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## **Editorial: Journal of NAST College – Inaugural Volume**

Welcome to the inaugural volume of the Journal of NAST College (JONC). It is with immense pride and great pleasure that we present this collection of scholarly articles, marking a significant milestone in NAST College's commitment to fostering academic inquiry and advancing knowledge. This journal is conceived as a vibrant platform for rigorous intellectual inquiry and the dissemination of cutting-edge, interdisciplinary research. Our core mission is to promote high-quality, impactful studies that address contemporary issues, drive innovation, and offer practical solutions contributing to global academic discourse. We are deeply committed to embracing the complexity of modern challenges by encouraging interdisciplinary collaboration and reflecting research that transcends traditional disciplinary boundaries. This first volume proudly features a rich tapestry of research-based articles and insightful reviews spanning a wide array of disciplines, including Management, Engineering, Information Technology and Economics and social sciences. Each submission has undergone a meticulous double-blind peer-review process, conducted by esteemed faculty members and expert reviewers with national and international recognition. This rigorous process ensures that every published work adheres to the highest standards of academic integrity, originality, and scholarly excellence.

The Journal of NAST College is an annual publication, committed to an open-access model, making all articles freely available on our official website. We extend a warm invitation to scholars and researchers from across Nepal and around the globe to contribute their original research, theoretical commentaries and empirical studies to our upcoming volumes. We aim to foster a dynamic intellectual community and plan to expand our platform through future initiatives, including conferences, workshops, and seminars to provide further opportunities for scholarly exchange and exposure. Detailed information on submission guidelines, ethical policies, and upcoming events will be regularly updated on our website.

We are deeply grateful to the authors whose dedication, perseverance, and commitment to knowledge are reflected in the exceptional articles within this volume. Our sincere thanks also go to our diligent reviewers and the members of our esteemed Editorial Board, whose expertise and rigorous oversight have ensured the quality and integrity of the research presented herein. Your invaluable support and active participation are fundamental to the journal's sustained growth and impact. Hence, we invite you to delve into the pages of this first volume, embark on a journey of discovery, and join us in celebrating the transformative power of ideas that will define the Journal of NAST College for years to come.

**Sincerely,**

The Editorial Board

Journal of NAST College

**Table of Contents**

Municipal Solid Waste Management Practices in Urban Areas of Bhimdatta Municipality, Nepal _____	1
AI-Powered Stock Forecasting: A Graph-Based Approach for NEPSE _____	22
Comparative Study Between NBC 105:2020 and IS 1893:2016 (Part 1) in torsionally irregular structure _____	35
Compartmental Epidemiological Models and Their Associated Incidence Rate _____	44
Seismic Fragility Curves for Non-Engineered Low-Rise Commercial Buildings in Far Western Nepal: A Case Study of Darchula _____	57
Failure and Maintenance of Flexible Pavement: A Case Study of Mahendranagar City Roads, Nepal _____	77
Shades of History: Reviving Nepal's Heritage through AI _____	91
Spatio-Temporal Weather Prediction with Graph Neural Networks _____	101
Resource Use Efficiency in Vegetable Production in the Kailali of Sudurpaschim Province _____	111
The Influence of the Service Flower Model on Customer Satisfaction at Restaurants in Dhangadhi _____	128

## Municipal Solid Waste Management Practices in Urban Areas of Bhimdatta Municipality, Nepal

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### Abstract

Effective municipal solid waste (MSW) management is essential for protecting public health, preserving environmental quality, and promoting sustainable urban development—particularly in rapidly urbanizing municipalities like Bhimdatta, Nepal. Despite national policies such as the Solid Waste Management Act (2011), many local governments continue to rely on unsustainable practices such as open dumping and unsegregated waste collection. This study aimed to assess the current status of MSW management in Bhimdatta Municipality by examining key aspects such as waste generation, composition, segregation practices, collection services, transportation methods, final disposal, and resource recovery. A mixed-methods approach was employed in Wards 4 and 18, which represent densely populated urban areas. Data were collected through structured questionnaires administered to 30 households, 63 commercial establishments, and 10 institutions, selected with a simple random sampling, key informant interviews with two municipal officials with purposively selected, and extensive field observations. Results revealed that 64.08% of respondents generated <0.5 kg of waste daily, dominated by organic waste (53%), followed by plastics/polythene (16%), and paper/cardboard (12%). Despite high satisfaction with door-to-door collection services, collection rates were high (86.40%), with 90.30% satisfaction, reasonable cost (81.55%), and convenient morning schedules (92.23%) significant gaps existed. 84.47% of respondents lacked waste segregation practices, and 95.14% of waste was transported manually via uncovered vehicles, causing spillage (9.71% occasional, 4.85% frequent). Final disposal relied on open dumping near a riverbank, 20 meters from settlements. Resource recovery efforts were minimal, with only 11.65% recycling plastics and 28.16% practicing composting. The study underscores an urgent need for targeted policies, strict enforcement of existing waste management regulations, and practical interventions—such as public awareness campaigns, infrastructure upgrades, and sustainable disposal technologies—to improve solid waste management practices.

**Keywords:** Public awareness, resource recovery, urban solid waste, open dumping, waste segregation

## Introduction

The increasing volume of municipal solid waste (MSW) in urban areas globally poses a significant environmental and public health challenge. MSW encompasses a variety of discarded materials originating from households, institutions, and commercial establishments (Lema et al., 2019; Maharjan et al., 2019; Teshome et al., 2022). Implementing effective and sustainable MSW management is crucial for enhancing urban living conditions, protecting public health and environment, boosting economic productivity, creating safe and dignified employment, and fostering sustainable urban development (Ezeah & Roberts, 2012).

Globally, MSW is taken as a rising issue, especially in cities of low-income countries such as Nepal. In the context of Nepal, the urgency of addressing MSW is further underscored by the country's commitment to the United Nations Sustainable Development Goals (SDGs), particularly Goal 3 (Good Health and Well-being), Goal 11 (Sustainable Cities and Communities), and Goal 12 (Responsible Consumption and Production) (Aryal & Adhikary, 2024). The rising volume of MSW in urban areas is primarily driven by population growth, unplanned urbanization, changing consumption patterns, and improved lifestyles (Hoornweg & Bhada-Tata, 2012; Teshome et al., 2022). Globally, urban populations are projected to increase from 54% in 2015 to 66% by 2050, with annual MSW generation expected to increase from 2.1 billion tonnes in 2023 to 3.8 billion tonnes by 2050, necessitating substantial financial investment and robust infrastructure (UNEP, 2024). This challenge is more pounced in lower-income countries, where the rate of increase is projected to surpass that of higher-income nations (Hoornweg & Bhada-Tata, 2012). Nepal's waste management systems face considerable pressure due to rapid and often unplanned urbanization, coupled with evolving consumption patterns, leading to increased waste generation and limited disposal options (Khanal, 2023). Nationally, the rate and composition of MSW are further influenced by variations in physical factors (e.g., altitude, temperature, rainfall, and humidity) and socioeconomic factors (e.g., population growth, urbanization, economic status, living standards, and consumption patterns). Across Nepal's 58 municipalities, about 1,435 tons of solid waste are generated daily, with urban areas contributing the majority at an average of 0.317 kg per capita per day (ADB, 2013).

Bhimdatta Municipality, situated approximately five kilometers east of the Indian border, exemplifies the challenges of rapidly urbanizing municipalities in Nepal. As a growing commercial hub, Bhimdatta experienced an average annual population growth rate of 2.28% between 1991 and 2021, driven largely by internal migration from surrounding hill and mountain districts (NSO, 2021). This demographic shift has intensified pressure on existing municipality's waste management systems. Field observations in the

municipality reveal ineffective waste management practices, including scattered piles of plastic and paper waste, open burning, waste-clogged drains, and foul-smelling gutters.

Despite the enactment of the Solid Waste Management Act (2011) and Solid Waste Management Rules (2013), which promotes decentralized, integrated, and community-based waste management system (CBS, 2021), urging local authorities to adopt more effective strategies (Khanal, 2023). However, its implementation remains inconsistent. Waste segregation at the source is limited, and waste collection efficiency varies—ranging from 70–90% in major cities to below 50% in smaller municipalities (ADB, 2013). Alarmingly, many municipalities still rely on environmentally harmful disposal methods such as open dumping (21%), open burning (32%), and waste piling along riverbanks (27%) (CBS, 2021). These unsustainable practices pose severe environmental and public health risks, including soil and groundwater pollution, disease transmission, and degraded air quality (Ferronato & Torretta, 2019). Open burning of waste emits hazardous pollutants like carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), sulfur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM<sub>10</sub>), contributing to air pollution and climate change (Wiedinmyer et al., 2014). Additionally, unmanaged waste sites emit harmful landfill gases such as CO<sub>2</sub>, CO, nitrogen, hydrogen sulfide, and ammonia, exacerbating environmental risks (Pokhrel & Viraraghavan, 2005). Moreover, uncontrolled disposal contributes to heavy metal pollution in water, soil, and plants (Vongdala et al., 2019) and increases greenhouse gas emissions, particularly methane, a potent driver of climate change (Çetinkaya et al., 2018).

While efforts such as community composting and awareness campaigns have been initiated, Nepal's recycling rate remains low. The effectiveness of proper waste disposal and segregation practices varies across regions due to inadequate infrastructure and limited public engagement (ADB, 2013; Khanal et al., 2023). As a result, MSW remains a persistent challenge in urban Nepal (Maharjan et al., 2019), reflecting trends observed in other developing countries facing the compounded pressures of population growth and poorly planned urbanization (Ferronato & Torretta, 2019). These issues highlight the gaps in **localized waste management strategies**, as noted in studies of similar municipalities in Nepal (Aryal & Adhikary, 2024; Rai et al., 2019).

Although several studies have evaluated MSW management in major urban areas and larger municipalities in Nepal (Rai et al., 2019; Pandey et al., 2023; Awasthi et al., 2023), there is a notable lack of research on smaller yet rapidly urbanizing municipalities such as Bhimdatta. Addressing this research gap is critical, as sustainable waste management requires an integrated approach encompassing waste segregation, collection, transportation, resource recovery, and environmentally sound disposal, supported by community participation and awareness (ADB, 2013; Dousti et al., 2017; Lema et al., 2019; Khanal et al., 2023). Accordingly, this study aims to conduct a comprehensive assessment of existing MSW management practices in Bhimdatta Municipality. The focus will be waste generation, composition,

segregation, collection, transportation, disposal, and resource recovery processes. The findings will provide evidence-based insights for municipal authorities, policymakers, and relevant stakeholders to formulate and implement effective, context-specific, and sustainable waste management strategies tailored to the challenges of Bhimdatta and similar municipalities in Nepal.

## **Materials and Methods**

### **Ethics Statement**

Research ethics is paramount in any scientific investigation, safeguarding the interests of the public, research participants, and researchers (Creswell, 2014). This study obtained formal ethical approval from Bhimdatta Municipality through a written consent letter. Prior to data collection, all respondents were thoroughly informed about the study's objectives, their voluntary participation rights, and their absolute freedom to withdraw at any time without any consequences. Consent was secured either verbally or by presenting the municipality-approved ethical approval letter. To guarantee the confidentiality and anonymity of participants, no identifying information was recorded during the data collection process.

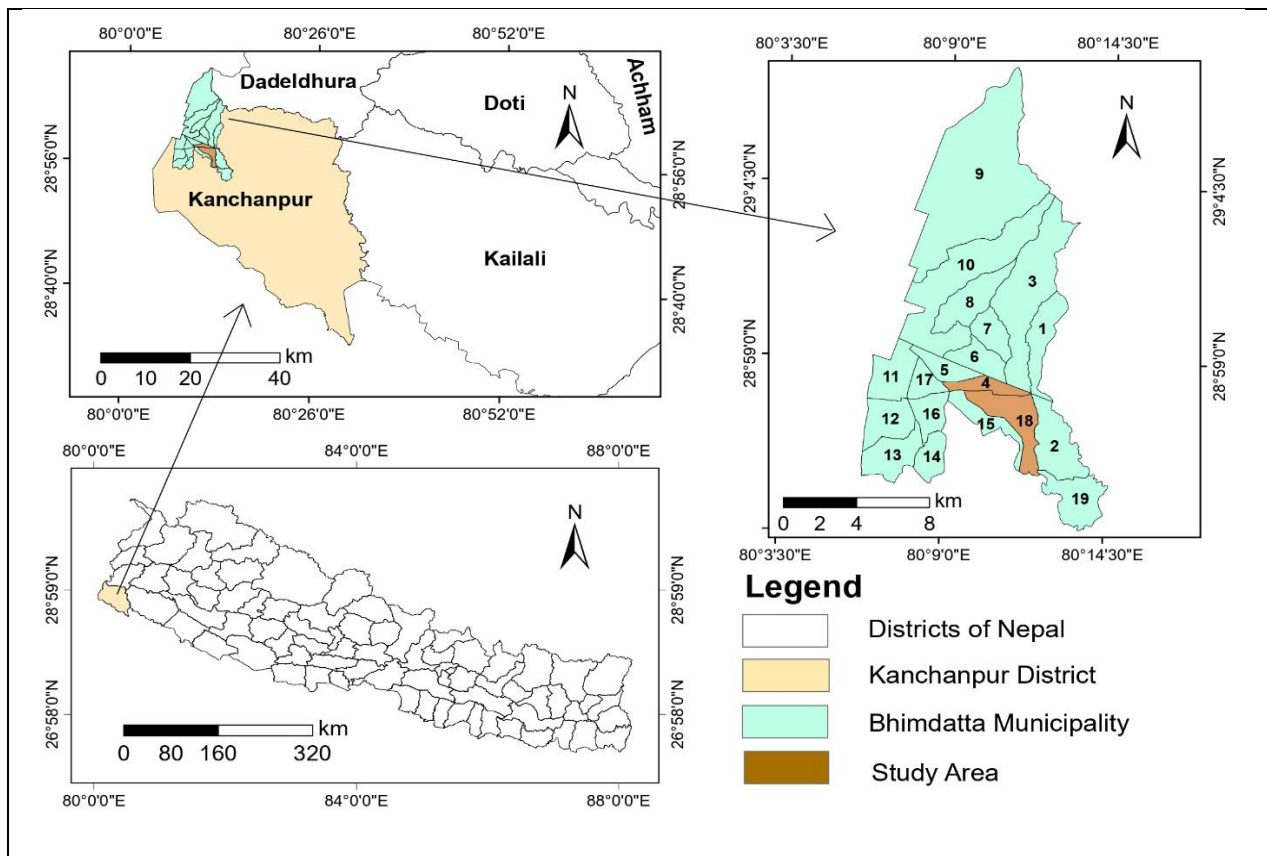
### **Description of Study Area**

Bhimdatta Municipality is located in the Kanchanpur District of Sudurpashchim Province, Nepal. Geographically, it lies between 28°52' to 29°08' North latitude and 80°06' to 80°15.5' East longitude (Figure. 1). The municipality covers an area of 171.24 square kilometers and exhibits predominantly flat terrain. However, its northern boundary reaches an elevation of approximately 1,192 meters above sea level, gradually sloping towards the south, where the lowest elevation is recorded at 222.5 meters (Bhimdatta Municipality, 2025). Administratively, Bhimdatta is divided into 19 wards. According to the 2021 national census, the total population stands at 122,320, with 27,570 households (NSO, 2021).

Climatically, Bhimdatta Municipality lies in Nepal's Terai region and experiences a tropical to subtropical climate with an average annual temperature that ranges from a summer maximum of 43°C to a winter minimum of 6.96°C. The municipality receives an average annual rainfall of approximately 1,575 millimeters, most of which falls during the monsoon season (Bhimdatta Municipality, 2025).

Economically, the municipality hosts a diverse and dynamic economy with major activities including agriculture, construction, wholesale and retail trade, vehicle and motorcycle repair services, financial and insurance services, hospitality, transportation and storage, government employment, and labor migration abroad (NSO, 2021). Formerly known as Mahendranagar, Bhimdatta is the oldest urban center in the region and was recently renamed through administrative decision. The municipality's urban fabric consists of residential areas, governmental and non-governmental offices, educational and healthcare

institutions, and commercial businesses. This diverse land use contributes significantly to the generation of municipal solid waste.



**Figure 1:** Map of (a) Nepal, (b) Kanchanpur district, and (c) Bhimdatta Municipality showing study area

### Research Design

The selection of an appropriate research design is fundamental for systematically collecting, analyzing, and interpreting data to address the research objectives effectively (Creswell & Creswell, 2017). This study, conducted from June 15 to June 30, 2024, employed a mixed-methods approach to integrate quantitative and qualitative data, thereby providing comprehensive and contextually rich insights into MSW management practices.

Due to logistical constraints—particularly limited resources and time—it was not feasible to directly quantify solid waste generation and composition using standardized field-based techniques such as the quartering method (Awasthi et al., 2023; Lohani et al., 2025) or commingled waste sampling at disposal sites (Pandey et al., 2023). Additionally, the absence of updated and reliable municipal records hindered the use of documentary analysis, despite its recognized methodological rigor (Mir et al., 2021). In response to these limitations, a structured, closed-ended questionnaire was employed to estimate daily waste generation and composition at the household, institute and commercial levels. Respondents were asked to select a predefined weight range that best represented their daily waste generation: <0.50 kg/day, 0.5–1.0 kg/day, 1.0–1.5 kg/day, 1.5–2.0 kg/day, 2.0–2.5 kg/day, 2.5–3.0 kg/day, and >3.0 kg/day. They

were also asked to indicate the percentage composition of various waste categories (organic waste, plastic/polythene, paper/cardboard, glass, metal, dust, and others). The mean percentage values for each waste type were then calculated across all responses to determine the overall waste composition. These results were visualized (Figure. 2 and Figure. 3) and analysed accordingly. Behavioral research supports the use of bounded estimation (using ranges) in enhancing the accuracy of self-reported data, as it minimizes over- or underestimation biases compared to open-ended questions (Tourangeau et al., 2000). Similarly, structured categorization has been shown to improve recall accuracy (Sudman & Bradburn, 1982). In many developing contexts, self-reported data on waste generation is often used due to similar practical constraints (Guerrero et al., 2013).

To complement the quantitative data, qualitative insights were gathered through structured questionnaires, key informant interviews (KIIs), and direct field observations. Moreover, triangulation of data from these multiple sources—specifically the cross-verification of questionnaire responses with KIIs and field observations—greatly enhanced the validity and credibility of the study’s findings (Creswell, 2014).

### **Sampling Strategies**

The study was conducted in Ward 4 and Ward 18 of Bedkot Municipality, Nepal. These wards were purposely selected due to their high population density and rapid urbanization, collectively accounting for 20.80% of the municipality’s total population, with the majority residing in these areas (NSO, 2021). Previous studies, ADB (2013) and Lohani et al. (2025), have identified households, commercial establishments, and institutions as primary waste sources. These categories were retained in this study, as they remain representative of urban waste generation patterns (Aryal & Adhikary, 2024; Awasthi et al., 2023).

Respondents for the questionnaire survey were selected through simple random sampling, with one respondent per waste source category to ensure diverse representation. A total of 103 respondents participated: 63 from commercial establishments, 30 from households, and 10 from institutions. Additionally, two municipal officials—the Environmental Officer and the Head of Administration—were purposively selected due to their direct oversight of MSW management of the municipality.

### **Data Sources and Collection Procedures**

#### **Primary Data Collection**

The following research instruments were employed for the collection of primary data.

#### **Key Informant Interviews (KIIs)**

KIIs were conducted with two municipal officials using a predefined questionnaire to gather detailed insights into the practice of MSW management, covering all stages from waste segregation to final disposal.

### **Structured Questionnaires**

Data was collected using a pretested and updated structured questionnaire. It included closed-ended questions to assess waste generation rate, composition, segregation, collection, resource recovery, and final disposal, including public awareness and participation in MSW management activities. Questionnaires were administered in person to a representative from each household, commercial establishment, and institutional facility. The questionnaire was adopted from different previous studies and customized according to the study area setup. It was initially prepared in English and translated into the local language, Nepali.

### **Field Observations**

Systematic field visits were conducted to validate data and capture real-time MSW practices. Observations included documenting overall MSW management practice. Photographic evidence was collected to support findings and enhance data triangulation.

### **Secondary Data Collection**

Secondary data sources were collected from various relevant sources, including previous research studies, government/non-government reports, and news articles, to provide supporting information on MSW to analyses and interpret the study's findings.

### **Reliability and Validity**

Prior to implementation, all research instruments were pilot tested on 10 households including commercials and institutions with similar attributes to the target population and then edited the questions to enhance clarity. To ensure data accuracy and reliability, a comprehensive two-day training session was provided to surveyors before field deployment, and throughout the fieldwork, the team leader closely supervised surveyors, providing ongoing guidance and necessary inputs to maintain high data collection standards.

### **Mapping and Data Analysis**

ArcGIS 10.8 software was employed to delineate the study area, as shown in Figure. 1. The quantitative data collected through the closed-ended structured questionnaires were analyzed using descriptive statistics, such as frequencies and percentages. The results were presented through pie charts and graphs wherever necessary to enhance clarity and facilitate easy interpretation. MS Excel 2013 was used for this

analysis. For the qualitative data obtained from interviews and observations, the responses were transcribed, coded, and categorized. The findings were then presented using direct and indirect quotations, employing expressive and persuasive language to effectively convey insights.

## Results and Discussion

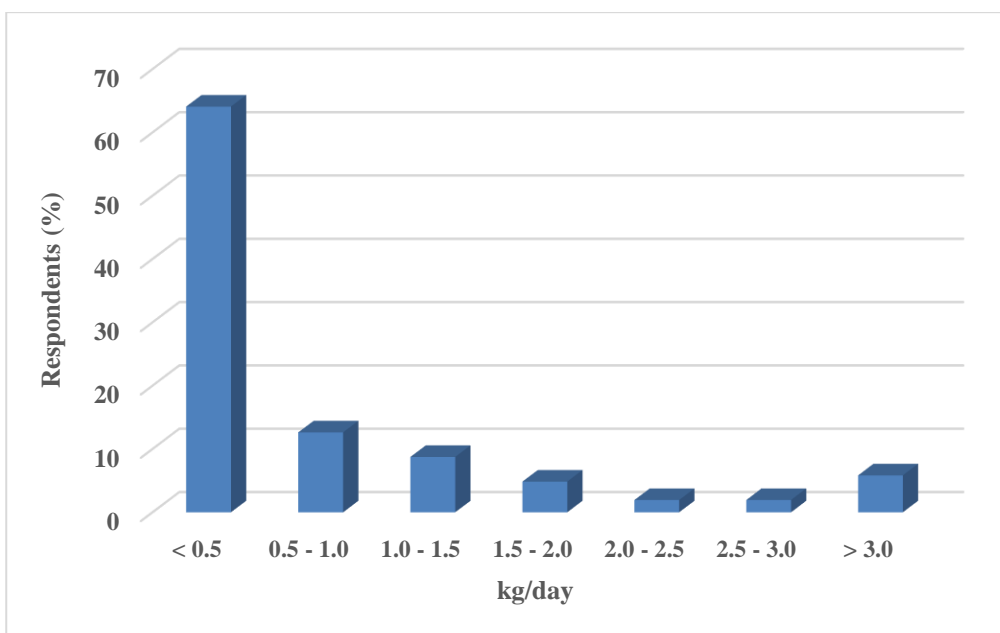
### Waste Generation and Composition

A municipal official stated, “Although we expect solid waste generation to rise, the municipality has not yet collected any data on its generation or composition”. This is despite Bhatta (2021) reporting in a news article that approximately 11 to 14 tons of waste were generated daily in the municipality.

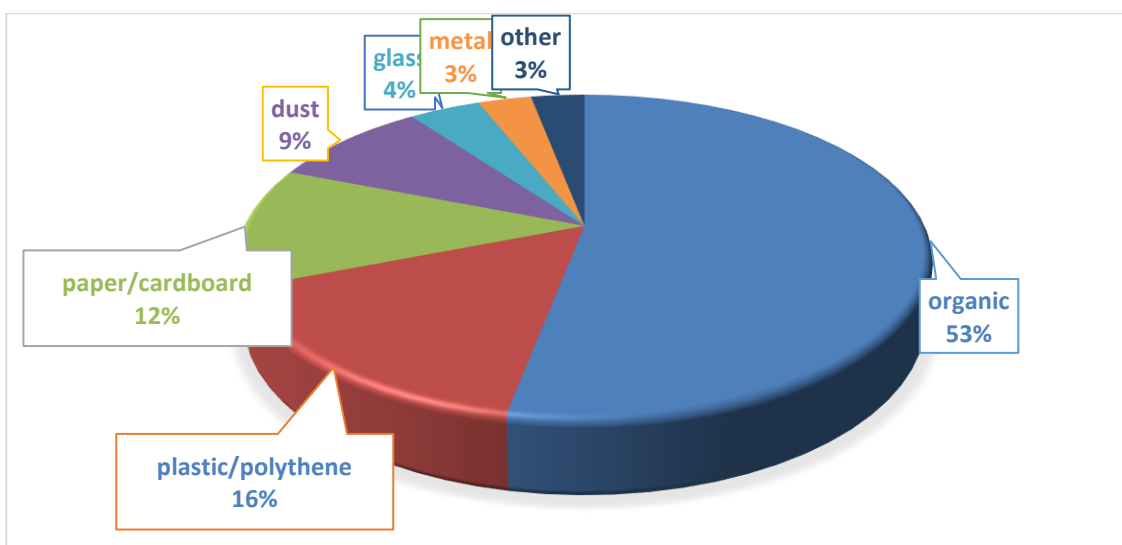
The study revealed that most respondents (64.08%) generated less than 0.5 kg of waste per day, while 12.62% produced between 0.5–1.0 kg/day, and 8.74% generated 1.0–1.5 kg/day. Higher waste generation levels were less common, with only 14.56% of respondents reporting more than 1.5 kg/day, and a small fraction (5.83%) generating over 3.0 kg/day. Very high waste generation levels (2.0–2.5 kg/day and 2.5–3.0 kg/day) were rare, with only 1.94% of respondents in each category (Figure. 2). These findings align with trends in other developing countries, where per capita waste generation is typically lower than in developed nations. For instance, in developed countries, MSW generation ranges from 0.8 to 1.4 kg/capita/day (Bundhoo, 2018), whereas in developing countries, it ranges from 0.3 to 0.5 kg/person/day (Mir et al., 2021). In Nepal, waste generation rates vary, with studies reporting 0.317 kg/capita/day across 58 municipalities (ADB, 2013), 0.078 kg/person/day (Pandey et al., 2023), and 0.0347 kg/person/day (Awasthi et al., 2023).

The waste composition in the municipality was dominated by organic materials, averaging 53% (range: 48%–61%), followed by plastic/polythene (16%; range: 6%–18%), paper/cardboard (12%; range: 9%–22%), glass (4%; range: 2%–7%), and metals (3%; range: 0%–11%). Dust accounted for 9% (range: 7%–11%), likely due to sweeping practices, while other waste types made up 3% (range: 3%–6%) (Figure. 3). This composition suggests significant potential for composting and recycling, as highlighted by ADB (2013). These findings are consistent with previous studies in Nepal, where organic waste typically constitutes the largest portion of MSW (44%–65%), followed by plastics (14%–16%), paper (5%–11%), glass, and metals (ADB, 2013; Pandey et al., 2023; Awasthi et al., 2023). However, comparisons with other developing countries reveal variations. For example, in India, Mir et al. (2021) found that nearly 90% of respondents generated organic waste, while in Ethiopia, Teshome et al. (2022) reported that plastics/bags/bottles were the most common waste type (45%), followed by food waste (18.8%) and paper/cardboard (16.9%). Such regional variability underscores the influence of local consumption patterns, waste management practices, public awareness, and socio-economic factors (ADB, 2013; Douth et al., 2017; Mir et al., 2021).

Field observations indicated a complete absence of waste segregation at the source across households, commercial establishments, and institutions. Residential areas primarily generated small quantities of organic waste, such as food scraps and vegetable peels, alongside mixed waste. In contrast, commercial establishments, including restaurants and shops, produced larger volumes of waste, with significant amounts of organic waste, plastics, and cardboard. Glass and metal waste were less common but more prevalent near beverage shops and restaurants, likely due to the disposal of bottles and cans. Dust, originating from sweeping activities, was a notable component of the waste stream in all zones. The overall waste composition included food waste, plastics, paper, textiles, rubber, metals, glass, dust, and hazardous materials, consistent with findings from previous studies in Nepal (ADB, 2013; Aryal & Adhikary, 2024).



**Figure 2:** Solid waste generated (in kg/day) on average by respondents



**Figure 3:** Average solid waste composition (in %) generated by respondents

## **Waste Segregation at the Source**

The study revealed significant gaps in waste segregation practices, with 84.47% of respondents not segregating waste at the source. Only 15.53% practiced segregation, with 11 respondents using a two-category system (organic and inorganic) and 5 adopting a three-category system (organic, recyclable, and non-recyclable). The lack of segregation poses serious public health and environmental risks, as it allows hazardous materials, including healthcare waste, to mix with general waste, increasing the spread of infectious diseases like Hepatitis B and HIV (WHO, 2014) and complicating recycling processes (Maharjan et al., 2019). A key infrastructural barrier was the absence of separate waste bins, reported by 15.53% of respondents, underscoring the need for municipalities to invest in appropriate infrastructure to support segregation (Sen, 2022). The primary reasons for non-segregation included lack of enforcement (65.05%) and lack of awareness (18.45%), while only 0.97% cited inconvenience, indicating systemic issues rather than personal choice. These findings align with Aryal and Adhikary (2024), who emphasized the need for public awareness campaigns, stricter enforcement, and investment in segregation facilities to improve waste management in Nepal. This trend reflects broader national challenges, where ineffective enforcement, limited resources, and insufficient public engagement hinder waste management efforts (Maharjan et al., 2019). In terms of waste storage, 48.54% of respondents used open bins, 42.72% used bins with lids, 6.79% stored waste in plastic bags (posing hygiene and pollution risks), and 1.95% used other methods.

Observations confirmed that most households and institutional workers did not practice waste segregation. However, commercial units, such as restaurants, often implemented two- or three-category segregation systems (Figure. 4 b). Organic waste was typically sold to pig farmers, while other segregated waste was sold to informal waste pickers. Waste storage methods varied, with commercial units consistently using lidded bins. Although infrastructure for waste segregation was completed, no equipment, machinery, or processing plants have been installed.

Interviews revealed that colored bins were distributed to urban households and public spaces three years ago, alongside orientation sessions to promote segregation. However, financial constraints halted the initiative, leading to a decline in segregation practices, with some residents repurposing bins for non-waste uses. The lack of enforcement of segregation regulations further reduced compliance. Additionally, the waste segregation center, completed nearly four years ago, remains non-operational due to missing machinery and equipment (Figure. 4c).

## **Collection and Transportation**

Interviews revealed that “door-to-door waste collection services were available in only 8 out of 20 wards, specifically Wards 4, 5, 6, 9, 10, 11, 18, and parts of Ward 3, in collaboration with a private partner.

Waste collection occurred between 7:00 am and 1:30 am, with varying frequencies across wards. Wards 4 and 18 received daily collection services, while Wards 5, 6, 9, 10, 11, and parts of Ward 3 had collection on alternate days. In Ward 6, a private partner collected waste from a limited number of houses near the main highway. Public areas were managed by the municipality, though a limited workforce posed challenges in maintaining cleanliness and timely waste removal. The municipality owned six vehicles for waste collection: two tippers, three tractors, one backhoe, and a three-wheeler cycle operated by a private partner. However, this fleet was insufficient for daily demands, requiring multiple trips to the disposal site. Tippers and tractors, primarily used for door-to-door collection, were operated by a team of five staff members: one driver, two collectors, and two workers managing waste inside the vehicle”.

The findings indicated that 86.40% of respondents received daily waste collection services, while 7.77% received service twice a week, and smaller proportions reported random, weekly, or once-a-week collection. High collection frequency is crucial in reducing illegal dumping and associated public health risks (Maharjan et al., 2019). Despite inconsistencies, 90.30% of respondents expressed satisfaction with the service, though 4.85% were dissatisfied, and an equal proportion remained neutral, suggesting areas for improvement. Financial participation was high, with 94.17% contributing to waste collection costs, and 81.55% finding the fees reasonable. However, 8.74% raised concerns about pricing, indicating a need for potential adjustments to address affordability, particularly for low-income households (Teshome et al., 2022). Collection timing was another critical factor, with 49.51% reporting collection between 7 am and 9 am, and 44.66% between 9 am and 12 noon. This morning schedule aligns well with residents’ routines, facilitating waste disposal before other activities, as noted by Sen (2022). However, 5.83% reported random collection times, indicating inconsistencies that may require attention to maintain public trust. While 56.31% found the timing convenient and 35.92% very convenient, 7.77% found it inconvenient, suggesting a need for more flexible scheduling. The door-to-door waste collection system was highly valued for its convenience and effectiveness, with all respondents (98.06%) reporting direct waste collection from their sources, with a rare reliance on roadside pickup or alternative methods (e.g., burning). This system is widely implemented in high-income countries (Bezama & Agamuthu (2019), which contrasts with other municipalities in Nepal, where only 42.14% of households had access to door-to-door collection (Aryal & Adhikary, 2024). In Ethiopia, 60.6% of households have access, but 72.5% express uncertainty about collection frequency, leading to dissatisfaction (Teshome et al., 2022). Similarly, in Ethiopia, only 26% of households receive monthly door-to-door collection, contributing to improper disposal practices (Lema et al., 2019). Regarding waste transportation, 95.14% of respondents stated that their waste was collected by large vehicles (trucks or tractors), while the remaining respondents reported collection by small vehicles (e.g., three-wheeler cycle. All respondents noted that the collection of vehicles was uncovered, with 9.71% observing occasional spillage and 4.85% reporting frequent

leakage. This finding aligns with Douthi et al. (2017) and highlights the need for improved containment systems to mitigate environmental pollution (Meza et al., 2020).

Observations confirmed that tippers and tractors were the main vehicles for manual waste collection and transportation to the open dumping site. However, these vehicles remained uncovered during collection and transport, and workers were observed mixing segregated waste in the vehicles. To increase capacity, vertical frames were welded onto the tippers and tractors. Waste collectors wore basic protective gear like masks and gloves but lacked boots (Figure. 4d).

In developed countries, advanced algorithms are used to optimize waste collection routes, reducing costs and improving efficiency with specialized vehicles like skip loader trucks and compactors (Tirkolaee et al., 2019). In contrast, waste transportation in developing countries such as in Ghana, waste collection relies on a mix of manual and mechanical means, such as tricycles and skip loader trucks, but suffers from insufficient vehicles, poor road conditions, and irregular schedules, leading to overflowing containers and indiscriminate dumping (Douthi et al., 2017). Furthermore, many municipalities in Nepal lack proper transfer stations, and waste is often transported directly to disposal sites using rickshaws, tractors, and dump trucks (ADB, 2013). Establishing transfer stations for further segregation and processing, as suggested by Maharjan et al. (2019), could streamline waste management and improve recyclable material recovery. These challenges are exacerbated by financial constraints, limited resources, inadequate infrastructure, rapid urbanization, a lack of public awareness, and administrative constraints, all of which hinder the development of efficient waste transportation systems (Douthi et al., 2017; Teshome et al., 2022; Tirkolaee et al., 2019).

### **Final Disposal**

Interviews revealed that the “waste was openly dumped at a temporary site in the Barakunda area of Ward Number 1 within the municipality. The municipality actively sought alternative sanitary landfill sites by negotiating with residents near government or private land. However, the process of using private land is complex and conditional. Landowners must submit a formal written request detailing the intended use of the land and obtain written consent from nearby residents before their land can be designated as a sanitary landfill site. As the current site nears capacity, the search for new temporary dumping sites is expected to continue”. This bureaucratic and community-dependent process reflects the municipality's lack of a comprehensive, long-term waste management strategy.

