

# SONAMARG TUNNEL: AN ENGINEERING MARVEL DRIVING CONNECTIVITY, TOURISM, ECONOMIC DEVELOPMENT, AND ENVIRONMENTAL SUSTAINABILITY

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## ABSTRACT

The Sonamarg Tunnel is a high-altitude road infrastructure project that is intended to be built on National Highway 1 (NH-1) in Jammu and Kashmir, and to help ensure reliable access to Sonamarg throughout the year, as well as help to strengthen the Srinagar-Ladakh corridor. The aim of the study is to assess the integrated engineering and regional development intervention of the tunnel by analyzing the connectivity it creates, the tourism and economic opportunity it offers and how it impacts on environmental sustainability. Methods: 104 fully completed questionnaires were received and were supplemented by official project and tourism data, and peer-reviewed literature, between July 29 and August 6, 2026, and a mixed-evidence design was used. Frequencies, percentages, means, and standard deviations were used in the analysis of the questionnaires, which were also given internal consistency testing, one-sample testing against the neutral midpoint, and Spearman correlations. Thematic coding of the open-ended responses was also applied. Results: Respondents showed slightly positive connectivity and service benefits ( $M = 3.21$ ,  $SD = 0.98$ ,  $\alpha = .89$ ) that were significantly higher than the neutral point ( $p = .033$ ). Tourism-development perceptions were also positive but more tentative ( $M = 3.21$ ,  $SD = 1.12$ ,  $\alpha = .92$ ,  $p = .065$ ), while economic-development perceptions were closer to neutral ( $M = 3.11$ ,  $SD = 1.03$ ,  $\alpha = .89$ ,  $p = .273$ ). The overall benefit-cost judgement was mixed ( $M = 3.02$ ), while the most popular was related to tunnel lighting, signage, ventilation and emergency arrangements ( $M = 3.41$ ). Traffic, safety, security and emergency management were the most frequent topics of open ended responses. Conclusion: The questionnaire indicates measurable and perceived benefit on connectivity and selected service outcomes, but it also reveals that benefits of tourism, economy and environment are not even. Traffic control, maintenance, local benefit capture, monitoring of the environment, and open post-opening traffic reporting are essential to long term success.

**KEYWORDS:** Sonamarg Tunnel, Z-Morh Tunnel, Himalayan tunnelling, connectivity, tourism development, regional economy, environmental sustainability

## INTRODUCTION

The design of mountain transport systems is limited in possibilities by steep terrain, unstable geology, snowfall, avalanches, landslides and the short construction seasons. These limitations are more significant in the western Himalaya where closure of roads causes significant time, reliability and safety costs. Historically called as Z-Morh Tunnel, the Sonamarg Tunnel is a vital link on NH-1 between Srinagar and the Sonamarg. The project was inaugurated officially on 13th January 2025. The official records are of an estimated 12 km project package consisting of the main tunnel, the egress tunnel and the approach roads, which cost over INR 2,700 crore at an altitude of over 8,650 ft (Government of India, Prime Minister's Office, 2025a, 2025b).

The tunnel holds importance as there were challenges related to access during certain times of the year owing to snowfall and avalanche prone road sections in Sonamarg. All-weather access may impact on the economic geography of the destination, by decreasing uncertainty, increasing the length of the operating seasons, and linking local enterprises to wider networks of visitors and supply. The project also serves as a part of Srinagar-Leh corridor. The government is confident that the portion of the road in conjunction with the Zojila Tunnel will be reduced from 49 km to 43 km and speed of travel will improve from 30 km/h to 70 km/h (Government of India, Prime Minister's Office, 2025a). The above figures are indicative of the combined future corridor and should not be considered as an actual effect of the opening of the Sonamarg Tunnel.

Infrastructure benefits are not a given. Although a tunnel could minimize exposure to avalanche and slope instability, it would need to include the development of the portals, disposal of the spoil, ventilation, drainage, and the use of

concrete and steel, as well as the use of excavation energy. Increased access can also lead to more traffic and increase the rate of tourism impact on sensitive alpine environments. Therefore, any evaluation that only considers the completion of the engineering or travel time reduction would not be comprehensive. The unit of analysis is the infrastructure-development system, which connects physical reliability and tourism, livelihoods, land-use change, emissions and ecological carrying capacity.

This paper presents a "whole-of-government" assessment based on evidence from the questionnaires filled out by the respondents in combination with open administrative records and peer-reviewed research. The questionnaire dataset provided includes 104 complete responses and information on characteristics of stakeholders, pre- and post-opening travel experience, perceived connectivity and safety outcomes, tourism and economic impacts, environmental issues, and management concerns. Contextual evidence such as official records and tourism statistics is kept to ensure that the perceptions of respondents are compared to engineering and regional-development evidence.

**Figure 1** *East Portal of the Sonamarg (Z-Morh) Tunnel*

Note. Official project photograph reproduced from the National Highways & Infrastructure Development Corporation Limited project page (NHIDCL, n.d.).



## LITERATURE REVIEW

### Himalayan Tunnelling and Engineering Risk

Geological uncertainty is not uniform rock behavior that is the hallmark of Himalayan tunnelling. The weak and fragile rock masses, faults, shear zones, groundwater ingress, squeezing, rockburst and high in-situ stress are some of the common areas of delay and support redesign identified in reviews of projects in India, Nepal, Bhutan and Pakistan (Goel, 2014; KC et al., 2022). It has been observed that the conditions of rock masses predicted during design, may be significantly different from the conditions encountered in the field, and that the types of support require adaptation as work progresses and contingencies must be planned for, as seen in case histories from the Maneri-Uttarkashi tunnel and other Himalayan projects (Goel et al., 1995a; Panthi & Nilsen, 2007a). It is also shown from uncertainty analysis that the squeezing stress has a significant variation (Panthi & Nilsen, 2007b; Panthi & Shrestha, 2018) with the stress state, rock mass strength and anisotropy.

Rock-mass classification systems are of assistance in making decisions, but do not replace engineering judgment of the specific site. The Q and RMR systems were used in the Indian application, and have yielded correlations between

the rock quality and support pressure, and spans and deformations, as well as limitations in highly squeezing ground (Goel et al., 1995b, 1996; Singh et al., 1992, 1997). The Q-system and subsequent critiques highlight the need for classification to be linked to stress assessment, geological mapping and instrumentation, and construction feedback (Barton et al., 1974; Palmstrom & Broch, 2006). Hoek (2001) also concludes, through synthesis, that there is a need for flexible means of support in poor rock conditions and disciplined monitoring of large tunnels. The studies conducted on the tunnel deformation, rockburst and probabilistic assessment further underline the significance of convergence and support stiffness measurements and assessment (Dwivedi et al., 2013; Jain & Rao, 2022; Naji et al., 2019; Panthi, 2012).

Geological variability, access, logistics and machine entrapment are other factors that influence the choice of conventional excavation or tunnel-boring. Mixed Himalayan conditions experienced by tunnel boring machines are described by Goel (2016) and the effect of anisotropic and low strength rock conditions in support design is described by Bhasin et al. (1995) and Kumar et al. (2004). In the case of the Sonamarg project, however, the engineering challenge is not so much the length of the tunnel as building and maintaining a safe tunnel in high altitudes, snow and geologically challenging conditions.

### **Transport Connectivity and Regional Economic Development**

Transport can impact economic performance through reductions in generalised travel costs and travel time, enhancement of reliability, increase in market reach and facilitating the reorganisation of location and supply chains by firms and workers. Banister and Berechman (2001) warn that transport investment will most effectively stimulate growth when interacting with a set of complementary institutions, skills, and land-use conditions. Lakshmanan (2011) also classifies the time saved as direct time saving according to his definition from the larger category of productivity's, logistics's, and agglomeration's impact. The road and transport infrastructure is associated with long run economic growth and manufacturing performance in India (Ghani et al., 2016; Pradhan & Bagchi, 2013; Tripathi & Gautam, 2010).

A causal study is a more subtle type of interpretation. Despite the positive effects on rural road access on labor and product markets, the benefits were distributed unevenly across regions (Asher & Novosad, 2020). Hedgehicks' arguments have been supported by the Indian case studies in railway history, which have shown that reducing trade costs can increase real income via market integration (Donaldson, 2018). Meta-analysis of infrastructure productivity and research on firm responses to new roads suggest positive, but inconsistent, impacts, depending on whether the road is located in a network, in congested areas, or when it is accompanied by complementary investment (Gibbons et al., 2019; Melo et al., 2013). The results suggest that the Sonamarg Tunnel can facilitate the local economic transformation but can't by itself guarantee it. The beneficiaries of the gains will be determined by skills, destination management, digital connectivity, waste systems, the quality of accommodation, and access to credit.

### **Tourism Accessibility, Seasonality, and Mountain Destinations**

Accessibility is necessary for destination development as it affects not only tourists' choice of destination but also the cost of the trip, the duration of the stay and where tourists spend money during that stay (Prideaux, 2000). The literature reviewed reveals cross-country associations between transport infrastructure and tourism development, and studies on the tourism growth and its effects on economic output show positive relationships that are dependent on the context (Brida et al., 2016; Khadaroo & Seetanah, 2007; Lee & Chang, 2008; Seetanah, 2011). The most striking mechanism in Sonamarg is the emergence of a year-round tourism system when a certain level of reliability of access to the area during winter is achieved – if the accommodation and emergency services are set up at the same time, and the products are created to suit the season.

The concentration of infrastructure, high sensitivity to ecological conditions and climate variability is especially critical to mountain tourism. Nepal (2005) outlines how the development of tourism infrastructure is unevenly distributed in remote mountain villages and communities, focusing economic benefits and environmental impacts. GIS facilitated planning and environmental impact assessment can be used to guide infrastructure development in low impact areas (Boers & Cottrell, 2007; Geneletti & Dawa, 2009). The studies have also brought into focus climate vulnerability, snow change and reliance on the quality of ecosystems in nature-based tourism in the Himalayas (Nyaupane & Chhetri, 2009; Steiger et al., 2024). Sustainability research thus goes beyond the question of the number of visitors to the next one: what amount is too much, what constitutes local ownership, what is meant by resilience and what about steady-state and/or managed-growth tourism? (Buckley, 2012; Hall, 2010; Saarinen, 2006).

