Ain Shams University
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Germany

Urbanization and its impact on biodiversity

Flora biodiversity assessment in relation to urban disturbance along the Wangchhu riparian zone, Thimphu: Bhutan

A Thesis submitted in the Partial Fulfilment for the Requirement of the Degree of Master of Science in Integrated Urbanism and Sustainable Design.

By:

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Supervised by:

Prof. Mohamed Salheen
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August 2021
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Abstract

Since the end of isolation in the 1960s, Bhutan has experienced rapid development, which has led to development in eco-sensitive zone such as along the river, steep slopes and forest, endangering the nature and future of humanity. Thimphu city has been experiencing a similar scenario, where most of Bhutan's population is living in 26 sq. km and physio-graphically experiencing a limitation to expand. Since then, the city's eco-fragile zone has experience encroachment, fragmentation, alteration, and destruction. Hence, this study aims to record, assess the biodiversity, and study the urban variables that affect the biodiversity along the Wangchhu riparian zone.

The research is based on the study of sample sites designated along the riparian zone of 30m from the riverbank. Primary data of flora and spatial are collected from the filed survey, and correlated using different methods. The framework adopted for the study resulted in understanding the flora characteristic of the city and urban factors that affect the vegetation along the corridor. Analysis of data showed rich species diversity, which is evenly distributed throughout the sample plots. The study also recorded invasive species along the study site. The record of urban variables and correlation with the flora study showed change in vegetation status and flora types as one move from south end toward north end of city.

It is evident that species diversity is affected by urban disturbance and there is the need for efficient monitoring and management of riparian corridors to create a sustainable settlement.

Key word: Riparian, biodiversity, disturbance, urbanization, habitat, diversity

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Glossary

COP-Convention on Biodiversity Conference of Parties
GNH-Gross National Happiness
IPBES-Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
ICUN-International Union for Conservation of Nature
IDH-Intermediate Disturbance Hypothesis
LD-Low Density
MD-Medium Density
MEA-Millennium Ecosystem Assessment
MoWHS-Ministry of Works and Human Settlement
OECD-Organization for Economic Cooperation and Development
P1- Plot Number 01
RGoB-Royal Government of Bhutan
SDGs-Sustainable Development Goals
TT-Thimphu Thromde (Municipality)
WB-World Bank
WWF-World Wildlife Fund
UN-United Nations
UV-Urban village

Chapter 01-Introduction

1.1 Global Biodiversity

The global species diversity has mostly remained mysterious given the limitless nature's capacity to support enormous life forms that are mostly unknown to humans. The taxonomic experts estimates that there are around 3 to 100 million species on the earth (Mora et al, 2011). Mora et al. (2011) predicts globally there are around 8.7 million (± 1.3 million species) eukaryotic species, which also includes around 2.2 million (± 0.18 million species) marine species. There is a total of 3.4 million to 3.9 million vascular plant species, and more than 2000 plant species are included yearly in the list. Additionally, biologists at Indiana University suggest that the earth could contain closely one trillion species of which only one-thousandth of 1 percent is discovered and 99.99 percent of species remain unknown to humans (Loceya et al 2016).

Despite the limited discovery of species, globally there is the challenge of rapid loss of species beyond recovery from the habitat. Several international research suggests that global species are declining at 50 to 100 times the natural rate due to the loss of the ecosystem caused by unsustainable human activities (NBC, 2009). The approximate rate at which species extinction is suggested to occur is 8-100 species per million species per year (Vricella, 2017).

The WWF: Living Planet Report 2014, reported that 52 percent of global biodiversity between 1970 and 2010. It presented that low-income countries were facing the greater loss of biodiversity, which account for a 58 percent drop. While middle-income countries suffered, 18 percent decline and increase of 10 percent in high-income countries. Although low-income countries suffered the highest biodiversity loss, high-income countries were consuming five times higher ecological resources (WWF, 2014).

The recent report by IPBES on global biodiversity and ecosystem shows that the rate of global biodiversity changes has been unprecedented during the past five decades. The report identified five direct drivers, which cause biodiversity loss leading to global impact so far. Direct drivers were namely alteration of land and sea uses, Exploitation of organisms, Climate change, Pollution, and increasing invasive alien species (IPBES, 2019). MEA (2005) and IPBES (2009) reports that there are also five indirect drivers, which cause changes in biodiversity and ecosystem services. These were demographic, economic, sociopolitical, cultural and religious, and scientific and technological, directly associated with human societal values and consumption habits.

The WWF report on Habitat at Risk (2002) urge for immediate action by stakeholders to conserve global biodiversity effectively. The study forecast that more than 70 percent of the habitats with rich and diverse ecosystems would be lost in the next ten decades. The lack of actions to restore and conserve biodiversity can further hasten the global rate of species extinction, which is currently about ten to hundreds of times greater than the average extinction rate that happened over 10 million years ago (IPBES 2019).

1.2 Global Biodiversity Conservation Initiative

The global concern on biodiversity loss, and actions to conserve and restore started to receive attention much later during the industrialization period and post-world war. It was in the year 1992, during the Earth Summit on Biological Diversity that international law acknowledged the importance of biodiversity conservation for sustainable human development. It was recognized as one of the key movements toward sustainable development (UNCED, 1992).

Soon, several biodiversity conservation efforts commenced internationally; one of the critical global scale projects is Global 200 by WWF. The project studied the

global pattern of biodiversity to identify ecoregions that has very rich biodiversity and ecosystem. For the first time, the project identified 238 ecoregions, which comprise 142 terrestrial, 53 freshwaters, and 43 marine priority ecoregions. The identified ecoregion in long term will ensure securing native habitats, native species, maintain essential ecological processes, and resilience of ecosystems to the ecological change. These ecoregions serve as critical in conserving the rich and healthy habitats for biodiversity on the planet (Olson et al. 2002). Most of the rich biodiversity found are near the water bodies such as the coastal region, wetlands, river systems, and tropical forests.

During the 10th COP meeting in Japan, the adoption of a "Strategic Plan for Biodiversity 2011-2020" marks the start of the UN's pledge on biodiversity conservation (SCBD 2014). The strategy plan agreed in 2010 comprised five strategic goals and the 20 Aichi Biodiversity Targets that accentuated effective and urgent action to achieve the 2050 Vision on Biodiversity, 'Living in Harmony with Nature'. The Aichi Biodiversity Targets focused on improving the state of biodiversity and response to divers affecting it (SCBD, 2020).

In 2015, with the expiration of "Millennium Development Goals"; "Sustainable Development Goals" (SDGs) or "17 Global Goals" were agreed by world leaders with a vision to create a better world by 2030 (UN 2020). Of these 17 goals, goal 14 (Life below Water) and 15 (Life on Land) explicitly focused on biodiversity. Biodiversity conservation is also a key factor in achieving some global goals such as goal 2; food security and improved nutrition and goal 6; Provision of Clean Water (SCBD, 2020).

On the contrary, SDGs contribute to addressing the divers of biodiversity loss and degradation by addressing climate change (SDG 12), exploitation of natural resources (SDGs 6, 12, 14, and 15), and pollution (SDGs 6,12 and 14) (UN 2020). Therefore, the conservation of biodiversity and achievement of SDGs are symbiotic and fundamental in achieving their goals.

1.3 Global Urbanization

Today, almost 4.2 billion world population reside in cities, which accounts for 55 percent of the total population and it is predicted to increase to almost 70 percent residing in cities (World Bank 2020). UNDP (2005) reports that by 2030 almost 1.75 billion new urban residents will be residing in small cities of developing

countries. The continuing trend of Urbanization is expected to consume 1.2 sq. km of new land within three decades, which will increases the stress on scarce land and natural resources (World Bank 2020).

Although the urban area covers less than 3 percent of the earth's surface, its location and urban fabric have a significant impact on biodiversity. Worldwide, it seems that urban growth occurs faster in low elevation coastal zones and valleys, which are rich in biodiversity and elsewhere (Elmqvist et al., 2013).

This urban growth affects biodiversity directly due to habitat fragmentation and destruction. Elmqvist et al. (2016) suggest that between 2000 to 2030, an urban area near the protected area could triple due to the continuous trend of urban expansion. Thus leading to encroachment in biodiversity hotspot areas that have a high concentration of endemic species.

Currently, 25 percent of the global protected areas lies within 17 kilometres of the city with a minimum population of 50,000. By 2030, this distance to likely to drop to 15 kilometers. Likewise, 29 percent of ecoregions that are home to 12 percent of the world’s terrestrial species will have more than one-third of the land as urban area (McDonald, 2008).

In the urban area, intense activities such as construction hasten the replacement of native species by non-native species (McKinney, 2005). A large city like New York has lost 578 native species, which accounts for a loss of almost 43 percent of original species. While the observed increase in 411 non-native species since the 1990s (DeCandido et al., 2004). A similar change has occurred in the suburbs of Berlin. Where non-native species have risen from 6 percent to 25 percent due to sub-urbanization in this area (Kowarik, 1995).

Although, biodiversity provides significant benefits to human health in cities. Urbanization has always undermined the importance of biodiversity through habitat degradation and destruction (Elmqvist et al., 2013), and these impacts are further worsen by the establishment of human settlement in biodiversity rich area such as coastal, riverside and so on (Alvey, 2006).

1.4 Biodiversity and Buddhism

Buddhism and nature have also been very close. The Buddhist idea of loving, kindness, and compassion extends beyond people and animals, it includes plants and the earth. The Buddhist philosophy's law of nature revolves around "Oneness" (Chaudhary et al, 2017). Buddhism is also regarded as a 'green' or 'eco-friendly' religion (James 2006).

The relation of nature and Buddhism existed from 2500 years ago, during the birth of Gautama Buddha. The Buddha was born in a forest, meditated and gain enlightenment beneath the Bodhi tree, and gave his teaching mediating below the tree. Thus, Buddhism values and principles are correlated with ecology (Henning, 1998). The Buddhist concept of unmitigated friendliness, compassion, and sympathy to all living creatures encourages respect, nurture, and preserve the natural environment. This concept refrains humans from causing harm to all forms of life, including plants (Kalupahana, 2009).

Bhutan is one of the last Mahayana Buddhism nations in the world. Buddhism has a significant part in the history of the country and people's way of life. Great saint Padmasambhava first introduced Buddhism in the 8th century A.D. The teaching has laid a foundation for the evolution of the unique culture and tradition of the nation (Dorje, 1990). The Mahayana Buddhism promotes an idea of co-existence with nature and discourage human from causing harm to nature (Kaewkhunok, 2019).

Biodiversity serves a predominant role in the lives of Bhutanese people, local communities venerate rich biodiversity such as wild animals, trees, mountains, ridges, river/stream, and lakes as these are considered an important part of spiritual well-being (NBC, 2009).

Therefore, the eco-friendly relationship between the Bhutanese and nature is due to the old beliefs and reinforced by Mahayana Buddhism's ideas of Oneness. These ideas have supported the government in implementing several biodiversity conservation interventions in the country.

1.5 Biodiversity and Constitution of Bhutan.

Bhutan is known as one of the top ten Biodiversity hotspots in world (Gillison, 2012). Biodiversity conservation has always been a vital national agenda for Bhutanese people. It was in 2008, Bhutan became a "Democratic Constitutional

Mnarchy" with an endorsement of " The Consitution of The Kingdom of Bhutan" n 2008. The Constitution contains a dedicated Article (5) on Environment, which mandates government and people to protect and conserve the environment for all time (NAB, 2008).

The environment is considered very important to the Bhutanese people and nation that in Article 5 (3) of the Constitution states:

> *"The Government shall ensure that to conserve the country's natural resources and to prevent degradation of the ecosystem, a minimum of 60 percent of Bhutan's total land shall be maintained under forest cover for all time."~The Constitution of The Kingdom of Bhutan.*

Additionally, Article 8 of the constitution also apprise Bhutanese citizens to recognize their "Fundamental Duties" to preserve, protect and respect the environment, culture, and heritage of the nation (NAB, 2008).

Today, the government of Bhutan has several laws that promote, conserve and protect the environment in addressing several environmental issues such as carbon dioxide emissions, ozone layer depletion, habitat loss or degeneration, and other issues such a water and waste management (Kaewkhunok, 2019).

Some of the important laws that promote and protect the environment in Bhutan are; the Environmental Assessment Act 2000, the Regulation for Environmental Clearance of Projects and the Regulation on Strategic Environmental Assessment 2002, the Environment Protection Act 2007, the Waste Prevention and Management Act of Bhutan 2009, the Water Act of Bhutan 2011, the Waste Prevention and Management Regulation 2012 and the National Strategy and Action Plan for Low Carbon Development that was formulated in 2012 (CBS, 1999).

Due to these comprehensive environmental policies in Bhutan, the Land use and Land cover of Bhutan (2016) assessment report show that Bhutan has a total of 70.77% land cover as forest, which excludes shrubs. The forest cover exceeds the requirement as per the constitution to date (MoAF, 2017).

1.6 Biodiversity and Gross National Happiness

In Bhutan, biodiversity is considered an important part of the nation's unique culture, social and economic conditions. Most of the developmental and political will are also strongly linked to the nation's environmental policies (Zurick, 2006). The importance of biodiversity is accentuated in the nation's development philosophy of GNH. The nation's largest economic contributor, hydropower solely depends on rich biodiversity.

It was during a conference abroad, King Jigme Singye Wangchuck coined the term GNH, which lead to the introduction of the GNH idea to the people of Bhutan. He said that "Gross National Happiness is more important than Gross National Product", where the nation's development not only focuses on economic growth but extends to well being of the people of Bhutan (MFA © 2020, Kaewkhunok, 2019).

The Center for Bhutan and GNH Studies (© 2020) defines GNH as "a holistic and sustainable approach for a nation's development". The approach seeks to balance material and non-material values in pursuit of happiness. His Majesty Jigme Khesar Namgyel Wangchuk announced GNH as "development with values: Fundamental values of kindness, equality, and humanity and necessary pursuit of economic growth" (MFA ©2020). Ever since the introduction of GNH idea as development philosophy to people of Bhutan. Bhutan's development is centered on four pillars of GNH, namely:

1) Equitable and sustainable socio-economic development,
2) Environment conservation,
3) Preservation and promotion of culture,
4) Good governance

These pillars are extended into 9 domains and 33 indicators. Out of 9 domains, the eighth domain is "Ecological diversity and resilience" which focuses on the environmental aspect. The eight domain has three subjective indicators that relate to the perception of environmental challenges, urban issues and responsibilities, and one objective indicator that relate to wildlife (Ura et al, 2012).

These indicators are a useful tool in measuring the impact of humans on nature and knowledge on the local environment, which is crucial in developing and promoting an eco-friendly approach in daily human intervention and identify divers of environmental deterioration (Ura et al. 2012). Therefore, Bhutan's GNH is multi-dimensional and venerates biodiversity as a very crucial value to the

nation. The idea of GNH is synergized into public administration and policies and links economic progress to environment conservation while in pursuit of human happiness (Zurick 2006). Globally, Bhutan became the first nation to introduce the GNH concept as new economic indicators that seek to balance development and environment protection, which is similar to the United Nation's concept of global agenda 17. Today, GNH is one of the major national plans that guide the development in the 21st century (Kaewkhunok, 2019).

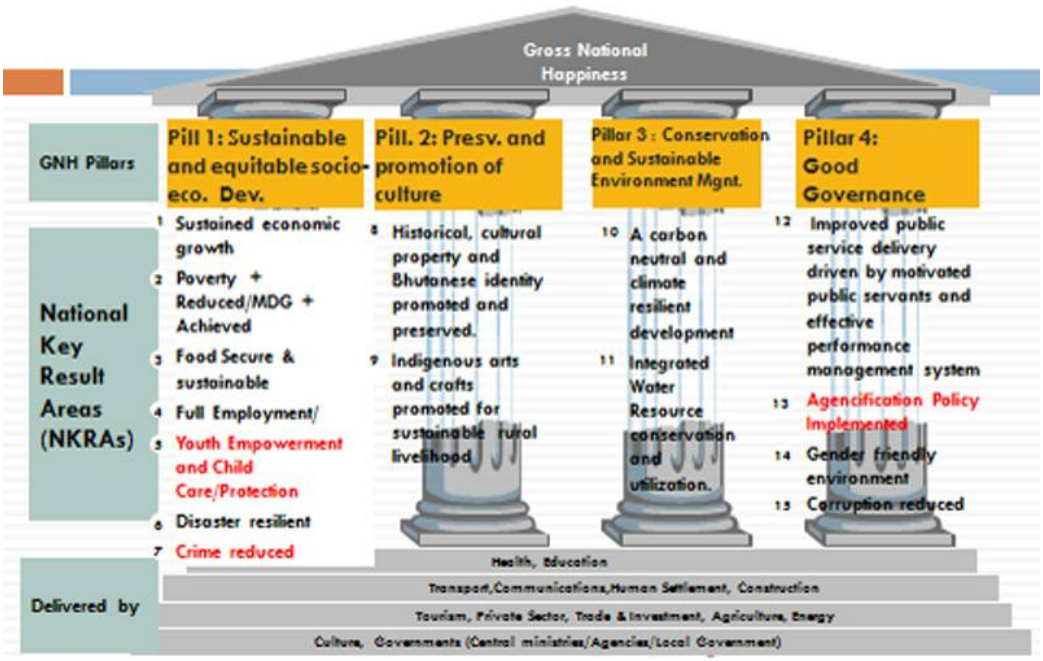

Figure 01. Pillars and National Key Result Areas of Bhutan Source: GNHC 2018

1.7 Research Objectives

It is important to understand how development affects biodiversity in an urban area. As riparians are very rich in flora diversity but also face several conservation challenges in urban areas due to human interference. In this research, the impact of urban development on biodiversity will be studied along the riparian corridor that passes through different levels of human activities.

The study aims to assess the flora species diversity in the riparian corridor under different degrees of urban development variables identified. The objectives of the study are:

1. Study and Document the flora diversity of the Wangchhu Riparian corridor.
2. Analyze the changes in flora composition and distribution in Disturbed Habitat and Semi-Disturbed Habitat.
3. Analyze which urbanization variables influence the biodiversity in Disturbed Habitat and Semi-Disturbed Habitat.

1.8 Research Questions

The broad research question is about understanding the flora species present in the riparian corridor in terms of species composition and diversity. Then explain why and which urban development variable influences the flora species at different habitats. At least three key questions have emerged for the study.

These are:

1. What are the flora composition present in the riparian corridor?
2. How diverse is flora along the riparian in Disturbed Habitat and Semi-Disturbed Habitat?
3. Which urbanization variables influence the biodiversity in Disturbed Habitat and Semi-Disturbed Habitat?

Chapter 02-Literature Review

2.1 Riparian Ecosystem

The word “Riparian” comes from the Latin term “ripa”, which means riverbank or shore, and it is generally considered as the strips of area next to the waterbodies with rich and diverse flood-tolerant vegetation. Landscape ecologists describe riparian strips as “corridors” due to linear characteristics, which provide continuous forest landscape by connecting upper forest and lower valley forest (MoF 1998).

In landscape, the riparian zone is an intermediate zone between aquatic and terrestrial ecosystems. It comprises diverse of communities, landforms, and the environment within the large landscape (Gregory t al. 1991). Vidon et al (2010) describe riparian as “semi-terrestrial areas lying at the interface of the terrestrial and aquatic environment that are often influenced by overbank flooding events and connect upland and aquatic environments through surface and subsurface hydrologic flow path”.

Riparian vegetation serve a significant role as a bio-filter by trapping pollutants such as heavy metals, pesticides, and other waste before it is channeled downstream. A buffer zone of minimum 20 m from the bank of the river with

grasses and understory plants is needed to act as an effective bio-filter. It is more effective in shallow and steady river flow (Finlayson et.al. 1992, WC, 1994). However, excess deposition of chemical pollutants in the zone cane degrade the soil and water nutrient, and lead to loss of rich flora and fauna in riparian ecosystem (Stevens et al. 1995).

Riparian zones serve as vital habitats for a variety of native flora and fauna, and a corridor for migratory fauna. Some animals live their whole life cycle in the riparian area, and others may use it as a source for food, shelter, and nursery site. International studies recommend that a minimum of 30 m buffer zone is needed to serve as an effective habitat corridor to achieve an extensive variety of flora communities (WC, 1994).

Riparian zone also provides high ecological services in improving the water quality, diversification of agroforestry and stock growth, and reduces bank erosion. It also increases the land value and generates the potential for eco-tourism to generate economic benefits (WRC, 2000).

Riparian zone creates microclimate for aquatic and terrestrial ecosystems. The vegetation protects the underlying soil and water from sunlight. This decreases the soil and air temperature in summer and reduces soil moisture loss. Thus, create an ideal condition for an extensive range of plants to grow in the zone. The thick canopy along the river also helps to reduce the sunlight up to 95 percent and regulate water temperature (Wilzbach 1989, Steven et al. 1995). Cooling of water help in increasing the dissolved oxygen, which directly benefits aquatic lives.

Decrease in vegetation along river or stream increases water temperature during summer reduces the species diversity and richness. In the case of aquatic life, some fishes are not able to survive if the temperature exceeds over 22-degree Celsus, increases competition from warm-water fishes, causes a change in species diversity and composition, and increases susceptibility to diseases (Hartman and Scrivener 1990, Voller 1998).

The herb and shrub's root system can help to improve the stability of river/stream banks for a longer duration by binding soil, rocks, and other organic materials together, which helps to reduce soil erosion, and prevent sediment from entering into the river system (Gregory and Ashkenas 1990). However, the deposit and suspension of sediments at the riparian area can affect the aquatic ecosystem by reducing light penetration into water and affect the habitat of small aquatic fauna.

2.2 Biodiversity

The conception of biodiversity is quite recent. The word "biodiversity" was earlier referred to as "biological diversity" by Dasmann (1968) in his book "A different kind of country", which was later contracted to "biodiversity' by Rosen (1985) while planning to conduct a National Forum on biological diversity (Adom et al 2019).
In 1992, the Convention on Biological Diversity described biodiversity as:

> *"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of an ecosystem."*

As biodiversity include a variety of ecosystems occurring in the desert, forest, wetlands, mountains, water bodies, and agricultural landscape. In each of these ecosystems, all living creatures interact with one another and with air, water, and soil. Thus, biodiversity can be understood in 3 major levels. Genetic diversity: a variety of genetic information within species and populations, Species diversity: Variety of species measured in terms of species richness and abundance, Ecosystem diversity: a variety of habitats, biotic communities, and ecological process in the biosphere (Rawat and Agarwal 2015, Adom et al 2019).

2.2.1 Value of biodiversity

Biodiversity serve as a vital natural resources that contribute to the well-being of humans by providing food, shelter, medicine, raw materials, and so on. Biodiversity plays a critical role in providing ecosystem services. It plays a major role in mitigating climate change and global warming through carbon sequestration to reduce the effect of ozone layer depletion. It also helps in balancing the regulation of the biochemical cycle and hydrological cycle. Rich biodiversity provides an important role in disaster risk reduction such as forests, wetlands, and mangroves help in reducing the extreme impact of floods, tsunamis, and droughts (Singh et al. 2006). In urban areas, helps to reduce flash flood, reduce water shortage problem through groundwater recharge, reduce heat island effect and control pollutions.

Biodiversity supports the intrinsic value that involves the emotional, spiritual, cultural, and religious aspects of humans. Rich biodiversity assists in providing emotional satisfaction from the aesthetic value of nature, silent meditation, listening to the sound of nature (Grant et al. 1992). Resources from nature are also used in performing rituals and as a part of traditional art and craft. Local communities also venerate plants, rocks, water bodies, and animals for spiritual protection. Likewise, Bhutanese place nature as an important part of their daily life, which include living and non-living part of an ecosystem.

2.2.2 Biodiversity in Bhutan

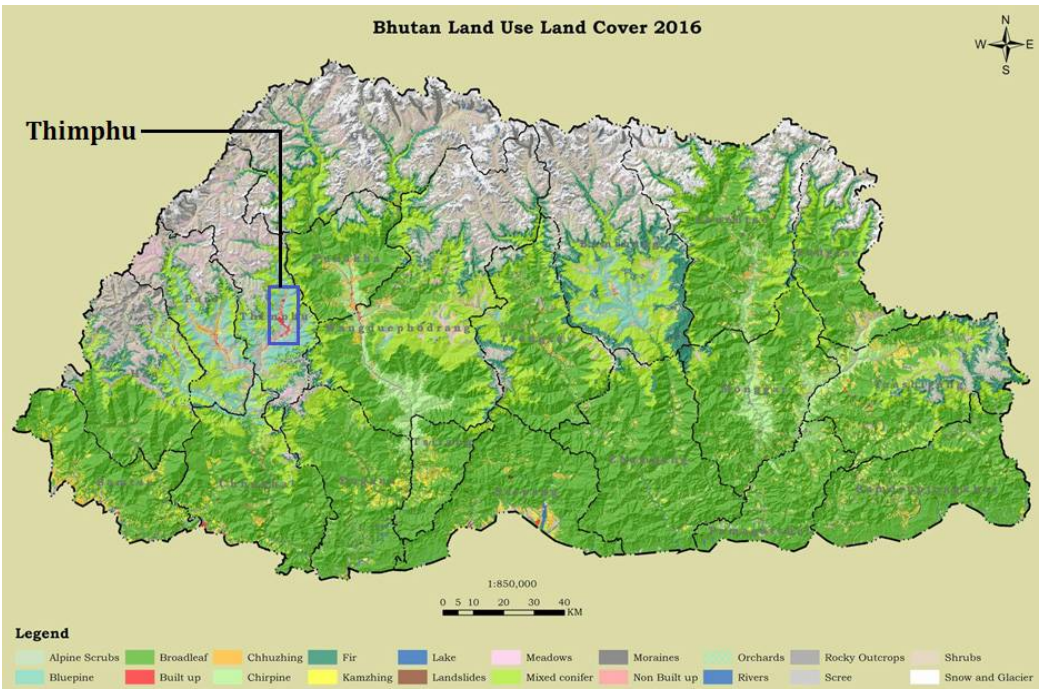

Figure 02. Land Use and Land Cover Map of Bhutan Source: MoAF 2017

Bhutan is a small Himalayan nation with an area of 38,394 sq. km, sandwich between China to the north and India to the South, east, and west (NLCS @ 2020). Bhutan being a small country is home to 11,248 species as of 2017. The country has become a conservation centerpiece of the Eastern Himalayan region for being known as one of the global biodiversity hotspots. Of the total species recorded, 5,369 were recorded for Plantae, 5,114 as an animal, 690 as Fungi, 55 Chromista, 18 to Eubacteria, and 2 to Protista (NBC, 2017).

The constitution of Bhutan (Article 5) requires the country to maintain at least 60

percent of land cover as forest. The land use and land cover assessment conducted in 2016 shows a national forest cover of 70.77 percent as shown in the figure 2, which excludes shrubs. Of this, 45.94 percent is Broadleaf, 13.53 percent is mixed Conifer, 6.02 percent is Fir, 2.64 is Chir pine and 2.64 percent is Blue pine. Of the total land cover, the Shrubs constitute 9.74 percent, 3.39 percent is Alpine Scrubs, cultivated agriculture land is 2.75 percent, and 2.51 percent as meadows (LULC 2016).

The recent National Forest Inventory (2018) conducted a systemic sampling of 2424 cluster plots surveyed within a 4 km by km grid spread across the country. It records a total of 448 tree species in forest and non-forest. The report shows that Thimphu and Gasa district has the lowest species recorded followed by Paro and Bumthang District. The species record in each of these districts is 44, 42, 52, and 56 respectively compared to the Zhemgang District with the highest record of 250 species. It is further observed that species diversity based on the Shannon index shows the lowest diversity index for Thimphu with 0.69 followed by Bumthang and Paro district, and Sarpang district has the highest diversity of 1.53 index (DoFP, 2018).

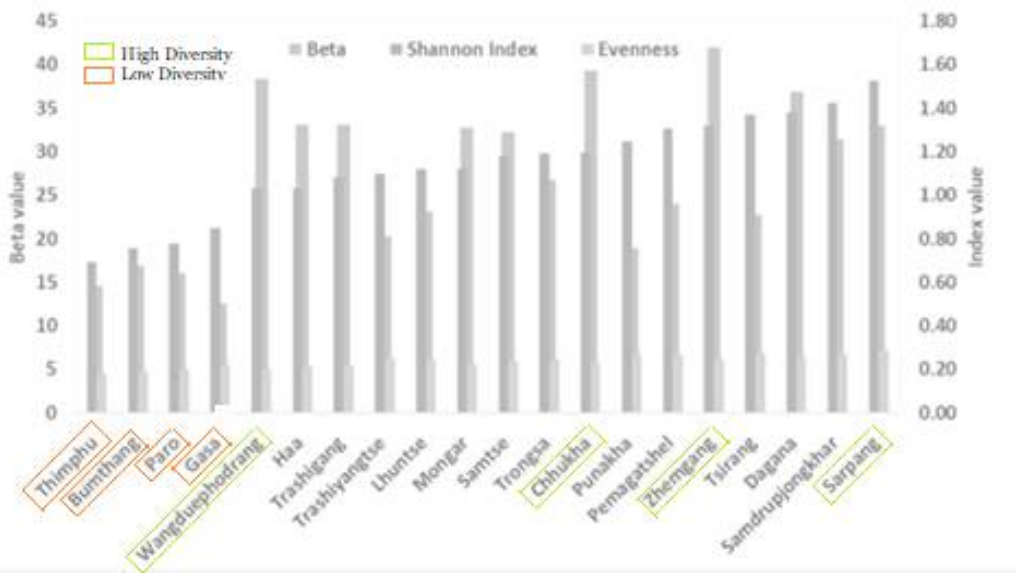

Figure 03. Diversity indices by Dzongkhag Source: MoFA, 2018

The national forest inventory (2018) indicates that such results can be due to elevation, change in vegetation, and urban development. The species diversity in broadleaf vegetation is greater compared to conifer vegetation that is commonly

found in Thimphu, Paro, and Bumthang District. These districts are also located at higher altitudes as compared to the rest of the district and are some of the biggest towns in the country.