The findings further indicated a heavy reliance on municipal waste collection services, with 96.12% of respondents depending on these services for final waste disposal, which ultimately leads to open dumping. There was limited engagement of respondents in composting or burning. Field observations corroborated that **open dumping** remains the predominant disposal method. The **Barakunda dumping site**, situated

at 28°59'28.1"N 80°11'46.0" E (Figure. 4e) is situated on **lowland terrain** near a **riverbank** and approximately **20 meters from human settlements**. The site was characterized by uncovered waste and the presence of scavenging **animals** (Figure. 4f). These findings align with studies conducted in other developing countries. For instance, Lema et al. (2019) in Asella town, Ethiopia, found that half of the respondents disposed of waste by dumping it in yards, ditches, rivers, or burning, a common practice in developing countries. Similarly, studies by Aryal and Adhikary (2024) in Nepal, and Birhanu and Berisa (2015) in Ethiopia, supported these observations. However, Douthi et al. (2017) highlighted deficiencies in landfill management in urban areas of Ghana, including the lack of cell planning, improper waste compaction, absence of regular waste cover, and inadequate leachate and gas collection systems. Such substandard conditions, as noted by Owusu-Sekyere et al. (2013), pose serious public health and environmental risks if landfill standards are not met.

The study underscores the urgent need for environmentally friendly disposal methods, as current practices do not align with sustainable waste management principles (Maharjan et al., 2019). Transitioning from open dumping to more sustainable methods, such as engineered landfills or waste-to-energy facilities, is essential for mitigating health and environmental risks and promoting long-term sustainability (Scarlat et al., 2018). The prevalence of improper waste management practices is attributed to a lack of public awareness and inadequate municipal services (Lema et al., 2019). Similar challenges have been documented in India by Mir et al. (2021) and in Nepal by Maharjan et al. (2019), highlighting issues such as insufficient resources, lack of public awareness, and poor enforcement of waste management regulations.

### **Resource Recovery**

The study revealed a significant gap in resource recovery practices, with 83.50% of respondents not engaging in recycling and only 2.91% occasionally recycling at the source. Among those who recycled, plastic was the most recovered material (11.65%), followed by paper/cardboard (1.94%) and glass (0.97%). Composting, a crucial resource recovery method, was practiced by only 28.16% of respondents. These findings align with previous research, such as Douthi et al. (2017), and Teshome et al. (2022), which also identified low recycling and composting rates in urban areas of developing countries. In developing countries, over 50% of MSW is compostable, yet composting practices remain limited. Composting is a simple, sustainable waste management method that supports recycling and offers benefits such as bio-fertilizer production, pollution reduction, income generation, and low operational costs. Therefore, it is recommended that all developing countries adopt composting practices (Adhikari, 2022). The low rates of recycling and composting observed in the current study and previous research underscore the critical role of policy frameworks and community education in driving behavioral change. For instance, Krishna and Chaurasia (2017) demonstrated that effective recycling programs require not only infrastructure but

also strong community participation and awareness. Effective resource recovery is essential for reducing landfill waste, conserving resources, and advancing the principles of a circular economy (Stępień et al., 2019). By fostering a culture of recycling and composting, municipalities can significantly reduce their environmental footprint and promote long-term sustainability (Khanal et al., 2023; Krishna & Chaurasia, 2017).

**Interviewees revealed that “the municipality itself did not actively engage in resource recovery initiatives.** Although a biogas plant was previously installed and functioning to convert organic waste into biogas. It was mainly used for cooking in the municipality staff’s quarter and had been non-operational for over a decade due to damaged components and the lack of repairs” (Figure. 4g). **Field observations confirm these findings, showing that the municipality still lacks resource recovery practices.** Instead, a small portion of residents engaged in limited resource recovery efforts, which were insufficient compared to the total waste generated (Figure. 4h). This underscores the urgent need for **institutional involvement, investment in recovery infrastructure,** and community engagement to enhance **sustainable waste management.**

### **Public Awareness and Participation**

The study revealed varying levels of public awareness regarding solid waste management, with 18.45% of respondents reporting a high level of awareness, while the majority (58.25%) rated their awareness as moderate. Additionally, 9.71% reported low awareness, and 8.74% were uncertain about their level of awareness. Despite these differences, a significant majority (87.38%) expressed a willingness to volunteer community clean-up drives, indicating a strong public interest in improving waste management practices. This enthusiasm presents a valuable opportunity for local authorities to engage the public more effectively through targeted educational interventions (Sapkota et al., 2015). For instance, the involvement of youths in at-source segregation has been a positive trend in some urban areas, demonstrating the potential for youth engagement to drive behavioral change (Khanal et al., 2023). In Bhimdatta Municipality, sanitation workers used whistles during clean-up drives to attract attention and encourage residents to participate. This initiative successfully engaged social organizations, community police, journalists, and political leaders, fostering a collective effort to maintain cleanliness, as reported by Bhatta (2016), in a news article. To capitalize on this enthusiasm, local authorities should prioritize interactive and modern approaches to awareness campaigns. The study found that 38.83% of respondents favored workshops and training programs, while 31.07% preferred social media outreach. Additionally, there was almost equal preference for school programs and the use of banners and posters. However, the study also uncovered a significant communication gap between local authorities and the community. While 87.38% of respondents reported receiving no information, only 1.94% occasionally received information from the municipality about waste management. This lack of communication highlights the need for improved

information dissemination and transparency to foster better community engagement and participation (Khanal et al., 2023). Moreover, when respondents were asked about the best method of waste disposal, composting emerged as the most favored option, with 72.82% of respondents supporting it. Additionally, 18.45% of respondents believed that a combination of composting and burning would be effective, while a smaller percentage (4.85%) favored burning alone. Notably, 3.88% of respondents considered dumping waste near riverbanks as a viable method, which highlights a concerning lack of awareness about the environmental hazards associated with such practices. This lack of awareness is particularly troubling, as improper disposal methods can lead to water contamination and other ecological issues (Lema et al., 2019). A significant 89.32% of respondents admitted they were unaware of the municipality's final waste disposal methods, while only 10.68% claimed to know about it. This indicates a major gap in public awareness regarding post-collection waste management, which could limit community participation in improving waste management practices. Lack of transparency about disposal methods may also reduce public trust and hinder efforts to promote waste reduction and proper segregation (Mir et al., 2021).





**Figure 4:** (a) Scattered piles of waste, (b) Segregated waste at the restaurant, (c) Segregation center had not started yet, (d) Door-to-door collection and transportation by larger vehicle, (e) Google maps of dumping site at Ward Number 1, (f) Open dumping, (g) Waste-to-energy (Biogas) plant, (h) Reuse of non-biodegradable waste (rare), (i) Municipal official (in between) for an interview, and (j) Questionnaire survey with the respondents,

## Conclusions

The study assessed existing municipal solid waste (MSW) management practices in Bhimdatta Municipality, a rapidly urbanizing area in Nepal. Key findings revealed that most respondents generated less than 0.5 kg of waste daily, with organic (53%) waste dominating the stream. Crucially, waste segregation at the source was largely absent, with only 15.53% of respondents practicing it. While waste collection services were generally reliable (86.40% of respondents) via door-to-door services using non-mechanized vehicles (tippers or tractor), and transportation was inefficient due to uncovered vehicles leading to spillage (9.71% occasional, 4.85% frequent). Final disposal relied heavily on open dumping. Resource recovery practices like recycling and composting were limited, with only 28.16% of respondents engaging in composting and plastic being the most recycled item (11.65%). Although public awareness towards waste management was moderate (58.25%), a strong willingness to participate in community clean-up drives (87.38%).

## Implications

The findings highlight the pressing need for targeted policies and practical interventions to enhance solid waste management in Bhimdatta Municipality. Priority actions include stricter enforcement of the Solid Waste Management Act (2011) and Solid Waste Management Rules (2013), alongside public awareness initiatives aimed at promoting waste segregation and proper waste management practices. These efforts should be supported through educational workshops, training programs, and the use of social media. Additionally, infrastructure improvements—such as the provision of segregated waste bins and the deployment of covered waste-collection vehicles—are essential. The implementation of verified segregated collection systems, expansion of community-based composting and recycling initiatives, and the adoption of sustainable disposal technologies, including engineered landfills and waste-to-energy facilities.

## Limitations of the Study

This study has several limitations. First, studies should employ direct quantification methods to obtain more accurate data. Second, the study was conducted in specific urban areas of the municipality with a relatively small sample size of 103 respondents, which may limit the generalizability of the findings to other regions or municipalities in Nepal. Finally, the study was conducted over a short period, which may not account for seasonal variations in waste generation and management practices.

## Recommendations

To address the identified challenges, the following practical solutions are recommended:

- Strengthening enforcement of existing waste management regulations and investing in infrastructure to support segregation and recycling.
- Launching targeted educational programs, including workshops, social media outreach, and school initiatives, to raise awareness and encourage community participation.
- Implementing mandatory waste segregation at the source, supported by the distribution of at least three color-coded bins.
- Promoting recycling and composting through incentives, improved infrastructure, and community engagement programs.
- Developing engineered landfills (e.g., sanitary landfills) or waste-to-energy facilities to replace open dumping.

## Future Research Directions

Future research should employ direct quantification methods, such as quartering waste sampling techniques, to obtain more accurate data on waste generation and composition. Longitudinal studies should be conducted to assess seasonal variations in waste generation and management practices.

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# AI-Powered Stock Forecasting: A Graph-Based Approach for NEPSE

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## Abstract

The stock market is a cornerstone of the financial ecosystem, yet forecasting price movements remains a formidable challenge due to the dynamic and interconnected nature of influencing factors. While conventional prediction models often fail to adequately represent these complex relationships, Graph Neural Networks (GNNs) have emerged as a promising alternative, offering superior accuracy by modeling financial data as interconnected graphs.

In this study, we introduce a visibility-based graph transformation technique to convert stock market features into a structured network, capturing long-memory dependencies. We then apply Graph Convolutional Networks (GCN) and Graph Attention Networks (GAT) to analyze trends and predict market behavior. Our experiments reveal that GCN outperforms GAT in modeling financial graph structures, demonstrating its robustness in deciphering intricate market relationships.

These results underscore the potential of GNN-driven approaches in stock market forecasting, providing actionable insights for investors and advancing predictive analytics in the Nepalese stock market (NEPSE).

**Keywords:** Graph Neural Networks (GNNs), financial forecasting, Graph Convolutional Network (GCN), Graph Attention Network (GAT), stock market prediction, Nepal Stock Exchange (NEPSE).

## Introduction

In an era of rapidly evolving financial markets, investors face mounting challenges in making data-driven decisions - particularly in emerging economies like Nepal where market volatility is high and sophisticated analytical tools remain scarce. The Nepal Stock Exchange (NEPSE) presents unique forecasting complexities due to its developing nature, limited historical data, and susceptibility to external shocks. This study investigates how Graph Neural Networks (GNNs) can transform stock market prediction in Nepal by modeling the intricate web of relationships between stocks, sectors, and market indicators.

Traditional prediction methods - including statistical models and conventional machine learning approaches - often fall short in capturing the dynamic, non-linear interdependencies that characterize

financial markets. While time-series models like ARIMA and sequential neural networks (LSTMs, RNNs) analyze temporal patterns, they typically treat stocks as independent entities, ignoring the crucial network effects that drive market movements. GNNs emerge as a powerful alternative, capable of:

- Explicitly modeling inter-stock relationships through graph structures
- Learning both local and global market patterns simultaneously
- Integrating heterogeneous data sources (price history, news sentiment, sector linkages)
- Adapting to evolving market conditions through temporal graph extensions

Our research pursues three key objectives:

1. Developing a novel GNN architecture optimized for Nepal's market characteristics
2. Quantifying the value of relational data in forecasting NEPSE trends
3. Establishing an automated framework for graph-based feature extraction from limited financial data

The study's potential contributions are twofold: methodological (advancing GNN applications in emerging markets) and practical (delivering actionable tools for Nepalese investors). By bridging the gap between traditional econometrics and cutting-edge graph AI, we aim to enhance risk assessment, portfolio optimization, and market stability in Nepal's growing financial ecosystem.

## Literature Review

Stock price prediction remains a formidable challenge due to the dynamic interplay of economic indicators, financial reports, global news, and investor sentiment. Traditional models often fail to capture these multifaceted and evolving relationships. To address this, **Qian et al. (2024)** proposed a **Multi-Relational Dynamic Graph Neural Network (MDGNN)**, which integrates dynamic graphs with Transformer architectures to model evolving financial dependencies. By capturing temporal shifts in stock correlations and market conditions, this approach outperformed state-of-the-art models on benchmark datasets. The study demonstrated that combining dynamic graph structures with Transformers significantly enhances forecasting accuracy, emphasizing the importance of modeling time-sensitive financial relationships.

The application of Graph Neural Networks (GNNs) in finance has gained momentum due to their ability to model complex interdependencies among stocks and financial entities. **Timothe Watteau (2024)** explored this potential by analyzing the **S&P100 index** using Spatio-Temporal Graph Neural Networks (STGNNs). The study introduced Temporal Graph Convolutional Networks (T-GCN, A3T-GCN) for stock trend forecasting, leveraging both spatial (inter-stock connections) and temporal (historical trends) data. Additionally, a Temporal Convolutional Graph Autoencoder was applied for deep graph clustering,

enabling the identification of stock groupings based on price movements. The framework provided a comprehensive solution for price prediction, clustering, trend classification, and portfolio optimization, showcasing GNNs' superiority over traditional methods.

Further advancing the field, **Chen et al. (2023)** investigated the synergy between Graph Convolutional Networks (GCNs) and Transformers for stock forecasting. Unlike conventional models that treat stocks in isolation, their approach incorporated inter-stock dependencies through multiple graph representations (e.g., correlation graphs). The study revealed that while multi-graph integration improved performance, the baseline GCN model outperformed complex multi-graph variants, highlighting challenges in constructing high-quality financial graphs. Among graph types tested, correlation graphs proved most effective, and hybrid architectures (e.g., multi-graph GCN and Transformer with graph masking) surpassed traditional LSTM models.

### **Key Takeaways from Literature**

1. **Dynamic graph models (e.g., MDGNN)** excel in capturing temporal shifts in market relationships.
2. **Spatio-temporal GNNs (e.g., STGNNs)** unify spatial and temporal data for holistic forecasting.
3. **Graph construction quality** is critical—simpler GCNs can outperform complex multi-graph setups when dependencies are noisy.

These studies collectively underscore the transformative potential of GNNs in financial markets, demonstrating their ability to model intricate relationships, adapt to volatility, and deliver actionable insights for investors.

## **Materials and Methods**

### **Data acquisition and Preprocessing**

#### **Data Collection**

The study employs daily trading data obtained from NEPSE Alpha, the official data repository of the Nepal Stock Exchange, covering the period through January 2024. The dataset encompasses 133 actively traded companies representing 11 distinct sectors (Table 1), with particular emphasis on financial institutions (commercial banks, development banks, and finance companies) and non-financial sectors (tourism, manufacturing).

Each daily record contains six fundamental market indicators:

1. Price metrics: Opening, closing, high, and low prices
2. Liquidity measures: Trading volume (quantity) and turnover (NPR)
3. Metadata: Company identifier, sector classification, and trading date

## Data Cleaning

A rigorous four-stage cleaning protocol was implemented:

### 1. Missing Data Treatment

We applied median imputation for continuous variables showing less than 15% missing values, while completely removing observations with over 30% missing features (affecting 2.1% of total records). For categorical variables, we preserved missing values as a separate category to maintain potential information value in the null responses.

### 2. Outlier Management

Our outlier handling process identified extreme values using modified z-scores with a threshold of  $|z| > 3.5$ . We winsorized the top and bottom 1% of price changes to reduce skewness while preserving overall distribution characteristics. Each potential outlier was cross-checked against recorded market events like circuit breakers to distinguish true anomalies from legitimate volatility.

### 3. Consistency Verification

All numeric formats and units were standardized across the dataset to ensure computational compatibility. Through manual verification, we corrected 23 instances of sector misclassification against the official NEPSE taxonomy. Temporal consistency was enforced by validating the sequence and completeness of trading dates for each security.

### 4. Duplicate Elimination

Using SHA-256 hashing of composite records, we detected and removed 17 duplicate entries. Uniqueness was further verified through business logic checks using (company, date) composite keys, ensuring no valid trading days were accidentally removed during deduplication.

## Graph Construction

### 1. Node Representation

Each node in our graph structure corresponds to a unique trading day within the time series data. The node feature vector comprises seven quantitative market indicators: opening price, closing price, daily high price, daily low price, percentage price change, traded volume, and traded value. While the published date is included as a node attribute, it serves solely as an identifier for temporal edge construction and is excluded from model training.

## 2. Stock-Specific Graph Formation

We construct individual stock graphs as independent topological structures, where each graph  $G_s = (V_s, E_s)$  represents the complete trading history of stock  $s \in S$  (the set of all stocks). This isolation preserves stock-specific patterns while allowing for later cross-stock relationship analysis.

## 3. Visibility Graph Edge Formation

The edge set  $E_s$  is generated using the visibility graph algorithm, which establishes connections between temporally separated price points based on mutual visibility in the time-price plane. For any two nodes  $(t_a, y_a)$  and  $(t_b, y_b)$  where  $t_a < t_b$ , a directed edge  $e_{ab}$  exists if and only if for all intermediate points  $(t_c, y_c)$ :

$$y_c < y_b + (y_a - y_b) \frac{t_b - t_c}{t_b - t_a}.$$

## Feature Selection for Graph Construction

**Price Feature Analysis:** The four price features (open, close, high, low) exhibited near-perfect multicollinearity in our preliminary analysis. Correlation coefficients consistently exceeded 0.95 across all sectoral groups, with variance inflation factors (VIF) ranging from 8.7 to 12.3, indicating substantial redundancy. Principal component analysis revealed that the first component explained 96.4% of total variance, suggesting these metrics capture nearly identical market information.

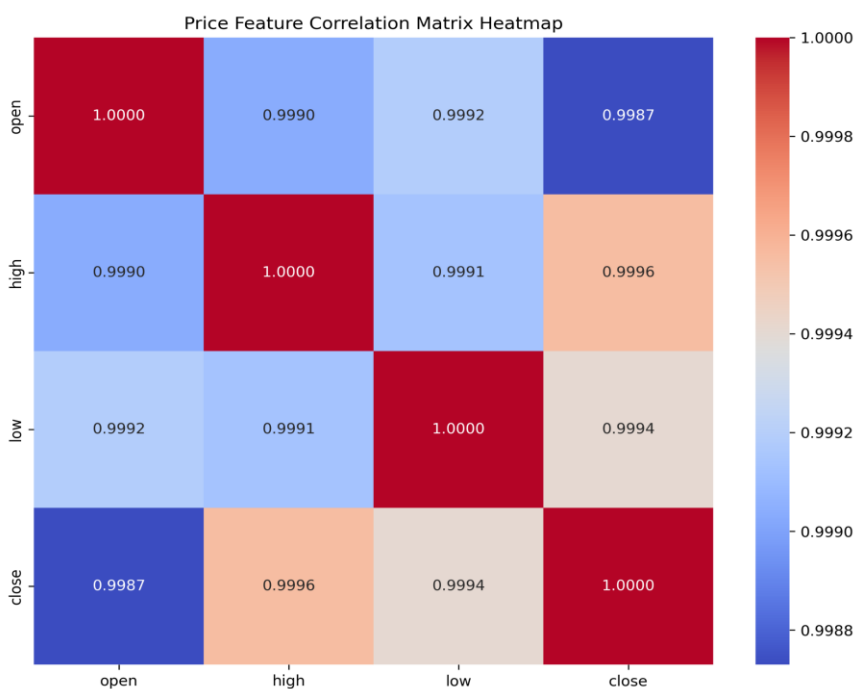
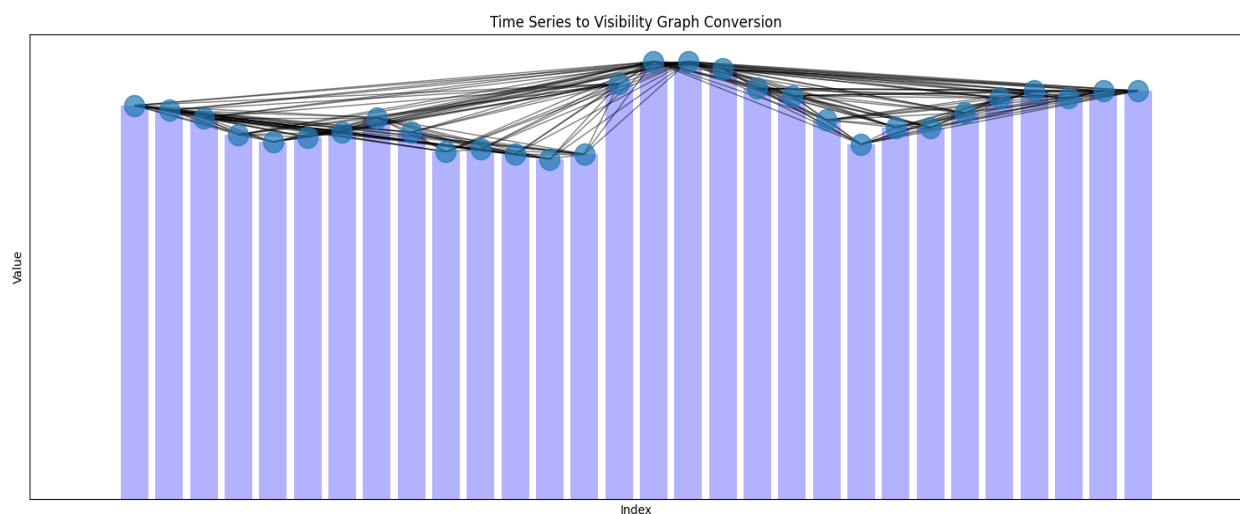


Figure 1: Correlation heatmap of Nabil bank

**Percentage Change Limitations:** While theoretically appealing for momentum strategies, percentage changes produced excessively dense graphs (average degree = 14.3) compared to raw prices (average degree = 5.1). This over connection led to severe over smoothing during GNN training, with node embeddings converging after just 2 layers (measured by cosine similarity  $> 0.95$ ).

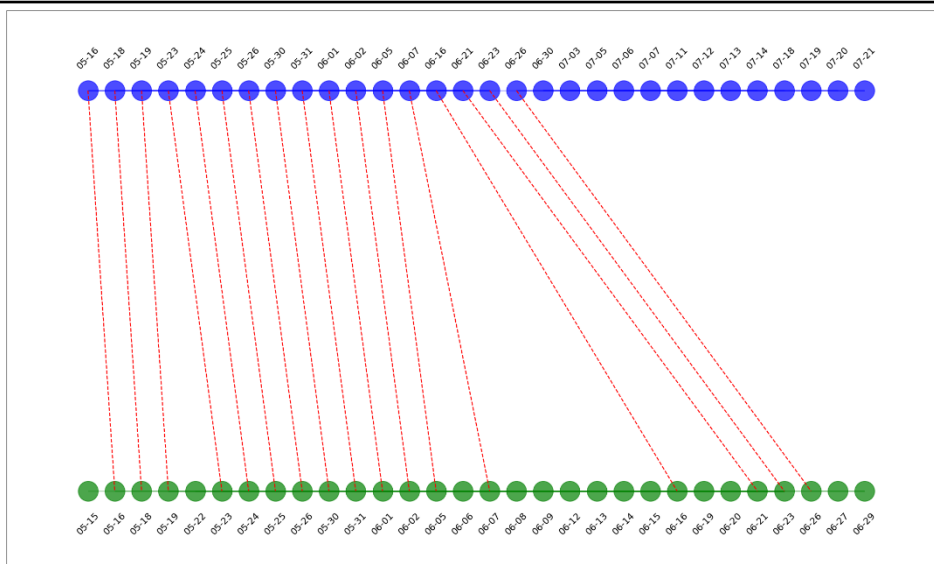
**Closing Price Justification:** We ultimately selected closing prices as they provide three key advantages: First, as the day's final auction result, they represent the most authoritative price benchmark. Second, their moderate autocorrelation produces graphs with ideal small-world properties. Third, direct alignment with our prediction target creates a coherent signal propagation path through the GNN architecture.

The 30-day window size was determined through sensitivity analysis, balancing memory requirements (15-day windows captured insufficient trends) and noise incorporation (45-day windows diluted recent patterns). As shown in Figure 2, this generates graphs that properly weight recent activity while maintaining historical context.



**Figure 2:** Graph visualization with bar chart

Sector graphs connect stocks within the same industry by linking their corresponding daily nodes. These inter-stock edges are created between nodes sharing identical trading dates, as shown in Figure 3. The process iterates through all stocks in a sector, forming complete daily connections across the entire group. This approach preserves individual stock patterns while capturing sector-wide relationships through synchronized temporal links. The resulting graphs maintain each stock's unique visibility graph structure while adding cross-equity connections that reflect shared market conditions.



**Figure 3:** Graph combining visualization

The connection strength between adjacent nodes is quantified through edge weights, which modulate information propagation in GNN architectures. We define the weight between nodes A and B as the absolute difference of their closing prices:  $w(A,B) = |A\_close - B\_close|$

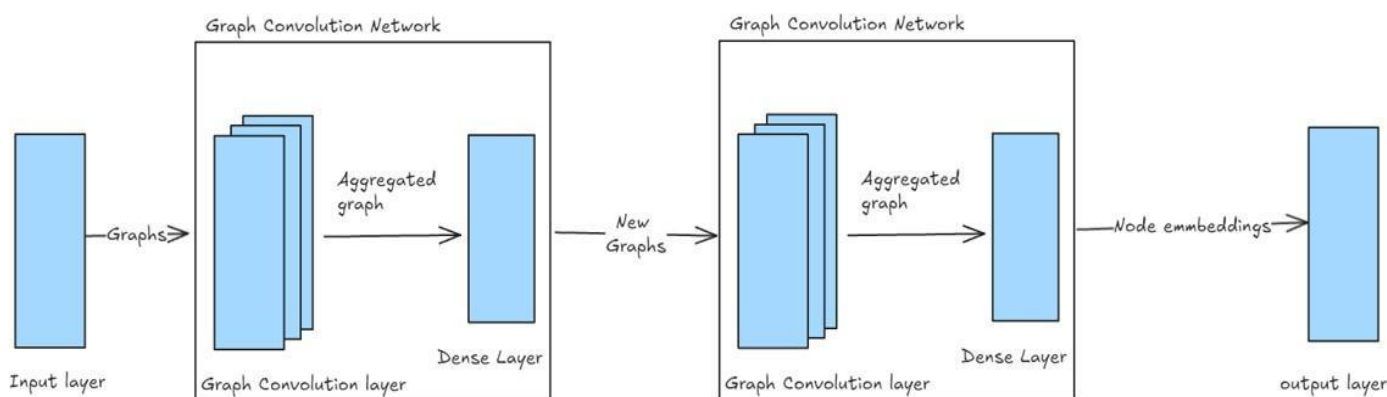
### Model Architecture

This study employs two graph neural network variants for stock market forecasting:

1. **Graph Convolutional Network (GCN)**
2. **Graph Attention Network (GAT)**

The subsequent sections detail each architecture's formulation and adaptation to financial time-series prediction.

### Graph Convolutional Network (GCN)



**Figure 4:** Graph Convolutional Network Architecture

A Graph Convolutional Network (GCN) shown in Figure 3; is a neural network architecture designed for semi-supervised learning on graph-structured data. In this context, a two-layer GCN is applied for

information pooling up to neighbors of a node's neighbors with a symmetric adjacency matrix A (binary or weighted). The model begins with the preprocessing step:

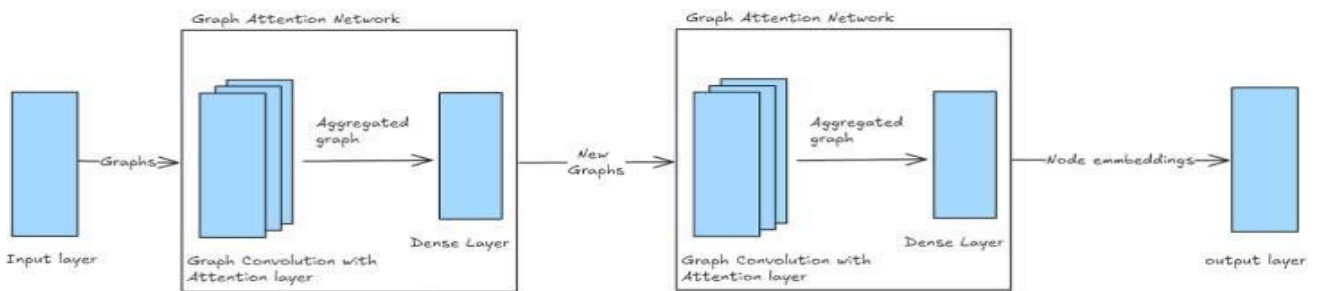
$$\hat{A} = \tilde{D}^{-\frac{1}{2}} \tilde{A} \tilde{D}^{-\frac{1}{2}}$$

The forward model then takes the simple form:

$$Z = f(X, A) = \text{softmax}\left(\hat{A} \text{ReLU}\left(\hat{A}XW^{(0)}\right)W^{(1)}\right).$$

In each graph convolution layer the information from neighbor nodes are aggregated and passed through a dense layer, applying learnable transformation to the combined feature vectors. The neural network weights (W) are trained using gradient descent. The updated graph representation from the first GCN block is passed into the second GCN layer, further aggregating the information from node's neighbor and the neighbor's neighbor.

### Graph Attention Network (GAT)



**Figure 5:** Graph Attention Network Architecture

A Graph Attention Network (GAT) shown in Figure 4; is a neural network architecture designed for processing graph-structured data by leveraging attention mechanisms to compute dynamic, node-specific representations by attending to features of neighboring nodes. This enables the model to focus on most relevant neighbors during feature aggregation. In graph creation, edge weights are computed as absolute difference between the values of connected nodes which is used as additional information to compute attention score. Each node computes attention coefficients ( $c_{ij}$ ) for its neighbors following feature transformation, parametrized by a weight matrix. and assigning attention coefficient:

$$e_{ij} = a(\mathbf{W}\vec{h}_i, \mathbf{W}\vec{h}_j)$$

$$\alpha_{ij} = \text{softmax}_j(e_{ij})$$

Once, the attention coefficients are computed, the features of neighboring nodes are aggregated using a weighted sum:

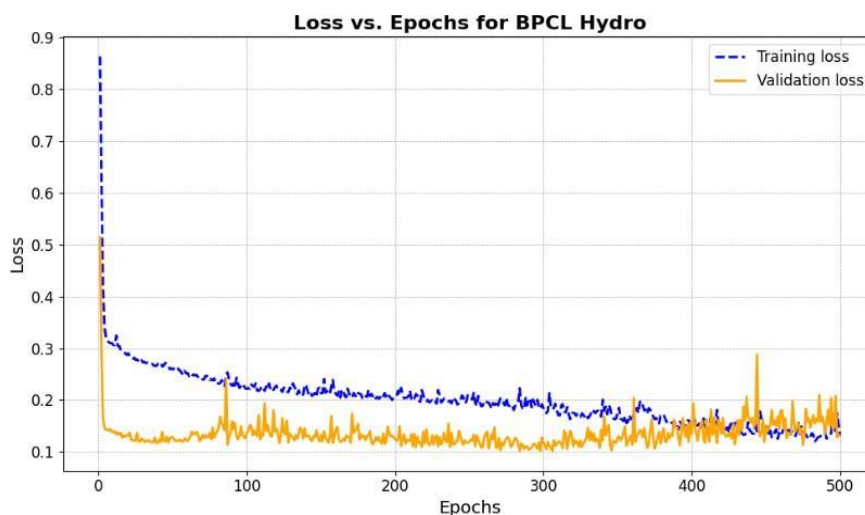
$$\vec{h}'_i = \sigma \left( \sum_{j \in \mathcal{N}_i} \alpha_{ij} \mathbf{W}\vec{h}_j \right).$$

## Result and Discussion

By utilizing two Graph Neural Network (GNN) architectures—Graph Convolutional Network (GCN) and Graph Attention Network (GAT)—we gained valuable insights into the effectiveness of graph-based models for financial time-series prediction. The key findings from our implementation are summarized below.

### 1. Stock-Wise Predictions

For stock-wise predictions, we employed visibility graphs to retain the time-series structure of each stock's features. Seven individual stocks were selected from each sector, and both GCN and GAT architectures were implemented to analyze their price trends. Figure 5 shows the loss curve for Butwal Power Company Limited (BPCL) Hydro.



*Figure 6: Stock-wise Prediction of NABIL Bank*

The results demonstrated that both models successfully captured the unique price patterns of independent stocks. This indicates that graph-based methods can effectively model individual stock dynamics by leveraging graph-structured time-series data. Figure 6 and 7 shows the stock-wise prediction of NABIL bank and ALICL bank respectively.



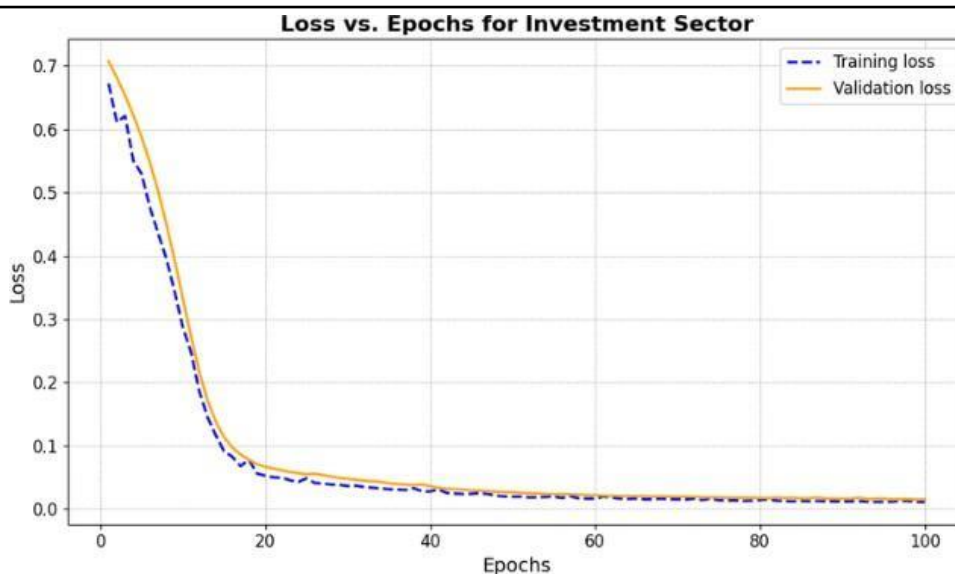
*Figure 7: Stock-wise Prediction of NABIL Bank*



*Figure 8: Stock-wise Prediction of Asian Life Insurance Company Limited*

## 2. Sector-Wise Predictions

For sector-wise predictions, multiple visibility graphs were constructed using stocks that shared the same date values within a sector. These visibility graphs were treated as intermediary subgraphs, which were then interconnected to form a larger sector-based graph structure. The Figure 8 shows the loss curve of model designed for investment sector.

