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RESEARCH ARTICLE OPEN ACCESS

Bridges in Nepal: Enhancing Connectivity and Economic Development

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Abstract:

Background: Nepal, known for its stunning mountainous landscape, is intersected by approximately 6,000 rivers. This unique geography necessitates the construction of numerous bridges, forming an extensive road network, including foot trails, which facilitate social interaction, cultural exchange, and economic growth. These structures connect a diverse population of over 125 ethnic groups, who speak 123 different dialects, to essential services, markets, and opportunities.

Objectives: This study explores the historical background of bridge construction in Nepal, presents the current status of bridges, and examines their impact on economic development. Additionally, it provides recommendations to support implementation agencies in addressing the challenges faced in bridge construction and proposes potential solutions.

Methods: The study is based on a review of government documents, peer-reviewed articles, and primary data from bridge construction projects to provide insights into the history, current status, and role of bridges in enhancing connectivity and economic growth.

Results: The construction of bridges alongside roads and trails in Nepal has substantially contributed to economic development and increased mobility, facilitating the smooth movement of people and goods across the country. This study provides a detailed account of the chronological development of bridges in Nepal and the subsequent economic growth enabled by improved mobility. It also addresses the improvements still required. To date, 1,656 bridges have been constructed on national highways, 435 on provincial roads, and 402 by the Department of Roads, Provincial Governments, and Local bodies on national highways, provincial roads, and local roads, respectively.

Conclusion: Additionally, over 10,000 trail bridges have been built along various trails, significantly enhancing connectivity and fostering economic development.

Keywords: Bridge, Local infrastructure, Roads, Economic development, Trail bridges.

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1. INTRODUCTION

Nepal is renowned for its awe-inspiring mountains and abundant hills. In addition to its natural splendor, Nepal boasts an extensive network of rivers, with a staggering 6,000 rivers in total [1]. This not only enhances the country's magnetism but also presents immense potential for the generation of hydroelectricity [2] and irrigation. Culturally, Nepal is incredibly diverse, with 125 cast/ethnic groups [3] and 123 dialects [4], creating a captivating fusion of traditions and languages. This diversity enriches Nepal's vibrant essence. Bridges in Nepal play a pivotal role in connecting communities across challenging terrains, facilitating social interaction, cultural exchange, and economic development. They provide easier access to essential services, markets, and opportunities, promoting industries, trade, tourism, and overall development, thereby contributing to the nation's prosperity.

The bridge construction is a vital component of Nepal's development agenda, aiming to enhance connectivity and foster inclusive growth across various regions [5]. The road network in Nepal has been affected greatly by seasons and monsoons. Thus, the enhancement of transportation network construction, including the construction of high-quality roads or other practical transportation infrastructure like bridges and tunnels, is a priority for populous hill areas to minimize the seasonal influence and provide better geographical accessibility [6].

Several organizations in Nepal are responsible for constructing bridges. The Department of Roads, the Department of Local Infrastructure, the provincial government, and local bodies oversee the construction of road bridges. On the other hand, the Department of Railways is in charge of constructing railway bridges. In addition, the Department of Local Infrastructure, the provincial government, and local bodies also play a role in overseeing the construction of trail bridges. Annually, around 400 motorable bridges and 700 trail bridges are built across the country.

The bridge construction is essential for enhancing connectivity and driving economic development. As a key component of a country's infrastructure heritage, bridges serve a fundamental function in transport networks that sustain the modern economy [7]. Numerous studies have examined the impact of bridge construction on connectivity and economic growth. According to Hawlader *et al*. (2024), the Padma bridge in Bangladesh, with an estimated annual increase of 1.3% to 2%, significantly contributes to the country's economic development by reducing travel time and transportation costs and improving connectivity [8]. The significant bridges of Bangladesh embody physical connections and symbols of progress, resilience, and transformation [9]. Infrastructural development occurs in societies where there is a positive relationship between the gross domestic product (GDP) and the per capita income of the country [10]. In low- and middle-income countries around the world, rural transportation infrastructure is a vital element for development in isolated communities [11]. The economic impact on surrounding businesses is evaluated by measuring changes in user costs and business revenues [12]. User costs include factors, such as driver delay costs, vehicle operating costs, and accident costs.

Economic development generates economic, social, and technical progress for nations. It flourishes in favorable social systems characterized by strong democracy and culture, sound economic management, an effective higher education system, and high levels of innovation [13]. Institutions play a crucial role in this context, as their evolution involves developing rules and expectations that govern human interactions, significantly impacting socioeconomic development [14]. After World War II, European countries expanded their physical capital, including roads and bridges, supported by strong institutions and a skilled workforce, which contributed to sustained long-term economic growth [13]. Investment in infrastructure projects, such as bridge construction, is vital for boosting economic development. However, economic development theories should prioritize the social well-being of people, emphasizing sustainable development over mere economic growth [15]. Economic growth, when unchecked, can often lead to long-term environmental, social, and health challenges. Infrastructure development, while vital, can have both positive and negative impacts across various domains, such as language, literature, culture, environment, agriculture, forests, and rivers [16].