### **Environmental Sustainability of Tunnel Corridors**

There are high embodied environmental costs associated with the construction of tunnels, and they can limit exposure of the surface to landslides, avalanches and sensitive slopes. The life-cycle studies highlight the following as dominating contributors: cement, steel, shotcrete, tunnel lining, energy used for excavation, energy used for machines, energy used for material transport and energy used for handling of spills (Damián & Zamorano, 2022; Lee et al., 2016; Lee et al., 2018; Rodríguez & Pérez, 2021). The emissions intensity (EI) is heavily dependent on the geological class of the excavation, the excavation rate, the support requirements and the logistics (Rodríguez et al., 2024; Zhao et al., 2022) for all three types of carbon models: conventional, tunnel-boring, and slurry-shield. These conclusions highlight

the need to integrate project-specific life-cycle assessment into any tunnel project – a tunnel can't just be called environmentally sustainable because it makes a route shorter or more stable.

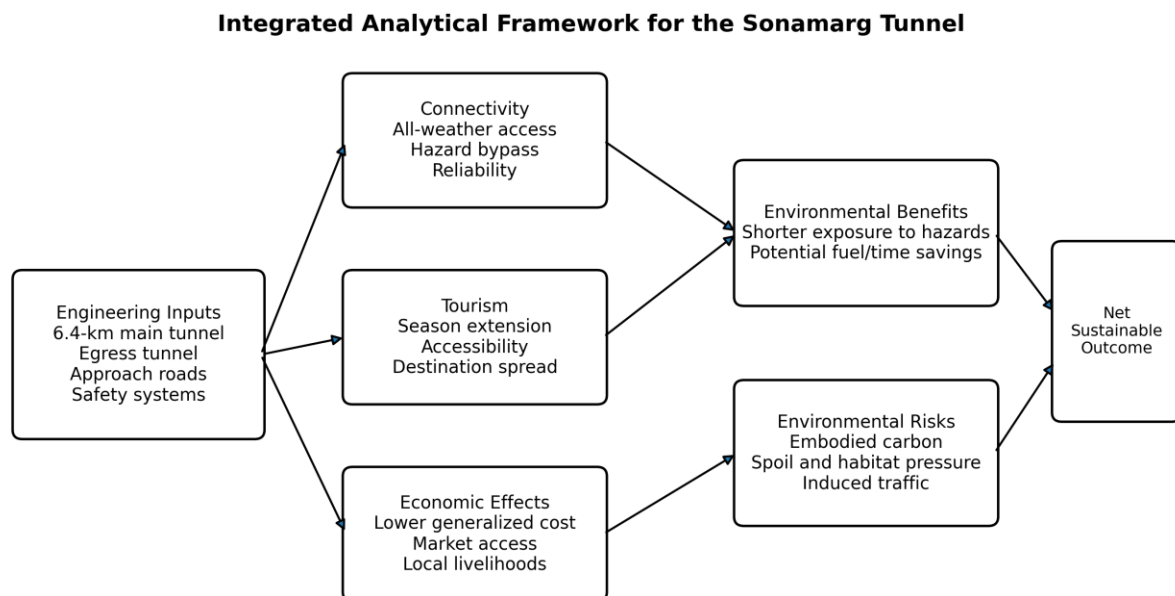
Vehicle tailpipe emissions are not the only aspect of operations that needs to be assessed but also the infrastructure and supply chains (Chester & Horvath, 2009). Linear infrastructure impacts include habitat fragmentation, changes in hydrology, wildlife mortality and intrusion into previously less-used natural areas (Benitez-Lopez et al., 2010; Coffin, 2007; Forman & Alexander, 1998; Laurance et al., 2009; Trombulak & Frissell, 2000). The sustainability question in the context of Sonamarg, is therefore, conditional and should be balanced against the embodied carbon, induced traffic, waste generation, construction spoil, portal development and pressure on alpine ecosystems.

### Research Gap

Existing research has a strong body of knowledge on mountain geotechnics, infrastructure related development, mountain tourism and road ecology, but these fields are typically studied in isolation. Limited evidence of post-opening of the Sonamarg Tunnel is available, which is integrated. The present study fills this gap by integrating a survey of stakeholders (N=104), with tourism and project data, to provide early evidence of perceived connectivity and an overview of the experiences of tourists, economic and environmental outcomes, while acknowledging that longer time-series and probability-based follow-up surveys are still needed for causal evaluation.

**Figure 2** *Integrated Analytical Framework for the Sonamarg Tunnel*

Note. The framework distinguishes enabling engineering outputs from economic, tourism, and environmental outcomes. Net sustainability depends on management of both benefits and risks.



### Research Objectives, Questions, and Hypotheses

#### Objectives

- To maintain the engineering and operational record of the Sonamarg Tunnel with authoritative records on the project.
- To measure the historical tourism-demand setting in Sonamarg using destination-level administrative data from the Jammu and Kashmir Tourism Department.
- Estimating indicative connectivity improvement associated with the official combined parameters of Sonamarg-Zojila corridor.
- To assess the probable effects that the tunnel will have on tourism, livelihoods and regional economic integration.
- To evaluate the environmental benefits and risks and formulate sustainable operating monitoring plan.

#### Research Questions

- RQ1: What are the engineering features that make the Sonamarg Tunnel special in the context of the transportation system in the Himalayas?
- RQ2: What do destination-level Sonamarg tourism statistics reveal about the historical demand base that may benefit from year-round access?

- RQ3: How big are the route, speed and travel-time changes indicated for the combined route of Sonamarg-Zojila corridor?
- RQ4: How can better access be a driver of local tourism and economic development?
- RQ5: What condition(s) in environmental management promotes a net sustainable outcome in the corridor?

### Hypotheses

- H1: Aim of the study: To test the hypotheses that an all-weather tunnel access will (1) increase the reliability of the corridor and (2) decrease the generalized travel cost compared to the avalanche prone surface route.
- H2: Better access has a positive relationship with tourism season extension and tourist demand.
- H3: Better corridor connectivity creates positive local and regional economic spillovers via market access, jobs and supply-chain integration.
- H4: Operational savings and hazard avoidance must be greater than the construction, induced traffic and ecosystem management costs for the environmental balance to be positive in the tunnel.

**Table 1** *Alignment of Research Questions, Indicators, and Evidence*

| Question | Key indicator                                | Data source                                               | Analytical method                              |
|----------|----------------------------------------------|-----------------------------------------------------------|------------------------------------------------|
| RQ1      | Length, altitude, project components, status | PIB and NHIDCL project records                            | Documentary analysis                           |
| RQ2      | Annual tourist visits and growth rates       | J&K Tourism Department: Sonamarg destination-level series | Descriptive statistics and year-on-year change |
| RQ3      | Route length, speed, calculated travel time  | Official corridor parameters                              | Percentage-change and time calculation         |
| RQ4      | Tourism and economic mechanisms              | Peer-reviewed transport and tourism literature            | Thematic synthesis                             |
| RQ5      | Carbon, ecology, spoil, induced traffic      | Tunnel LCA and road-ecology literature                    | Conditional evidence matrix                    |

## METHODOLOGY

### Research Design

The study design was a mix of primary questionnaire responses, quantitative administrative records and qualitative evidence synthesis. The questionnaire offers a preliminary snapshot from stakeholders on their views just after the opening, and the official project and tourism documentation offer an external baseline of facts. This design is suitable for a project that has just opened to traffic, and for which long series of traffic, livelihood, environmental and destination level timeseries are not yet available.

### Primary Questionnaire and Administrative Data

The first set of questionnaires provided for this study had 104 complete responses between 29th July and 6th August, 2026. It comprised 50 questions, 15 of which were one to five agreement items related to connectivity and services, tourism, economic development, environmental risks and management and overall benefit-cost perceptions, and the remaining 40 questions were stakeholder profile, place of residence, education, occupation, association with the corridor, pre-tunnel travel, familiarity and use of the tunnel, purpose of the trip, season, mode, and sources of information. There were 50 questions, 15 of which were one to five agreement items focused on connectivity and services, tourism, economic development, environmental risks and management, and overall perceptions of benefit-cost, while the other 40 questions dealt with stakeholder profile, place of residence, education, occupation, association with the corridor, pre-tunnel travel, familiarity and use of the tunnel, purpose of the trip, season, mode, and sources of information. There was no missing data in the questionnaire. The administrative sources were the releases made by the Press Information Bureau for January 2025, NHIDCL project records, and the destination-level yearwise tourist-arrival table for Sonamarg supplied by the Jammu and Kashmir Tourism Department, Srinagar (2014-2025). There is no documentation of the sampling/recruitment process in the response file provided, therefore the questionnaire is considered a non-probability respondent sample and is not assumed to be representative of the regional population as a whole.

### Secondary Evidence

Fifty-four peer-reviewed studies were chosen for analysing four main fields: Himalayan tunnel engineering, transport and economic development, mountain tourism and environment sustainability. Studies that had DOI numbers, open access versions, methods that are established and/or had a direct relevance to the Himalayan and tunnel context were given priority. The literature was used for interpretation of mechanisms and risks and not as a project specific monitoring.

## Variables and Analysis

Descriptive analyses of the project and tourism baseline variables were undertaken, including project length, main-tunnel length, altitude, reported cost, project status, Sonamarg annual domestic, foreign, and total tourist arrivals for 2014-2025, year-on-year visitor change, route length, and official speed benchmarks.

The frequency and percentage for the profile variables of the questionnaire was used to summarize them. Responses to Q14, which asked multiple questions, were broken down into individual information-source categories.

The ratings for Q15-Q49 were recorded on 1-5 scale and then coded as Likert analysis. The mean, standard deviation and proportion of items scored 4-5, 3 and 1-2 respectively were computed. The questionnaire structure was used as the basis for four internally coherent composites: connectivity, service benefits (Q15-Q22); tourism-development benefits (Q24-Q29); economic-development benefits (Q32-Q38); and environmental-management adequacy (Q44-Q46).

Cronbach's Alpha was used to assess the composite reliability in the inferential analysis. One-sample t tests were used to compare the composite means with the neutral point of 3. All the composite indexes were correlated with the overall benefit-cost judgment index (Q49). The supplied dataset is not a documentation of probability sampling and the statistical tests are used in an exploratory way.

Open-ended analysis: responses made to Q50 were coded into mutually exclusive primary-action themes. Trend and corridor calculations for documentaries were used to get a triangulation of the state of affairs from the survey perceptions and official evidence.

