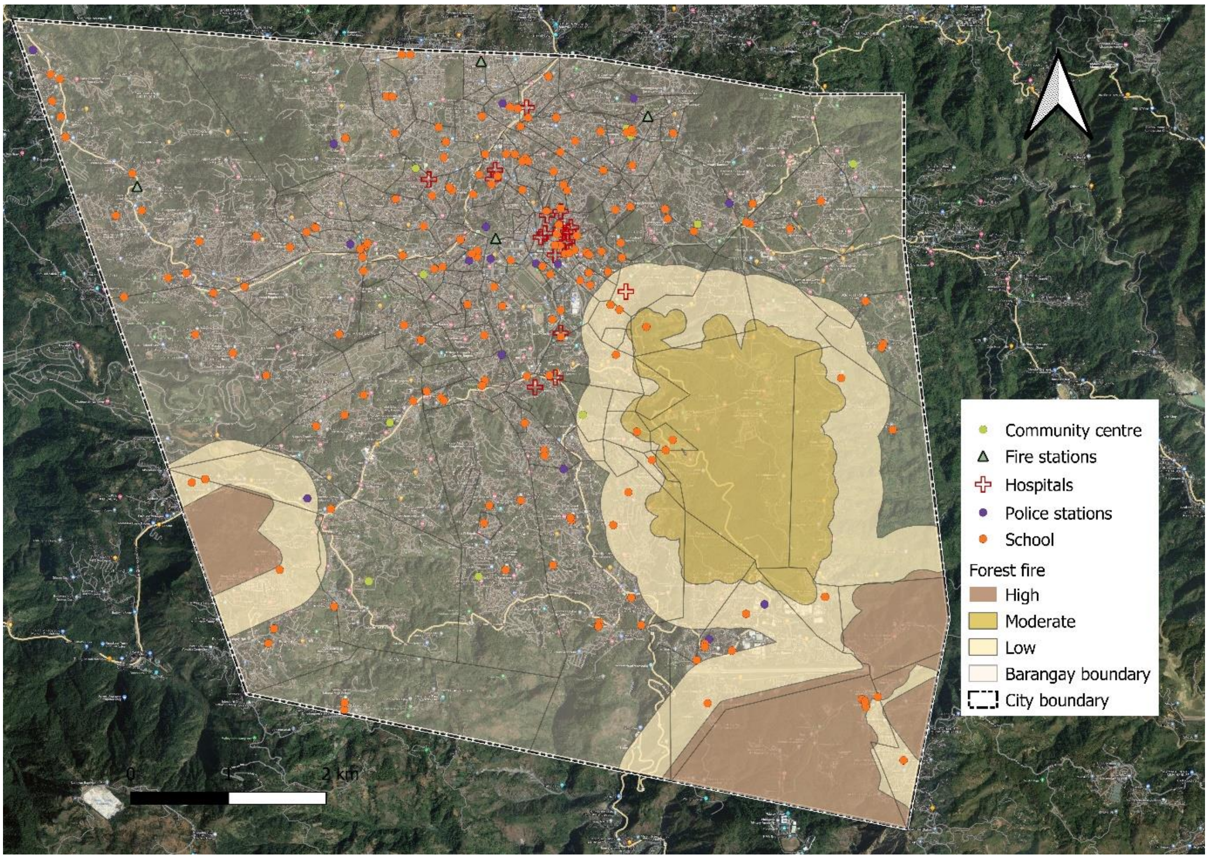


Figure 53: Forest fire exposure of essential buildings of Baguio
Source: Author

Schools located in the city's west and southwest parts are most exposed to forest fire. Four out of 200 schools are located within a high exposure area. Four schools are located in a moderate and 14 in a low exposure area. Besong Saddle Ps and Dontogan Elementary School lie in the Pine tree zone and thus are highly exposed to forest fires. One hospital, Torsine Store Park Clinic, is located within a low exposure area, along with two police stations and a community center (Figure 52). At a city scale, the number of essential buildings exposed to this hazard is not big, however, each of them plays an important role at the community scale. These buildings hence need to adopt reinforced measures against a potential sudden forest fire, including evacuation and preservation of the physical asset.

All city's fire stations are located away from areas with highest forest fire exposure which, combined with existing traffic jams, creates a high vulnerability to the hazard since prompt fire extinction service may be difficult to provide if a forest fire disaster occurs.

b. Transportation

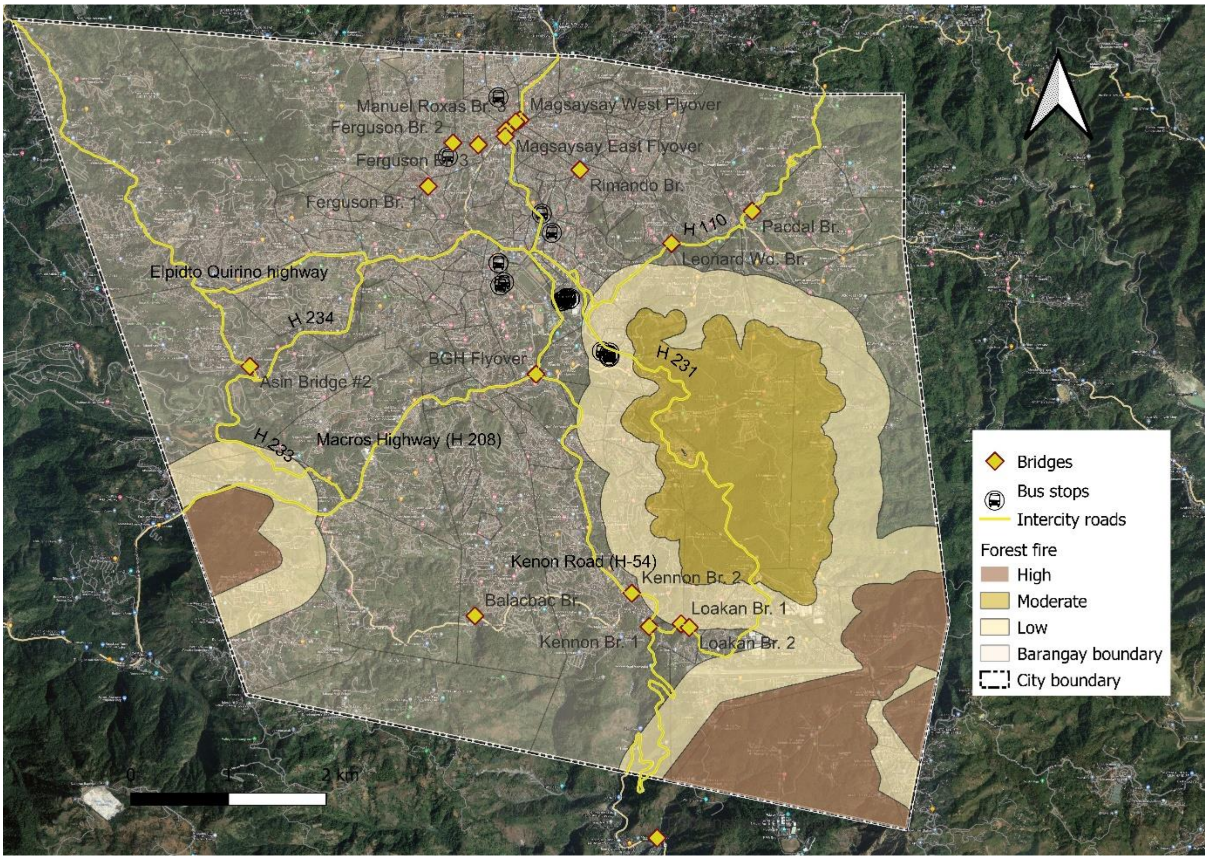


Figure 54: Forest fire exposure of transportation sector of Baguio
Source: Author

Four intercity roads crossing Baguio represent the city transportation system's backbone. Most of them do not intersect forest fire exposure areas. The **H231 highway**, connecting the CBD to the southeastern part of the city, is characterized by a high presence of pine forests, It passes through Camp John Hay forest in Greenwater village and the Country Club Village barangay, both exposed to forest fires. Loakan bridges 1 & 2 and bus stops located on the H231 road segment lie within a low to a moderate exposure to forest fire zone. About 750 m of the **Kennon Road (H-54)**, connecting the Northwest area to the Kennon Road in the south, are located within a low exposure area, which is also within a 100 m proximity of the high exposure zone in Camp 7 barangay.

A fire damaged road is likely to hamper the movement of people and goods, obstruct regular as well as critical services required to rescue people during hazard events (Fraser, Chester, & Underwood, 2022). The municipality may hence consider fire prevention measures to avoid potential damage to most exposed road infrastructure.

c. Water Supply and Management

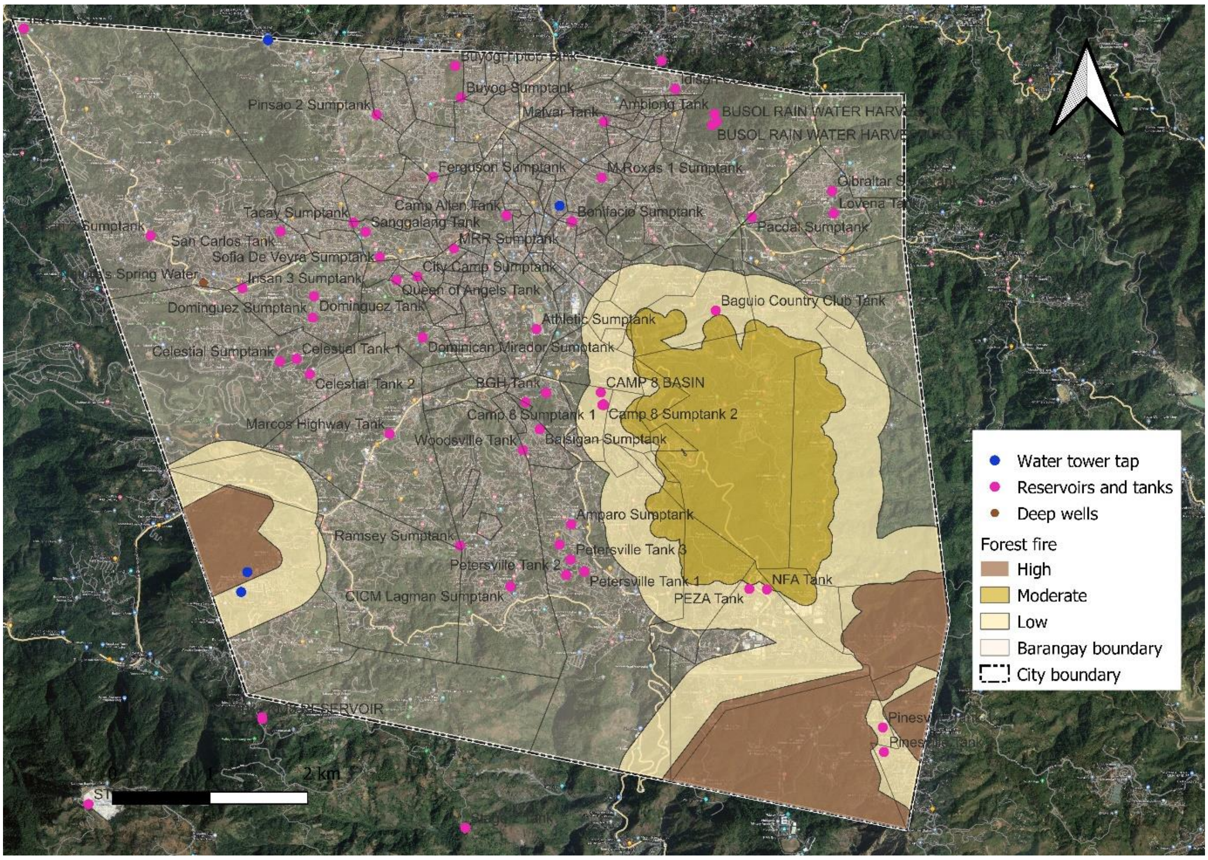


Figure 55: Forest fire exposure of water supply, Baguio
Source: Author

Forests help maintain water sources, and hence deep wells located near forest areas are likely to generate a more stable and sustainable water provision (Anderson, Hoover, & Reinhart, 1976) (Dudley & Stolton, 2003). At the same time, water sources exposed to the forest fire hazard have a high contamination chance, which is likely to compromise their usage. Forest fires related contamination of external water bodies (streams, lakes, and water reservoirs) results in a change of odor, color, and composition due to chemical leaching from burned residues. The presence of suspended solids in the contaminated water requires additional treatment (Uzun, et al., 2020) (Schulze, Fischer, Hamideh, & Mahmoud, 2020).