However, bridge construction in Nepal faces significant safety challenges, including falls, electrical shocks, and machinery-related incidents [17]. Safety measures are often implemented reactively rather than proactively after accidents occur. Contributing factors include inadequate safety training, lack of proper safety gear, poor oversight, budgetary constraints, insufficient risk assessment, and a cultural acceptance of risk. Addressing these issues requires stricter regulation enforcement, improved training, regular safety audits, and a shift towards a proactive safety culture to reduce accidents and improve worker safety [18].

Globally, bridge failures continue to occur despite advancements in engineering, design codes, and technology. Key contributing factors include aging infrastructure, inadequate maintenance, design flaws, construction errors, natural disasters, and increased loads. Even with expertise and innovation, these issues can lead to catastrophic consequences if not properly addressed [19].

Nepal ranks among the top 20 most multi-hazard-prone countries in the world [20]. Earthquakes, floods, and landslides are the major disasters in terms of damages and losses. Several bridges were damaged by floods and landslides in 1993, again in September 2024, and by the 2015 earthquake, disconnecting various districts and the capital city, Kathmandu. Regular inspections, maintenance, and updated standards are essential to prevent future failures.

In this article, we will analyze the bridges constructed by various organizations in Nepal. Additionally, we will emphasize the importance of improving transportation infrastructure, particularly bridges, in enhancing connectivity, ensuring safer and more sustainable infrastructure, and facilitating economic growth in the region.

2. LITERATURE REVIEW

2.1. Historical Background of Bridge Construction

The historical context highlights the importance of Nepal's first-ever bridge, which was built in 1810 and crossed the Bagmati River in Thapathali, Kathmandu (Fig. **1**). This bridge was carefully constructed in just one year, using timber piles and a superstructure.

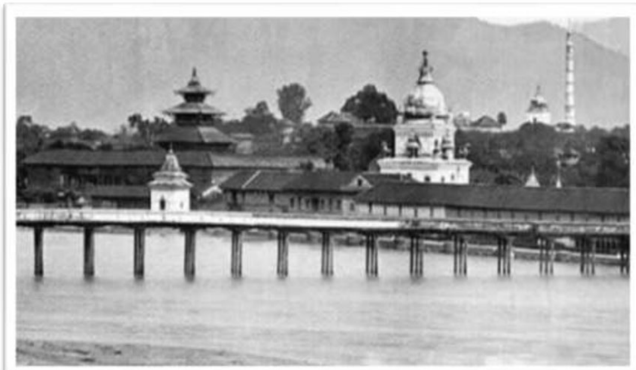

Fig. (1). First timber bridge built at thapathali over bagmati river, Kathmandu.

In 1917, the "Amlekhgunj, Bhimphedi Road" became the first motorable road, with several steel truss bridges constructed along its route. Figs. (**2** and **3**) display some of the bridges built during that period.

Fig. (2). Steel truss bridge over the nibuwatar river.

Fig. (3). Steel truss bridge over the tansin river.

After Nepal established democracy in 1950, it prioritized infrastructure development to promote national integration. Central to this effort was the construction of highways, including the East-West Highway (Mahendra Highway), which linked the country's borders across the southern plains, and north-south routes that connected remote regions to central areas like Kathmandu. These projects aimed to improve transportation, foster unity among diverse regions, and support economic development by enhancing trade, mobility, and access to services [21].

The construction of national highways in Nepal began in 1956, with the first one connecting the Indian border to the capital city, Kathmandu. In 1971, the Siddhartha Highway was built, linking the Indian border to Pokhara. Along this highway, the first prestressed bridge was constructed over the Jhumsa Khola. A notable milestone was achieved in 1993 with the construction of the first cable-stayed bridge across the Karnali River [22]. Additionally, the history of modern suspension bridges in Nepal dates back to 1900, when the first one was built across the Trishuli River [23]. Notably, a concrete arch bridge was constructed over the Bhote Koshi River at Kodari, on the Chinese border, in 1965 [24].

The local communities showcased their Indigenous craftsmanship and collaborative spirit by constructing different trail bridges. One notable example is the Baglung bridge, which featured an iron chain link. This bridge served as a testament to the community's ability to overcome rivers and difficult terrains [25] (Fig. **4**). During the early 20th century, Prime Minister Chandra Shamser of Nepal took the lead in initiating the construction of modern trail bridges [23]. To accomplish this project, the Nepalese government enlisted the expertise of the Scottish Company Luis Harper. Due to their successful efforts, trail bridges were built at various locations, including Nuwakot (Trishuli River), Sanghutar (Likhu River), Mangaltar (Roshi River) (Fig. **5**), Bharyang Bhurung (Thopal River), Charchare (Tinau River), Matela Bridge (Jajarkot), Dolalghat (Sunkoshi River) and others. Engineer Kumar Narsingh Rana played a crucial role in providing technical guidance for the construction of these bridges. In total, the company built 29 suspension trail bridges in Nepal [26]. This initiative marked a significant development in introducing modern bridge technology to Nepal. Switzerland has been helping Nepal to build trail bridges since the 1960s [27]. In November 2023, Nepal opened its 10,000th trail bridge. These bridges have made it easier for people in remote areas to access healthcare and education and have boosted business.

Fig. (4). Indigineus baglung technology trail bridge over the myagdi khola, Myagdi.

Fig. (5). Mangaltaar trail bridge, Kavre.