## Validity, Ethics, and Limitations

Construct interpretation was enhanced by triangulation of the questionnaire responses, administrative data and peer-reviewed literature. There were 104 complete questionnaire records in the questionnaire file and all calculations reported are repeatable from the values given in the responses. There was also high internal consistency for the composites of connectivity (alpha = .89), tourism (alpha = .92), economic (alpha = .89) and environmental-management-adequacy (alpha = .82). Important limitations remain. No information on the sampling frame, recruitment method, response rate, consent procedure, or institutional ethics approval is included in the response file, but should be included by the researcher prior to submitting the paper to the journal, if applicable. The data set can be used for respondent level descriptive and exploratory inferential analysis, but cannot be used to make prevalence estimates in the population or causal statements. Additionally, there were some answers on the questionnaire that were given based on perception and four of the records had an actual category of 'Option 3' in the duration-of-association question which was not recoded from it without any source documentation.

**Table 2** *Open Data Sources and Reproducible Measures*

| Source                           | Coverage               | Variables used                                 | Role in analysis                                 |
|----------------------------------|------------------------|------------------------------------------------|--------------------------------------------------|
| PIB project releases             | January 2025           | Length, cost, altitude, route and speed claims | Project profile and corridor scenario            |
| NHIDCL project page              | Current project record | Completion status and project photograph       | Administrative verification                      |
| J&K Tourism Department, Srinagar | Sonamarg, 2014-2025    | Domestic, foreign, and total tourist arrivals  | Destination-level trend and growth analysis      |
| Peer-reviewed literature         | 1974-2024              | Mechanisms, risks, methods                     | Interpretive synthesis and hypothesis assessment |

## RESULTS

### Project Engineering Profile

The official project profile confirms that the package of the Srinagar-Sonamarg road-tunnel is a large project located at a high altitude. The package is approximately 12 km in length, consisting of a 6.4 km main tunnel, an approach road and a parallel egress. The total cost of the project package is more than INR 2,700 crore, implying an implied cost of INR 225 crore per kilometer (based on the whole project package) or INR 422 crore per kilometer (based on the length of the main tunnelling package). These ratios are descriptive and should not be used as measures of efficiency when compared to each other, since approaches, safety systems, financing and other facilities are included in the package. The engineering complexity of the project is a result of its height above 8,650 ft, the avalanche hazard and the geological context of the Himalayas (Government of India, Prime Minister's Office, 2025a, 2025b; NHIDCL, n.d.).

**Table 3** *Sonamarg Tunnel Project Profile*

| Attribute | Officially reported value                            |
|-----------|------------------------------------------------------|
| Location  | Srinagar-Sonamarg section of NH-1, Jammu and Kashmir |

| Attribute             | Officially reported value                                            |
|-----------------------|----------------------------------------------------------------------|
| Project status        | Completed and inaugurated January 13, 2025                           |
| Total project package | Approximately 12 km                                                  |
| Main tunnel           | 6.4 km                                                               |
| Other components      | Egress tunnel and approach roads                                     |
| Altitude              | Above 8,650 ft (approximately 2,637 m)                               |
| Reported cost         | More than INR 2,700 crore                                            |
| Primary function      | All-weather access bypassing avalanche- and landslide-prone sections |

#### Tourism Demand Trend: Sonamarg

The corrected destination-level series shows that tourist arrivals in Sonamarg were substantially lower than the earlier Jammu and Kashmir-wide totals. Total arrivals increased from 119,576 in 2014 to 215,559 in 2018, before falling sharply to 39,426 in 2019 and 3,680 in 2020. The series then rebounded to 229,752 in 2021 and 629,361 in 2022, declined to 501,377 in 2023, reached 850,479 in 2024, and stood at 395,235 in 2025. The pattern is therefore highly volatile rather than a simple continuous upward trend. All figures are Sonamarg-specific administrative counts supplied by the Jammu and Kashmir Tourism Department, Srinagar.

These destination-level data provide the appropriate tourism baseline for this study. They should not be interpreted as evidence that the tunnel itself caused an increase in tourist arrivals. In particular, the annual total fell from 850,479 in 2024 to 395,235 in 2025, so a simple post-opening growth claim is not supported by the annual series. Monthly visitor data, season-specific occupancy, length of stay, access conditions, and a longer post-opening time series are required before attributing tourism change to the Sonamarg Tunnel.

#### Figure 3

##### Tourist Arrivals in Sonamarg, 2014-2025

Note. Destination-level administrative tourist-arrival counts for Sonamarg supplied by the Jammu and Kashmir Tourism Department, Srinagar. Total arrivals equal domestic plus foreign arrivals. The very large 2021 year-on-year percentage reflects the extremely low 2020 base and should be interpreted cautiously.

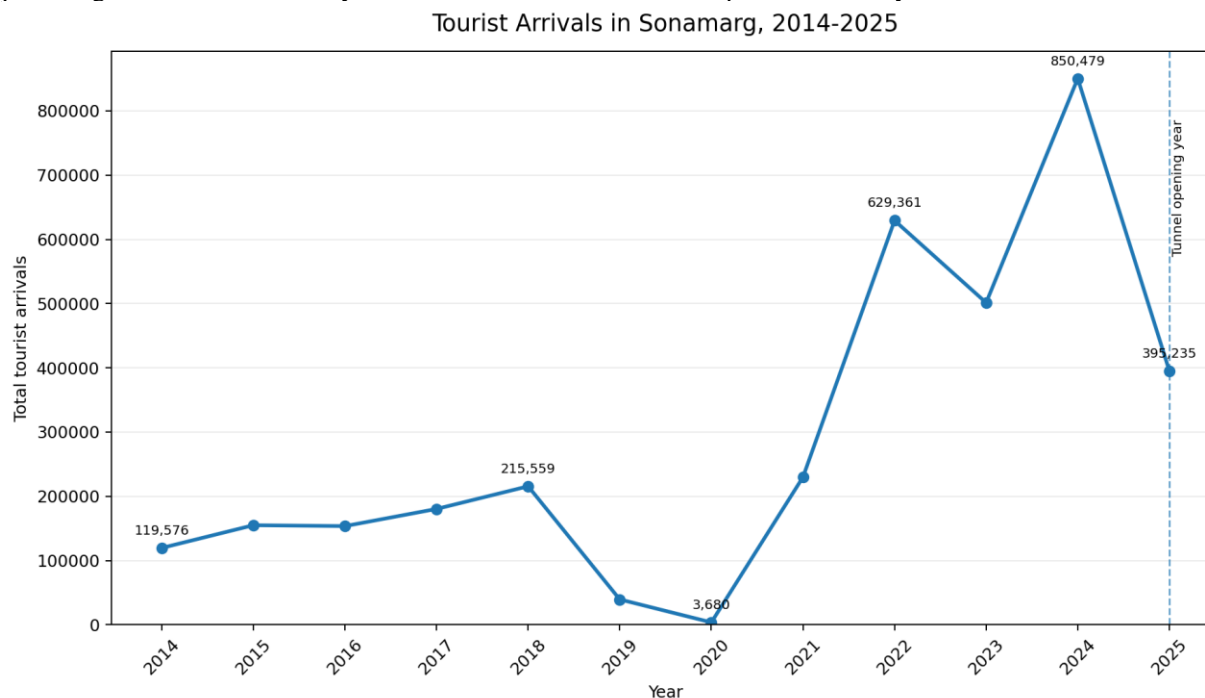


**Table 4:** Yearwise Tourist Arrivals in Sonamarg and Annual Growth, 2014-2025

| Year | Domestic | Foreign | Total visits | Year-on-year change (%) |
|------|----------|---------|--------------|-------------------------|
| 2014 | 115,038  | 4,538   | 119,576      | -                       |
| 2015 | 150,964  | 3,983   | 154,947      | 29.6                    |
| 2016 | 149,098  | 4,487   | 153,585      | -0.9                    |
| 2017 | 171,916  | 8,384   | 180,300      | 17.4                    |
| 2018 | 205,268  | 10,291  | 215,559      | 19.6                    |
| 2019 | 31,563   | 7,863   | 39,426       | -81.7                   |
| 2020 | 3,674    | 6       | 3,680        | -90.7                   |
| 2021 | 229,740  | 12      | 229,752      | 6143.3                  |
| 2022 | 626,751  | 2,610   | 629,361      | 173.9                   |
| 2023 | 492,632  | 8,745   | 501,377      | -20.3                   |
| 2024 | 833,920  | 16,559  | 850,479      | 69.6                    |
| 2025 | 385,442  | 9,793   | 395,235      | -53.5                   |

**Connectivity Scenario**

Government has estimated that the combined corridor of Sonamarg-Zojila will have a reduction of routes from 49 km to 43 km and benchmark speed from 30 kmph to 70 kmph in the future. These values suggest that the distance fell by 12.2% and the speed increased by 133.3%. Using the simple travel-time identity, a preliminary estimate of the time savings is 36.9 minutes, or 98.0 - 61.1 minutes (62.4%). This does not include any stopping costs, congestion costs, weather control costs, tolling costs, security check costs, or operational restrictions. Therefore, it is not a journey time study but a transparent scenario (Government of India, Prime Minister's Office, 2025a).

**Figure 4** Indicative Travel-Time Comparison for the Combined Sonamarg-Zojila Corridor

Note. Calculated from the official route-length and benchmark-speed values. The future scenario includes the Zojila Tunnel and must not be attributed to the Sonamarg Tunnel alone.