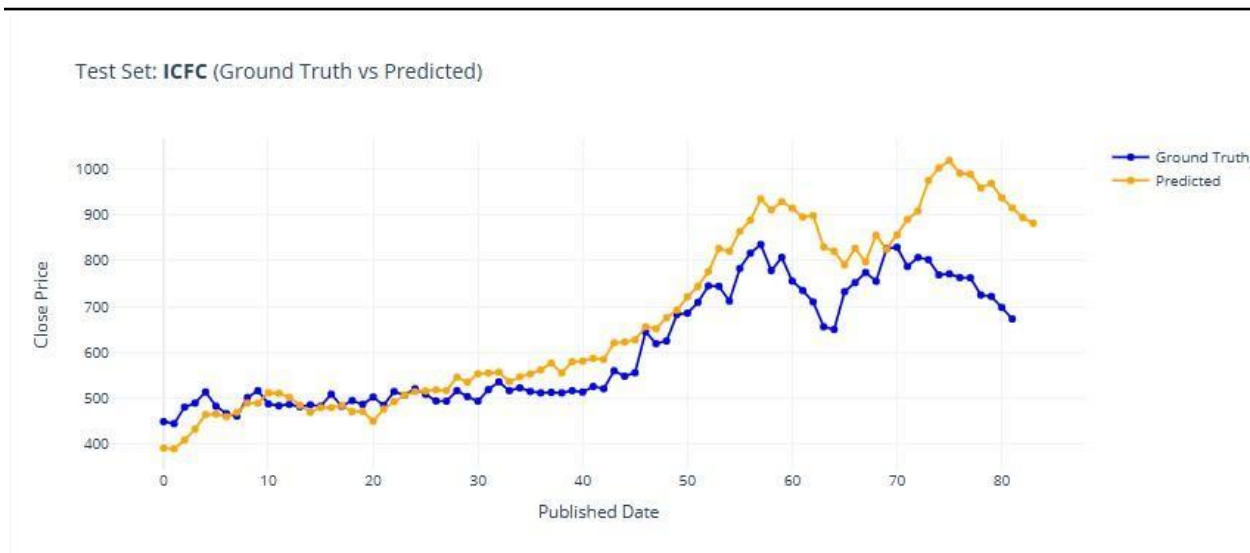


**Figure 9:** Loss vs epoch of model designed for investment

The models were applied across various sectors, including Finance, Commercial, Development, Hotel and Tourism, Hydro, Investment, Life Insurance, and Merged Share. During implementation, it was observed that GCN outperformed GAT in sector-wise modeling. As a result, sector-based predictions were carried out exclusively using the GCN architecture, reinforcing its superior ability to extract meaningful financial dependencies across multiple stocks in a sector. Figure 9 and 10 showing the finance sector-wise prediction for Guheswori Merchant Banking & Finance Limited and ICFC Finance respectively.



**Figure 10:** Sector-wise Prediction (Finance) on Guheswori Merchant Banking & Finance Limited (GMFIL)



**Figure 11:** Sector-wise Prediction (Finance) on ICFC Finance Limited (ICFC)

The results highlight the effectiveness of graph-based models in stock market analysis. The visibility graph approach successfully preserved the underlying temporal dependencies, while GCN proved to be more effective than GAT for sector-level forecasting. These findings suggest that graph-based financial modeling has significant potential for enhancing stock market prediction strategies.

## Conclusion

This project successfully demonstrated the potential of Graph Neural Networks (GNNs) for stock price forecasting in NEPSE. By transforming stock data into visibility graphs, we effectively captured temporal dependencies and relationships between stocks. The implementation of both GCN and GAT architectures enabled predictions at both individual stock and sector levels, highlighting the effectiveness of graph-based financial modeling. The sector-wise predictions further illustrated how stocks within the same sector influence each other, reinforcing the importance of inter-stock relationships in financial forecasting.

To further enhance the model's capabilities, several improvements can be considered. Implementing a Spatio-Temporal Graph Neural Network (STGNN) would allow the model to capture both spatial and temporal dependencies, improving forecasting accuracy. Additionally, extending the model to predict stock prices over a longer range of days would enhance its practical applications for long-term investment strategies. Finally, developing a model that can forecast the entire NEPSE index rather than individual stocks or sectors would provide a broader market outlook, benefiting investors and financial analysts. These advancements would further solidify the role of GNN-based models in stock market prediction, making them more robust and widely applicable in financial analysis.

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# Comparative Study Between NBC 105:2020 and IS 1893:2016 (Part 1) in torsionally irregular structure

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## Abstract

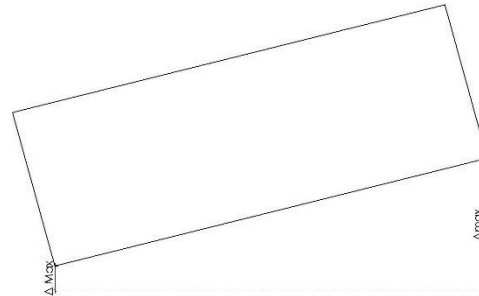
Nepal lies in seismically vulnerable zone. Nepal has been hit by major earthquakes since long time, among them earthquake of 1990, 2015 AD, Jajarkot earthquake are prominent and destructive earthquakes in Nepal. In these above listed earthquakes Nepal has suffered huge loss of property and life. To minimize the losses Nepal has developed and implemented its own code NBC 105:1993 till 2019. Since Nepal lie in Indian sub-continent and NBC 105:1993 did not get updated, hence Nepal has been using IS 1893:2002 and IS 1893:2016 widely. After the NBC 105 was updated in 2020 there were major changes in the code. The major changes seen in the code are 4 types of soil type was introduced, seismic zoning was done different than IS code. The serviceability criteria are also introduced in the code. So, this article studies about comparative study between the codes in different soil types in torsionally irregular structure. The value of base shear is less by 40.57 %, 18.52% and 43.32% from IS code with respect to NBC Code in hard soil, medium soil and soft soil respectively. The value of storey drift in X direction is less than 38.95%, 14.63% and 40.60 % from IS code with respect to NBC Code in hard soil, medium soil and soft soil respectively. The value of storey drift in Y direction is less than 40.92%, 16.64% and 42.01 % from IS code with respect to NBC Code in hard soil, medium soil and soft soil respectively. Hence due to adaptation of latest seismic index result in higher lateral forces in the torsionally irregular structures in NBC 105:2020.

**Keywords:** *Lateral loads, Torsional Irregularity, Response spectrum*

## Introduction

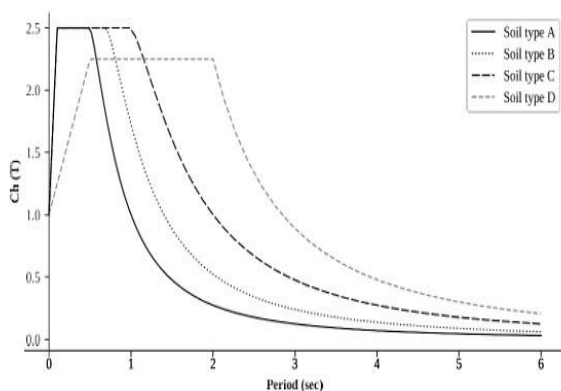
A lateral load has been most prominent loads in the structure while designing. Since earthquake forces results in failure of structures and result in loss of life and property designing of earthquake resistant structures is necessary. To design such structures use of codes is very important. Since Nepal lies in earthquake prone zone, between two giant tectonic plate, Indo Australian plate and Asian Plate Nepal have faced various major and minor earthquakes. To estimate the lateral forces use of codes in accurate way is must. So, India being our nearest neighbor we have been using IS and NBC code for estimation of lateral force. The building having irregularity in mass, geometry, load distribution etc. result in torsion. Torsionally irregularity is present when maximum horizontal displacement to minimum displacement in extreme edges due to lateral force is greater than 1.5 in the direction of lateral force.

Numerically it can be written as  $D_{\max}/D_{\min} > 1.5$  in such case we can tell as torsionally irregular, where  $D_{\max}$  is maximum displacement in plan at extreme edge and  $D_{\min}$  is minimum displacement in plan at extreme edge.

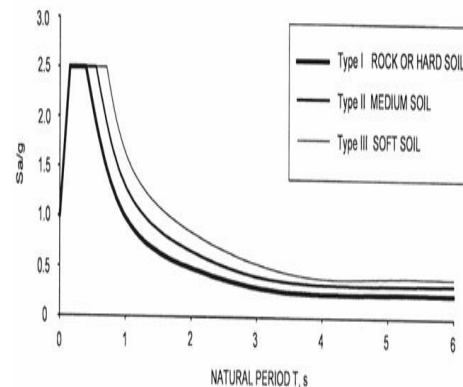


**Figure 1:** Torsionally Irregularity

Response spectrum method is a linear dynamic analysis method used to determine peak response of structure during a seismic event. The plot of displacement, velocity and acceleration is studied during a seismic event. From these curves are plotted and used for analysis of structures. Since it represents the peak value, it is conservative method of analysis. NBC 105:2020 has proposed four types of soil type whereas IS 1893:2016 part 1 has proposed three types of soil type. Response spectrum method has been used for studying.



**Figure 2:** Response Spectrum Curve as per IS NBC



**Figure 3:** Response Spectrum Curve as per IS NBC

Seismic codes are general guidelines for designing the structures such that we can minimize the loss. The IS code and NBC 105:2020 has different seismic parameters that result in variation of earthquake force. There is wide variation of base shear, storey drift etc. when compared.

### Overview between the two Codes

Nepal Building code NBC 105: 2020 Seismic Design of building in Nepal is a revision of the earlier version of NBC 105:1994. The code is based on probabilistic approach. The code has basically two objectives, damage limitation objective and life safety objectives based in earthquake ground motion with a return period of 20 years and 475 years. The code is applicable for low rise to tall structures made of concrete and steel structures. The analysis for ultimate and serviceability limit has been adopted in this code.

IS 1893:2016 (Part 1) is a revision of the earlier version IS 1893:2002 published by Bureau of Indian Standard based on deterministic approach. Part 1 deals about the earthquake resistant design of buildings applicable for all the types of buildings.

**Table 1: Difference between IS and NBC Code**

S.N.	Parameters	IS 1893:2016	NBC 105:2020
1	Time Period ( $T_a$ )	$T = 0.075 h^{0.75}$ (Bare MRF building without Infill Walls) $T = 0.09 * h / \sqrt{d}$ (for All type of Building) Where h is height of Building in m d is base dimension in m	$T = K_t * H^{3/4}$ Where $K = 0.075$ for MRF concrete frame. Where, H= Height of the building from foundation/rigid basement.
2	Percent in imposed Load	$LL \leq 3.0$ - use 25% $LL \geq 3.0$ - use 50%	Storage Purpose -60% other Purpose- 30% Roof - Nil
3	Importance Factor (I)	Other Building= 1.0 Residential, Commercial= 1.2 School, Hospital=1.5	Ordinary Building= 1.0 School, Cinema, colleges, malls=1.25 Hospital=1.5
4.	Storey Drift	0.004 times Storey height	For ULS-0.025* Storey height For SLS- 0.006* Storey Height
5.	Base Shear coefficient	$A_h$ $A_h =$ Design horizontal Acceleration coefficient	ULS, $C_d(T1) = C(T1) / (R_\mu * \Omega_\mu)$ SLS, $C_d(T1) = C_s(T1) / \Omega_s$ $R_\mu =$ Ductility Factor $\Omega_s, \Omega_u =$ over strength Factor $C(T1) =$ Elastic Site Spectra for ULS $C_s(T1) =$ Elastic Site Spectra for SLS
6.	Design lateral Force	$V_B = A_h * W$	$V = C_d(T1) * W$
7	Load Combination	1.5 (DL+LL) 1.2(DL+LL±EQX±0.3EQY) 1.5(DL±EQX±0.3EQY) 0.9(DL)±1.5(EQX±0.3EQY) 1.2(DL+LL±EQY±0.3EQX) 1.5(DL±EQY±0.3EQX)	1.2DL+1.5LL DL+1LL±(EQX±0.3EQY) DL+1LL±(EQY±0.3EQX) Where, l = 0.6 for storage facilities = 0.3 for other usages

		0.9(DL) $\pm$ 1.5(EQY $\pm$ 0.3EQX)	
8	Seismic Zone Factors	Seismic zone is divided in to 4zone.	different seismic zone interpolated for different regions.

## Literature Review

**Shrestha R et. al. (2024)** studied RCC model having G+8 Storied building with regular configuration using static and dynamic method in ETABS in medium soil type. The base shear by NBC 105:2020 is greater by 35% than the IS 1893:2016. Also, area of reinforcement, storey drift and displacement obtained using NBC 105:2020 is greater than that of IS 1893:2016. Also, researcher found that NBC 105:2020 is more conservative and leads to uneconomical structure rather than that of IS code.

**Adhikari Basanta et al., (2023)** analysed 2 and 3 storey building using equivalent static method using IS and NBC code. The reinforcement needed in building using NBC is greater 22.59% and 16.26 % than IS code in columns in 2 storey and 3 storey building. For beam NBC requires less 7.24% and 0.65% less compared to IS code for 2 storey and 3 storey respectively. Also, the total reinforcement needed by NBC code is 3.60% and 6.38% higher compared to IS code in 2 storey and 3 storey respectively.

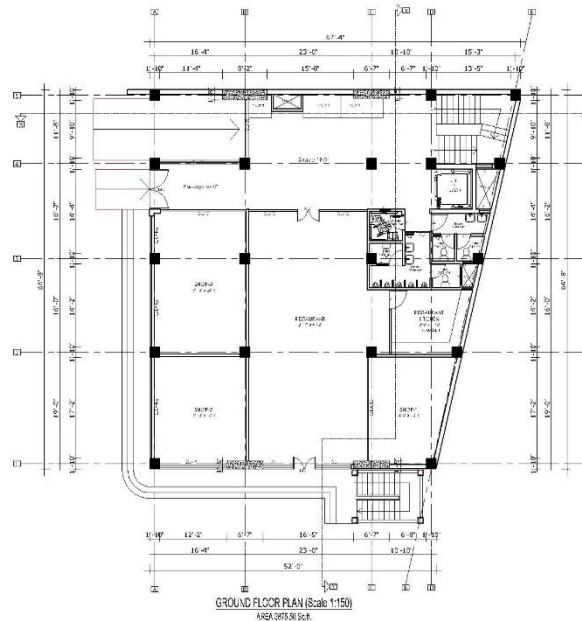
**Shrestha Jagat K et al., (2021)** studied for assessment of impact of the linear and nonlinear static and linear dynamic analysis in two and four storey building using IS and NBC code. After the analysis base shear of the building is greater by 60% in NBC 105:2020 compared to NBC 105:1994.

**Banjara Rajesh et al., (2021)** analysed low rise RC building of three storey and staircase cover. The base shear value is greater by 104%, 116% and 157% by ultimate limit state (ULS) NBC 105:2020 to serviceability limit state (SLS) NBC 105:2020, IS 1893:2016 and NBC 105:1994. Also, storey drift is higher by 4%, 4% and 150% by ultimate limit state (ULS) NBC 105:2020 to serviceability limit state (SLS) NBC 105:2020, IS 1893:2016 and NBC 105:1994.

**Pandit Prateek Raj et al., (2019)** studied about the base shear, displacement and reinforcement demand in G+21 Storey building using NBC 105:1994 and IS 1893:2016 code. According to Seismic coefficient method base shear by IS code in soil type I is 32.2% greater, 43.32 % greater in soil type II and 11.64% less in soil type III than that of NBC respectively. According to Seismic coefficient method inter storey drift ratio by IS code in soil type I is 29.95 % greater, 40.91 % greater in soil type II and 13.19% less in soil type III than that of NBC respectively. According to Seismic coefficient method total reinforcement by IS code in soil type I is 34.57 % greater, 46.48 % greater in soil type II and 19.16% more in soil type III than that of NBC respectively.

## Materials and Methods

The building taken for study is basement+ four storey with staircase cover is taken into consideration for study. The building has built up area of 3875.50 Sq. Ft. In our analysis we have considered bare frame model. All the outer wall adopted is 230mm. The building is torsionally irregular due to geometry.



**Figure 4:** Typical Floor Plan

**Table 2:** Input Parameters

S.N.	Materials	Property Value
1	Characteristics strength of concrete ( $F_{ck}$ )	M25
2	Yield strength of rebar ( $F_y$ )	500 MPa
3	Unit weight of RCC	25 KN/m <sup>3</sup>
4	Unit weight of Brick Masonary	20 KN/m <sup>3</sup>

**Table 3:** Section Properties

S.N.	Section	Size
1	Floor Beam	375mm*600mm
2	Secondary Beam	230mm*350mm
3	Column Size	550mm*550 mm
4	Shear wall 1	2000mm*425mm
5	Shear wall 2	2500*500mm
6	Partition wall	115mm thick
7	Outer wall	230mm thick

## Results

### A. Base Shear

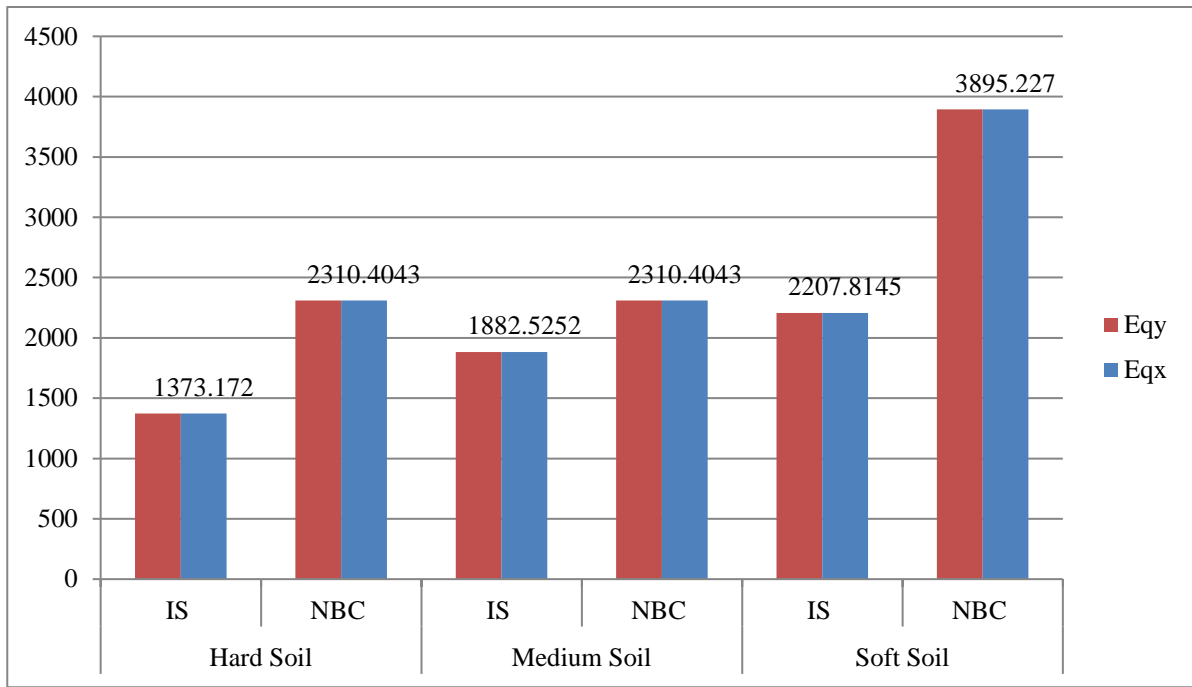


Figure 5: Base shear values in different soil types

While analyzing the base shear by using both codes we can see that base shear from IS code is lesser than from NBC in all three soil types. It is observed that base shear from IS code is lesser by 40.57% as compared to NBC code in hard soil type, 18.52% lesser as compared to NBC code in medium soil type, lesser by 43.32% as compared to NBC code in soft soil type. Also, there is great deviation between base shear values in soft soil.

Based on the design base shear, NBC code has higher values due to design horizontal acceleration coefficient since NBC uses higher coefficient values. The reason behind the above result is the zone factor as per IS code is 0.36 but NBC has 0.4. Response Reduction factor as per IS code is 5 however for NBC code it is 4 times over strength factor, resulting in higher design horizontal acceleration coefficient.

**B. Storey Drift**

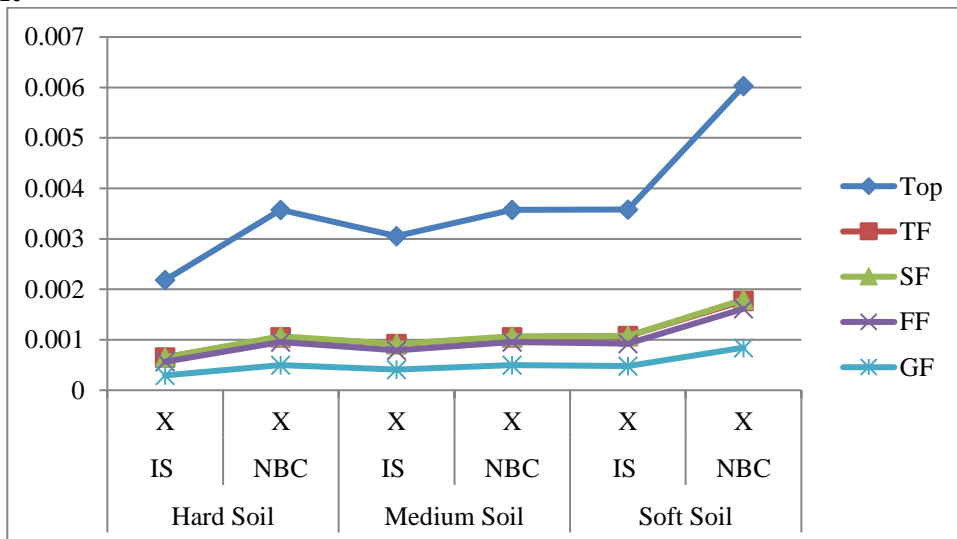
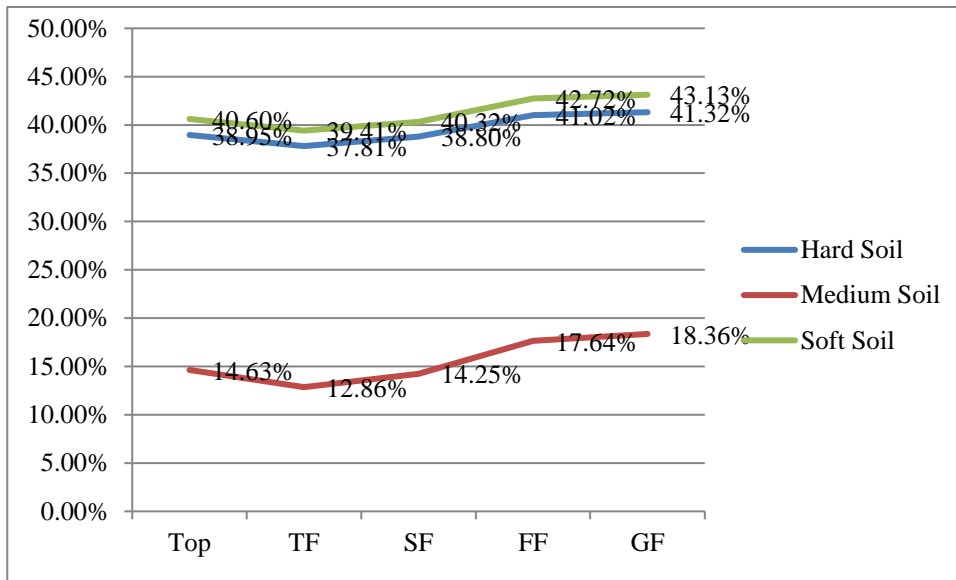
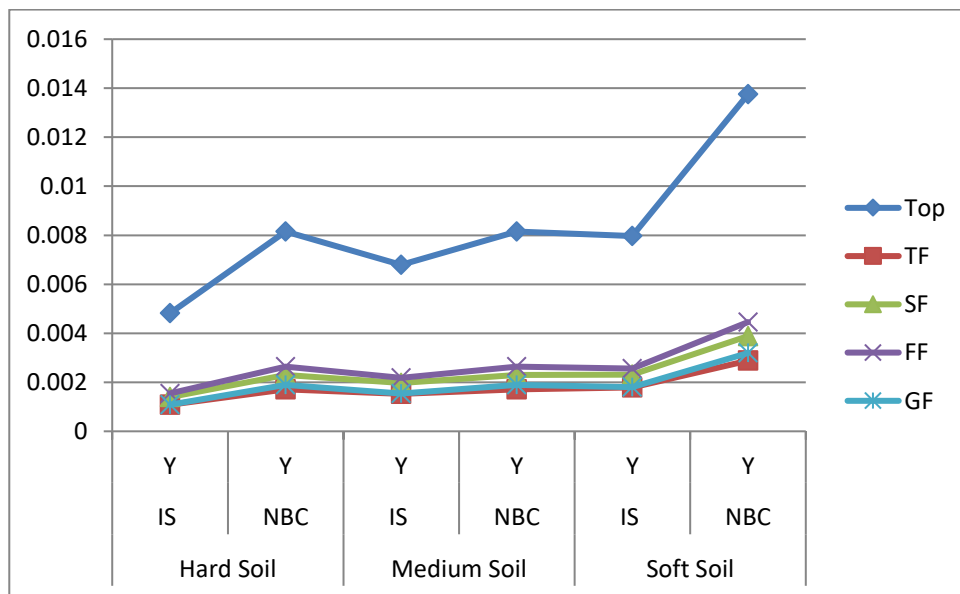


Figure 6: Storey Drift in X Direction in different soil type

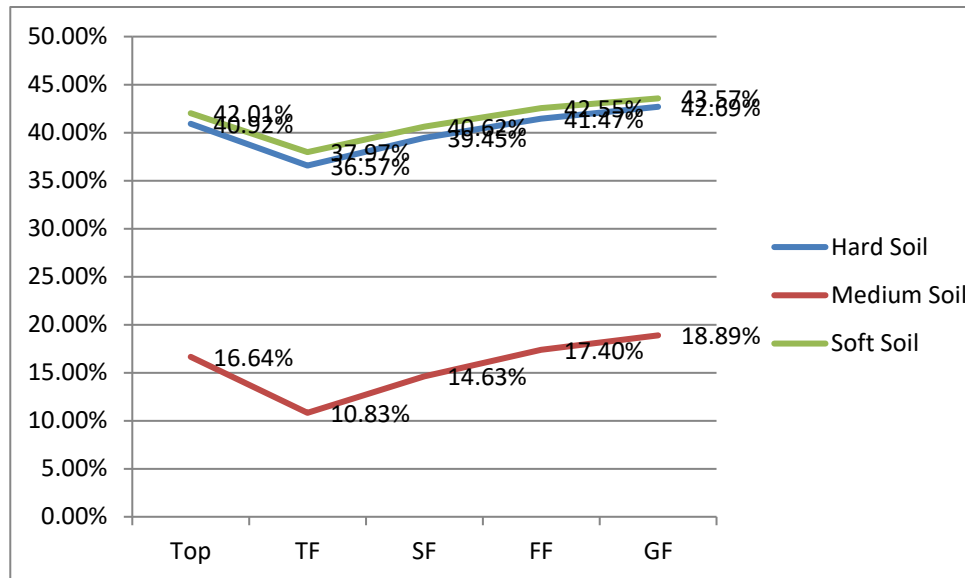


**Figure 7:** Comparison of storey drift between IS to NBC code to X Direction in different soil types

From above diagram it is observed that drift ratio in X direction is greater in NBC code as compared to IS code. Maximum drift ratio/displacement is seen in Top floor due to mass irregularity. The storey drift ratio is less than 38.95% ,14.63% and 40.60% respectively in hard, medium, soft soil from IS code with respect to NBC Code in X direction. The least deviation in storey drift is seen in medium soil and maximum deviation of storey drift is seen in soft soil.



**Figure 8:** Storey Drift in Y Direction in different soil types



**Figure 9:** Comparison of storey drift between IS to NBC code to Y Direction in different soil types

From above diagram it is observed that drift ratio in Y direction is greater in NBC code as compared to IS code. Maximum drift ratio/displacement is seen in Top floor due to mass irregularity. The storey drift ratio is less than 40.92% ,16.64% and 42.04% respectively in hard, medium, soft soil from IS code with respect to NBC Code in Y direction. The least deviation in storey drift is seen in medium soil and maximum deviation of storey drift is seen in soft soil.

From above result it is observed that Storey drift from NBC code is higher than that IS code. The higher lateral force results in higher displacement and similar for storey drift.

## Conclusion

Based on the analysis of torsionally irregular building using IS and NBC code base shear is less by 40.57% as compared to NBC code in hard soil type, 18.52% lesser as compared to NBC code in medium soil type, lesser by 43.32% as compared to NBC code in soft soil type. The storey drift ratio is less than 40.60% in IS code to NBC code in X direction in soft soil, 38.95% in hard soil and 14.63% in medium soil. The storey drift ratio is less than 42.01% in IS code to NBC code in Y direction in soft soil, 40.92% in hard soil and 16.64% in medium soil.

NBC code has higher values due to design horizontal acceleration coefficient since NBC uses higher coefficient values. The reason behind the above result is the zone factor as per IS code is 0.36 but NBC has 0.4. Response Reduction factor as per IS code is 5 however for NBC code it is 4 times over strength factor, resulting in higher design horizontal acceleration coefficient. Similarly for Storey drift from NBC code is higher than that IS code. The higher lateral force results in higher displacement and similar for storey drift.

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# Compartmental Epidemiological Models and Their Associated Incidence Rate

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## Abstract

Compartmental models in epidemiology are used to construct mathematical models reflecting the dynamic properties of infectious diseases, analyze the dynamic behavior of the model so formed, and perform some simulations. The research results help to predict the growth of infectious diseases, determine the key factors of their spread, and seek the optimum strategies for preventing and controlling their spread. This paper focuses on different compartmental models used in epidemiology. Different disease transmission rates applied to these models are mentioned. Different incident rates bilinear ( $\beta SI$ ), saturated ( $\frac{\beta SI}{1+\alpha I}$ ), nonlinear ( $\beta SI^p$ ), and standard Incidence ( $\frac{\beta SI}{N}$ ) have been comparatively studied

**Keywords:** Compartmental model, transmission rate, nonlinear incidence.

## Introduction

### Historical Background

Epidemic dynamics is an important method of studying the spread of infectious diseases. It is based on the specific property of population growth, the spread rule of infectious disease, and the related social factors, etc. Communicable diseases have been a great challenge to humankind since the beginning of human history. At present, we still have a deal with infectious diseases like measles, AIDS, Plague, Malaria, T.B., Dengue, SARI, and COVID-19. Millions of people die annually from these diseases, and billions of others are infected. These diseases will soon be eliminated with the improvement in medical science care and the awareness process. Communicable diseases caused by various microbes, pathogens or microorganisms have been a threat to public health (Martcheva, 2015). They are caused by pathogens and can be easily transmitted from one infected person to another non-infected person. The most common examples are influenza or flu, measles, rubella, HIV, mumps, malaria, and smallpox (Brauer et al., 2012; Waltman, 2013). The emergence and reemergence of infectious diseases have become a significant worldwide problem. So, a Proper understanding of disease transmission dynamics caused by existing and new pathogens facilitates devising prevention tools (Foppa, 2016; Dym, 2004). Prevention tools against the transmission of disease need to be developed. The implementation and proper use of these sophisticated tools against microbes is another challenge. This article addresses some theoretical frameworks and intends to provide some basic information about the infection mechanisms of microbes,

their orientation, control mechanisms and the role of mathematical models in epidemiology (Murray, 2001; Banerjee, 2021).

Most infectious disease dynamic models are based on the compartment structure of the disease. First provided by Kermack and McKendrick in 1927, the compartment structures for dynamic models were developed by numerous other bio-mathematicians in 1932 onwards. Those who recover from viral diseases such as influenza, measles, swine flu, and chikungunya develop immunity to the same virus. The SIR model can be used to describe these illnesses. Furthermore, those who recover from bacterial illnesses such as gonorrhoea, the bubonic plague, tuberculosis, syphilis, etc., do not develop immunity and are susceptible to re-infection. The SIS model can be used to investigate the dynamics of these illnesses.

The main objective of this paper is to overview of compartmental epidemiological models that incorporate different forms of incidence rates.

### **Importance of Compartmental Models in Epidemiology**

Compartmental models are fundamental in epidemiology because they provide a simplified yet powerful framework for understanding how diseases spread in populations. Their importance lies in the following key aspects:

- 1) Simplification of the complex system: Compartmental models divide a population into groups (compartments) based on disease status, such as susceptible (S), infected (I), recovered (R). This abstraction allows researchers to study the dynamics of disease transmission without needing to track every individual.
- 2) Predicting disease spread: These models help forecast future outbreaks, estimate the peak of infections, and predict how long an epidemic might last by modelling transitions between compartments using differential equations.
- 3) Evaluating control strategies: Compartmental models are crucial for simulating interventions such as vaccination programs, quarantine and isolation, social distancing, treatment or antiviral use. They help to determine the effectiveness and optimal timing of these interventions.
- 4) Estimating epidemiological parameters: They enable estimation of key parameters like basic reproduction number, infection and recovery rates, and herd immunity thresholds. These estimates inform public health decisions.
- 5) Flexibility and extendibility: Models can be adapted to include: Age structure, spatial effects, latent periods (e.g., SEIR models), behavior change, reinfection or waning immunity.
- 6) Guiding policy and public health decisions: Governments and health agencies use compartmental models for Planning resource allocation (e.g., hospital beds, vaccines), implementing timely interventions and communicating risks to the public.

### ***Fundamental Forms of Compartmental Models***

Compartmental models are mathematical frameworks used in epidemiology to describe the spread of infectious diseases within a population. These models divide the population into different compartments like susceptible ( $S$ ), exposed ( $E$ ), infected ( $I$ ), recovered ( $R$ ) and immune ( $M$  or  $P$  or  $Y$ ) based on disease status and describe transitions between these compartments using differential equations. Parameters  $\beta$  and  $\gamma$  are used to represent transmission rate and recovery rates. These compartmental models predict outbreaks, evaluate control measures (e.g., vaccination, quarantine), and estimate the basic reproduction number ( $R_0$ ). Age-structured models (Consider different transmission rates based on age groups), spatial models (incorporate geographic spread), and stochastic models (include random variations to capture uncertainty in disease spread) are some extended forms of these models.

#### **Models Without Latent Periods**

In these models, the infected individuals become infectious immediately (Martcheva, 2015). These models are as follows:

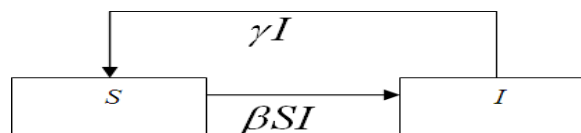
- 1. SI Model:** In this model, the infectives cannot recover from the infection. It is represented in Diagram 2. The model equations are:



**Figure 2:** *SI model*

$$\frac{dS}{dt} = -\beta SI, \text{ and } \frac{dI}{dt} = \beta SI$$

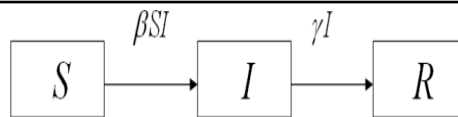
- 2. SIS Model:** In this model, the infected individuals are recovered but gain no immunity from infection. It is a represented diagram. 3. The model equations are:



**Figure 3:** *SIS model*

$$\frac{dS}{dt} = -\beta SI + \gamma I, \text{ and } \frac{dI}{dt} = \beta SI - \gamma I.$$

- 3. SIR Model:** In this model, the infectives obtain permanent immunity to the disease after recovering from infection. It is represented by diagram 4.



**Figure 4: SIR model**

$$\frac{dS}{dt} = -\beta SI,$$

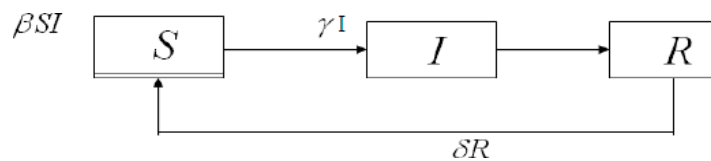
$$\frac{dI}{dt} = \beta SI - \gamma I$$

$$= BI(S - \rho) \text{ where } \rho = \frac{\gamma}{\beta}$$

$$\frac{dR}{dt} = \gamma I$$

**4. SIRS Model:** In this model, the recovered individuals may have only temporary immunity after they recover from infection. Diagram 5 represents this model.

