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# Development of Bridge Management System for Existing Bridge in Nepal Using Analytical Hierarchy Process

Manoj Sharma Wagle [a], Shreedhar Khakurel [b], Samrat Poudel [c]

[a, b, c] *Department of Civil Engineering,Pashchimanchal Campus, IOE, Tribhuvan University, Nepal*
[a] waglemanoj2017@gmail.com, [b] khakurelshreedhar45@gmail.com, [c] Samrat@ioepas.edu.np

**Abstract**
Bridge Management System (BMS) is a rational and systematic management approach that includes all the activities for the proper management of bridges as vital transportation infrastructure. The bridges in Nepal were constructed 60 years back.The failure rate of bridges has tremendously increased in the last five years.The formulation of practical based Bridge Rating Expert System (BREX) for the condition assessment of bridges along with their application for the proper management of bridge network was main outcome of the study. The Maintenance, Repair and Rehabilitation strategy was adopted through proper prioritization of bridge via Condition rating. The expert opinion survey for the BREX was done via Analytical Hierarchy process (AHP), Whereas criteria for the studies were finalized through literature review. The pairwise comparison of the criteria and sub criteria was done for Multi-Criteria Decision-Making(MCDM) process.The weightage of Criteria and Sub criteria for the Maintenance,Repair and Rehabilitation prioritization ranking of bridges was then finalized through Expert responses in AHP. It was found that Piers has the highest weightage of 28.4% among nine sub-criteria. Similarly, the decreasing order of top five ranked Sub-criteria weightage was Deck Structure (24.1%), Bearings (18.5%), Abutments, wing wall and retaining walls (14.1%) and Bridge protection and river training works (8.9%) respectively. The 12 bridges within the kaski district were studied for maintenance prioritization of Bridges.

**Keywords**
Bridge Rating Expert System (BREX), Bridge Management System (BMS), Multi-Criteria Decision Making (MCDM), Maintenance Prioritization, Analytical Hierarchy Process(AHP)

## 1. Introduction

Bridges are critical assets of transportation networks for safety, reliability and functionality of transport services. Utilizing the limited resources available to transportation organisations; infrastructure asset managers are in charge of making sure that these bridges comply with stringent safety criteria. To facilitate strategy development and to present decisions to stakeholders, a life cycle analysis is commonly performed [1]. Development of road networks and bridges in Nepal started around sixty years ago. During the starting phase, most of the major works for development of bridge network was done through the technical and financial assistance of donor agencies. Later, the task was taken up by the Different departments of Nepal Government like Department of Roads (DoR) and DoLIDAR. Today, around 250-300 bridges are built annually by DoR alone, and of a similar range by the provincial and local governments (DOR).The maintenance of bridges was more expensive than to build new ones. Several Bridges have deteriorated considerably in recent years due to increase in traffic volume, the increase in weights of vehicle and structural aging [2, 3]. In last five years, more than 50 bridge failures have been reported in national media. Thus, to ensure the safety and serviceability of bridges, the Practical based cost-effective Bridge Management System (BMS) is must in Nepal.

### 1.1 Study Area

This study was conducted for the development of BMS of Existing Bridges within Nepal. Twelve Out of twenty-six bridges of Kaski district under DoR inventory were considered for the study, analysis and deployment of BMS for Condition Ranking with maintenance and improvement plan as Shown in Figure 1.

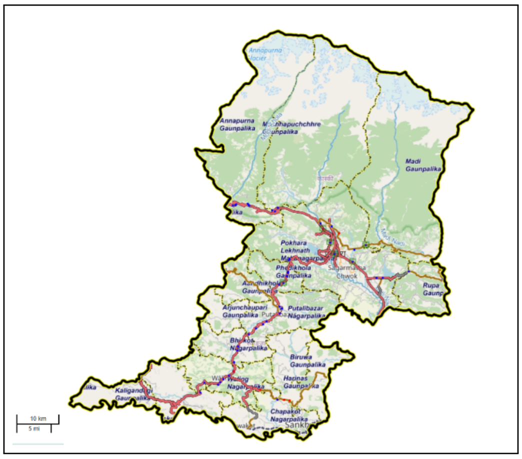

**Figure 1:** Bridges in Kaski District

### 1.2 Statement of Problem

Development of road networks and bridges in Nepal started around sixty years back through different donor agency and departments of government. During early stage of bridge development, critical works were done through the technical and financial assistance of donor countries like Russia, UK, India, China, etc.Later, Department of Roads (DoR) and DoLIDAR took over the bridge development task from donor agencies. In the present scenario, around 250-300 bridges are built annually by DoR alone and in a similar range by provincial and local governments. Thus, constructed Bridges fail at different stage of their life cycle before the design lifespan. However, if we analyze the trend of bridge failure of Nepal, the failure rate was tremendously increased in last five years. In 2017-2021,more than 50 bridge failures have been reported in national media.