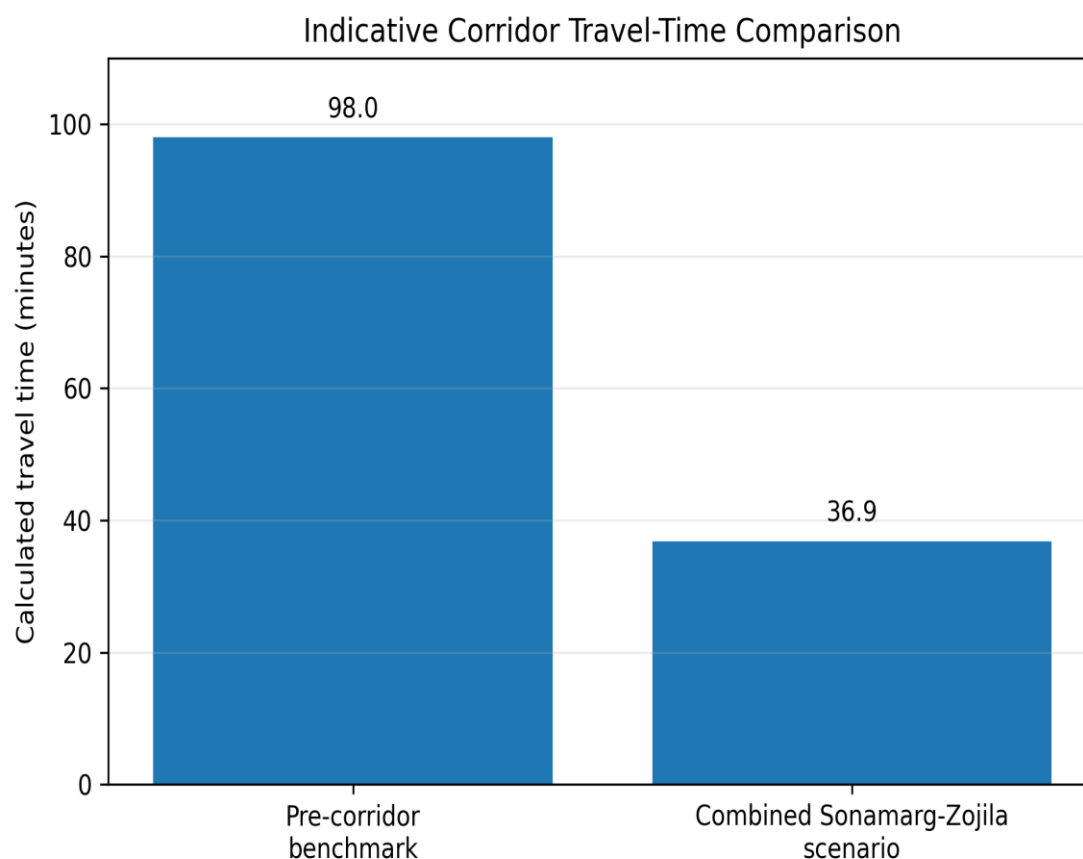
**Integrated Hypothesis Assessment**

**Table 5: Evidence-Based Assessment of the Hypotheses**

| Hypothesis | Result                                                                      | Evidence                                                                                                                                                                                                                      | Interpretive boundary                                                                                                                                                                                 |
|------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| H1         | Supported with caution                                                      | Connectivity/service composite $M = 3.21$ , $SD = 0.98$ ; $t(103) = 2.16$ , $p = .033$ ; journey-time reduction and road-safety items were above neutral.                                                                     | Perceptual survey evidence; not a direct before-after traffic study.                                                                                                                                  |
| H2         | Partially supported by perceptions; not yet corroborated by annual arrivals | Tourism-development composite $M = 3.21$ , $SD = 1.12$ ; $t(103) = 1.87$ , $p = .065$ . Sonamarg total arrivals were 850,479 in 2024 and 395,235 in 2025.                                                                     | The perception scale was not significant at .05, and the annual destination series does not establish a post-opening increase. Monthly and multi-year post-opening data are required for attribution. |
| H3         | Not yet strongly supported                                                  | Economic-development composite $M = 3.11$ , $SD = 1.03$ ; $t(103) = 1.10$ , $p = .273$ . Respondents were divided on market access, jobs, and local business gains.                                                           | Economic perceptions remain close to neutral; objective income, employment, cost, and business data are required.                                                                                     |
| H4         | Supported as a conditional proposition                                      | Overall benefit-cost judgment was neutral ( $M = 3.02$ , $p = .875$ ), while environmental-management adequacy was also neutral ( $M = 3.05$ ). Its correlation with overall benefit judgment was $\rho = .54$ , $p < .001$ . | Suggests that perceived net benefits depend materially on credible environmental and operational management.                                                                                          |

### Primary Questionnaire Data Analysis

A total of 104 cases were included in the analysis of the respondents. The local residents (59.6%) and tourists/visitors (14.4%) were the largest stakeholder groups followed by local business owners or employees (10.6%), drivers/transport operators (7.7%), government/agency staff (5.8%) and two other respondents. The age group of 25-34 constituted the largest population (61.5%) while 57.7% were living in Sonamarg/Ganderbal district. Before the opening of the tunnel, 88.5% of the respondents had visited the Srinagar-Sonamarg route previously and 52.9% had crossed the tunnel more than 10 times. While this experience profile enhances the relevance of the answers for the initial operational evaluation, it also does not eliminate the non-probability sampling limitation.

**Table 6: Selected Respondent Characteristics (n = 104)**

| Characteristic        | Category                       | n  | %    |
|-----------------------|--------------------------------|----|------|
| Stakeholder           | Local resident                 | 62 | 59.6 |
|                       | Tourist/visitor                | 15 | 14.4 |
|                       | Local business owner/employee  | 11 | 10.6 |
|                       | Driver/transport operator      | 8  | 7.7  |
|                       | Government/agency staff        | 6  | 5.8  |
| Residence             | Other                          | 2  | 1.9  |
|                       | Sonamarg/Ganderbal district    | 60 | 57.7 |
|                       | Elsewhere in Jammu and Kashmir | 26 | 25.0 |
|                       | Elsewhere in India             | 17 | 16.3 |
|                       | Outside India                  | 1  | 1.0  |
| Pre-opening route use | Yes, frequently                | 65 | 62.5 |

|                    |                        |    |      |
|--------------------|------------------------|----|------|
|                    | Yes, occasionally      | 27 | 26.0 |
|                    | No / not sure          | 12 | 11.5 |
| Tunnel use         | More than 10 times     | 55 | 52.9 |
|                    | 6-10 times             | 12 | 11.5 |
|                    | 2-5 times              | 14 | 13.5 |
|                    | Once                   | 16 | 15.4 |
|                    | Never                  | 7  | 6.7  |
| Recent trip season | Summer                 | 72 | 69.2 |
|                    | Winter                 | 21 | 20.2 |
|                    | Other / not applicable | 11 | 10.6 |
| Main travel mode   | Private car/taxi       | 74 | 71.2 |
|                    | Bus/shared transport   | 17 | 16.3 |
|                    | Other / not applicable | 13 | 12.5 |

Note. Percentages are based on 104 complete responses. Categories are condensed only where indicated.

Personal travel experience, news media, and government/official sources were most common information sources about the tunnel, with 49 respondents in each reporting this information, followed by social media (47.1%), family/friends/colleagues (26.0%), and tour operators/businesses (12.5%). These percentages do not add to 100% as there was the opportunity for more than one selection to be made within Q14.

Add up the results of the hypotheses tests and summarize the findings.

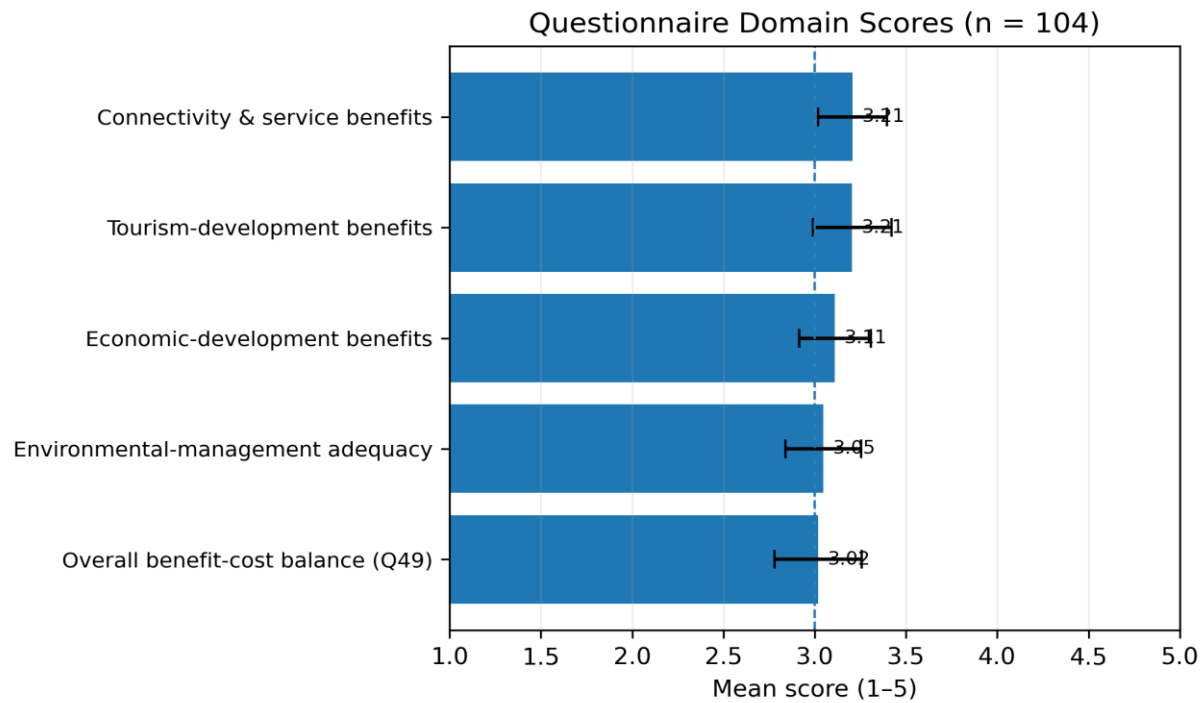
The mean (SD) for the connectivity and service-benefit scale (Q15-Q22) was 3.21 (0.98) and it showed high internal consistency ( $\alpha = .89$ ). Its mean was modestly but significantly above the neutral midpoint,  $t(103) = 2.16$ ,  $p = .033$ , 95% CI [3.02, 3.40]. The tourism-development scale (Q24-Q29) was highly reliable ( $\alpha = .92$ ) and had the same rounded mean of 3.21 (SD = 1.12), but the one-sample test did not reach the .05 level,  $t(103) = 1.87$ ,  $p = .065$ , 95% CI [2.99, 3.42]. The economic-development scale (Q32-Q38) was also reliable ( $\alpha = .89$ ) but remained close to neutral ( $M = 3.11$ , SD = 1.03),  $t(103) = 1.10$ ,  $p = .273$ . Environmental-management adequacy (Q44-Q46) was reliable ( $\alpha = .82$ ) and essentially neutral ( $M = 3.05$ , SD = 1.08),  $t(103) = 0.45$ ,  $p = .651$ . Similarly, the item "Q49: Benefits outweigh economic, social, and environmental costs or risks" did not show a significant difference ( $M = 3.02$ , SD = 1.25),  $t(103) = 0.16$ ,  $p = .875$ .