The model equations are:



**Figure 5: SIRS model**

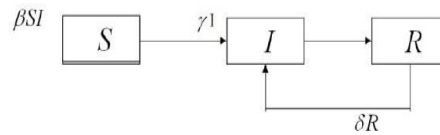
$$\frac{dS}{dt} = -\beta SI + \delta R,$$

$$\frac{dI}{dt} = \beta SI - \gamma I$$

$$\beta I(S - \rho), \text{ where } \rho = \frac{\gamma}{\beta}$$

$$\frac{dR}{dt} = \gamma I - \delta R.$$

**5. SIRI Model:** In this model, the infective individuals cannot obtain permanent immunity to the disease when they recover from infection. Diagram 6 represents in model: The model

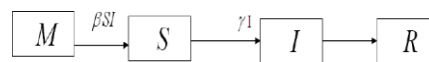


**Figure 6: SIRI model**

equations are:

$$\frac{dS}{dt} = -\beta SI, \frac{dI}{dt} = \beta SI - \gamma I + \delta R = \beta I(S - \rho) + \delta R, \text{ where } \rho = \frac{\gamma}{\beta}, \text{ and } \frac{dR}{dt} = \gamma I - \delta R.$$

- 6. MSIR Model:** Babies are not born into the susceptible compartment for many illnesses, such as measles, but are instead immune to the illness for the first several months of their lives because of maternal antibodies (either through the placenta or through colostrum). This can be shown by including an M class (for maternally derived immunity) at the beginning of the model. It is represented by diagram 7.

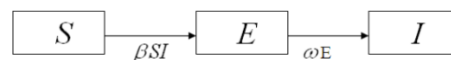


**Figure 7: MSIR model**

### Models with Latent Periods

There is often a considerable period during which the affected person is infected but not yet contagious for many serious infections. In the course of this latent time, the person is in the exposed compartment (E) ( Martcheva, 2015). The following are these models:

- 1. SEI Model:** This model is represented by Diagram 8



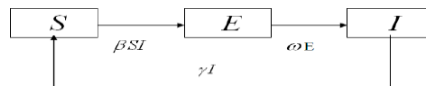
**Figure 8: SEI model**

- 2. SEIR Model:** In this model, the population is broken into four compartments: susceptible, exposed, infectious and recovered. This model is represented by Diagram 9.



**Figure 9: SEIR model**

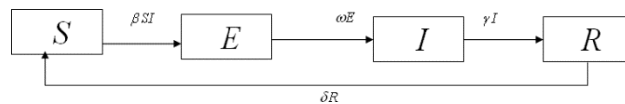
- 3. SEIS Model:** In this model, the population is broken into four compartments: susceptible, exposed, and infectious again susceptible. Diagram 10 represents this model.



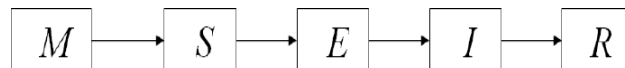
**Figure 10: SEIS model**

4. **SEIRS Model:** The population is divided into five compartments in this model: susceptible, exposed, infectious, recovered, and susceptible again. The representation of this model is Diagram 11
5. **MSEIR Model:** The MSEIR model is used for epidemiological classes in cases of disease where the factors of latency period and passive immunity are present. Diagram 12 serves as a representation of this model.

where M is births and passive immunity.



**Figure 11: SEIRS model**



**Figure 12: MSEIR model**

### Different Disease Transmission Rates

Infectious diseases can be transmitted by direct contact. The contact rate of infection, represented by  $P(N)$ , is the number of people contacted by an infectious per unit of time. Depending on the population as a whole,  $N$ . The persons may become infected if they come into contact with an infectious susceptible. Assume that there is a  $\beta_0$  probability of infection for every contact. Subsequently, the function  $\beta_0 N$  is referred to as an adequate contact rate, denoting the degree of infection caused by the infectious agents and typically reliant on the bacterial or viral toxicity and environmental conditions.

The average rate at which susceptible individuals come into contact with infected persons per unit of time is known as the contact rate, and it is commonly represented by the symbol  $\beta$ .

$$\beta = \text{contact rate} \times \beta_0.$$

For example, if an average individual has 10 contacts per day and the probability of disease transmission per contact is 0.2 (20%), then  $\beta = 10 \text{ contacts/day} \times 0.2 \text{ transmission/contact} = 2$

This means that each susceptible individual is effectively exposed to the infection at a rate of 2 contacts per day.

To determine the unit of  $\beta$ , we need to consider the units of its components: the average number of contacts per susceptible individual per unit of time and the probability of disease transmission per contact. The unit of  $\beta$  will be a combination of these units. An average number of contacts per susceptible individual per unit time has units of “contacts” per “unit time” (e.g., contacts per day, contacts per week), and the probability of disease transmission per contact is a dimensionless quantity, as it represents a probability or a ratio. To obtain the unit of  $\beta$ , we multiply the units of the average number of contacts per susceptible individual per unit of time by the dimensionless unit of the probability of disease transmission per contact.

### **Force of Infection**

The force of infection (often denoted by  $\lambda$ ) is a crucial concept in the mathematical modelling of infectious diseases. It quantifies the rate at which susceptible individuals become infected. Essentially, it measures the risk of infection for a susceptible person per unit of time, based on the current epidemiological conditions.

It represents the rate at which susceptible individuals become infected per unit of time. It can be approximated as: The force of infection =  $\frac{\text{Total Infected individuals}}{n \times T}$  where T is period (1 year = 365 days).

The effective daily transmission rate ( $\beta$ ) in the population is given by

$$\beta = \frac{\text{force of infection}}{\frac{S}{N}}$$

Assuming the initial number of susceptible individuals S is approximately the total population N, ( $S(t) \rightarrow N$ ), especially at the beginning of the outbreak:

### **Bilinear incidence**

If the contact rate is proportional to the total population size, i.e.  $P(N) = kN$ , then the incidence  $\beta IS$ , where  $\beta = \beta_0 k$ , is called the transmission coefficient. This type of incidence is called a bilinear incidence or a simple mass action incidence. The transmission rate  $\beta$  is often assumed to be proportional to the product of the susceptible and infectious populations. It is called “bilinear” because it is a product of two linear terms: S and I. Bilinear incidence models are used in epidemiology to study the dynamics of various infectious diseases, including influenza, HIV/AIDS, and sexually transmitted infections. Most of the standard epidemiological models used a bilinear incidence rate. In this incidence rate, it is assumed that the population is homogeneously mixed and is normally used for airborne diseases. However, in case of a large number of susceptible or population is not homogeneously mixed (i.e. heterogeneous mixing), it is not realistic to consider the bilinear incidence rate due to the number of susceptible with which every

infective contact is limited within a definite time. It allows researchers to explore how changes in the size of the susceptible and infectious populations affect the spread of the disease over time and to evaluate the potential impact of interventions such as vaccination or behavior change campaigns.

### Standard Incidence

If the contact rate is constant, i.e.  $P(N) = k$ , then the incidence  $\beta \frac{SI}{N}$ , where  $\beta = \beta_0 k$  is called the standard incidence. If S, I, and N are several susceptible, infectious, and total populations at time t, respectively, then  $\frac{S}{N}$  and  $\frac{I}{N}$  represent the susceptible and infectious fractions, respectively.

If  $\beta$  is the average number of adequate contacts of a single susceptible with other members of the population per unit time, then  $\frac{\beta I}{N}$  is the average number of contacts with infectives per unit time of a single susceptible and  $\beta \frac{I}{N} S$ , that is,  $\frac{\beta IS}{N}$  is the number of new cases per unit of time due to the S susceptible. Thus,  $\frac{\beta IS}{N}$  is the rate at which the susceptible population becomes infected. This form of horizontal incidence is called the standard incidence (proportionate mixing incidence) because it is formulated from the basic principles. The standard incidence rate adjusts the bilinear form by normalizing it for the total population N (usually the sum of susceptible, infected, and recovered individuals). This Incidence rate  $\beta S \frac{I}{N}$  is useful in models where the population size is large and possibly variable.

### Saturated Incidence Rate

Saturated incidence rates are used in epidemic models when the transmission rate of the disease does not increase indefinitely with the number of infected individuals but instead levels off or saturates as infection levels rise. This can reflect real-world constraints such as limitations on the number of effective contacts due to behavioral changes, healthcare capacity, or other social factors. Saturated incidence rates are often represented using Michaelis-Menten kinetics, also known as the Holling type II functional response in ecological models. They are used to model scenarios where the incidence rate plateaus as the number of infected individuals becomes large, preventing the unrealistic assumption of unlimited growth in infection rate. The most commonly used saturated incidence rates are  $\frac{\beta SI}{1+\alpha S}$  and  $\frac{\beta SI}{1+\alpha I}$ .

### Nonlinear Incidence Rate

Nonlinear incidence rates in epidemiological models like the SIR and SIS models extend beyond the simple bilinear form and capture more complex interactions in disease transmission. These nonlinear rates can better represent various real-world scenarios where the rate of new infections does not increase proportionally with the number of susceptible and infected individuals. Liu et al. (1986, 1987) introduced

a non-linear incidence rate of the form  $\beta I^p S^q$ , which shows a much wider range of dynamic behaviors than do those with a bilinear incidence rate  $\beta IS$ . These behaviours are determined mainly by  $p$  and  $\beta$ , and secondly by  $q$ . For these models, there may exist multiple equilibria in the feasible region, and thus the model becomes more general and informative. For more application of this incidence rate, one can refer to (Dubey et al., 2015; Grigorieva et al., 2016; Wang et al., 2021). Different types of nonlinear incidence rates commonly used in SIR and SIS models are  $\frac{\beta SI}{1+\alpha I}$ ,  $\frac{\beta SI}{1+\alpha S}$ ,  $\frac{\beta SI}{1+\alpha S+\gamma I}$ ,  $\frac{\beta SI}{1+\alpha(S+I)}$ .

Nonlinear incidence rates in SIR and SIS models provide a richer framework for modelling disease dynamics by incorporating more realistic factors such as saturation effects, population interactions, and behavioral responses. They allow for more accurate predictions and better insights into the spread and control of infectious diseases compared to simple bilinear models.

### Non-monotonic Incidence Rate

A non-monotonic incidence rate in epidemiological models like the SIR or SIS models captures the complex dynamics where the rate of new infections does not simply increase or decrease with the number of susceptible or infected individuals but can also exhibit peaks and troughs. This can model phenomena where the infection rate might increase up to a certain point and then decrease, reflecting various real-world scenarios such as behavioral changes, resource limitations, or public health interventions. Capasso & Serio (1978) proposed a non-monotonic incidence rate  $g(I)S = \frac{\beta IS}{1+\alpha I^2}$  in which  $g(I)$  is non-monotonic, that is,  $g(I)$  increases when  $I$  is small and decreases when  $I$  gets large. In this incidence rate,  $\beta I$  measures the force of infection, and  $\frac{1}{1+\alpha I^2}$  describes the psychological or inhibitory effect from the behavioural change of the susceptibles when the number of infectives gets large. This is important because the number of effective contacts between infectives and susceptibles decreases at high infective levels due to the quarantine of infectives or due to the protective measures by the susceptible.

The general incidence rate  $g(I).S = \frac{\beta I^p}{1+\alpha I^q}$  was given by Liu et al. (1986) and used by many authors (Moghadas & Gumel, 2002; Alexander & Moghadas, 2004; Khan et al., 2015). Logistic Incidence Rate ( $\beta SI(1 - \frac{I}{K})$ ), Oscillatory Incidence Rate ( $\beta SI \sin(\omega I)$ ), Threshold-Based Incidence Rate ( $\beta SI \frac{A}{B+I^2}$ ),

Holling Type III Functional Response ( $\frac{\beta SI^2}{1+\alpha I^2}$ ), General Polynomial Form ( $\beta SI \left(1 - \frac{I}{K}\right)^n$ ) are some of the other monotonic incident rates.

Non-monotonic incidence rates in SIR and SIS models offer a powerful tool for capturing the complex dynamics of disease spread. They reflect realistic scenarios where infection rates can increase up to a

point and then decrease, exhibiting peaks and troughs due to various internal and external factors. These models are crucial for accurately predicting and managing epidemic behaviors in complex environments.

Apart from the above-discussed incidence rates, several incident rates are investigated by researchers and provide detailed qualitative analyses of the models. In the case of the Yoga awareness model, the disease transmission rate can be considered as  $\beta e^{-cM} SI$ , where  $M$  is the Yoga awareness infected mass and  $c$  is constant (Bhatta, 2024).

### **Discussion of Key Study**

Different compartmental models have been used in epidemiology because different diseases and public health questions require models with different levels of complexity and realism. Each compartmental model captures specific aspects of disease transmission, progression, and control strategies.

The SIR model is used for diseases where recovery gives long-term immunity (e.g., measles, COVID-19 in some cases). The SEIR model adds an exposed (latent) class for diseases with an incubation period (e.g., Ebola, COVID-19). The SIS model is used for diseases with no lasting immunity where recovered individuals become susceptible again (e.g., gonorrhea). The SEIRS model accounts for waning immunity, where recovered people may lose immunity and become susceptible again.

The **bilinear, saturated, standard, and nonlinear incident rates** are important in mathematical modelling, especially in epidemiology and population dynamics. Each of these incident rates describes how a disease spreads based on the interaction between susceptible and infected individuals. Bilinear is basic and commonly used in SIR models. It assumes direct proportionality between susceptible ( $S$ ) and infected ( $I$ ) and has no saturation effect. Saturated incident rate accounts for behavioral or medical constraints limiting infection spread. Saturation occurs when infected individuals increase, and is suitable for modelling diseases with limited healthcare or contact. The standard rate is used in models with heterogeneous populations. It is a generalization of the bilinear model. A non-linear rate is applied in complex epidemiological models.

### **Conclusion**

Various compartmental epidemic models have been studied. The mathematical modelling of different infectious diseases is mentioned. Different compartmental models are used to ensure that the model closely reflects the biological, social, and environmental realities of the disease being studied, thereby improving understanding, prediction, and control of epidemics.

This work also highlights the important relationship between different incident rates. Bilinear incident rate is used in basic SIR/SEIR models. Saturated incident rate is applied for diseases like COVID-19 with

behavioral constraints and it is more realistic under high infection loads and limits explosive outbreaks. It captures more realistic contact saturation. Non-linear incident rates are used for great propagator situations and vector-borne diseases. It captures nonlinear infection dynamics (e.g. clustering). Standard incident rates are used when the total population varies and are normalized by total population size.

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## Seismic Fragility Curves for Non-Engineered Low-Rise Commercial Building in Far Western Nepal : A Case Study of Darchula

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### Abstract

Seismic vulnerability assessment of non-engineered reinforced concrete (RC) buildings in Far Western Nepal, including Darchula, is crucial due to their inadequate structural performance under earthquake loading. These buildings, typically designed for gravity loads, often feature soft-story mechanisms caused by weak ground stories, making them highly susceptible to seismic failure. This study evaluates the seismic performance of three low-rise (5-story) RC structures using capacity curves, fragility curves, and failure mapping techniques. The capacity curve analysis reveals that NERcA exhibits the weakest base shear capacity, while NERcC shows the highest strength, indicating variations in construction quality and reinforcement detailing. Failure mapping demonstrates

that plastic hinges form primarily in columns rather than beams, contradicting the column-weak-beam design philosophy, and soft-story failure is evident due to irregular stiffness distribution. Fragility analysis further highlights the high probability of failure at lower spectral displacements, with steep fragility curves indicating significant vulnerability, even under moderate seismic loads. The results underscore the need for seismic retrofitting, improved construction practices, and adherence to modern seismic codes to enhance structural resilience. Implementing these measures is critical to reducing seismic risks and preventing catastrophic failures in earthquake-prone regions.

**Keywords:** *Non-engineered buildings, HAZUS methodology, Fragility Curve, Pushover analysis*

### Introduction

Nepal, located in the seismically active region, experiences frequent earthquakes due to the convergence of the Indian and Eurasian tectonic plates shown in [Figure 1](#). While the majority of earthquakes in Nepal have magnitudes between 4 and 6 and typically cause little to no damage, those exceeding magnitude 6.5 have historically resulted in significant destruction. Major earthquakes, such as those in 1833, 1934, 1980, 1988, 2011, and 2015, have highlighted the vulnerability of the country, with damage influenced by factors like energy release, duration of shaking, focal depth, and the resilience of building infrastructure in Nepal (Chaulagain et al., 2018). Reinforced concrete (RC) buildings are very common in Nepal. Nowadays the construction of RC buildings is growing rapidly. In Nepal, many building codes are

developed based on the type of buildings and materials to be constructed. Codel provision was also revised based on the seismic vulnerability in the structures. To construct earthquake-resisting buildings, it is important to follow the codel provision but for many reasons, people construct RC buildings without consulting with an engineer and they usually do not follow the codel provisions (Paudel et al., 2024; Sapkota et al., 2024). Non-engineered low-rise commercial buildings are widespread in developing regions like Khalnga Darchula, particularly in earthquake-prone areas such as Far Western Nepal (Bohara, 2023). These buildings are typically constructed with little or no professional engineering oversight, relying instead on local masons and traditional construction practices. Due to limited access to resources, many buildings are constructed by local masons without proper engineering guidance, similar to construction practices in Northeastern India (Chandra Dutta et al., 2021). The vulnerability of these structures is exacerbated by poor design and construction quality, making them prone to collapse during seismic events. The absence of proper design standards, poor construction quality, irregular mass distribution, and irregular infill wall distributions often lead to increased susceptibility to earthquake-induced damage (R. K. Adhikari & D'Ayala, 2020; Gautam et al., 2015; Parajuli & Kiyono, 2015; Poudel & Chaulagain, 2024).

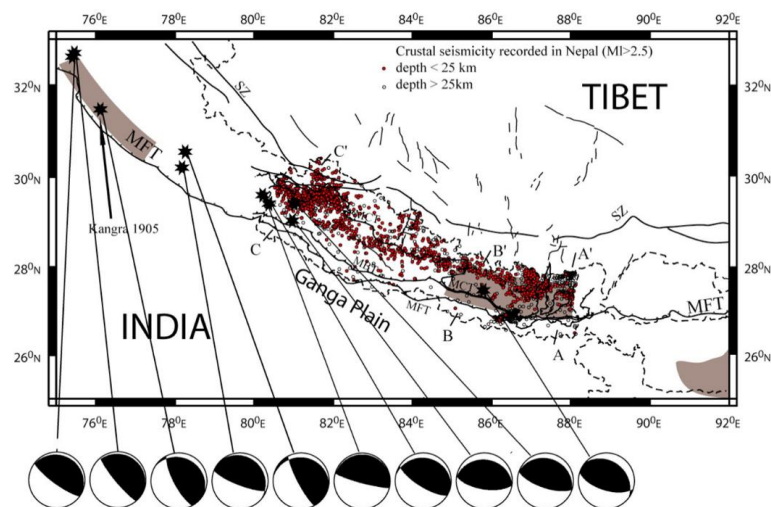
Recent studies in regions with similar building typologies, including parts of Northeastern India and Nepal, highlight that many non-engineered structures, especially those featuring reinforced concrete (RC) frames with infilled masonry, are highly vulnerable in seismic zones (Chandra Dutta et al., 2021). The lack of uniformity in infill walls and inadequate design and construction quality further exacerbates this vulnerability (KARAŞIN et al., 2017; Varum et al., 2018). Additionally, the practice of using open ground storeys, irregularity in mass distribution without sufficient engineering input is common, often leading to severe structural weaknesses during earthquakes (Abdel Raheem et al., 2018; Khanal & Chaulagain, 2020; Krishnan & Thasleen, 2020; Özmen et al., 1998; Ravikumar et al., 2012). The country has experienced numerous devastating seismic events, including the catastrophic 1934 Bihar-Nepal earthquake (Mw 8.0) and the 2015 Gorkha earthquake (Mw 7.8). These events caused widespread damage to infrastructure and resulted in a significant loss of life, particularly in rural and urban areas where non-engineered buildings dominate. Most residential and commercial structures in Nepal are either masonry or reinforced concrete (RC) buildings with masonry infills (Dutta et al., 2015; Gautam & Chaulagain, 2016).

In the context of low-rise buildings, especially in earthquake-prone regions like Nepal, fragility curves serve a critical role in assessing structural resilience (Chapagain & Chaulagain, 2024). Many low-rise buildings, such as non-engineered residential and commercial structures, are typically built with little or no seismic design consideration. These buildings often use materials like masonry infills, and due to budget constraints and lack of engineering expertise, their construction may not meet earthquake-resistant

standards. Fragility curves help in evaluating how such buildings are likely to perform under seismic stress, identifying which structural elements are more vulnerable and estimating the probability of different levels of damage (Gautam et al., 2021).

This study focuses on the development of seismic fragility curves for non-engineered low-rise commercial buildings in Darchula, Far Western Nepal. Fragility curves are an essential tool for assessing the probability of structural damage under varying earthquake intensities. By employing a nonlinear static analysis approach, this research aims to quantify the vulnerability of these buildings, considering local construction practices and design deficiencies. The insights gained from this study can inform future construction guidelines, helping to mitigate the risks associated with non-engineered buildings in high seismic regions.

Moreover, the results of this research may be applicable not only in Darchula but in other regions with similar building practices, thereby contributing to the broader understanding of seismic risk in rural and underserved areas. The findings can serve as a critical resource for policymakers, engineers, and builders in enhancing the resilience of low-rise commercial structures against earthquake hazards.



*Figure 1. Historical earthquakes in the Himalayan of Nepal (monitored between 1985–1998) (Jouanne et al., 2004)*

### **Brief description of Code based building construction**

The Nepal National Building Code (NBC), developed by the Department of Urban Development and Building Construction, was first drafted in 1993–1994 and adopted in 2003 after 1988 earthquake in Nepal (Fujiwara et al., 1989). It became part of the official gazette in 2006. Compliance with the NBC 1994 is mandatory in all municipalities and some rural municipalities in Nepal. However, before the NBC promulgation, various international codes, such as Indian, British, and American standards, were utilized for structure construction in Nepal. Since the enactment of the Building Code Act in 1994 and its

enforcement in 2003, urban housing construction in

Nepal has advanced significantly, with many new structures adhering to the Nepal National Building Code (NBC) to meet seismic demands at that time. Many other provisions and rule have been developed including NBC 201, 202, and 205, offer a set of guidelines designed to improve the safety and durability of residential and commercial buildings, particularly for low- to low-rise structures. The mandatory rules of thumb (MRT) provided by NBC have been widely adopted for owner-built houses, offering ready-to-use dimensions and detailing for beams, columns, and other structural components. NBC 205: 2012 (MRT rule) for example, recommends that columns for buildings up to three storeys have a minimum size of 300mm x 300mm with at least four 12-16mm diameter bars and appropriate spacing of stirrups to improve lateral load resistance (Mahal & Kathmandu, 2070). The NBC 205 again revised with some new advanced guidelines in 2024 for low-rise buildings up to 3 stoeyses. The Nepal National Building Code (NBC) 205:2024, titled "Ready-to-Use Detailing Guideline for Low-Rise Buildings," offers standardized design and detailing practices to enhance the structural integrity and seismic resilience of low-rise constructions in Nepal (NBC 205, 2024). The code specifies dimensions and reinforcement details for structural elements based on building height and seismic considerations such as in three-story buildings, recommended beam sizes include 250 mm x 355 mm and 300 mm x 380 mm, with corresponding reinforcement details provided to ensure adequate strength and ductility in structures. Reinforcement bars are specified to meet the minimum yield strength of 500 N/mm<sup>2</sup>, conforming to NS: 191-2046 standards. The code emphasizes the use of closed stirrups with 135° hooks and a minimum hook length of 65 mm to enhance confinement in columns and beams. Despite the existence of numerous building codes in Nepal, including the National Building Code (NBC) and additional guidelines like IS 1893, construction practices in rural and hilly regions frequently stray from these standards, resulting in structural shortcomings and increased vulnerability to earthquakes (R. K. Adhikari & D'Ayala, 2020; Dutta et al., 2015; Sehgal apoorva., 2017). This problem is particularly noticeable in areas such as Darchula, where both reinforced concrete (RC) and unreinforced stone masonry buildings are built with insufficient compliance to code requirements (Bohara, 2023). These infractions severely weaken the seismic performance of structures, highlighted by the common occurrence of soft-story designs in the area. Such buildings, often featuring an open ground level for commercial purposes, do not possess adequate lateral stiffness to withstand earthquake forces, which directly violates NBC regulations. Furthermore, issues in reinforcement detailing, like improper beam-column connections, incorrect stirrup spacing, and inadequate rebar anchorage, compromise the structural stability of these buildings. Such practices are widespread in Mahakali Municipality, where the mix of traditional construction methods and a lack of technical oversight intensifies these problems. The region's hilly landscape and dependence on non-engineered methods heighten the risk, making low cost nonengineered Rc buildings vulnerable to failure during seismic activities. Tackling these issues necessitates not only stricter enforcement of building

codes but also broad initiatives to raise awareness and build capacity for earthquake-resistant construction practices in rural area.

### **Building Typologies**

The following building types are commonly found in Darchula, highlighting their characteristics and vulnerabilities:

#### **Traditional Construction (unreinforced masonry):**

Stone in mud, dry stone and block or brick-in-mud buildings: These structures are prevalent in rural areas. Stone-in-mud buildings, using undressed stones, dressed stone and mud mortar, and brick-in-mud buildings, which combine fired bricks with mud mortar, are also susceptible to earthquake damage due to weak tensile strength and poor lateral load performance (See Figure 2 (a), (e)).

#### **Modern Masonry:**

Brick, Rc block and Stone in cement mortar buildings: This category includes masonry buildings, which utilize fired bricks and block set in cement mortar, offering improved durability compared to traditional methods. Stone masonry buildings with cement mortar also enhance strength but depend on quality construction techniques to withstand seismic conditions as shown in Figure 2.

#### **Reinforced Concrete Buildings:**

Non-Engineered RC moment-resisting frame buildings: These buildings feature reinforced concrete frames with unreinforced brick masonry infill walls and these buildings are constructed without considering the code provision and designed properly. Common in urban and peri-urban areas, these structures often lack proper engineering oversight, resulting in vulnerabilities during earthquakes due to inadequate detailing and design as shown in Figure 2.

Engineered RC moment-resisting frame buildings: Representing a more modern approach, these buildings are designed under the supervision of qualified engineers and they include robust connections between beams and columns, providing better performance under seismic forces. The cast-in-situ concrete slabs for floors and roofs further enhance their structural integrity.

#### **Other Building Types:**

Mixed buildings: These structures combine elements of traditional and modern construction, such as stone and adobe or brick-in-mud with cement. However, these mixed systems often demonstrate poor performance during earthquakes due to inconsistencies in material strength and load distribution.



*Figure 2: Common construction practice in structures in Darchula*

## Methods and modeling

### Studied buildings

To evaluate the seismic performance of typical non-engineered RC buildings in Far Western Nepal, particularly in Darchula, three representative models NERcA (Non-Engineered Reinforced Concrete Model A), NERcB (Non-Engineered Reinforced Concrete Model B), and NERcC (Non-Engineered Reinforced Concrete Model C) were selected. The region is characterized by steep hillsides, poor road connectivity, and limited access to engineering supervision, which has resulted in the widespread construction of low- to mid-rise RC commercial buildings without adherence to seismic codes (Bohara, 2023). These structures are typically built by local masons, using informal techniques and low-strength materials, making them especially vulnerable to earthquake-induced damage. Recent field surveys, including those conducted by the authors, revealed common structural deficiencies such as soft stories, irregular mass distribution, and inadequate reinforcement detailing, which further justify the selection of Darchula as a representative location for seismic fragility assessment (Bohara, 2023). Moreover, there is a lack of existing research focused on seismic risk in this remote region, despite the known exposure and vulnerability. By selecting Darchula, this study aims to fill a critical knowledge gap and provide context-specific insights that can inform risk reduction strategies and retrofitting priorities for similar hilly regions in Nepal and beyond (Bohara et al., 2025).

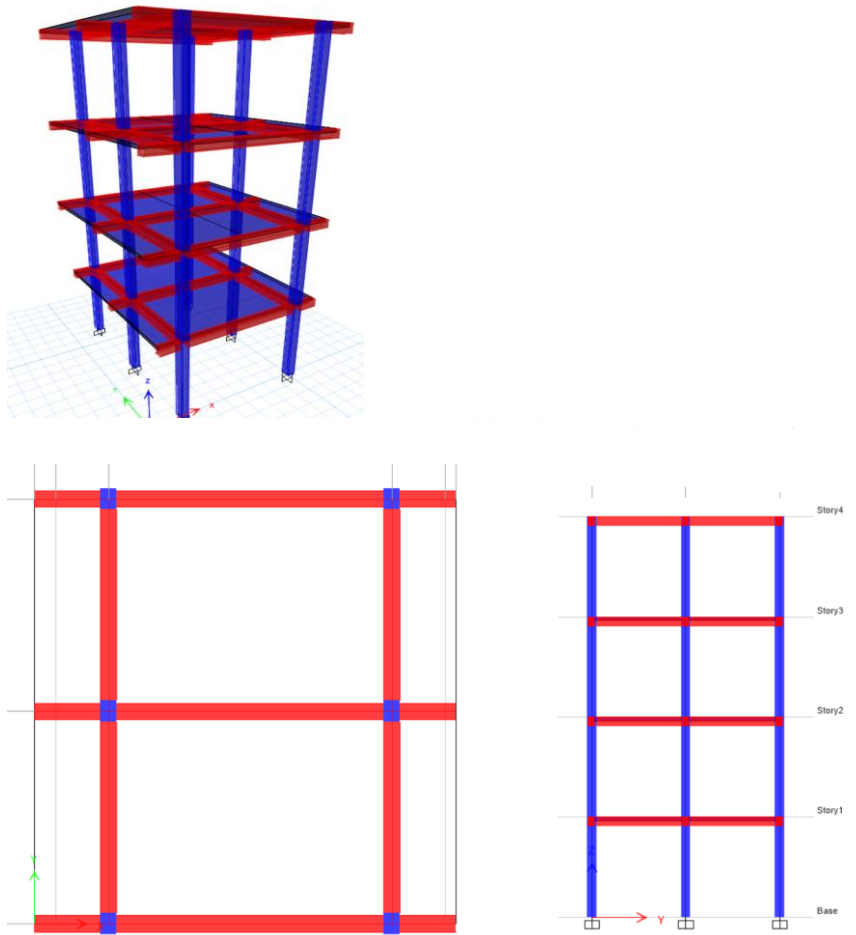
These models were derived from a detailed field survey of existing RC commercial buildings in the Mahakali Municipality, ensuring their relevance and representativeness of the local building stock. The selection was guided by observed variations in geometry, number of stories, construction quality, and reinforcement detailing. Model NERcA, a compact 4-story commercial building, features a single bay with modest dimensions of 6 m in length and 4 m in breadth, utilizing smaller column sizes of 230 x 300 mm and its 3D view, elevation and plan as shown in Figure 3. In contrast, NERcB also stands at 4 stories but showcases a more extensive footprint of 12 m by 7.5 m and three bays (as shown in Figure 4), allowing for greater interior flexibility. Its larger column dimensions (300 x 300 mm) enhance its structural capacity, making it better equipped to handle both vertical and lateral loads. Model NERcC, the tallest at 5 stories, combines varying story heights (2.8 m for lower stories and 3.2 m for upper stories) and a spacious four-bay layout, ideal for diverse commercial uses (see Figure 5). With robust column sizes similar to NERcB, NERcC offers improved structural integrity, crucial for seismic resistance due to its height. Together, these models reflect the evolving architectural landscape in Darchula, highlighting the shift from traditional construction practices to modern, engineered solutions capable of addressing the seismic challenges of the region.

In this study, the structural modeling of the selected RC buildings (NERcA, NERcB, and NERcC) was carried out using a nonlinear static pushover analysis approach. The models were constructed using lumped plastic hinge elements at both ends of beams and columns to simulate nonlinear behavior, consistent with FEMA-356 (FEMA 356, 2000) recommendations. This method was chosen for its computational efficiency and ability to capture key post-yield performance characteristics of non-engineered RC structures.

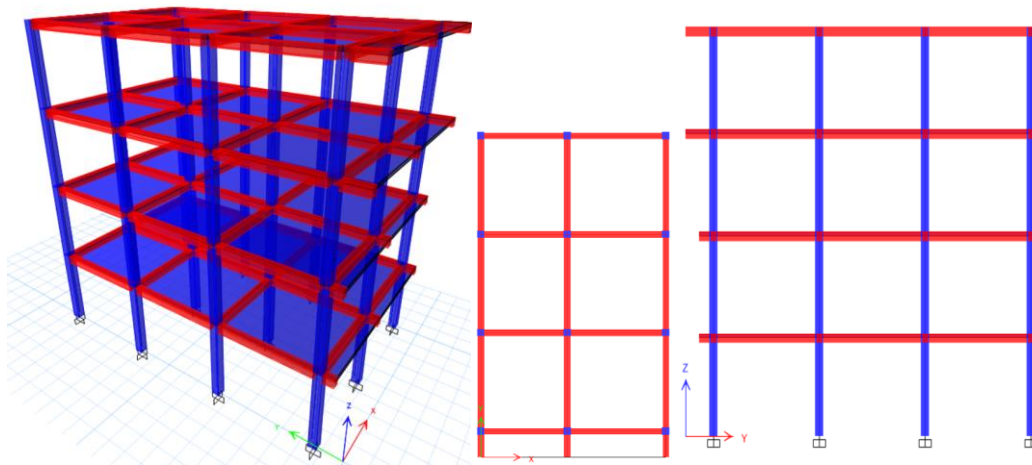
The material properties assigned to the models were based on field observations and typical values documented for non-engineered constructions in Far Western Nepal. For concrete, a compressive strength ( $f_c$ ) of 20 MPa was used, reflecting low-strength concrete commonly mixed on-site. The reinforcement steel was modeled with a yield strength ( $f_y$ ) of 415 MPa, consistent with locally available deformed bars. An elastic modulus of 25 GPa was assumed for concrete and 200 GPa for steel. The models did not explicitly incorporate infill-frame interaction, due to the lack of reliable in-situ data and the variability of infill wall properties and configurations across buildings. However, the absence of this interaction is acknowledged as a limitation in the analysis. The infill walls were assumed to contribute mass but not stiffness, representing a conservative assumption for structures with weak or poorly connected masonry infill. Future studies may incorporate equivalent strut models or panel zone modeling to capture these effects more accurately.

The three selected models exhibit a notable increase in dead loads on the upper stories, primarily due to the additional weight of the walls and the cantilever extensions from the beams. As the height of the buildings increases, the upper floors possess a greater carpet area, attributable to the slabs that extend over the increased beam dimensions. This configuration results in an accumulation of structural loads as one progresses to the upper stories, significantly influencing the overall behavior of the buildings under seismic conditions.

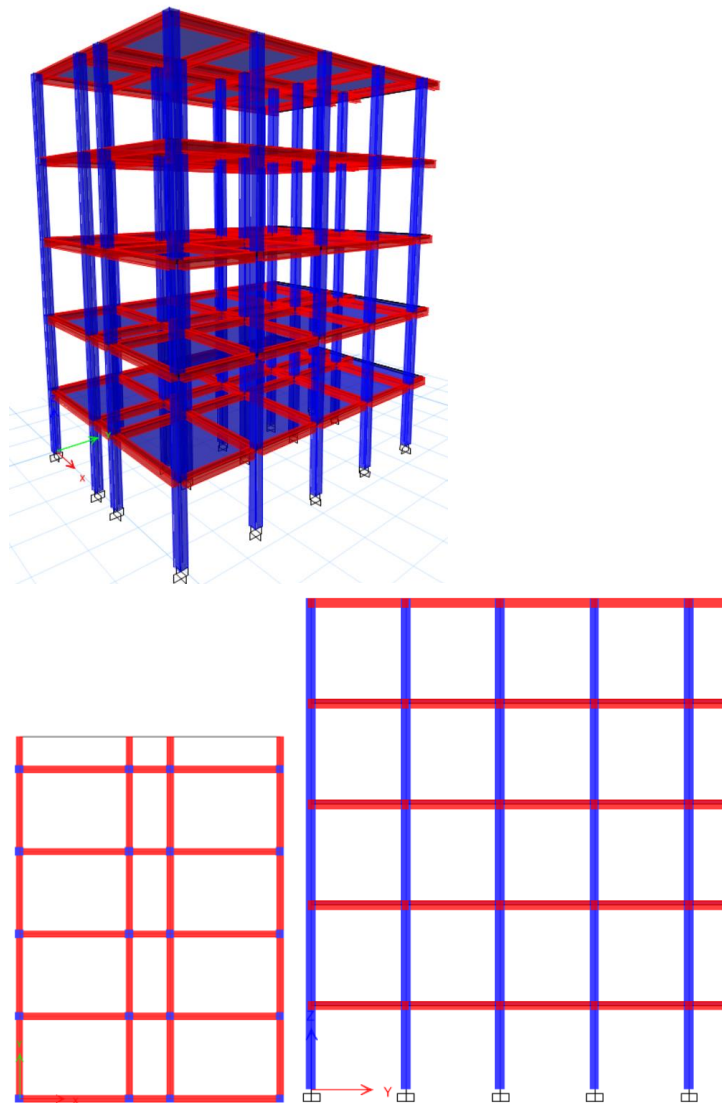
The increased dead load on the upper floors is particularly critical in the context of seismic performance. With the added weight, the demand on the structural elements such as beams and columns increases, necessitating careful consideration of their capacity to withstand lateral forces during seismic events. Furthermore, the cantilevered beams, while providing additional floor space, contribute to increased bending moments and shear forces, which can compromise the integrity of the structure if not adequately designed.