2.2. Bridge Failure

Bridges are critical to transportation, and their failure can have severe consequences. Failures are caused by internal factors like design errors, construction mistakes, poor maintenance, and material defects, as well as external factors, such as hydraulic issues (accounting for 85% of U.S. bridge failures), collisions, overloads, environmental degradation, and natural disasters [28]. Bridges in China, India, and the USA are failing significantly earlier than their intended design life of 100 years. The average age at failure is 23.60 years in China, 34.53 years in India, and 51.70 years in the USA [29]. Unfortunately, comprehensive literature on bridge failure studies in Nepal is not available. There have been isolated studies on bridge failures in Nepal in recent times. Many road bridges in Nepal are being constructed without adequate consideration of geo-hazards and, in particular, river-flow dynamics [30]. During the 2015 earthquake, several bridges investigated during field reconnaissance suffered minor damage to expansion joints and decks, while some decks were slightly displaced [31]. Additionally, four bridges on the Prithvi Highway and two bridges on the Tribhuvan Highway were washed away in the 1993 floods. In July 2021, a motorable bridge in Bhadgaun, Tanahun district, Nepal, collapsed during a massive flood in the Chhabdi Khola [32]. Furthermore, on April 6th, 2021, two spans of the under-construction Thimura–Devghat bridge collapsed [33]. In total, 44 motorable bridges and 11 trail bridges were damaged due to the 2024 floods. Based on the systematization of available bridge collapse data, it is clear that human factors play a major role in structural failure [19]. Bridge collapses lead to loss of life, service disruptions, and significant economic impacts due to delays in transportation and increased costs. This early failure underscores the need for improved maintenance, design, and infrastructure management to prevent premature deterioration.

3. MATERIALS AND METHODS

The article utilizes secondary data from a range of sources, including the following primary sources:

3.1. Government Agencies

A significant portion of the data was sourced from government agency websites, which are known for their comprehensive and reliable nature. These sources provide vital statistics and pertinent information essential for the study.

3.2. Peer-reviewed Articles

Data were extracted from peer-reviewed articles that underwent a thorough evaluation by experts in the field prior to publication, ensuring the credibility and scientific validity of the findings presented.

3.3. Primary Data from Bridge Construction Projects

Certain data were directly gathered from project reports in which the authors were actively involved. This primary data offers unique and valuable insights into bridge construction practices.

By integrating data from government sources, peer-reviewed literature, and primary data, the article adopts a robust and well-rounded approach to the topic of bridge construction and economic development in Nepal. This analysis examines various types of bridges built in Nepal, from their inception to their current status. It outlines the findings and offers recommendations for improved bridge construction utilizing available resources. Additionally, the discussion includes aspects of economic development related to bridge construction.

4. RESULTS AND DISCUSSION

4.1. Bridges under the National Highway

Among the approximately 100,000 km of roads in Nepal, categorized under various types, the Government of Nepal, in 2019, designated 80 national highways, comprising 14,913 km of roads, as strategic roads under the responsibility of the Ministry of Physical Infrastructure and Transport (MoPIT) and the Department of Roads (DoR). There are 1,656 bridges on these highways [34]. These bridges are classified into seven categories: Arch Brick Masonry, Arch RCC, Bailey, Cable-stayed, Multicell Box Culvert, Prestressed Girder, RCC T Beam, RCC Slab, Steel Plate Girder, Steel Truss, and Suspension Bridges. Arch bridges predominantly work in compression, suspension bridges in tension, beam bridges in bending, and truss bridges in both tension and compression. The number of bridges in each category and their respective lengths are provided below in Table **1** [34].

Table 1. Highway bridges in Nepal.

S. No.	Bridge Type	Total Nos	Length, m	Length, %	Max. Span, m
1	Arch Brick Masonry	3	41.16	0.05	10
2	Arch RCC	46	2051.31	2.51	114
3	Bailley	5	237.9	0.29	52
4	Cable Stayed	1	500	0.61	375
5	Multicell Box Culvert	16	275.9	0.34	0
6	Prestress	27	2821.55	3.46	60
7	RCC Slab)	516	10414.91	12.75	151
8	RCC T Beam	835	50580.69	61.94	100
9	Steel Plate Girder	68	4254.83	5.21	60.8
10	Steel Truss	73	5999.72	7.35	125
12	Suspension	2	270.9	0.33	151
13	Vented Causeway	1	100	0.12	
14	Unidentified	63	4115	5.04	
Total		1656	81663.87	100	