**Table 7: Composite Questionnaire Results and One-Sample Tests Against Midpoint 3**

| Construct                             | Items   | M    | SD   | alpha | t(103) | p    | 95% CI       |
|---------------------------------------|---------|------|------|-------|--------|------|--------------|
| Connectivity and service benefits     | Q15-Q22 | 3.21 | 0.98 | .89   | 2.16   | .033 | [3.02, 3.40] |
| Tourism-development benefits          | Q24-Q29 | 3.21 | 1.12 | .92   | 1.87   | .065 | [2.99, 3.42] |
| Economic-development benefits         | Q32-Q38 | 3.11 | 1.03 | .89   | 1.10   | .273 | [2.91, 3.31] |
| Environmental-management adequacy     | Q44-Q46 | 3.05 | 1.08 | .82   | 0.45   | .651 | [2.84, 3.26] |
| Overall benefits outweigh costs/risks | Q49     | 3.02 | 1.25 | —     | 0.16   | .875 | [2.78, 3.26] |

Note. Higher scores indicate stronger agreement with the wording of each item. Alpha = Cronbach's alpha. Tests are exploratory because probability sampling was not documented.

**Figure 6:** Mean Questionnaire Scores by Analytical Domain



Note. Error bars show approximate 95% confidence intervals. The dashed line marks the neutral midpoint of 3.

#### Item-Level Response Pattern

There is greater variation at the item level than in the overall means. The most favourable response was for Q22, regarding the level of lighting, signage, ventilation and arrangements in case of an emergency in the tunnel, with  $M = 3.41$  and 53.8% of respondents scoring 4-5. The perceptions of the other items (freight reliability, convenience for families, older visitors, and people with mobility needs; journey-time reduction; and road safety) were also fairly positive (49.0%, 51.0%, 48.1% and 49.0% respectively). Meanwhile, Q30 expressed concern of peak-period overcrowding ( $M = 3.28$ ), and Q39 of emerging affordability pressures pertaining to housing, land or rent costs ( $M = 3.23$ ). Respondents were less positive about the need for a monthly public dashboard (Q48,  $M = 2.87$ ), and views on hazard reduction (Q40,  $M = 2.96$ ), biodiversity protection (Q46,  $M = 2.97$ ), and carrying-capacity controls (Q47,  $M = 2.97$ ) were divided.

**Table 8:** Detailed Likert Results for Q15-Q49

| Item | Short statement                                                 | M    | SD   | Agree 4-5 (%) | Neutral 3 (%) | Disagree 1-2 (%) |
|------|-----------------------------------------------------------------|------|------|---------------|---------------|------------------|
| Q15  | The tunnel has improved year-round accessibility to Sonamarg.   | 3.12 | 1.35 | 41.3          | 28.8          | 29.8             |
| Q16  | Journey times on the corridor are now more predictable.         | 3.01 | 1.18 | 31.7          | 37.5          | 30.8             |
| Q17  | Travel disruptions caused by heavy snowfall and avalanche-prone | 3.08 | 1.30 | 36.5          | 31.7          | 31.7             |

|     |                                                                                  |      |      |      |      |      |
|-----|----------------------------------------------------------------------------------|------|------|------|------|------|
|     | sections have...                                                                 |      |      |      |      |      |
| Q18 | The tunnel has reduced the total time required for my journey.                   | 3.28 | 1.37 | 48.1 | 25.0 | 26.9 |
| Q19 | Access to medical, emergency, and essential services has improved.               | 3.17 | 1.32 | 44.2 | 28.8 | 26.9 |
| Q20 | The movement of goods, supplies, and freight has become more reliable.           | 3.32 | 1.35 | 49.0 | 26.9 | 24.0 |
| Q21 | Overall road safety on the Sonamarg corridor has improved.                       | 3.28 | 1.33 | 49.0 | 26.0 | 25.0 |
| Q22 | Tunnel lighting, signage, ventilation, and emergency arrangements appear adeq... | 3.41 | 1.30 | 53.8 | 24.0 | 22.1 |
| Q23 | Congestion, security checks, or operating restrictions continue to cause subs... | 3.19 | 1.22 | 43.3 | 30.8 | 26.0 |
| Q24 | Year-round tunnel access is likely to increase winter tourism in Sonamarg.       | 3.10 | 1.38 | 40.4 | 25.0 | 34.6 |
| Q25 | The tunnel has made Sonamarg a more attractive destination for visitors.         | 3.14 | 1.38 | 42.3 | 26.9 | 30.8 |
| Q26 | Improved access has made travel more convenient                                  | 3.30 | 1.27 | 51.0 | 21.2 | 27.9 |

|     |                                                                                  |      |      |      |      |      |
|-----|----------------------------------------------------------------------------------|------|------|------|------|------|
|     | for families, older visitors,...                                                 |      |      |      |      |      |
| Q27 | Better accessibility is likely to encourage visitors to stay longer in the area. | 3.26 | 1.32 | 50.0 | 24.0 | 26.0 |
| Q28 | The tunnel supports the development of new winter, adventure, and nature-base... | 3.25 | 1.30 | 47.1 | 27.9 | 25.0 |
| Q29 | Tourism businesses can operate for more months of the year because of improve... | 3.18 | 1.27 | 40.4 | 35.6 | 24.0 |
| Q30 | Improved access is contributing to overcrowding during peak periods.             | 3.28 | 1.23 | 44.2 | 33.7 | 22.1 |
| Q31 | Tourism growth should be linked to clear visitor-capacity and destination-man... | 3.21 | 1.26 | 46.2 | 27.9 | 26.0 |
| Q32 | The tunnel has improved access to customers, suppliers, and wider markets.       | 3.02 | 1.42 | 38.5 | 29.8 | 31.7 |
| Q33 | Transport and logistics costs for local households or businesses have decreased. | 3.03 | 1.35 | 37.5 | 29.8 | 32.7 |
| Q34 | The tunnel has created new employment opportunities                              | 3.08 | 1.36 | 39.4 | 30.8 | 29.8 |

|     |                                                                                  |      |      |      |      |      |
|-----|----------------------------------------------------------------------------------|------|------|------|------|------|
|     | in the local area.                                                               |      |      |      |      |      |
| Q35 | Local small businesses are benefiting from increased accessibility.              | 3.08 | 1.20 | 38.5 | 33.7 | 27.9 |
| Q36 | Local businesses are purchasing more goods and services from nearby suppliers.   | 3.22 | 1.26 | 44.2 | 29.8 | 26.0 |
| Q37 | Improved access has reduced dependence on a short summer earning season.         | 3.16 | 1.30 | 45.2 | 25.0 | 29.8 |
| Q38 | The economic benefits of the tunnel are being distributed fairly among local ... | 3.19 | 1.29 | 47.1 | 23.1 | 29.8 |
| Q39 | Improved connectivity is increasing land, rent, or housing costs in ways that... | 3.23 | 1.29 | 47.1 | 26.9 | 26.0 |
| Q40 | The tunnel reduces exposure to avalanche-, landslide-, and other hazard-prone... | 2.96 | 1.30 | 40.4 | 22.1 | 37.5 |
| Q41 | Smoother traffic flow through the corridor can reduce unnecessary idling and ... | 3.07 | 1.29 | 38.5 | 31.7 | 29.8 |
| Q42 | Tunnel construction and maintenance create substantial                           | 3.02 | 1.23 | 36.5 | 30.8 | 32.7 |

|     |                                                                                  |      |      |      |      |      |
|-----|----------------------------------------------------------------------------------|------|------|------|------|------|
|     | carbon, material, and ...                                                        |      |      |      |      |      |
| Q43 | Better access is increasing traffic and visitor pressure on the fragile mount... | 3.21 | 1.15 | 41.3 | 32.7 | 26.0 |
| Q44 | Excavated material, solid waste, drainage, and wastewater appear to be manage... | 3.12 | 1.21 | 43.3 | 27.9 | 28.8 |
| Q45 | Air quality, water quality, and tunnel energy use are being monitored adequat... | 3.05 | 1.21 | 38.5 | 32.7 | 28.8 |
| Q46 | Biodiversity and sensitive ecosystems near tunnel portals and access roads ar... | 2.97 | 1.35 | 38.5 | 25.0 | 36.5 |
| Q47 | Parking limits, public transport, land-use controls, and carrying-capacity ru... | 2.97 | 1.36 | 41.3 | 20.2 | 38.5 |
| Q48 | Government agencies should publish a monthly public dashboard covering traffi... | 2.87 | 1.32 | 31.7 | 30.8 | 37.5 |
| Q49 | Overall, the benefits of the Sonamarg Tunnel outweigh its economic, social, a... | 3.02 | 1.25 | 36.5 | 32.7 | 30.8 |

Note. Agreement is defined as recorded scores of 4 or 5; disagreement as 1 or 2. The response file stores numeric scores rather than textual scale labels.

#### **Associations with Overall Benefit-Cost Judgment**

Spearman's rank-correlations of respondents' ratings of the main benefit domains with their ratings of overall benefits of the tunnel indicated that the more positive the ratings of the main benefit domains, the more positive the ratings of

the overall benefits of the tunnel. The highest correlations between Q49 and the other items were with connectivity/service benefits ( $\rho = .40$ ,  $p < .001$ ), tourism-development benefits ( $\rho = .40$ ,  $p < .001$ ), economic-development benefits ( $\rho = .43$ ,  $p < .001$ ) and, most strongly, perceived environmental-management adequacy ( $\rho = .54$ ,  $p < .001$ ). The latter finding is especially relevant to H4, as the overall rating of the project is seen to be strongly linked to the perceptions of management of the following: waste, air/water quality, energy consumption and biodiversity.