This year alone, national newspapers have reported 21 motorable bridges failed till now in different parts of the country. Among the 21 bridges, 11 bridges failed during construction phase and remaining after completing structural works. The loss from the failure of bridge is about two billion rupees as per Government Agency. More importantly though, the series of bridge failures has created an environment of fear among the users whose livelihood (both social movement and business) may be affected.

The main cause of the of failure of such bridges are structural aging, traffic load increment along with improper construction methodology, inferior quality of works, faulty design and poor maintenance. There are several factors to take into account to ensure the safety of a bridge in different stages of Life cycle like design, building, and maintenance. In Nepal Infrastructure Management System especially in bridge is rarely done for maintenance, safety measures and other precaution in Life Cycle Analysis (LCA) context. So, this concept of Life Cycle Analysis can be very advantageous in determining the health of structure. Since, bridges are of great economic as well as social valued structure, their structural health monitoring along with maintenance and rehabilitation Plan via optimized and robust BMS must be done.

Thus, developed BMS should assist decision makers at all bridge management levels to select optimum solutions from an array of cost-effective alternatives for every action needed to achieve the desired levels of service within the funds allocated and to identify future funding requirements [4].

### 1.3 Objectives

The specific objectives of this research included as follows:

• To develop a Bridge Rating Expert System (BREX) as per national context

• To find the condition rating of bridges in Kaski District for Maintenance and Improvement Plan.

## 2. Methodology

This study was to evaluate the bridge Condition based on visual inspection through BREX as a practical based BMS optimized for Nepal. The Bridge database of DOR, DoLIDAR and other agencies was used for inventory of Bridges.The state-of-art literature review of BMS was conducted to optimize the factors the bridge rating system. The weightage of different factors were obtained through Experts opinion via AHP. The procedural steps in this research were outlined in the flow chart of methodology given below in Figure 2.

### 2.1 Data Collection and Sample Size

The Primary data was obtained from questionnaire survey based on AHP from Experts where-as the criteria and sub-criteria was finalized through literature review.The Secondary data for the study were collected via reports of DoR and research article published earlier.

AHP is a powerful and flexible decision-making mathematical method developed in the 1970's by Dr. Thomas Saaty [**?**, **?**].The Analytic Hierarchy Process (AHP) uses pairwise comparison of both qualitative and quantitative criteria for prioritization through weight-age given by Experts. According to Ferrari et al.(2019),AHP does not always require statistically significant sample size for its use [5, 6, 7]. There is no strict requirement on the minimum sample size for AHP analysis. Some studies used sample sizes ranging from four to nine [8].Hence responses from 14 experts allover the nepal were used in AHP.

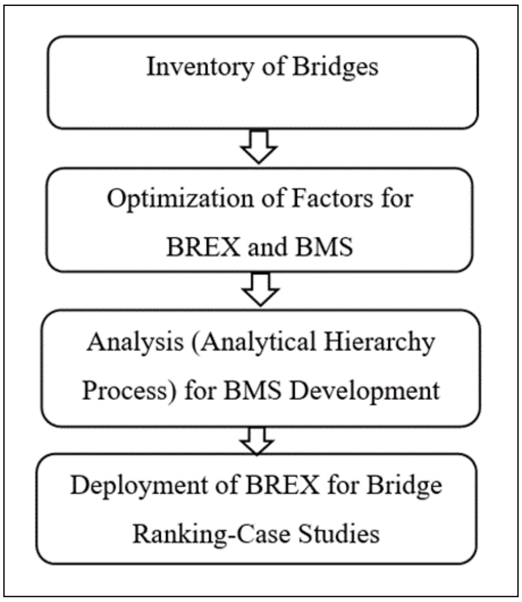


**Figure 2:** Flowchart of Research Methodology

## 2.2 Data Analysis

The responses from the experts were collected in scale from 1 to 9 through pairwise comparison as in table 1 and table 2 [9]and the comparison matrix was generated with response and their reciprocal values in transpose position.Aggregated Comparison matrix was obtained by computing geometric mean of values of the respondents.Pairwise comparison values obtained from the experts were analyzed using spreadsheet to obtain the final weights of all criteria and sub criteria with Consistency check.