Bhutan has a very rich network of biodiversity commonly known as the Bhutan Biological Conservation Complex (B2C2). The country started the protection of rich biodiversity in the 1960s and by 1999, biological corridors were established to connect all the protected areas. Today, the protected area coverage is almost 20,000 sq. km which corresponds to 51.32 percent of the country's area (WWF @ 2020). Around 9 percent of forest area is recognized under sustainable forest management (DoFPS, 2014). The remaining forest area is facing human pressure due to increasing demand for forest resources and destruction (FRDD, 2005, FRMD, 2013). The Department of Forest (DoF) reports that more than 1,300 hectares of forest are cleared between 2001-2005 for infrastructure development and agricultural production. Of this, more than 70 percent of the total area is due to land-use conversion, road, and power transmission lines construction work (MoAF 2009).

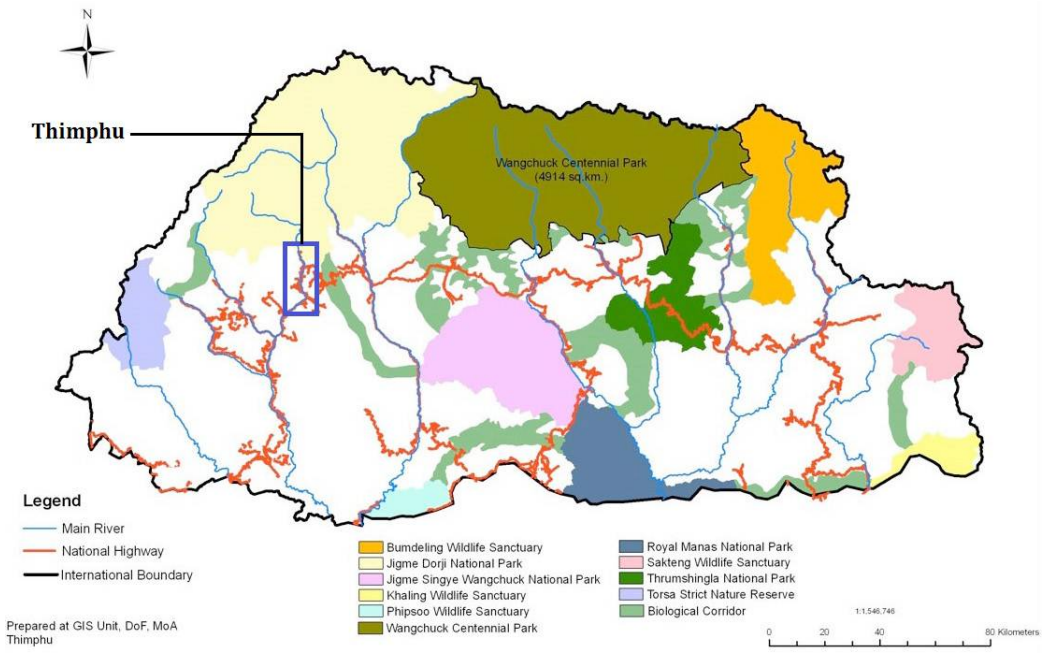

Figure 04. National Protected Areas of Biological Corridors of Bhutan Source: MoAF, 2018

Similarly, Thimphu city has lost most of its eco-fragile are to the pressure of urbanization. Marshlands that existed along the river near Taba, Lanjophakha, and Babesa were habitats for winter migrant birds and the forest area between

Langjophakah and Taba served as a corridor for Bears and Leopards are lost to human development (MoWHS, 2018). Thimphu valley was once a bird paradise with habitats for a variety of bird species such as globally endangered Wood Snipe and migratory birds like Ferruginous Duck, Tufted Duck, and other birds. Today, only marshland above the swimming pool is preserved as the ecological park with minimal human interferences (MoWHS 2004). Due to the loss of major habitats along the river, only a few migratory birds like ducks are seen near the Babesa Waste treatment plant, which was a rich marshland.

Since the development of 2000, most of the environment-sensitive zones along the river were reduced to more than 50 percent of its area. Today, the environment conservation zone accounts for 4.49 percent of total area of the citye city. The conservation zone along the stream was reduced from 30 m to 15 m buffer and was also affected by the presence of private land ownership along the zone. During the rationalization of the land use plan, some of the environment and semi-environment zones such as the environment conservation zone and agri-based environment were converted to UV2-MD zone, which is a mixed-use medium density zone (MoWHS, 2018). Today UV2 MD has become the dominant land use that accounts for 14.22 percent of the total area. Whereas, the environment zone has experienced a reduction of an area with rapid urban development as tabled below.

Table 1. Land use in 2002 and 2017 as per Thimphu Structure Plan 2002-27 Source: MoWHS, 2018

	2002		2017		
Precinct	Area (sq.km)	%	Area (sq.km)	%	Decrease/ Increase in area
Dzong	1.028	4.26	0.986	4.12	-0.14
Environment Conservation (E1)	2.704	11.19	1.076	4.49	-6.7
Forest Environment (E2)	4.359	18.04	3.953	16.51	-1.53
Agricultural Environment (E3)	0.182	0.76	0.026	0.11	-0.65
Agri-based Environment (E4)	3.961	16.4	5.103	21.31	4.91
Endowment	0.812	3.36	1.87	7.81	4.45
National Open Green Space (G1)	0.726	3	0.335	1.4	-1.6
Green Space System (G2)	0.807	3.34	0.552	2.3	-1.04
Heritage (H)	0.358	1.48	0.225	0.94	-0.54
Institutional (I)	0.319	1.55	1.82	7.6	6.05

Neighborhood Node (NN)	0.21	0.87	0.081	0.34	-0.53
Royal Use ®	0.187	0.77	0.22	0.92	0.15
RBG Area (RBG)	0.817	3.38	0.817	3.41	0.03
Traditional Village (TV)	0.259	1.07	0.232	0.97	-0.1
Urban Core (UC)	0.547	2.26	0.469	1.96	-0.3
Urban Hub (UH)	0.086	0.36	0.113	0.47	0.11
Commercial (UV1)	0.794	3.29	0.271	1.13	-2.16
Residential Low Density (UV2-LD)	0.272	1.12	0.129	0.54	-0.58
Residential (UV2)	5.329	22.06	5.416	22.6	0.54
Residential (UV2-I)	n/a	0	1.522	6.36	6.36
Residential (UV2-II)	n/a	0	0.488	2.04	2.04
Residential Medium Density (UV2-MD)	n/a	0	3.406	14.22	14.22
Knowledge City	0.055	0.23	n/a	0	-0.23
Public use & Service areas	n/a	0	0.253	1.06	1.06
Restriction Corridor	0.347	1.43	n/a		-1.43

2.3 Disturbance

The disturbance is recognized as a crucial part of the ecological process (Grimm et al. 2017). White and Pickett (1985) gave the widely quoted description of disturbance: “any relatively discrete event in time that disrupts ecosystems, community, or population structure and changes resources, substrate availability, or the physical environment.” Whereas, disturbed habitat is a temporal change in environmental conditions that lead to an evident change in the natural ecosystem (Capucchio, et al. 2019). Disturbances in an ecosystem are instigated either by natural or humans. The frequency and magnitude of disturbance to the ecosystem determine the fluctuations in species diversity (Karki et al. 2017). Therefore, the study focus on the magnitude of human disturbances recorded along an urbanization gradient. In ecology, human-dominated ecosystems such as conurbations are generally considered as “disturbed systems”, and humans as disturbance agents and activities as a disturbance (Grimm et al. 2017).
Some of the disturbances to urban biodiversity consist of habitat loss, degradation, alteration, soil modification, and transformation of landscape for

urban development, which couple with pollutions, nutrient availability, increase in invasive species, and other abiotic drivers (Elmqvist et al. 2016, Anna et al. 2020). An increase in population is also one of the major factors causing change to biodiversity due to the exploitation of natural flora and fauna in the Himalayas region (Karki et al. 2017). The MEA (2005) report identified some of the major human disturbances such as habitat change, land-use change, Pollution, exploitation, the introduction of invasive species, demographic change, technology advancement, and economic activities are identified as direct and indirect drivers that cause pronounced changes to biodiversity in global biodiversity.

It is observed that human-induced disturbance to the ecosystem increases stress on local species diversity, composition, and richness (Anna et al. 2020) and homogenization (McKinney, 2006). Thinley et al. (2019) study on invasive species in the mountainous region in Bhutan suggests that change in land management, development of hiking trails, recreational, deforestation, and upland agriculture, coupled with climate change has accelerated the rate of invasion by alien species in the vulnerable ecosystem of Bhutan. It is also perceived that plant species richness and diversity increase along the urban-rural gradient and alien species increase with decreasing distance to the city (Vakhlamova et al. 2014). This explains that the disturbed system alters the species composition, life form, and habitats. Connell (1978) and Grime (1973) proposed a relationship between disturbance and species richness or diversity, which is widely known as the Intermediate Disturbance Hypothesis (IDH). It predicts that diversity is highest at the moderate disturbance level. The disturbance of the ecosystem at an early stage increases the resources availability and opportunity for the succession of superior species. This trend is amplified by disturbance agents, which further increases the earlier succession species (Catford et al. (2011), Bendix et al. (2017)). With increasing disturbance and succession of new species, there is a shift in the curve to peak such that diversity is maximum. The superior species successfully colonize the earlier species due to the trait to adapt to the fluctuating environments and compete for resources. Thus leading to a decrease in diversity and richness with increasing disturbance to an ecosystem (Svensson et al. 2012). Overall the international studies show that the prolonged disturbance to the ecosystem impacts the species composition and colonization by superior species.

2.4 Urbanization

Understanding the term “Urbanization” has multiple interpretations, differing from country to country or Institutes which are case-specific. In general, Urbanization is understood as a process where a rural area is transformed into an urban area due to economic development or industrialization. However, other causative factors that may lead to urbanization or can define the phenomenon are demographical, economy, area/boundary, and political reasons.

Urbanization is referred to as a shift in population from rural to urban areas which are driven by push-pull factors. Another concept of defining urbanization is also described as the process of changes in which the society's way of life adapts from rural to urban lifestyle (NLM, 2014).

The Organization for Economic Cooperation and Development defines urbanization demographically as an increase in the proportion of a population residing in the urban areas and a process whereby a larger portion of the population becomes permanently concentrated in a relatively small area, thus forming a city (OECD, 2003).

It is also defined as a process of becoming an urban area, an increase of movement of people to urban areas, an increase of urban area or population, which implies a change in economic, social, and cultural aspects. (Hussain, Imitiyaz, 2018).

Since defining the phenomenon is very difficult due to the use of various concepts or involving two or more criteria, but also over time changes of definition occur due to new or unforeseen factors. However, urbanization is primarily linked to or formation of urban areas/settlements.

In a study conducted by UN-Habitat for the 2030 agenda for Sustainable Development, it analyses concepts and definition of urbanization in the countries worldwide. It is observed that two-third of countries use the administrative definition to classify urban areas. Whereas, 49 countries were making use of population size and density to define. (UN-Habitat, 2017). A country such as Sweden defines a built-up area with at least 200 households with gaps of more than 200 meters between settlements as urban (iied, 2014).

2.4.1 Urbanization in Bhutan

In the case of Bhutan, an urban area is defined by a law that requires to fulfill 4 conditions out of 5 criteria: an area should have a minimum population size of 1500 inhabitants, a threshold population density of 1000 person per sq. km, more than 50% of people should be non-dependent on primary economic activities, a minimum area required to form settlement should be not less than 1.5 sq. km and the area should have the economic potential to generate revenue to sustain its operation and management (RGoB, 2007).

Urbanization in Bhutan has increased from 30.9% in 2005 to 37.8% by 2017. The major portion of the population resides in Thimphu city which accounts for 15.8% of the nation's population (PHCB, 2017). Thimphu being a primary urban settlement and the capital of Bhutan is the center for politics, bureaucracies, and finances. The city is experiencing unprecedented urban growth over decades which was once a small rural settlement in a Thimphu valley covered by paddy fields and apple orchards with few houses in the middle of fields.

Thimphu city has spatially and demographically become the biggest settlement of Bhutan since its establishment as capital in 1955. The first urban development in 1986 guided the development of the city through the 1990s and in 1999 the city expanded from 8 sq. km to the existing 26 sq. km (SEA, 2017).

Since then, Thimphu has been a center of attraction, providing matrices of opportunities. In 2002, it had 43,479 residents which have almost doubled to 79,185 residents by 2005. The national urban growth rate was only 7% and for Thimphu, it was about 13.5%. (PHCB, 2005). If the rate remained constant and there were no interventions to regulate the growth, it was predicted that by 2020 more than 50% of the population will be residing in urban areas (BNUS 2008). Today, Thimphu is home to 114,551 people which accounts for 71% of the urban population of four major cities in Bhutan. It is the dense city of Bhutan having 3029 people per sq. km (BNUS 2008).

Urbanization in Thimphu has peaked in recent years majorly due to the rural-urban migration trend in Bhutan. People from surrounding areas and the eastern region are migrating to the capital in search of quality life, job opportunities, business and market diversity, other reasons. It is observed that the eastern region has the highest negative net migration, with an out-migration as high as 73,816 and in-migration accounting for 28122 (PHCB 2005). Urbanization may have brought in huge labor resources and improved the economy of local and

regional. It has also pressurized the city resources which was not planned for the additional population.

2.4.2 Biodiversity and Urbanization

With rapid urbanization, it is crucial to understand the ecosystem in an urban area to ensure that settlements are planned for the sustainability of residents and nature. While conservation of biodiversity remains overruled national and city priority with a focus on intensification of economic activities and support system. This has always led to exploitation, encroachment, and conversion of forestland for human development (MoAF 2009). For example, In 2001-2005 Bhutan experience a loss of 1300 hectares of forest land to human development, which included land cleared for power transmission, roads, agriculture production. Roads and power transmission lines accounted for more than 70 percent of forest area converted to other land uses.

Globally, land-use conversion is identified as one of the main drivers of biodiversity loss. Land-use change mostly led to habitat fragmentation, intense use of land, degradation of land, and ultimately loss of natural habitat (Sela et al, 2000). It is evident through several urban-rural gradient studies that intense land use in urban has a larger impact on biodiversity as compared to less intense land use in the rural or peripheral area. In the urban area, the urbanization within riparian areas has led to a loss of original riparian habitats and plant species diversity. This is majorly due to the increasing area of impervious surface, which decreases the permeation of rainwater into the soil, and intense anthropogenic pressure exerted on this eco-fragile area, which usually runs through a human settlement (Cao et al, 2019).

Moreover, the diversity of species is strongly related to the habitat condition, which is directly intervened by human development. Several studies (McKinney, 2002, Cao et al, 2019, Tenzin & Hasenauer, 2016, Wangchuket al, 2014) show that physical changes along the gradient have a direct influence on species diversity, especially in the case of native species. It is observed that habitat loss in the urban area is high as the habitat loss curve steepens from the rural area toward the city center, left with numerous small habitat patches (Collin et al, 2000). The intense built environment directly lead to loss of habitat which reciprocates to the reduction in species richness in urban are.

Given the fact that biodiversity loss is rapid in an urban area. The urban area has

also become a habitat for some of the important species that need to be protected from extinction. McKinney (2002) suggests that around 60 percent of the United States' endangered and rare species are found in the metropolitan area. Of this, 29 percent are found in the 35 fastest-growing metropolitan areas. An increase in built surfaces affected biodiversity (McKinney, 2002). It is important to study biodiversity in an urban area for the conservation and protection of this species, before being lost all time.

2.5. Concept and Framework

2.5.1 Concept and Framework: International Practices

A literature review on Urbanization, Biodiversity, and Conservation by McKinney (2002) discussed a study of plant diversity on an urban-rural gradient. The study focused on the impact of urban expansion on native ecosystems. To understand the compositional and diversity changes along the gradient, population density, road density, air and soil pollution, average temperature, rainfall, and impervious surface were encompassed. The analysis of these metrics with species composition and diversity show that highly urbanized area generally has species that thrive with human activities. Additionally, the study also shows that there are relatively few native species in a highly urbanized area.

Another study on urbanization and biodiversity conducted by Pennington et al (2009) shows that land-use structure can influence the species diversity and abundance of riparian and how it can aid in management efforts. The study site focused on two tributaries passing through different urban land uses. To understand the biodiversity of the two sites, a record of flora diversity and composition was made. The landscape variables such as impervious surface in 250 m radius of a plot, distance to nearest road and railroad from plot center, a total built area in 250 m from plot center were also studied. The analysis of the variables indicated rich species in the riparian area. However, the exotic and native species show different responses with an increasing level of urbanization along the riparian.

2.5.2 Concept and Framework: National (Bhutan) Practices

Research conducted by Tenzin and Hausenauer (2016) on tree species composition and diversity concerning anthropogenic disturbance shows that species composition, richness, and diversity vary in each zone of agriculture, sem-disturbed zone, and forest. To understand the specimen study in each zone, the research observed anthropogenic activities such as distance close to human settlement, road, accessibility to each zone, logging in the zone, and grazing or fodder. The study shows that forests have the maximum species richness and diversity, followed by a semi-disturbed zone and least in a settlement agriculture zone.

Wangchuk et al (2014) conducted a different study on understory vegetation along the disturbance gradient in the Himalayan conifer forest. The study examined the species richness, diversity, and density of the vegetation along the gradient of grazing and logging disturbance. Data were collected from 12 sites to conduct specimen studies under different disturbances. Additionally, soil samples were collected to analyze the pH and nutrients of each site. One of the key findings was that general disturbance leads to an increase in the availability of resources and an increase in species diversity and richness. Therefore, combined grazing and logging resulted in higher species richness and diversity.

Based on the existing practices in the country and around the world, similar concepts and framework is developed to understand urbanization's impact on biodiversity in the case of the riparian corridor in Thimphu city.

The research intends to understand the biodiversity of the riparian corridor by the study of flora composition and diversity. The specimen will be collected from two zones are disturbed Habitat and semi-disturbed habitat.

To analyze the specimen study with urban development, four urban variables are identified. These are urban built surfaces within a 100m radius from the plot center, population density in the area, permissible land uses, and human activities within a 100m radius from the plot center.

Key Concept: Flora composition, diversity, Disturbed Habitat, Semi-disturbed Habitat, Riparian, Urban, Development.

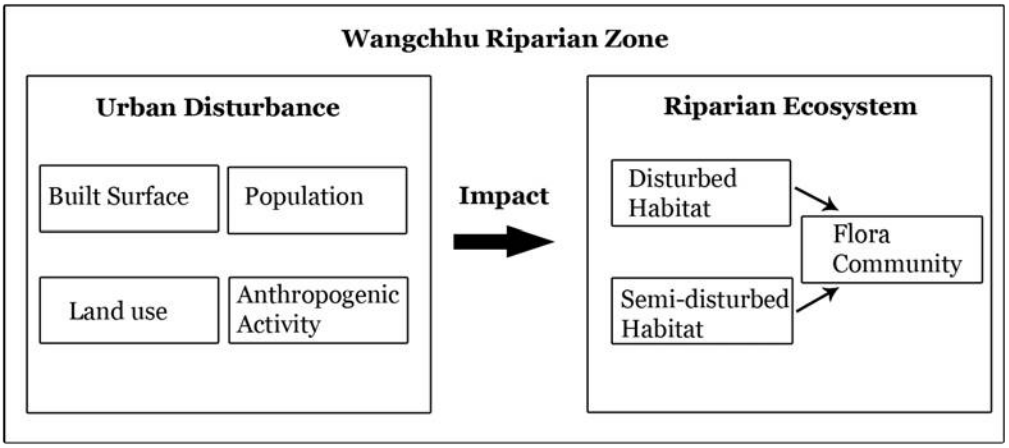

Figure 05. Operationalization of Concept

Table 2. Urban variables and Indicators

Concept	Variables	Indicator	Scale
Urban Development	Built Surface	The built surface area is within a 100m radius from the plot center (%).	Low,Moderate, High
	Population Density	No. of people residing per unit area.	Low, Medium, High
	Land Use	Level of permissible human activities as per land-use plan	Low-Medium, High
	Anthropogenic Activity	No. of human interference (Active and Passive) within 100m radius from the plot center (count).	Low, Medium, High
Riparian Corridor	Disturbed Habitat	Diversity of Flora: Shannon indices, Simpson indices, Evenness.	Low, Medium, High
		Composition of Flora: Life form, family, Invasive, and Dominance.	Low, Medium, High
	Semi-disturbed Habitat	Diversity of Flora: Shannon indices, Simpson indices, Evenness.	Low, Medium, High
		Composition of Flora: Life form, family, Invasive, and Dominance.	Low, Medium, High

Chapter 03-Research Method

3.1 Study Area: Thimphu

Thimphu is the capital of Bhutan since the 1960s. It is located 2248 meters above the sea level and at 27°28′00″North and 89°38′30″East. It is the biggest urban settlement in Bhutan with 15 urban villages of equal or more than 1 sq. km of total area. It spread 15 kilometers from Dechencholing at North to Babesa at South, and 3 km wide. The city is surrounded by mountains rising over 3800 m and lies in the temperate zone dominated by confiner forests (TT @ 2020). The city is linearly spread along the river Wangchhu, which is the main river of the Wangchhu basin. The Source of the river is majorly from the large watershed, which is covered by a Pine forest. As soon as the river enters the city boundary near the Pangrizampa monastery, the level of human influence increases till it crosses the city boundary near Baba Lhakhang. Today, there are many activities alongside the river such as residential buildings, recreational areas, commercial and industrial activities, and parks. Some of the recent environmental disturbances along the river are a disturbance to the natural riverbank, change in river course, and disposal of untreated waste.

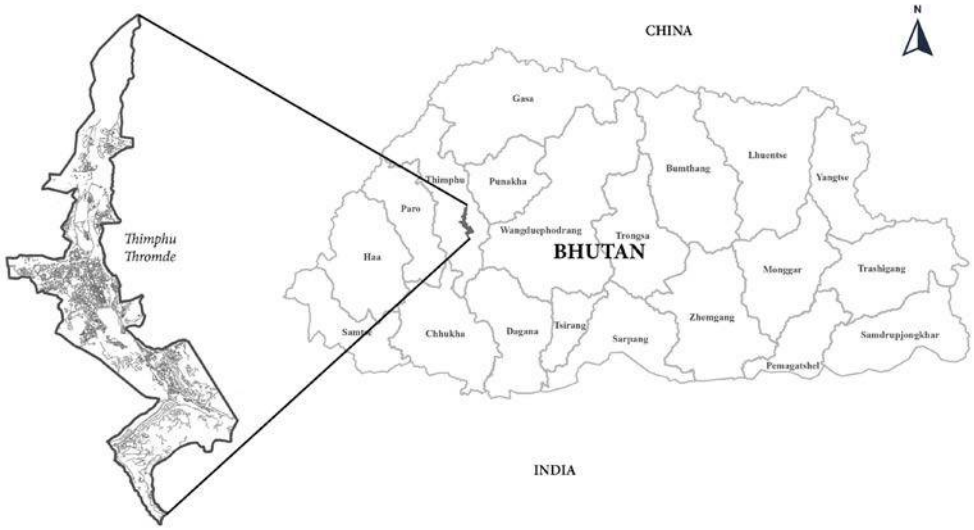

Figure 06. Location of Thimphu

3.5 Approach

The research is based on the quantitative and qualitative method that involves direct observation, field survey and desk research. In the case of direct observation, the researcher directly observes the events, then describes and analyzes them. It can be simply used to gather information about a condition (Centellas, 2016). Field survey is conducted as per the Biodiversity monitoring and social survey protocol of Bhutan (DoFPS, 2020) and international practices for the collection of flora specimens and recording. The Desk research involved the study of relevant studies such as scientific journals and reports to extract data that are relevant to study aims and objectives.

The study area is categorized into study sites as disturbed and semi-disturbed habitats. It is categorized based on the literature review on concepts of disturbance, morphological growth, land cover, and population. The literature review on ecology disturbances widely defines disturbance as change or disruption to the natural ecosystem by biotic and abiotic stress. A city in ecology is broadly considered as a disturbed system and associated with urban activities as disturbance agents. The study focus on a gradient of urban development along the riparian zone and its influences on the species biodiversity. Disturbed habitat is characterized by densely built and populated areas of the central and southern parts of the city. The natural landscape of this area is disturbed and an artificial landscape is created to suit human development needs. Whereas semi-disturbed

habitat consists Northern part of the city, where natural vegetation is still left untouched despite some degree of human development. The dense forest in Dechencholing and Taba are still kept undisturbed by development and some river island and marshlands in Langjophaka, Hejo, Dechencholing, and Kabesa are still intact with few human disturbances.

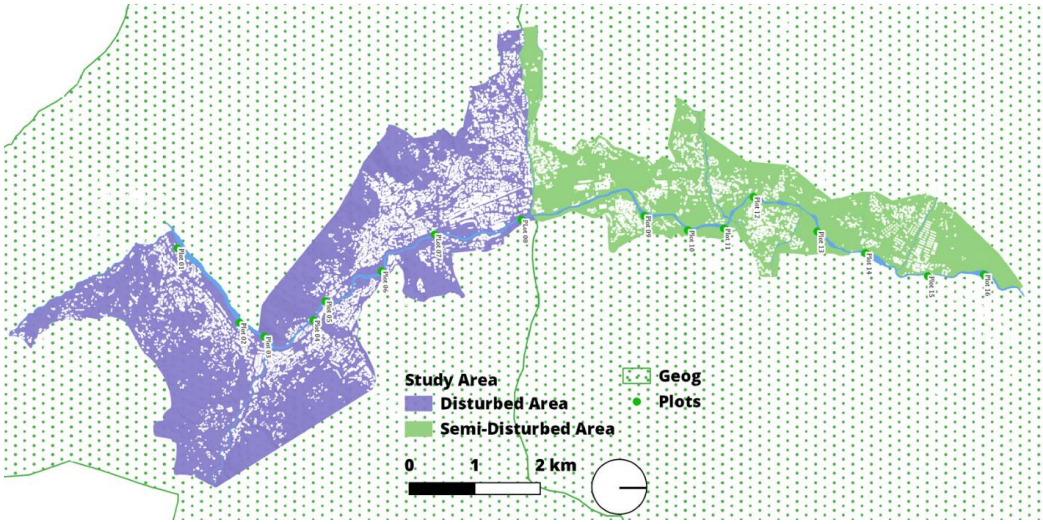

Figure 07. Map of a study area

3.6 Data Collection

The flora survey carried is a stratified Quadrat Sampling survey. The sampling site was selected through the desktop and field visits conducted to understand the surrounding urban characteristic, safety, and accessibility to sample plots. The sampling plots are be located within the buffer area of 30m from the riverbank on both sides, as the 30 m buffer is considered as an environmentally protected zone for the riparian ecosystem as per the Forest and Conservation Act, 1995. A total of 16 plots were studied, with 8 plots each in two habitats. Each plot was located at an interval of 1 km apart. However, some plots were placed below 1 sq. km due to safety and accessibility to the proposed site, and respect for the security of the Royal palace zone.

During the field survey, the nylon rope, wooden peg, cane, and measuring tape will be used to set up the quadrat using the trigonometric method as described in the Biodiversity monitoring and social survey protocol of Bhutan (DoFPS, 2020). A plot size adopted in the survey was 20x20 m (400 sq. m) for trees, 5x5 m (25 sq.m) for shrubs, and 2x2 m (4m2) for herbs.

The specimen collection of herbs were conducted first to avoid the damage to herbs and loss of specimens by human action. Then the survey for shrubs and trees was conducted. The collection and recording of flora specimens were conducted through the standard Herbarium Technique adopted by National Biodiversity Center at Thimphu. Kobotoolbox (see appendices) was used for the recording data and images of the specimen from sample plots. The data recorded were then extracted in an excel file for data cleaning and validation with an expert. The specimen observed in sample plots were recorded specified to flora type. In the case of the tree, diameter at breast height (DBH) was measured at a threshold height of 1.3 m, and the count was recorded, and for shrubs and herbs, both count and cover were recorded during the field survey.

Apart from flora data, observation of the surrounding environment within a 100m radius from the center of the plot was also recorded. Spatial data were firstly mapped using the QGIS 3.12.3 using the google satellite map extracted using the SAS. Planet 200718.10081 and 2020 Othro-map of Thimphu city from Thimphu municipal office. Spatial observations were mapped in QGIS and photographed for record and reference.