#### Open-Ended Management Priorities

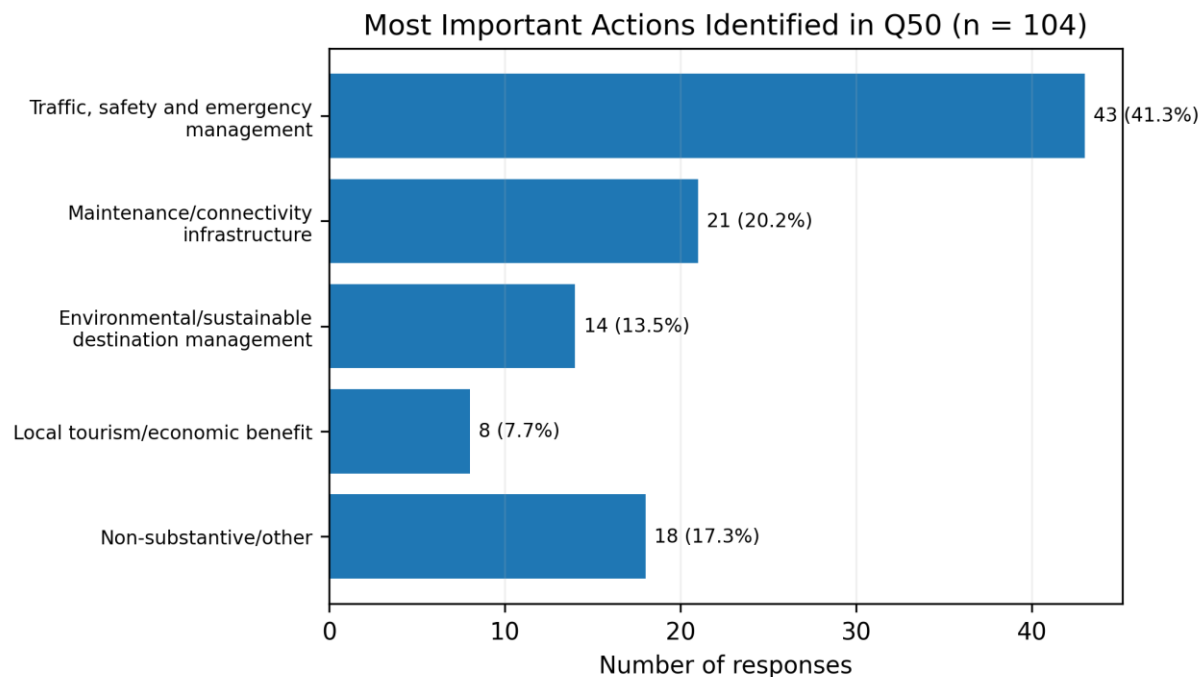
“What is the top priority that authorities should take to address the issue?” (Q50) Each response was coded by main emphasis to yield an operational priority. The dominant theme (43 responses, 41.3% of all responses) was traffic, safety, security and emergency management, such as automatic traffic management, signalling, CCTV, overspeed control, security checks, hazard monitoring and emergency response. Next were maintenance and connectivity infrastructure (21; 20.2%), environmental or sustainable-destination management (14; 13.5%) and local tourism/economic benefit measures (8; 7.7%). 18 responses (17.3%) were not substantive enough or specific enough to be assigned to a policy category. Of 86 responses that were substantively coded, the safety, traffic and emergency management category had the highest percentage of responses at 50.0%, with a clear preference for the ability to operate reliably and in a controlled manner, not just for access expansion.

**Table 9: Primary Themes in Open-Ended Question Q50**

| Primary theme                                    | n  | % of all responses | % of substantive responses |
|--------------------------------------------------|----|--------------------|----------------------------|
| Traffic, safety and emergency management         | 43 | 41.3               | 50.0                       |
| Maintenance/connectivity infrastructure          | 21 | 20.2               | 24.4                       |
| Environmental/sustainable destination management | 14 | 13.5               | 16.3                       |
| Local tourism/economic benefit                   | 8  | 7.7                | 9.3                        |
| Non-substantive/other                            | 18 | 17.3               | —                          |

Note. Responses were assigned to one primary theme based on the principal action requested. Non-substantive/other responses were excluded from the substantive-response denominator.

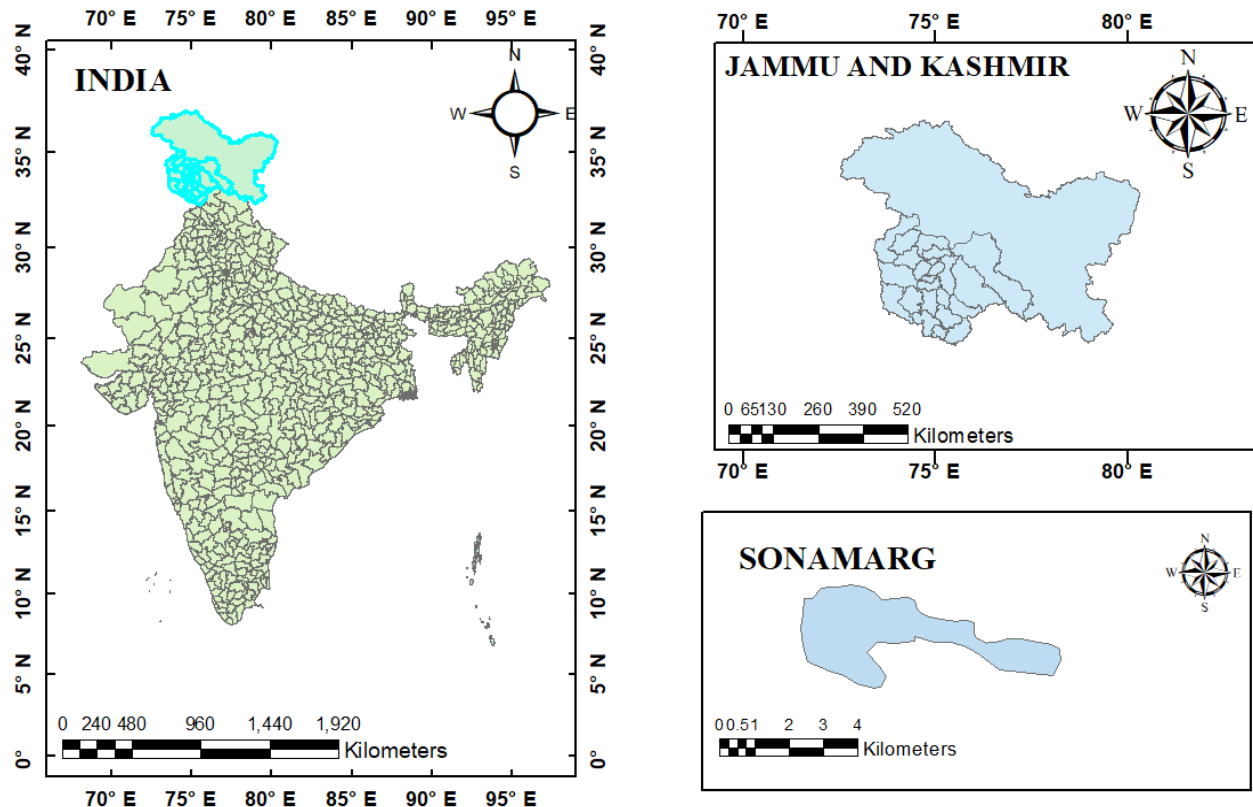
**Figure 7: Priority Actions Identified in the Open-Ended Responses**



Note. Percentages shown in the figure use the full sample of 104 responses.

## Study Area

Sonamarg, which means ‘meadow of gold’ has, as its backdrop, snowy mountains against a cerulean sky. Sonamarg is located in the Ganderbal district of Jammu and Kashmir Union Territory, India. With its Latitude:  $34^{\circ} 18' 13''$  N (North) Longitude:  $75^{\circ} 17' 54''$  E (East). The climate of Sonamarg is very bracing; but the rainfall is frequent though not heavy, except for two or three days at a time in July and August with fine spell in between. From Sonamarg, trekking routes lead to the Himalayan lakes of Vishansar Lake, Krishansar Lake, Gangabal Lake and Gadsar Lake, stocked with Snowtrout and Brown trout and Satsar, glacier-fed and surrounded by banks of alpine flowers.



## STUDY AREA MAP OF SONAMARG

Source: Arch GIS and Google earth

## DISCUSSION

### Engineering Significance and Connectivity

The Sonamarg Tunnel is not only a distance problem but it's an engineering problem. This is supported by the early questionnaire results, which also indicate that the perceived benefits are not widespread. Respondents were very positive about the connectivity/service composite ( $M = 3.21$ ,  $p = .033$ ), as well as their perception of the road safety and ease of travel for tunnel facilities, their perception of the reliability of freight transportation, and their perception of an improved journey time. Meanwhile, the predictability of the journey itself was almost neutral ( $Q16$ ,  $M = 3.01$ ), while further congestion, security checks or operating restrictions delays had  $M = 3.19$ . The results indicate that the fixed infrastructure has positively affected some aspects of access, but that access to the operational management is an important factor in the achievement of access reliability.

The improvement in travel-time that has been calculated for the combined corridors is sufficient to change corridors of travel and service planning, and the official travel-time reduction criterion should be checked in the field using instruments before and after the project. Examples of recommended indicators are median and 95th percentile travel time, annual closure hours, crash and incident rates, freight delay, emergency-response time and seasonal traffic volumes. Because of the possibility of more severe disturbance causing more economic damage than routine travel time, reliability measures should be provided in addition to the average speed.

### The use of tourism to drive economic development.

The corrected tourism series provides a destination-specific baseline for Sonamarg rather than a Jammu and Kashmir-wide proxy. It also shows substantial year-to-year volatility: arrivals reached 850,479 in 2024 and then fell to 395,235 in 2025. Accordingly, the administrative data do not support a simple claim that the tunnel has already increased

tourist arrivals. The questionnaire nevertheless provides early evidence on stakeholder expectations and experience. Tourism-development perceptions averaged 3.21; respondents were comparatively positive about convenience for families, older visitors, and people with mobility needs (Q26,  $M = 3.30$ ) and the likelihood of longer stays (Q27,  $M = 3.26$ ). However, the composite did not differ significantly from the neutral midpoint, and respondents also expressed concern about peak-period overcrowding (Q30,  $M = 3.28$ ). The appropriate interpretation is therefore one of potential opportunity accompanied by management pressures, not demonstrated tourism growth caused by the tunnel. However, in terms of numbers, this does not necessarily translate into inclusive development. The economic-development scale was neither significantly positive nor negative ( $M = 3.11$ ,  $p = .273$ ), suggesting that a positive impact of the changes in market access, employment, local business performance and reduced seasonality is not yet universally apparent. The affordability-risk item was somewhat higher (Q39,  $M = 3.23$ ); therefore, maybe the housing pressure will arise along with its opportunities. The results of these surveys underscore the importance of monitoring jobs by residence and enterprise ownership, local procurement, wages, prices, hotel occupancy, length of stay, and keeping tourism revenue in Ganderbal district.