At present, out of four water taps, two are exposed to forest fires: one is located in a high exposure zone and another one in a low exposure zone. Similarly, reservoirs and tanks in Camp 8 watershed reservation and Camp John Hay have low exposure. Seven out of 59 reservoirs and tanks are within the low exposure area, and 9 are located within 300m of this low exposure zone. This challenge is likely to increase as water demand grows along with the city and the tourism growth. Indeed, the municipality faces challenges with acquiring new drilling areas to make deep wells and is considering relying more on external water sources.

d. Wastewater Management (Drainage and Sewage)

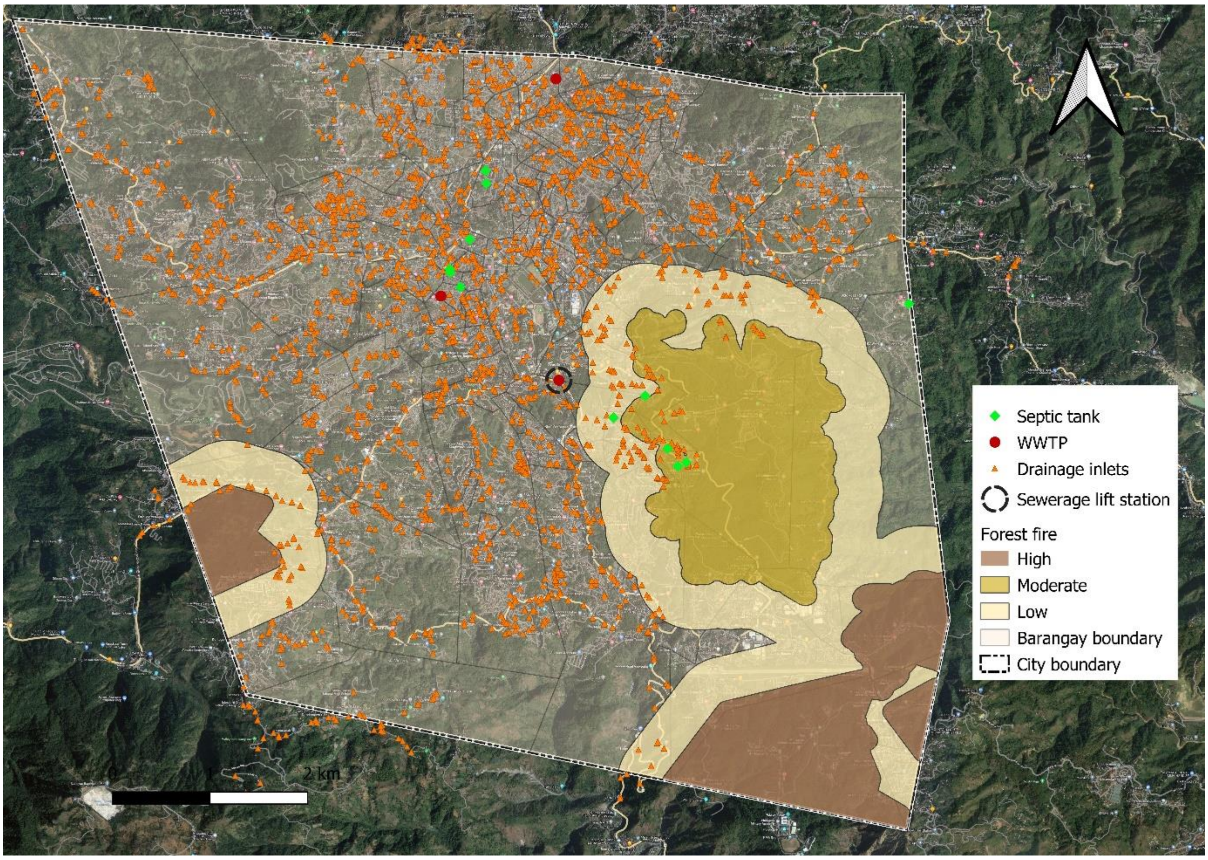


Figure 56: Forest fire exposure of wastewater management of Baguio
Source: Author

In Baguio, 45 out of 2,525 drainage outlets are in areas with high exposure to forest fires. In addition, 157 drainage outlets are within a moderate and 231 within a low hazard zone. Forest fires may significantly affect the generated runoff. They may cause an increase in the runoff due to decreased vegetation and soil percolation rate, hence augmenting pressure on the existing drainage system. Fire may damage and destroy the distribution infrastructure and block drainage pipes due to the debris flow (Montana Department of Environmental Quality, 2012).

4.5.2.2 Social Sector's Exposure to Forest Fire

The rising population within Baguio led to encroachment of forest reservations (Estoque & Murayama, 2013). The diminishing boundary between forest and urban settlement jeopardizes its safety due to rising forest fire threats. About 18% of the city's population is exposed to forest fire based on their proximity to the urban and peripheral forests.

12% of the population is in low exposure areas, 2% in moderate and 4% are highly exposed to forest fire in Baguio. High-density barangays such as Camp 8, Dagsian Upper, Dagsian Lower, DPS Area, Engineer's hill, Gabriela Silang, Greenwater Village, Hillside, Macroville and Scout Barrio are located adjacent to the urban forest and are moderately exposed to the forest fire. Similarly, Apugan-

Loakan, Loakan Proper, and Liwanag Loakan are barangays with moderate density within high exposure zone.

Almost all the high and medium population density barangays are located out of the forest fire exposure areas (Figure 57). This contributes to reducing the potential number of casualties resulting from a forest fire. However, some informal settlements may get affected by forest fires: Camp John Hay, Busal watershed, and Forbes Parks Parcel 1 and 3.

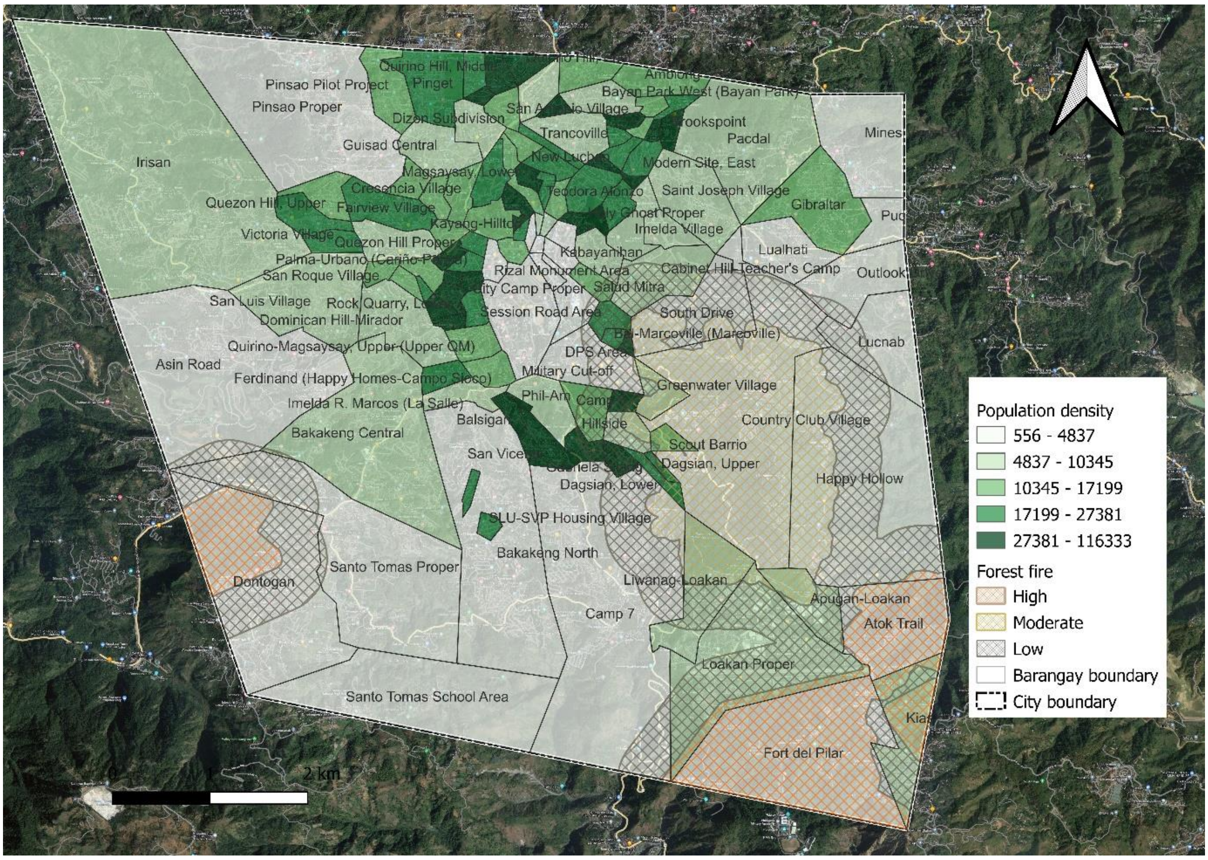


Figure 57: Forest fire exposure of social sector of Baguio
Source: Author

4.5.2.3 Economic Sector's Exposure to Forest Fire

a. Tourism

Forests are a prominent tourist attraction in Baguio (City planning and development office, 2018). Hence, this has led to the development of tourist infrastructure such as cafés, fast food centers, hotels and restaurants in proximity to the urban and peripheral forests. 27 of 330 restaurants are in the moderately exposed area, and 35 are in the low exposed area of the city.

Choco-late de Baterol, Fog Photo Café, J.Co., Illy, Mr. Beans Café, Opulence Café, Starbucks, and Studio Café are spread across Camp John Hay, which is a forest reservation, hence are moderately exposed to the forest fire. Other 9 cafés of 107 have low exposure to forest fire.

Overall, tourism-related services have low exposure to forest fires. Four of 47 hotels in Baguio have low exposure, and 2 have moderate exposure to forest fire. Similarly, 1 of 130 fast food center is located in a high exposure area, 4 is moderate, and 8 have low exposure to forest fire. Out of 12 hostels, 4 are located in low hazard areas and 2 have moderate exposure to forest fire.