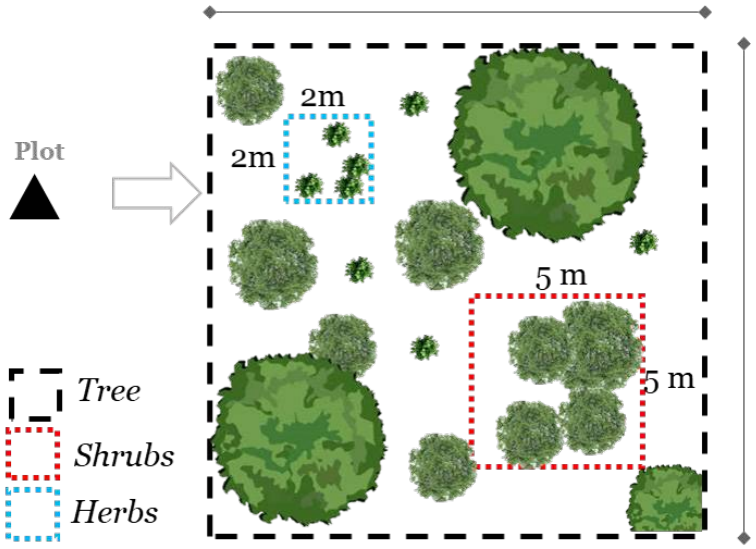

Figure 08. Plot sizes for specimen collection

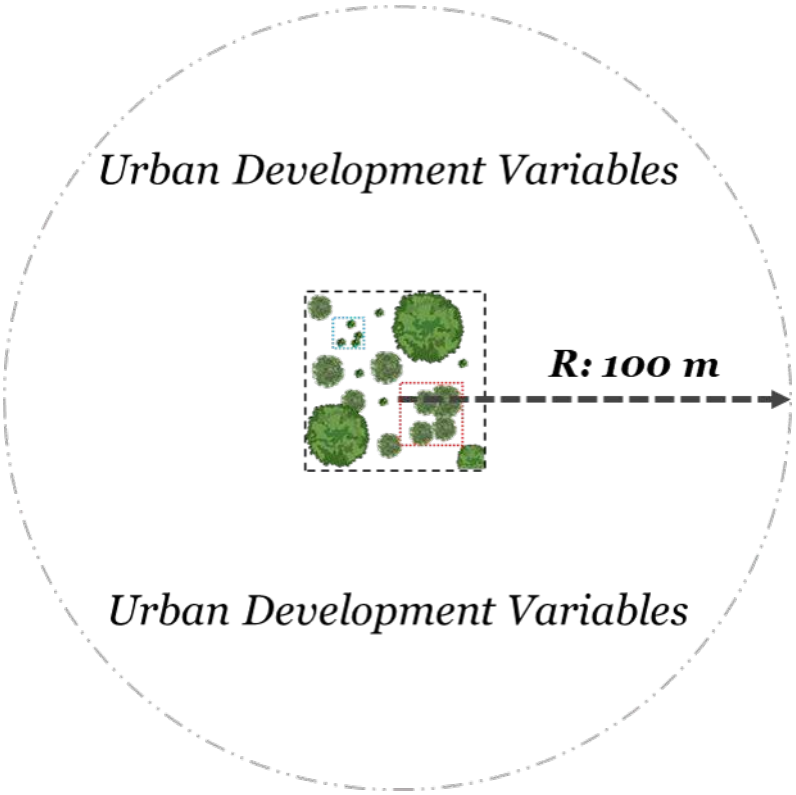

Figure 09. 100 m radius for spatial data collection

3.7 Data Analysis

3.7.1 Data Analysis: Flora data Analysis

The statistical data analysis for the flora was conducted in the form of descriptive statistics and inferential statistics. Descriptive statistics include summarizing the data and describing the data in sum, mean, average, and differences in the form of simple tables, graphs, and charts. The descriptive statistics were computed in the micro soft excel version 2013. The inferential statistic was used to test the hypothesis and understand the causal relationships between several variables used in the study. Inferential studies mostly include plotting correlations between urban and flora data. The program PC-ORD version 5 was utilized for conducting inferential studies.

The flora species were analyzed quantitatively by computing diversity, composition, and dominance using appropriate methods. To compute the diversity and evenness of flora species, Shannon-Wiener Index (H') and Simpson's Index

(λ) were adopted which is based on the method conducted by Magurran (1988) and Rosenzweig (1995) to study ecological diversity. The formula adopted were:

Shannon-Wiener index (H')

$$H = -\sum_{i=1}^{S} p_i * \ln p_i$$

Where H' is Shannon's diversity index, "i" is a number of species and "Pi" is the proportion of species to total species. The value of "Pi" is then multiplied with the natural logarithm "ln Pi". The product is then summed and multiplied with -1 to get the diversity index as shown in table 05.

Table 3. Computation of Shannon –Wiener index.

Sp. Nr	Species	i	Pi=i/sum of i	lnPi= Logarithm of Pi	Pi*lnPi	H'=(Pi x lnPi)* -1
1	*Species A*	10	0.104	-2.262	-0.236	1.058
2	*Species B*	1	0.01	-4.564	-0.048	
3	*Species C*	60	0.625	-0.47	-0.294	
4	*Species D*	20	0.208	-1.569	-0.327	
5	*Species E*	5	0.052	-2.955	-0.154	
	Sum of i	96		Sum of Pi x lnPi	-1.058	

$$E_H = \frac{H}{Hmax} = \frac{H}{\ln S}$$

Shannon's equitability or evenness is calculated by dividing the H' by Hmax, where Hmax is the natural logarithm of total species richness recorded "lnS". The evenness value is computed between 0 and 1 with I being complete evenness.

Simpson's diversity index (D) is also computed to measure the characteristic of diversity in the flora community. The index is the dominance index since it gives more weight to dominant or common species. The "ni" represents a number of individuals in the "i" species. "N" represents a total number of species (Bano et.al, 2017).

$$D_{sim} = \sum_{i=1}^{S} \left(\frac{n_i(n_i - 1)}{N(N-1)} \right)$$

Table 4. Computation of Simpson's diversity index

Simpson (D)				Sum n(n-1)/N(N-1)
	n	**n(n-1)**	**N(N-1)**	**D**
Species A	23	506	1980	0.33
Species B	3	6		
Species C	5	20		
Species D	3	6		
Species E	11	110		
	45	648		

The dominance of species is studied to understand the relative importance of species related to the degree of influence it has on the ecosystem. The dominance was determined through the density of species (Ghavzan et.al, 2006).

3.7.2 Data Analysis: Spatial Data Analysis

Spatial analysis was done using the open-source program QGIS 3.12.3. The spatial analysis computed were Weighted Overlay Analysis (WOA) and density mapping of four urban variables. The pair-wise comparison based on Analytic Hierarchy Process (AHP) proposed by Saaty (1988) was adopted to determine the weightage for each variable. The weightage developed from the AHP was tested to assess the consistency of the matrix to minimize inconsistency equal to below 10 percent. To compute pair comparison, Saaty's scale as shown in table 7 was adopted to represent the level of urban variables in the study area.

Table 5. Scale for pair comparison Source: Saaty, 1988. Minale et.al, 2019.

Intensity	Scale	Explanation
1	Equal	Two activities contribute equally to the objectives.
3	Moderate	Experience and judgment slightly favor one activity over another.
5	Strong	Experience and judgment strongly favor one activity over another.
7	Very strong	Activity is strongly favored and its dominance demonstrated in practice.

9	Extreme	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of the above non zero	If the values are below 1 and compared with adjacent judgment	

The weights were developed based on the pairing of rating such that the matrix product of Axy and Ayx is equal to 1 as shown in the matrix below. Where Axy represents the value of row x and column y of the matrix. Similar computations were done for remailing variables. The pair compared values are normalized to find the weightage of each variable as shown in tables 9

Step 1: Adopt Saaty's Scale for each variable as per research objectives. The scale is determined based on the file observation and record as shown in table 6.

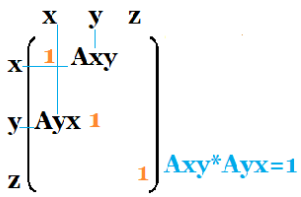

Table 6. Computation of AHP using Satty's Scale-Step 1

	Built Surface	Population	Land Use	Anthropogenic activities
Built Surface	1	1	0.333	0.2
Population	1	1	0.333	0.25
Land Use	3	3	1	0.333
Anthropogenic activities	5	4	3	1
Sum	10	9	4.667	1.783

Step 2: Calculate the proportion of each variable relative to the total of the variable. Example: In the case of built surface to built surface it was computed as 1/10=0.1, population to the built surface was 1/10=0.1, and so on for other variables as shown in table 7

Table 7. Computation of AHP using Satty's Scale-Step 2

	Built Surface	Population	Land Use	Anthropogenic activities	Weights
Built Surface	0.1	0.111	0.071	0.112	0.099
Population	0.1	0.111	0.071	0.14	0.106
Land Use	0.3	0.333	0.214	0.187	0.259
Anthropogenic activities	0.5	0.444	0.643	0.561	0.537

Step 3: Calculate the average of each variable to find the weights. The total weights should sum to a value of 1 or 100 percent.
The weights are multiplied with the raster value during the WOA to develop a Raster file of a multi-overlaid layer, which indicates the level of vulnerability or impact in the area by urban variables.

Chapter 04- Spatial Analysis and Results

4.1 Morphological growth and associate changes

Until the 1960s, Thimphu was formed by several small clusters of traditional villages located around and within the proximity to dzong (fort), which served as the central force overlooking administration and religious activities (Walcott, 2009). The dzong was usually built at the center or hilltop that overlooked the valley and settlements. These provided strategic location in war affairs and administration of the settlement. Most of part of the valley was covered by paddy fields and thick forests, which were infested with wild animals. During those periods, there existed no concept of town, commercial hub or market center, schools, and health care center. People would travel days to trade with neighboring countries or bartered their goods with individual houses (REC, 1994). The villages were inter-connected by mule tracks which were dotted by small religious structures such as chorten, mani dangrims, and religious prayer flags. These structures served as critical landmarks and nodes for travelers (Norbu, 2008).

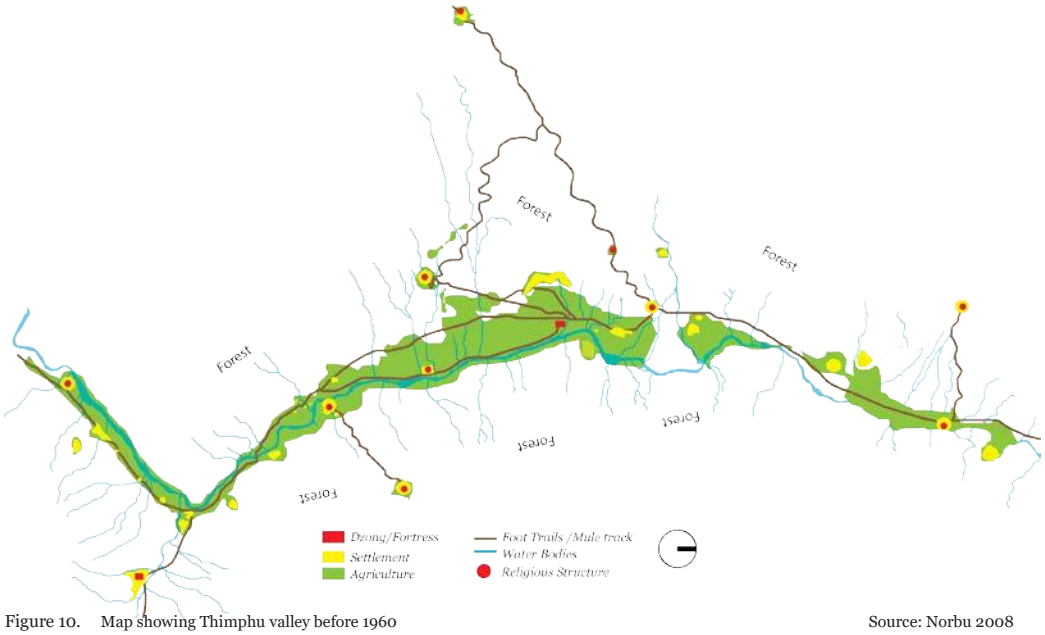

Figure 10. Map showing Thimphu valley before 1960 Source: Norbu 2008

It was only in 1961 that Bhutan began to modernize with the construction of the nation's first road, which would connect the nearest Indian town to the capital city. By 1960, the capital is shifted to Thimphu, and the concept of the town was introduced with the concept of land use planning in the core city and surrounding settlements. New schools, several government institutions, and retail services were also established to cater to new residents migrating from another part of Bhutan (Walcott, 2009). Within few decades, Thimphu valley has developed into the nation's first town of 8.3 square kilometers total area that stretched 11 km from Dechencholing in the north to Simtokha in the south with an average width of 1 km wide (DUDH, 1987). Population count was grown to 14,500 by the 1980s and urban land was haphazardly developed to meet the housing demand. In 1984, residential was major land use that accounts for 26.6 percent of the total area. Whereas agriculture and forestry still dominated other urban land uses of commercial, institutional and industrial.

Within two decades, Thimphu's population has grown to 43,479 from 14500 in 1984 (MoWHS, 2004). The city was also extended to an existing area of 26.6 sq. km from 8.3 sq. km in the 1980s. Several old villages at peripheral were added to the new city jurisdiction. These villages were majorly lived on the cultivation of land, livestock raising, and orchard farming, and most of the urban services were located in the core city (MoWHS, 2004). Was in 2003, the city initiated

the development of a comprehensive development plan “Thimphu Structure Plan 2002-27” that would guide the city’s growth in the 21st century for 25 years.

Figure 11. Agricultural land cover in 1983, Thimphu Valley Source: B&F Collection

Since the new plan, the city underwent rapid urban development with population count increasing from 79185 in 2005 (NSB, 2005)to 114555 in 2017 (NSB, 2017), and complete conversion of private agriculture land to residential and commercial use.

In the 1980s, the majority of the land cover of Thimphu valley was Chhuzhing (wetland) at the plain valley, which was prime land for paddy cultivation. The slope area was covered with apple orchards and a single farmhouse (DUDH, 1987). Today, most portion of the valley is built, which accounts for 37.4 percent of the total area of the city and wetland has reduced to 2.7 percent, followed

Figure 12. Dense urban development at city center and towards the south of THimphu

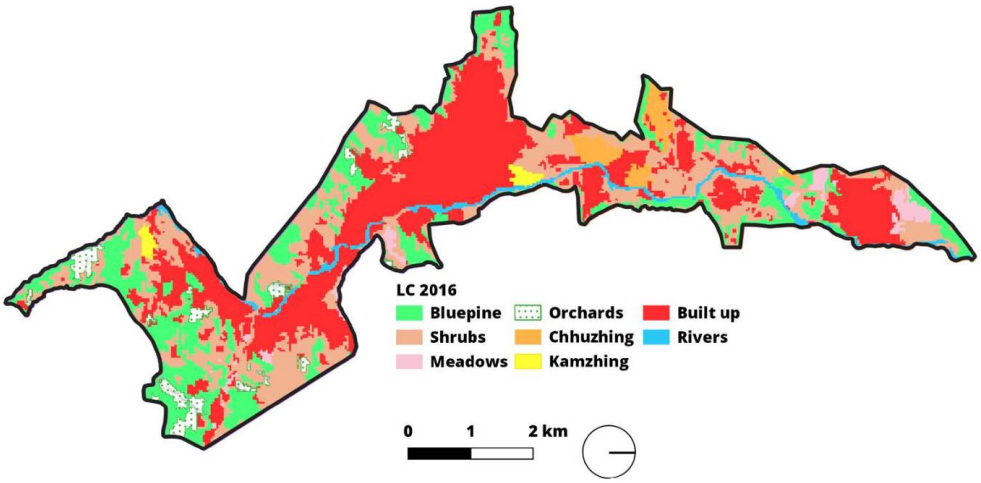

Figure 13. Land cover map of Thimphu, 2017 Source: MoAf, 2017

by 3.59 percent covered by Orchards. In terms of green cover, the majority of vegetation cover is a shrub, which covers 29.5 percent of total land than 20.72 percent of land cover by Blue pine forest (MoAF, 2017).

The land cover study of the city clearly shows two types of urban development that are dense and continuous urban development from Core city spreading towards the South of city and dispersed and concentrated urban development towards the north of city. The urban development in the core and south of the city accounts for more than 70 percent of the city's built surface that is mostly mapped along the river. Whereas, shrub and conifer are located away from the river at slopes. Towards the north of city, most of the vegetation cover and wetlands are along the river and streams with dotted human settlement.

Table 8. Land cover of Thimphu in 2017 Source: MoAF, 2017

Land Cover	Area (sq.m)	Cover %
Built-up	9.813	37.4
Shrubs	7.75	29.5
Bluepine	5.439	20.7
Orchards	0.942	3.6
Rivers	0.775	2.9
Chhuzhing (Wetland)	0.709	2.7
Meadows	0.604	2.3
Kamzhing (dry land)	0.22	0.8
Total Area	26.251	

4.1 Land use

Thimphu city development has been guided by a 25 years Structure Plan 2002-27 since the beginning of the 21st century. The land development in the city is based on 26 urban precincts plan as shown in the map below. About 16.5 percent of the total area within Thimphu city is under forest cover, which is mainly on the hill slopes. The second major dominant land uses UV2-MD accounting for 15 percent of the total area. UV2-MD is a medium density mixed-used land type, which allows commercial and institutional use along with residential use. Whereas precinct types in the core areas are designated as sub precincts, which are majorly commercial and private institutional uses. Land type Urban Hub and Urban Village-1 are allowed with major commercial and small industrial uses.

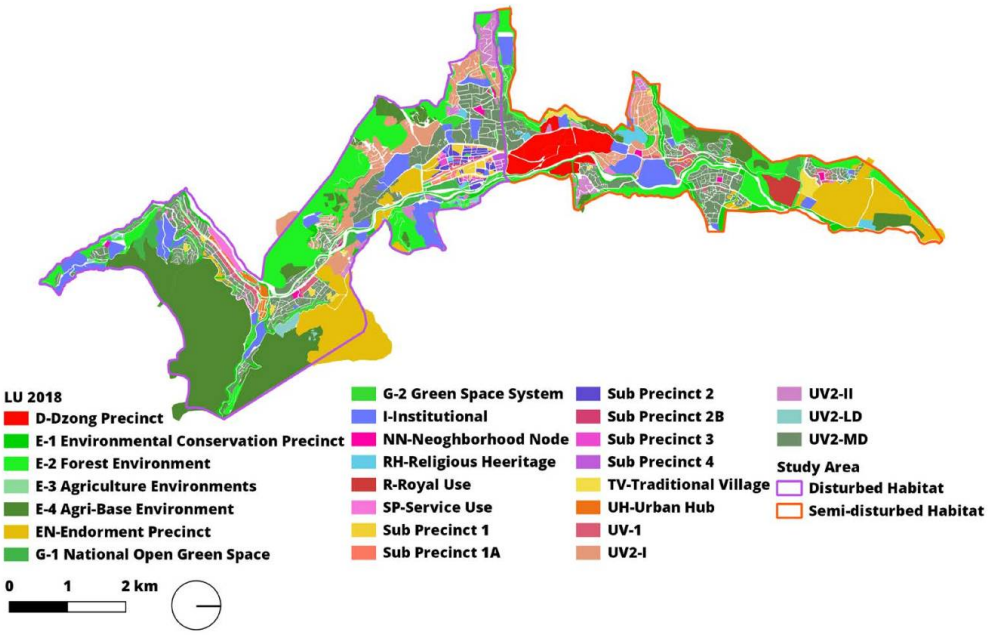

Figure 14. Land Precinct Map of Thimphu Source: TT 2015

With rapid urbanization and real estate development since the late 1990s, land which was covered by paddy field and forest have drastically converted to residential and commercial use. Today, only 0.13 percent of land is dedicated for agriculture use and some acres of land under the Dzong precinct (4.97 percent) are cultivated by the Ministry of Agriculture and Forestry as a part of the cultural landscape conservation effort. Agri-based environment precinct is a farm-house land type with an orchard and some livestock raising. However, with development

pressure and escalation of land value, most of the plots are fragmented into small plots for residential use. As per the environment conservation act of Bhutan, a green buffer of 15 m on both sides of the stream and 30 m at the river are mandatory. The city has designated about 5.4% of land as an environmental conservation zone, which is also no development zone to conserve the rich ecosystem of the Wangchhu river riparian corridor and adjoining streams. The conflict with nature and human are recorded majorly on this riparian corridor as people are encroaching the river and stream banks for development purpose, disposing of waste, altering river bank width and disturbing natural ecosystem for human benefits.

Table 9. Precinct distribution in Thimphu Source:TT, 2015

Urban Villages	2000	2005	2017
Babesa	1781	2826	5930
Simtokha	2453	2045	8204
Lungtenphu	1571	6799	16693
Changbangdu	2808	7153	9163
Changzamtog	2808	7153	13159
Core	5428	12537	9714
Yangchenphug	999	5641	6755
Kawang Chenjo	0	1102	868
Changangkha	1925	5711	6165
Lower Motithang	3367	8056	8875
Upper Motithang	3509	2323	3416
Zilukha	1414	2942	2961
Hejo Samtenling	4062	4298	7160
Taba	2242	4711	8856
Dechencholing	4044	6234	6632
Total Population	38411	79531	114551

The strollology along the 15-kilometer riparian corridor shows that there are seven major land uses in the study site. As the study site is located along the riparian corridor, all the sample plots fall under the environmental zone as per the precinct plan. The major land use recorded are residential and commercial uses, followed by recreational uses as shown in figure 15. The plots 1 to 8 are recorded with maximum land uses that are human-centric compared to remaining plots in the riparian zone. These plots were majorly dominated by Residential, recreational, and commercial uses. Three plots recorded industrial uses, which

deal with the preparation of ready-to-use construction materials, automobile repair businesses, and automobile junkyard. These Industrial activities were located very next to the river. Thus causing frequent disturbance to the river and adjacent vegetation.

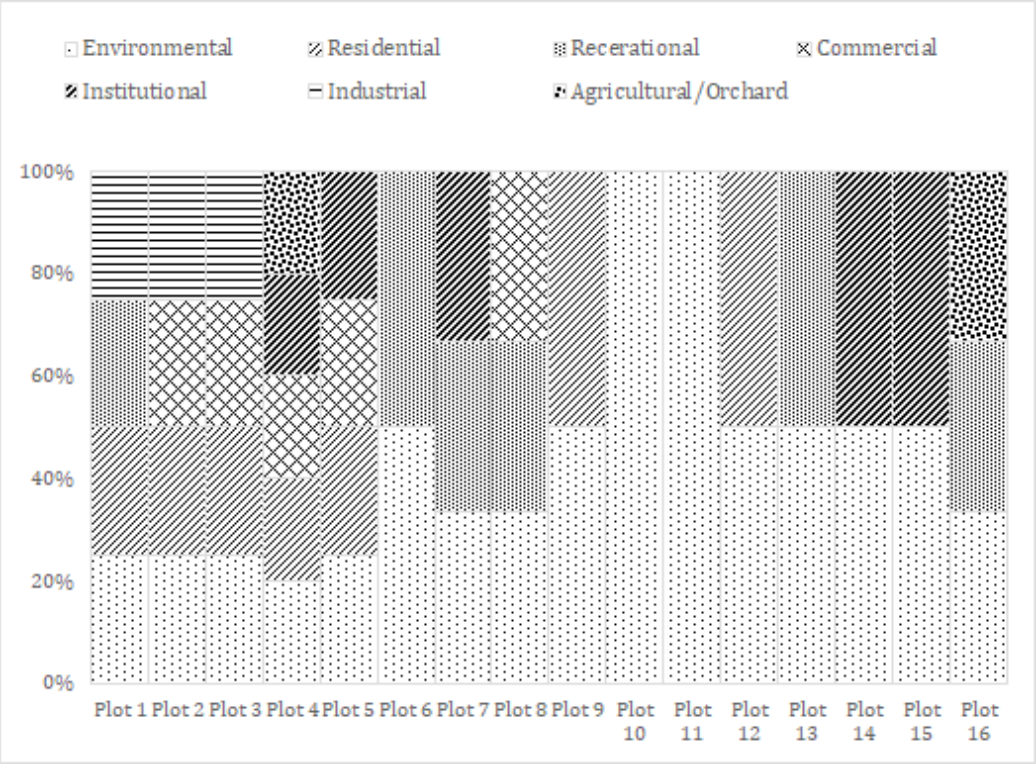

Figure 15. Precinct Composition in the Study Area

The land uses in plot 9 to 16 was mostly environmental use, which was characterized of conifer trees and dense shrubs. There were few residential, recreational, and institutional uses along the riparian corridor. The institutions recorded were one government school and a monastic school, which was enclosed by a boundary wall. Only, Plot 16 was recorded with an agricultural land use of paddy field. Since these plots are away from the city center and major road network, the development and disturbance in the area are very low compared to plots in the southern part of the city and the city center. The plots in the northern side are less disturbed and environment as major land use as it transit towards village settlement and thick forest at high mountains.

The vegetation growth along the Wangchhu has gradient characteristic, which

improves as one moves from extreme south at Babesa endpoint to Pangrizampa at the North end of the city. Whereas the human development and interference to nature and riverbank are reverse to vegetation characteristics.

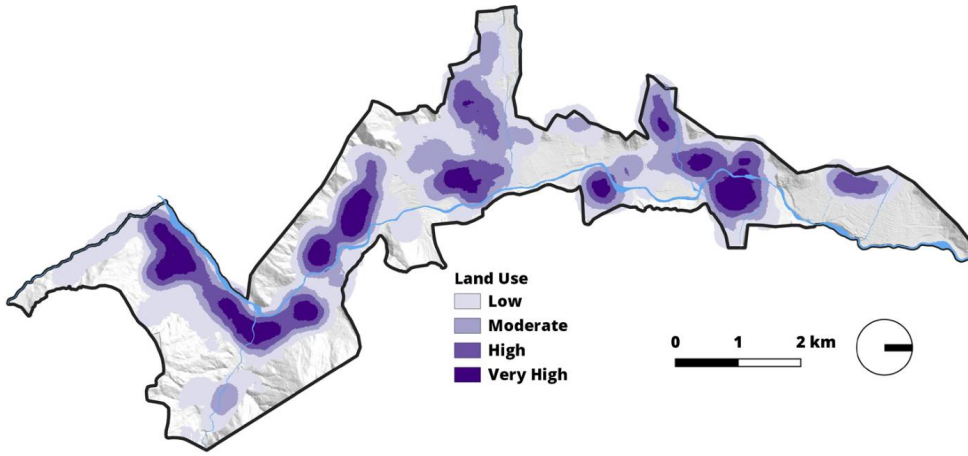

Figure 16. Land use intensity map

Analytic Hierarchical Process (AHP) of land use based on Satty's (1988) scale was used to compare the land use intensity that could have a higher impact on vegetation. The density mapping of land use shows the majority of sample plots in the city center and south of the city have a very high impact than those plots in the North of the city. Most of these high concentrations are along the riparian corridor. Plot 1,2,3,4,5,6 and 8 are located closer to the high-impact area. The north part of the city has a lower level of impact at plots 9, 10, 11, and 12 due to recent development activities in this area compared to plots 13, 14, 15, and 16, which shows no impact.

Figure 17. Industrial Activities along the riparian corridor

Figure 18. Scrap business at Babesa (left), Institutional Building at Lanjophaka (Right)

Figure 19. Forest cover in the north of the city and River-island as one of the sample plot

4.3 Built Area

Thimphu city is one of the densely built cities in the country. It has around 12300 structures in a total area of 26.6 sq. km, which means there are approximately 462 structures in 1 sq. km. As 1 sq. km is equivalent to a local area and Thimphu has 15 local areas as per the Structural plan 2002-27 (MoWHS, 2004). With modern construction, there are very few traditional buildings built of earth and timber. Traditional construction practices have been replaced by concrete, and steel with CGI sheet as a roofing material. These can only lead to an increase in surface runoff and less filtration of water into the earth. Dominant housing typology found in Thimphu is apartment type, followed by a few two-storied houses for single-family.

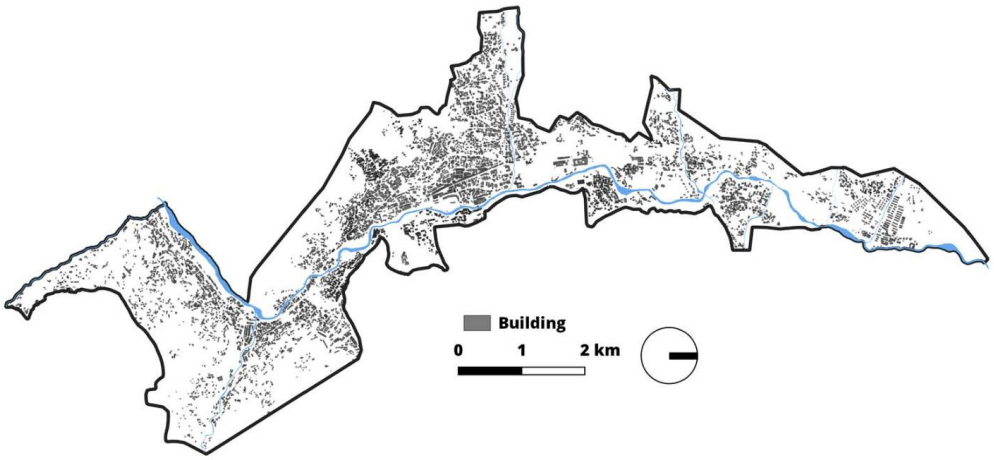

Figure 20. Buildings in the Study area Source:MoWHS and TT, 2020

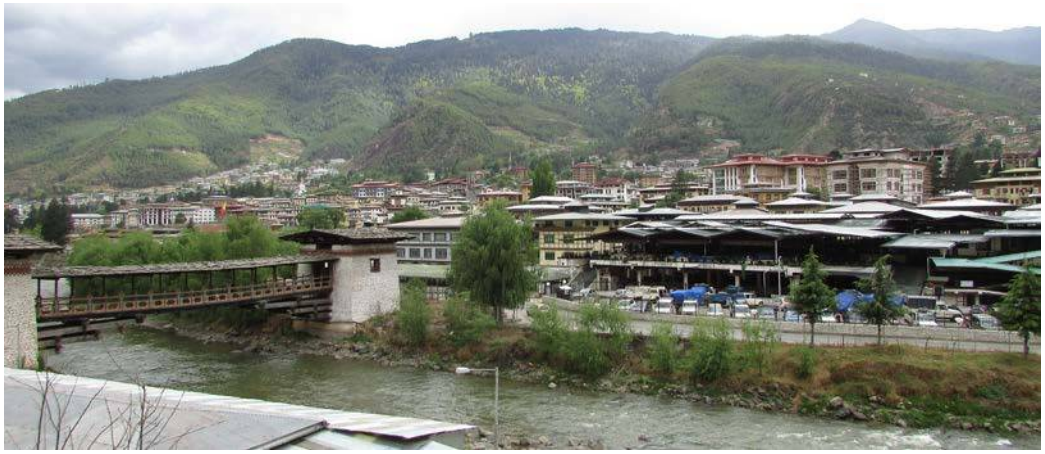

Figure 21. Dense contemporary building at city center, Thimphu 2021.