### Environmental Sustainability

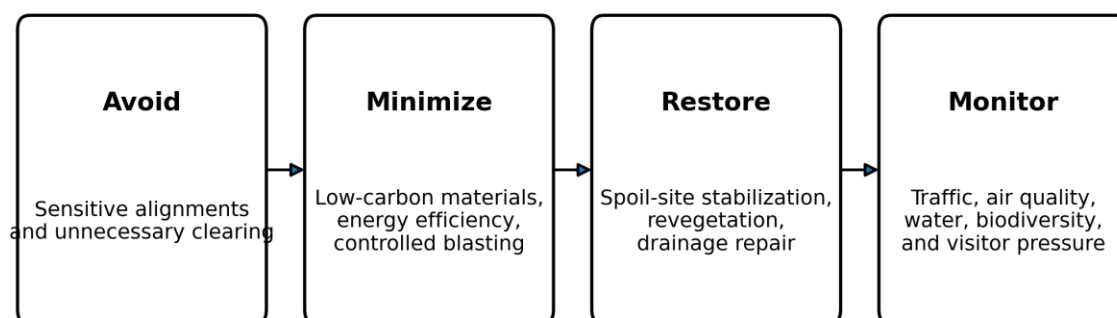
It is no doubt that there are 2 sides to the tunnel's environmental argument, and that's why the questionnaire is ambiguous. Respondents agreed that there has been an increase in traffic and visitor pressure (Q43,  $M = 3.21$ ), but were near neutral on questions of carbon/material impacts (Q42,  $M = 3.02$ ), hazard reduction (Q40,  $M = 2.96$ ), waste/drainage management (Q44,  $M = 3.12$ ), environmental monitoring (Q45,  $M = 3.05$ ) and biodiversity protection (Q46,  $M = 2.97$ ). The most important finding was that perceived environmental-management adequacy was most highly related to the overall benefit-cost judgment ( $\rho = .54$ ,  $p < .001$ ). This helps to justify a conditional view on sustainability: When the respondents also consider the possibility of environmental management as credible, they are more likely to perceive the tunnel as useful.

A good sustainability program should follow this hierarchy of avoid, minimize, restore and monitor. Construction and maintenance records need to measure the amounts of cementitious materials, steel, electricity, diesel, amount of spoils, transport distances and waste recovery. Monitoring should be carried out for incidents, drainage water, air quality, traffic composition, ventilation demand and electricity to the tunnel, and operations should be carried out. The carrying capacity thresholds, public transport, parking control, solid-waste management, wastewater treatment, and ecological restrictions on development around portals and access roads, as well as monitoring of biodiversity around portals and access roads, should be included in the destination management. These measures turn sustainability from a 'word' to an 'auditable performance system'.

**Figure 5:** *Environmental Management Hierarchy for the Sonamarg Corridor*

Note. The hierarchy integrates construction-phase mitigation with long-term monitoring of traffic, tourism pressure, and ecosystems.

## Environmental Management Hierarchy for Mountain Tunnel Corridors



## Policy and Monitoring Recommendations

Create an open post-opening dashboard that provides data on traffic, travel time, closures, incidents, tunnel-energy use and maintenance performance on a monthly basis.

Continue destination-level tourism monitoring for Sonamarg, including monthly domestic and foreign arrivals, occupancy, length of stay, tourism expenditure, winter-season activity, and access disruptions, so that annual totals can be interpreted alongside seasonality and operating conditions.

Re-administer present questionnaire at regular intervals on a documented sampling frame, recruitment protocol and panel component to monitor over time changes in perceptions of residents, visitors, businesses, and transport-operator perceptions.

Finalise a project specific life cycle carbon and material-flow assessment including construction records, operation, maintenance and induced traffic.

Implement carrying capacity and land use controls that will correlate water and wastewater use with accommodation and solid waste, emergency and ecological capacity.

Integrate the Sonamarg and Zojila projects into one corridor in respect of safety management, freight planning, public transport and environment reporting for safety.

## CONCLUSION

All-weather connectivity, tourism seasonality, and regional market access are areas in which the Sonamarg Tunnel could influence the Himalayan corridor. The questionnaire evidence from 104 respondents is modestly positive for perceived connectivity and selected service benefits, including journey-time reduction, road safety, freight reliability, and accessibility for a broader range of visitors. Tourism-development perceptions are positive but not definitive, while economic benefits remain close to neutral and concerns about overcrowding and affordability are visible. The corrected Sonamarg-specific administrative tourism series is highly volatile and records 850,479 arrivals in 2024 and 395,235 in 2025; therefore, the paper does not claim that the tunnel has already produced a measurable increase in tourist arrivals. The importance of environmental and operational management to the project's overall legitimacy remains clear: perceived environmental-management adequacy had the strongest correlation with the overall benefit-cost judgment, and open-ended responses most often emphasized traffic, safety, security, emergency management, maintenance, and environmental management. Future research should combine repeat probability- or stratified-sample surveys with monthly destination-level tourism data, objective traffic and safety records, local income and employment indicators, and life-cycle environmental measures to identify longer-term effects more reliably.

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### Data Availability Statement

Administrative project data and the Sonamarg destination-level tourist-arrival series were obtained from the official sources identified in the references and from the supplied Jammu and Kashmir Tourism Department yearwise table. The primary questionnaire response file was provided by the researcher and is summarized in aggregated form in Tables 6-9. Respondent-level questionnaire data should be shared, if at all, in compliance with the consent, privacy, and institutional-ethics requirements of the original data collection.

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### Conflict of Interest

The author does not have any conflict of interest to declare.

## REFERENCES

1. Asher, S., & Novosad, P. (2020). Rural roads and local economic development. *American Economic Review*, 110(3), 797-823. <https://doi.org/10.1257/aer.20180268>
2. Banister, D., & Berechman, Y. (2001). Transport investment and the promotion of economic growth. *Journal of Transport Geography*, 9(3), 209-218. [https://doi.org/10.1016/S0966-6923\(01\)00013-8](https://doi.org/10.1016/S0966-6923(01)00013-8)
3. Barton, N., Lien, R., & Lunde, J. (1974). Engineering classification of rock masses for the design of tunnel support. *Rock Mechanics*, 6, 189-236. <https://doi.org/10.1007/BF01239496>
4. Benitez-Lopez, A., Alkemade, R., & Verweij, P. A. (2010). The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biological Conservation*, 143(6), 1307-1316. <https://doi.org/10.1016/j.biocon.2010.02.009>
5. Bhasin, R., Barton, N., Grimstad, E., & Chrysanthakis, P. (1995). Engineering geological characterization of low-strength anisotropic rocks in the Himalayan region for assessment of tunnel support. *Engineering Geology*, 40(3-4), 169-193. [https://doi.org/10.1016/0013-7952\(95\)00055-0](https://doi.org/10.1016/0013-7952(95)00055-0)

6. Boers, B., & Cottrell, S. (2007). Sustainable tourism infrastructure planning: A GIS-supported approach. *Tourism Geographies*, 9(1), 1-21. <https://doi.org/10.1080/14616680601092824>
7. Brida, J. G., Cortes-Jimenez, I., & Pulina, M. (2016). Has the tourism-led growth hypothesis been validated? A literature review. *Current Issues in Tourism*, 19(5), 394-430. <https://doi.org/10.1080/13683500.2013.868414>
8. Buckley, R. (2012). Sustainable tourism: Research and reality. *Annals of Tourism Research*, 39(2), 528-546. <https://doi.org/10.1016/j.annals.2012.02.003>
9. Chester, M. V., & Horvath, A. (2009). Environmental assessment of passenger transportation should include infrastructure and supply chains. *Environmental Research Letters*, 4(2), Article 024008. <https://doi.org/10.1088/1748-9326/4/2/024008>
10. Coffin, A. W. (2007). From roadkill to road ecology: A review of the ecological effects of roads. *Journal of Transport Geography*, 15(5), 396-406. <https://doi.org/10.1016/j.jtrangeo.2006.09.006>
11. Damian, R., & Zamorano, C. I. (2022). Environmental impact assessment of high-speed railway tunnel construction: A case study for five different rock mass rating classes. *Transportation Geotechnics*, 36, Article 100817. <https://doi.org/10.1016/j.trgeo.2022.100817>
12. Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review*, 108(4-5), 899-934. <https://doi.org/10.1257/aer.20101199>
13. Dwivedi, R. D., Singh, M., Viladkar, M. N., & Goel, R. K. (2013). Prediction of tunnel deformation in squeezing grounds. *Engineering Geology*, 161, 55-64. <https://doi.org/10.1016/j.enggeo.2013.04.005>
14. Forman, R. T. T., & Alexander, L. E. (1998). Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29, 207-231. <https://doi.org/10.1146/annurev.ecolsys.29.1.207>
15. Geneletti, D., & Dawa, D. (2009). Environmental impact assessment of mountain tourism in developing regions: A study in Ladakh, Indian Himalaya. *Environmental Impact Assessment Review*, 29(4), 229-242. <https://doi.org/10.1016/j.eiar.2009.01.003>
16. Ghani, E., Grover Goswami, A., & Kerr, W. R. (2016). Highway to success: The impact of the Golden Quadrilateral project for the location and performance of Indian manufacturing. *The Economic Journal*, 126(591), 317-357. <https://doi.org/10.1111/eoj.12207>
17. Gibbons, S., Lyytikainen, T., Overman, H. G., & Sanchis-Guarner, R. (2019). New road infrastructure: The effects on firms. *Journal of Urban Economics*, 110, 35-50. <https://doi.org/10.1016/j.jue.2019.01.002>
18. Goel, R. K. (2014). Tunnelling through weak and fragile rocks of Himalayas. *International Journal of Mining Science and Technology*, 24(6), 783-790. <https://doi.org/10.1016/j.ijmst.2014.10.008>
19. Goel, R. K. (2016). Experiences and lessons from the use of TBM in the Himalaya-A review. *Tunnelling and Underground Space Technology*, 57, 277-283. <https://doi.org/10.1016/j.tust.2016.02.015>
20. Goel, R. K., Jethwa, J. L., & Dhar, B. B. (1996). Effect of tunnel size on support pressure. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 33(7), 749-755. [https://doi.org/10.1016/0148-9062\(96\)00020-4](https://doi.org/10.1016/0148-9062(96)00020-4)
21. Goel, R. K., Jethwa, J. L., & Paithankar, A. G. (1995a). Indian experiences with Q and RMR systems. *Tunnelling and Underground Space Technology*, 10(1), 97-109. [https://doi.org/10.1016/0886-7798\(94\)00069-W](https://doi.org/10.1016/0886-7798(94)00069-W)
22. Goel, R. K., Jethwa, J. L., & Paithankar, A. G. (1995b). Tunnelling through the young Himalayas-A case history of the Maneri-Uttarkashi power tunnel. *Engineering Geology*, 39(1-2), 31-44. [https://doi.org/10.1016/0013-7952\(94\)00002-J](https://doi.org/10.1016/0013-7952(94)00002-J)
23. Government of India, Prime Minister's Office. (2025a, January 11). PM to visit J&K and inaugurate Sonamarg Tunnel project on 13th January. Press Information Bureau. <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2092091>
24. Government of India, Prime Minister's Office. (2025b, January 13). Prime Minister Shri Narendra Modi inaugurates Sonamarg Tunnel in Jammu and Kashmir. Press Information Bureau. <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2092468>
25. Hall, C. M. (2010). Changing paradigms and global change: From sustainable to steady-state tourism. *Tourism Recreation Research*, 35(2), 131-143. <https://doi.org/10.1080/02508281.2010.11081629>
26. Hoek, E. (2001). Big tunnels in bad rock. *Journal of Geotechnical and Geoenvironmental Engineering*, 127(9), 726-740. [https://doi.org/10.1061/\(ASCE\)1090-0241\(2001\)127:9\(726\)](https://doi.org/10.1061/(ASCE)1090-0241(2001)127:9(726))
27. Jain, A., & Rao, K. S. (2022). Empirical correlations for prediction of tunnel deformation in squeezing ground condition. *Tunnelling and Underground Space Technology*, 125, Article 104501. <https://doi.org/10.1016/j.tust.2022.104501>
28. Jammu and Kashmir Tourism Department, Srinagar. (n.d.). Yearwise tourist arrivals in Sonamarg, 2014-2025 [Administrative data table].
29. KC, D., Gautam, K., Dangi, H., Kadel, S., & Hu, L. (2022). Challenges in tunneling in the Himalayas: A survey of several prominent excavation projects in the Himalayan mountain range of South Asia. *Geotechnics*, 2(4), 802-824. <https://doi.org/10.3390/geotechnics2040039>