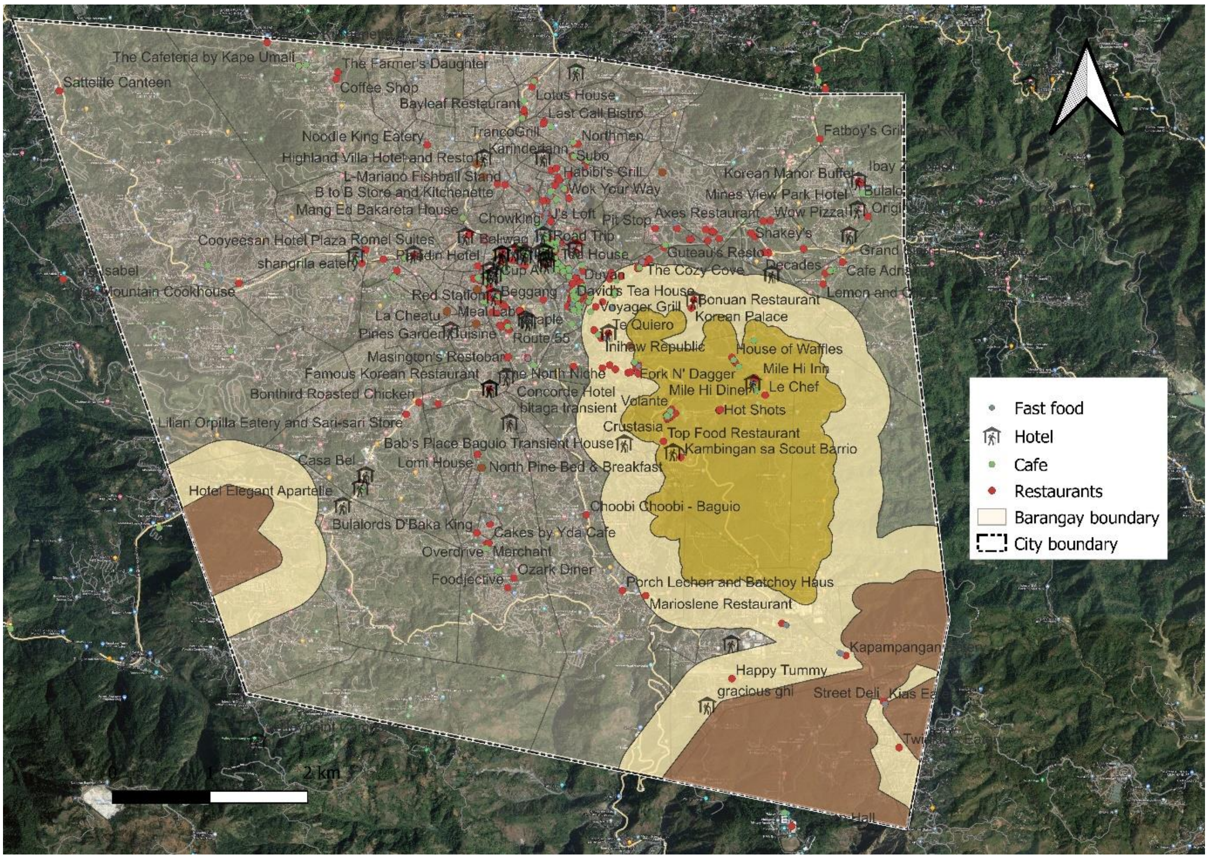


Figure 58: Forest fire to the economic sector of Baguio
Source: Author

b. Heritage and Culture

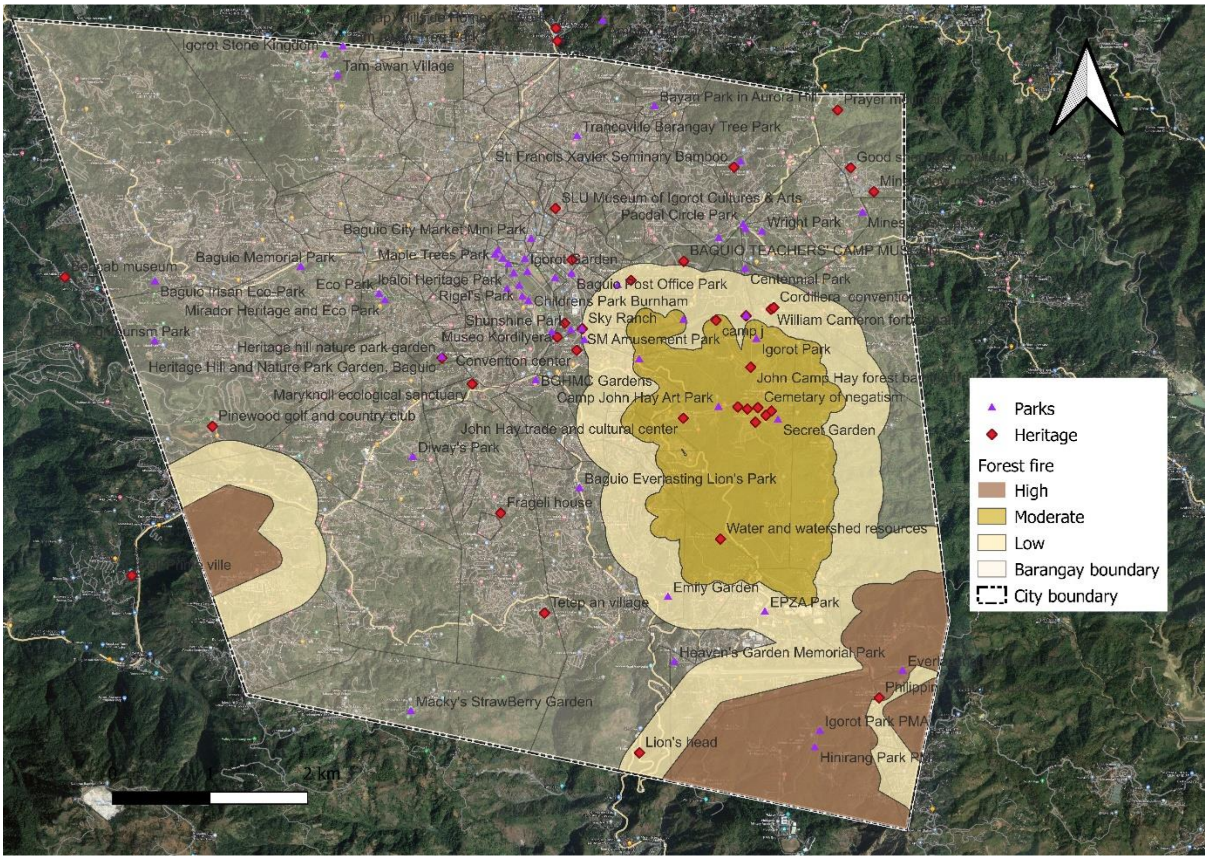


Figure 59: Forest fire exposure of heritage and culture of Baguio
Source: Author

Forest fires may destroy natural attractions such as tracks, vistas, and viewpoints which may be irreplaceable (Boustras & Boukas, 2013). This will thus reduce nature-based tourism and the dependent economy. The threat of fire also affects tourist interest and perception of the place.

In Baguio, 1 of 36 recreation spots is in high exposure, 10 in medium exposure and 6 in low exposure areas. The highly exposed area is the famous Philippine Military Academy. The medium exposed area such as, Bell Amphitheater, Butterfly Sanctuary, Cemetery of Negativism, Horse Back Riding Camp and John Hay Trade and Cultural Center is within the Country Club Barangay that consist of urban forest.

Similarly, 3 of 54 parks are in the high exposure zone, 5 is moderate and 6 have low exposure to forest fire in Baguio.

c. Commercial and Industrial Assets

The commercial sector is within 500m of the low exposure zone of forest fire in Baguio City. The industrial sector is within the low exposure zone of forest fire in Baguio City. It is about 800m away from the high exposure zone. The damage to industry affects the local employment and wages. The industries will want a relocation, by conceiving the prior location as a constant threat. Hence, affects the labor market and economic growth of Baguio City (Spence, 2016).

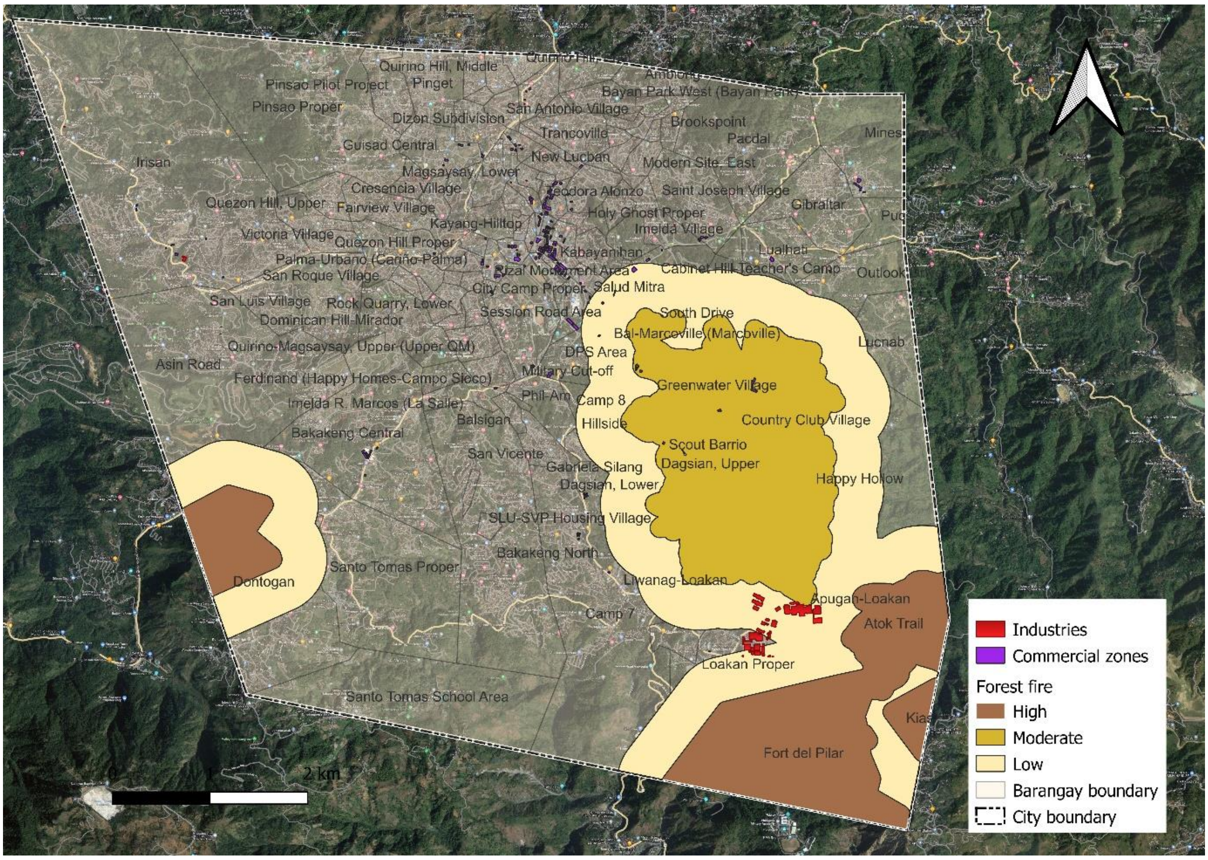


Figure 60: Forest fire exposure of commercial and industrial infrastructure in Baguio
Source: Author

4.5.2.4 Existing Land Use and City Planning Exposure to Forest Fire

Over 6% of the city area is at a high risk of forest fires. Barangays such as Apugan-Loakan, Atok Trail, Dontogan, Fort del Pilar, Happy Hollow, Kias, Loakan Proper, and Santo Tomas Proper have the maximum exposure due to their proximity to periphery forests. The proposed land use map suggested transforming the Camp John Hay area into a residential zone, which may increase these residents' exposure to forest fire.

A commercial zone and General Institutional zone proposed in Fort del Pilar barangay may act as a secondary growth pole apart from CBD and invite future urban development (Figure 60). However, this development will fall within a high-risk exposure area, which calls for defining preventive measures.