**Figure 3:** Model NERcA 3D modeling, plan and elevation



**Figure 4:** Model NERcB 3D modeling, plan and elevation



*Figure 5: Model NERcC 3D modeling, plan and elevation*

## Results and discussion

### Nonlinear analysis

Nonlinear analysis plays a vital role in assessing the seismic performance of structures, particularly in earthquake-prone areas. In this study, nonlinear static analysis procedures (NSPs), specifically the pushover analysis, were employed due to their relatively simple application. While NDPs offer a more detailed understanding of a structure's response to seismic events, they demand considerable computational resources and time. Recent research has indicated that the results obtained from NDPs such as maximum roof displacements and base shears are often comparable to those derived from NSPs, making NSPs a practical choice for evaluating the seismic behavior of reinforced concrete (RC) frame buildings (Ali & Sanghai, 2021; Bohara & Saha, 2022; Goel RK & Chopra, 2004; Mwafy & Elnashai, 2001). In seismic performance evaluation, a capacity curve is defined by three key control points such as design capacity, yield capacity, and ultimate capacity of the structure. Each of these control points

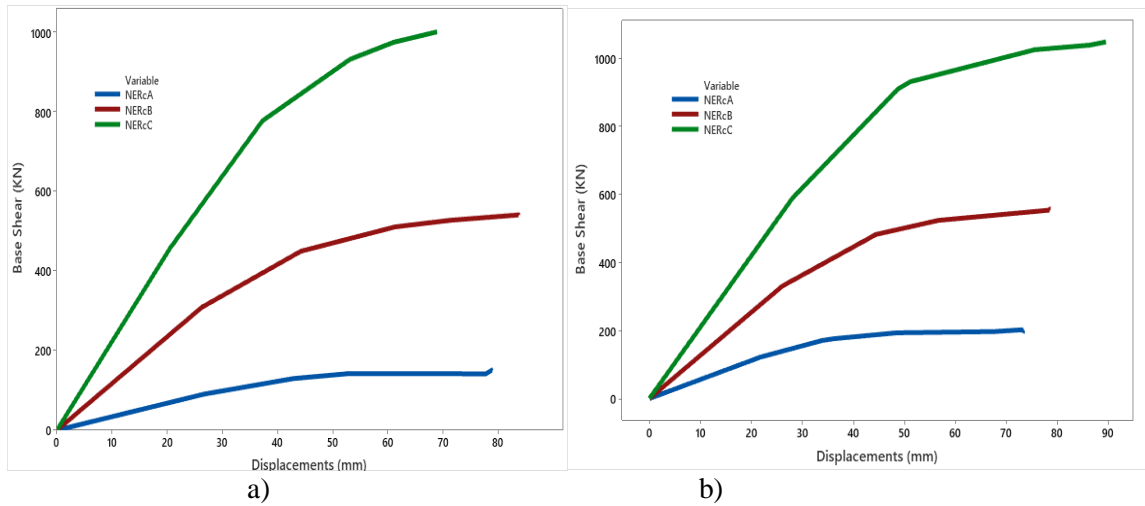
represents a critical phase in the behavior of a structure under increasing lateral loads, offering insight into its strength, deformation, and potential failure mechanisms (Mwafy & Elnashai, 2001).

The nonlinear static pushover analysis in this study was performed using a displacement-controlled approach in both the X and Y directions. A uniform lateral load pattern proportional to the building mass was applied to simulate the distribution of seismic forces across the structure, consistent with recommendations for regular frame systems as outlined in FEMA 356 (FEMA 356, 2000). The models were constructed as three-dimensional RC moment-resisting frames using lumped plastic hinge elements to represent nonlinear behavior. Plastic hinges were defined at both ends of beams and columns based on the ASCE 7-16 (ASCE, 2016), which follow American standards for nonlinear hinge modeling. The default hinge properties including M3 moment hinges for beams and P-M2 (axial-flexure) interaction hinges for columns were assigned to critical locations in the structure. These hinge models account for yielding, post-yield stiffness, and ultimate deformation capacity, ensuring that the simulated behavior reflects realistic inelastic mechanisms observed in non-engineered RC buildings.

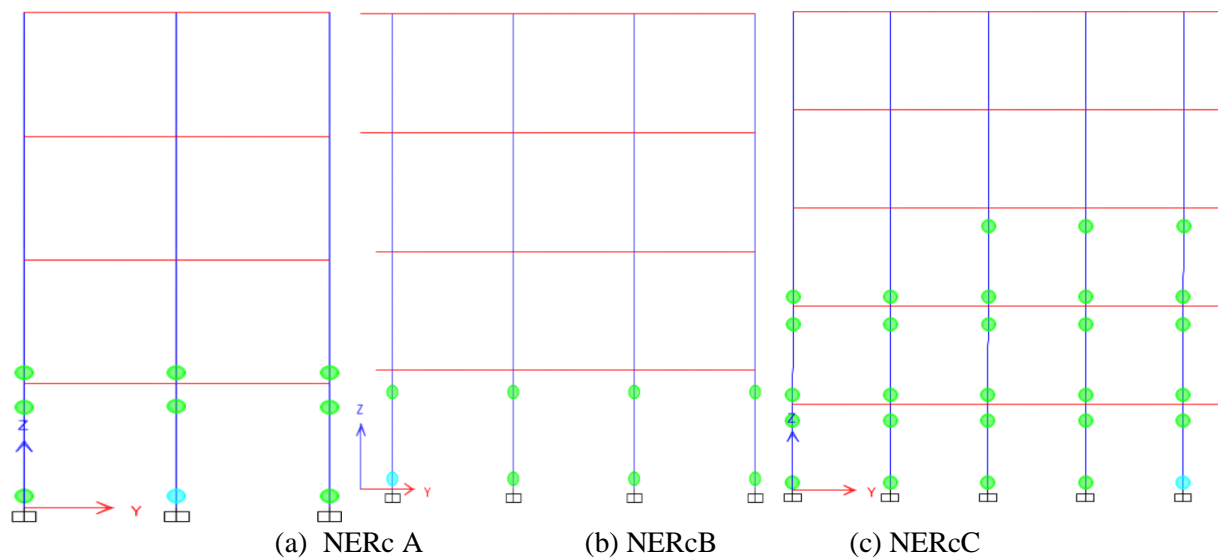
All analyses considered gravity loads comprising full dead load and 25% of the live load, as per common practice in seismic analysis of RC buildings. The control node was located at the roof level to monitor global displacement and identify capacity points (Mazza & Vulcano, 2008). Infill walls were modeled as non-structural mass only, with no stiffness contribution, to reflect construction practices typical in Darchula. These modeling assumptions were made to balance analytical rigor with computational feasibility, and they align with international best practices for fragility assessment using pushover methods.

The seismic performance analysis of three low-rise (4 and 5-storey) non-engineered reinforced concrete (NERc) buildings was conducted to evaluate their structural capacity and failure mechanisms. The capacity curves presented in Figure 6 illustrate the relationship between base shear and top-story displacement in both the x and y directions. Among the models analyzed, NERcA exhibits the lowest base shear capacity, highlighting its weak structural resistance under lateral loads. In contrast, NERcC demonstrates the highest strength, while NERcB falls in between, indicating variations in construction quality and reinforcement detailing. The failure mapping in Figure 7 provides critical insights into hinge formations, revealing that the first plastic hinges predominantly appear in columns rather than beams, contradicting the strong column-weak beam design philosophy recommended in modern seismic codes. The observation of initial plastic hinge formation in columns, rather than beams, highlights deviations from recommended seismic design philosophy. While this study identifies such behavior, detailed analysis of contributing factors such as reinforcement inadequacies and construction deficiencies remains a topic for further investigation. Additionally, the models exhibit soft-story failure, attributed to irregular

stiffness distribution across the height of the structures. These findings emphasize the vulnerability of non-engineered buildings to seismic forces and the urgent need for retrofitting measures to enhance resilience and mitigate collapse risks in earthquake-prone regions.



**Figure 6:** Base shear vs Displacement a) Along x axis b) y axis



**Figure 7:** Failure mapping

### Fragility Curve from Nonlinear Static Pushover Analysis

A fragility curve is a probabilistic tool used in seismic vulnerability assessment to quantify the likelihood of different damage states of a structure under varying levels of seismic intensity (R. Adhikari et al., 2022; AL-saedi & Yaghmaei-Sabegh, 2024). When derived from nonlinear static pushover analysis, fragility curves provide insights into how a building responds to increasing lateral forces, offering a detailed assessment of its vulnerability to earthquakes. The fragility curve is then developed by relating this capacity curve to seismic demand parameters, such as peak ground acceleration (PGA) or spectral

displacement ( $S_d$ ), and determining the probability that the structure will reach or exceed specific damage states. The first step in creating fragility curves is to define different damage states for the building, such as slight, moderate, extensive, and complete damage. These damage states correspond to increasing levels of structural deterioration, from minor cosmetic damage to structural failure. Using the pushover capacity curve, thresholds for each damage state are determined. These thresholds are usually related to key structural responses, such as displacement or deformation levels at critical points (e.g., roof displacement). The fragility curve is expressed as a cumulative probability function, where the x-axis represents the intensity of the earthquake (spectral acceleration) and the y-axis shows the probability that the building will reach or exceed a specific damage state.

In the present study, the fragility curves for reinforced concrete (RC) buildings are developed using the HAZUS (Hazus Earthquake Model Technical Manual Hazus 4.2 SP3, 2020) methodology. HAZUS®-MH MR5, initially developed by the Federal Emergency Management Agency (FEMA) (Fema, 2005) for seismic risk and loss assessment in the U.S., has become widely used around the world due to its adaptability to different building types and seismic environments. The methodology provides a systematic framework for assessing the seismic vulnerability of buildings and infrastructure based on fragility curves. The damage state thresholds are defined in terms of spectral displacement ( $S_d$ ), based on the yielding ( $S_{dy}$ ) and ultimate ( $S_{du}$ ) values derived from the pushover curve and converted into an acceleration-displacement response spectrum (ADRS) format:

**Table 1: Damage states for buildings**

Damage State	Threshold values of d [mm]
$S_{d1}$	$0.7 \cdot S_{dy}$
$S_{d2}$	$S_{dy} = S_{dy}$
$S_{d3}$	$S_{dy} + 0.25 (S_{du} - S_{dy})$
$S_{d4}$	$S_{du}$

**Development of Fragility Functions**

The fragility curve follows a lognormal distribution and represents the probability of a structure reaching or exceeding a specific damage state under a given seismic intensity (Ahmad et al., 2018; Akbari et al., 2015; Kadid et al., 2008). These curves are constructed using the relationship between seismic demand (such as spectral displacement,  $S_d$ ) and structural capacity (derived from the capacity curve).

The fragility curve is mathematically expressed as:

$$P[D \geq DS] = \varphi \left[ \frac{\ln(S_d) - \ln(S_{dm})}{\beta} \right] \dots \dots \dots (1)$$

Where:

$P[D \geq DS]$  is the probability of exceeding a particular damage state.

$\phi$  is the cumulative distribution function of the standard normal distribution.

$S_d$  is the spectral displacement.

$S_{dm}$  is the median spectral displacement at which the damage state is expected or occur.

$\beta$  is the logarithmic standard deviation.

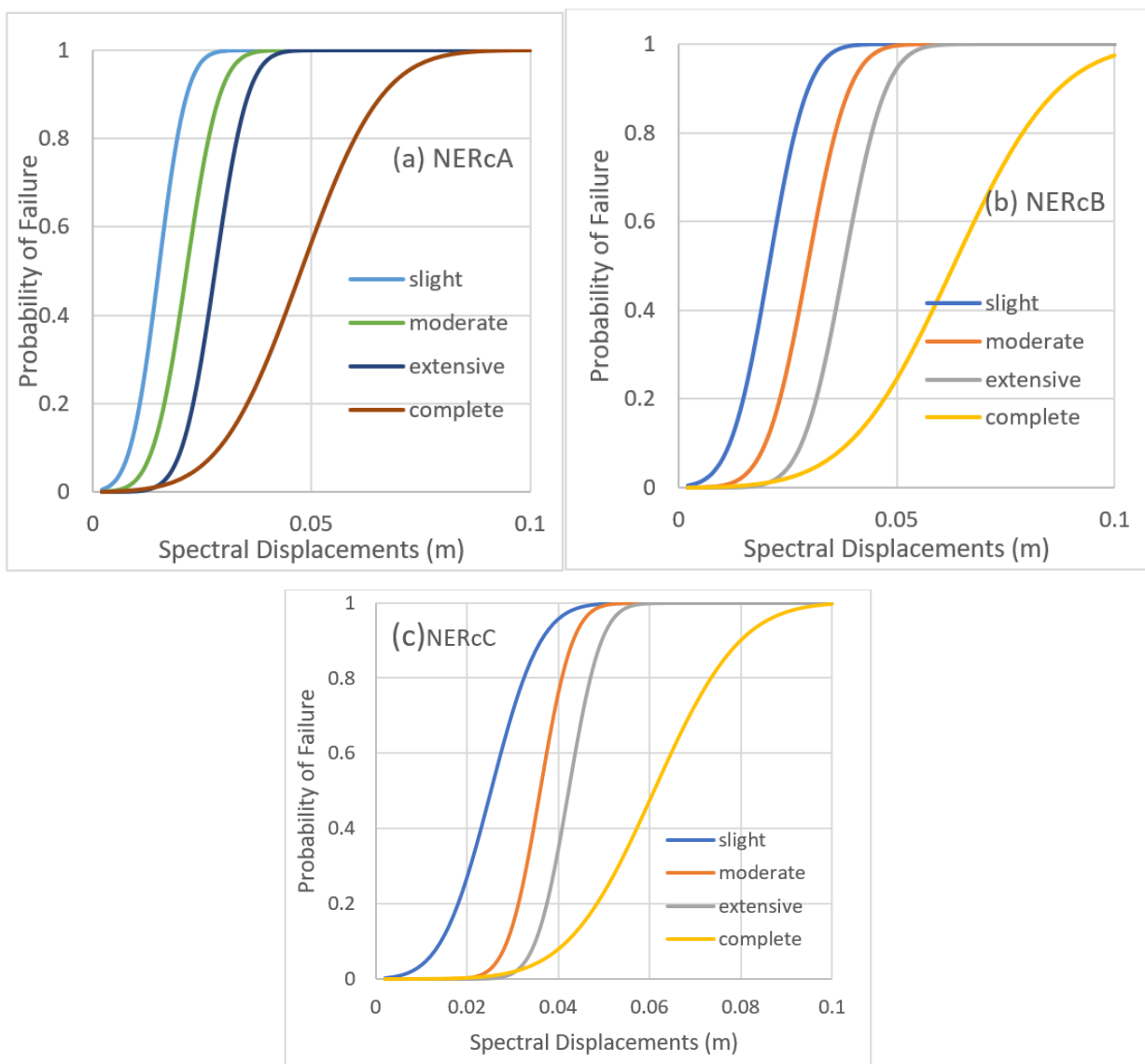
The standard deviation ( $\sigma$ ) for each damage state was determined by fitting a normal cumulative distribution function (CDF) to the probabilities listed in Barbat (Barbat et al., 2008) Table 2. For a given structure, the spectral displacement thresholds ( $S_{d1}$ ,  $S_{d2}$ ,  $S_{d3}$  and  $S_d$ ) were established as the mean displacement values corresponding to slight, moderate, extensive, and complete damage states. The optimization process aimed to minimize the sum of squared errors between the empirical probabilities from Table 2 and the CDF values of the normal distribution at these spectral displacement points. By iteratively adjusting  $\sigma$ , the best statistical fit was achieved while keeping the mean values fixed. This procedure was applied independently to each structure and damage state to ensure accuracy in fragility curve development. The fragility curves in the provided Figure 8 illustrate the probability of failure of non-engineered Rc (NERcA, NERcB and NERcC) buildings across different damage states slight, moderate, extensive, and complete based on spectral displacement values. The curves indicate that buildings exhibit a significantly higher probability of failure at lower spectral displacements. This suggests that NERc buildings have lower seismic resilience due to inadequate reinforcement detailing, limited ductility, and insufficient lateral strength. The steep slope of the curves, particularly for slight and moderate damage states, further highlights the structural vulnerability of these buildings, emphasizing their susceptibility to seismic demands even at relatively small displacements. These findings reinforce the importance of implementing and enforcing modern seismic design codes to enhance structural safety.

The dispersion ( $\beta$ ) for each fragility curve was determined by fitting a lognormal cumulative distribution function to empirical damage probabilities based on Barbat et al. (2008) (Barbat et al., 2008) . An optimization algorithm was used to minimize the sum of squared errors between the fitted CDF and the target data at spectral displacement thresholds corresponding to each damage state. The steepness of the fragility curve for NERcA reflects low dispersion and early structural failure, which is characteristic of buildings with minimal capacity and brittle failure modes. In contrast, the wider dispersion for NERcC indicates a broader range of displacement capacity and uncertainty in performance due to increased complexity and variation in load distribution. It should be noted that variability due to ground motion

characteristics and material randomness was not modeled explicitly, and future work may explore these effects using dynamic time-history simulations.

**Table 2:** developed by Barbat et al to construct fragility curves (Barbat et al., 2008)

Condition	$P_{\beta}(1)$	$P_{\beta}(2)$	$P_{\beta}(3)$	$P_{\beta}(4)$
$P_{\beta}(1)$	0.5	0.119	0.012	0
$P_{\beta}(2)$	0.896	0.5	0.135	0.008
$P_{\beta}(3)$	0.992	0.866	0.5	0.104
$P_{\beta}(4)$	1	0.988	0.881	0.5



**Figure 8:** Fragility curves for (a) model A, (b) model B and (c) Model C.

## **Conclusion**

The seismic hazard in the Far Western region of Nepal, including Darchula, poses a significant risk due to the prevalence of non-engineered, low-rise reinforced concrete (RC) buildings. These structures are primarily designed to withstand gravity loads with minimal or no consideration of seismic forces. A common deficiency observed is the presence of weak ground stories, often used for commercial purposes, which result in a pronounced soft-story effect that substantially increases their vulnerability to earthquake damage.

This study's findings reveal critical structural deficiencies in non-engineered RC buildings, with model NERcA exhibiting the lowest lateral capacity and earliest onset of failure. Notably, plastic hinges were observed to form prematurely in columns rather than beams, violating the strong column–weak beam design principle and highlighting poor construction practices. Fragility analysis further quantifies this vulnerability, demonstrating that these buildings have a high probability of reaching damage states at relatively low spectral displacement values. The steep slopes of fragility curves for slight and moderate damage emphasize their susceptibility even under moderate seismic demands.

These structural weaknesses are exacerbated by the use of low-quality construction materials, lack of seismic detailing, and widespread non-compliance with relevant building codes, collectively elevating the seismic risk in the region. To reduce collapse risk and enhance resilience, the implementation of practical seismic retrofitting strategies—such as RC jacketing, steel bracing, and improved joint detailing—is critical. Additionally, stricter enforcement and adaptation of modern seismic codes are urgently needed, especially in remote, earthquake-prone areas where construction oversight is limited.

It is important to recognize the limitations of the current study. The nonlinear static pushover analysis employed is deterministic and does not capture the variability inherent in seismic ground motions, including frequency content, duration, and site-specific effects. As a result, the fragility curves developed do not incorporate uncertainties related to record-to-record ground motion variability. We explicitly acknowledge this limitation and recommend that future research incorporate Incremental Dynamic Analysis (IDA) or other probabilistic dynamic methods to provide a more comprehensive and robust assessment of seismic vulnerability.

## **Conflict of Interest**

Authors declare that no conflict of interest.

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# Failure and Maintenance of Flexible Pavement: A Case Study of Mahendranagar City Roads, Nepal

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## Abstract

Sustainable urban mobility hinges on the structural integrity and serviceability of road infrastructure, particularly in developing regions like Nepal, where flexible pavements dominate the arterial network. This study systematically evaluates the failure mechanisms of flexible pavements across six critical urban road segments: Streets 1 to 5 and the Hospital Line of Mahendranagar City, through field inspections guided by ASTM D6433-20 standards. The primary objective was to classify distress types, determine causative factors, and recommend context-appropriate maintenance interventions. The assessment revealed a disproportionately high prevalence of potholes and edge failures, attributed to inadequate drainage, substandard construction practices, and prolonged neglect of routine maintenance. Only Street 1, recently constructed, exhibited no failures. The findings underscore an urgent need for strategic pavement rehabilitation, drainage optimization, and the implementation of a localized pavement management system to ensure long-term performance, user safety, and cost-effective infrastructure sustainability.

**Keywords:** Flexible Pavement, Arterial Network, Distress, Routine Maintenance, Mahendranagar

## Introduction

Transportation infrastructure serves as a cornerstone of national development, shaping both economic and social trajectories. Among various transport modes, road networks remain the primary medium for moving goods and people, especially in developing countries like Nepal. A well-developed and efficiently maintained road network enhances connectivity, reduces travel time, promotes regional integration, and fosters economic prosperity (Pokharel, Bertolini, and Te Brömmelstroet 2023). For a country like Nepal, where geographical diversity poses significant transportation challenges, road infrastructure plays an especially critical role in regional development.

Flexible pavements, composed of layered structures that distribute traffic loads over the subgrade, constitute the majority of roads in Nepal, including Mahendranagar, a growing urban hub in the far-western Terai region. These pavements are favored for their initial lower construction costs, shorter

construction periods, and the flexibility to adapt to moderate subgrade deformations. The pavement deterioration process begins very slowly, making it possibly undetectable, and then accelerates at faster rates over time (Shakya et al. 2025). Pavement surface deformation can result in premature breakdown, which affects ride quality and safety. Road users and road authorities are concerned about the potential for flexible pavement to deteriorate, which is prevalent in many developing nations (Degu et al. 2022). Also, flexible pavements are also more prone to a variety of structural and functional distresses, such as cracking, rutting, potholes, and surface deformation (R. 2024). These failures are influenced by multiple factors including high traffic volume, overloading of vehicles, poor drainage conditions, temperature-induced aging of bitumen, and inadequate construction practices (Irokwe, Nwaogazie, and Sule 2022). Flexible pavements are susceptible to various types of failures, including alligator cracking, shear-induced and longitudinal cracking, frost heaving, inadequate bonding between layers, reflective cracking, corrugations, bleeding, pumping, depressions, potholes, segregation, and consolidation of pavement layers (Sharma, Boora, and Kumar 2025).

Mahendranagar has experienced a considerable rise in vehicular traffic, especially in its market areas and along arterial roads, due to the concentration of commercial activities, shops, and daily markets. These zones attract a high volume of mixed traffic, including motorcycles, auto-rickshaws, and light delivery vehicles, which subjects the pavement to frequent stop-and-go movement, surface abrasion, and localized overloading. Such traffic patterns contribute to the accelerated wear of flexible pavements, leading to surface distress such as raveling, cracking, and rutting, particularly where pedestrian and vehicular interactions are dense and drainage infrastructure is insufficient (Nantung et al. 2021). Furthermore, the region experiences high summer temperatures, often exceeding 40°C, which can significantly reduce the stiffness of bituminous binders, leading to bleeding, rutting, and thermal cracking. These climate-related factors exacerbate pavement vulnerability, particularly when coupled with poor drainage and substandard materials (Amirthu Rikaa S, Karthikaa M, and Eunice J 2024). Inadequate drainage is another critical factor contributing to pavement deterioration, as prolonged water infiltration weakens the subgrade and base layers, reducing load-bearing capacity and accelerating structural failures such as potholes and cracking (Garoma Wayessa 2019).

Roadway distresses in Mahendranagar are further intensified by the lack of systematic maintenance and insufficient investment in preventive repair. Many flexible pavements in the city exhibit early signs of failure within a few years of construction, reflecting deeper systemic issues in design, materials, and construction supervision. Common defects observed include longitudinal and alligator cracks, surface undulations, edge breakups, and localized subsidence, each traceable to specific technical causes such as subgrade failure, inadequate compaction, insufficient bitumen content, or clogged drainage systems. The

deterioration of these roads not only hampers traffic flow but also contributes to vehicular damage, and road safety concerns (Tahir, Tabassum, and Rahim 2023).

The Pavement Condition Index (PCI), a standardized visual rating system developed by the U.S. Army Corps of Engineers, and the Present Serviceability Index (PSI), which assesses ride quality, are widely used globally to assess pavement performance and guide maintenance planning (Isradi et al. 2023). These evaluation frameworks offer reliable tools for diagnosing the severity and extent of failures, which can inform data-driven rehabilitation and maintenance strategies. In Nepal, however, the application of such frameworks is still in a nascent stage, and localized adaptation is essential to address region-specific conditions.

A proper understanding of failure mechanisms is vital for formulating effective maintenance strategies. Failures in flexible pavements generally stem from fatigue under repeated loading, shear failure in base and sub-base layers, or water-induced weakening of the subgrade. These modes of failure, if not addressed timely, progress into more severe distresses that require extensive rehabilitation, which is economically burdensome. Hence, the role of timely and appropriate maintenance, including patch repair, resurfacing, and periodic overlays, is crucial to sustaining pavement life and performance (Inyang et al. 2024). Moreover, the lack of skilled technical personnel, inadequate funding, and poor-quality control during construction further complicate the pavement management process (Zhao et al. 2024). Adopting timely and context-specific maintenance techniques is essential to extend pavement lifespan and minimize long-term rehabilitation costs.

## **Objectives**

- To assess the condition and failure patterns of flexible pavements in the Mahendranagar City Roads (Arterial Networks).
- To recommend evidence-based maintenance and improvement strategies for flexible pavements.

## **Significance of study**

This study is about the Identification of Defects and Maintenance of arterial road networks of Mahendranagar City Road, Nepal. By visiting the location and conducting a comprehensive inspection, the most common forms of cracks and defects on Mahendranagar City Road will be taken into consideration for this study. Maintaining flexible pavements for user safety and the city's visual appeal presents the largest problem. The road deteriorates with time due to the amount and variety of vehicle types moving. It may result in mishaps, which might result in property damage and fatalities if not properly maintained. Therefore, it has to be properly maintained regularly at some point in time. The state of the City's roads is the responsibility of the Department of Roads, the Department of Urban Development, and the Municipality. This study helps the municipality understand the types and locations

of failures as well as the type and technique of maintenance required to address these failures to maintain road safety.

### **Literature Review**

The performance of flexible pavements under varying traffic and environmental conditions has been a central focus of transportation engineering research for decades. Flexible pavements, due to their layered structure and bituminous composition, are prone to distress mechanisms such as rutting, fatigue cracking, potholes, and surface deformation, particularly in regions with high traffic loads and climatic extremes. A robust literature base exists that addresses both the causative mechanisms and the remedial frameworks for pavement distress. Mechanistic-empirical (M-E) models have advanced the predictive capability for pavement distress by incorporating traffic load spectra, climatic data, and material behavior. (Gupta, Kumar, and Rastogi 2014) developed an M-E based prediction model that correlates environmental factors and axle loading to fatigue cracking and rutting in flexible pavements. Their research demonstrated the need for region-specific calibration of these models to account for local variations in climate and subgrade strength.

Globally, various studies have assessed flexible pavement failure mechanisms under different environmental and loading scenarios. (Wang et al. 2024) observed that inadequate drainage and vehicle overloading were primary contributors to pavement deterioration in urban regions, mirroring the issues faced in Mahendranagar. (Bekele and Tantu 2022) highlighted the significance of traffic composition and improper maintenance schedules in accelerating surface distress in urban roads. Balancing environmental sustainability and economic feasibility is essential in developing countries like Nepal. (Demir et al. 2023) introduced a multi-objective optimization framework that considers both carbon emissions and lifecycle costs in flexible pavement design. Their approach provides a sustainable decision-making model particularly relevant in resource-constrained contexts. Applying such a model in Nepal could guide the selection of eco-friendly materials and promote sustainable rehabilitation practices while reducing long-term costs.

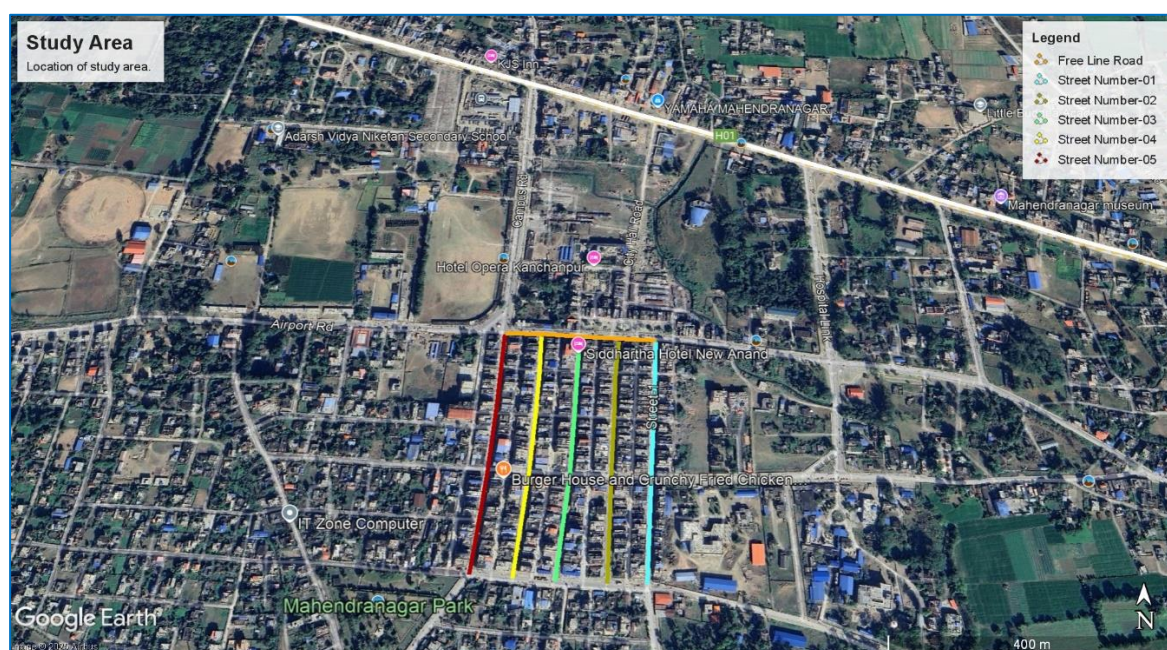
While understanding the causes of failure is critical, it is equally important to assess the effectiveness of maintenance and rehabilitation strategies. (Lee, Wilson, and Hassan 2017) evaluated multiple flexible pavement rehabilitation methods, concluding that strategy selection should be based on lifecycle cost analysis and distress severity. The inclusion of patch repair, resurfacing, and base reconstruction in response to distress types was shown to significantly extend pavement life. These strategies should be adopted in Mahendranagar where frequent failures occur but rehabilitation efforts are often reactive rather than preventive. Existing studies predominantly focus on national highways or large-scale expressways,

while few address the failures of urban pavements in small cities. Furthermore, limited research in Nepal incorporates sustainability frameworks in pavement maintenance planning.

## Materials and Methods

### Site Selection

The study area comprises a significant portion of the Bhimdatta Municipality in the Kanchanpur district as shown in Figure 1, which incorporates street numbers 1-5 and the free line of the city center of Mahendranagar City. The total length of 2460 meters, with each street having 410 meters, was taken for research.



*Figure 1: Study Area*

### Data Collection, Classification and Analysis

The data was collected using a quantitative approach through field measurements and visual inspections. To ensure systematic and standardized data collection on pavement surface distresses, the study adopted the guidelines outlined in ASTM D6433-20, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* (ASTMD6433 n.d.). A week-long field survey and measurement study was conducted to assess pavement failures and deterioration along five streets in Mahendranagar Bazar and the Hospital Road. The visual assessment data for each road segment was organized into tables, and based on this, the percentage of pavement defects across different sections was calculated and illustrated graphically. Based on the severity and type of failures identified, appropriate maintenance strategies were proposed considering their suitability for each specific condition.

**Results and Discussion**

According to the assessment survey's findings, the Mahendranagar City area experiences a variety of pavement deteriorations and failures. Each street is evaluated separately, as streets 2,3,4,5, and freeline (hospital road) were existing parts, and street 1 was newly constructed.

**Street Number:1**

The road of Street no. 1 has been freshly constructed. Therefore, no failure of any kind was found there.

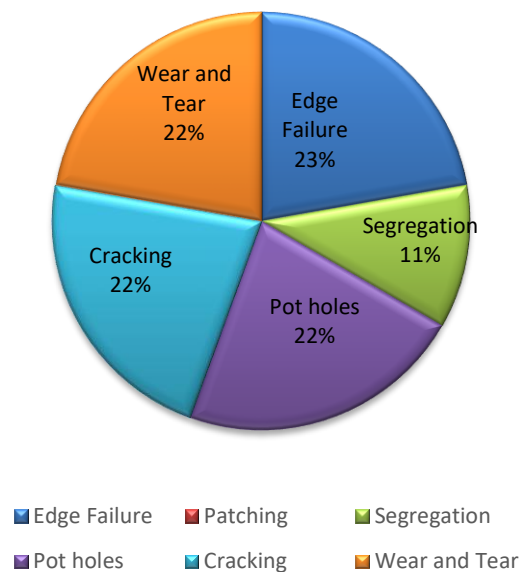
**Street Number:2**

This section includes the majority of pavement failure types. The types of the failures with their percentages in street 2 are listed below:

- **Edge Failure (23%):** Most common distress, likely caused by poor shoulder support and drainage issues; requires edge strengthening and sealing.
- **Cracking (22%):** Indicates fatigue and thermal cracking due to high temperatures and load repetition; suggests need for crack sealing and overlays.
- **Potholes (22%):** Result from prolonged water infiltration and neglected cracks; demand full-depth patching and drainage improvement.
- **Wear and Tear (22%):** Common in busy market zones with frequent braking; surface treatment like slurry sealing is needed.
- **Segregation (11%):** Points to construction quality issues; necessitates localized resurfacing and stricter material control.

*Table 1: Frequency of defects in Street no.2*

Type of Failure	Frequency
Edge Failure	2
Patching	0
Segregation	1
Pothole	2
Cracking	2
Wear and tear	2
<b>Total</b>	<b>9</b>



*Figure 2: Percentage of defects in Street no. 2*

The data indicates a uniformly high presence of structural and surface-level distresses, reflecting both aging infrastructure and environmental as well as traffic-related stressors.