Thimphu city is one of the densely built cities in the country. It has around 12300 structures in a total area of 26.6 sq. km, which means there are approximately 462 structures in 1 sq. km. As 1 sq. km is equivalent to a local area and Thimphu has 15 local areas as per the Structural plan 2002-27 (MoWHS, 2004). With modern construction, there are very few traditional buildings built of earth and timber. Traditional construction practices have been replaced by concrete, and steel with CGI sheet as a roofing material. These can only lead to an increase in surface runoff and less filtration of water into the earth. Dominant housing typology found in Thimphu is apartment type, followed by a few two-storied houses for single-family.

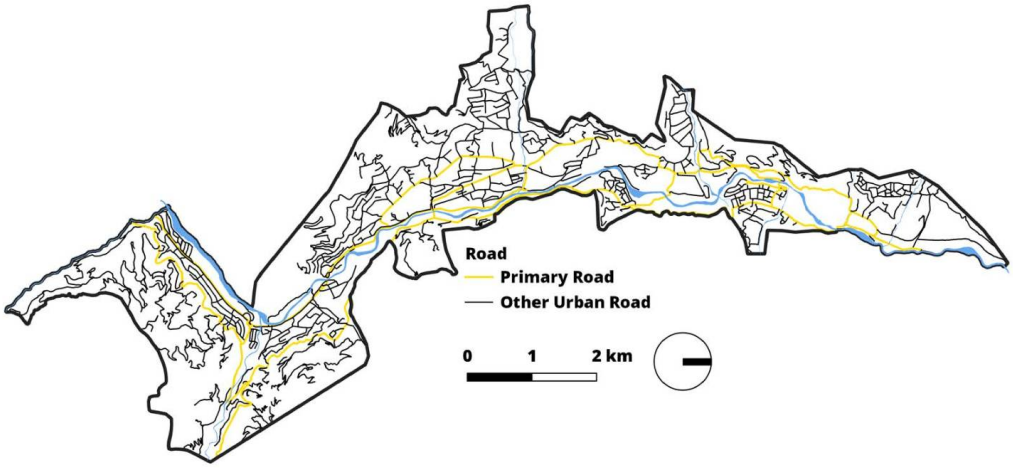

Figure 22. Road network map of Thimphu, 2021 Source: TT, 2021

The building and road layer was considered as a built-up area. Density mapping of built-up areas along the study area shows that the city center has a high density of built surface that equally stretches towards the south end of the city. This is due to the high number of high-rise buildings and wide roads along the river. Whereas, the area towards the north of the city has low built up, which is sparsely developed. The area has less built surface due to less urban development as it is away from the city center and major road network that connects the city to neighboring cities.

A paired comparison of built-up area in sample plots shows that plot 7, 5 and 1 has a maximum built area, whereas plot 16, 15, 14, 13, 11 and 10 in the north part of the city has a minimal built area as shown in table 11. Most of the land in the northern part is vacant or less concentrated with a cluster settlement pattern.

Figure 23. Four lane road or Express way (Left) Two lane road (Right)

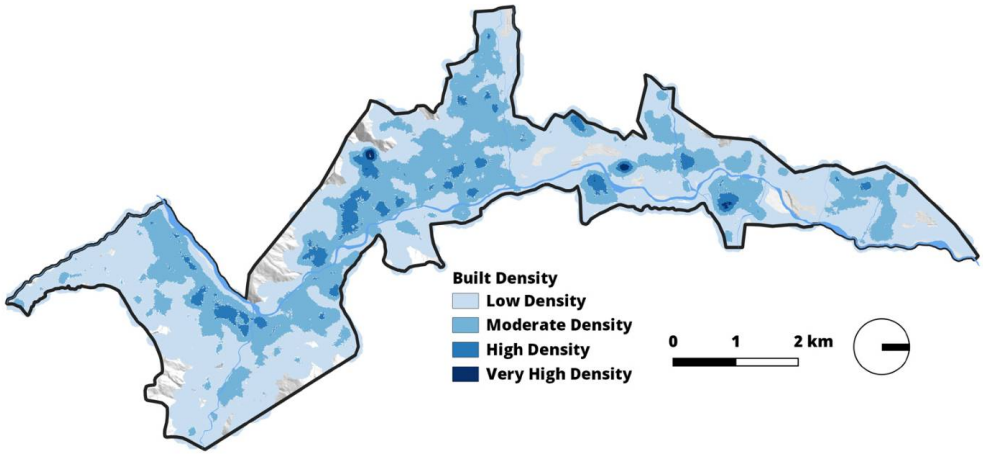

Figure 24. Building density of Thimphu, 2021

Table 10. Bulit-up pair comparison of study area

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
Built up	0.10	0.09	0.03	0.16	0.07	0.06	0.22	0.05	0.05	0.04	0.04	0.04	0.01	0.01	0.01	0.01

Figure 25. Densely built up in Changzamtog at the South of city (left), Upcoming development in Pamtsho at the North of city (Right)

4.4 Population

Thimphu city is divided into 15 urban villages for city planning purposes. The city is the center of ten ministry offices, several civil society offices, financial institutions, and private companies. The city houses 114, 551 population in 26.6 sq. km, which accounts for 15 percent of the national population. The city population is expected to grow up to 200,000 in the next 20 years (NSB, 2014). A comparative analysis of population since 2000 show that the city population

has increased almost three times. Very steep population growth was experienced in urban villages of Babesa, Simtokha, Lungtenphu, Changzamtog, Hejo and. This growth coincided with the rapid urban development from 2004 with the implementation of several local area plans. Babesa, Lungtenphu, Changbangdu and Changzamtog were planned in 2004. Whereas Taba and Hejo were planned in 2008 (Norbu, 2018).

Table 11. Urban Village Population distribution of Thimphu Source: NSB, 2005, 2017, MoWHS 2004

Urban Villages	2000	2005	2017
Babesa	1781	2826	5930
Simtokha	2453	2045	8204
Lungtenphu	1571	6799	16693
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Hejo Samtenling	4062	4298	7160
Taba	2242	4711	8856
Dechencholing	4044	6234	6632
Total Population	38411	79531	114551

The recent PHCB (2017) reported 114555 population in the city. The maximum population was recorded in Lungtenphu urban village, followed by Changzamtog and core city, which accounts for 13159 and 9714 respectively. A total of 88942 population that accounts for about 78 percent of the city population is concentrated in the South and the city center. The concentration of population is due to the location of the high-rise buildings, major public amenities, and early development in the Southern part of the city. Whereas, other parts of the city represents only 22 percent of the total population due to few development activities.

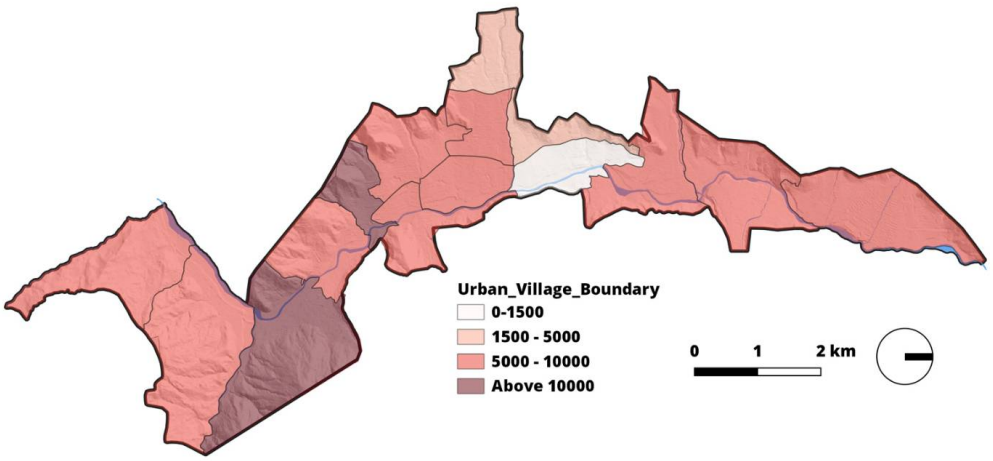

Figure 26. Urban Village wise population map of Thimphu Source: NSB 2017

The density mapping of the population shows most of the people concentrated along the river, primary road, and dense urban development. The sample plots are located in proximity to densely populated zones. The high density is recorded near plots 3, 4 5,6, and 7. Whereas one plot at the north has a high density, that is plot 12 due to proximity to recent development in Taba urban village. Plot 13, 14, 15, and 16 have low density due to settlements such as monastic schools, residential and government institutions in the proximity.

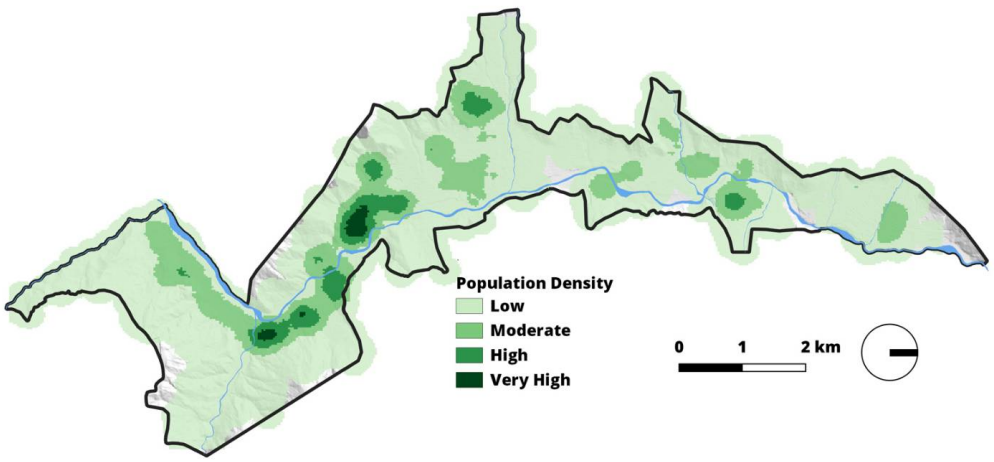

Figure 27. Population density map of Thimphu

4.5 Anthropogenic activities

Anthropogenic activities were based on the field observation accounted along the 15 km riparian corridor of Wangchhu. It was observed that the width of the riparian corridor at the south and core area was narrow that some of the properties and infrastructures are built closer to the river edge. While the riparian corridor width at the north increases as it gets moves from the city center. The vegetation cover along the riparian also gets denser. Walks along the corridor have been recorded with seven common human activities that disturbed the natural setting of an ecosystem. These are the disposal of household solid wastes, Construction debris, Automobile waste, active recreational activities, picnic and walking trails along the river. The household waste disposed at banks of the river was mostly plastic bags, food wrappers, and plastic bottles which are not degradable and can affect the flora and fauna of aquatic and terrestrial. The common construction debris include bricks, concretes, wood flakes, and earth were disposed of at the bank, which covers the natural topsoil and existing vegetation. The waste from automobiles is majorly produced from repair workshops and junkyards located near the riverbank and some are directly disposed into the river or disposed on the ground. Alteration of the natural landscape was majorly occurring in the disturbed area at the south part of the city in Babesa and Semtokha. The alteration was done by disposing of soil near the riverbank to create land for development purposes. Thus choking the river, disturbing the natural flow of rive, and destroying the ecosystem. The alteration also led to fragmentation of habitat and discontinuous corridor at the disturbed area. The riparian corridor was used for the recreational purpose of long-range traditional archery, traditional dart game, and cycling. There are also a few picnics and resting spots, and a long walking trail along the river that passes through dense vegetation and connects to the road.

Figure 28. Alteration of natural Landscape (lleft). Automobile waste disposal (right).

Figure 29. Construction bedris disposal (left). Household waste disposal (right)

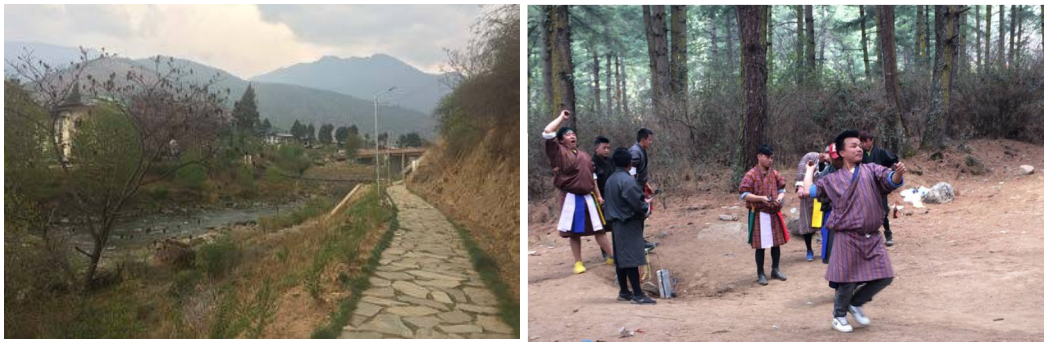

Figure 30. Fothpath along the river at city center (left). Recreational activities at riparian zone in Taba (right)

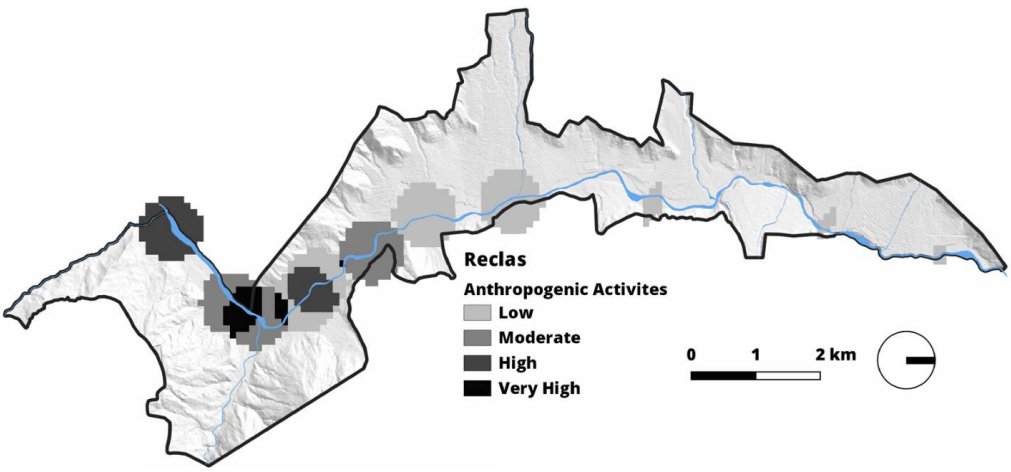

Figure 31. The intensity of anthropogenic activites in the study area

Mapping of anthropogenic activities in sample plots shows that the lower part of the city area has a maximum record of human interference in the riparian corridor. The high intensity of activity was recorded in Plot 1,2,3,4 and 5. It is due to the proximity of the corridor to intense land use and human settlement that creates constant contact to this part of the riparian corridor. Whereas plots

6, 7, and 8 had comparatively low disturbance due to the long distance from the settlement. The sample plots in the north of the city were found to have low and null activities that disturbed the natural setting of the riparian ecosystem. This is due to less accessibility to the habitat despite having settlements in proximity. The plots at the lower end of the river are easily accessible by humans and animals.

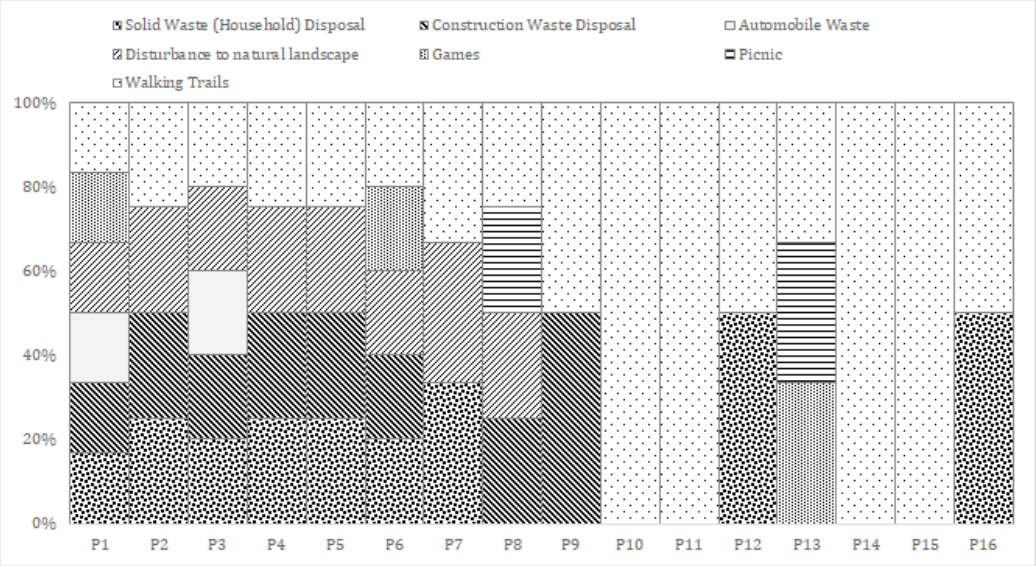

Figure 32. Distribution of anthropogenic activites in the study area

4.6 Assessment of urban disturbances.

Criteria weights of four urban variables have been determined by pair-wise comparison in the Analytical Hierarchical Process according to Saaty's (1988) scale. The scale available for pair comparison is as shown in table 12. The determination of scale for each variable was based on the observation and records from sample plots in the riparian corridor. The paired comparison of four variables resulted in that built surface weights 0.099, which means that it has almost 10 percent influence on the vulnerability of vegetation of the study area. Likewise, population, land use, and anthropogenic activities have percentage influence of 10.6 percent, 25.9 percent, and 53.7 percent respectively as shown in Table 13. Weights of urban variables were checked against the consistency ratio (C.R) as shown in the table below. The C.R for urban variables was 2.5 percent, which is within the acceptance ratio of less or equal to 10 percent inconsistency.

Table 12. Rating scale of Satty (1988)

Extremely	Very high	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
1/9	1/7	1/5	1/3	1	3	5	7	9

Table 13. Pair comparison of four urban variables

	Built Surface	Population	Land Use	Anthropogenic activities	Criteria Weights
Built Surface	0.1	0.111	0.071	0.112	0.099
Population	0.1	0.111	0.071	0.14	0.106
Land Use	0.3	0.333	0.214	0.187	0.259
Anthropogenic activities	0.5	0.444	0.643	0.561	0.537

The raster cell value of each urban variable was computed using a raster classifier in QGIS 3.12.3. The cell values of each variable were multiplied by the criteria weights determined through AHP. The resulting cells of high raster values indicate more vulnerable areas for vegetation, whereas lower raster values indicated less vulnerable vegetation degradation. The output raster values are reclassified into four range from 1 to 4. 4 implies that the vegetation has very high vulnerability and 1 indicate areas with low vulnerability.

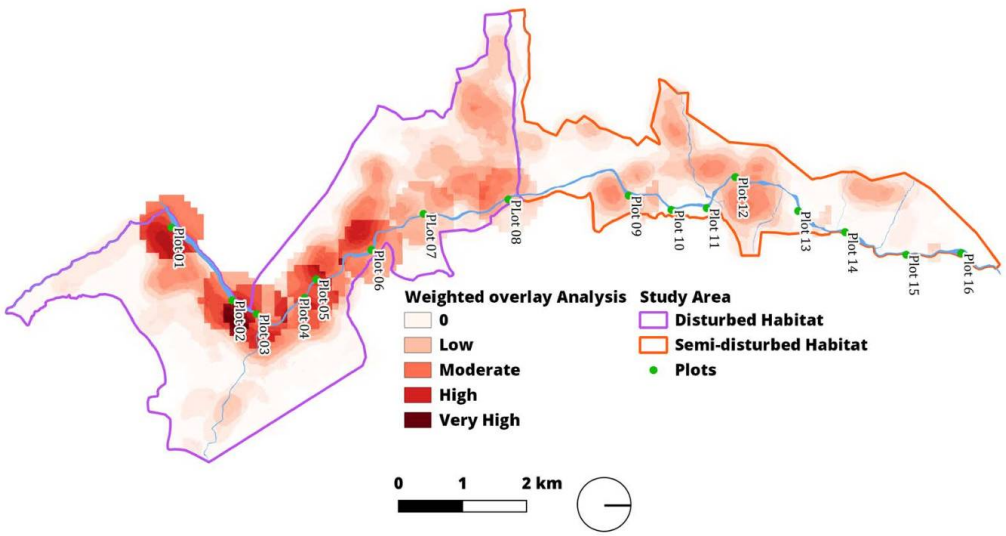

Figure 33. Intensity of Urban Disturbance in the stdy area.

The weighted overlay analysis shows that sample plots 1,2 and 3 have a very high disturbance that would increase the vulnerability to natural vegetation degradation (Amare and Semegn, 2019). Sample plot 13, 14, 15 and 16 in semi-disturbed habitat has low urban disturbance that could cause a minimum effect on the natural vegetation.

Overall, the riparian zone in the south part and core of the city is highly affected by urban development activities that create a challenging environment for plants to thrive and adapt to their stressful surroundings. Whereas the northern part of the city has a low level of disturbance, and most of the natural vegetation is still exists. Therefore, the plots in the south and city center are classified as Disturbed Habitat and plots in the north of the city as semi-disturbed habitat due to some degree of disturbances to vegetation as shown in table 14.

Table 14. Plot wise disturbance level in the study area

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
	Disturbed Habitat								Semi-disturbed Habitat							
Disturbance Level																
	Very High				High			Moderate					Low			

Figure 34. Recently constructed temporary house in the riparian zone at Babesa

Chapter 05-Flora Analysis and Results

5.1 Flora species richness

The study area of a 15 km stretch along the Wangchhu riparian corridor is observed with 101 species that include 12 species of trees, 24 shrub species, and 65 herb species. Among the species recorded within 16 plots along the riparian zone, the highest recorded species were herbs accounting for 64 percent of total species followed by 24 percent by shrub and tree making 12 percent of the recorded species as shown in figure 34. Similar observations on species richness were found across the 16 plots as shown in tables 10, 11, and 12. In few plots, either shrubs or trees were recorded as null. However, all the plots were recorded with herb lifeforms.

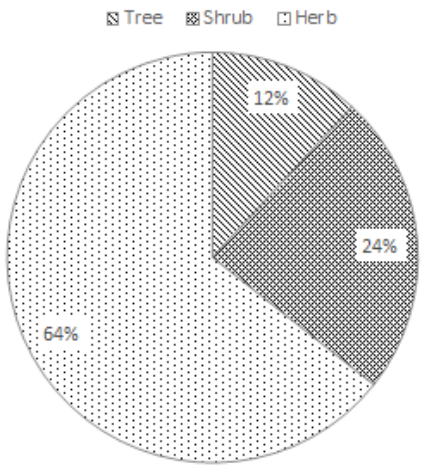

Figure 35. Distribution of flora species richness in the study area

5.1.1 Tree Species Richness

A total of 12 species were recorded among 16 plots. Plot 7 recorded 5 species as the highest count that consist of *Cupressus himalaica, Cedrus deodara, Prunus persica, Querecus griffith,* and Q*uercus semecarpifolia,* and followed by plot 8 and 14 with 4 species in each plot, which consisted of trees such as *Rhus hookeri, Pinus wallichiana, Populus Ciliate, Salix babylonica, Salix wallichiana* and *Enonymus grandifloras*.

Apart from two plots with null tree species, plots 2 and 13 were recorded the lowest species richness with only one tree species of *Salix babylonica* and *Pinus wallichiana* respectively as shown in table 15.

Table 15. Record of tree species richness along the Wangchhu riparian corridor. If species are recorded (1) and if not recorded (0)

Species Nr.	Botanical Name	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	Total
Sp1	*Cupressus himalaica*	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	2
Sp2	*Cedrus deodara*	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2
Sp3	*Enonymus grandiflorus*	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
Sp4	*Juniperus indica*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Sp5	*Pinus wallichiana*	0	0	0	0	0	0	0	1	0	1	1	0	1	1	1	0	6
Sp6	*Populus ciliate*	1	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	5
Sp7	*Prunus persica*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Sp8	*Querecus griffithi*	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	3
Sp9	*Quercus semecarpifolia*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2
Sp10	*Rhus hookeri*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Sp11	*Salix babylonica*	1	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	6
Sp12	*Salix wallichiana*	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0	5
Sub Total		2	1	0	3	2	2	5	4	2	2	3	2	1	4	3	0	

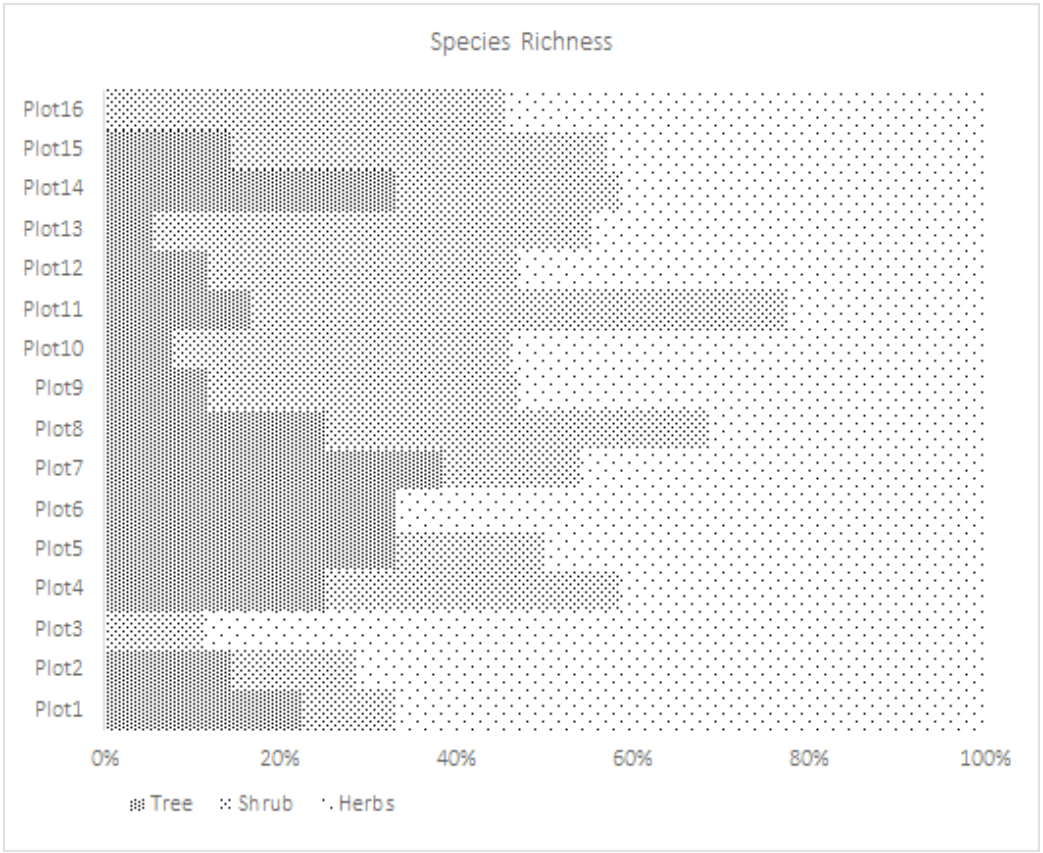

Figure 36. Species richness of Trees, Shrubs, and Herbs in each plot

During a comparative study of species richness between Disturbed and Semi-disturbed habitat, it was observed that disturbed habitat has high richness than the semi-disturbed area with species richness of 11 and 7 species respectively. Out of 12 species recorded, both the habitat was recorded with 6 common species and 6 completely different species as listed in table 16. It was also observed that Salix babylonica was recorded the most in disturbed habitat and Pinus wallichiana in semi-disturbed habitat.

Table 16. Common species recorded in two Habitat types.

Species Nr.	Botanical Name	Disturbed Area	Semi-Disturbed Area
Sp3	*Cupressus himalaica*	1	0
Sp5	*Cedrus deodara*	1	0
Sp2	*Enonymus grandiflorus*	0	1
Sp4	*Juniperus indica*	1	0

Sp6	*Pinus wallichiana*	1	1		
Sp10	*Populus ciliate*	1	1		
Sp7	*Prunus persica*	1	0	If species are	
Sp8	*Querecus griffithi*	1	1	recorded (1) and if	
Sp9	*Quercus semecarpifolia*	1	1	not recorded (0)	
Sp1	*Rhus hookeri*	1	0		
Sp11	*Salix babylonica*	1	1		
Sp12	*Salix wallichiana*	1	1		Common
	Sub Total	11	7		Different

5.1.2 Shrub Species Richness

A 15 km Wangchhu riparian corridor was recorded with 24 shrub species. Of these, Plot 11 recorded the highest species richness of 11 varieties followed by plot 10 with 10 species. Common species found in these locations are *Artemisia moorcroftiana, Berberis griffithiana, Elaeagnus parvifolia,* and P*hyllanthus recticulatus*. Out of 16 plots, only one plot (plot 6) was recorded with null species and four plots (Plot 1, 2, 3, and 5) were recorded with only one species, which is common species to all these plots. A species recorded in these four plots is Artemisia moorcroftiana. It was also widely recorded in most of the plots along the riparian corridor as shown in table 17.