The consistency of each respondent was calculated i.e., consistency ratio (CR) as ratio of consistency index (u) to the corresponding random index which is permissible for less than 0.1 for each comparison matrix [10, 11].

**Table 1:** Scale for Relative importance

| Importance intensity | Explanation |
|---|---|
| 1 | Equally important |
| 3 | Moderately more important |
| 5 | Strongly more important |
| 7 | Very strongly more important |
| 9 | Extremely more important |
| 2, 4, 6, 8 | Intermediate values between the two judgments |
| Reciprocals | Reciprocal for inverse comparison |

### 2.2.1 Field Inspection of Bridges for Case Studies

The each Sub-criteria elements of Bridges were visually inspected for Condition rating (0-4 Scale) and Extent Rating (0-4 Scale) based on the DoR Guidelines [12, 13].The aggregated condition score (ACS) of each bridge was calculated by weighted mean of each element with the weight-age from calculated from Bridge Rating Expert System (BREX) through AHP. The Final ACS for each Bridge was calculated by Multiplying importance factor (IF) with ACS whereas IF was calculated as aggregated effect of Road Type (RT), Detour Time (DT) and Traffic Index measured as vehicle Per day (TI) for the prioritization for maintenance as per DoR guidelines [12, 13].The flow chart of the inspection and calculation was as below in figure 3. The Calculation Procedure as per figure 3 for Adjusted Condition Rating(ACR), Aggregated Condition Score(ACS), Importance Factor(IF) and Final ACS was done as shown below [14, 15]:

$$ACR = (CR * ER)/4 \quad (1)$$

$$ACS = \sum_{i=1-9} ((ACR_i * W_i)/W_i) \quad (2)$$

$$FinalACS = ACS * IF \quad (3)$$

$$where, IF = RT * .04 + DT * 0.1 + TI * 0.5 \quad (4)$$

**Table 2:** Pairwise comparison of Criteria

| Criteria A | | | | Vs. | Criteria B | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 |

# 3. Results and Discussion

## 3.1 Evaluation Criteria and Sub criteria for Bridge Condition Rating

Different parameters and bridges elements for the bridge condition rating were studied,which were prioritized and optimized as per their significance in

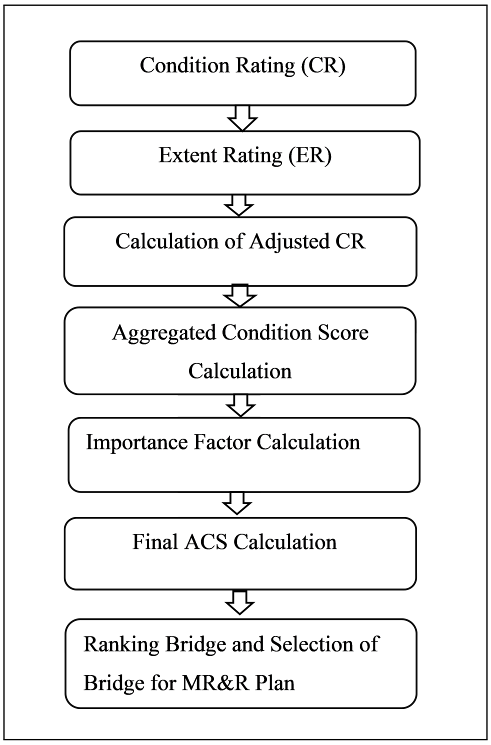


**Figure 3:** Field Inspection and Calculation Flowchart

the context of Nepal.From the literature and guidelines DoR,the four criteria with their sub-criteria altogether nine were selected parameters for the study to investigate the condition of bridges.Those data were grouped into sub categories as follows in Table 3:

**Table 3:** The Criteria and Sub-criteria for Bridge Condition Rating

| S.N | Criteria | Sub-Criteria |
|---|---|---|
| 1 | Ancillary Works | Approach Road, Embankment and Drainage |
| 2 | | Bridge Deck Surface, Drainage and Footpath |
| 3 | | Parapet, Railings and Guardrails |
| 4 | | Joints |
| 5 | Superstructure | Deck Structure |
| 6 | | Bearings |
| 7 | Substructure | Abutments, Wing wall and Retaining walls |
| 8 | | Piers |
| 9 | Training Works | Bridge Protection Works & River Training |