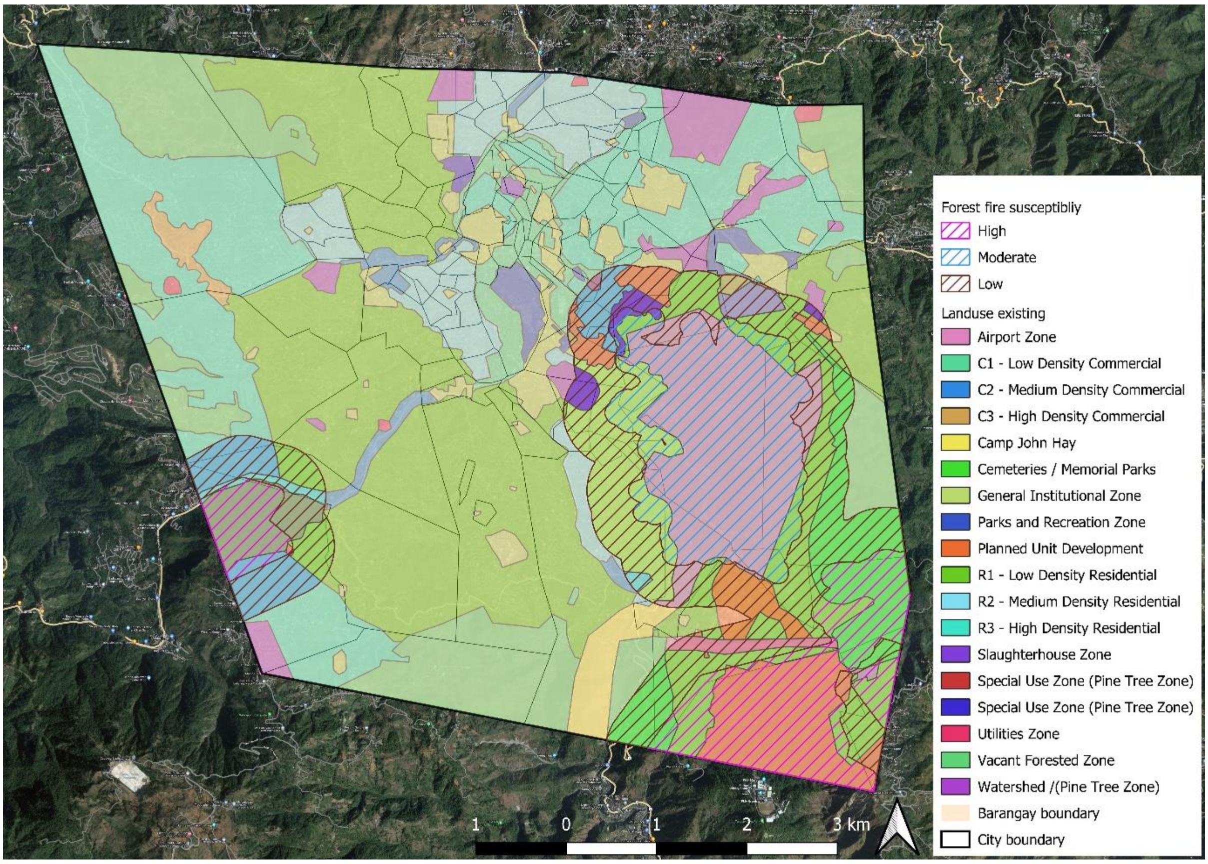


Figure 61: Existing land use exposure to forest fires
Source: Author

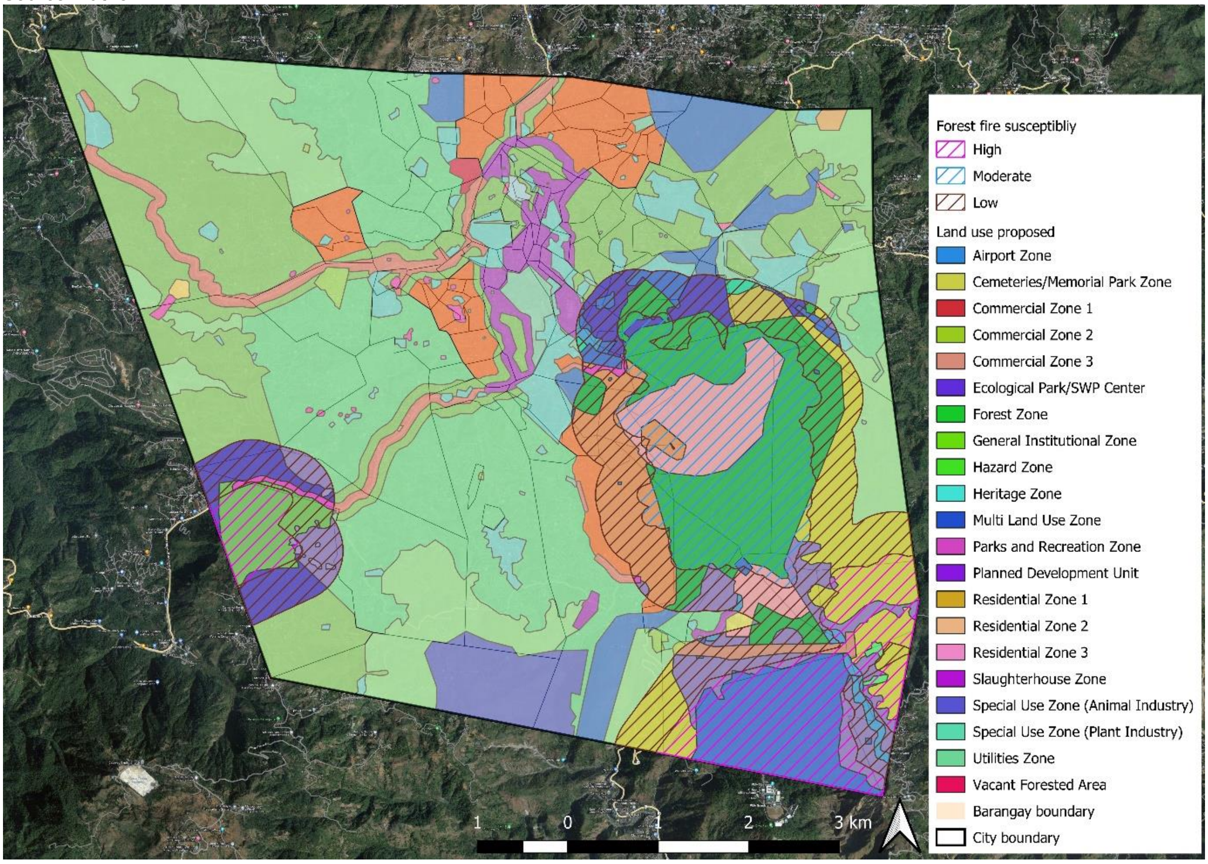


Figure 62: Future land use exposure to forest fires
Source: Author

4.5.3 Conclusion

Forest fires are not considered a risk in the existing Baguio’s planning documents. It is not surprising because the city has not witnessed such incidences in the past. However, increasing forest fire incidences in Baguio’s vicinity and worldwide coupled with Baguio’s projected temperature increase are indicative of an upcoming risk growth for Baguio City. Forest fire prone zones should benefit from enhanced resilience provisions such as nearby fire stations, appropriate building construction materials, and awareness raising to lower man induced incidents.

3.6 Urban Heat Island Effect

UHI effect is considered as a man-made phenomenon rather than a natural hazard, however it has been included to the analysis considering its importance for the city's planning and investments. Satellite data shows that UHI is significantly affecting the city and mitigating it should be one of the city's priorities.

3.6.1 Urban Heat Island Assessment of Baguio City

3.6.1.1 Overview

Heat islands are areas which record higher temperatures compared to other neighboring areas. Heat islands are usually constructed and paved surfaces such as buildings, roads or parking lots. They tend to absorb and re-emit solar heat more than natural landscapes such as waterbodies and green areas. Areas with a higher concentration of paved surfaces and lack of greenery hence become islands of higher temperature compared to their surroundings. Often observed in urban areas, and therefore termed as UHI effect, this phenomenon may generate very negative impacts, such as severely affecting sensitive population categories' health or significantly increasing usage of indoor air conditioning.

Remote sensing helps detect UHI by collecting LST data at different locations of a city and comparing the outputs. Several researchers studied UHI using LST (thermal band) from satellite remote sensing, including Landsat missions by the US Geological Survey (USGS) (Martin, Baudouin and Gachon, 2015). The community of researchers recognize the potential of Landsat-derived LST in reflecting urban thermal properties.

It is important to highlight that **LST and air temperature are measured in very different ways**, and hence their respective results cannot be compared. Air temperature is typically measured by a local meteorological station at a height of 2 meters above the ground and provides data on the temperature of the air at the time of the measurement. LST, on the other hand, measures temperature of a solid surface. It is therefore not surprising to notice a sizable difference between the air temperature of Baguio (average annual value of 21°C), and the LST utilized for the UHI assessment.

3.6.1.2 UHI Triggering Factors

Urban areas comprise a number elements absorbing heat, and human activities such as motorized transportation or industrial processes generate additional heat. Therefore, heat islands tend to form in areas combining a number of the following elements (Martin, Baudouin and Gachon, 2015):

- **Ratio of built-up versus natural ecosystems and building/infrastructure materials**: Urban materials such as asphalt and concrete reflect less solar energy and absorb more heat compared to natural surfaces such as green areas and waterbodies. Due to slow heat dissipation from urban surfaces, urban areas experience unusually high temperature at night. Green areas and water bodies, on the other hand, cool the air through evaporation and transpiration.
- **Urban form**: The distance between roads and buildings, as well as their location versus natural airflows in each specific location, influence wind flow and natural shading. Tall buildings on narrow streets have a canyon effect. Urban physical features such as building heights, orientation and distance between buildings are often not optimized versus the local context's sun trajectory, air flows and natural ventilation, increase the UHI effect.
- **Anthropogenic heat**: Vehicles, air-conditioning units, and industrial facilities emit heat into the urban environment, and further contribute to the UHI effect.

3.6.1.3 UHI in Baguio City

An analysis of LST time series, as per the methodology described in Chapter 2, identified a significant UHI in Baguio's representative built-up areas. Specifically, it identified that in 2001, the CBD's mean LST was 6°C higher than in a city's forest area and 10°C higher than in a nearby rural area (Tables 27 and 28). Importantly, this difference further increased 20 years later. In 2021, it became 10°C higher than in the forest area and an impressive 14°C higher than in the rural area.

In addition, the LST data series show that while mean LST decreased by 4°C in the forest area and increased by only 2°C in the rural area between 2001 and 2021, it went up by 8°C in the CBD. These results showed that LST increase was directly proportional to urban/impervious expansion and inversely proportional to green expansion. These findings validated the findings of Spatiotemporal Variation of Urban Heat Islands for Implementing Nature-Based Solutions: A Case Study of Kurunegala, Sri Lanka (Ranagalage et al. 2020), which reported similar results.

Statistics	Densely built-up area		Rural area		Rural Green area	
	2001	2021	2001	2021	2001	2021
min (°C)	29	36	22	14	24	24
mean (°C)	36	42	26	28	30	26
max (°C)	45	48	30	32	41	35
standard deviation	3	2	2	2	3	1

Table 27: Statistics of Land Surface Temperature (LST) over different land use zones/areas
Source: Author

Statistics	Changes in °C			Changes in %		
	Densely built-up area	Rural area	Green area	Densely built-up area	Rural area	Green area
min	7	-8	0	25	-35	0
mean	5	2	-4	15	7	-15
max	3	2	-6	6	8	-17
standard deviation	-1	0	-1	-28	9	-99

Table 28: Changes in statistics of Land Surface Temperature (LST) from 2001 to 2021 over different land use zones/areas
Source: Author

Such outcomes lead to concluding that:

- The existing CBD experiences higher temperature in contrast to the old CBD of 20 years ago. It can be deduced that the areas experiencing higher urbanization have higher temperature increments.
- The decreasing LST over the green area may be attributed to the growth of canopy and trees in the forest area over a 20-year time span.

The UHI effect in Baguio confirms the strong relationship between urbanization and temperature rise. The assessment demonstrated that greening measures would be very effective in reducing UHI in Baguio City, and hence in capping its future electricity consumption for indoor cooling (air conditioning).