Table 17. Record of shrub species richness along the Wangchhu riparian corridor

Sp. No	*Botanical Name*	*P 1*	*P 2*	*P 3*	*P 4*	*P 5*	*P 6*	*P 7*	*P 8*	*P 9*	*P 10*	*P 11*	*P 12*	*P 13*	*P 14*	*P 15*	*P 16*
Sp1	*Artemisia moorcroftiana*	*1*	*1*	*1*	*1*	*1*	*0*	*0*	*1*	*1*	*1*	*1*	*1*	*0*	*0*	*1*	*1*
Sp2	*Berberis aristata*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*
Sp3	*Berberis griffithiana*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*1*	*1*	*1*	*1*	*0*	*1*	*1*
Sp4	*Colquhounia coccinea*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*
Sp5	*Cotoneaster sp*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*1*	*0*	*0*	*1*	*0*	*0*
Sp6	*Elaeagnus parvifolia*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*1*	*1*	*1*	*1*	*0*	*1*	*0*	*1*	*1*
Sp7	*Elaeagnus umbellata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Sp8	*Hedera nepalensis*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp9	*Leptodermis amoena*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Sp10	*Ligustrum compactum*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Sp11	*Lonicera glabrata*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sp12	*Lonicera quinquelocularis*	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Sp13	*Morus australis*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp14	*phyllanthus recticulatus*	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0
Sp15	*Prinsepia utilis*	0	0	0	1	0	0	0	0	1	0	1	1	1	0	1	1
Sp16	*Rosa brunonii*	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1	0
Sp17	*Rosa sericea*	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
Sp18	*Rubia hispidicaulis*	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0
Sp19	*Rubus biflorus*	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
Sp20	*Rubus pectinarioides*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sp21	*Rubus pungens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp22	*Salix obscura*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp23	*viburnum continifolium*	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Sp24	*Zanthoxylum sp*	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0	0
Sub Total		1	1	1	4	1	0	2	7	6	10	11	6	9	3	9	5

An assessment of species richness between two habitats shows that semi-disturbed habitat has high species richness of 22 species than disturbed habitat with only 10 species. Out of 10 species recorded in disturbed habitat, 8 species were also recorded in semi-disturbed habitat. Common species found in these habitat are *Artemisia moorcroftiana, Berberis griffithiana, Elaeagnus parvifolia, Lonicera quinquelocularis, Lonicera quinquelocularis, Prinsepia utilis, Rosa brunonii, Rubia hispidicaulis* and *Zanthoxylum species*. *Artemisia moorcroftiana* is the only shrub that was widely found in most of the plots whereas B*erberis griffithiana, Elaeagnus parvifolia,* and *Prinsepia utilis* was mostly observed in semi-disturbed habitat.

Table 18. Common species recorded in two Habitat types.Note: If species are recorded (1) and if not recorded (0)

Species Nr	Botanical Name	Disturbed Habitat	Semi-disturbed Habitat
Sp1	*Artemisia moorcroftiana*	1	1
Sp2	*Berberis aristata*	0	1
Sp3	*Berberis griffithiana*	1	1
Sp4	*Colquhounia coccinea*	0	1
Sp5	*Cotoneaster sp*	0	1
Sp6	*Elaeagnus parvifolia*	1	1
Sp7	*Elaeagnus umbellata*	0	1
Sp8	*Hedera nepalensis*	0	1
Sp9	*Leptodermis amoena*	0	1

Sp10	*Ligustrum compactum*	1	0	
Sp11	*Lonicera glabrata*	1	0	
Sp12	*Lonicera quinquelocularis*	1	1	
Sp13	*Morus australis*	0	1	
Sp14	*phyllanthus recticulatus*	0	1	
Sp15	*Prinsepia utilis*	1	1	
Sp16	*Rosa brunonii*	1	1	
Sp17	*Rosa sericea*	0	1	
Sp18	*Rubia hispidicaulis*	1	1	
Sp19	*Rubus biflorus*	0	1	
Sp20	*Rubus pectinarioides*	0	1	
Sp21	*Rubus pungens*	0	1	
Sp22	*Salix obscura*	0	1	
Sp23	*viburnum continifolium*	0	1	Common
Sp24	*Zanthoxylum sp*	1	1	Different
		Sub Total 10	22	

5.1.3 Herb Species Richness

A total of 65 herb species were recorded in 16 plots sampled along the Wangchhu riparian corridor. Out of which plot 10 recorded 14 species as the highest species richness followed by plot 9, 12, and 15 recordings 9 species each as shown in the figure. Whereas plot 5 recorded only three species namely Festuca stapfii, Pennisetum clandestinum, and Verbascum thapsus, and plot 6 and 11 recorded four species.

It is observed that semi-disturbed habitat has a high species richness of 49 species when compared to disturbed habitat with 27 species recorded. Of 65 species 11 species have been recorded in both habitats. Among the 27 species in disturbed habitat 5 species namely Conyza stricta, Equisetum sp, Pennisetum clandestinum, Verbascum Thapsus, and Taraxacum parvulum were commonly recorded. Whereas the semi-disturbed habitat recorded only two species of grass that is Digitaria sp and Ophiopogon intermedius in most of the plots. Some of the species such as Pennisetum clandestinum , Verbascum Thapsus , Equisetum sp , Digitaria sp, Rumex Nepalensis, Oxalis Corniculata, Pteridium aquilinum, and Rumex Nepalensis are categorized as invasive (NBC, 2017) or weed species (Parker, 1992) that are harmful to the surrounding species.

Table 19. Common and Different species recorded in two Habitat types. Note: If species are recorded (1) and if not recorded (0)

Species Nr.	Botanical Name	Disturbed Habitat	Semi-disturbed Habitat
Sp1	*Agrimonia pilosa*	0	1
Sp2	*Anaphalis triplinervis*	0	1
Sp3	*Arundinella bengalensis*	0	1
Sp4	*Berberis asiatica*	0	1
Sp5	*Calamagrostis nivicola*	0	1
Sp6	*Cannabis sativa*	0	1
Sp7	*Carex speciosa*	0	1
Sp8	*Cirsium wallichii*	0	1
Sp9	*Clematis montana*	0	1
Sp10	*Clinopodium umbrosum*	1	0
Sp11	*Colquhounia sp*	0	1
Sp12	*Conyza canadensis*	1	0
Sp13	*Conyza stricta*	1	0
Sp14	*Crotalaria sp*	0	1
Sp15	*Desmodium sp*	0	1
Sp16	*Digitaria sp*	0	1
Sp17	*Drynaria propingua*	0	1
Sp18	*Equisetum sp*	1	1
Sp19	*Fagopyrum cymosum*	1	1
Sp20	*Festuca arundinacea*	1	0
Sp21	*Festuca stapfii*	1	0
Sp22	*Fragaria nubicola*	0	1
Sp23	*Galium aparine*	0	1
Sp24	*Gentiana Ccapitata*	0	1
Sp25	*Geranium polyanthus*	0	1
Sp26	*Geranium procurrens*	1	1
Sp27	*Hederan nepalensis*	0	1
Sp28	*Holcus lanatus*	1	0
Sp29	*Holcus nepalensis*	0	1
Sp30	*Isodon sp*	0	1
Sp31	*Jasminum humile*	0	1
Sp32	*Juncus iinflexus*	1	0
Sp33	*Ligustrum compactum*	0	1

Sp34	*Lonicera sp 1*	0	1
Sp35	*Morus australis*	0	1
Sp36	*Myriactis wallichii*	0	1
Sp37	*Onychium contiguum*	0	1
Sp38	*Ophiopogon bodinieri*	1	1
Sp39	*Ophiopogon intermedius*	1	1
Sp40	*Oplismenus sp*	0	1
Sp41	*Oxalisc corniculata*	1	1
Sp42	*Paspalum sp*	1	0
Sp43	*Pennisetum clandestinum*	1	0
Sp44	*Plantago depressa*	1	0
Sp45	*Poa dzongicola*	1	0
Sp46	*Poa pratensis*	0	1
Sp47	*Poa sp*	1	1
Sp48	*Potentilla supina*	0	1
Sp49	*Prangos sp*	1	0
Sp50	*Pteridium aquilinum*	1	1
Sp51	*Pteris cretica*	0	1
Sp52	*Rumex nepalensis*	1	1
Sp53	*Salvia sp*	0	1
Sp54	*Seneue scandens*	0	1
Sp55	*Solanum americanum*	1	0
Sp56	*Stellaria vestita*	0	1
Sp57	*Taraxacum eripodum*	1	1
Sp58	*Taraxacum parvulum*	1	1
Sp59	*Thalictrum virgatum*	0	1
Sp60	*Tragopogon dubius*	1	0
Sp61	*Trifolium repens*	0	1
Sp62	*Verbascum thapsus*	1	0
Sp63	*Viola macloskeyi*	0	1
Sp64	*Yushania microphylla*	0	1
Sp65	*Yushania sp*	1	0
	Sub Total	27	49

Common

Different

5.2 Species diversity

A diversity of tree, shrub, and herb species was studied for each plot to understand the level of flora specimen diversity in the riparian corridor which will eventually benefit a larger ecosystem of the city. During the site visits and data collection, several bird species were seen in the sample plots, which could mean that the riparian corridor is serving as a rich ecosystem.

Figure 37. Some of the avifauna species seen within the sample plots

The study shows that the riparian corridor is rich in tree diversity with most of the plots diversity index above 0.5 H' (Shannon index) and has evenly distributed tree species above 0.5 Hmax (evenness). Among 16 plots, two plots (plot 3 and 16) were recorded with NULL and two plots (plot 2 and 13) were observed to have 0 H' diversity due to the presence of a single type of tree species in each plot that is Salix babylonica and Pinus wallichiana respectively. Whereas the plot 7 and 14 were found to have highest index of 1.366 H' and 1.188 H' respectively.

Table 20. Species diversity and evenness index of riparian corridor

	Tree			Shrub			Herb		
Plot No	*Shannon Index (H')*	*Evenness (Hmax)*	*Simpson Index (D)*	*Shannon Index (H')*	*Evenness (Hmax)*	*Simpson Index (D)*	*Shannon Index (H')*	*Evenness (Hmax)*	*Simpson Index (D)*
P1	0.41	0.592	0.714	0	0	0	1.285	0.717	0.353
P2	0	0	1	0	0	1	0.886	0.551	0.454
P3	NA	NA	NA	0	0	1	1.565	0.752	0.209
P4	0.868	0.79	0.4	0.531	0.383	0.439	0.194	0.121	0.933
P5	0.693	1	0.4	0	0	1	0.6	0.546	0.655
P6	0.637	0.918	0.524	NA	NA	NA	1.14	0.823	0.35
P7	1.336	0.83	0.268	0.451	0.65	0	0.899	0.502	0.556
P8	0.99	0.714	0.464	1.425	0.795	0.154	1.27	0.789	0.305
P9	0.5	0.722	0.6	1.037	0.579	0.154	1.441	0.656	0.315
P10	0.576	0.831	0.591	1.664	0.723	0.298	2.35	0.89	0.051
P11	0.703	0.64	0.575	1.693	0.706	0.109	1.09	0.786	0.318
P12	0.377	0.544	0.75	1.147	0.64	0.187	1.638	0.745	0.24
P13	0	0	1	1.446	0.658	0.2	1.381	0.664	0.336
P14	1.188	0.857	0.332	0.879	0.8	0.2	0.42	0.261	0.821
P15	0.911	0.829	0.385	1.767	0.804	0.136	1.838	0.837	0.159
P16	NA	NA	NA	1.058	0.657	0.327	1.431	0.799	0.203
Average	0.574	0.579	0.572	0.819	0.462	0.347	1.214	0.652	0.391

In the case of shrub diversity, the Shannon diversity in sample plots ranges from 0.000 to approximately 1.800 H'. This is due to 50 percent of the sample plots been recorded with NULL or only ONE species and the remaining 50 percent of plots with Shannon index above 1.000 H'. Thus presenting complete two different shrub vegetation types in a single riparian corridor. Out of 16 plots, only one plot (plot 6) was recorded with NULL shrub species and four plots (Plot 1, 2, 3, and 5) with ONE species of Artemisia moorcroftiana, which is also commonly found in most of the sample plots. Plot 15 is recorded with the highest diversity index of 1.767 H' and evenness of 0.804 Hmax among 16 plots. Overall the riparian corridor has very good shrub diversity of 0.819 Average H' and moderate evenness of shrub species distribution.

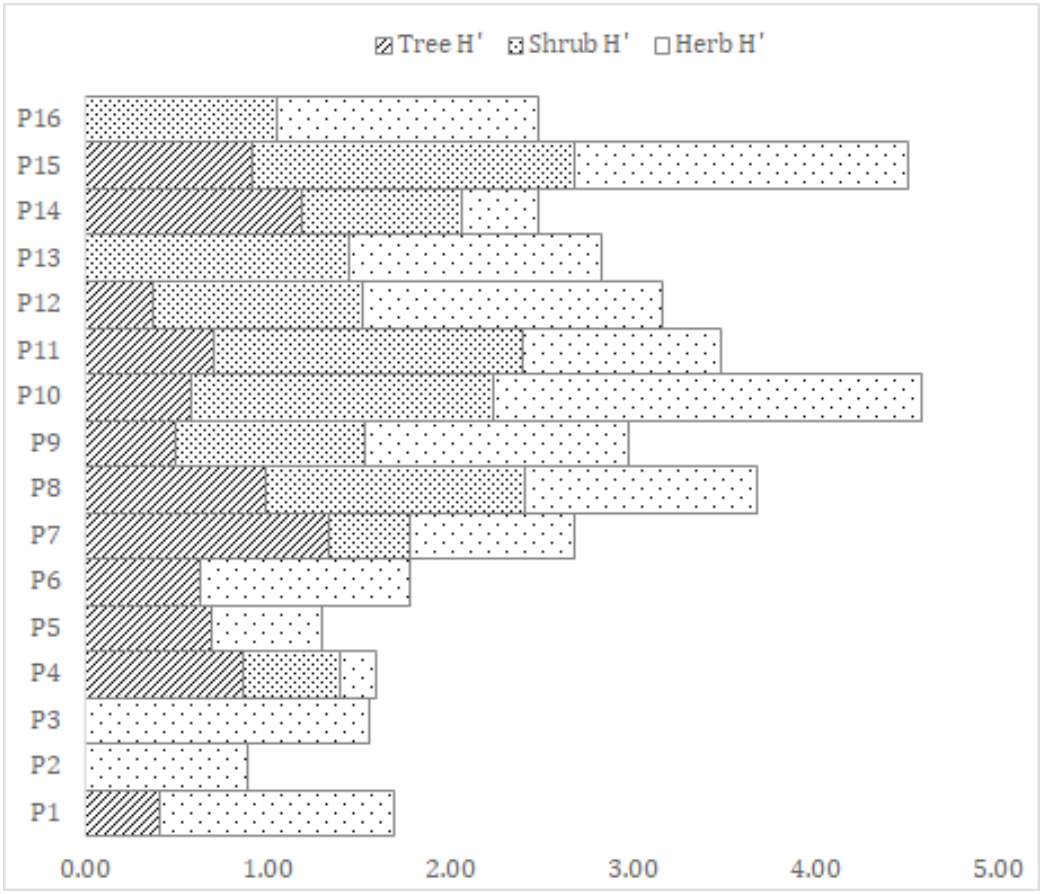

Figure 38. Shannon diversity (H') of Tree, shrub, and Herb of sample plots

The herb diversity in the riparian corridor is very high when compared with tree and shrub diversity. The diversity index of herb ranges from 0.42 H' to 2.35 H' with an average Shannon diversity index of 1.214 H'. Comparatively the evenness of the herb distribution is recorded high with an average of 0.652 Hmax when compared with tree and shrub evenness index. Plot 14 was recorded with low diversity of 0.42 H' this could be due to the location of the site as a river island that is prone to monsoon floods, which frequently disturbs the growth of vegetation on the site. Whereas plot 10 is recorded with the highest Shannon diversity index of 2.35 H' and evenness of 0.89 Hmax. The high diversity in the plot is due to higher species richness in the plot with 14 different species in a single plot which are also evenly distributed.

The comparative diversity study of two habitats for trees, shrub, and herb show that only tree diversity is recorded high in disturbed habitat with 1.862 H' whereas shrub and herb diversity is low than semi-disturbed habitat. Although,

the diversity of tree and herb in both the habitat is almost similar the shrub diversity of two habitats are different. Thus showing different shrub vegetation characteristics in two habitats. The shrub diversity for semi-disturbed habitat is recorded 2.547 H' and 1.435 H' for disturbed habitat. This difference can be due to frequent disturbance to the natural landscape by human development, and other urban activities in the surroundings. The evenness recorded throughout the habitat is above 0.5 Hmax, which indicates an even distribution of species in the habitats. Moreover, the Simpson Index recorded is also below 0.4 D' indicating the minimum dominant species along the corridor.

Table 21. Species diversity and evenness in two habitats

	Disturbed Habitat			Semi-Disturbed Habitat		
	Tree (400 sq.m)	*Shrub (25 sq.m)*	*Herb (4 sq.m)*	*Tree (400 sq.m)*	*Shrub (25 sq.m)*	*Herb (4 sq.m)*
Species richness	11	10	27	7	22	49
Shannon Index (H')	1.862	1.435	2.451	1.46	2.547	2.645
Evenness (Hmax)	0.777	0.653	0.735	0.75	0.824	0.663
Simpson Index (D')	0.202	0.327	0.124	0.275	0.105	0.118

5.3 Invasive Species

A total of 20 invasive species are recorded from 16 sample plots, which account for one-third of the total herb species recorded in the study area. The species is categorized as invasive based on A pictorial guide to major invasive plants species of Bhutan (NBC, 2018), Centre for Agriculture and Bioscience International-Invasive Species compendium (CABI, 2020), List of Invasive species recorded from Bhutan (MoAf, 2014), and Weeds of Bhutan (Parker, 1992). The study shows that. Equisetum sp., Digitaria sp., Pennisetum clandestinum, Oxalis corniculata, Rumex nepalensis, and Verbascum Thapsus are the most recorded invasive species in the study area. Invasive species belonging to Equisetum sp., and Rumex nepalensis are commonly recorded near the riverbank or marsh area. Whereas Pennisetum clandestinum, Verbascum thapsus, and Oxalis corniculata are recorded near road, foot trails, and disturbed soil. These species were mostly observed in a highly disturbed area and semi-disturbed area species of Digitaria sp. is mostly recorded.

The correlation of Invasive species to disturbance intensity shows weak positive

relation (r=0.0651). Thus indicating that there is an almost equal distribution of invasive species throughout the sample plot with most recorded in the highly disturbed area.

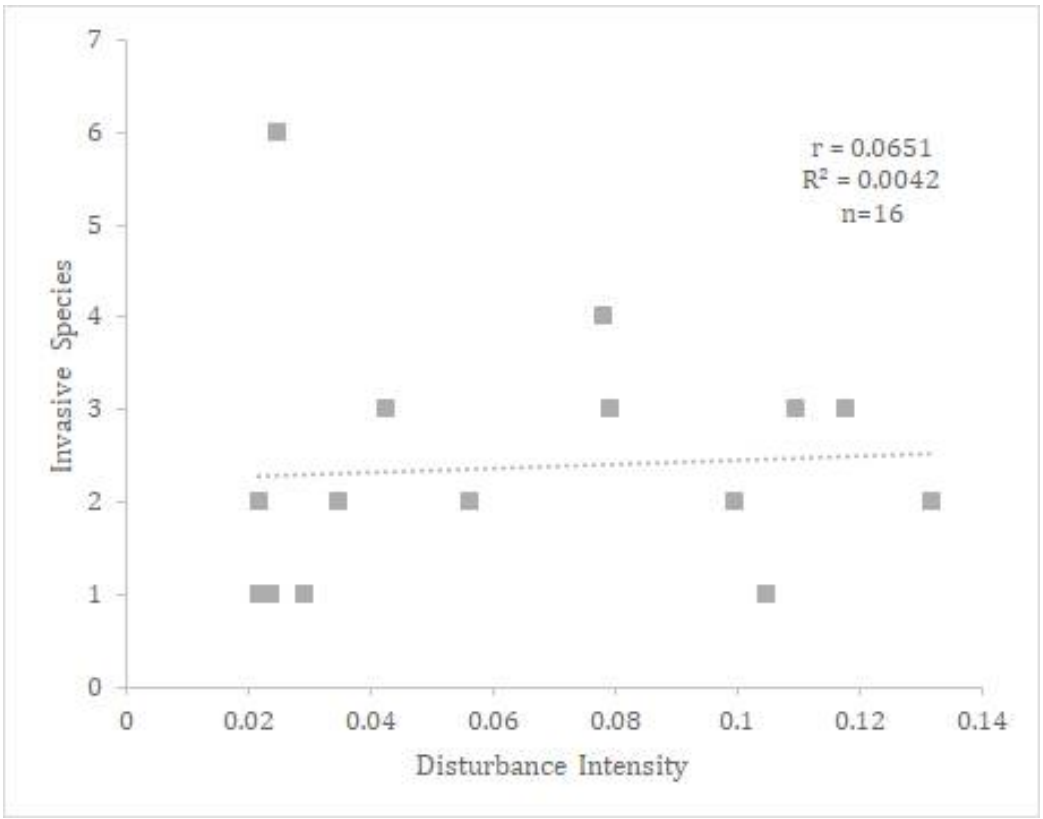

Figure 39. Relation between invasive species to urban disturbance

Figure 40. Invasive species: Equisetum sp. (left) Verbascum thapsus (mid) Pennisetum clandestinum (right)

5.4 Species Composition

5.4.1 Species Composition: Flora family Composition

A total of 101 species are recorded from 16 plots which belong to 52 flora families where 12 species of trees belong to 7 flora families, 24 shrub species to 13 families, and 64 herb species to 32 families as shown in the table below. Among the three families, Salicaceae and Pinaceae were recorded the most in the riparian corridor that is in 12 and 8 plots respectively. This shows that the riparian area is majorly covered by Salicacea and Pinaceae tree families. It is observed that plot 7 has the rich tree family composition with the existence of 4 numbers tree families out of 7 total families recorded in the area.

Figure 41. Number of flora families recorded along the riparian corridor

A total of 24 shrub species were recorded in the Wangchhu riparian corridor, which can be further grouped into 13 shrub families. It is observed that Compositae and Rosacea are the most common shrub family found in the corridor. These two family species are recorded in 12 and 11 plots out of 16 plots in the area. The least recorded are *Araliaceae, Euphorbiaceae, Moraceae Oleaceae,* and *Silicaceae* shrub family, which is recorded only in one plot each. Plot 10 and 11 located in the semi-disturbed area are recorded with high shrub families of eight numbers

each out of 13-shrub families found in the Wangchhu riparian corridor. Whereas plot 1, 2, 3 and 5 located in disturbed area has single shrub family commonly recorded, which is *Compositae*.

The herb species is recorded with the highest family composition with 33 numbers, which record 65 herb species in the area. Out of 33 families, *Gramineae* is found in 15 plots out of 16 plots followed by *Composite* and *Conyallariaceae* recorded in 9 and 8 numbers of plots respectively as shown in the table above. It is observed that plots 10 and 9 are recorded with maximum herb families of 11 and 9 counts followed by plots 12 and 13 with eight numbers of herb families. These plots are located in the semi-disturbed area of the riparian corridor. Thus informing that semi-disturbed habitat are rich in herb species compared to disturbed habitats.

Table 22. Flora families recorded in the Wangchhu riparian corridor

Family	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	Total
Tree																	
Anacardiaceae	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	1
Celastraceae	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	2
Cupressaceae	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	2
Pinaceae	-	-	-	-	-	+	+	+	-	+	+	-	+	+	+	-	8
Rosaceae	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	1
Fagaceae	-	-	-	-	+	-	+	-	+	-	-	-	-	-	+	-	4
Salicaceae	+	+	-	+	+	+	-	+	+	+	+	+	-	+	+	-	12
Sub Total	1	1	0	2	2	2	4	3	2	2	3	1	1	3	3	0	
Shrub																	
Araliaceae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	1
Berberidaceae	-	-	-	-	-	-	-	+	-	+	+	+	+	-	+	+	7
Caprifoliaceae	-	-	-	-	-	-	+	+	-	+	-	-	+	-	-	-	4
Compositae	+	+	+	+	+	-	-	+	+	+	+	+	-	-	+	+	12
Elaeagnaceae	-	-	-	+	-	-	-	+	+	+	+	-	+	-	+	+	8
Euphorbiaceae	-	-	-	-	-	-	-	-	-	+	+	-	+	-	-	-	3
Labiatae	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	1
Moraceae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	1
Oleaceae	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	1
Rosaceae	-	-	-	+	-	-	+	+	+	+	+	+	+	+	+	+	11
Rubiaceae	-	-	-	-	-	-	-	+	-	-	+	+	+	-	+	-	5

Rutaceae	-	-	-	+	-	-	-	-	-	-	+	-	+	+	-	-	4
Salicaceae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	1
Sub Total	1	1	1	4	1	0	2	7	3	8	8	4	7	2	6	4	
Herb																	
Apiaceae	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Araliaceae	-	-	-	-	-	-	-	-	-	+	+	-	+	-	-	-	3
Asteraceae	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	1
Berberidaceae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	1
Cannabceae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1
Caprifoliaceae	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	1
Caryophyllaceae	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	2
Compositae	+	-	+	+	+	-	+	+	-	+	-	+	-	-	+	-	9
Convallariaceae	-	-	-	+	-	-	-	+	+	-	+	-	+	+	+	+	8
Cyperaceae	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	1
Dennstaedtiaceae	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	2
Drynarioidea	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	1
Equisetaceae	-	+	-	+	-	-	-	+	+	-	-	-	-	-	-	-	4
Fabaceae	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	1
Gentianaceae	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	1
Geraniaceae	-	+	-	-	-	-	-	-	+	+	-	+	-	-	-	-	4
Gramineae	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	15
Juncaceae	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	1
Labiatae	+	-	+	-	-	-	-	-	-	+	-	-	-	-	-	+	4
Leguminosae	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	3
Moraceae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	1
Oleaceae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	2
Oxalidaceae	+	-	-	-	-	-	+	-	-	-	+	+	-	-	-	-	4
Plantaginaceae	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	1
Polygonaceae	-	+	-	-	-	+	-	-	-	-	-	+	-	+	-	-	4
Pteridaceae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	2
Ranunculaceae	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	2
Rosaceae	-	-	-	-	-	-	-	-	+	+	-	-	-	-	+	+	4
Rubiaceae	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	1
Scrophulariaceae	-	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-	3
Solanaceae	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	1

Violaceae	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	1
Sub Total	4	5	4	4	3	2	6	6	9	11	4	8	8	4	7	5	

5.4.2 Flora family composition in two habitats.

A total of 52-flora families consisting of tree, shrub, and herb species are recorded riparian corridor. Out of the total, 29 flora families are recorded in disturbed habitat and 42 flora families in semi-disturbed habitat as shown in figure 42. It is observed that disturbed habitat has more count of tree family as compared to semi-disturbed habitat with only four families out of seven tree families recorded in the corridor. Whereas the semi-disturbed habitat has more shrub and herb families, which alone represent almost 80 percent of species family. Thus, representing richness in species and diversity compared to disturbed habitat.

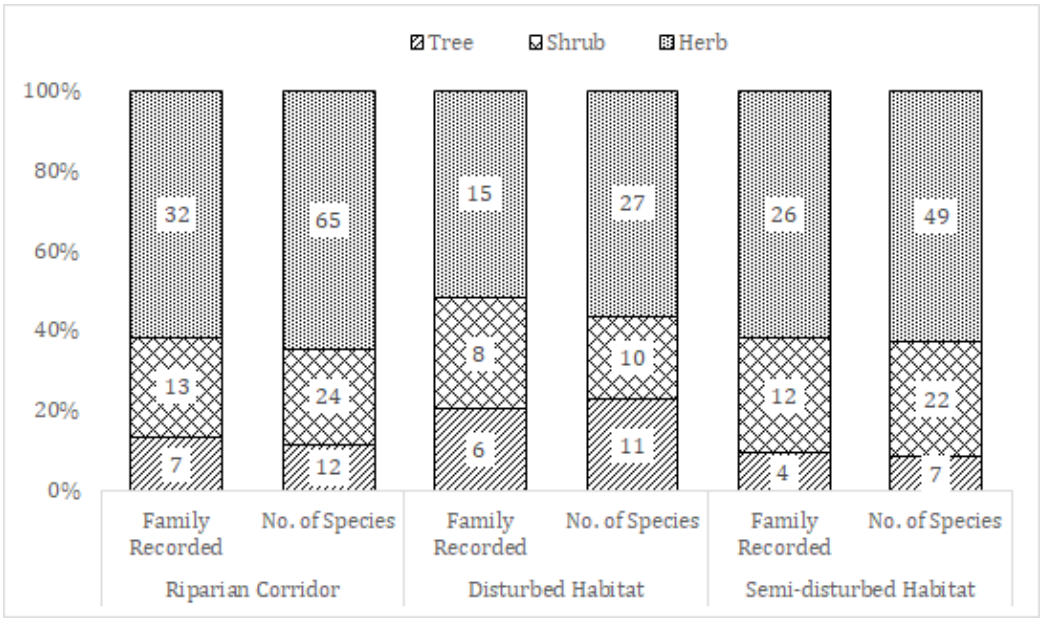

Figure 42. Flora family composition in two habitats

From 12 tree species, the majority of species belong to the *Salicaceae* family group. The disturbed habitat is recorded with maximum species and family groups. It is found that six out of seven family groups can be found in the disturbed habitat. On other hand, semi-disturbed habitat is recorded with four family groups of *Celastraceae, Pinaceae, Fagaceae,* and *Salicaceae*. It is observed that all the

species of *Salicaceae* and *Fagaceae* family groups are recorded in both habitats. Whereas, no species belonging to the *Celastraceae* family group is recorded in the disturbed area.

A total of 24 shrub species can be grouped into 13 flora families. Out of which eight family groups can be found in disturbed habitat and 12 flora family groups recorded in semi-disturbed habitat. The family group *Oleaceae* is the only family, which is not recorded in semi-habitat. It is observed that the *Rosacea* is the only shrub family group with maximum species and all the six species are recorded in semi-disturbed habitat and only two species are recorded in disturbed habitat.