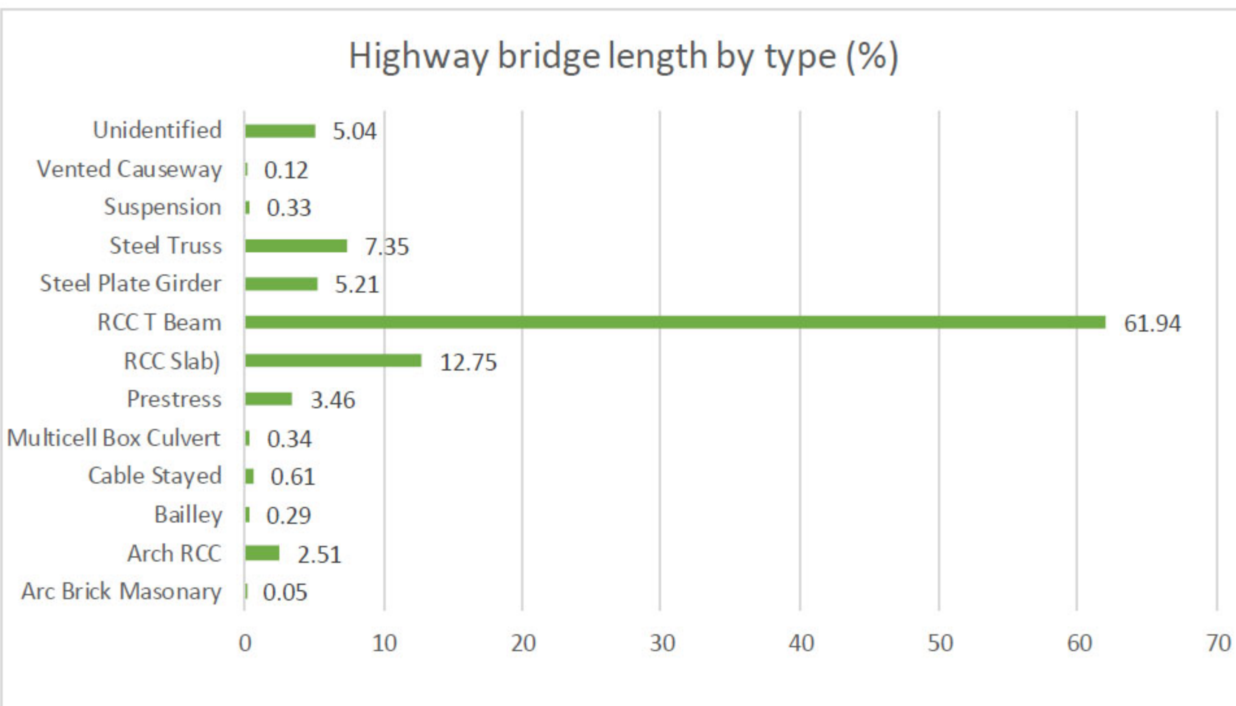

Fig. (6). Percentage distribution of bridge lengths by type on national highways.

Table 2. Motorable bridges and trail bridges completed by provinces (2018/19 to 2022/23).

Province	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Paschim	Total
Motorable Bridge, Nos.	72	19	102	85	106	22	29	435
Trail Bridges, Nos.	88	100	13	63	31	55	46	396

Note: Source: Province Governments.

About 85% of highway bridges are concrete bridges. RCC T-beam bridges are the most common type in the country. The number of prestressed T-girder and box girder bridges is also increasing. The percentage distribution of bridge lengths is provided below in Fig. (**6**).

4.2. Bridges under Province / Local Government

Bridge construction work under local governments began in 2011 through the Local Road Bridge Program (LRBP). Technical support for these bridges was provided by the Swiss Agency for Development and Cooperation under the Motorable Local Road Bridge Programme (MLRBP). The bridges were built through the District Development Committees (DDC) and District Technical Offices (DTO). Approximately 402 bridges were constructed on local roads across 75 districts during MLRBP Phases I to III. Nepal was declared a federal country after the promulgation of the Nepal Constitution in 2015. The country now has 7 provincial governments and 753 local units. Each province and some local units are involved in constructing motorable and trail bridges. A total of 435 motorable bridges and 396 trail bridges were constructed by provincial governments between the fiscal years 2018/19 and 2022/23, as mentioned below in Table **2**.

Table 3. Bridge types in nepal and their significance.