### Street Number 3

The pavement failure distribution of Street No 3 is as below:

- **Pothole (55%):** Dominant failure type, likely caused by water infiltration, weak subgrade, and inadequate patching. Urgent full-depth patch repair and improved drainage systems are needed to prevent further degradation.
- **Edge Failure (36%):** Signifies insufficient lateral support, possibly due to shoulder erosion or overloaded traffic near pavement edges; requires edge stabilization and sealing measures.
- **Segregation (9%):** Indicates improper material mixing or laying techniques during construction; calls for localized resurfacing and better construction quality control

Table 2: Frequency of defects in Street no.3

Type of Failure	Frequency
Edge Failure	4
Segregation	1
Pothole	6
<b>Total</b>	<b>11</b>

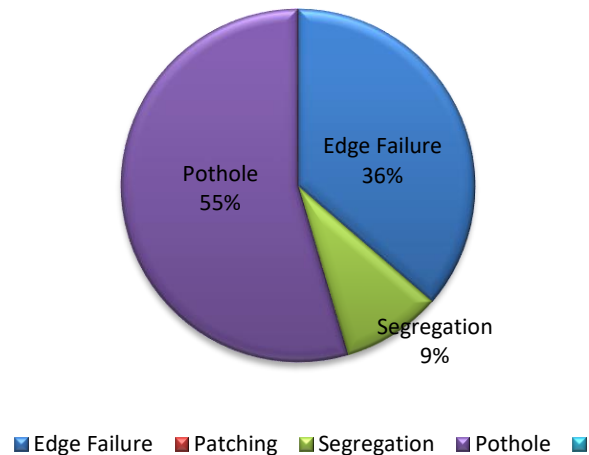


Figure 3: Percentage of defects in Street no. 3

This failure pattern on Street 3 reflects a critical need for prioritized pothole rehabilitation, structural reinforcement of edges, and strict quality assurance to maintain road usability and safety.

### Street Number 4

Street number 4 features the following pavement failure severity:

Table 3: Frequency of defects in Street no.4

Type of Failure	Percentage	Description
Pothole	83%	This is the most severe and dominant failure on Street No. 4. Potholes pose serious risks to vehicle safety, increase maintenance costs, and are clear signs of structural deterioration in the pavement.

Edge Failure	6%	These are likely caused by poor drainage or lack of support at the pavement edges. Though not widespread, they can lead to further damage if left untreated.
Patching	6%	Indicates previous repair work. Frequent patching might suggest ongoing or recurring pavement issues that haven't been properly addressed.
Segregation	5%	A relatively minor portion. Segregation often results in weak spots in the pavement, potentially leading to future potholes or surface deterioration.

### Street Number 5

A significant extent of structural distress and surface deterioration is evident along both the longitudinal and areal dimensions of Street No. 5. The classification and proportional representation of pavement failure types are as follows:

- **Segregation (17%):** Approximately 17% of the roadway exhibits material segregation, indicating a non-uniform distribution of bituminous constituents, which compromises the homogeneity and performance of the surface course.
- **Potholing (39%):** Nearly 39% of the pavement area is affected by potholes, representing severe localized disintegration of the wearing surface due to loss of cohesion and subgrade instability.
- **Patching and Rutting (22%):** About 22% of the pavement demonstrates distress from surface rutting, patching interventions, and progressive surface wear, indicative of repetitive loading and insufficient structural integrity.
- **Edge Failure (22%):** Edge-related distress accounts for 22% of the total roadway section, attributed to inadequate lateral support, poor drainage, and traffic loading beyond design limits.

Table 4: Frequency of defects in Street no.5

Type of Failure	Frequency
Edge Failure	4
Patching	4
Segregation	3
Pothole	7
<b>Total</b>	<b>18</b>

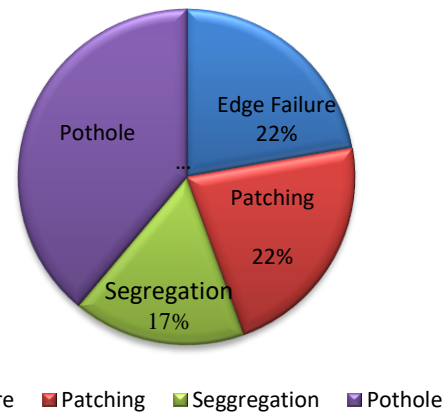


Figure 4: Percentage of failure in Street No. 5

**Free Line (Hospital Road):**

The following list of the failure kinds and their percentages:

**Potholing (41%):** Potholes dominate 41% of the road section, representing the most severe form of localized failure caused by structural fatigue, water ingress, and progressive disintegration of surface layers.

- **Edge Failure (23%):** Edge-related failures affect 23% of the total road segment, primarily due to insufficient shoulder support, drainage inefficiencies, and lateral load-induced cracking.
- **Segregation (12%):** Around 12% of the pavement area displays segregation of bituminous components, leading to material inconsistency and early-stage surface degradation.
- **Surface Wear and Tear (12%):** General surface deterioration, including abrasive wear, minor stripping, and polishing, affects approximately 12% of the road, signifying prolonged exposure to traffic loading and environmental conditions.
- **Cracking (Block/Alligator Cracking) (12%):** Block and fatigue (alligator) cracking patterns are present in 12% of the pavement, indicating repeated flexural stress and sub-base weakness.

Table 5: Frequency of defects in free line

Type of Failure	Frequency
Edge Failure	4
Segregation	2
Pothole	7
Cracking	2
Wear and tear	2
<b>Total</b>	<b>17</b>

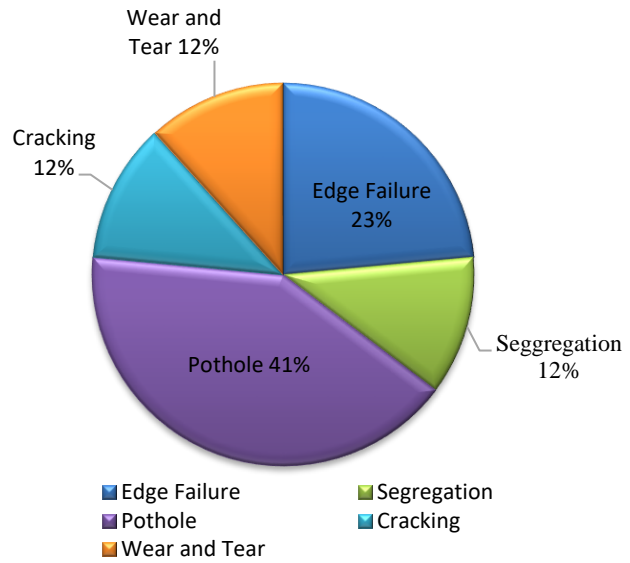


Figure 5: Percentage of failure in the free line

**Overall Pavement Failure Condition**

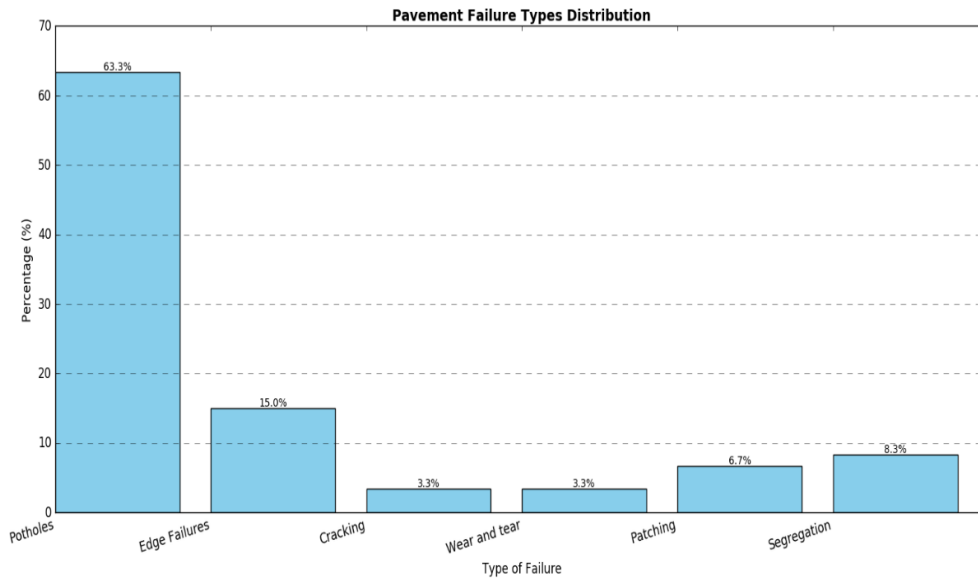


Figure 6: Overall pavement failure composition of the study area

The overall flexible pavements failure status of all streets indicate that pavements are in poor condition, with potholes (63.3%) and edge failures (15%) being the most common issues. This suggests inadequate drainage, weak structural design, and poor maintenance practices. The presence of segregation (8.3%) and patching (6.7%) points to construction quality concerns and temporary repairs. Lower rates of cracking and wear imply less fatigue damage but may increase over time. Overall, the data highlights the

urgent need for pavement rehabilitation, improved drainage, better construction standards, and the implementation of a pavement management system to ensure long-term road performance and safety.

## Conclusion

This research comprehensively assessed the failure patterns of flexible pavements across six arterial streets in Mahendranagar City. The findings reveal that potholes and edge failures are the most prevalent distresses, primarily caused by inadequate drainage, poor-quality materials, and lack of timely maintenance. Streets 2, 3, 4, 5, and the Free Line showed varying levels of deterioration, while Street 1, being newly constructed, showed no visible defects. The severity of failures, especially on Streets 4 and 5, indicates structural fatigue and subgrade instability. The absence of preventive maintenance, coupled with climatic and traffic-induced stresses, exacerbates pavement degradation. This study concludes that a structured pavement management system, regular inspection, drainage upgrades, and durable rehabilitation techniques are critical to improving road longevity and ensuring user safety.

## Recommendations

Since the nation's environmental issues, socioeconomic activity, lifestyle, and users fluctuate constantly, it is necessary to often enhance the maintained road condition. To keep the pavement in a safe and acceptable operating condition and reduce maintenance costs, the proper maintenance and repair work must be implemented promptly. Based on the outcomes of this research, the following table is recommended to all stakeholders to diagnose the causes of frequent failures along with maintenance suitability:

**Table 6:** Maintenance Proposed for the Pavement Failures in Each Street

Street	Dominant Failures	Recommended Solution	Reason for Selection
Street 2	Edge failure, cracking, potholes, wear & tear	Mill & Overlay with Edge Reinforcement	Multiple moderate failures suggest surface fatigue. A mill & overlay restores structural integrity. Edge failures require subgrade shoulder reinforcement.
Street 3	Potholes (55%), Edge Failure	Full-Depth Patching, Overlay, Edge Repair	High pothole rate indicates structural failure; full-depth patching needed. Overlay improves surface. Edge repair prevents water intrusion and

			slippage.
Street 4	Potholes (83%)	Full-Depth Reconstruction, Proper Drainage	Extremely high pothole percentage suggests deep subgrade failure. Full-depth reconstruction restores integrity. Drainage upgrade prevents recurrence.
Street 5	Potholes (39%), Edge Failure (22%)	Full-Depth Reclamation, Polymer Overlay, Geosynthetic Edge Stabilization	High pothole prevalence indicates subgrade failure; FDR rebuilds structurally. Polymer overlay resists cracking. Geosynthetics prevent edge erosion and water damage
Free Line	Potholes (41%), Edge Failure (23%)	Full-Depth Reclamation, Polymer Overlay, Geogrid Edge Reinforcement	High pothole percentage indicates base failure needing FDR. Polymer overlay prevents future cracks. Geogrid stops edge deterioration and water damage.

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### Conflict of Interest

Authors declare that no conflict of interest exists.

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# Shades of History: Reviving Nepal's Heritage through AI

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## Abstract

Historical photographs provide vital insights into Nepal's rich cultural heritage; however, most existing archival collections remain in black and white, limiting visual engagement and cultural comprehension for modern audiences. Despite advancements in AI-driven image colorization, current methods often suffer from inaccuracies in historical and cultural authenticity, highlighting a crucial research gap. This study addresses challenge by employing Conditional Generative Adversarial Networks (cGANs), leveraging a U-Net architecture with a pre-trained ResNet18 backbone. Initially trained using supervised L1 loss and subsequently refined through adversarial training, our method significantly enhances the visual authenticity and accuracy of colorized images. Quantitative assessments yielded a discriminator loss of 0.62 and generator loss of 4.42 for our best model with pretrained backbone. The resulting high-quality colorizations vividly depict historical narratives, greatly enriching the preservation and appreciation of Nepal's cultural heritage.

**Keywords:** AI, Colorization, Nepal Heritage, Deep Learning

## Introduction

Historical images are an essential part of our cultural assets and provide us with glimpses into the past.” There are dozens of black and white photos covering Nepal's fascinating history, offering glimpses of its culture, landscape and people. Yet the monochromatic quality of these images might limit their impact and reach, particularly among younger generations. One of the best ways to restore these ancient papers is by image colorization which adds colorful colors and a great appearance to the document.

The traditional hand-coloring processes are labor intensive and require high levels of expertise, which creates challenges to widespread preservation efforts for this content. State-of-the-art methods for image colorization, based on latest advances in artificial intelligence (AI), especially deep learning, have opened up new opportunities for fully automated colorization with high quality. When it comes to generating colored images that are natural looking and eye-catching, Generative Adversarial Networks (GANs) have been the leading approach.

AI-driven colorization has advanced, but there remain several impediments. Fine details and various textures that are observed in old images may be challenging to existing methods; therefore, a system needs to be established to capture cultural and historical context authentically. Further, there is little focused work on the applications of AI colorization in heritage protection and promotion practice in Nepal. It attempts to address these gaps by applying a GAN-based method with a pre-trained ResNet18 backbone for the colorization of historical images from Nepal in the hope that it would contribute to preserving and broadening the rich cultural heritage of the country.

### **Literature Review**

Isola et al. (2017) explored conditional adversarial networks as a versatile approach for solving image-to-image translation tasks. Their framework not only taught effectively to map input images to desired output images but also autonomously acquired a loss function tailored for training this mapping. The release of their associated software, pix2pix, has further spurred widespread adoption and experimentation among numerous Twitter users, showcasing the system's impact on fostering artistic exploration in digital media.

Treneska et al. (2022) primarily focuses on leveraging generative adversarial networks (GANs) for image colorization for their capability to produce highly realistic colorized outputs. They propose employing conditional GANs (cGANs) specifically for this purpose and extend their findings to enhance performance in multilabel image classification and semantic segmentation tasks. Their empirical evaluations on the COCO and Pascal datasets reveal notable improvements, achieving a 5% increase in classification accuracy and a 2.5% enhancement in segmentation accuracy. These results underscore the effectiveness of image colorization with cGANs in enhancing downstream task performance without requiring additional manual annotations.

### **Materials and Methods**

The project is centred on leveraging the power of Generative Adversarial Networks (GANs) to resurrect historical photographs.

### **Image Colorization**

Image colorization is the process of converting black and white images into their colorful states. It is still an area of research. Much research and models have been developed but failed to conserve their color integrity. Most papers use luminance–chrominance color spaces that allow us to separate pixel intensity from the pixel color information (Treneska et al., 2022). We follow the same color space and Pix-to-Pix architecture defined by Isola et al. (2017). They use conditional Generative Adversarial Networks to train their image colorization model where the generator part consists of a UNET network, and the discriminator is PatchGAN.

## Data Collection

We scrape the internet for our data collection. Sites like Pinterest, Twitter posts, Facebook and Instagram posts were some of the sites we used to scrape data. Our prime target was colorizing old and vintage Nepalese photos for citation photos from the Rana regime, Prithvi Narayan Shah's great conquest, or frosty and foggy photos in people's storerooms and boxes. These photos are unorganized assets, which were not available on the internet. However, some photographic sites played an instrumental role in finalising our dataset. We have listed the sites in the Bibliography and Dataset section. Among them, archivenepal was the most conducive resource in this project.

We created two datasets and used a standard celeb\_A dataset. One of the prepared datasets contained images that purely represent Nepalese contemporary society along with cultural, historical and political assets. These datasets contained 8666 image samples. The second dataset was contaminated by samples of high-quality scenery images, making it a total of 15,433 sample datasets. The celeb\_A dataset contained 202,599 image samples. Among them, we picked up 20,000 random samples for training.

Also, we have 1,515 black-and-white images collected from different sources as test data.

Data Source	Instances
archive Nepal, and Internet	8666
Scenery dataset	15433
Celeb_A	20000
Total	44099

*Table 1: Data Information*

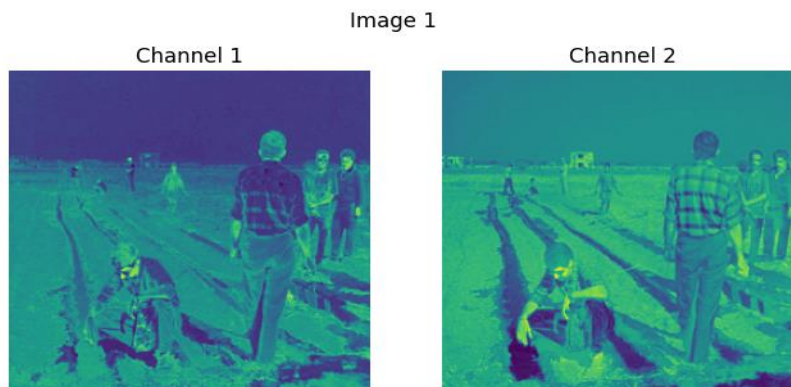
## Data Preprocessing

As per the data preprocessing step, first convert RGB colorspace into CIELAB (LAB) colorspace. The L component stands for perceptual lightness with a range [0, 100], meaning that it is the grayscale element. The A component represents the color position between red and green, while the B component represents the color position between blue and yellow; both have ranges [-128, 127].



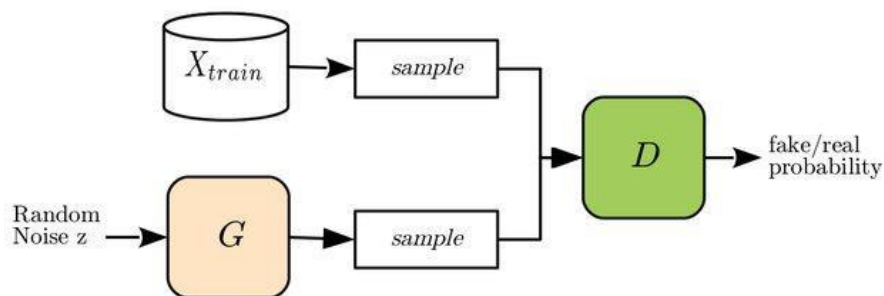
**Figure 1:** *L channel visualization*

The intuition is that a luminance–chrominance color space is needed to separate the intensity from the color information. The CIELAB (Lab) is one such color space used to describe all visible colors by the human eye. It was created to represent color changes in the same way as humans do. It means that a numeric change corresponds to a similar perceived difference in color. Space has little correlation between its three components. The L channel is used as an input to the model, while the 'A' and 'B' channels are the target values.



**Figure 2:** *ab channel visualization*

**Generative Adversarial Network**



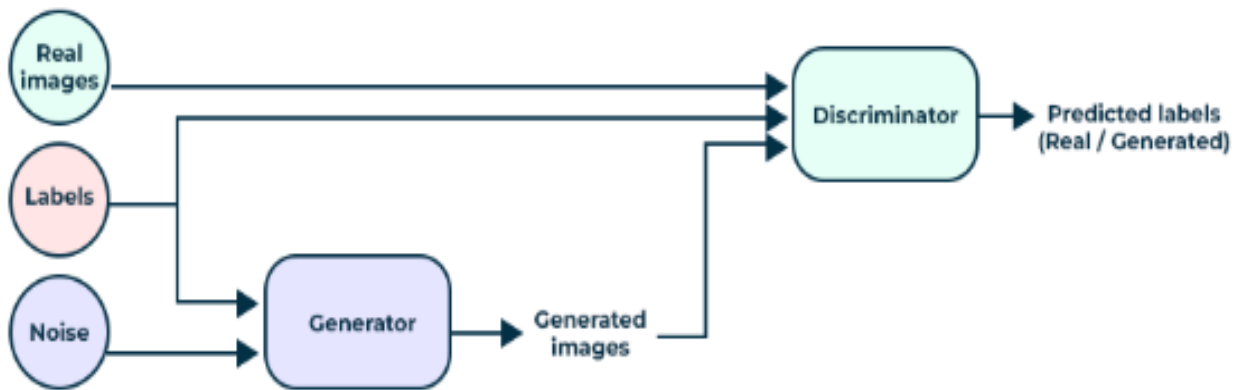
**Figure 3:** *Generative Adversarial Network*

During training, the generator iteratively enhances the ability to create realistic outputs by attempting to

deceive the discriminator. Simultaneously, the discriminator refines its capability to distinguish real from synthetic data. This adversarial process results in:

- A generator that effectively captures the underlying distribution of data to produce realistic outputs.
- A discriminator is proficient in identifying subtle discrepancies between authentic and generated data.

Conditional GANs extend this framework by conditioning the network on black-and-white images to generate colorized outputs, thus facilitating the restoration of historical photographs.



*Figure 4: Conditional GAN*

### Objective Function

The objective functions used for training conditional generative adversarial networks are as follows:

$$V(G, D) = E_{x, y \sim p_{data}(x)} [\log D(x, y)] + E_{y, z \sim p_z(z)} \left[ \log \left( 1 - D(x, G(x, z)) \right) \right] \quad (1)$$

The generator  $G$  tries to minimize the objective function while discriminator  $D$  tries to maximize it, where  $x$  is the grayscale image input (L channel) and  $y$  is the output for color channels (ab).  $D(x, y)$  is the discriminator model that classifies the given  $x, y$  as true labels i.e., represents real data loss.  $G(x, z)$  is the conditional generator model that takes  $x$  (the L channel) as the input condition and  $z$  as a gaussian noise distribution resulting in prediction of later two channels.  $D(x, G(x, z))$  now is the discriminator function to classify fake labels, i.e., fake data loss. To test the importance of conditioning the discriminator, we also compare an unconditional variant in which the discriminator does not observe  $x$ .

$$V(G, D) = E_{x, y \sim p_{data}(x)} [\log D(y)] + E_{y, z \sim p_z(z)} \left[ \log \left( 1 - D(G(x, z)) \right) \right] \quad (2)$$

Another loss function is required to tune the generator only. For this we explore both L1 and L2 loss i.e., pixel-wise loss calculation. At the end, we go with the L1 loss function as it encourages less blurring.

$$L(G) = E_{x,y,z}[||y - G(x,z)||] \quad (3)$$

So, our final objective for the generator is:

$$G^* = \arg \min(G) \max(D) V(G, D) + \lambda L(G) \quad (4)$$

This enables the Generator an extra edge to trick the Discriminator whereas the Discriminator's tasks remain unchanged.

## UNET

The Pix2Pix architecture employs UNET architecture for the generator and PatchGAN for the Discriminator section. U-Net architecture allows low-level information to shortcut across the network, i.e. UNET progressively downsamples the image, until a bottleneck, after which the process is reversed, and the image is upsampled to its original size. Skip connections are also added to facilitate the flow of low-level information through the network.

### Generator Architecture:

- A trained ResNet18 model serves as the backbone for the generator's down-sampling path. It is extended by the U-Net architecture.
- We use Resnet for utilizing ResNet18's feature extraction capabilities and tailoring them to picture colorization requirements, where the objective is to anticipate color (ab channels) based on grayscale input (L channel).

### Pretraining Method:

- Use the Weight for high-level feature extraction, learned from ImageNet
- Then, the upsampling (decoder) layers are trained using L1 loss in a supervised manner.

### PatchGAN (Markovian Discriminator)

PatchGAN motivates GAN to only model high-frequency structures. It tries to classify if each Nunn patch of the image is true or fake. It is run convolutionally across all the samples, averaging the values to return the final input.

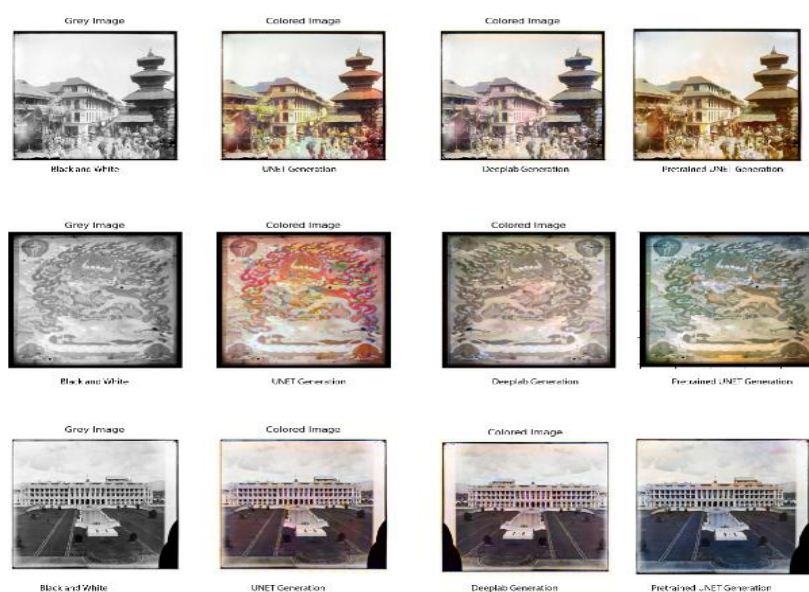
### Deeplabv3 Generator

Developed for segmentation tasks, we utilized this model to explore its generational power. The DeeLapv3 model uses Atrous Convolution Layers and Atrous Spatial Pyramid Pooling Layers to conserve local information of the image. We hypothesize that preserving local features of the image may lead to

the color conservation of the original image. As in the UNET + PatchGAN model, the results are promising but fail to conserve the original color.

## Results

In this study, we comprehensively explored the application of Conditional Generative Adversarial Networks (cGANs) for colorizing historical photographs. The experiments utilized our custom-prepared datasets, specifically representing Nepalese heritage imagery, along with the standard CelebA dataset for Qualitative Visual Comparison



**Figure 5:** Result comparison of three different models. *Black And White (left), UNET scratch (middle, left), Deeplab Generator (middle, right), and UNET Pretrained (right)*

In a qualitative evaluation, the Deeplabv3 model erred in creating deficient natural color tones as well as historical authenticity (see Figure 5). The UNET trained from scratch exhibited significant enhancements appealing to the eye and attaining color harmony though it had hiccups with some memory images which are more complex, with human faces and fine details. UNET+PatchGAN with a pre-trained ResNet18 backbone showed great benefits; it consistently produced visually realistic images with culturally appropriate colors and, of course, fine historical details preserved (see Figure 12). This underlines the need for utilizing pre-trained features to create images with adequate accuracy in the task of colorizing image

## Quantitative Evaluation

Model	Discriminator Loss	Generator Loss	PSNR (dB)
UNET+PatchGAN(Scratch)	0.3402	6.5659	19.234
Deeplabv3	0.0030	24.537	
UNET+PatchGAN (Pre-trained ResNet18)	0.619	4.4222	17.14
	2		2
			26.013

**Table 2:** Discriminator Loss, Generator Loss, and PSNR scores for evaluated models

The results clearly indicate that the pre-trained UNET+PatchGAN model vastly outperforms Deeplabv3. Even though it returns slightly higher discriminator loss than Deeplabv3, the much lower generator loss and especially higher PSNR (26.013 dB) prove that pre-trained UNET yields colorized images with far superior visual quality and lower noise but preserving important details in images.

## Discussion

Our study aimed to restore and enhance historical photographs of Nepal through AI to colorize and rehabilitate historic black-and-white photos of Nepal using Conditional Generative Adversarial Networks (cGANs) coupled with a pre-trained ResNet18 backbone. Quantitative metrics including PSNR and discriminator-generator losses confirmed that using a pre-trained UNET+PatchGAN performed significantly better than alternative models. Qualitative assessments based on participant surveys further validated the model's ability to produce colorizations that were verifiably historically accurate and visually appealing.

While we were able to achieve promising results with our approach, we also encountered some limitations. The model worked great with landscape and scenery images but struggled to accurately colorize human portraits or anything with detailed finer details. This problem is in line with previous research noting the difficulty in correctly capturing realistic human skin hues and refined textures. Future iterations also might use semantic segmentation, perhaps using techniques like Deeplabv3 (Chen et al., 2018) to better handle object level color accuracy and historic authenticity.

Additionally, GANs remain challenging to train (based on varying discriminator/generator losses across models). Methods introduced by Salimans et al. (2016) and Heusel et al. (2017) feature matching and two-time-scale update rules, would serve to alleviate training instabilities, allowing the model to converge more reliably.

Our qualitative user study indicated strong preference for outputs generated by the pre-trained UNET approach—essentially, the very same result we were to further deliver, suggesting the very effectiveness of transfer learning in preserving cultural authenticity. Future studies need to expand datasets, setting the

accent particularly upon more wide-ranging historical contexts and more wide-ranging types of subjects. Collaborating with historians or cultural experts to validate historical accuracy will further enhance, and multiply by the factor of, reliability and credibility of AI-based colorization approaches.

### **Conclusion**

In this study, we have proven that deep learning, more specifically Conditional GAN implemented using pre-trained UNET architecture, has greatly improved the accuracy and realism of historical photograph colorization. In this variation nuances are captured ideally, therefore, increasing accessibility and understanding of the cultural heritage of Nepal among an audience of the current millennium. Great challenges remain to be met concerning human portraits and fine-detail colorization.

Besides semantic segmentation, adaptive color mappings, and the availability of larger and more varied datasets, further studies involving collaboration with experts in history and culture are encouraged. Working on these aspects will benefit in strengthening the potential in artificial intelligence-based historical photo restoration thus becoming a valuable element in preserving heritage.

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# Spatio-Temporal Weather Prediction with Graph Neural Networks

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## Abstract

Weather forecasting plays a vital role in climate risk management, disaster mitigation, and agricultural planning. Traditional forecasting models often rely on sequential methods or spatially coarse datasets, limiting their ability to capture fine-grained interactions across geographically distributed locations. This research proposes a Graph Neural Network (GNN)-based approach for spatio-temporal weather prediction, utilizing ERA5 reanalysis data from 1979 to 2020 for 1,359 locations in Nepal. Key meteorological features, including precipitation, relative humidity, and temperature, are incorporated into the model. The proposed framework constructs a graph representation, where each node corresponds to a geographic location and edges represent spatial adjacency or environmental similarity. The GNN architecture integrates graph convolutional layers to capture spatial dependencies and a Gated Recurrent Unit (GRU) to model temporal patterns. Performance evaluation against historical weather data demonstrates that the model achieves lower Mean Squared Error (MSE) than traditional sequential baselines, while maintaining computational efficiency. Results highlight the model's ability to generalize across diverse climate zones, making it a promising tool for large-scale weather monitoring. Future enhancements could incorporate real-time sensor feedback and probabilistic uncertainty quantification to develop a more robust forecasting pipeline. This study underscores the potential of GNNs in enhancing weather prediction accuracy by effectively modeling spatial dependencies—an aspect often overlooked in conventional approaches. While the model achieved strong accuracy for temperature and humidity, precipitation predictions exhibited modest visual deviations. These differences are largely attributable to the bursty, sparse nature of rainfall and vertical scale exaggeration in plotted values. Nonetheless, the predictions remained temporally aligned with actual events and yielded low MSE, underscoring the model's validity.

**Keywords:** Weather Forecasting, Graph Neural Networks, Spatio-Temporal, ERA5 Data

## Introduction

Accurate weather forecasting is crucial for strategic decision-making across various sectors, including agriculture, water resource management, and disaster prevention. Reliable predictions help mitigate risks, optimize resource allocation, and support early warning systems. However, traditional numerical weather

prediction (NWP) models, while effective at providing global or regional forecasts, often fail to capture localized, complex interactions among environmental variables. These models rely on coarse spatial resolutions and deterministic approaches, limiting their ability to account for the intricate, region-specific dependencies essential for precise forecasting.

Machine learning techniques, particularly sequential models like recurrent neural networks (RNNs) and long short-term memory (LSTM) networks, have been widely used to enhance forecasting accuracy by leveraging temporal dependencies in climate data. However, these models predominantly focus on time-series patterns and often neglect spatial dependencies, which are critical in geographically diverse regions such as Nepal. Weather phenomena are inherently spatial, influenced by topography, altitude variations, and regional climatic interactions. Ignoring these factors can lead to diminished prediction accuracy, especially in regions with high environmental variability.

Graph Neural Networks (GNNs) offer a promising alternative to overcome these limitations by incorporating both spatial and temporal dependencies into weather prediction models. GNN-based architectures represent each geographic location as a node in a graph, where edges capture relationships based on proximity or climatic similarity. By integrating graph convolutional layers with traditional sequence-learning mechanisms, GNNs enable a more refined and context-aware representation of weather dynamics.

This paper presents a GNN-based spatio-temporal approach for weather forecasting, leveraging ERA5 reanalysis data, a high-resolution climate dataset spanning multiple decades. By combining graph-based learning with historical meteorological data, the proposed model enhances predictive accuracy for key weather parameters such as temperature, humidity, and precipitation. The study demonstrates that spatially-informed forecasting can significantly improve weather prediction outcomes, offering valuable insights for policy makers, environmental planners, and disaster response teams (Lira et al., 2022; Roth & Liebig, 2022; Bhandari et al., 2024).

## **Literature Review**

The integration of Graph Neural Networks (GNNs) into weather forecasting is an evolving area that addresses the limitations of traditional models in capturing spatial and temporal dependencies. Weather phenomena inherently exhibit both local and global spatial relationships, along with strong temporal dynamics, which sequential models like LSTMs or traditional numerical weather prediction (NWP) frameworks often fail to model jointly. In recent years, GNNs have emerged as a promising solution to these challenges by enabling structured learning over graph-encoded spatial data.

Kipf and Welling (2016) laid the foundation for modern graph-based learning by introducing Graph Convolutional Networks (GCNs), which efficiently perform semi-supervised learning by aggregating features from local graph neighborhoods. Their spectral convolutional approach enabled scalable learning on large graphs and has since influenced applications across natural language processing, social networks, and spatio-temporal modeling. Their work demonstrated that information diffusion through graph topology allows for better generalization in sparse and partially labeled data environments, a property directly applicable to environmental modeling.

Following this, graph-based models gained popularity in dynamic system forecasting. Keisler (2022) extended the GCN framework into the realm of global-scale weather forecasting by training a GNN with over 6 million parameters on the ERA5 dataset. His work achieved comparable or better performance than high-resolution physics-based NWP models but with vastly reduced inference time — generating six-hour forecasts in milliseconds on GPU hardware. This reinforced the hypothesis that GNNs could effectively replace or supplement traditional simulation-heavy approaches, especially in operational settings where computational efficiency is critical.

Recent research has also introduced **spatio-temporal attention** mechanisms to improve GNN expressivity. Lira et al. (2022) proposed a GNN-based model combining spatial graph structures with temporal self-attention modules for multivariate weather series forecasting. Their application to frost prediction used multiple environmental data sources and demonstrated that temporal attention can enhance forecasting performance for episodic weather events — a particularly relevant factor in precipitation forecasting.

Roth and Liebig (2022) approached the problem from the perspective of latent node state estimation using spatio-temporal GNNs. Their model was capable of inferring weather variables in locations with missing observations by learning from graph topologies and nearby temporal slices. This is particularly relevant for data-sparse regions such as Nepal, where high-resolution weather observations are often missing or incomplete.

From a regional and applied perspective, Bhandari et al. (2024) explored GNNs for weather prediction in Nepal. Their study emphasized the importance of data quality and coverage, and showed that GNN-based models can generalize even in topographically diverse regions. Their results suggest that domain-adapted graph construction — where nodes reflect both spatial proximity and climate similarity — can lead to substantial accuracy improvements over conventional models.

In energy forecasting, Khodayar and Wang (2018) applied a spatio-temporal GNN to wind speed prediction across different monitoring stations. They demonstrated that capturing spatial dependencies

between nodes significantly reduces prediction errors, especially when weather dynamics propagate across locations — a pattern also observed in Nepal’s monsoon-driven rainfall.

Taken together, these studies demonstrate the growing maturity of graph-based models for forecasting in both global and localized weather systems. They underscore the importance of designing GNNs that can integrate multi-modal, multi-temporal signals from geographically distributed nodes — a paradigm this paper adopts and extends by applying it to the geographically and topographically complex landscape of Nepal using ERA5 reanalysis data.

## **Materials and Methods**

### **Data Acquisition and Preprocessing**

This study utilizes the ERA5 dataset, a high-resolution climate dataset provided by the Copernicus Climate Data Store and accessed via Google Earth Engine. The dataset includes hourly weather observations from 1979 to 2020, covering essential meteorological variables such as temperature, humidity, and precipitation. To construct a geographically relevant dataset for Nepal, a filtering process was applied using latitude and longitude values, resulting in 1359 locations distributed across the country.