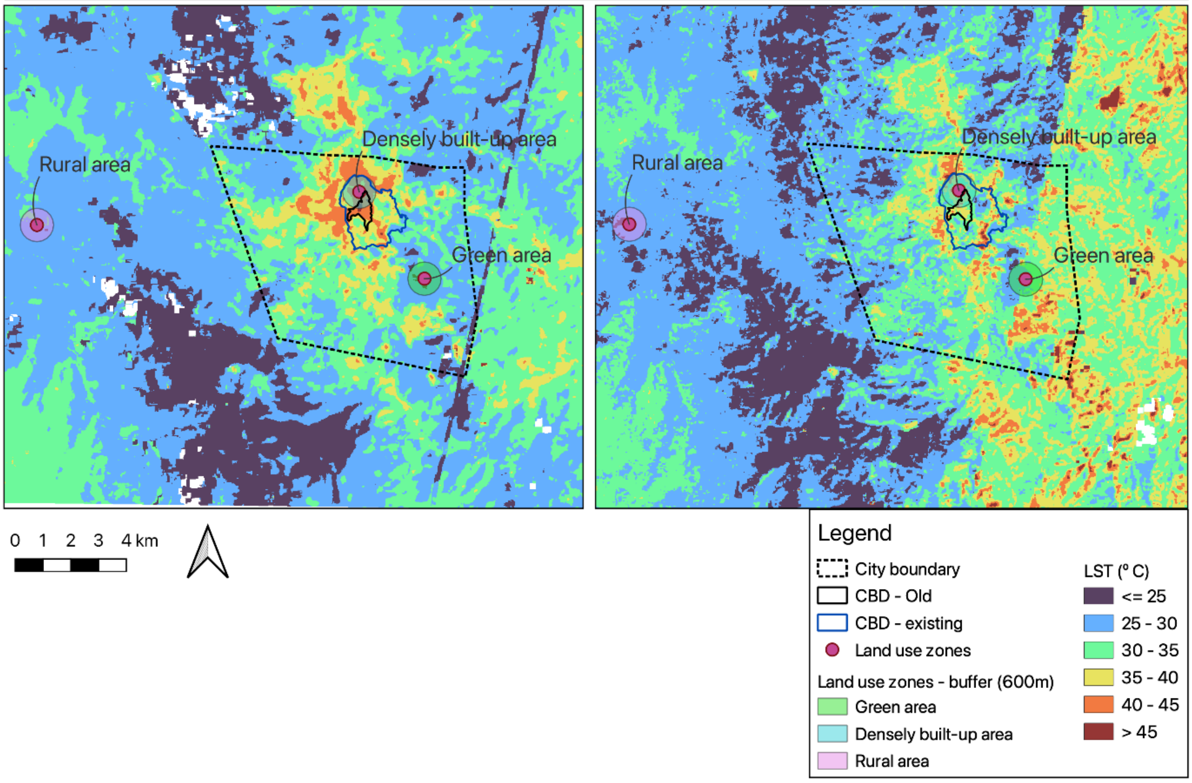


Figure 63: "Land Surface Temperature (LST) spatial distribution for 2001 (left) and 2021 (right) overlaid with Central Business District
Source: Author

3.6.1.4 Climate Change Impact on UHI

Climate change has no exclusive influence on the UHI effect. However, a steady climate change temperature increase over Baguio is likely to further intensify the UHI, making built-up areas disproportionately hotter.

The Climate Change Assessment revealed that the **number of summer days with a daily temperature above 25° C would leap from 55 days over 1981-2010 to 170 days under RCP 4.5** and 207 days under RCP 8.5 over 2031-2060. Coupled with an increasing UHI is densely populated areas, this is likely to highly increase the usage of air conditioning in the city, hence reducing its climate change mitigation efforts, and to cause noticeable thermal discomfort for lower income and vulnerable populations.

3.6.1.5 UHI's Impact on Baguio

Pleasant temperature throughout the year is one of the main reasons for which tourism activity is sustained and dynamic in Baguio. Many tourism-related services such as hotels, cafés, restaurants and shops fall in the CBD area. Rising temperature due to the UHI effect can significantly affect tourism-related livelihoods. In this view, the hospitality sector may relocate to cooler pockets in the city to serve the tourism demand. However, this would land the city in a vicious loop: development in cooler pockets would further increase the extent of the UHI effect.

3.6.2 UHI Sectoral Exposure Assessment

UHI and climate change effects on temperature share similar consequences and tend to feed each other. For example, UHI increases the energy demand through increasing air conditioning (AC) demand. This, in turn, fuels climate change through burning primary energy sources for additional electricity required for AC. The difference, to an extent, lies in the scale of interventions. While the climate change is a global phenomenon and can only be mitigated with global efforts, the UHI effect remains local, is the product of local actions, and can be tackled with local interventions.

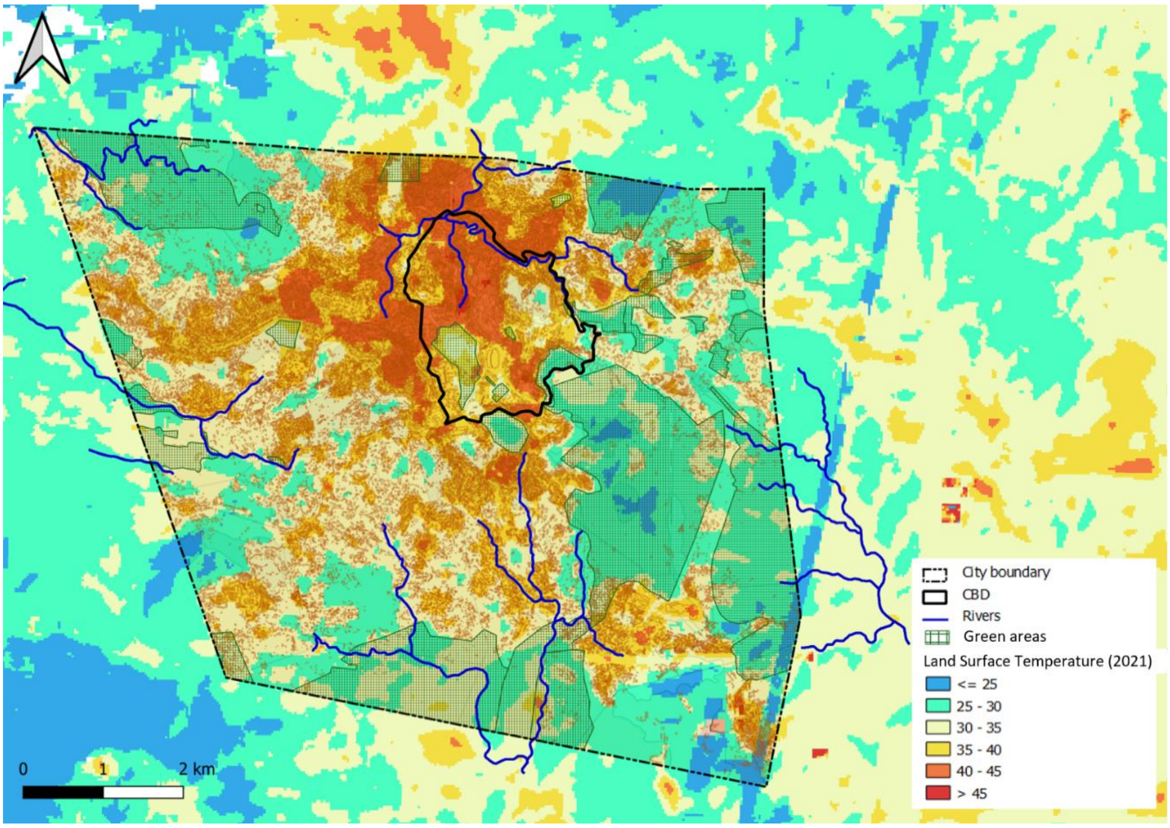


Figure 64: UHI effect in Baguio City
Source: Author

4.6.2.1 Infrastructure Sector's Exposure to UHI Effect

a. Essential Buildings

Essential buildings in very high-temperature zones will face reduced work productivity and cause fatigue to inhabitants. It may also trigger heat-related health issues in people getting long-hour exposures.

b. Transportation

Very high-temperature pockets in cities affect the transportation sector, such as melting of asphalt roads and distortion of rails at around 60 °C. Baguio City may not face such a situation in the near future. However, the combined effect of UHI and climate change can convert certain areas into very high-temperature pockets in the city under limited or non-existent cooling measures.

In the Northern part of Baguio, most of intercity roads are in high UHI area (Figure 65). This part of the city is the most built and urbanized. A high presence of impervious surfaces such as road networks, buildings and open built spaces is the result of a consolidated and car dependent urban structure, which generates the UHI phenomenon.

Private vehicles and jeepneys are the main mobility means in Baguio City, which generates traffic congestion, air pollution, high greenhouse gas emissions, and the phenomenon of heat transfer and radiation occurring between the air and the soil surface, which leads to UHI. To reduce UHI, this mobility pattern needs to be replaced with a combination of walkability, cycling and efficient public transportation.

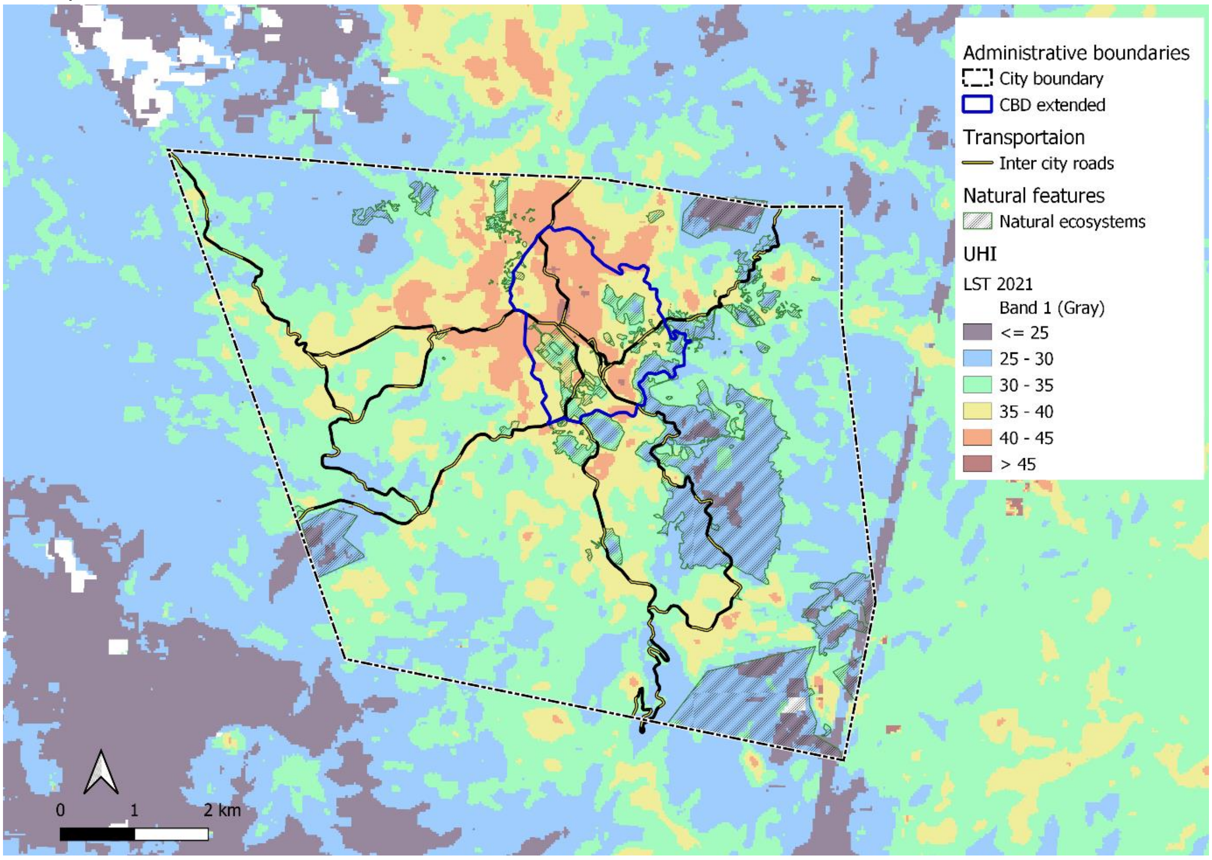


Figure 65: UHI effect and natural ecosystems
Source: Author

c. Water Supply and Wastewater Management

UHI increases water demand in the affected areas and causes evaporation of water sources leading to reduced water supply. This phenomenon is likely to be particularly affecting the northern part of the city, where UHI is the strongest. UHI also increases the temperature of water flowing into urban streams. It affects the aquatic ecosystem by rising stream water temperature.

Facilitating draining of excess storm water through patented vents into small, vegetated areas along the roads may help address these effects in two manners:

- This measure would require greening the city center, which in itself will lower the UHI;
- It partially cools down street surfaces, which controls UHI as well.

d. Energy

UHI's impact on the energy sector may be highly significant. Energy demand in very high-temperature pockets is bound to increase with the growing demand for cooling. In parallel, AC systems release heat into the streets, causing more outdoor heating. This cycle may lock the affected built-up area into a vicious loop of heating and cooling. Nature-based solutions are most effective to break it.