Bridge Types	Descriptions
Arch bridge	An arch bridge is a bridge with abutments at each end shaped like a curved arch. Arch bridges work by transferring the weight of the bridge and its loads partially into a horizontal thrust that is restrained by the abutments on either side. Most of the elements of arch bridges are in compression. Arch bridges are one of the main types of bridges in civil engineering [35]. The arch-type construction is unique in that it is the only structural type where the strength of the material is fully utilized [36]. These bridges are particularly suitable for spanning deep gorges and rivers in mountainous areas. Most of the arch bridges in Nepal have been built with support from the Chinese government. In 2001, a group of 15 Nepalese engineers received training on arch bridge construction in the People's Republic of China. Following their training, an arch bridge with a span of 35 meters was designed and constructed over the Bagmati River at the Chobhar Gorge. This is likely the first concrete arch bridge designed and built by Nepali engineers and contractors. The Government of Nepal has also built several notable arch bridges, including the Network Arch Bridge, Through Arch Bridge, and Deck Arch Bridge.
Network Arch Bridges	The Network Arch Bridge is a type of tied arch bridge (also known as a bowstring arch) that combines features of a tied arch bridge and trusses in a single system [37]. Network arch bridges typically have spans ranging from 30 meters to 380 meters. The Dhobikhola Bridge on the Araniko Highway is the first network arch bridge in Nepal, completed in 2020. The bridge has a total length of 51.45 meters, with an arch span of 50.35 meters and an arch rise of 9.68 meters, resulting in a span-rise ratio of 5.20. The bridge features two arch ribs, with a rib width of 1.0 meter and a depth of 1.70 meters at the ends and 1.03 meters at the midspan. It is supported by a pile foundation and utilizes lead rubber bearings. The bridge width is 12.00 meters on the downstream side and 10.50 meters on the upstream side. The twin bridge was constructed at a cost of NPR 131,385,000, including PS and VAT [38]. A photo of the Dhobikhola Network Arch Bridge is shown in Fig. (**7**).
Through-Arch Bridge	A through-arch bridge features a bridge deck positioned at the springing line of the arch. The thrust is typically absorbed by a tie rod or girder that connects the two ends of the arch, creating what is known as a tied-arch bridge, also referred to as a bowstring arch bridge or Langer girder bridge. The Nadipur Bridge over the Seti River in Pokhara is a through-arch bridge with an 80-meter span (Fig. **8**). Constructed with a steel truss, the bridge was completed in 2019 at a cost of NRS 112.5 million. Another notable example is the Ramdi Bridge over the Kali Gandaki River (Fig. **9**).
Deck Arch Bridge	A deck arch bridge has its deck located above the crown of the arch, which is the typical design for a true arch bridge. This is the most common type of arch bridge, ideal for crossing valleys with stable rock walls. The Sino-Nepal Friendship Bridge over the Bhotekoshi River, which links Kodari in Nepal with Zhangmu (Khasa Bazar) in China, is an example of a deck arch bridge (Fig. **10**). It is a reinforced arch bridge with a prestressed concrete deck girder on top. The bridge is 45 meters long and 8 meters wide and was built in 1964. However, it was severely damaged by the 2015 earthquake and has since been replaced by a beam-type bridge. The Mugling Arch Bridge over the Trishuli River on the Prithvi Highway is the longest deck arch bridge in Nepal. Completed in 2019, it was built by a Nepali contractor under a design-and-build model. The bridge has a total length of 160 meters, with a 120-meter arch span and two 20-meter side spans. The arch rise is 16.28 meters, resulting in a span-to-rise ratio of 7.37. The arch rib is 1.0 meters wide and 2 meters deep, while the bridge itself is 10.6 meters wide. The construction cost, including PS and VAT, was NRS 103,860,000 [39]. A photo of the Mugling Arch Bridge is shown below in Fig. (**11**). This bridge is a landmark structure with the longest concrete deck span of 120 meters in South Asia. The Kochalighat Kuine Bridge on the Chisapani-Babiyachaur-Badichaur-Surkhet Road is a three-span continuous open spandrel concrete deck arch bridge completed in 2023. The bridge has a total length of 300 meters, with arch spans of 87.40 meters, 99.10 meters, and 100.10 meters. The arch rise for the second span is 18.20 meters, giving it a span-to-rise ratio of 5.5. The bridge features three arch ribs, each with a width of 0.9 meters and a depth of 1.50 meters. It has a pile foundation at the right arch block and an open foundation on a rock at the left arch block. The bridge is 11.00 meters wide and was constructed at a cost of NRS 339,661,000, including PS and VAT [40]. A photo of the Kochalighat Kuine Bridge is shown below in Fig. (**12**) in the appendix.

(Table 3) contd.....

Bridge Types	Descriptions
Truss Bridge	A truss bridge is a type of bridge whose load-bearing superstructure is composed of a truss, a framework of connected elements that often form triangular units. These elements may experience tension, compression, or sometimes both in response to dynamic loads. Two notable truss bridges in eastern Nepal are shown below in Fig. (**13**) (Mulghat Bridge) and Fig. (**14**) (Piluwa Khola Bridge). The Mulghat Bridge, located on the Koshi Highway over the Tamor River, was built in 2036 BS (1979 AD) with support from the UK Government. It is 200 meters long. The Piluwa Khola Bridge, on the Mude-Khandbari Road, is a single-span, 96-meter-long steel truss bridge with a single-lane carriageway of 4.25 meters and a 1-meter walkway on one side adjacent to the carriageway, giving it a total width of 5.95 meters. This bridge was completed in 2009.
Extra-dosed Bridge	Combining elements of both girder and cable-stayed bridges, extra-dosed bridges provide an efficient solution for medium-span requirements with reduced cable usage. Three extra-dosed bridges are currently under construction in Nepal: (1) over the Bakaiya River as part of the Kathmandu-Terai Fast Track (Expressway) Road Project (Fig. **15**), (2) over the Seti River on the Kathmandu-Pokhara Highway, and (3) over the Narayani River on the East-West Highway (Fig. **16**). The Bakaiya extra-dosed bridge has a 120-meter main span and a 65-meter side span. It also includes five spans of 35-meter-length prestressed I girders, giving it a total length of 425 meters. The Seti River extra-dosed bridge consists of two parallel bridges, each with a total length of 190 meters and a width of 13 meters. The twin Seti River extra-dosed bridges are expected to be completed in 2026 at a cost of over one billion NRS. The Narayani extra-dosed bridge will have a total length of 420 meters.
Cable-stayed Bridge	Nepal has only one cable-stayed bridge located over the Karnali River. The Karnali cable-stayed bridge, built in 1993, features a main span of 325 meters and a side span of 175 meters, with a single pylon rising over 120 meters above the deck. A picture of the Karnali cable-stayed bridge is shown below in Fig. (**17**) [22].
Suspension Bridge	A suspension bridge is a type of bridge where the deck is suspended below the main cables by vertical suspenders. Key components of a suspension bridge include the main cable, towers, suspenders, main girder, and anchorages. One example of a suspension bridge in Nepal is the Old Mugling Bridge, which is shown below in Fig. (**18**). Another example of a suspension bridge is the Bheri Bridge at Chinchhu over the Babai River (Fig. **19**).