Table 23. Tree family composition in two habitats

Family	Riparian Corridor		Disturbed Habitat		Semi-disturbed Habitat	
(Tree)	Family Recorded	No. of Species	Family Recorded	No. of Species	Family Recorded	No. of Species
Anacardiaceae	+	1	+	1	-	0
Celastraceae	+	1	-	0	+	1
Cupressaceae	+	2	+	2	-	0
Pinaceae	+	2	+	2	+	1
Rosaceae	+	1	+	1	-	0
Fagaceae	+	2	+	2	+	2
Salicaceae	+	3	+	3	+	3
Sub Total	7	12	6	11	4	7

Table 24. Shrub family composition in two habitats

Family (Shrub)	Riparian Corridor		Disturbed Habitat		Semi-disturbed Habitat	
	Family Recorded	No. of Species	Family Recorded	No. of Species	Family Recorded	No. of Species
Araliaceae	+	1	-	0	+	1
Berberidaceae	+	2	+	1	+	2
Caprifoliaceae	+	3	+	2	+	2
Compositae	+	1	+	1	+	1
Elaeagnaceae	+	2	+	1	+	2
Euphorbiaceae	+	1	-	0	+	1
Labiatae	+	1	-	0	+	1
Moraceae	+	1	-	0	+	1
Oleaceae	+	1	+	1	-	0
Rosaceae	+	6	+	2	+	6
Rubiaceae	+	2	+	1	+	2

Rutaceae	+	1	+	1	+	1
Salicaceae	+	2	-	0	+	2
Sub Total 13		24	8	10	12	22

The herb species recorded are grouped into 32 flora families. A total of 15 species are found to be from the same family group of *Gramineae* and 7 species from *Compositae*. Out of 15 species of *Gramineae* group, 8 each is recorded in both the habitats and out of 7 species of *Compositae* group, four species are recorded in disturbed habitat and five species in semi-disturbed habitat. It is observed that semi-disturbed habitat is recorded with maximum herb family group than disturbed habitat, which accounts to 26 and 15 family groups respectively. There are five family groups with their entire species recorded in both habitats. These are *Convallariaceae, Dennstaedtiaceae, Equisetaceae, Oxalidaceae,* and *Polygonaceae*.

Table 25. Herb family composition in two habitats

Family (Herb)	Riparian Corridor		Disturbed Habitat		Semi-disturbed Habitat	
	Family Recorded	No. of Species	Family Recorded	No. of Species	Family Recorded	No. of Species
Apiaceae	+	1	+	1	-	
Araliaceae	+	1	-	0	+	1
Asteraceae	+	1	+	1	-	0
Berberidaceae	+	1	-	0	+	1
Cannabceae	+	1	-	0	+	1
Caprifoliaceae	+	1	-	0	+	1
Caryophyllaceae	+	1	-	0	+	1
Compositae	+	7	+	4	+	5
Convallariaceae	+	2	+	2	+	2
Cyperaceae	+	1	-	0	+	1
Dennstaedtiaceae	+	1	+	1	+	1
Drynarioidea	+	1	-	0	+	1
Equisetaceae	+	1	+	1	+	1
Fabaceae	+	1	-	0	+	1
Gentianaceae	+	1	-	0	+	1
Geraniaceae	+	2	+	1	+	2
Gramineae	+	15	+	8	+	8

Juncaceae	+	1	+	1	-	0
Labiatae	+	4	+	1	+	3
Leguminosae	+	3	-	0	+	3
Moraceae	+	1	-	0	+	1
Oleaceae	+	2	-	0	+	2
Oxalidaceae	+	1	+	1	+	1
Plantaginaceae	+	1	+	1	-	0
Polygonaceae	+	2	+	2	+	2
Pteridaceae	+	2	-	0	+	2
Ranunculaceae	+	2	-	0	+	2
Rosaceae	+	3	-	0	+	3
Rubiaceae	+	1	-	0	+	1
Scrophulariaceae	+	1	+	1	-	0
Solanaceae	+	1	+	1	-	0
Violaceae	+	1	-	0	+	1
Sub Total	32	65	15	27	26	49

5.4.3 Lifeform Composition

The study of 16 sample plots in the Wangchhu riparian corridor shows that the vegetation type mostly consists of deciduous species. The tree species is recorded with three types of lifeforms such as deciduous, evergreen confers, and evergreen type. Of this category majority of the tree is a deciduous type with commonly found trees of *Populus ciliate, Salix babylonica,* and *salix wallichiana*. The evergreen conifer of *Pinus wallichiana* is also recorded in most of the sample plots. Whereas some of the evergreen conifer and trees such as *Juniper indica, Cupressus himalaica, Querecus griffithi,* and *Querecus semecarpifolia* are recorded least along the riparian corridor. However, most of the sample plots (P9-16) located in semi-disturbed habitat shows a high representation of evergreen conifer type vegetation than the sample plots (plot 1-8) are disturbed habitat, which is mostly deciduous type.

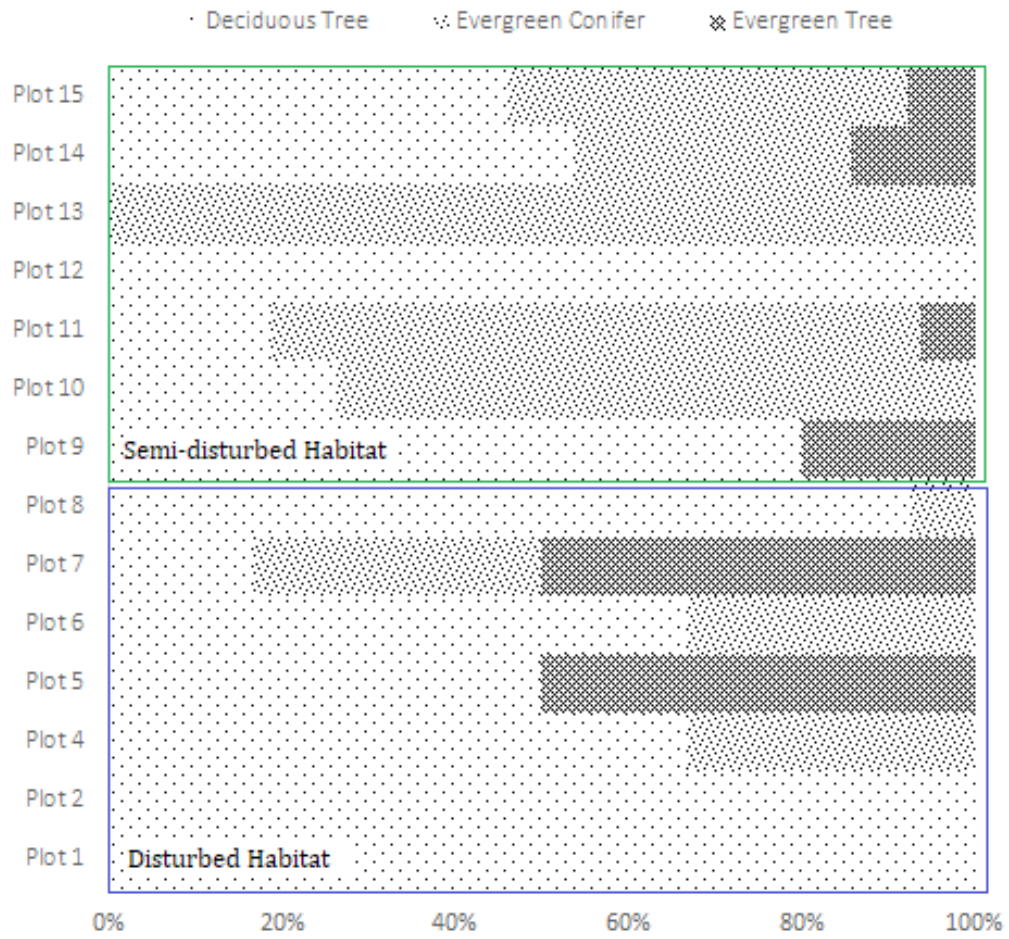

Figure 43. Life form composition of tree in the riparian corridor

The shrub species recorded in the study are majorly found to be deciduous type, followed by some semi-evergreen shrub and few evergreen shrubs found in both the habitat. The sample plots in disturbed habitat show that vegetation type is primarily a deciduous type with some semi-evergreen and evergreen shrubs recorded in plots four, seven, and eight. Since NULL shrub is recorded in plot six, the graph of plot 6 is omitted in the study. A single species belonging to the family of *Compositae (Artemisia moorcroftinia)* is the only deciduous shrub that is commonly found across the riparian corridor. Although the deciduous shrubs are common in semi-disturb habitats, all the plots in semi-disturb habitats also show a mix of different lifeforms compared to disturbed habitats. Some of the evergreen and semi-evergreen shrub found belongs to families of, *Rosaceae (Rosa brunonii, Berberis griffithiana)* and *Rutaceae (Zanthoxylum*

sp). Whereas, common deciduous shrubs recorded in semi-disturbed habitats are *Compositae (Artemisia moorcroftinia), Rosaceae (Prinsepia utilis),* and *Elaeagnaceae (Elaeagnus parvifolia)*.

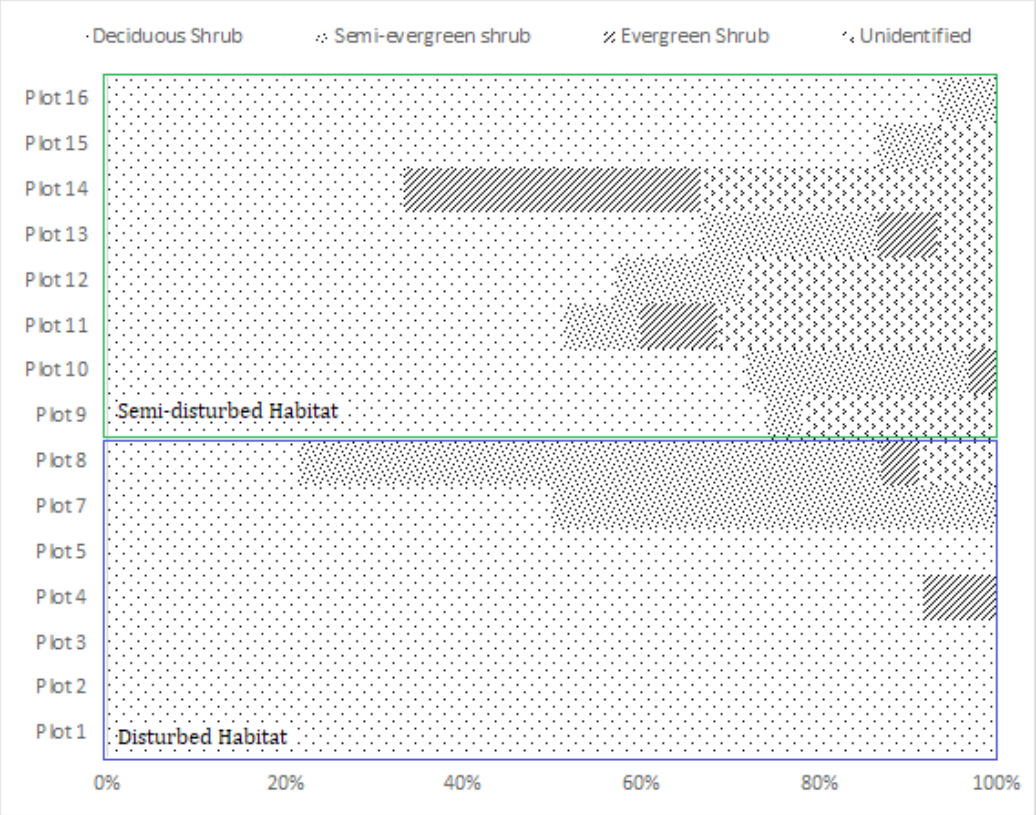

Figure 44. Life form composition of shrub in the riparian corridor

A total of herbs composed of 32 families with 65 species are recorded in 16 sample plots, of which 30 species are deciduous, 16 species are evergreen, 9 species are semi-evergreen and 11 species are an unidentified group. Throughout the plots, evergreen herbs are recorded with high ground cover compared to deciduous and semi-evergreen herbs since the field study and sample collection were done in the spring season (late April to mid-May). It is a season of rejuvenation and regrowth of flora. Although the record of species shows a high richness of deciduous species, it is recorded less ground cover, which is observed differently in the case of evergreen herbs.

The herbs recorded in two habitats has an almost equal representation of three lifeforms. whereas, plot 4 shows the maximum ground cover by evergreen species that belong to the family of C*onvallariaceae (Ophiopogon intermedius)* and

plot 5 was recorded majorly with semi-evergreen species belong to the family of *Gramineae (Festuca stapfii)*. Plot 14 in semi-disturb habitat shows that a species belonging to the family of *Geramineae (Digitaria sp)* has maximum ground cover than other species. The rest of the plots in semi-disturb habitat show that deciduous and evergreen with major ground coverage. The deciduous species of *Oxalis corniculata* and evergreen species of *Hedra nepalensis* are recorded with high ground cover among 27 species in the habitat.

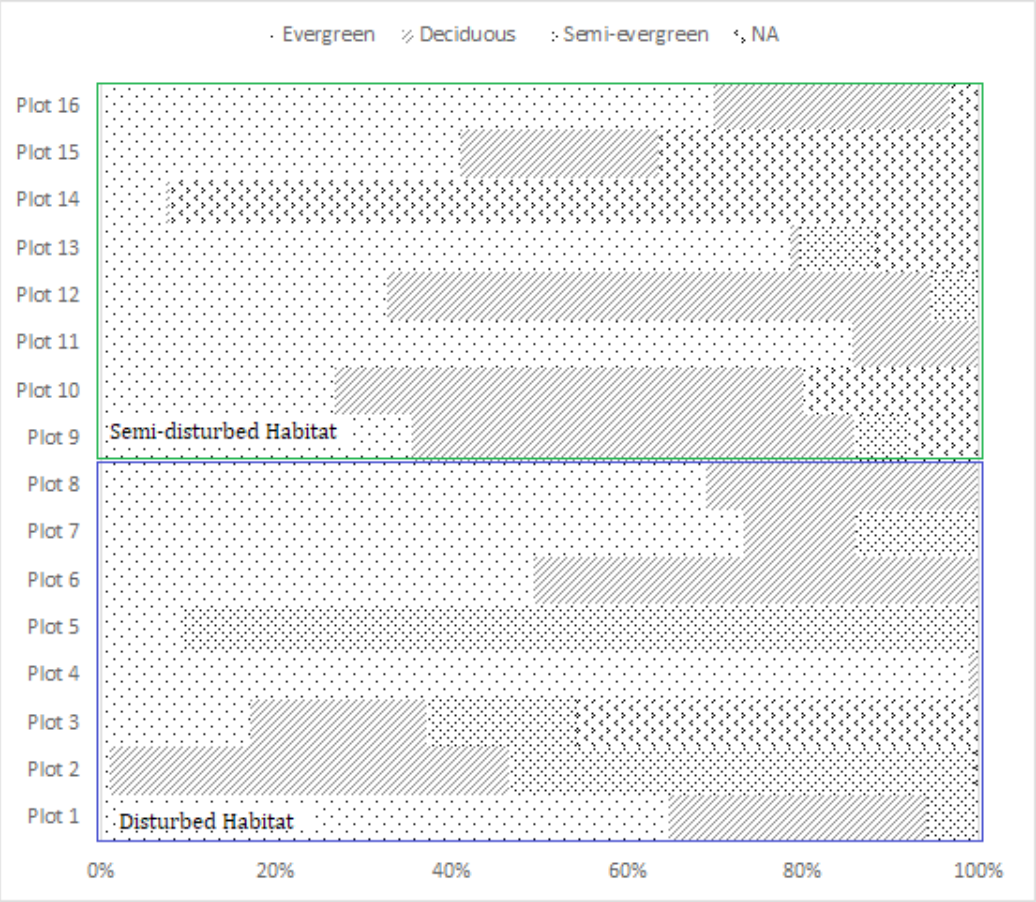

Figure 45. Life form composition of the herb in the riparian corridor

5.5 Species Dominance

Figure 46 shows the tree dominance curve recorded based on the relative density of trees in the study area. The study showed *Salix babylonica (Sp 11)* as the most dominant tree with sum relative density (RD) of 4.177, followed by *Pinus wallachiana (Sp 5), Populus ciliate (Sp 06),* and *Salix wallachiana (Sp 12)* as

shown in appendices. Whereas the least dominant species recorded are *Querecus griffithi (Sp 8), Rhus hookeri (Sp 10), Prunus persica (Sp 7),* and *Juniperus indica (Sp 4)*. Most of these species were found in disturbed habitats as a part of the up-gradation of the urban landscape by city officials. Similarly, *Salix babylonica* is common in disturbed habitats due to its low cost and characteristic to acclimatize in an urban environment. The semi-disturb habitat is dominated by *Pinus wallichiana* (Sp 05). It is a common evergreen conifer found in the Thimphu valley.

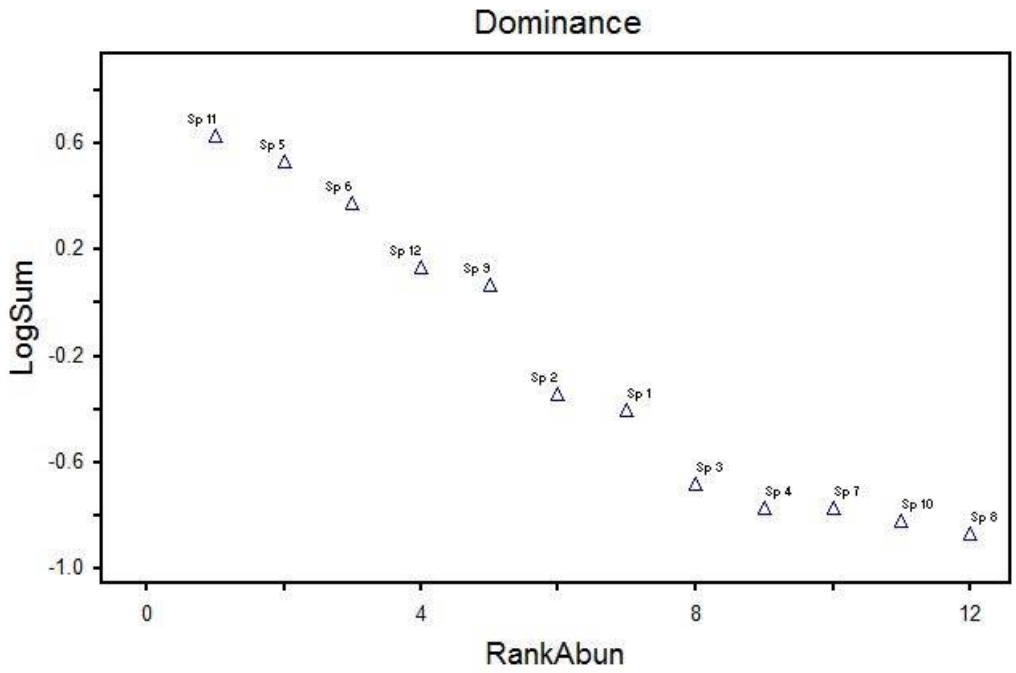

Figure 46. Tree species dominance in the study area

Figure 47. Dominant tree species: Salix babylonica (left), Pinus wallichiana (mid), Populus ciliata (right)

In the case of shrub, the most dominant species recorded was species one that belong to a family of *Compositae (Artemisia moorcroftiana)*, followed by the species six of *Elaeagnaceae (Elaeagnus parvifolia)*. The least dominant species recorded were *Hedra nepalensis (Sp 8) and Prinsepia utilis (Sp 2)* belonging to a family of *Araliaceae* and *Rosaceae* respectively (refer appendices for specimen identity). The sample plots in disturbed habitat (that is plots 1 to 8) were majorly dominated by *Artemisia moorcroftiana*, followed by *Elaeagnus parvifolia*. The plots in semi-disturbed habitat (plot 9 to 16) recorded *Elaeagnus parvifolia* and *Zanthoxylum sp* as dominant species, followed by R*oas sericea, Prinsepia utilis, cotoneaster sp,* and A*rtemisia moorcroftiana*.

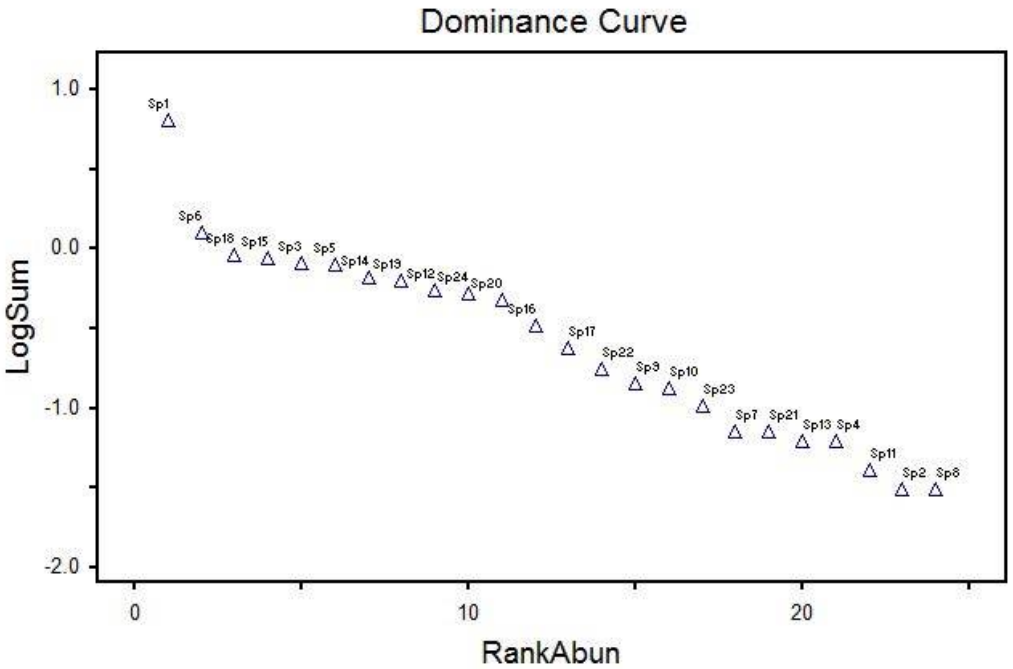

Figure 48. Shrub species Dominance curve of the study area

Figure 49. Dominant shrub: Artemisia moocroftiana (left), Elaeagnus parvifolia (mid), Zanthoxylum sp. (right)

The dominant species among the herbs in the riparian corridor are *Ophiopogon intermedius (Sp 39),* followed by *Pennisetum clandestinum (Sp 42), Ophiopogon bondinieri (Sp 38),* and *Digitaria sp (Sp 16)*. The least dominant species recorded are *Prangos sp (Sp 49), Plantago depressa (Sp 4), Solanum Americacum (Sp 56), Lonicera sp (Sp 34) 1, Seneue seandens (Sp 55)*. The disturbed habitat (plot 1-8) was majorly dominated by *Pennisetum clandestinum,* which is an invasive species identified by NBC. The sample plots in semi-disturbed habitat were majorly dominated by *Ophipogon intermedius*, followed by *Digitaria sp* and *Hedra nepalensis*. Some of the common weeds recorded in semi-disturbed habitats were *Cannabis sativa, Stellaria vestita, Equisetum sp, Digitaria sp, Yushania microphylla, Oxalis corniculate,* and *Galium aparine,* which had relatively low ground cover than other species.

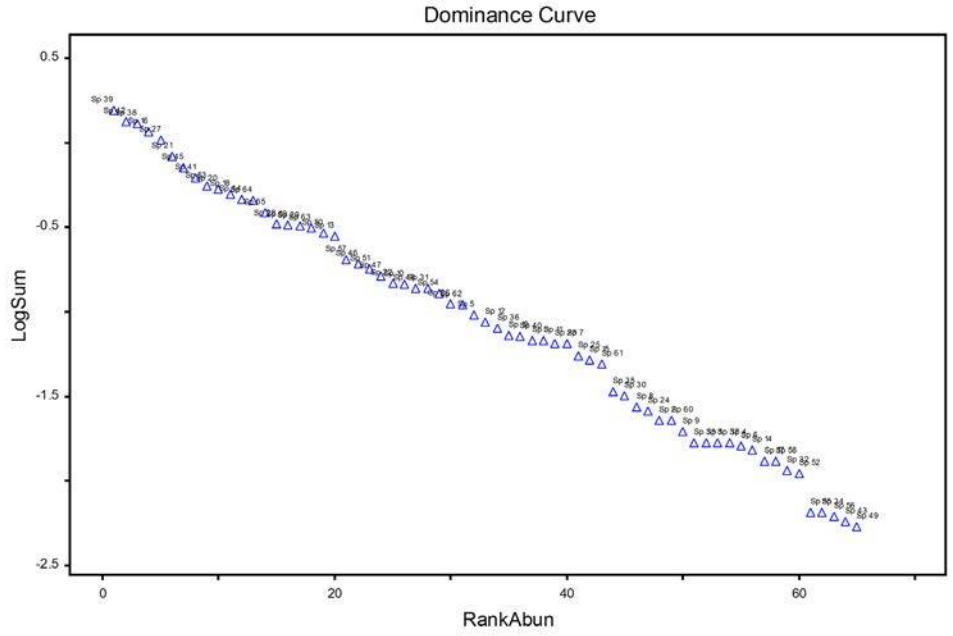

Figure 50. Herb species Dominance in the study area

Figure 51. Dominante herb species: Ophiopogon intermedius (left), Pennisetum clandestinum (mid), Digitaria sp (right)

5.6 Cluster Analysis of riparian corridor.

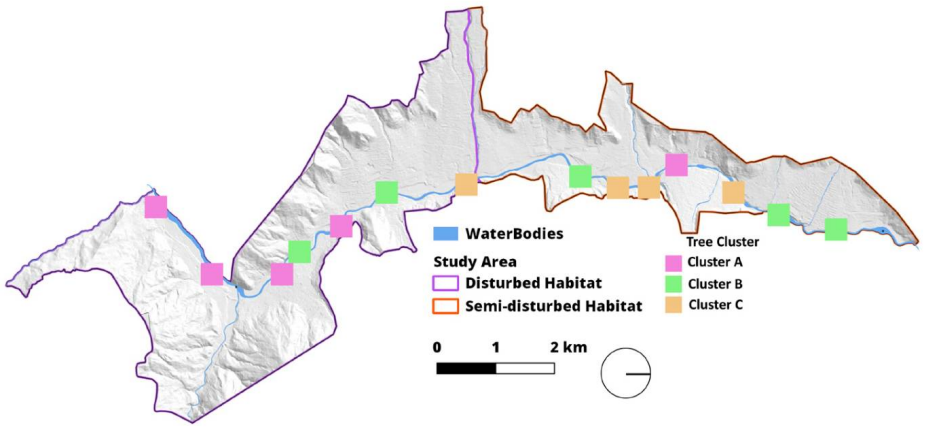

Figure 52. Tree Cluster in the study area

The clustering of tree species was expressed in terms of relative frequency to study the similarity of sample plots in the riparian corridor as shown in the figure below. The study shows that a total of 12 tree species is clustered into three tree groups at a similarity index of 50 percent. Cluster A is majorly represented by sample plots in disturbed habitat, which is dominated by *Salicaceae (Salix babylonica)*. This species is easy to grow and is usually planted by the human at the edge of the property as a boundary and to enhance the landscape. The cluster B consist mixture of sample plots from both the habitat. *Salicaceae (Salix wallichiana)* and F*agaceae (Querecus griffithi)* are dominant species recorded in two habitats. Cluster C represents semi-disturbed habitat and the dominant species recorded in *Pinus wallichiana*. The vegetation in these plots is evergreen conifers.

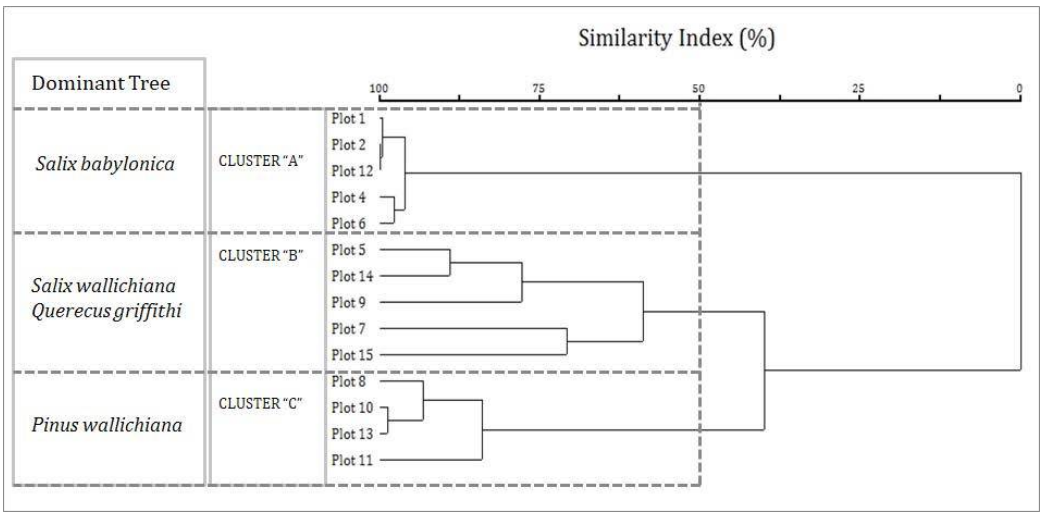

Figure 53. Tree cluster analysis of riparian corridor.