4.6.2.2 Social and Economic Sectors' Exposure to UHI

As of today, Baguio City benefits from very comfortable temperatures, praised by visitors. However, over the dry season and during the middle of the day hours, an outdoor thermal discomfort is already felt in densely built-up city areas, where temperatures are at their highest. A similar discomfort is felt if walking along big road axes. This situation is generating the following consequences:

- Visitors and residents may spend less time outdoors and more time in their vehicles, instead of reversing this trend, which is likely to make the city further dependent of them and may incite it to widen existing roads, which in turn will exacerbate the vicious UHI spiral;

- The city's indoor thermal comfort may get increasingly dependent on the AC usage, which will result in significantly higher electricity bills and noticeably higher GHG emissions related to electricity consumption;

- Residents with lower incomes may suffer thermal discomfort;

- Commercial areas will continue developing indoors, which will further distance the city from its intangible heritage and related outdoor commercial activities such as street vendors or semi-covered markets;

- Overall, the above may lead to health degradation due to heat affecting most vulnerable population categories and insufficient time spent outdoors;

- A higher cooling related electricity consumption may occur during industrial processes, further enhancing production costs and UHI in the industrial area.

In the long run, UHI coupled with climate change-induced rising temperatures, may negatively affect the tourism sector if thermal comfort no longer meets visitors' expectations (Figure 66). More tourism may be directed outside of Baguio City instead, into neighboring and less urbanized municipalities.

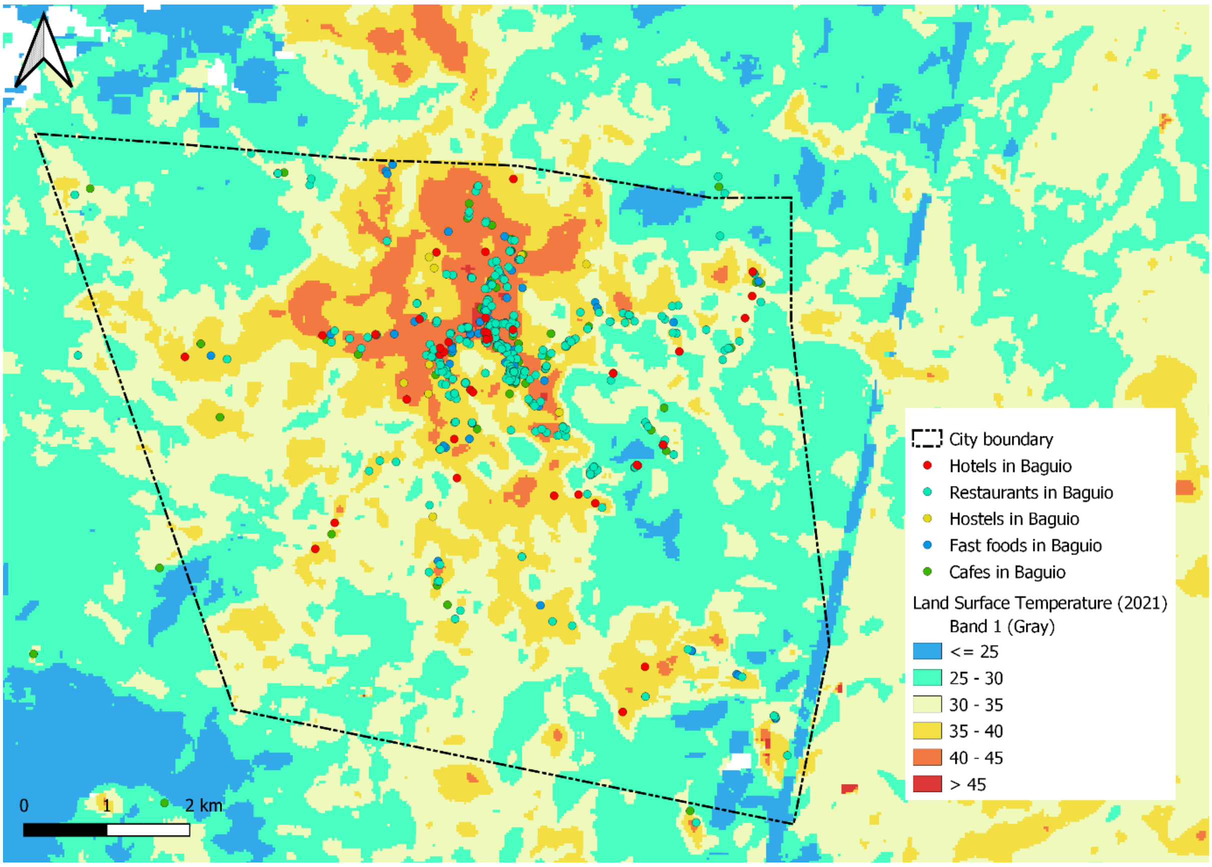


Figure 66: Tourism-relate service sector and UHI
Source: Author

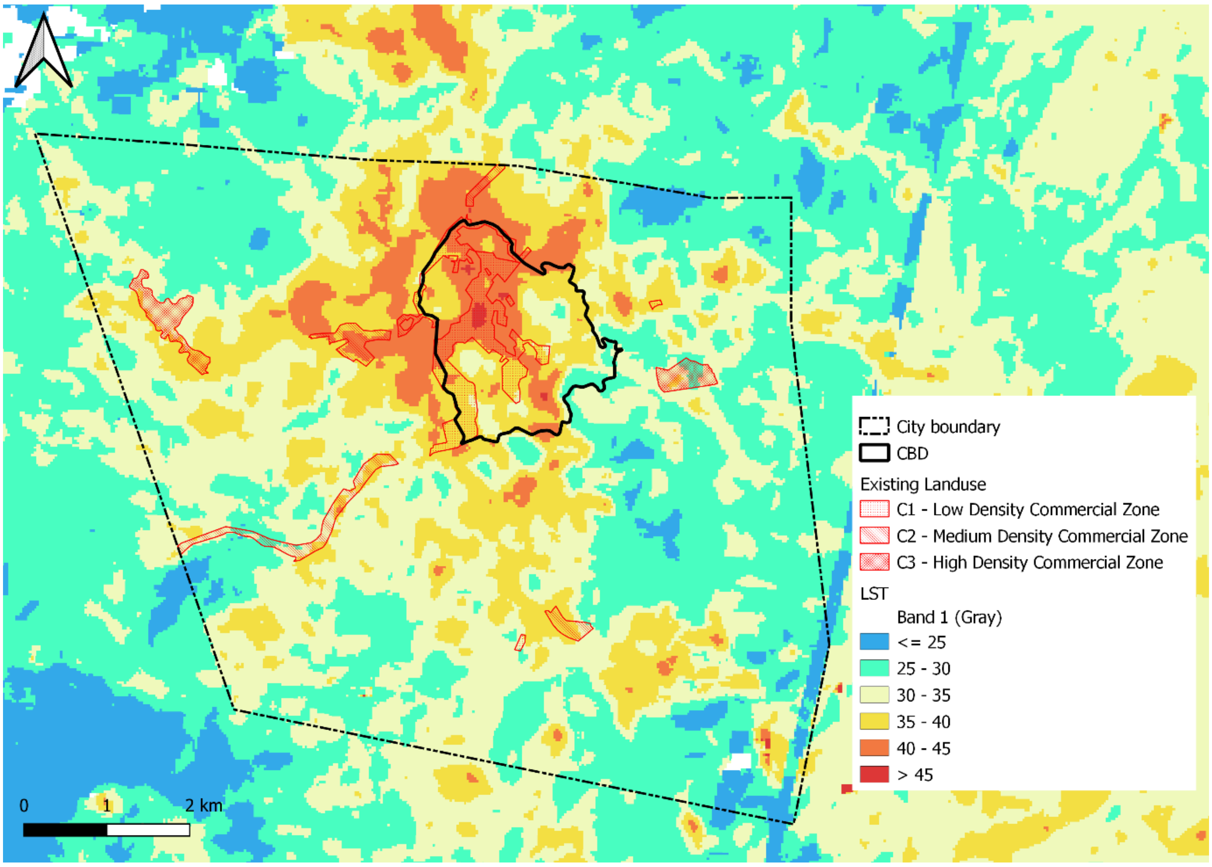


Figure 67: UHI and commercial zones in Baguio
Source: Author

3.6.3 Conclusion

The city has not yet officially acknowledged urban heat island as a challenge. However, as per the Enforced Policy of the City Environment Code, particularly in Section 36, Article 8-Green Building Policy, it is recommended that building designs incorporate rooftop water harvesting to deal with water stress due to anticipated temperature rise. Implementation is planned for the period of 2023-2030. The initiative Urban Greening Project advocates increased forest cover in the city. Currently, the project is limited to forest areas, could consider including greening urban streets to mitigate the UHI effect.

4. Multi-hazard Exposure Sector Risk Assessment

Multi-hazard mapping helps visualize which areas of the city are exposed to higher risk hazards. An MHM is compiled based on individual hazard maps brought under one denominator. Such a map further supports informed and prioritized urban development decision-making. The methodology used for the present MHM is detailed in Chapter 2 on Methodology. This Chapter summarizes Baguio's sectoral exposure to multi-hazards.

Summary: Multi-Hazard Mapping

All hazards have different risk scores in different city areas, which means that each hazard exposes different city areas in a different manner. To be in a position to compare levels of exposure between different hazards, a GW was assigned, and a weighted overlay analysis was conducted. A **GW** of each hazard is a normalized value out of 1, so that the sum of all hazard's weighted values equals to 1 (Table 29).

Hazard	Frequency	Severity	Risk score	Global weight	Round of vaue	
	(f)	(s)	(f x s)			
Landslides	1	0.99	0.98	0.362962963	0.36	**GW1**
Floods	0.87	0.99	0.86	0.318518519	0.32	**GW2**
Earthquakes	0.29	0.99	0.29	0.107407407	0.11	**GW3**
Sinkholes	0.58	0.5	0.29	0.107407407	0.11	**GW4**
Forest fires	0.46	0.6	0.28	0.103703704	0.1	**GW5**
		Sum	2.7		1	

Table 29: Global weights for the hazard maps
Source: Author

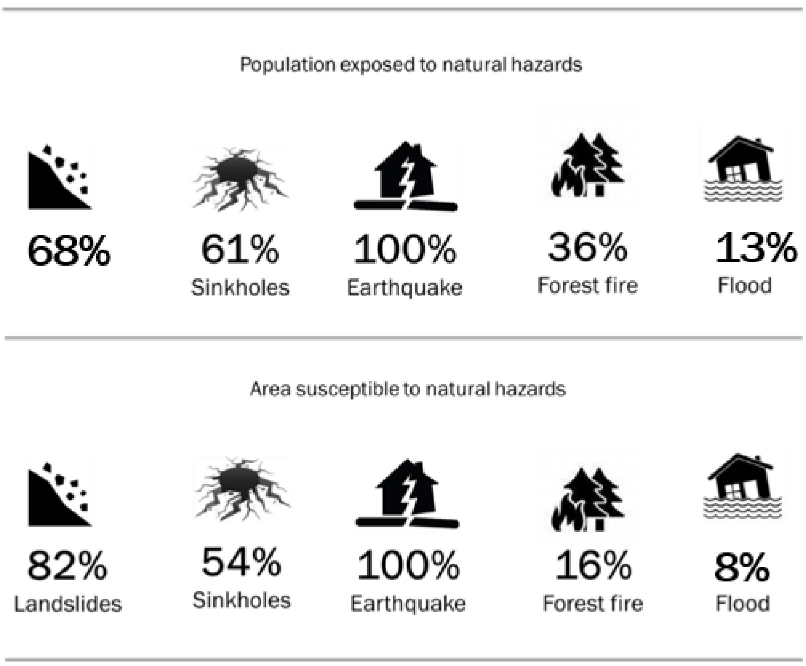


Figure 68: Population and area share exposed to each natural hazard
Source: Author