4.3. Existing and Under-construction Special Bridges (Signature Bridge)

The Karnali Geruwa (Kothiyaghat) Bridge on the Postal Highway in Bardiya District is currently the longest motorable bridge in Nepal. The bridge consists of 21 spans, with a total length of 1,015 meters. It was completed in 2015 at a contract value of NPR 1,181,309,865, including VAT and PS. The second-longest motorable bridge is the Rapti Bridge in Dang District, which is 865 meters long and 10.5 meters wide. It was completed in 2019. The third-longest bridge in Nepal is the Mahakali Bridge over the Mahakali River at Dodhara Chandani. This bridge is 800 meters long and 23.87 meters wide, accommodating four lanes. It has 16 spans, each 50 meters in length. The superstructure is a double-cell prestressed concrete box girder with a depth of 2.75 meters (inclined webs) and is simply supported. The bridge features pot-fixed bearings and pot-PTFE-free bearings. It has 408 pile foundations, each with a 1.2-meter diameter and a depth of 28 meters.

From a technological perspective, the span length of a bridge is more significant than its total length. The longest-span road bridge in Nepal is the Karnali Bridge at Chisapani, which is located on the border between Bardiya and Kailali districts. This cable-stayed bridge has a span of 325 meters and is considered the first modern signature bridge in Nepal. It was constructed by a Japanese contractor. Following the Karnali Bridge, the longest-span bridges in Nepal are suspension bridges over the Trishuli River at Mugling on the Prithvi Highway and the Marsyangdi River on the Anbukhaireni-Gorkha Highway. Both bridges have a span of 125 meters. Several bridges in Nepal span 120 meters, including the Arun Nadi steel truss bridge at Leguwaghat and the Sabha Khola steel bridge near Tumlingtar in the Sankhuwasabha district. A span of 117 meters was achieved on a suspension bridge over the Bheri River on the Kohalpur-Surkhet Road. A steel bridge with a span of 100 meters was constructed over the Tamor River on the Dharan-Dhankuta Road in 1980.

Fig. (7). Network arch bridge over the dhobikhola, Kathmandu.

Fig. (8). Nadipur bridge over the seti nadi, Pokhara.

The Kathmandu-Terai Fast Track (KTFT) Project involves the construction of several significant concrete bridges, including the Dhedre Bridge, which has a main span of 135 meters. This bridge is being built using the free cantilever method with a prestressed concrete box girder design. Among the various tall bridges in the KTFT Project, the tallest motorable bridge is currently under construction over the Jitpur Khola, with a pier height of 72 meters. All bridges in this project are concrete structures with pile foundations. The bridge types in Nepal and their significance are mentioned in Table **3**.

Fig. (9). Ramdi bridge over the kaligandaki river.

Fig. (10). Dech arch bridge over the bhotekoshi river in nepal-china border.

Fig. (11). Mugling arch bridge over the trishuli river.

Fig. (12). Kochalighat kuine multi-span arch bridge over the karnali river.

Fig. (13). Mulghat bridge over tamor river.

Fig. (14). Piluwa khola truss bridge.

Fig. (15). The proposed extra-dosed bridge *over the bakaiya river*.

Fig. (16). The proposed extra-dosed bridge over the narayani river.

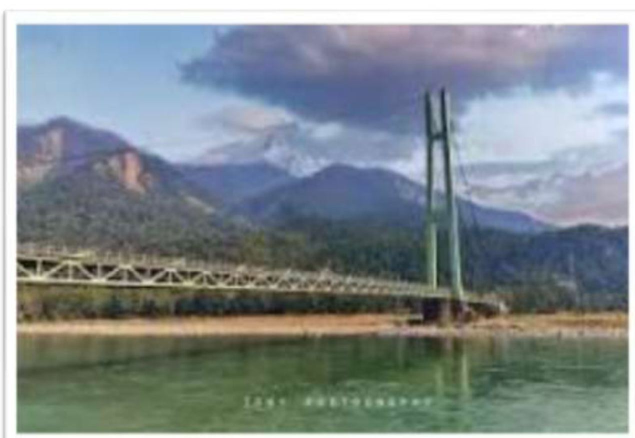

Fig. (17). Karnali cable-stayed bridge.

Fig. (18). Mugling bridge over the trishuli river.

Fig. (19). Bheri bridge at chhinchu.

4.4. Trail Bridges

Trail bridges are crucial in Nepal, especially in remote areas, as they can span great distances with minimal support points, making them ideal for crossing deep valleys and wide rivers. The systematic construction of trail bridges began in 1960 with support from the Swiss Development Cooperation (SDC), which is a highly successful development partnership organization [41]. To facilitate the construction of trail bridges throughout the country, the Government of Nepal established the Suspension Bridge Division. In 1990, with support from the Swiss government, the Bridge Building at Local Level (BBLL) program was launched. This program, working with local bodies, such as District Development Committees (DDCs), Village Development Committees (VDCs), and municipalities, constructed several short-span trail bridges (less than 120 meters for suspended bridges and less than 100 meters for suspension bridges). Nepal celebrated the completion of 10,000 trail bridges in November, 2023. Approximately 1.8 million people use trail bridges daily in Nepal. Some major trail bridges are listed below in Table 4.