30. Khadaroo, J., & Seetanah, B. (2007). Transport infrastructure and tourism development. *Annals of Tourism Research*, 34(4), 1021-1032. <https://doi.org/10.1016/j.annals.2007.05.010>
31. Kumar, N., Samadhiya, N. K., & Anbalagan, R. (2004). Application of rock mass classification systems for tunneling in Himalaya, India. *International Journal of Rock Mechanics and Mining Sciences*, 41(5), 852-857. <https://doi.org/10.1016/j.ijrmms.2004.03.147>
32. Lakshmanan, T. R. (2011). The broader economic consequences of transport infrastructure investments. *Journal of Transport Geography*, 19(1), 1-12. <https://doi.org/10.1016/j.jtrangeo.2010.01.001>
33. Laurance, W. F., Goosem, M., & Laurance, S. G. W. (2009). Impacts of roads and linear clearings on tropical forests. *Trends in Ecology & Evolution*, 24(12), 659-669. <https://doi.org/10.1016/j.tree.2009.06.009>
34. Lee, C.-C., & Chang, C.-P. (2008). Tourism development and economic growth: A closer look at panels. *Tourism Management*, 29(1), 180-192. <https://doi.org/10.1016/j.tourman.2007.02.013>
35. Lee, J.-H., Kim, K. J., Kim, E. W., & Kim, H. R. (2018). Environmental load estimating model of NATM tunnel based on standard quantity of major works in the early design phase. *KSCE Journal of Civil Engineering*, 22(4), 1040-1051. <https://doi.org/10.1007/s12205-017-1795-z>
36. Lee, J.-H., Shim, J.-A., & Kim, K. J. (2016). Analysis of environmental load by work classification for NATM tunnels. *KSCE Journal of Civil and Environmental Engineering Research*, 36(2), 307-315. <https://doi.org/10.12652/KSCE.2016.36.2.0307>
37. Melo, P. C., Graham, D. J., & Brage-Ardao, R. (2013). The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. *Regional Science and Urban Economics*, 43(5), 695-706. <https://doi.org/10.1016/j.regsciurbeco.2013.05.002>
38. Naji, A. M., Emad, M. Z., Rehman, H., & Yoo, H. (2019). Geological and geomechanical heterogeneity in deep hydropower tunnels: A rock burst failure case study. *Tunnelling and Underground Space Technology*, 84, 507-521. <https://doi.org/10.1016/j.tust.2018.11.009>
39. National Highways & Infrastructure Development Corporation Limited. (2025, April 11). Zojila Tunnel: A gateway to Ladakh's prosperity. <https://www.nhidcl.com/en/blog/zojila-tunnel-gateway-ladakh-prosperity>
40. National Highways & Infrastructure Development Corporation Limited. (n.d.). Z-Morh Tunnel Project on NH-01. <https://www.nhidcl.com/en/kashmir/Project/z-morh-tunnel-project-nh-01>
41. Nepal, S. K. (2005). Tourism and remote mountain settlements: Spatial and temporal development of tourist infrastructure in the Mt Everest region, Nepal. *Tourism Geographies*, 7(2), 205-227. <https://doi.org/10.1080/14616680500072471>
42. Nyaupane, G. P., & Chhetri, N. (2009). Vulnerability to climate change of nature-based tourism in the Nepalese Himalayas. *Tourism Geographies*, 11(1), 95-119. <https://doi.org/10.1080/14616680802643359>
43. Palmstrom, A., & Broch, E. (2006). Use and misuse of rock mass classification systems with particular reference to the Q-system. *Tunnelling and Underground Space Technology*, 21(6), 575-593. <https://doi.org/10.1016/j.tust.2005.10.005>
44. Panthi, K. K. (2012). Evaluation of rock bursting phenomena in a tunnel in the Himalayas. *Bulletin of Engineering Geology and the Environment*, 71, 761-769. <https://doi.org/10.1007/s10064-012-0444-5>
45. Panthi, K. K., & Nilsen, B. (2007a). Predicted versus actual rock mass conditions: A review of four tunnel projects in Nepal Himalaya. *Tunnelling and Underground Space Technology*, 22(2), 173-184. <https://doi.org/10.1016/j.tust.2006.04.005>
46. Panthi, K. K., & Nilsen, B. (2007b). Uncertainty analysis of tunnel squeezing for two tunnel cases from Nepal Himalaya. *International Journal of Rock Mechanics and Mining Sciences*, 44(1), 67-76. <https://doi.org/10.1016/j.ijrmms.2006.04.013>
47. Panthi, K. K., & Shrestha, P. K. (2018). Estimating tunnel strain in the weak and schistose rock mass influenced by stress anisotropy: An evaluation based on three tunnel cases from Nepal. *Rock Mechanics and Rock Engineering*, 51, 1823-1838. <https://doi.org/10.1007/s00603-018-1448-7>
48. Pradhan, R. P., & Bagchi, T. P. (2013). Effect of transportation infrastructure on economic growth in India: The VECM approach. *Research in Transportation Economics*, 38(1), 139-148. <https://doi.org/10.1016/j.retrec.2012.05.008>
49. Prideaux, B. (2000). The role of the transport system in destination development. *Tourism Management*, 21(1), 53-63. [https://doi.org/10.1016/S0261-5177\(99\)00079-5](https://doi.org/10.1016/S0261-5177(99)00079-5)
50. Rodriguez, R., Bascompta, M., & Garcia, H. (2024). Carbon footprint evaluation in tunnels excavated in rock using tunnel boring machine (TBM). *International Journal of Civil Engineering*, 22, 995-1009. <https://doi.org/10.1007/s40999-023-00935-0>
51. Rodriguez, R., & Perez, F. (2021). Carbon foot print evaluation in tunneling construction using conventional methods. *Tunnelling and Underground Space Technology*, 108, Article 103704. <https://doi.org/10.1016/j.tust.2020.103704>
52. Saarinen, J. (2006). Traditions of sustainability in tourism studies. *Annals of Tourism Research*, 33(4), 1121-1140. <https://doi.org/10.1016/j.annals.2006.06.007>

53. Seetanah, B. (2011). Assessing the dynamic economic impact of tourism for island economies. *Annals of Tourism Research*, 38(1), 291-308. <https://doi.org/10.1016/j.annals.2010.08.009>
54. Singh, B., Goel, R. K., Jethwa, J. L., & Dube, A. K. (1997). Support pressure assessment in arched underground openings through poor rock masses. *Engineering Geology*, 48(1-2), 59-81. [https://doi.org/10.1016/S0013-7952\(97\)81914-X](https://doi.org/10.1016/S0013-7952(97)81914-X)
55. Singh, B., Jethwa, J. L., Dube, A. K., & Singh, B. (1992). Correlation between observed support pressure and rock mass quality. *Tunnelling and Underground Space Technology*, 7(1), 59-74. [https://doi.org/10.1016/0886-7798\(92\)90114-W](https://doi.org/10.1016/0886-7798(92)90114-W)
56. Steiger, R., Knowles, N., Poll, K., & Rutt, M. (2024). Impacts of climate change on mountain tourism: A review. *Journal of Sustainable Tourism*, 32(9), 1984-2017. <https://doi.org/10.1080/09669582.2022.2112204>
57. Tripathi, S., & Gautam, V. (2010). Road transport infrastructure and economic growth in India. *Journal of Infrastructure Development*, 2(2), 135-151. <https://doi.org/10.1177/097493061100200204>
58. Trombulak, S. C., & Frissell, C. A. (2000). Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, 14(1), 18-30. <https://doi.org/10.1046/j.1523-1739.2000.99084.x>
59. Zhao, J., Kou, L., Jiang, Z., Lu, N., Wang, B., & Li, Q. (2022). A novel evaluation model for carbon dioxide emission in the slurry shield tunnelling. *Tunnelling and Underground Space Technology*, 130, Article 104757. <https://doi.org/10.1016/j.tust.2022.104757>