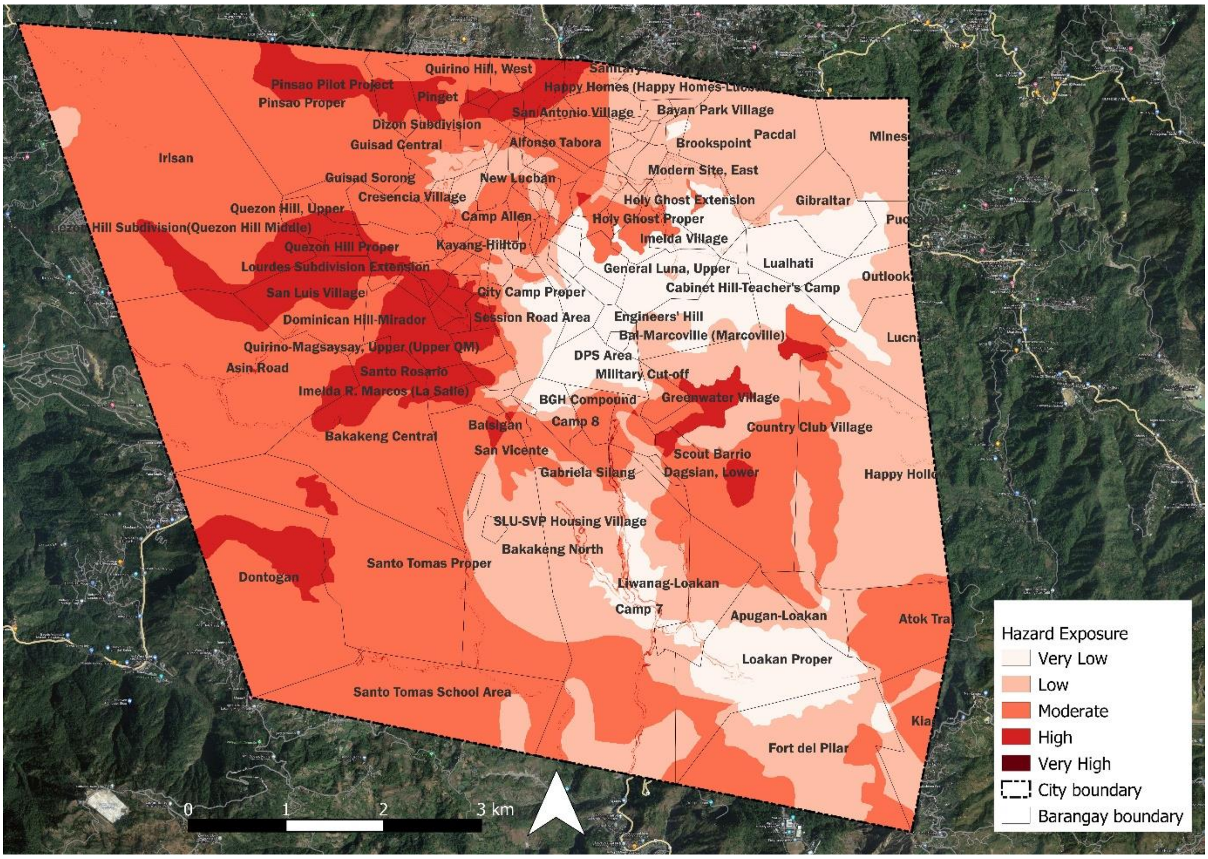


Figure 69: Multi-hazard exposure map, Baguio
Source: Author

Nearly 28% of the total city's surface falls under a low multi-hazard exposure zone; 11% fall under a very low exposure zone and 10% under a high exposure zone. The rest of the city, or nearly 51% of its surface, fall under a moderate risk category. Very high exposure zones cover less than 1% of the surface and are not visible from citywide multi-hazard risk maps. They are thin strips which combine very high exposure to landslides and very high exposure to floods (50-year return period floods), which can be visualized in GIS from the maps provided to the city.

Baguio's multi-hazard exposure may be divided into two main macro-areas: the western part of the city is mainly falls under a moderate to a high exposure zones, and the Eastern part predominantly falls under a very low to a moderate exposure zones, with a few small high exposure zones.

The multi-hazard exposure assessment identified four types of key most exposed sectors, namely: essential buildings; transport; wastewater and water supply; tourism and culture sectors. All these sectors are vital for the city's socioeconomic development, and particular attention hence needs to be given to building their climate resilience.

4.1 Essential Buildings

Essential buildings serve basic community needs such as health, safety, and education. In Baguio, over 30% of essential buildings—53 schools, 15 hospitals, 4 police stations and 1 fire station—are located within the CBD area, while the remaining 70% of essential buildings—147 schools, 3 hospitals, 12 police stations, 3 fire stations and 10 community centers—are outside the CBD area. When overlaid with the MHM, **50% of total essential buildings fall into a moderate to high to risk category**, followed by 21% of buildings under a low risk and 29% under a very low risk.

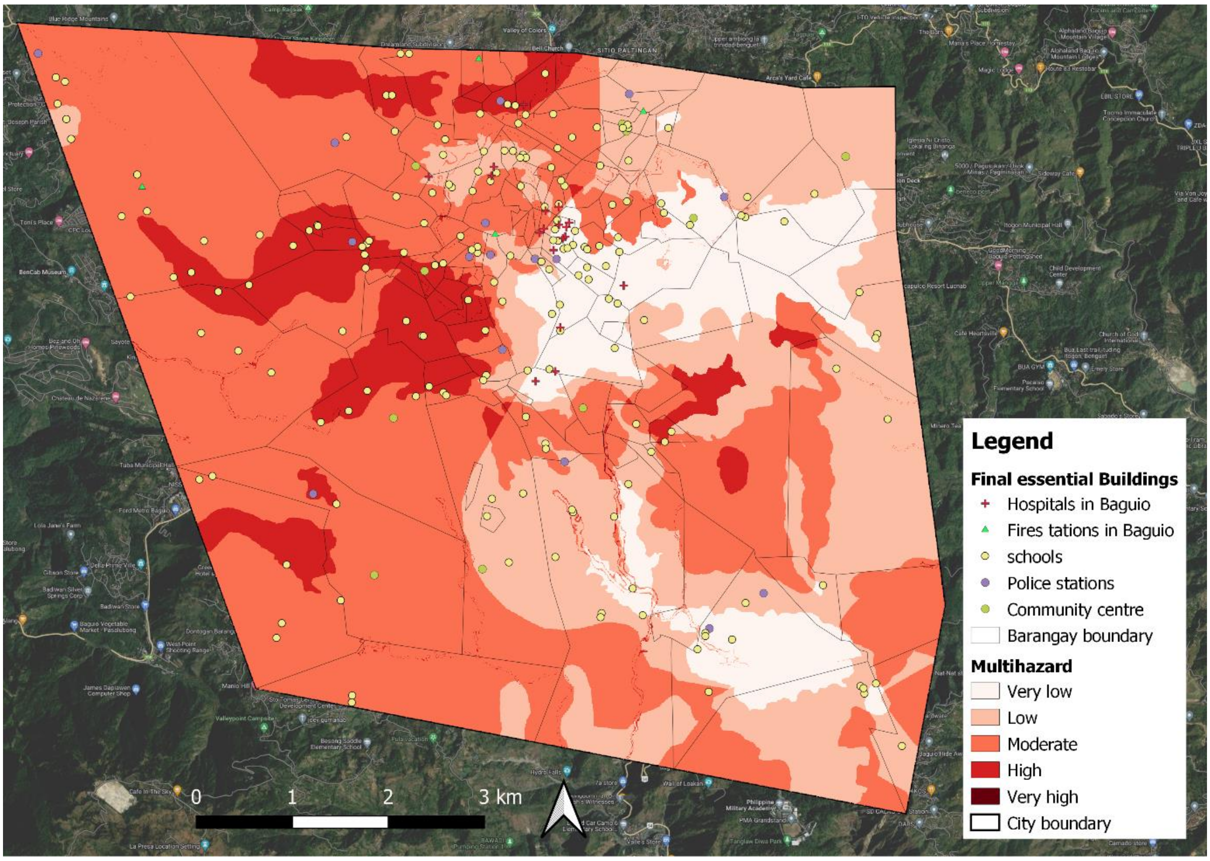


Figure 70: Multi-hazard exposure to essential buildings
Source: Author

Most essential buildings within the CBD fall into a low-risk category: 53% of them fall into a low-risk category compared to only 18% outside the CBD area.

In terms of types of essential buildings outside the CBD area, hospitals and fire stations fall under medium risk, however their number is very limited with most of these being located within the CBD. The number of schools, on the other hand, is sizable: 88 of them fall under a moderate to a high-risk categories. This makes Baguio's children highly susceptible to hazard risks.

	Type of Essential Buildings	Numbers of Buildings (A)	High (H)	Moderate (M)	Low (L)	Very low (VL)
Area/ numbers within CBD	Schools	53	0	14	10	29
	Hospitals	15	0	6	0	9
	Fire Stations	1	0	0	1	0
	Police Stations	4	0	2	1	1

	Community Centers	0	0	0	0	0
Total (A) = (VH+H+M+L)		**73**	**0 (0%)**	**22 (30.14%)**	**12 (16.44%)**	**39 (53.42%)**
Area/ Numbers outside CBD	Schools	147	39	49	31	28
	Hospitals	3	1	1	0	1
	Fire Stations	3	0	2	1	0
	Police Stations	12	3	4	3	2
	Community Centers	10	2	2	4	2
Total (A) = (VH+H+M+L)		**175**	**45 (25.71%)**	**58 (33.14%)**	**39 (22.29%)**	**33 (18.86%)**
Total		**248**	**45 (18.15%)**	**80 (32.26%)**	**51 (20.56%)**	**72 (29.03%)**

Table 30: Multi-hazard analysis facts pertaining to Essential buildings
Source: Author

The above shows that the city needs to prioritize the following:

- Increase the number of hospitals outside the CBD area, so that they can be timely reached in case of a disaster by all Baguio residents and visitors;
- Strengthen disaster resilience of schools and community centers. In addition to making children highly exposed and vulnerable when located in highly exposed areas, these are also common evacuation and safety centers during disasters and need to be highly resilient to them themselves.

4.2 Transport

Primary city roads and intercity roads are critical life arteries connecting the residents and visitors to the city and intercity assets. They also play a key role when a disaster occurs: their quality during and past a disaster determines the quality of rescue, evacuation, and recovery operations.

Baguio City has eight intercity roads, which are also primary intercity arteries: Elpidio Quirino Highway (H54), Magsaysay Avenue (H 204), Macros Highway (H 208), H 233, H234, Kennon Road (H 54), H 231 and H 110. A spatial multi-hazard analysis revealed that 59% of these roads' stretches within the city boundaries are exposed to a moderate to high risk, followed by 22% falling under a low-risk zone and 19% under a very low-risk zone.

As with essential buildings, the CBD road stretches are less exposed compared to the rest of the city. Within the CBD, 19% of roads' stretches fall under moderate risk zones while outside the CBD area it is 67%. Major roads exposed to risk outside the CBD are the Elpidio Quirino highway (H 54), Marcos Highway (H 208), Highway H 234 and Highway H 233. Of these, the Elpidio Quirino Highway (H 54) and Marcos Highway (H 208) are the two roads that connect the western part of the city to the CBD, and hence to hospitals. This is important because the western part of the city is most prone to multi-hazards. Nearly 7.3 km of the Elpidio Quirino Highway and 1.12 km of the Marcos highway fall under a moderate to high-risk zones. Other important roads on the western part of the city - Highway H 234 and Highway H 233 – also fall under a high-risk zone.