Table 4. Some major trail bridges in Nepal.

S. No.	Name of Trail Bridge	Height, m	Span, m	Location	Completion Date
1	Dodhara Chandani Trail Bridge (1453 m length)		225*4	Dodhara Chandani over Mahakali	2005
2.	Kamala Trail Bridge (1501m length)			Dhanusha-Siraha	2024
1	Kushma Bungy Foot Bridge	200	490	Kushma, Parbat	2019
2	Bhote Koshi	160	166	Kodari, Dolakha Region	1999
3	Samrong khola/ Jhinu Danda	140	287	Ghandruk, Kaski	2018
4	GandakiGolden/ Baglung Parbat	122	567	Baglung	2020
5	Kushma Gyadi	117	344	Kushma, Parbat	2010
6	Kushma Mudikuwa	117	359	Kushma, Parbat	2016
7	Kushma Balewa	117	347	Kushma, Parbat	2013
8	Myagdi footbridge	85	250	Baglung, Parbat	2019
9	Baglung- Bhakunde	85	222	Baglung, Parbat	2018
10	Bega banduk	85	365	Begkhola	2018

Trail bridges are constructed not only across rivers but also along their banks. An example is the Yarubagar Cantilever Trail Bridge (Fig. **20**). This bridge was built following the devastating Gorkha earthquake in 2015, which caused significant damage to the trail leading to upper Gorkha due to flooding and made it impossible to open a new trail because of the steep vertical cliffs along the Budhi Gandaki River. This bridge is notable as the first cantilever bridge in Nepal. It spans 195 meters and was constructed at a cost of NRs. 38 million in 2016.

Fig. (20). Yarubagar cantilever bridge, Gorkha.

4.5. Issues on Bridge Construction Practices in Nepal

Current bridge investment practices in Nepal are often ad-hoc and lack rational planning, leading to suboptimal resource utilization. Several bridges fail each year during and after construction. Common issues include:

4.5.1. Bridge Project Selection

Bridge project selection is driven by political or local pressures rather than actual road network needs.

4.5.2. Reliance on Conservative Designs

Reliance on conservative designs prioritizes safety over innovative, cost-effective solutions. Most bridges in Nepal are functional template designs, like RCC T-beams and slabs, but they lack aesthetic appeal and engineering efficiency and fail to incorporate sustainability and resilience, which are crucial for modern, durable, and environmentally responsible infrastructure [42].

4.5.3. Bridge Site Locations

Bridge site locations are influenced by local preferences instead of expert assessments.

4.5.4. High Demand for Bridges Nearby

High demand for bridges nearby results in inefficient network utilization.

4.5.5. Improper Design of Falsework, Scaffolding, and Formworks

Improper design of falsework, scaffolding, and formworks results in bridge failure during construction.

4.6. There are no Proper Records and Lessons Learned from Bridge Failure

To ensure value for money in bridge construction, Nepal should adopt the following rational investment practices:

4.6.1. Detailed Demand Analysis

Conduct thorough analyses and future demand projections to determine the appropriate capacity and type of bridges.

4.6.2. Network-centric Selection

Align bridge project selection with road network needs, avoiding constructions motivated by other factors.

4.6.3. Minimize Bridge Numbers

Maximize the use of existing or nearby bridges, along with connecting roads, to reduce the need for additional structures.

4.6.4. Expert-driven Decisions

Base decisions on bridge type and site selection on expert assessments rather than local political pressures. Sustainable bridges for future generations must meet holistic, integrated criteria, encompassing economic, environmental, and social considerations [43].

4.6.5. Innovations and Technologies

Adopt innovative designs and modern technologies to improve economic efficiency in bridge projects.

4.6.6. Timely Completion

Ensure projects are completed within the intended timelines by allocating necessary resources and implementing effective contract administration.

4.6.7. Capacity Building

Strengthen the capacity of domestic designers, engineers, and contractors to deliver cost-effective bridge projects.

4.6.8. Poper Design

Poper Design of formworks, falsework, and scaffolding.

4.6.9. Maintain Bridge Failure Records

Maintain bridge failure records and document lessons learned from bridge failure.

4.6.10. A Strong Institution

A strong institution for the research and development of standards, guidelines, and codes for bridges.

Public capital investment in Nepal's transport sector is low by both global and South Asian standards [44]. To stimulate economic growth, the country needs to increase its infrastructure investment, including in bridges. Given the scarcity of resources, investment decisions must be meticulously analyzed for their returns. With over 6,000 rivers and streams, Nepal requires a vast number of motorable and trail bridges to expand connectivity. As a result, there is increasing public and political demand for new roads and bridges. However, the combination of significant investment needs, low traffic volumes, and the absence of holistic and integrated development programs has limited the full socio-economic potential of the road transportation sector.

By implementing these recommendations, Nepal can improve its transport network, foster economic development, and maximize the socio-economic benefits of its infrastructure investments.

4.7. Bridge Construction and Economic Development

Nepal heavily relies on its road network for transportation, as it is a landlocked country with limited rail and waterway options. Roads are crucial for Nepal's economic and social development, facilitating 90 percent of the country's goods and passenger transport. The government's policy, which focuses on development at every level, has now shifted towards infrastructure building, economic corridors, and transborder connectivity [45], including expanding the road network and constructing bridges to promote mobility, trade, tourism, and market access for agriculture and industry.