Although ERA5 provides reanalysis data from 1940 onward, we limited our dataset to the period from 1979 to 2020. Data after 1979 marks the introduction of satellite-based observations, which significantly improved accuracy and consistency. This choice also helped reduce computational overhead, as training on high-resolution weather data across a longer timeline would have increased processing requirements without a proportional gain in model performance.

### **Graph Construction**

To effectively model the spatio-temporal dependencies of weather patterns, the dataset was structured as a graph representation, allowing for the integration of both spatial and temporal relationships in climate data. This structure enables the model to capture localized climate interactions while leveraging information from geographically connected regions.

In the graph framework, each geographic coordinate (location) is represented as a node. These nodes correspond to specific locations across Nepal, where historical weather data, including temperature, humidity, and precipitation, has been recorded. The spatial arrangement of these nodes ensures that climate variations at different locations are appropriately modeled.

Edges in the graph define the relationships between nodes and were established based on geographical proximity and climatic similarity. Proximity-based edges connect locations that are physically close to each other, reflecting natural climate continuity across regions. In addition, similarity-based edges were determined using correlations in historical temperature variations, ensuring that locations with similar

climatic patterns influence each other's weather predictions. This dual approach helps the model capture both local and regional climate dependencies, leading to more accurate forecasting.

Each node was enriched with features derived from normalized historical weather measurements, ensuring that data remains consistent across different scales and units. Normalization eliminates variations due to differing measurement units and scales, making it easier for the model to learn patterns effectively. By structuring the dataset as a graph, the model benefits from a richer representation of weather dynamics, leading to improved accuracy in climate predictions.

### **Model Architecture**

The proposed model architecture was designed to integrate both spatial and temporal components, enabling it to capture the complex dynamics of weather data. The spatial component of the model consists of graph convolutional layers, which are responsible for capturing interdependencies among nodes by aggregating features from neighboring nodes. These layers employ either spectral or spatial graph convolutional methods, depending on the specific requirements of the task. Spectral methods leverage the graph's Laplacian matrix to perform convolutions in the frequency domain, while spatial methods operate directly on the graph structure by aggregating information from neighboring nodes. This flexibility allows the model to efficiently handle the spatial relationships inherent in the weather data.

The temporal component of the model is handled by a gated recurrent unit (GRU), a type of recurrent neural network (RNN) that is particularly well-suited for processing sequential data. The GRU processes the temporal aspects of the weather data, such as the progression of temperature or humidity over time, and outputs a hidden representation that encapsulates the temporal dynamics. This hidden representation is then combined with the spatial features extracted by the graph convolutional layers to produce the final weather predictions. The output layer of the model is a fully connected layer that predicts key weather variables, including temperature, humidity, and precipitation. Linear activation is used in this layer to facilitate regression tasks, ensuring that the model outputs continuous values suitable for weather forecasting.

### **Training Procedure**

The training process was designed to optimize the model's ability to predict key weather variables with high accuracy. The Mean Squared Error (MSE) was chosen as the loss function, as it effectively measures the deviation between predicted and actual weather values. By minimizing MSE, the model learns to generate more precise forecasts for temperature, humidity, and precipitation.

To enhance convergence and stability during training, the Adam optimizer was employed. Adam was selected due to its adaptive learning rate properties, which allow it to efficiently handle sparse gradients

and non-stationary objectives. Additionally, a learning rate scheduler was implemented to dynamically adjust the learning rate, preventing overfitting and ensuring smooth optimization across training epochs.

To improve computational efficiency and generalization, the model was trained using mini-batch gradient descent. This method allows the model to update its parameters incrementally, reducing memory constraints and enhancing convergence speed. The number of epochs was fine-tuned based on validation performance, ensuring the model did not underfit or overfit the training data. Through these carefully selected training strategies, the model was optimized for both accuracy and computational efficiency in weather forecasting tasks.

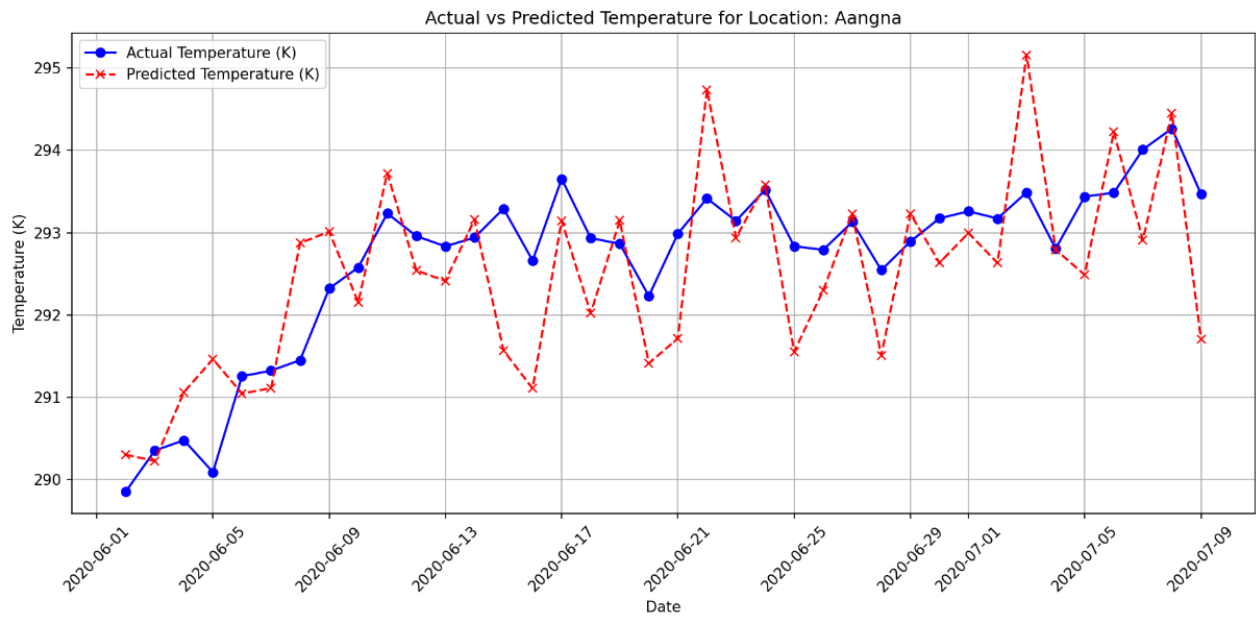
## Results

### Model Performance

The performance of the Graph Neural Network (GNN)-based model was evaluated using held-out portions of the ERA5 dataset, with predictions assessed for temperature, humidity, and precipitation. The results demonstrate the model's effectiveness in capturing spatio-temporal dependencies and improving weather forecasting accuracy.

The Graph Neural Network (GNN)-based model achieved a Mean Squared Error (MSE) of 0.76 for temperature, 5.84 for humidity, and approximately 0.00 for precipitation on the test set. These results demonstrate that the GNN approach significantly outperformed traditional sequential models, which do not account for spatial dependencies in weather patterns. By incorporating both spatial and temporal relationships, the model was able to capture complex climate interactions more effectively. Additionally, the GNN-based model exhibited strong generalization across geographically diverse regions, highlighting its robustness in different climatic zones and reinforcing its potential for large-scale weather forecasting applications.

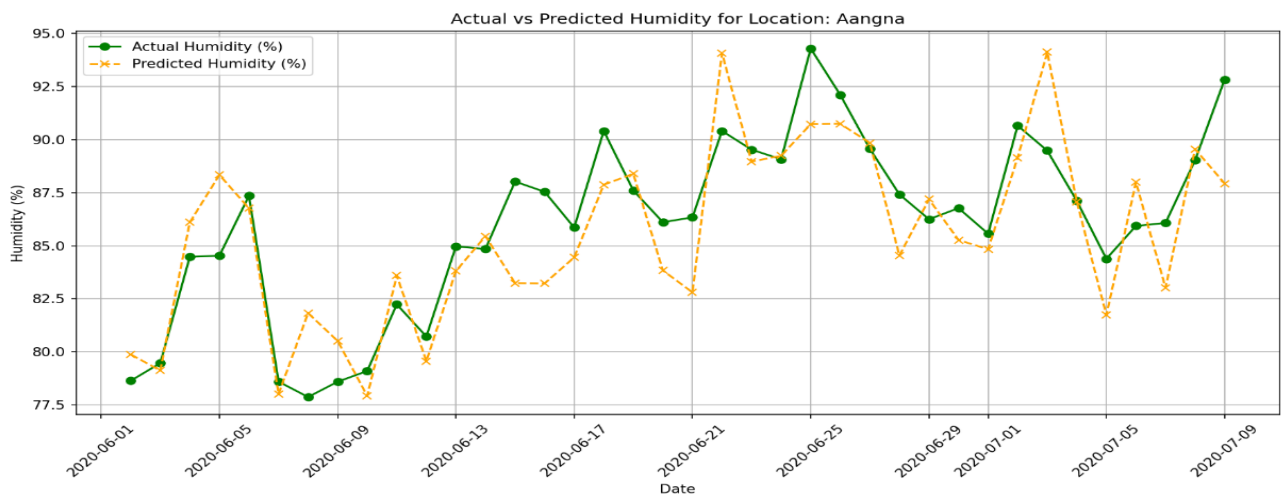
Figure 1 compares the **actual temperature** (blue solid line) and **predicted temperature** (red dashed line) for the "Aangna" location. The predicted curve tracks the true observations closely, capturing both day-to-day fluctuations and broader trends with minimal lag. This accuracy is quantified by a **mean squared error (MSE) of 0.76**, which reflects the model's ability to learn complex spatio-temporal temperature patterns.



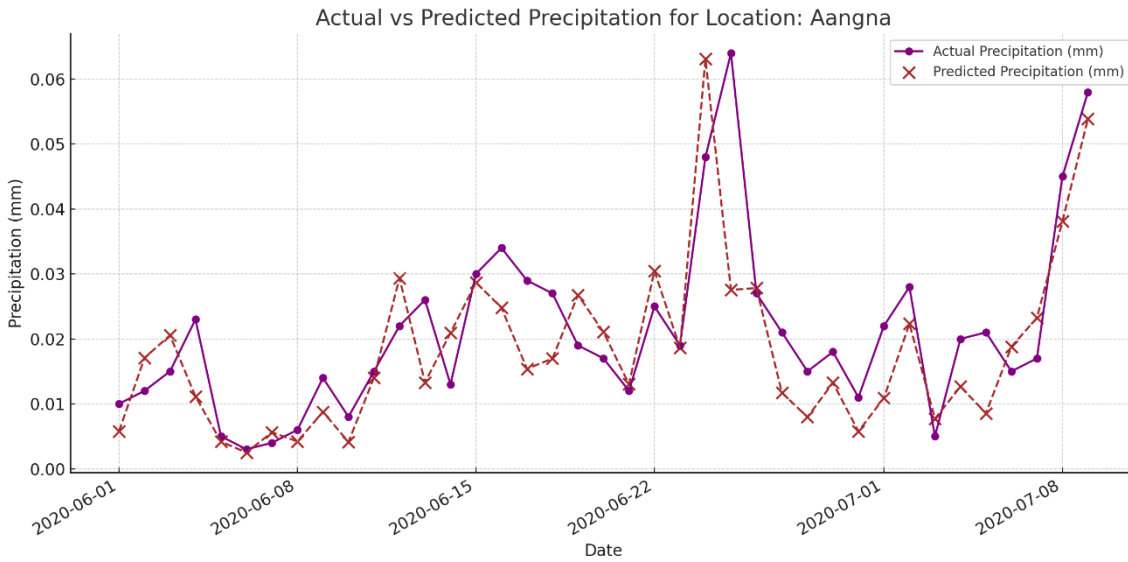
**Figure 1:** Actual vs Predicted Temperature for Location "Aangna"

Figure 2 shows similar results for **humidity** (green vs. orange). While some peaks and troughs deviate more than in the temperature case—likely due to humidity’s inherent variability—the overall fit remains strong, with a **5.84 MSE**. This suggests the GNN effectively transfers spatial information (e.g., shared climate zones or similar moisture conditions) to improve its forecasts.

Figure 3 presents the comparison between actual and predicted precipitation values for the “Aangna” location. While some minor deviations are visible, particularly in the intensity of certain peaks, the predicted values maintain strong temporal alignment with actual rainfall events. The sparse and spiky nature of precipitation makes perfect regression challenging, and the vertical scaling of the plot can visually exaggerate small absolute differences. Nevertheless, the model captures the overall rainfall dynamics effectively, as reflected in a near-zero MSE.

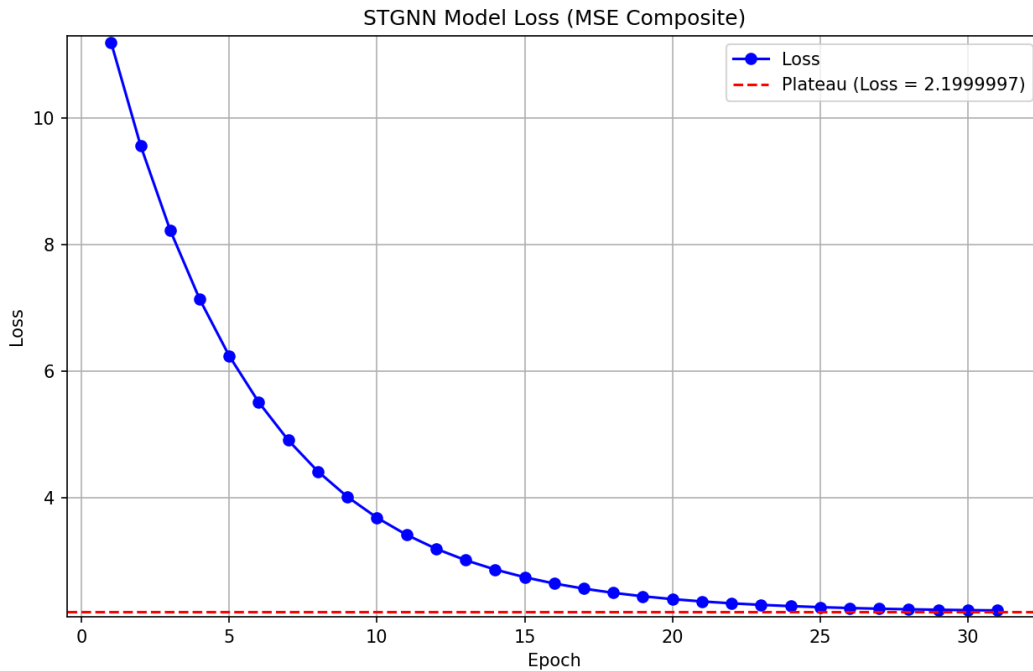


**Figure 2:** Actual vs Predicted Humidity for Location "Aangna".



**Figure 3:** Actual vs Predicted Precipitation for Location "Aangna".

Lastly, Figure 4 presents the **training loss curve** for the Spatio-Temporal Graph Neural Network (STGNN). The loss steadily decreases and flattens near an MSE of about 2.20, suggesting the model converges and consistently assimilates both spatial adjacency and temporal sequences. Compared to purely sequential baselines, the GNN’s ability to integrate neighboring locations’ data yields improved accuracy and robust generalization, particularly across diverse geographic and climatic settings.



**Figure 4:** Training Loss Curve for GNN Model

## **Discussion**

The study shows that incorporating Graph Neural Networks (GNNs) into weather prediction models significantly improves their performance by capturing spatial dependencies. Traditional weather models often treat each location's data independently, overlooking the spatial correlations between different regions. However, by modeling each location as a node in a graph and establishing connections based on geographical proximity or similar weather patterns, GNNs can learn more complex relationships between local and regional climates.

Despite the improvements, there are still limitations. The quality and resolution of input data can limit the accuracy of predictions, especially in areas with insufficient data collection. Additionally, the current model focuses on deterministic predictions, meaning it gives a single forecast without uncertainty estimation. Adding probabilistic forecasting could provide more valuable insights into the range of possible weather outcomes, which would be critical for applications like disaster response where understanding forecast uncertainty is vital.

The precipitation forecasts also reveal that the model is sensitive to temporal patterns in rainfall but tends to slightly misestimate amplitude in highly variable conditions. These deviations are consistent with challenges observed in similar studies and reflect the complex, non-linear structure of precipitation processes. Improvements may include probabilistic methods or uncertainty-aware loss functions to better capture such stochastic behavior.

## **Conclusion**

This study highlights the effectiveness of Graph Neural Networks (GNNs) enhanced with gated recurrent units (GRUs) for temporal modeling in weather forecasting. By combining spatial adjacency data with temporal sequences, GNNs can generate more accurate and resilient weather predictions compared to traditional sequential models. This fusion of spatial and temporal information allows for better representation of the complex interactions within weather systems.

Future developments could include incorporating real-time data from Internet of Things (IoT) sensors and employing ensemble techniques for uncertainty quantification. These upgrades would improve the accuracy of localized weather forecasts, making the system more adaptable to fluctuating climate conditions. Such advancements would be particularly valuable for decision-makers in fields like agriculture, infrastructure planning, and disaster management, where precise, dynamic forecasting is crucial for effective planning and response.

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# Resource Use Efficiency in Vegetable Production in the Kailali of Sudurpaschim Province

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## Abstract

This study aimed to examine factors affecting, resources use efficiency and returns to scale in vegetable production by analyzing impact of resources utilization in Kailali. Applying quantitative causal survey including descriptive research design, it explored impact of resources utilization and socio-economic factors through structured questionnaire from 100 farmers by random sampling. Though, there are extensive researches of agriculture, inputs and returns to scale, very few papers explored in Kailali. Data analysis was carried by *frequencies, mean, SD, t-test, Durbin-Watson test* and *multiple regression model* using *Cobb-Douglas production function*. *Indian Vegetables* were major responsible for no expected price of vegetables in Dhangadhi Sub-Metropolitan city, Godawari Municipality and Kailari Rural Municipality. This study showed socio-economic factors of farmers played decisive role in resource use efficiency and returns to scale. Education level, extensive service, land, chemical fertilizer and seed were statistically significant to returns from vegetable to farmers whereas subsidy, household size, pesticide and labour could not support to income of farmers. Since efficiency ratio is greater than unity, the resources are underutilized. Chemical fertilizer and pesticide were underutilized and need to increase cost by 10.37% and 72.11% respectively whereas seed and labour were overutilized due to the efficiency ratio is less than unity and need to decrease cost by 14.05 % and 95.88 % respectively for their optimum allocation. Land was underutilized. Lack of training, exposure, education level and extension service were reasons for inefficient use of resources and decreasing returns to scale in production. It is recommended farmers should have technical knowledge for optimizing resources which would increase production and productivity, and increasing returns from vegetable production.

**Keywords:** *Agriculture, Farmers, Resource use efficiency, Returns to scale, Vegetable production*

## Introduction

This quantitative causal survey study on the resource use efficiency and returns to scale in vegetable production is based on Kailali, Terai region of Sudurpaschim province. It analyzes factors affecting, utilization of resources and returns to scale, collecting data through quantitative causal survey. Vegetable is cash crop in Nepal especially in Hill and Terai region. It is a major component in Nepalese economy which provides huge employment and major source of income, and supplying plenty of nutrients for

millions of people (NPDP, 2017). Potato is one of the major vegetables in Nepal. The area, production and productivity of vegetables have been reported to be 192,410 ha, 3,299,750 Mt and 17.15 Mt/ha, respectively in Nepal in the year 2020/21 (MoF, 2021).

Agriculture is the largest sector of Nepalese economy among the south-Asian developing countries that contributed 23.95 % of GDP in the year 2022/23 (MoF, 2023). The system of whole productivity is low and inefficient in Nepal due to lack of resource use efficiency that leads decreasing returns to scale (Shrestha, 2016). Fifteenth development plan has emphasized on production and productivity of agriculture sector in Nepalese economy (NPC, 2019). Vegetable crops includes a large number of plants, mostly annual and a few perennials, grown for their edible leaves, stems, flowers, buds, flowers fruits and roots. They are integral parts of a balance diet and are considered as protective foods and prevent several diseases.

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*Mt =Metric ton, ha= hectare, SD=Standard Deviation*

Vegetable crops give 5 to 10 times more yield per unit area than cereals and millets. Potato leads in production followed by Tomato, Chilly, Onion, Cabbage and Brinjal (Gopalakrishnan, 2007).

The resource use efficiency refers to the value of all inputs used to obtain a product technically efficient must choose the one that attracts the minimum value of inputs (Chetroui & Calin, 2013). In general sense resource use efficiency is technical efficiency. It is the ability of a farm to produce the maximum level of outputs from the given resources. It helps to produce the given level of outputs from the minimum quantity of inputs by using the fixed technology in production process. Price efficiency is occurred from allocative efficiency that makes the equality of the marginal product and the marginal cost to each other (Shrestha et al., 2016). Resource use efficiency is needed to find the resources are whether overused or optimally used or underused. Inefficient use of resources increases the cost of production which results low return from vegetable production (Ishtiaque et al., 2017).

Despite higher production of the vegetables, import of them has been continued in Kailali. The district imports 30,000 ton of vegetables worth Rs.500 million per year from India. A big chunk of these vegetables enter the country through *Gauriphanta custom point*. Despite domestic production, demand for vegetables is growing which is fulfilled from imported vegetables (<https://kathmandupost.com/money/2018/04/24>). Kailali accessed inputs, extension services, markets, infrastructures and government incentive (Subsidy) that gives resource use efficiency and returns to scale. Most of the farmers have given the priority in vegetable production in Terai (Shrestha et al., 2015).

Farmers produce vegetables for subsistence level in Sudurpaschim province. This research paper may help in commercialization and modernization of vegetables production throughout the region and all over the country. A scale factor measures the returns to scale and interprets the elasticity coefficients of

variables by using Cobb-Douglas production function in production of a particular product (Beattie & Taylor, 1985). The general objective of this study is to analyze the resource use efficiency and returns to scale in vegetable production.

Remote rural farmers are partially informed about the utilization of inputs like hybrid seed; fertilizer, pesticides and types of soil that causing low production and low productivity. They have no knowledge to utilize various resources like seed, fertilizers, and pesticides. Farmers are producing the vegetables in traditional technique. Resource use efficiency identifies whether the resources optimally used or underused or overused in production process. Production cost increases due to inefficient use of resources and resulting low returns from vegetable production (Devkota et al., 2018). Resource use efficiency ensures vegetable security in Nepal. Government of Nepal has invested in agriculture development but productivity is low. Most households have no secured of vegetables production. It does not give benefit to small holder farmers in society. Due to lack of optimum utilization of available resources in cultivation of vegetable production like lack of technical knowledge, low education level, and extensive service, the productivity and production is low in Nepalese economy.

The leading inputs used in vegetable production are labor, seed, bullock and chemical fertilizer. Labour is used for farm preparation, weeding and harvesting. Hired and family labours are both used in production but male labour has dominant role in Nepalese farms (Bajracharya & Sapkota, 2017). Due to traditional technology, resources have not been utilized and low productivity is seen in agriculture sector in Nepal (Paudel et al., 2019). The finding of this study can guide farmers and policy makers to formulate new plans. It can further support to implement the targeted programs toward raising the output of vegetable in Sudurpaschim province. Interested researcher would be supported from this study in vegetable fields. Farmers can familiarize to use various inputs in vegetable production. At present, the state, provincial and local governments have the objectives to reform and increase productivity in agriculture sector.

There are only few literatures dealing with resource use efficiency and returns to scale in vegetable production of Sudurpaschim province in Nepal. So far, very limited study tries to capture factors affecting, resource use efficiency and returns to scale of vegetables production in Kailali district. In my knowledge, no any formal literatures have explained the utilization of resources, returns to scale, and determinants of vegetable production in Terai region of Sudurpaschim province.

Utilization of labour, fertilizers, farm size, seeds, fertilizer are highly significant in maize production in Eastern Nepal (Sankhuwasabha district) ((Shrestha et al., 2015). The resources like seed, bullock, fertilizer and labour are over utilized regarding of production of maize in Sindhuli district in Nepal. (Dahal & Rijal, 2019). Jhapa district has showed the decreasing returns to scale in rice production regarding the

efficient use efficiency of rice production in Nepal (Subedi et al., 2020). The above literatures show that the efficiency of resources use in agriculture sector have been conducted in high hill of Eastern, hilly district and Terai district (Jhapa) but there are no perfect studies of the resource use efficiency and returns to scale in Kailali in Sudurpaschim province. Therefore, this study aims to contribute in addressing this research gap by conducting a study on the resource use efficiency and returns to scale in vegetable production in Kailali.

The objectives of this study were: To identify the factors affecting in resource use efficiency, to analyze the resource use efficiency and to show the type of returns to scale in vegetable production.

Technical efficiency is affected by various farmers' socio economic and demographic factors such as educational level, extension service, credit facility, family size, fertilizer, and improved seeds (Basnayake & Gunaratne, 2002). Credit facility, fertilizer quantity, output price organized and household head are significant in the productivity of vegetable farmers (Xaba & Masuku, 2013). Cobb-Douglas production function is used to predict the significance of inputs in income from cash crops. The cost made in labour, fertilizers and seed have significantly effect on gross income of coffee (Acharya et al., 2014). Thus this study had the hypothesis: H<sub>1</sub>: Education level, extensive service, household size, farm size, seed cost, labour cost, chemical fertilizer cost, pesticide cost and access of subsidy have significant effect in income of vegetable production, H<sub>2</sub>: There is optimum utilization of resources by farmers in vegetable production, and H<sub>3</sub>: Increasing returns to scale is applied in vegetable production.

## Methods and materials

### Study Area

This study was conducted in Kailali district which is located in the Terai region of Sudurpaschijm province. The study area included Dhangadhi Sub-Metropolitan City, Godawari Municipality and Kailari Rural Municipality that are *Pocket Areas* and *Superzone* for agriculture sector. The reason of selecting this district was its cultivated area of potato and others (tomatoes, cauliflower, cabbage, Radish, Broccoli) were 198788 and 284000 hectare respectively. Similarly the total output of them was 3325231 and 2993000 Metric Ton. The most common vegetables are Potatoes, Tomatoes, Cauliflower, Cabbage, Radish, Brinjal, Green Leafy vegetables like mustard, spinach, squash, and many other seasonal local vegetables. But the productivity of potato and others were 16.17 and 14.02 Metric Ton per ha in FY2020/21 (MoALD, 2022). Prime Minister Agriculture Modernization Project (PMAMP) FY 2016/17 has the objective of commercialization, mechanization and modernization of agriculture sector in Nepal. Kailali is major *Superzone* for agriculture under this project. Thus, this research could help to this project and all other stakeholders in agriculture field for efficient use of resources and returns to scale in different region of a country. It can make self-sufficiency in vegetable Sudurpaschim province.

### Research Design

Causal survey research design was used to find the impact of explanatory variables in vegetable production. It explained an issue by collecting data in numerical form that gives finding of the issue in research. The main tool of measurement in this design was structured questionnaire which collected objectives and reliable numeric data (Apuke, 2017, Dulock, 1993). This study was based on quantitative method, applying descriptive research design to find the impact of independent variables to dependent variable, using structured questionnaire for data collection from the field.

### Sample Size

When designing a research, the most common question is how large should be the sample (Dawson, 2002). Greener (2008) argued that there is no exact answer to sample size while Zikmund et al., (2013) explained that formally identifying the proper sample size requires applied statistical theory. Generally, the appropriate sample size needs three criteria: the level of confidence, the level of precision and variability degree in the attributes being measured (Miaoulis & Michener, 1976).

Krejcie and Morgan is a popular method to estimate the appropriate sample size in research. Krejcie and Morgan (1970) have stated the following formula to estimate the sample size:

$$S = \frac{X^2 NP (1-P)}{d^2 (N-1) + X^2 P(1-P)}$$

S = required sample size

$X^2$  = the table value of chi-square for one degree of freedom at the desired confidence level (3.841)

N = the population size

P = the population proportion (assumed to be 0.50 since this would provide the maximum sample size)

d = the degree of accuracy expressed as a proportion (0.05)

Based on above formula, the total sample size was 100 farmers (households of farmer). Thus, the data was collected from the primary source from field survey in the study sites.

### Tools and Techniques of Data Collection

Frequencies, mean, SD, t-test, multiple regression model using Cobb-Douglas production function were applied to find the impact of inputs and socio-economic factors in production in this study. Simple random sampling technique is the purest form of probability sampling and is commonly used in research. Under this technique, all items of the population have equal chance of being selected in this study. This method is used only in those studies where the entire population can be listed (Pant, 2011). It is the technique in which each and every unit in the population has an equal and independent chance of being included in the sample (Gupta, 2009 p.15.15). Thus simple random sampling technique was used for data collection.

$SD=Standard\ deviation, t-test=t-ratio$

Initially, descriptive statistics such as minimum, maximum, frequency mean and standard deviation was calculated. In second stage, regression model using Cobb-Douglas production function was used to identify the contribution of explanatory variables to dependent variable, and to analyze the resource use efficiency and returns to scale in vegetable production.

## Econometric Model

### Model of Identifying Factors Affecting

Gujarati et al., (2012) explains the general multiple regression function as

$$Y_i = \beta + \beta_i X_i + u_i ; i = 1 \dots \dots \dots n$$

where,  $Y_i$  = Dependent variable ,  $X_i$ = Explanatory variables ,  $\beta$  = Constant term,  
 $\beta_i$  = Unknown estimated regression coefficients,  $u_i$  = Error term

Thus regression equation of this study can be written as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + u_i$$

where,  $Y$ : Returns from vegetable production in Nepalese Rupees (Rs), (dependent variable), explanatory variables were:  $X_1$ : Households size, measures as number of family members,  $X_2$ : Education level, measured in different level of schooling,  $X_3$ : Extensive service from government (Dummy; 0 for no receipt, 1 for receipt ),  $X_4$ : Land, in Katha,  $X_5$ : Seed cost, in Rs,  $X_6$ : Chemical fertilizer cost, in Rs,  $X_7$ : labour cost in Rs,  $X_8$ : Pesticide cost Rs, in Rs,  $X_9$ : Access of subsidy (Dummy; 0 for no receipt, 1 for receipt ),  $u_i$ : error term. By the test of multicollinearity of independent variables they were regressed in this study.

### Model of Analyzing Resource Use Efficiency

Cobb-Douglas production function has been used to assess resource use efficiency following the methods mentioned by Rahman and Lawal (2003).

$$Y = \beta X_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} X_5^{b_5} e^{u_i} ; i = 1 \dots \dots \dots n.$$

Now in this study ,  $Y = \beta X_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} X_5^{b_5} e^{u_i}$

Where  $X_1$ : Land, in Kattha,  $X_2$ : Seed cost, in Rs,  $X_3$ : Chemical fertilizer cost, in Rs,  $X_4$ : labour cost in Rs,  $X_5$ : Pesticide cost in Rs

$r = \frac{MVP}{MFC}$  ; Where,  $r$  = Efficiency ratio , MVP is Marginal Value of Product which means increased in unit of inputs results increment the additional units of output in production. MFC (Marginal Factor Cost) is equal to unity in competitive market structure.

$$\text{Now, } MVP = \beta_i \frac{\bar{Y}}{\bar{X}}$$

Where  $\beta_i$ = Estimated regression coefficient of input  $X_i$ ,  $\bar{Y}$ = Geometric mean value of output

$\bar{X}$  = Geometric mean value of  $i^{\text{th}}$  resource used.

Decision rule:

When  $r = 1$ ; it implies the inputs are used efficiently (optimum) utilization,  $r > 1$ ; it implies the inputs are underutilized and therefore output would be increased if more of that input is employed and  $r < 1$ ; it implies the inputs are over utilized and therefore both output and profit would be maximized if less of that input is employed (Mbanasor, 2002).

Finally, the relative percentage change in MVP is calculated using following way:

$$D = (1 - \text{MFC}/\text{MVP}) \times 100$$

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*Rs=Nepalese Rupees, one Katha=0.0126441 hectare*

$$D = \left(1 - \frac{1}{r}\right) \times 100, \text{ Where,}$$

D= absolute value of percentage change in MVP of each resource (Mijindadi, 1981)

### **Model of identifying the Returns to Scale**

Dwivedi (2013, p. 258) argued the summation of respective coefficients inputs obtained from Cobb–Douglas production function gives the value of returns to scale.

$\text{RTS} = \sum \beta_i$ ; Where  $\sum \beta_i$  = Sum of coefficients of inputs.

## **Results**

### **Descriptive Statistics of Variables**

The descriptive statistics of the variables used in this study was presented in **Table 1**. The household size of vegetable farming was joint family system where value being 8.04 in average. The majority of household head (78.42%) was male. Male household head had dominated role for decision making in various matters including technology used in vegetable production. The education level was minimum zero means some farmers were illiterate and few were of masters level where mean value was 2.18 that indicated basic level education of farmers dominated the study sites. The land was small in size where average size being 6.81. Majority of farmers had less than 7 Katha of land for cultivation of vegetables. From **Appendix1**, the major number of farmers (61.8%) accessed extensive service by the government and non-government institutions. Government provided subsidy for the purpose of increase in productivity to farmers in the study sites. The access of subsidy was 64.7% in the study areas given by government. Farmers (34%) were facing shortage of chemical fertilizer in the period of plantation or initiation, after harvesting they were not getting expected price of outputs due to free entry of Indian vegetables (45.1 %) in the study sites.

**Table 1: Descriptive Statistics of Variables of Vegetable Farms**

Variables	Mean	Standard Deviation	Minimum	Maximum
Household size	8.04	3.04153	3.00	16.00
Education level	2.18	1.15	0	5
Extensive service	1.37	0.49	1	2
Farm size	6.81	4.19	2	25
Seed cost	20613.30	14418.44	2400	70000
Chemical fertilizer cost	4384.92	4326.28	100.00	35800.00
Labour cost	21208.21	22215.58	0	137500
Pesticide cost	2981.50	2610.51	240.00	14000.00
Access of subsidy	1.34	0.48	1	2

Source: Field Survey (2024). Note: N = 100.

The mean, standard deviation, minimum and maximum values had been presented in the **Table 1**. Standard deviation is deviation taken spread from mean. If standard deviation is less than mean value, then the data set is consistent and vice versa (Khadka, 2020). Standard deviation signifies the spread of distribution.

#### *RTS = Returns to Scale*

The term standard deviation is generally used for variability of sample distribution, through it is also used to mean population variability (Singh, 2007). Except labour cost, other explanatory variables were consistent in this study. It leads the data of these inputs were closer to mean value in vegetable production in this study sites.

#### **Conditions Tested for Regression Model**

According to Singh (2007), if the value of Adjusted  $R^2$  is 75 %, then the model is very good, if it is 50% to 75 % then it is good, if it is 25 to 50 %, it is fair and if it is up to 25 % the model is poor.

**Table 2: Model Summary (dependent variable: b)**

Model	R	$R^2$	Adj. $R^2$	Std. Error of the Estimate	Durbin-Watson
1	0.81 <sup>a</sup>	0.66	0.61	0.44	1.98

Source: Computation through SPSS (2024).a = Predictors: (Constant).

Table 2 explained the regression model was good for the study because  $R^2$  and Adj.  $R^2$  were 66 and 61 % respectively. The linear regression model is based on the assumption of non-auto correlation. If there is autocorrelation, it poses serious problem. Durbin -Watson test is used to detect the presence of autocorrelation. When the value of Durbin -Watson test is 1.5 to 2.5, then there is no autocorrelation (Aryal & Gautam, 2001). Thus the Durbin –Watson value (1.98) showed no autocorrelation in this study.

#### **Factors Affecting to vegetable farms**

The results of the multiple regression of the research had been presented as **Table 3**. Null hypothesis was rejected due to the p-value (listed in the column called Sig.) was smaller than the alpha level (1%, 5% and 10 % significant level).