	Road Name	Area in km (A)	High (H)	Moderate (M)	Low (L)	Very low (VL)
Area/Roads within CBD	Elpidio Quirino Highway (H 54)	0.48		0.11	0.37	
	Magsaysay Avenue (H 204)	1.62		1.32	0.30	
	Marcos Highway (H 208)	0.22			0.10	0.12
	H 233	0				
	H 234	0				
	Kennon Road (H 54)	1.64			0.26	1.38
	H 231	1.64			0.24	1.40
	H 110	1.96				1.96
Total (A)= (VH+H+M+L)		**7.55**	**0**	**1.43 (18.94%)**	**1.26 (16.74%)**	**4.86 (64.32%)**
Area/Roads outside CBD	Elpidio Quirino Highway (H 54)	7.28	3.60	3.68		
	Magsaysay Avenue (H 204)	0.88	0.76	0.12		
	Marcos Highway (H 208)	4.39		3.95	0.44	
	H 233	3.97	0.41	3.56		
	H 234	2.06	0.20	1.86		
	Kennon Road (H 54)	7.15		1.78	4.42	0.95
	H 231	6.12	0.8	2.74	1.30	1.28
	H 110	2.94			1.98	0.96
Total (A) = (VH+H+M+L)		**34.78**	**5.77 (16.60%)**	**17.68 (50.84%)**	**8.14 (23.39%)**	**3.19 (9.17%)**
Total		**42.33**	**5.77 (13.63%)**	**19.11 (45.15%)**	**9.40 (22.21%)**	**8.05 (19.02%)**

Table 31: Multi-hazard analysis facts pertaining to transportation
Source: Author

Within the CBD area, the stretch of 1.32 km of Magsaysay Avenue (H 204) road connects the city with other major municipalities such as Tublay or Kapangan falls under a moderate risk zone.

H-110 is the safest highway compared to other routes as it lies within the least hazard prone area. The stretch of Kennon Road (1.64 km) and H 231 (1.64 Km) within the CBD area are also comparatively safe.

The information above needs to be looked at through the lens of landslide proneness which, as per the information communicated by the city to the ADB, affects all intercity road entries to the city.

The city reported to have been locked in for nearly a month during a major earthquake which triggered major landslides which, in turn, blocked road entries to the city.

It is important to design safe citywide rescue, evacuation and basic amenities' supply routes considering exposure features identified above, as well as diversity the location of hospitals to cover the city more equitably with medical services.

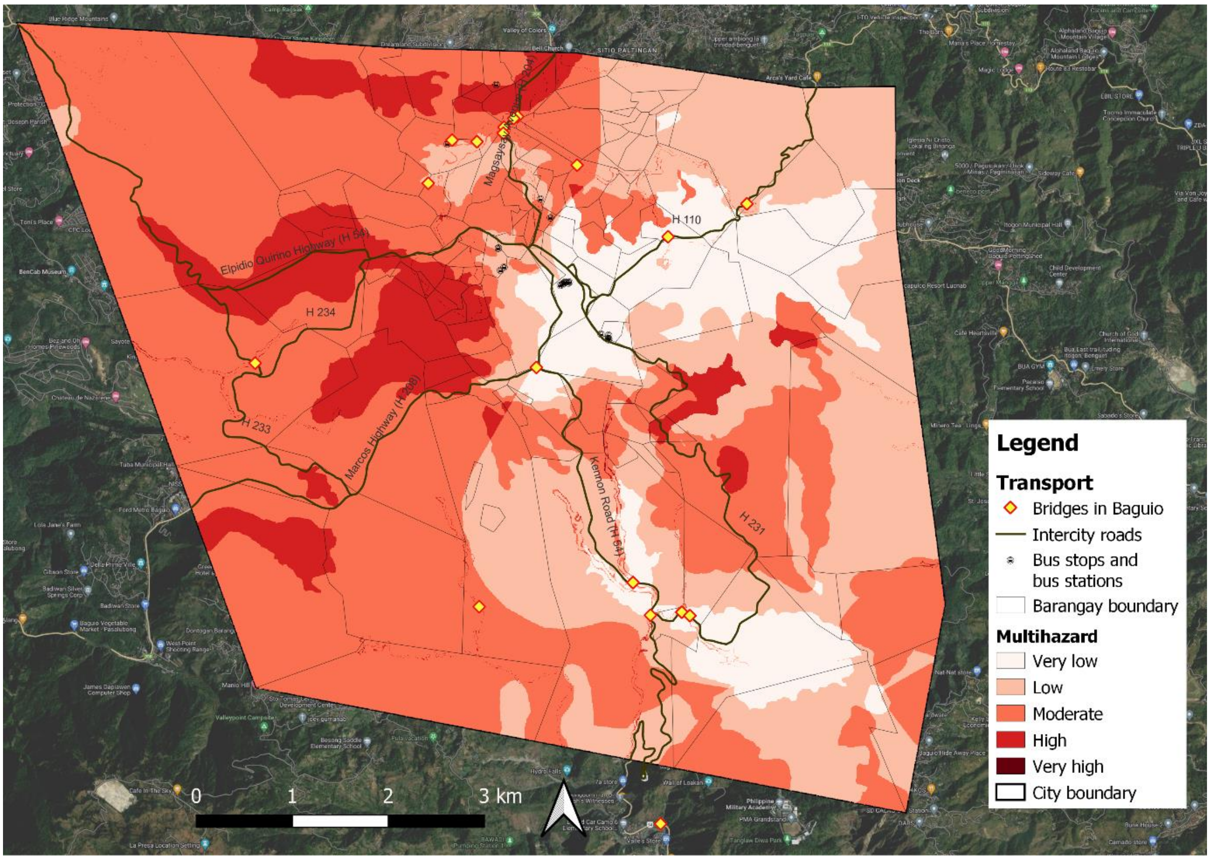


Figure 72: Multi hazard exposure to transportation
Source: Author

4.3 Water Supply and Wastewater Management

Similar to essential buildings and mobility, water supply and drainage management are critical to the city's functioning. A lack of good quality water may generate major health hazards, disrupt functioning of evacuation centers and hospitals, and slow down the city's overall socioeconomic activities. Affected natural and artificial drainage channels may promptly lead to flash floods and, if affected beyond 2-3 days, also lead to longer floods in the city.

Multi-hazard assessment of the sector revealed that nearly 55% of water related infrastructure is exposed to a moderate to a high risk, 22% to low risk, and only 23% or less than one-quarter to very low risk. As earlier, the western part of the city remains the most exposed: its whole value chain of water supply and wastewater system is under moderate to high risk.

In an emergency context, an adequate water storage is critical, however 29 out of 56 reservoirs and water tanks are in the moderate to a high-risk zone outside the CBD area. An operational drainage water discharge is also important to evade water logging forming flash floods. However, 1,262 drainage inlets are located under a moderate to a high-risk zones outside the CBD area, which makes the city vulnerable to flash floods and rainfall-induced landslides.

Comparatively, within the CBD area, water related infrastructure is at lower risk. Nearly 35% fall under a moderate to a high-risk zones versus 57% outside the CDB, and 40% fall under a low-risk zone versus 21% outside the CBD.

	Wastewater and water supply related infrastructure	Numbers of connection (A)	High (H)	Moderate (M)	Low (L)	Very low (VL)
Area/infrastructure within CBD	Drainage inlets	316		111	78	127
	STP	0				
	Septic tanks	2		1	1	
	Reservoirs	3		1	1	1
	Water tower taps	1		1		
	Deep wells	0				
Total (A)= (VH+H+M+L)		**322**		**114 (35.4%)**	**80 (24.8%)**	**128 (39.8%)**
Area/infrastructure outside CBD	Drainage inlets	2209	400	862	475	472
	STP	3	2			1
	Septic tanks	10	2	6	1	1
	Reservoirs	56	12	17	18	9
	Water tower taps	3	1	2	0	0
	Deep wells	1	1	0	0	0
Total (A) = (VH+H+M+L)		**2282**	**418 (18.3%)**	**887 (38.9%)**	**494 (21.6%)**	**483 (21.2%)**
Total		**2604**	**418 (16.1%)**	**1001 (38.4%)**	**574 (22.0%)**	**611 (23.5%)**

Table 32: Multi-hazard analysis facts pertaining to wastewater and water supply management
Source: Author

The above calls for the following measures:

- Review the water supply considering its exposure to multi-hazards and identify most critical water supply sources and channels which need to be disaster proofed in such a way that water supply to schools, evacuation centers, hospitals and residents remains constant during disaster times.
- Review the wastewater management system considering its exposure to multi-hazards and prepare a disaster resilience plan for critical drainage canals.

4.4 Tourism and Culture

Baguio's economy is heavily connected to tourism-related activities. As such, it is not only important that tourism-related facilities are resilient to the combination of hazards affecting the city, but equally that the city visitors perceive the city as safe. In addition to disaster proofing tourism and culture related areas, it is hence equally critical to disaster proof essential buildings, transport routes and water management so that Baguio can be a safe city

As per the present multi-hazard assessment, nearly 30% of the hospitality and recreation facilities fall under a moderate to a high-risk zones, the rest located under a low or a very low-risk zones. Most of these facilities situated in the CBD area, including cafés, fast food outlets, restaurants, hotels, hostels, recreation spot and parks, are at a low or a very low risk. They represent 62% of hospitality and recreational facilities versus only 37% outside the CBD area.

	Type of Buildings	Numbers of Buildings (A)	High (H)	Moderate (M)	Low (L)	Very Low (VL)
Area/Tourism buildings within CBD	Cafés	69		10	10	49
	Restaurants	195		37	35	123
	Fast foods	99		24	10	65
	Hostels	5		3	1	1
	Hotels	15		3	6	6
	Recreation spots	8		1		7
	Parks	19		3	11	5
Total (A)= (VH+H+M+L)		**410**		**81 (19.8%)**	**73 (17.8%)**	**256 (62.4%)**
Area/Tourism buildings outside CBD	Cafés	38	8	12	5	13
	Restaurants	135	23	28	20	64
	Fast foods	31	3	9	9	10
	Hostels	7	3	0	2	2
	Hotels	22	4	9	4	5
	Recreation spots	28	2	12	8	6
	Parks	35	7	9	9	10
Total (A) = (VH+H+M+L)		**296**	**50 (16.9%)**	**79 (26.7%)**	**57 (19.3%)**	**110 (37.2%)**
Total		**706**	**50 (7.1%)**	**160 (22.7%)**	**130 (18.4%)**	**366 (51.8%)**

Table 33: Multi-hazard analysis facts pertaining to tourist structures
Source: Author

In view of Baguio planning to create alternative growth hubs and to distribute the tourism inflow more uniformly across the city's surface, identifying safer areas for tourism-related facilities will be critical to enhance socioeconomic opportunities related to tourism for the city.

4.5 Conclusion

Multi-hazard mapping showcased that the CBD is comparatively safer than other city areas, and that the western part is most exposed to multi-hazards. It is important that Baguio City prepares sectoral disaster resilience plans for sectors which are central to its safety and operational functioning: essential buildings, transport routes, water supply and wastewater management, and tourism. The multi-hazard assessment help identify safest areas where disaster support infrastructure may be located. For example, the airport zone falls under a low-risk category and could concentrate relief and shelter operations for the city.

5. Conclusion

The present CRVA report utilized outputs of the Climate Change Assessment and thorough data collection at the city level to prepare a hazard risk matrix, hazard and multi-hazard risk maps, sectoral maps, and conduct a sectoral exposure analysis of Baguio City. It identified which city areas, assets and barangays are exposed to various hazards, and the degrees of this exposure. It established that climate change will, either in a short or in a long run, affect all natural climate and geophysical hazards in the city: landslides, floods, earthquakes, forest fires and sinkholes – and exacerbate all of them. In particular, forest fires and sinkholes will become moderate risk hazards in the future instead of low-risk hazards today.

The results of the CRVA, coupled with separately provided GIS maps which can be overlaid as per the city's interests and priorities, are a practical and easy-to-use tool for Baguio's decision-makers to identify priority climate adaptation actions. A number of such most impactful actions have been proposed by the ADB team, validated with the municipality and summarized in an Investment Roadmap.

6 Annexes

Annexes have been provided as separate Excel files and downloadable file projects.

Annex 1: Hazard frequency and severity data collection tables

Annex 2: Hazard risk matrix tables

Annex 3: Barangay-wise exposure assessment table

Annex 4: GIS project

Annex 5: HEC HMS outputs

Annex 6: HEC RAS outputs

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