Nepal has achieved its goal of connecting all 77 district headquarters with the national road system. However, 20 out of 753 rural municipality centers remain inaccessible. About 20 years ago, Nepal had one of the smallest road networks in the world, but it has since grown rapidly. In 1998, the road density for both Strategic Road Networks (SRN) and Local Road Networks (LRN) was estimated at 13.7 km per 100 km^2. By 2016, it had increased to 49.6 km per 100 km^2. The SRN expanded from 4740 km in 1998 to 15,404 km in 2016, while the LRN increased by 1200%, from 4780 km in 1998 to 57,632 km in 2016 [46]. Bridges have also been constructed to ensure year-round access, turning roads into all-weather routes.

The economic benefits of improved connectivity and infrastructure development in Nepal are well-documented across various studies, highlighting the crucial role of transportation infrastructure in driving economic growth and improving livelihoods. The Asian Development Bank (ADB) found that enhanced connectivity in Nepal leads to significant economic benefits [47]. Improved road networks and infrastructure have been linked to economic growth, as they facilitate better access to markets, reduce transportation costs, and improve the overall business environment. Dhungel (2020) analyzed the period from 1994 to 2018 and found a positive correlation between infrastructure development and economic growth in Nepal [48]. This era witnessed the construction of numerous bridges and transport infrastructures, which improved road conditions, geometry, paving, and safety elements, thereby promoting trade and mobility.

A specific example of the economic impact of infrastructure is the Beni-Jomsom road construction project. Roubal (2014) highlighted that this road brought about significant changes for the resident population, altering their economic structures and enhancing their economic capabilities through improved mobility [49]. The construction of a bridge in Nepal was found to affect freight costs and volumes, as well as access to physical infrastructure like education and health facilities, and had social, cultural, and economic impacts, including the establishment of micro-industries and businesses [5]. Once the bridge was constructed, road transport access to the remote settlements in the Karnali zone of Nepal became significantly easier, enhancing connectivity and facilitating travel and trade in the region [50].

Shively and Thapa (2016) studied the role of roads and bridges in moderating price levels and volatility in Nepal’s rice and wheat markets [51]. Their findings suggest that transportation infrastructure explains roughly half of the spatial and temporal variation in price mark-ups between regional and local markets, indicating the importance of connectivity in price stabilization and market integration. Similarly, improved connectivity has also been associated with reduced transportation costs, which play a significant role in determining agricultural input use and the prices of agricultural products and food.

In mountainous regions, foot trails and trail bridges have been improved for last-mile transportation. These transportation infrastructures play a vital role in regional stability and economic growth in landlocked countries, like Nepal, which can transform the countries from landlocked to land-linked [52]. Likewise, according to a post-bridge building assessment conducted in 2015, the average daily traffic per trail bridge was 208, which amounted to about 1.4 million people using trail bridges for various reasons, such as visiting market centers, going to school and health service centers, attending social functions, doing agricultural works and performing household chores [23]. The construction of 10,000 bridges up to November, 2023, with Swiss technical support, has improved living conditions for 19 million people, reducing travel times by 2.5 hours. This led to a 16% increase in school attendance and a 26% rise in health center visits. Additionally, 20% of the bridges have become hubs for local businesses, boosting economic activity in the surrounding areas [27].

Overall, these studies underscore the multifaceted impact of transportation infrastructure, including bridges, on Nepal's economic landscape, demonstrating that investments in roads, bridges, and connectivity yield substantial economic and social benefits.

CONCLUSION

Bridges are an indispensable part of Nepal's infrastructure, providing vital connections across the country's rugged terrain. The development of various types of bridges, supported by multiple agencies, has been crucial in promoting social interaction, cultural exchange, and economic growth. As Nepal continues to progress, the construction and maintenance of bridges will remain a top priority to ensure sustainable growth and connectivity for its diverse population.

The increasing use of prestressed concrete bridges in Nepal is driven by the local availability of cement and aggregate, making this method both practical and economical. Arch bridge designs are often the most cost-effective solution when the topography allows, providing a budget-friendly option for specific landscapes. For long spans, prestressed cantilever concrete box girders are well-suited, offering both strength and stability. Likewise, extra-dosed bridges are effective for medium spans between 100 and 220 meters and are more economical than cantilever concrete box girders, provided the necessary technology is available.

In summary, the strategic selection of bridge types based on local conditions and resources is critical for Nepal's ongoing development. By utilizing appropriate technologies, materials, and rational investment practices, Nepal can continue to enhance its infrastructure, improving connectivity and fostering growth throughout the country. The continued advancement of bridge technology and increased construction will significantly impact reliable mobility in remote areas and the seamless operation of the national road network. Bridges are a key component of Nepal's infrastructure and have undeniably played a major role in driving the country's economic development. However, a rational investment policy, proper design, and proper institutional change are crucial.

The impact of bridges on the economic development of Nepal extends beyond infrastructure, offering broader opportunities for development and research. Following are some potential areas for future exploration: long-term economic analysis, including GDP growth and industrial expansion, social and technical developments, including improvement of education, healthcare, and technology, sustainability of similar projects and environmental impacts, and comparative studies of different types of bridges and their suitability for Nepal's geography.

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It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

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