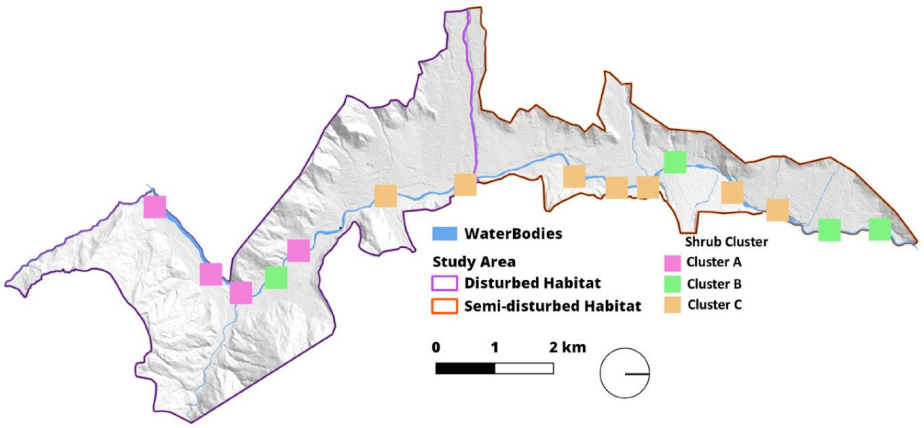

Figure 54. Shrub Cluster in the study area

The clustering of shrub species at the 50 percent similarity index shows that the riparian corridor has three clusters of shrub vegetation. Cluster A in the figure strongly represents the disturbed habitat and with the *Artemisia moorcroftiana* as the only dominant shrub in the area. This indicates the Artemisia moorcroftiana has higher adaptableness to human surroundings. The cluster B consist of plot 12, 15 and 16 located in semi-disturbed habitat and single plot 4 of disturbed habitat. The species record of plot 4 shows a similar record to the semi-disturbed area as shrubs in plot 4 were at the edge of the apple orchard to serve as a natural fence to defend the crops from animals and humans. The shrubs in the area are either planted or left undisturbed to benefit the yield. Cluster B is dominated by *Elaeagnus parvifolia*. The shrub is a thorny woody plant that bears small citrus fruits that are edible by humans and animals. Cluster C represents shrubs mostly recorded in semi-disturbed habitats. Plot 8 and 7 in disturbed were recorded with shrubs commonly found in semi-disturbed habitats such as *Rosa brunonii,* which are left undisturbed due to their flowering and thick thorny stems. Other dominant shrubs recorded were *Zanthoxylum sp, Cotoneaster sp, Berberis griffthiana,* which are thorny and woody shrubs. These shrubs provide a safe habitat for small birds and fruits to feed.

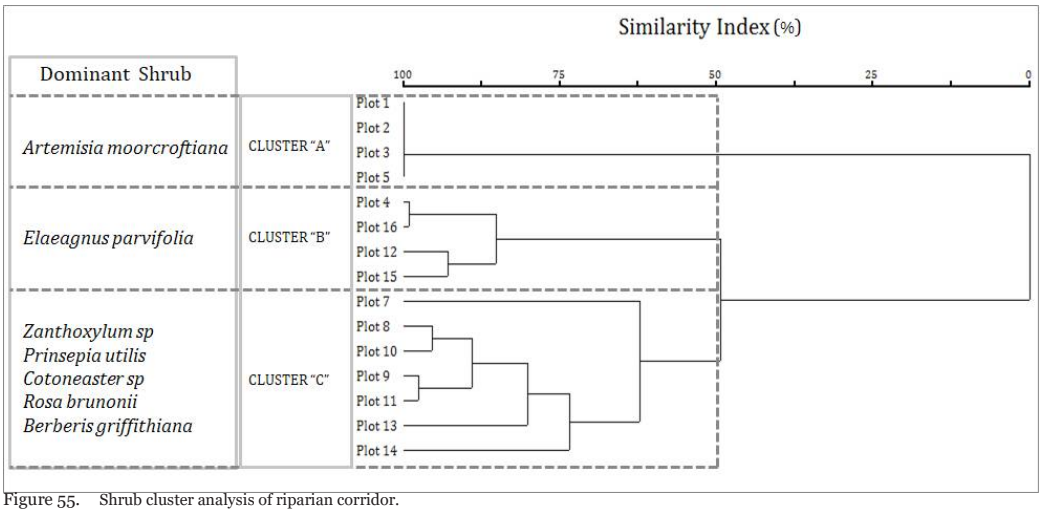

Figure 55. Shrub cluster analysis of riparian corridor.

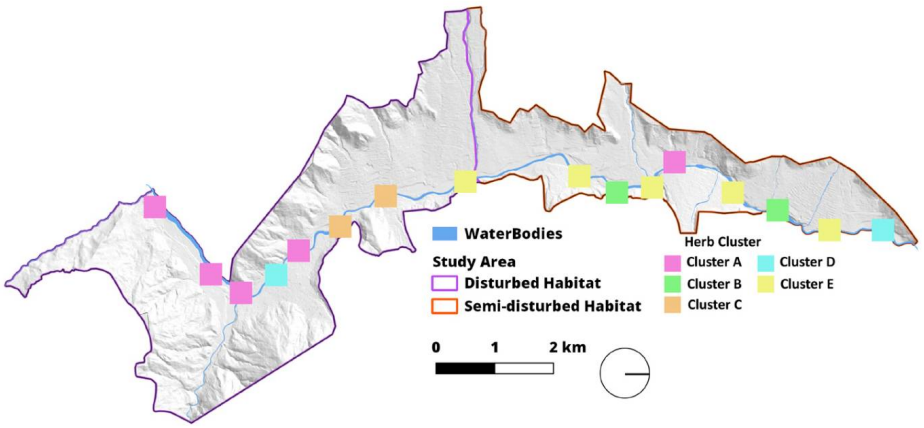

Figure 56. Herb Cluster in the study area

A total of 65 herb species is clustered into 5 groups at a similarity index of 50 percent. Most of the dominant species recorded in both habitats are grass species. Cluster A and C majorly represents disturbed habitat with Poa dzongicola, Festuca Arundinacea, and Pennisetum clandestinum as dominant species, respectively. Pennisetum clandestinum recorded in disturbed habitat is classified as one of the invasive species of Bhutan. Cluster B and E majorly consist of sample plots from semi-disturbed habitats. Dominant species in the two clusters are Digitaria species, and Ophiopogon intermedius and Hedra nepalensis respectively. Cluster C consists of plots 4 and 16 which have similar herb vegetation. This could be due to a similar land-use type at proximity to the site, which is described under the spatial analysis of the site. The dominant species recorded is Ophiopogon

bondineri. The root of Ophiopogon bondineri is observed to have root nodules that can fix nitrogen in the soil whereas Ophiopogon intermedius does not have root nodules.

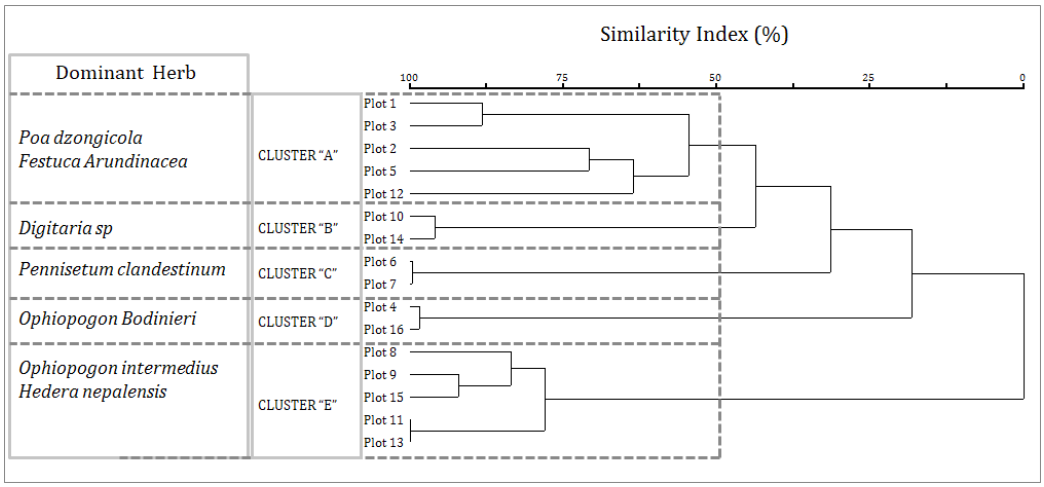

Figure 57. Herb cluster analysis of riparian corridor.

5.7 Association of Species diversity with disturbance.

The comparative study of flora diversity and disturbance show tree diversity along the corridor is similar in both the disturbance level with a range of 0 to 1.3 H'. The shrub diversity and vulnerability mapping show that diversities in disturbed habitat are low than in semi-disturbed habitat and vulnerability is high in disturbed habitat. This shows that shrub diversity is low in the high disturbance. The herb diversity in most of the sample plots is above 1.0 H'. The herb diversity in semi-disturbed habitats has comparatively high than in disturbed habitats. Therefore, herb diversity is very high ranging from 1.3 to 2.3 in the low disturbed area. The shrub and herb diversity has an inverse relation to the disturbance and tree diversity does not show a significant relationship with the level of disturbance.

It is also observed that herb and shrub diversity show negative relation (r=-0.3851, r=-0.8717, respectively) to the intensity of urban disturbance observed in sample sites. The diversity of herbs and shrubs are decreasing as the intensity of disturbance in the site increases. A dense cluster of points is observed in low disturbance indicating max plots with high diversity.

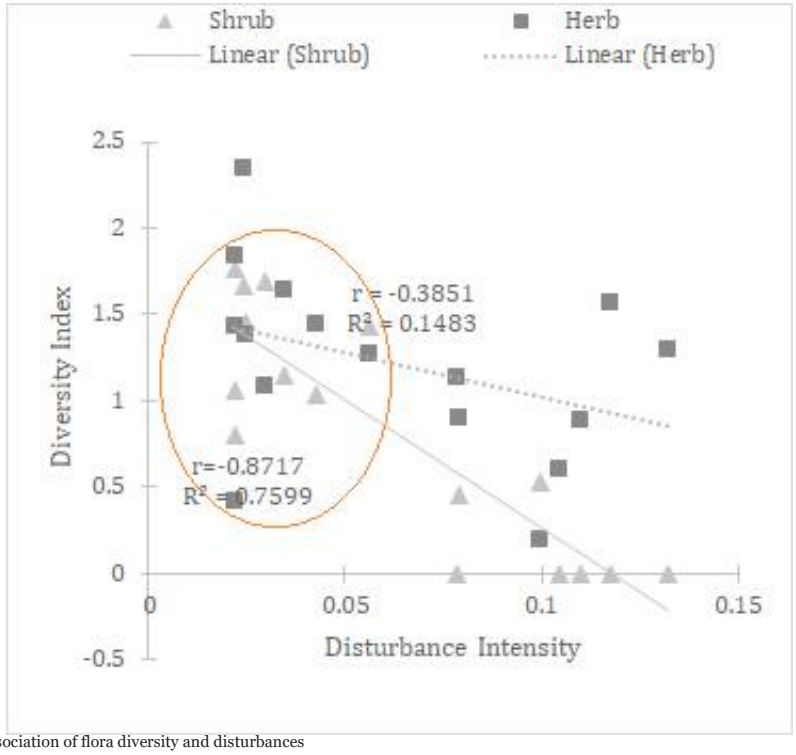

Figure 58. Association of flora diversity and disturbances

5.8 Association of flora richness and disturbances

The association of flora richness to disturbance of the study area shows a strong negative correlation (r=-0.7276, n=16). The species richness is found to decrease as the magnitude of disturbance in the area increased. The intense disturbance observed in the site is destruction and alteration of the natural landscape, and direct waste disposal from the residential and industrial area. Sample plot 15 and 10 are observed with a low disturbance that recorded almost one-fourth of the total species. Most of the high disturbances are observed in the south part of the city and some disturbance in the north of city. The IDH suggests that species diversity or richness is maximum at the intermediate disturbance and lowest in the high disturbance. Therefore, based it could be stated that the south part of city is experiencing a higher magnitude of ecological disturbance with the least species richness and the north part is in the intermediate stage or early post-stage with high richness at risk of richness reduction.

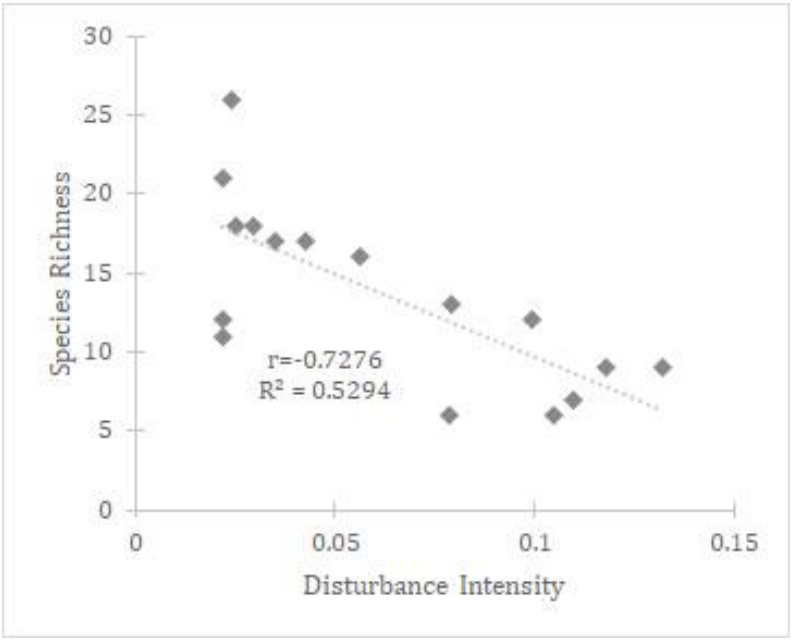

Figure 59. Correlation of species richness to disturbance intensity

5.9 Association of flora species and disturbances.

The value of each sample plot to urban variables was determined through pair comparison of AHP using Saaty's (1987) scale. Canonical correspondence analyses were used to deter mine the relationship between flora species in samples against the urban variables at each plot along the riparian corridor.
The biplot of the tree show group of species and the plots on the left of Axis 2 has positive correlations to urban variables. Whereas the length of each arrow showed the magnitude of urban variables' effect on the species in sample plots. The position of each variable arrow concerning each axis indicates the correlation with the factor.

Table 26. Correlations of urban variables for tree species

	Axis 1	Axis 2	Axis 3	
Built Surface		-0.807	-0.243	-0.015
Population		-0.499	0.361	-0.478
Land Use		-0.499	0.519	0.044
Anthropogenic Activities		-0.629	0.435	0.275

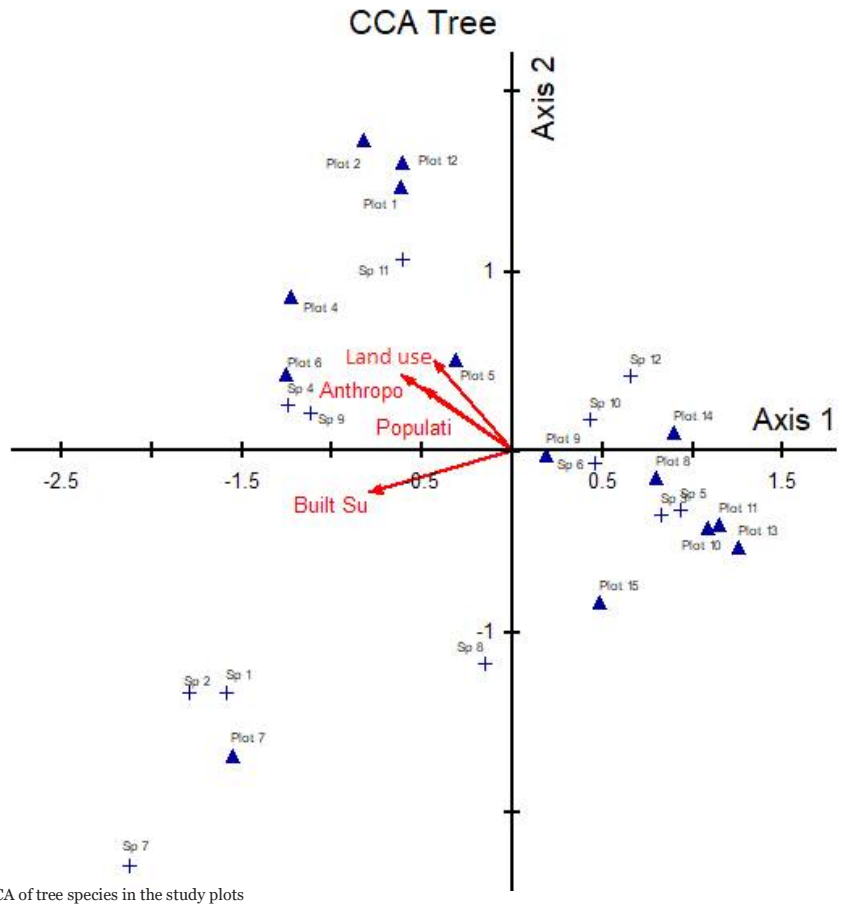

Figure 60. CCA of tree species in the study plots

The presence of tree species of Q*uerecus griffithi (Sp 9), Juniperus indica (Sp 4), Salix babylonica (Sp 11), Querecus semecarpifolia (Sp 8), Cedrus deodara (Sp 1), Cupressus himalaica (sp 2),* and *Pinus persica (Sp 7)* has a positive correlation to the urban variables as compared to species on the right of axis 2. Species of *Querecus griffithi (Sp 9), Juniperus indica (Sp 4),* and *Salix babylonica (Sp 11)* were closely related to the high urban disturbance area. These plants can adapt to high urban disturbance. The axis of anthropogenic activities and built surface show a high correlation of -0.63 and -0.81 to species distribution compared to land use and population as shown in the table above. The species in right are vulnerable to disturbance. The plots on the left of axis 2 majorly represent disturbed habitat and plots on right are semi-disturbed habitats that have a negative correlation to the variables.

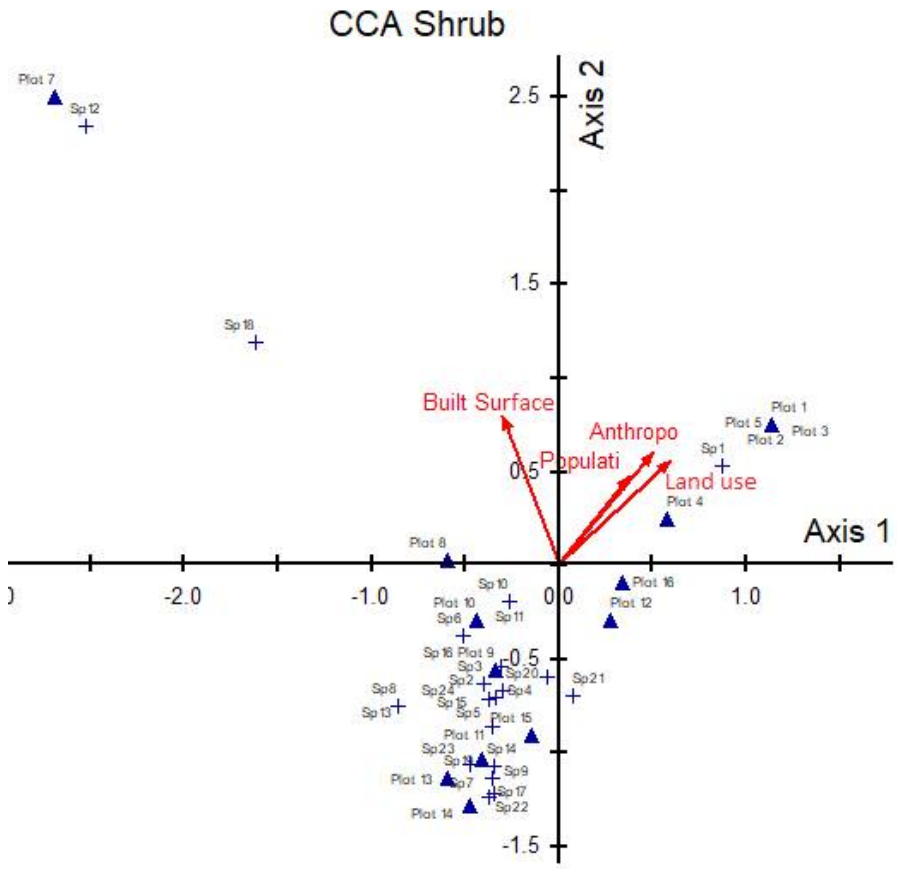

Figure 61. CCA of shrub species in the study plots

CCA of shrub shows that most of the species below axis 1 have a negative correlation with the urban variables. Thus indicating that these shrubs are unable to withstand the disturbance of urban growth. The urban variable built surface has less correlation to the other three variables, whereas Anthropogenic and population are in a similar direction that indicates similar impact to species. Land use has a high correlation to population and anthropogenic activities. Species Lonicera quinquelocularis (Sp 12) and Rosa brunonii (Sp 18) have a positive correlation to built surface. Species Artemisia moorcroftinia (Sp 1) is the only species that have adapted to urban variables. The sample plots of 1, 2, 3, 4, and 5 have a positive correlation to the urban variable, which indicates that it has a high level of disturbance.

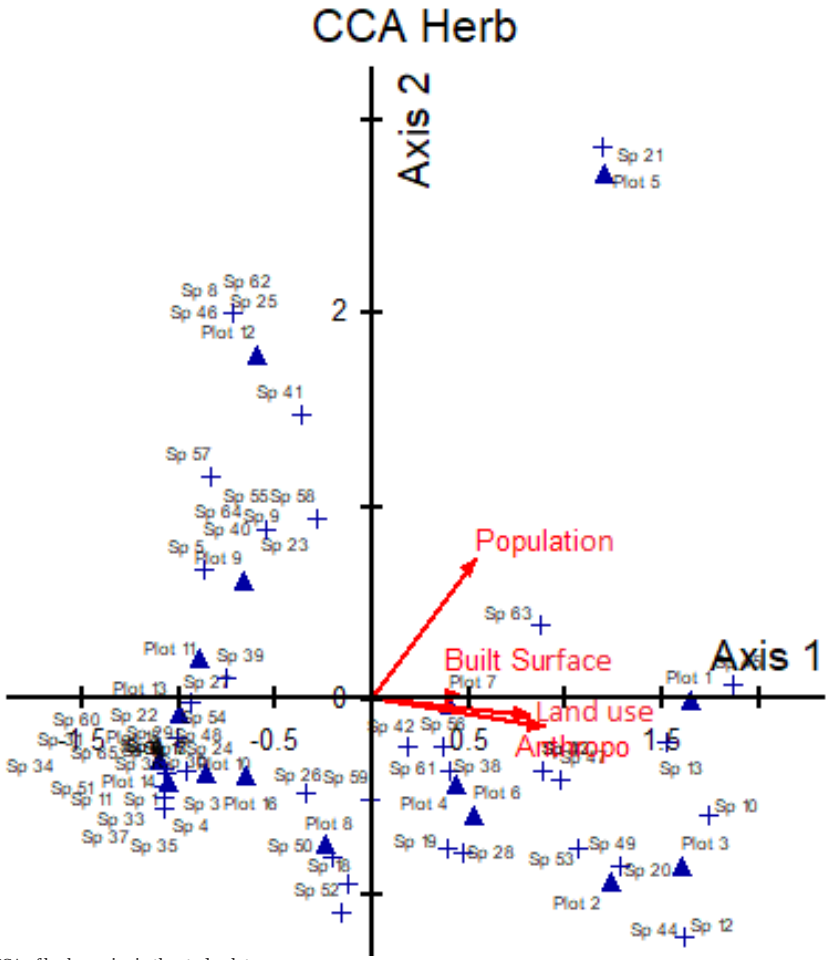

Figure 62. CCA of herb species in the study plots

A cluster of species and plots on the left of axis 2 indicates no correlation to the urban variables. These species are vulnerable to urban disturbance and plots have a low level of urban disturbance than the right side of axis 2. Species of Ophiopogon bodinieri (Sp 38), Pennisetum clandestinum (Sp 42), Poa Sp (Sp 47), Solanum americacum (Sp 56), Tragopogon dubius (Sp 61), and Verbascum thapsus (Sp 63) are very close to the arrows of built surface, land use and anthropogenic activities. These species can grow in harsh conditions of urban development than some of the species plotted away from variables. Some of these species are invasive and weed that can grow in such conditions. Population, land use, and anthropogenic activities show a high magnitude of influence than the built surface on the herb species. The plots on the right of axis 2 strongly represent sample plots in disturbed habitat that indicate higher disturbance compared to plots on the left side.

Chapter 06- Conclusion

6.1 Urban disturbances along the Wangchhu riparian corridor

Thimphu, being the capital has been experiencing rapid urbanization with a growth rate of 13.5 percent compared to the national urban growth rate of 7 percent (NSB 2005). Today, the population of the city has increased more than ten times to 114,555 residents (NSB, 2017) from 10,000 residents in 1977 (Rose, 1977). Most of the people are residing in Changzamtog, Lungtenphu, Simtoha, and Babesa in the south, and Core area in the city center with a population equal to or more than 10,000 residents. It is equivalent to the population size of the national-level city as per the Thromde (urban) Act of Bhutan 2007 or Class A city as per Thromde rules of Bhutan 2011. Therefore, the sample plots in these areas showed a high level of human interference with natural vegetation. Thus, a high population count causing a high level of disturbance to the ecosystem.

On other hand, the city's landscape has drastically changed from a complete agricultural valley to the nation's dense urban land within few decades. A larger portion of the city's land that was utilized for paddy cultivation with a small city core and commercial center near the dzong (fortress) has transformed into a densely built area (REC 1994, MoWHS 2004).

Since the rapid development in the early 21st century, development has

pressurized the riparian corridor that led to the reduction of 30 m river buffer in most parts of the river in the core and south of the city. Marshlands in Babesa, which serve, as a critical ecosystem is lost to the recent urban development of intense land use along the river in the Simtokha and Babesa area. However, some of the marshlands such as River Island near langjophaka, Dechencholing, and Kabesa still exist, and are found to be at risk of high human disturbances such as recreational activities, space to conduct unhealthy activities, household and construction waste disposal from surrounding and upstream.

With urbanization, some of the urban forests and wetlands in the city were converted to developable land due to private land ownership. Although all the sample plots were located within the environmental zone, most of the sample plots in the south are in proximity to a dense residential, commercial, and industrial zone that easily exposed the ecosystem to frequent disturbances and impact from surrounding land uses.

Whereas, plots 9, 14, and 16 are River Island, and other plots in the semi-disturbed area are in the environmental zone, which is inaccessible to humans. The plots in the north of city have low-level urban disturbance to the ecosystem compared to samples plots in the south and core of the city. It shows that intense land uses that are human-centric located in and around the plots increase the level of disturbances to natural vegetation.

Rapid urban development has also brought in challenges in waste management. Waster from automobiles, construction projects, and households are becoming difficult to manage. Household waste and construction debris disposal were recorded in most of the sample plots. These wastes were usually found to be disposed of along the riverbanks at disturbed habitats. Sample plots at the disturbed area were recorded with liquid automobile waste such as engine oil and grease from auto repair and scrap disposal. This waste was openly disposed of into the river and soil, which created an unhealthy landscape for the growth of native species.

Riparian corridors in the south and core area were filled with construction debris like earth from building foundations, which was also used to extend the land for development and road work. The direct disposal in the natural landscape led to a loss of topsoil and the destruction of existing natural vegetation that favored the growth of superior plants that can adapt.

The natural landscape in the south and core area are mostly altered to develop the site for construction purposes and create discontinuous habitat along the

riparian corridor. The corridor also has a long stretch of walking trails that passes close to the river and is dotted with picnic spots, resting sites, and recreational sites for traditional games that affect the natural setting of riparian vegetation. Pair comparison of plots using Saaty's (1987) scale showed that sample plots in disturbed habitat were recorded with maximum human interference than semi-disturbed. The weighted overlay analysis of urban variables also shows that disturbed habitat has high intensity than semi-disturbed habitat with low human disturbance to riparian vegetation.

Since the development of the city is not equally distributed with major development in the core and southern part of the city, the city authorities need to redistribute the development equally to all the local areas in the city. If not the development could encroach on the existing rich riparian zone in the North and surrounding natural vegetation at the higher valley. It is found that development was majorly concentrated in core and southern part of the city, which have led to rapid and uncontrolled development in the area and impact on the ecosystem. With the rapid development and lack of urban land, there is an encroachment on riparian areas, and regulation to maintain a 30 m buffer zone of no development is not strictly followed in the southern stretch of the river. The city Authority should strictly monitor any development near the river and also discourage any development of public infrastructure in this area other than the low impact or eco-friendly development upon environmental impact assessment.

Open disposal of waste should be monitored and provide adequate service to the zone. There is a need of enhancing waste collection services from households and disapproval of disposal of construction debris long the riverbanks. The automobile junkyard and automobile repair should be located away from ecologically sensitive zone and provided adequate waste management plant and plan to avoid open disposal to the environment.

The city needs to access the impact of the project on biodiversity at the local and city level and accordingly provide an alternative to enhance the biodiversity of the area. The authority needs to identify and conserve the rich riparian zone to serve as a reservoir of genetic material for the future.

City authorities should also monitor and discourage active recreational activities along the corridor, as it disrupts and destroys the natural habitat. The city office needs to collaborate with games and sports organizations to coordinate on approval of active recreational activities in sensitive zones.

6.2 Flora diversity and composition along the Wangchhu riparian corridor

The study area was recorded with a total of 101 flora species from 16 plots categorized into high disturbance areas as disturbed habitat and semi-disturbed habitat as low disturbance along the Wangchhu riparian corridor. The flora study conducted within the river buffer of 30 m showed that two habitats have high flora diversity ranging from 1.43 to 2.64 H'. The habitats showed high tree diversity of 1.46 to 1.86 H'. Whereas, semi-disturbed habitat recorded high shrub and herb diversity of 2.54 H' and 2.64 H' respectively. The flora species along the riparian corridor were also evenly distributed with an evenness index of above 0.5 Hmax. Flora diversity of the riparian corridor shows a positive correlation to species richness. The higher the richness, the higher is the diversity. Disturbed habitat has high tree species richness and high tree diversity. Likewise, semi-disturbed showed similar results, as shrub species richness was high and diversity was also high compared to disturbed habitat. The herb species has similar results of high richness and diversity to disturbed habitats.

Salix babylonica was commonly recorded in the disturbed habitat, where natural landscapes are completely lost or altered for human development. Salix babylonica was commonly found at the traditional archery range, open space, and private plots along the river. It was planted at the edges to provide natural shade for archers, a fence to safeguard the space, and a protection wall for an arrow to create a safe environment for the game. It is the most preferred tree species due to its ability to grow easily with low care and monitoring. Thus replacing the earlier tree species. The tree is very delicate to wind storms and risks to human lives. The plantation along the pathways and institutions should be avoided to reduce the disaster. It is also observed that Salix babylonica are planted alongside the river banks due to their adaptability, requiring more water by a tree and reduce slope failure at banks. However, plantations along the flow path could have a negative impact during heavy monsoon as it may block the river load and create artificial dams that could cause floods in the lower stream (MoWHS, 2017).