**Table 3: Coefficients and Collinearity Statistics (dependent variable = a) (VIF)**

Variables	Standard Error	Coefficient (β)	t-ratio	Sig. (p-value)	Collinearity Statistics	
					Tolerance	VIF
Ln_Household size	0.14	-0.04	-0.43	0.663	0.754	1.326
Ln_Educationlevel	0.11	0.17	2.18	0.033**	0.910	1.099
Ln_Extension service	0.18	-0.43	-5.35	0.001*	0.827	1.210
Ln_Farm size	0.21	0.35	2.29	0.025**	0.227	4.399
Ln_Seed cost	0.10	-0.18	-1.80	0.076***	0.561	1.781
Ln_Chemical fertilizer cost	0.27	0.31	2.48	0.016**	0.353	2.837
Ln_Labour cost	0.01	0.01	0.11	0.913	0.585	1.708
Ln_Pesticide cost	0.06	0.07	0.53	0.595	0.327	3.058
Ln Access of subsidy	0.29	-0.13	-1.56	0.122	0.728	1.33

Source: Field Survey (2024). \*, \*\* and \*\*\* indicate statistically significant at 1%, 5% & 10 % level of significance, respectively. \* $p < 0.01$  \*\* $p < 0.05$ . \*\*\* $p < 0.1$ . Computation through SPSS. a = Ln\_Income from vegetable Production.

VIF = Variance Inflation Factor

VIF measures the variance of the estimated regression coefficient is inflated if the explanatory variables are correlated. VIF is calculated as:

$$VIF = \frac{1}{1-R^2} = \frac{1}{\text{Tolerance}}$$

The tolerance is calculated which is the inverse of the VIF. More likely is the multicollinearity among the variables if there is lower the tolerance. The value of VIF shows the correlation to each input. If VIF = 1, then the explanatory variables are not correlated to each other in the model. If the value of VIF is from ranges  $1 < VIF < 5$ , it specifies that the explanatory variables are moderately correlated to each other's (Shrestha, 2020). Explanatory variables should only be allowed if its VIF is less than five (5) in a regression analysis (Akinwande et al., 2015). **Table 3** showed the VIF of every explanatory variable is less than five. Thus, there was no issue of multicollinearity in this study.

The first objective of this study was to identify the factors affecting in resource use efficiency and returns to scale in vegetable production at the household level in the selected study sites. Multiple regression model by using Cobb- Douglas production function had been carried out to find results.

Table 3 indicated extensive service was highly significant (1% level of significance), whereas education level, land and chemical fertilizer were moderate significant (5 % level of significance) and seed cost was

significant only at 10 % to income from vegetable production to farmers. Other explanatory variables were insignificant in vegetable production in the study sites.

### Analysis of Resource use Efficiency in Vegetable farms

It was the second objective of this study. The resource use efficiency calculated by MVP and MFC was explained in econometric model. The value of 'r' showed whether the inputs were optimum, under or over utilized in vegetables production.

**Table 4:** Analysis of Resource Use Efficiency in Vegetable farms

Variables	Coeff.( $\beta$ )	MVP	MFC	r	D-value	Efficiency	Source: Field Survey (2024)
Ln_Land	0.35	6270.84	1	6270.84	185.94	Underutilized	
Ln Seed cost	-0.18	1.16	1	-1.16	14.05	Over utilized	
Ln Chemical Fertilizer cost	0.31	10.37	1	10.37	10.37	Underutilized	
Ln Labour cost	0.01	0.04	1	0.04	95.88	Over utilized	
Ln Pesticide cost	0.07	3.58	1	3.58	72.11	Underutilized	

**Returns to Scale**

### in Vegetable farms

It was third objective of the study. By the summation of regression coefficients ( $\beta$ ), returns to scale are calculated (Basu & Fernald, 1997). It showed the types of returns to scale in production.

**Table 5:** Returns to scale in vegetable farms

Variables	Coeff. ( $\beta$ )
Ln Household size	-0.04
Ln Education level	0.17
Ln Extensive service	-0.43
Ln Farm size	0.35
Ln Seed cost	-0.18
Ln Chemical Fertilizer cost	0.31
Ln labour cost	0.01
Ln Pesticide cost	0.07
Ln Access of subsidy	-0.13
Sum of Coefficient( $\beta$ )	0.13

Source: Field Survey (2024)

The returns to scale parameters presented in **Table 5** for vegetables farmers in the study sites was computed by the addition of coefficients of explanatory variables. The sum of the coefficient of

explanatory variables was 0.13 which indicated decreasing returns to scale to the farmers in the study sites.

## DISCUSSION

Majority of household head are male (68%) of vegetable production (Dahal et al., 2019). This study had male dominant in vegetable production (78.42%) (**APPENDIX 1**) who decided to apply the inputs including technology in vegetable production in study sites. Majority of the farmers had not got expected price (93.1%) in the study sites. Import from India was major cause of it. But some farmers of *Kailari Rural Municipality* found distinct situation. They were producing organic vegetables and gave priority to local seeds, pesticides and fertilizers in vegetable production. Therefore, their products were demanded in Indian market (*Suda*). Hence, they had no marketing problem of the vegetable outputs. They got reasonable price. Again, one of the interesting matters was; they themselves made pesticides to control crop diseases. They made liquid spray by mixing lots of local herbs and shrubs like *Neem* (one type of local plant) and others, which were found in locality.

Over 700 farmers got subsidy in agriculture sector in Kailari rural municipality, especially in *Pabera Village*, and other local bodies of Kailali district. *Prime Minister Agriculture Modernization Project (PMAMP) FY 2016/17* was lunched in Kailali district to enhance productivity and commercialization of agriculture sector. But access of subsidy was insignificant in vegetable production. It showed there was no positive impact of subsidy in agriculture production, productivity and increasing returns to scale. It was concluded that without farmers' awareness, higher education, attitude to commercialize farming, counseling, extensive services from local governments the production and productivity of agriculture sector in Kailali district and even in Nepal is not possible.

When average value is greater than the value of standard deviation then the data shows the consistent of the series (Livingston, 2004). **Table 1** revealed farm size, seed cost, chemical fertilizer cost and pesticide cost were consistent inputs in production whereas labour cost was inconsistent in this study sites.

Resources used and returns to scale in agriculture sector depend on socio-economic and demographic factors of farmers. They are major affecting factors and significant for improving farmers' efficiency for vegetable production (Andaregie & Astatkie, 2020). **Table 3**, showed extensive service is highly significant, and education level, land(land), chemical fertilizer and seed were statistically significant resources in vegetable production. They affected the resource use efficiency and returns to scale. But access of subsidy household size, labour cost and pesticide cost were found to be statistically insignificant in this study sites.

The resources like seed, bullock, fertilizer and labour were overutilized regarding of production of maize in Sindhuli district in Nepal (Dahal & Rijal, 2019). Household size, farm size, seed, labour and chemical

fertilizer cost affect the resource use efficiency to farmers in vegetable production which were underutilized in vegetable production. Higher cost of inputs, small farm size, and inadequate capital are major constraints in vegetable production. They reduce the efficiency and productivity of farmers (Ajibare et al., 2022). Table 4 showed the resource use efficiency analysis showed that the major inputs in vegetable production. Farm size, chemical fertilizer and pesticide were underutilized and need to increase their cost whereas seed and labour cost were over utilized and need to decrease their cost for optimum allocation of these inputs. This might be lack of training to farmers and insufficient extensive service to farmers in study sites

The overall productivity of resources presents the returns to scale of various inputs in production. The summation value of elasticity of land, labour, fertilizer and seed is  $0.75 < 1$ , shows farmers are producing in decreasing returns to scale. Managerial inefficiency of farmers in using inputs creates diseconomies scale of resources that provides the decreasing returns to scale in production (Weldegiorgis et al., 2018). Table 5 revealed the sum of coefficients was 0.13 that shows the decreasing returns to scale in production of this study. Thus, this study showed the socio-economic factors of farmers that play decisive role in resource use efficiency and returns to scale.

### **Conclusions and implications**

Vegetable production is one of the major components of agriculture sector to ensure food security, nutritional value and reduce poverty in Terai regions of Nepal. The objectives of this study were to investigate factors affecting, use of resources and returns to scale in vegetable production in Kailali of Nepal. The results indicated that education level, extensive service, farm size, seed cost and chemical fertilizer affected in vegetable production. Farm size, chemical fertilizer and pesticide were underutilized and need to increase their cost whereas seed and labour cost were over utilized and need to decrease their cost for optimum allocation of these inputs. This study indicated decreasing returns to scale. This might be due to lack of training exposures to farmers and insufficient extension service to farmers in study site. This study concludes that the scarce resources must be used efficiently to get increasing returns to scale in production of any crops. Government and stakeholders should give priority to resource use efficiency and increasing returns to scale, and technical knowledge in agriculture practice. Hence, broader understanding of the socio- economic, demographic factors and resources used enhances the farmers' efficiency in agriculture development in Nepal.

The findings of this research might be applied for understanding the socioeconomics demographic factors, resource utilization and returns to scale in agricultural sector that enhances the productivity in Nepalese agriculture sector and developing an effective mechanism to use optimum use of resources(inputs) through the various measures such as enhancing education level, increase in land, managing organized market to farmers. It would be highly recommendable to enrich the farmers with appropriate technical

information, exchange of ideas and exposure, so they could be able to obtain optimum price for their resources for increasing production and returns from vegetable production.

Apart from agriculture sector, this research will be equally applied in manufacturing companies, small, medium and large-scale industries. Entrepreneurs who want to involve innovative products needs analyze the resource utilization and returns to scale. They can use its findings for future business plans formulation

### **Relevance to the UN Sustainable Development Goals**

United Nation (UN) has given the Seventeen Sustainable Development Goals (SDGs) that should be fulfilled up to 2030. The first goal of sustainable development by the UN is: *No poverty*. It aims eradicating extreme poverty by applying technology and mobilization of resources (NPC, 2020). Poverty alleviation is the main objective of economic plan of Nepal since the 7<sup>th</sup> plan. Nepal has subsistence level farming. This study may help to apply improved seeds, new machineries, and supply of chemical fertilizers in time, and increase in access of subsidy to farmers. Ultimately, it results commercialization and modernization of agriculture sector. Thus, this study may support to fulfill the first objective of the SDGs (no poverty) in Nepal. NPC (2020) states the UN Sustainable Development Goal-2 is *Zero Hunger*. It aims to end hunger, achieve food security and improved nutrition. Thus, this study may support to achieve zero hunger targeted by SDGs.

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**APPENDIX: 1**

## Socio-economic and Demographic Features of Vegetable Farmers:

Variables	Frequency	%
Gender	Frequency	%
Male	80	78.42
Female	20	19.6
Types of Seed	Frequency	%
Improved	70	68.6
Local	4	3.98
Both	26	25.5
Education level	Frequency	%
Uneducated	7	6.9
Basic level	21	20.6
Secondary level	33	32.4
Bachelor level	27	26.5
Masters level	10	9.8
Others	2	2
Extensive service	Frequency	%
Access	63	61.8
No	37	36.3
Marketing	Frequency	%
Whole sellers	4	3.9
<i>Hatbazzar</i>	33	32.4
Community	42	41.2
Community and <i>Hatbazzar</i>	33	32.4
Expected Price	Frequency	%
No expected price	95	93.1
Cause of no expected price	Frequency	%
Dominance of whole sellers	9	8.8
No storage facility	21	20.6
Lack of organized market	18	17.6
Entry of Indian vegetables	46	45.1
Others	1	1
Access Subsidy	Frequency	%
Yes	66	64.7
No	34	33.3

Source: Field Survey (2024). Two farmers did not sell the output

# The Influence of the Service Flower Model on Customer Satisfaction at Restaurants in Dhangadhi

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## Abstract

The restaurant industry in Dhangadhi, Nepal, faces increasing competition and evolving customer expectations, necessitating comprehensive service strategies to enhance customer satisfaction. This study investigates the impact of the Flower of Service model, which encompasses core and supplementary services (information, order-taking, hospitality, and exceptions), on customer satisfaction in Dhangadhi's restaurants. Utilizing a convenience random sampling method, data were collected from 489 restaurant customers through a structured questionnaire employing a 5-point Likert scale. Reliability tests confirmed high internal consistency (Cronbach's Alpha > 0.89 for all variables). Univariate analysis revealed moderate satisfaction levels across all service elements (mean scores ~3.42–3.51), with exceptions showing the highest variability.

Correlation analysis indicated strong positive relationships between customer satisfaction and all service elements, with hospitality exhibiting the highest correlation ( $r = 0.923$ ). Regression analysis confirmed that order-taking, hospitality, and exceptions significantly influence customer satisfaction, with hospitality being the most impactful ( $\beta = 0.53$ ,  $p < 0.001$ ). Surprisingly, information showed a non-significant effect, suggesting baseline expectations are met.

These findings highlight the critical role of hospitality, order-taking, and exception handling in enhancing dining experiences. The study recommends that restaurant managers in Dhangadhi prioritize staff training in hospitality and streamline order-taking processes to foster customer loyalty and strengthen market competitiveness.

**Keywords:** *Flower of Service, Customer Satisfaction, information, Order taking, Hospitality, Exception*

## Introduction

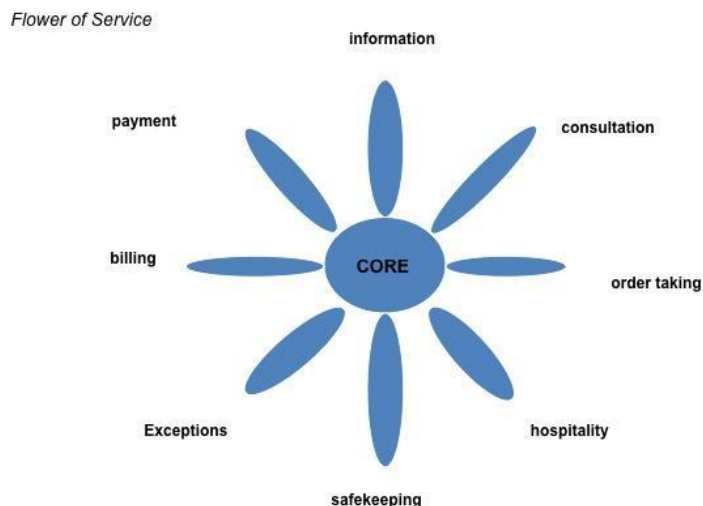
The term "Flower of Service" refers to core and supplementary services that can enhance a firm's service levels and client satisfaction when understood and executed effectively. Clients often experience various issues when interacting with service providers, such as parking difficulties, unfriendly staff, uncomfortable waiting areas, and unclear invoicing. These issues are related to

the concept of the "Flower of Service," which highlights the importance of both core and supplementary services in delivering a satisfying client experience.

(Lovelock & Wirtz, 2012) explain the Flower of Service is a service concept that describes the main product of a service company added by supplementary services depicted in the form of the flower where despite the good company's core product; if the supplementary services provided are not good, the whole will be not beautiful.

While first-time clients may focus on core service satisfaction, loyal clients tend to prioritize supplementary services. Therefore, firms should focus on the entire client experience, including both core and supplementary services, to foster client loyalty.

The core service is the primary benefit that satisfies the main need of the customer, such as the delivery of fresh flowers in a flower delivery service. Surrounding this core service are supplementary services, which can be categorized into facilitating services and enhancing services. Facilitating services include information, order-taking, billing, and payment, which support the delivery of the core service. Enhancing services add extra value, such as consultation, hospitality, safekeeping, and exceptions (e.g., special requests or problem-solving). When both core and supplementary services are understood and executed effectively, they can significantly improve a firm's service quality, customer satisfaction, and competitive advantage.



### **Problem Statement:**

The restaurant industry in Dhangadhi, a rapidly growing city, faces increasing competition and evolving customer expectations. To stand out and achieve high levels of customer satisfaction, restaurants must provide comprehensive service experiences that go beyond just food quality. The Flower of Service concept, introduced by Christopher Lovelock, offers a framework for enhancing

customer experiences by categorizing various supplementary services that complement the core product.

Despite its potential, there is limited empirical research on the practical application and effectiveness of the Flower of Service concept in the context of restaurants in Dhangadhi. This gap in knowledge presents a challenge for restaurant managers seeking to implement effective service strategies to boost customer satisfaction.

### **Objective:**

This study aims to analyze the impact of the Flower of Service concept on customer satisfaction in restaurants in Dhangadhi. Specifically, it will

Analyze how each component of the Flower of Service (information, order-taking, hospitality, exceptions) influences customer satisfaction.

- Identify which supplementary services are most critical to enhancing the overall dining experience.
- Provide actionable insights and recommendations for restaurant managers to improve service quality and customer satisfaction.

### **Research Questions:**

1. How do the individual components of the Flower of Service concept affect customer satisfaction in Dhangadhi's restaurants?
2. Which supplementary services are perceived as most valuable by customers?
3. What are the common gaps in service provision that negatively impact customer satisfaction?

### **Significance of the Study:**

Understanding the impact of the Flower of Service concept on customer satisfaction can help restaurant owners and managers in Dhangadhi design better service strategies. By identifying key areas that enhance the dining experience, restaurants can tailor their services to meet customer needs more effectively, leading to higher customer retention, positive word-of-mouth, and a stronger competitive position in the market.

### **Literature Review**

The study by Hashem (2018) explores various dimensions of service quality in the context of hospital services, employing Lovelock's supplementary service model. This model identifies key

elements that augment core services, enhancing customer satisfaction and value. This literature review focuses on four critical variables from the study: Information, Order Taking, Hospitality, and Exceptions.

McGoldrick and Pieros (1998) argued that servicescape can act as image differentiation among other service provider organization. Andreu et al. (2006) suggested that “with competition among various industries, managers are encouraged to take into account spectators’ experience in the service provider’s environments as a potential tool for differentiation”. Through servicescape, organizations can reposition itself through alluring messages and communicating positive messages in new markets to capture more share, profit and customer base. Harris and Eze (2007) assert that “physical facilities are visible manifestations of the intangible services that inexperienced audience rely on to make judgments on its competence and its appropriateness and the same can be said for experienced spectators because in certain instances they may find it difficult to evaluate services even after the consumption of an experience”. Outward appearance of an organization is considered as packaging of service, because of its visualization, which is another important aspect of servicescape (Liu & Jang, 2009). Mofoka (2012) claimed that physical surroundings of service organization played the same role as physical goods are communicated to the consumers.

The American Society for Marketing (2008) defined service as the set of benefits and activities that are bound for sale or that are related to a particular item or product. Kotler (2003) on the other hand defined service as the behavior that results from the contact between the provider of the service and the receiver (customer) while Gummesson (2004) saw that service is the characteristics, properties and features of the service that ends up in satisfying the customer and meet their expectations.

### **Information**

Information is a crucial facilitating supplementary service, essential for guiding customers in the usage of core products and services. Lovelock et al. (2011) emphasized that adequate information provision is vital for customer satisfaction, as it helps mitigate uncertainties and enables informed decision-making. In the context of hospitals, information dissemination through leaflets, websites, front desk interactions, and informative boards is fundamental. The study by Hashem (2018) reveals that patients value accessible and comprehensive information, which includes usage instructions, pricing, service hours, and notifications of changes.

The statistical analysis in Hashem's study indicates that patients generally have a positive perception of the information provided by hospitals, with a mean score of 3.5147 on a 5-point

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scale. This suggests that hospitals are performing adequately in this area, although there is room for improvement, particularly in enhancing website satisfaction and staff communication.

Recent studies further underscore the importance of information in the restaurant context. Kim and Lee (2020) found that clear and timely information delivery, such as menu details and allergen information provided through digital platforms or staff interactions, significantly enhances customer trust and satisfaction in restaurants. Additionally, Zhang et al. (2023) highlighted that real-time updates on wait times and reservation statuses via mobile apps positively influence customer perceptions of service quality, emphasizing the growing role of technology in information provision.

### **Order Taking**

Order taking is another critical component of service delivery, involving the accurate and efficient processing of customer requests and reservations. According to Lovelock et al. (2011), a smooth and polite order-taking process minimizes customer effort and enhances satisfaction. In hospital settings, this includes the registration of patient information, prompt response to patient needs, and efficient handling of room service and nursing requests.

Hashem's study reports a mean score of 3.4455 for order taking, indicating a positive but improvable performance. Key areas highlighted include the readiness of employees to assist, the efficiency of the registry process, and the responsiveness of nursing staff, particularly during night shifts. Despite these strengths, the study suggests that errors in patient information and occasional delays in service provision remain concerns that need addressing.

Efficient and courteous order taking ensures that customers do not face unnecessary delays or complications. Meat Lovers Yogyakarta, for example, welcomes customers warmly, assists them in seating, and offers the option to either self-serve or be assisted by the staff. This personalized service helps in enhancing customer satisfaction (Liem & Isfianadewi, 2020). A recent study by Gupta and Sharma (2022) in the restaurant industry found that streamlined order-taking processes, including the use of digital ordering systems, significantly reduce wait times and improve customer satisfaction, particularly in fast-casual dining settings.

### **Hospitality**

Hospitality in healthcare involves the warmth and courtesy extended to patients and visitors. It encompasses staff attitudes, the overall atmosphere, and the efforts made to ensure a pleasant

experience. Lovelock (1992; 1995) and subsequent studies have underscored the importance of hospitality in enhancing customer satisfaction and loyalty.

In Hashem's research, hospitality received a mean score of 3.5271, reflecting generally positive perceptions. Factors contributing to this score include the welcoming nature of staff, their courteous behavior, and their commitment to assisting patients and visitors. However, there is variability in experiences, suggesting that consistency in hospitality practices needs further improvement to achieve uniformly high standards across all hospital departments. Recent research by Nguyen and Tran (2021) in the restaurant sector emphasizes that staff friendliness and personalized interactions are key drivers of customer loyalty. Their study found that customers value staff who demonstrate genuine care and attentiveness, which aligns with the hospitality component of the Flower of Service model. Furthermore, Li and Wang (2024) noted that creating a welcoming ambiance through staff training and servicescape design significantly enhances customer satisfaction in restaurants, particularly in competitive urban markets.

### **Exceptions**

The management of exceptions refers to how well a service provider handles special requests, complaints, and unforeseen issues. Effective exception handling is critical for maintaining customer trust and satisfaction, as highlighted by Lovelock et al. (2011).

Hashem's study finds that exception handling in hospitals is perceived less favorably, with a mean score of 2.3237, indicating significant dissatisfaction among patients. Issues such as cleanliness, hygiene, staff uniformity, and the perceived cost of services compared to other hospitals are major areas of concern. This suggests that hospitals need to enhance their protocols for managing exceptions, ensuring that they meet patient expectations and industry standards more consistently. In the restaurant context, a study by Chen and Lin (2023) found that effective handling of customer complaints and special requests, such as dietary accommodations, significantly improves customer retention and satisfaction. Their research highlights the importance of staff training in problem-solving and flexibility to address unique customer needs. Similarly, Patel et al. (2022) emphasized that proactive exception management, such as offering compensations for service failures, can turn negative experiences into positive ones, fostering customer loyalty.

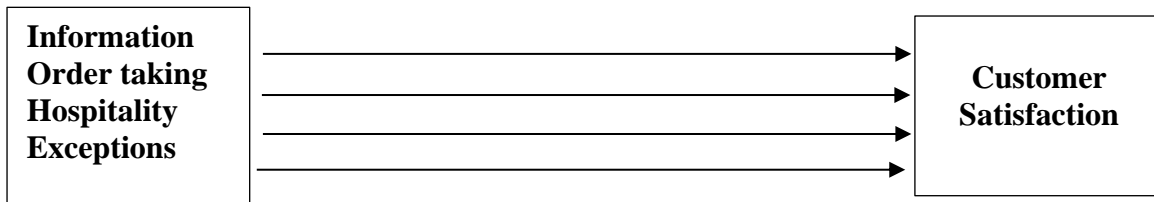
### **Conceptual Framework**

A conceptual framework is a system of ideas that provides structure for research or practice. It consists of key concepts, variables, relationships, theories, and assumptions, guiding the

organization and interpretation of information. In this research the following conceptual framework created.

### Independent Variables

### Dependent Variables



### Hypothesis

- **H1:** *Information positively and significantly influences customer satisfaction in restaurants*
- **H2:** *Order taking positively and significantly influences customer satisfaction in restaurants*
- **H3:** *Hospitality positively and significantly influences customer satisfaction in restaurants*
- **H4:** *Exceptions positively and significantly influences customer satisfaction in restaurants.*

### Research Design

Research design is a framework or blueprint for conducting a research study. It outlines the procedures for collecting, measuring, and analyzing data. A well-constructed research design ensures that the research question is addressed effectively and that the findings are valid and reliable.

### Method

This study adopts a causal-explanatory research model based on the Flower of Service framework, supported by descriptive and inferential statistical analysis.

The researcher intentionally design questionnaire as the main tool for collecting data in the study. The questionnaire was divided into two main sections for thorough analysis. The initial part concentrated on collecting demographic information, essential for grasping the characteristics of the study sample. The second section focused on exploring the variables related to the 'flower of service.' To ensure accurate responses, a Likert 5 scale was used, offering a range from 'strongly agree' (5) to 'strongly disagree' (1) for participants to convey their opinions effectively. This approach not only ensured a systematic data collection process but also provided a nuanced understanding of participants' perspectives on the 'flower of service' phenomenon.

## Population and sample

The study aimed to examine customer satisfaction with restaurant services in Dhangadhi, Nepal. The research targeted local residents who frequent restaurants in the city. A well-structured questionnaire was randomly distributed to 500 customers of different restaurants in dhangadhi to ensure an adequate response rate. Out of the 500 questionnaires distributed, 489 were returned, which is sufficient for further analysis according to Cochran's (1963) minimum sample size recommendation of 384.

The study employed a convenience random sampling method to select the sample, which comprised both male and female consumers from various restaurants in Dhangadhi. Only fully completed surveys were included in the analysis. The questionnaire covered various aspects of customer satisfaction, including staff ability, product satisfaction, service responsiveness, cleanliness and overall serviceability of restaurants from the customer's perspective.

## Result and Discussions

This study's first step is testing the outer model, which includes validity and reliability tests. This testing step aims to determine the relationship between the latent variable and the indicator that measure the variables.

**Table 1:** Profile of the Respondents

Variables	Categories	Frequency	Percent
Gender	Male	210	53.98
	Female	179	46.02
<b>Total</b>		<b>389</b>	
Age	Below 24	129	33.16
	25-30	121	31.11
	31-35	92	23.65
	Above 35	47	12.08
<b>Total</b>		<b>389</b>	

**Source:** Questionnaire Survey, (2024)

The table summarizes demographic characteristics of a surveyed population based on gender and age categories. In terms of gender, 210 individuals (53.98%) identified as Male, while 179 individuals (46.02%) identified as Female. Regarding age distribution, the majority of respondents were Below 24 years old, comprising 129 individuals (33.16%). The 25-30 age group accounted

for 121 individuals (31.11%), followed by 92 individuals (23.65%) in the 31-35 age bracket, and 47 individuals (12.08%) who were Above 35 years old.

This data illustrates the gender and age composition of the surveyed sample, highlighting notable proportions across different demographic segments.

### Table 2 : Reliability Test Result

Cronbach's Alpha: This column provides the Cronbach's Alpha values for each latent variable. Cronbach's Alpha is a measure of internal consistency or reliability. It indicates how well a set of items (questions or statements) measures a single unidimensional latent construct. The value of Cronbach's Alpha ranges from 0 to 1, with higher values indicating higher reliability.

Variable	Cronbach' Alpha
Information	0.897
Order taking	0.902
Hospitality	0.907
Exception	0.919
Customer Satisfaction	0.901

**Source:** Questionnaire Survey, (2024)

The table indicates that all variables have high to excellent reliability as measured by Cronbach's Alpha. Information has a Cronbach's Alpha of 0.897, showing a very high level of internal consistency. Order taking, with a Cronbach's Alpha of 0.902, exhibits excellent reliability. Hospitality also demonstrates excellent internal consistency with a Cronbach's Alpha of 0.907. Exception, having the highest reliability in the table with a Cronbach's Alpha of 0.919, indicates strong internal consistency. Finally, Customer Satisfaction has a Cronbach's Alpha of 0.901, reflecting excellent reliability. These high values suggest that the items used for each variable consistently measure the same underlying construct.

Univariate Analysis of Lovlock service flower elements and customer satisfaction

Descriptive statistics	Mean	S.E of Mean	Median	St. Deviation	Variance
Information	3.45	0.19	3.45	3.75	0.37
Order	3.51	0.19	3.53	3.81	0.36
Hospitality	3.42	0.18	3.41	3.49	0.29

Exception	3.42	0.20	3.41	3.96	0.33
Satisfaction	3.45	0.18	3.47	3.57	0.32

**Source:** Questionnaire Survey, (2024)

The table provides a detailed univariate analysis of customer satisfaction across various dimensions of the Lovelock service flower model: Information, Order, Hospitality, Exception, and overall Satisfaction. Each element is characterized by key descriptive statistics. The mean ratings for Information, Order, Hospitality, Exception, and Satisfaction are 3.45, 3.51, 3.42, 3.42, and 3.45 respectively, indicating a generally positive but moderately variable level of satisfaction. Standard errors of the mean range from 0.18 to 0.20, suggesting reliable estimates of these means. Median values, slightly higher than the means (ranging from 3.41 to 3.53), imply a skewed distribution towards higher satisfaction levels. Standard deviations, spanning from 3.49 to 3.96, indicate variability in customer perceptions across these dimensions, with Exception showing the highest variability.

Overall, while the mean scores reflect a satisfactory level of service, discrepancies between mean and median values suggest areas for further scrutiny to understand the distribution and potential outliers influencing customer satisfaction within each service aspect.

### Correlations

	Satisfaction	Information	Order	Hospitality	Exception
Satisfaction	1				
Information	0.856	1			
Order	0.886	0.899	1		
Hospitality	0.923	0.868	0.877	1	
Exception	0.908	0.881	0.905	0.944	1

**Source:** Questionnaire Survey, (2024)

The correlation table presents the relationships between customer satisfaction and the four elements of Lovelock's service flower (Information, Order, Hospitality & Exceptions) from a questionnaire survey. All elements show strong positive correlations with customer satisfaction, indicating that improvements in these areas are associated with higher satisfaction levels. Hospitality has the highest correlation with satisfaction (0.923), followed by Exception (0.908), Order (0.886), and Information (0.856). The elements are also highly interrelated, with notable correlations among themselves, particularly between Exception and Hospitality (0.944). This suggests that these service elements collectively contribute to overall customer satisfaction.

### Regression Analysis

Hypothesis	Independent Variables	$\beta$	Std. Error	T	Sig(p)	Result
H1	Information	0.04	0.27	0.996	0.320	Rejected
H2	Order	0.26	0.042	5.404	0.000	Accepted
H3	Hospitality	0.53	0.045	9.541	0.000	Accepted
H4	Exception	0.13	0.057	2.099	0.036	Accepted

**Source:** Questionnaire Survey, (2024)

The regression analysis table examines the impact of four independent variables (Information, Order, Hospitality, Exceptions) on customer satisfaction, testing specific hypotheses (H1, H2, H3, H4). For each hypothesis, the table shows the standardized coefficient ( $\beta$ ), standard error, t-value, significance level (Sig (p)), and the result. H1, which posits that Information affects satisfaction, is partially accepted due to a non-significant p-value (0.320) but  $\beta$  of 0.26. Conversely, H2 (Order) is accepted with a  $\beta$  of 0.26 and a highly significant p-value (0.000), indicating a strong positive impact on satisfaction. H3 (Hospitality) has the highest  $\beta$  (0.53) and a significant p-value (0.000), suggesting it is the most influential factor. H4 (Exception) is also accepted with a  $\beta$  of 0.13 and a significant p-value (0.036), indicating a positive but smaller impact. Overall, Order, Hospitality, and Exception significantly contribute to customer satisfaction, with Hospitality being the most impactful.

### Conclusion and Recommendation

The univariate analysis of Lovelock's service flower elements (Information, Order, Hospitality, and Exception) and customer satisfaction reveals insightful patterns. The elements have similar average ratings, indicating that customers generally perceive these service aspects consistently. The central tendencies, as measured by the mean and median values, are closely aligned, suggesting that there is a common level of satisfaction among the surveyed elements. The variability in responses is moderate, but Exception stands out with the highest spread, implying that customer experiences with exceptions (such as handling special requests and problem-solving) vary more widely compared to other elements.

The correlation analysis strengthens these findings by showing strong positive relationships between customer satisfaction and all four elements. Hospitality has the highest correlation with customer satisfaction, highlighting its pivotal role. This high correlation indicates that improvements in Hospitality are closely linked to increases in overall satisfaction. The strong

interrelation among the elements suggests that they do not operate in isolation; instead, they collectively enhance the overall customer experience. For instance, effective Information provision can facilitate smoother Order Taking, which in turn can enhance perceptions of Hospitality and efficient handling of Exceptions.

Regression analysis further clarifies the impact of each element on customer satisfaction. While Information, surprisingly, does not significantly impact satisfaction (potentially due to customers already having baseline expectations of adequate information), Order, Hospitality, and Exception do have significant positive effects. Among these, Hospitality emerges as the most influential factor, with the highest beta coefficient. This dominance of Hospitality suggests that the manner in which customers are treated and the overall ambiance play crucial roles in shaping their satisfaction. Order and Exception, though slightly less influential, still significantly contribute to satisfaction. Efficient Order Taking ensures smooth transactions and minimizes frustrations, while effective management of Exceptions addresses unique customer needs and resolves issues promptly.

In conclusion, the analysis underscores the critical role of Order, Hospitality, and Exception in driving customer satisfaction. The prominence of Hospitality as the most significant contributor indicates that a warm, welcoming environment and attentive service can significantly enhance customer experiences. This suggests that restaurant managers in Dhangadhi should prioritize these elements, particularly Hospitality, to boost customer satisfaction. By focusing on these areas, restaurants can foster a loyal customer base, positive word-of-mouth, and a stronger competitive position in the market.

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1. Articles should have **3500 to 6000** words (including references and appendices).
2. Times New Roman in 12-point font size with single space is to be followed.
3. APA 7th edition style should be followed.
4. The author's name, affiliation and email address should be on a separate page (first page), and the **title** (maximum 15 words), the **abstract** (150 to 250 words), and the **keywords** (4-6 words).
5. Tables, charts and graphs should be numbered and clearly visible in black and white (Follow APA 7th edition style).
6. If there is any **acknowledgment or declaration**, it should be mentioned before references. Appendices should be placed after references.
7. Authors will be responsible for plagiarism. Plagiarized writing from any author might result in cancelling that particular author from submitting writing in this journal later on. To be specific, similarity index should be below 20%.
8. The article should be in MS word file form.
9. The article should be submitted through email at: [rmc@nast.edu.np](mailto:rmc@nast.edu.np).
10. The research-based articles should have the following format:
  - **Title** (within 15 words, specific and informative reflecting the main issue/theme)
  - **Abstract** (between 150 to 250 words with background information of the issue or problem, objective or hypothesis, methods, findings and the implication/conclusion/novelty)
  - **Keywords** (4-6 words, should be descriptive, the title words should not be repeated.)
  - **Introduction** (should raise the research problem/issue with background, state the context, problem statement with its significance or rationale of the study and the objectives/research questions/hypothesis)
  - **Literature Review** (Optional as it may be the part of Introduction; theoretical, thematic, policy and empirical review providing a description, summary, and critical evaluation of the works in relation to the research problem being investigated with the research gap.)
  - **Materials and Methods** (research method, research design, population and sample/participants sampling strategy, research site/context, tools/ materials, and analysis and interpretation procedure)
  - **Results** (What? summarize the main findings of your research with statistics/tables/Figures or themes with textual data/verbatim/quotes/artifacts or both if mixed methods)

- **Discussion** (Why that happened? interpret and describe the significance of your findings/results with critique and arguments/counter arguments linking with relevant theories and previous studies; A combined Results and Discussion section is often appropriate.)
- **Conclusion** (derive conclusion from the results and discussion being reflective, implication, recommendation for future research related to your topic; no references)
- **References** (APA 7th edition)

11. However, theoretical articles or literature review papers can have varying thematic sub-headings in the body part with Introduction and Conclusion followed by References.

12. The submissions must be original and must not be submitted for publication nor under consideration for publication in another journal.



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