Artemisia moorcroftiana was recorded as a dominant shrub in disturbed habitats. It was recorded in the disturbed landscape where construction debris such as earth and materials were disposed of. Shrub richness and diversity in disturbed were recorded low as it is related to maximum exposure to human interference such as alteration of a landscape by removing the shrub vegetation

for human-oriented land development. The disturbed habitat was recorded with fewer herb species despite high diversity. The dominant species recorded was Pennisetum clandestinum. It was recorded only in disturbed habitats near road edges and construction debris. The disturbed habitat was recorded with more invasive species such as Conyza Canadensis, Equisetum sp, Pennisetum clandestinum, Clinopodium umbrosum, Trifolium repens, Oxalis corniculate, Rumex nepalensis, and Verscum thapsus. These species were recorded also recorded in altered landscapes and high population zone of the city.

The semi-disturbed habitat is majorly covered by conifer forest and dominated by Pinus wallachiana. Pinus wallachiana is a native to the Himalayan region and is also abundantly recorded in the Thimphu valley. The habitat was recorded with rich shrub species mostly belonging to families of Rosaceae, Elaeagnaceae, Berberidaceae, and Compositae. Elaeagnus parvifolia was recorded as a dominant shrub in the area. It was recorded in the area with less human interference and natural landscape. The shrubs' vegetation was characterized by thorny and woody shrub species such as Rosa sericea, Rosa brunonii, Rubus pungens, Rubus biflorus, berberis griffthiana, Zanthoxylum sp, and Prinsepia utilis, which made the habitat inaccessible to humans. Most of the herb species recorded were only found in semi-disturbed habitats, which were native to the region. These herbs were most found under the canopy of dense shrub and tree species. Ophiopogon intermedius was a dominant species in semi-disturbed habitats. Few species of disturbed habitat such as Trifolium repens and Oxalis corniculate were also recorded in semi-disturbed habitat. These may be due to the presence of few human activities in proximity to the habitat.

Although, both the habitat showed a high diversity of flora species, it was observed that both habitats were recorded mostly with different species composition and richness. Urban development has disturbed most of the earlier natural ecosystem and affected the flora species, richness, and composition, and shortly if native species and habitat are not conserved, the city may lose its natural ecosystem and place for existing avifauna species.

It is also concerning that one-third of herb species are recorded as invasive. It was mostly recorded in highly urbanized areas in the south and core of the city, which is also invading the semi-disturbed area in the northern part of city. If it is not monitored and controlled, it may soon overtake the growth of native species in semi-disturbed habitat and will be difficult to control in the future.

In the case of tree species, it was very distinct that disturbed habitats were

predominantly vegetated with Salix babylonica and Pinus wallaciana in semi-disturbed habitat. There is a need of planting diverse trees in the city that could enhance the existing biodiversity to benefit a wide range of flora and fauna in the urban areas.

Currently, the city authority does not have a city-level biodiversity inventory or reports to monitor and maintain the health of the city's flora and fauna. With rapid development, there is a need of creating a city biodiversity inventory, which would keep a record of flora and fauna in the city. These records could help the city in achieving one of the most important goals of Gross National Happiness, which is conserving the rich biodiversity of Bhutan for all time. Constant maintaining and monitoring of biodiversity can also help to conserve and protect the existing riparian from losing healthy nature to urban pressure.

There is also a need for collaboration between city authorities and forestry organizations in conducting constant research on urban biodiversity. It is also important that developers and planners are aware of urban ecology and its role in creating a sustainable human settlement. Lack of knowledge on urban biodiversity can lead to prioritizing human needs over environment conservation.

6.3 Future research

The study scope is limited to the study of flora composition and diversity concerning four urban variables within a 30m river buffer. A similar study should be extended to open and green spaces located in an urban neighborhoods to conserve the local biodiversity, and green areas at city peripheral to develop Green Belt.

The study recorded invasive plants in disturbed and semi-disturbed habitat. There is a need for a comprehensive study on invasive species to identify the causative factors that are creating the ideal environment for the growth of these species and develop control measures before they invade natural vegetation within the city and Thimphu valley.

There is a need of studying the characteristics of each flora species to determine the benefit and harm to nature and humans. Such a study can be utilized to provide ecological service to urban development and avoid economic loss of the city. Some of the degraded vegetation can also be revived through the study of native flora species than introducing exotic species.

There is also a need of reviving the allocation of some land uses at proximity to sensitive zones and developing controlled guidelines to avoid or reduce direct disturbance to natural vegetation. As some of the incompatible land uses such as the Automobile and construction industries are located next to the ecologically sensitive zone. Thus, affecting the vegetation and leading to loss or fragmentation of habitat.

This study could be utilized as a baseline to understand the vegetation characteristic of the city and study periodical vegetation characteristics. The study can also be studied further using other environmental factors such as soil pH, nutrient content, slope gradient, aspect, and other environmental factors. Data collection also include DBH of tree and shrubs with height, which could be used to conduct other ecological studies.

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Appendix

Table 27. List of flora species recorded in the study area

Species																			
Nr.	Botanical Name	Origin	Invasie	Family	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15	Plot 16
TREES																				
Sp1	*Rhus Hookeri*	Native		Anacardiaceae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sp2	*Enonymus Grandiflorus*	Native		Celastraceae	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Sp3	*Cupressus Himalaica*	Native		Cupressaceae	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Sp4	*Juniperus Indica*	Native		Cupressaceae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Sp5	*Cedrus Deodara*	Non-Native		Pinaceae	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Sp6	*Pinus wallichiana*	Native		Pinaceae	0	0	0	0	0	0	0	1	0	1	1	0	1	1	1	0
Sp7	*Prunus persica*	Native		Rosaceae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Sp8	*Querecus Griffithi*	Native		Fagaceae	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0
Sp9	*Quercus semecarpifolia*	Native		Fagaceae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
Sp10	*Populus Ciliate*	Native		Salicaceae	1	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0
Sp11	*Salix Babylonica*	Native		Salicaceae	1	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0
Sp12	*Salix wallichiana*	Native		Salicaceae	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0
SHRUBS																				
Sp1	*Hedera nepalensis*	Native		Araliaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp2	*Berberis aristata*	Native		Berberidaceae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Sp3	*Berberis griffithiana*	Native		Berberidaceae	0	0	0	0	0	0	0	1	0	1	1	1	1	0	1	1
Sp4	*Lonicera glabrata*	Native		Caprifoliaceae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sp5	*Lonicera quinquelocularis*	Native		Caprifoliaceae	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Sp6	*viburnum continifolium*	Native		Caprifoliaceae	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Sp7	*Artemisia Moorcroftiana*	Native		Compositae	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1
Sp8	*Elaeagnus parvifolia*	Native		Elaeagnaceae	0	0	0	1	0	0	0	1	1	1	1	0	1	0	1	1
Sp9	*Elaeagnus Umbellata*	Native		Elaeagnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Sp10	*phyllanthus recticulatus*	Native		Euphorbiaceae	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0
Sp11	*Colquhounia coccinea*	Native		Labiatae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Sp12	*Morus Australis*	Native		Moraceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp13	*Ligustrum compactum*	Native		Oleaceae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sp14	*Cotoneaster sp*	Native		Rosaceae	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0
Sp15	*Prinsepia Utilis*	Native		Rosaceae	0	0	0	1	0	0	0	0	1	0	1	1	1	0	1	1
Sp16	*Rubus Biflorus*	Native		Rosaceae	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
Sp17	*Rubus pectinarioides*	Native		Rosaceae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sp18	*Rubus Pungens*	Native		Rosaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp19	*Rosa Brunonii*	Native		Rosaceae	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1	0
Sp20	*Rosa sericea*	Native		Rosaceae	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
Sp21	*Leptodermis Amoena*	Native		Rubiaceae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Sp22	*Rubia hispidicaulis*			Rubiaceae	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0
Sp23	*Zanthoxylum sp*	Native		Rutaceae	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0	0
Sp24	*Salix Obscura*	Native		Salicaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

HERBS

Sp1	*Prangos sp*	Native		Apiaceae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sp2	*Hedera Nepalensis*	Native		Araliaceae	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0
Sp3	*Tragopogon Dubius*	Non-Native		Asteraceae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Sp4	*Berberis Asiatica*	Native		Berberidaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp5	*Cannabis sativa*	Native	Invasive	Cannabceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Sp6	*Lonicera sp 1*	Native		Caprifoliaceae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sp7	*Stellaria vestita*	Native	Invasive	Caryophyllaceae	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Sp8	*Anaphalis Triplinervis*	Native		Compositae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp9	*Cirsium wallichii*	Native		Compositae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sp10	*Conyza Canadensis*	Non-Native	Invasive	Compositae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sp11	*Conyza stricta*	Native		Compositae	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Sp12	*Myriactis wallichii*	Native		Compositae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Sp13	*Taraxacum Eripodum*	Native		Compositae	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0

Sp14	*Taraxacum Parvulum*	Native		Compositae	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
Sp15	*Ophiopogon Bodinieri*	Native		Convallariaceae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Sp16	*Ophiopogon intermedius*	Native		Convallariaceae	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0
Sp17	*Carex speciosa*	Native		Cyperaceae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sp18	*Pteridium aquilinum*	Native	Invasive	Dennstaedtiaceae	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
Sp19	*Drynaria propingua*	Native		Drynarioidea	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sp20	*Equisetum sp*	Native	Invasive	Equisetaceae	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0
Sp21	*Seneue scandens*	Native		Fabaceae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Sp22	*Gentiana Capitata*	Native		Gentianaceae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sp23	*Geranium Procurrens*	Native		Geraniaceae	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Sp24	*Geranium polyanthus*	Native		Geraniaceae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sp25	*Arundinella bengalensis*	Native		Gramineae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp26	*Calamagrostis nivicola*	Native		Gramineae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Sp27	*Digitaria sp*	Native	Invasive	Gramineae	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0
Sp28	*Festuca Arundinacea*	Native		Gramineae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sp29	*Festuca stapfii*	Native		Gramineae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Sp30	*Holcus Lanatus*	Native		Gramineae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Sp31	*Holcus Nepalensis*	Native		Gramineae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp32	*Oplismenus sp*	Native		Gramineae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Sp33	*Pennisetum clandestinum*	Non-Native	Invasive	Gramineae	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Sp34	*Paspalum sp*	Native		Gramineae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sp35	*Poa dzongicola*	Native		Gramineae	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sp36	*Poa Pratensis*	Native	Invasive	Gramineae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sp37	*Poa sp*	Native		Gramineae	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Sp38	*Yushania Microphylla*	Native	Invasive	Gramineae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Sp39	*Yushania sp*	Native		Gramineae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sp40	*Juncus Iinflexus*	Native		Juncaceae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Sp41	*Clinopodium umbrosum*	Native	Invasive	Labiatae	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sp42	*Colquhounia sp*	Native		Labiatae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp43	*Isodon sp*	Native		Labiatae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Sp44	*Salvia sp*	Native		Labiatae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Sp45	*Crotalaria sp*	Native		Leguminosae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Sp46	*Desmodium sp*	Native		Leguminosae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sp47	*Trifolium Repens*	Native	Invasive	Leguminosae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sp48	*Morus Australis*	Native		Moraceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp49	*Jasminum humile*	Native		Oleaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp50	*Ligustrum compactum*	Native		Oleaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp51	*Oxalis Corniculata*	Native	Invasive	Oxalidaceae	1	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0
Sp52	*Plantago depressa*	Native		Plantaginaceae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Sp53	*Fagopyrum cymosum*	Native		Polygonaceae	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Sp54	*Rumex Nepalensis*	Native	Invasive	Polygonaceae	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0
Sp55	*Onychium Contiguum*	Native		Pteridaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp56	*Pteris cretica*	Native		Pteridaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Sp57	*Clematis Montana*	Native	Invasive	Ranunculaceae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Sp58	*Thalictrum virgatum*	Native		Ranunculaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp59	*Agrimonia pilosa*	Native		Rosaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sp60	*Fragaria nubicola*	Native		Rosaceae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Sp61	*Potentilla supina*	Native	Invasive	Rosaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sp62	*Galium aparine*	Native	Invasive	Rubiaceae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Sp63	*Verbascum Thapsus*	Native	Invasive	Scrophulariaceae	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0
Sp64	*Solanum Americanum*	Native	Invasive	Solanaceae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Sp65	*Viola Macloskeyi*	Native		Violaceae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Figure 63. One-day training on Flora Survey (left) Going to Site through the forest (mid) Crossing Wangchhu river (right)

Figure 64. Figure 62: Plot set up at site (left) scale representing 1 percent cover (mid) Recording of specimen (right)

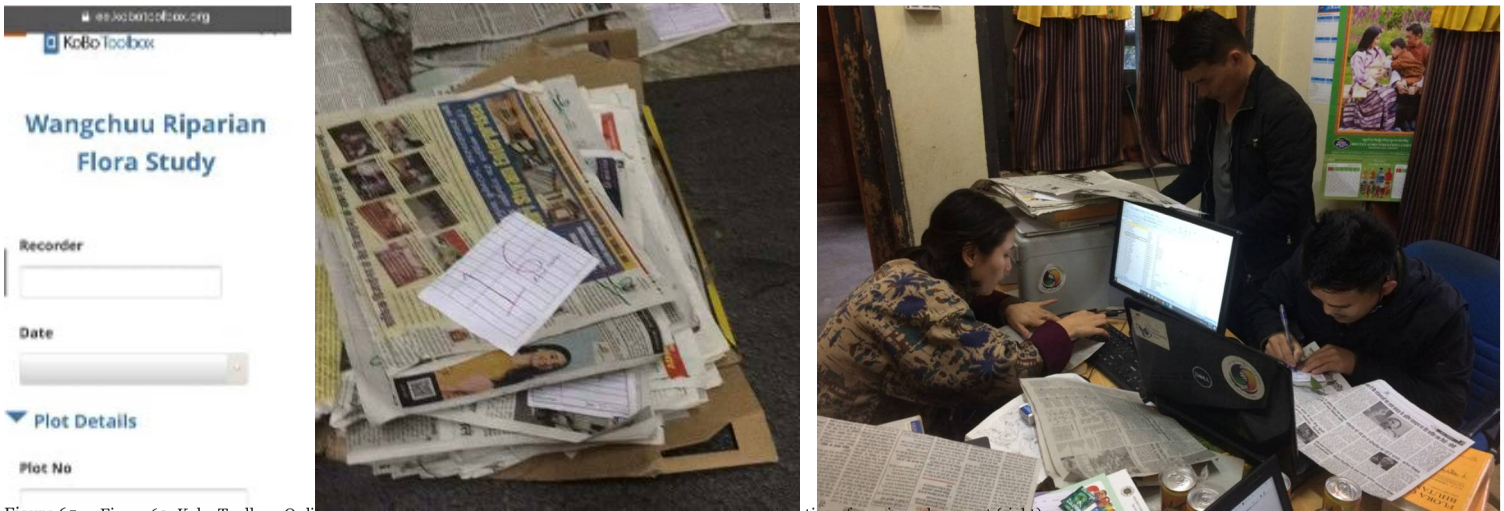

Figure 65. Figure 63: Kobo Toolbox: Online data collection app (left) Compilation of specimen (mid) Identification of specimen by expert (right)

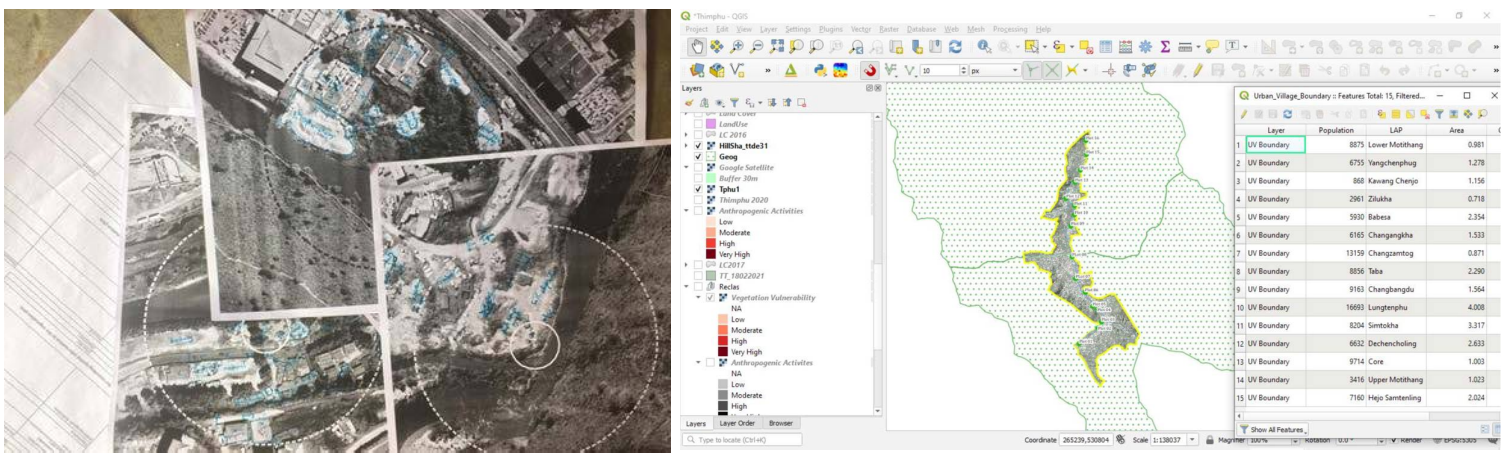

Figure 66. Figure 64: Recording of urban variables on map (left) QGIS for analysis (right)

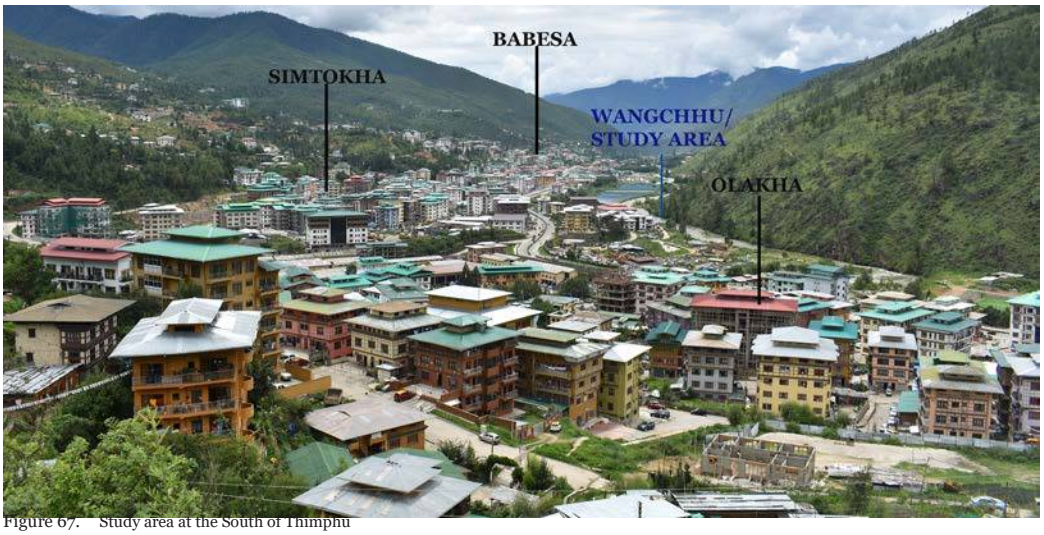

Figure 67. Study area at the South of Thimphu

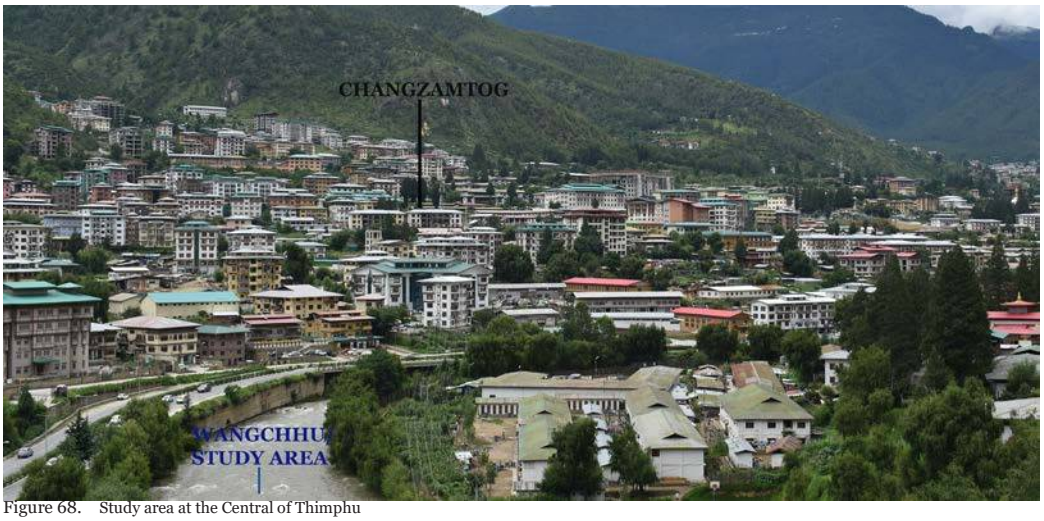

Figure 68. Study area at the Central of Thimphu

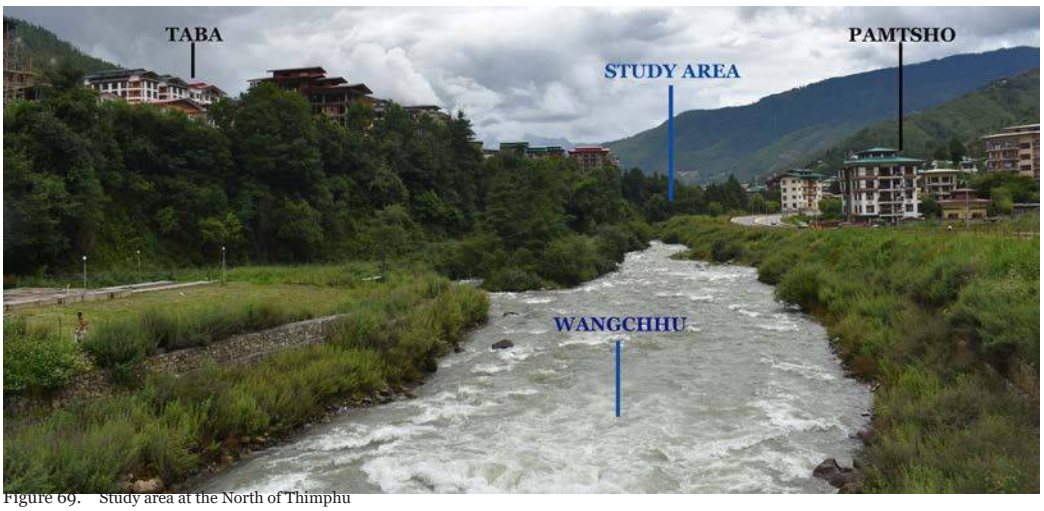

Figure 69. Study area at the North of Thimphu

Tree

Cedrus deodara

Cupressus himalaica

Enonymus grandiflorus

Juniperus indica

Pinus wallichiana

Populus ciliate

Prunues persica

Querecus griffithi

Querecus semecarpifolia

Tree and Shrub

Rhus hookeri

Salix babylonica

Salix wallichiana

Artemisia moorcroftinia

Berberis aristata

Berberis griffithiana

Colquhounia coccinea

Cotoneaster sp

Eleaegnus parvifolia

Shrub

Eleaegnus umbellata

Hedra nepalensis

Ligustrum compactum

Leptodermis amoena

Lonicera glabrata

Lonicera quinquelocularis

Morus australis

Phyllanthus recticulatus

Prinsepia utilis

Shrub

Rubia hispidicaulis

Robus biflorus

Robus pectinarioides

Robus Pungens

Rosa brunonii

Rosa sericea

Salix Obscura

Viburnum continifolium

Zanthoxylum sp

Herb

Agirimonia pilosa

Anaphalis sp

Arundinella bengalensis

Berberis asiatica

Calamagrostis sp

Cannabis sativa

Carex speciosa

Cirsium wallichii

Clematis montana

Herb

Clinopodium umbrosum

Colquhonia sp

Conyza canadensis

Conyza stricta

Crotalaria sp

Desmodium sp

Digitaria sp

Drynaria propingua

Equisetum sp

Herb

Fagopyrum cymosum

Festuca arundinacea

Festuca stapfii

Fragaria nubicola

Galium aparine

Gentiana Capitata

Geranium procurrens

Geranium polyanthus

Holcus lanatus

Herb

Holcus nepalensis

Isodon sp

Jasinium humile

Juncus inflexus

Myriactis wallichii

Onychium contiguum

Ophiopogon bodinieri

Ophiopogon intermedius

Oplismenus sp

Herb

Oxalis corniculata

Pennistum clandestine

Plantago depressa

Plaspalum sp

Poa dzongicola

Poa pratensis

Poa sp

Potentilla supina

Prangos sp

Herb

Pteridium aqulinum

Pteris cretica

Rumex nepalensis

Salvia sp

Seneue seandens

Solanum americacum

Stellaria vestita

Taraxcum eripodum

Taraxcum parvulum

Herb

Tragopogon dubius

Trifolium repens

Thalictrum virgatm

Viola macloskeyi

Verbascum thapsus

Yushania microphylla

Yushania sp

نبذة مختصرة

عزلة في الستينيات ، شهدت بوتان تطورًا سريعًا ، مما أدى إلى التطور في المنطقة الحساسة
على طول النهر والمنحدرات الشديدة والغابات ، مما يعرض للخطر طبيعة ومستقبل البشرية.
نة ثيمفو سيناريو مشابهًا ، حيث يعيش معظم سكان بوتان على مساحة 26 كيلومترًا مربعًا
ون من قيود على التوسع فيزيائيًا بيانيًا. منذ ذلك الحين ، شهدت المنطقة الهشة بيئيًا في المدينة
ى والتجزئة والتغيير والدمار. ومن ثم ، تهدف هذه الدراسة إلى تسجيل وتقييم التنوع البيولوجي
سة المتغيرات الحضرية التي تؤثر على التنوع البيولوجي على طول منطقة نهر وانغتشو.
على دراسة مواقع العينات المحددة على طول منطقة النهر على بعد 30 مترًا من ضفة النهر. يتم
نات الأولية للنباتات والمكان من المسح الميداني وربطها باستخدام طرق مختلفة. نتج عن الإطار
عد للدراسة فهم الخصائص النباتية للمدينة والعوامل الحضرية التي تؤثر على الغطاء النباتي على
ممر. أظهر تحليل البيانات تنوعًا غنيًا في الأنواع ، والذي يتم توزيعه بالتساوي في جميع أنحاء قطع
الأرض.
أيضًا الأنواع الغازية على طول موقع الدراسة. أظهر سجل المتغيرات الحضرية والارتباط بدراسة
غيرًا في حالة الغطاء النباتي وأنواع النباتات مع تحرك المرء من الطرف الجنوبي إلى الطرف
الشمالي للمدينة.
ى تنوع الأنواع يتأثر بالاضطرابات الحضرية وهناك حاجة لرصد وإدارة ممرات النهر بشكل فعال
لإنشاء مستوطنة مستدامة.
ت المفتاحية: ضفاف النهر ، تنوع بيولوجي ، اضطراب ، تحضر ، موطن ، تنوع

رارقإ

لماكتملا نارمعلا ةجرد بلع لوصحلل تراجتوش ةعماجو سمش نيع ةعماج يف ةمدقم ةلاسرلا هذه 2021 ةنس ثحابلا ةفرعمب هزاجنإ مت دق ةلاسرلا هذه هيوحت يذلا لمعلا نإ .مادتسملا ميمصتلاو

يف ميلسلا يملعلا بولسلإا عبتا دق هنأو يصخشلا هثحب ةصلاخ وه مدقملا لمعلا نأ ثحابلا رقيو اذه لك ةيملعلا عجارملا نم هذوخؤملا داوملا بلإ ةراشلإا..ةلاسرلا ءازجأ فلتخم يف هناكم يف

كلذب ينم رارقإ اذهو

:عيقوتلا

يجرود جنازيك :ثحابلا

2021 سطسغأ :خيراتلا

يجولويبلا عونتلا بلع هريثأتو رضحتلا

ةيرضحلا تابارطضلااب قلعتي اميف تاتابنلل يجولويبلا عونتلا مييقت ناتوب :وفميت ، وشتغناو رهن ةقطنم لوط بلع

مادتسملا ميمصتلاو لماكتملا نارمعلا يف ريتسجاملا ةجرد بلع لوصحلل ةمدقم

يجرود جنازيك

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مكحلا ةنجل

يجراخلا نحتملا..... .د.أ
.....ذاتسأ
..... ةعماج

..... .د.أ
.....ذاتسأ
..... ةعماج

..... .د.أ
.....ذاتسأ
..... ةعماج

عيقوتلا

.....:ةشقانملا خيرات

ايلعلا تاساردلا

ةزاجلإا متخ
.../.../... ةيلكلا سلجم ةقفاوم

.....:خيراتب ةلاسرلا تزيجأ
.../.../... ةعماجلا سلجم ةقفاوم

سمـــــش نيع ةعماج

تراجتوتش ةعماج

MM/DD/YYYY

يجولوبيلا عونتلا بلع هريثأتو رضحتلا قلعتي اميف تاتابنلل يجولوبيلا عونتلا مييقت ةقطنم لوط بلع ةيرضحلا تابارطضلااب ناتوب :وفميت ، وشتغناو رهن

مادتسملا ميمصتلاو لماكتملا نارمعلا يف ريتسجاملا ةجرد بلع لوصحلل ةمدقم ةلاسر

دادعإ
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2021 سطسغأ