## 3.2 Criteria and Sub-Criteria Weightage via AHP Response

The criteria weights obtained from 14 respondents via AHP survey is represented in the following figure 4:

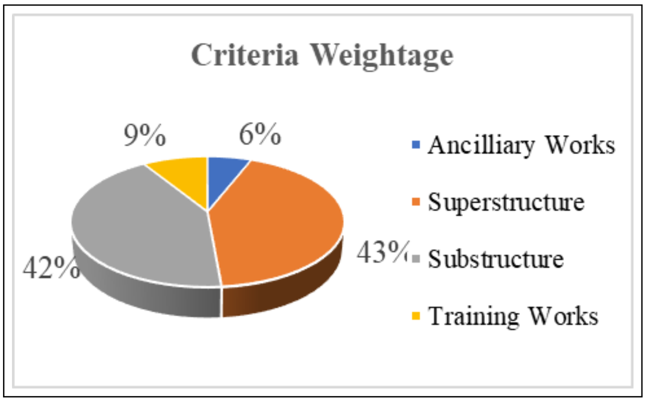


**Figure 4:** Final Criteria Weightage

Among four criteria, superstructure has highest priority with weightage 43%. Similarly, Substructure has 42% weightage followed by Training works with 9%. The Ancillary works has least weightage given with 6%.

Weights obtained for sub criteria under the four criteria are shown in the following bar chart as in figure 5.

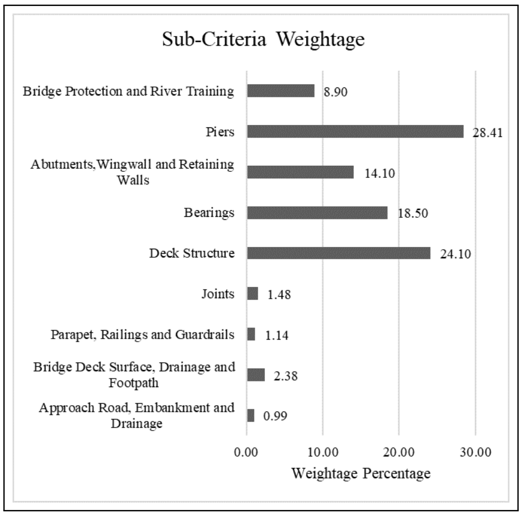


**Figure 5:** Final Global weights of Sub-Criteria

Above figure shows that Piers has the highest weightage of 28.41% among the nine sub criteria. Similarly, Deck structure (24.10%), Bearings (18.50%), Abutments, Wingwall and Retaining Walls (14.1%), Bridge protection and River Train-ing Works (8.90%) , Bridge Desk Surface, Drain-age and Footpath (2.38%), Joints(1.48%), Parapet, Railing and Guardrails (1.14%) And Approach Road, Embankment and Drainage (0.99%) respectively.The contribution of Approach Road, Embankment and Drainage has least on safety and serviceability on Bridge system as it focuses on user safety and others parameters and hence the sub criteria Approach Road, Embankment and Drainage has obtained lowest weightage with 0.99%.

### 3.3 Case Study

The aggregated condition score of 12 bridges of Kaski district was calculated with visually inspected datasheet using Condition rating(CR)and Extent ratings(ER) guidelines of DoR as per table 4 and table 5 [14].Similarly (0-9,NA scale) being used from differnt agencies with 0 as Critical codition,9 as New condition whereas 10 or NA as Not applicable.Thus adopted from (0-4) and (0-9) were made inter-convertible as in table 6 [14]. The score (0-4 Scale) of each sub-criteria was aggregated with weightage from Experts opinion i.e.,BREX from AHP.The prioritization was done based on Final ACS which was calculated using importance factor considering detour time,traffic index and road type of each bridge site.The detour time indicates the time needed for roundabout through alternative routes if failure occurs.The traffic index indicates no of vehicles per day through that highway/bridges.The linkage of bridge with the highway types has great importance as per importance of road type with the traffic volume as well. The ACS and Final ACS with importance factor is shown in Table 7.

#### 3.3.1 Prioritization of Bridges for maintenance

The prioritization of bridges for the maintenance was done as per the condition rating and Importance factors governed by each bridge with their road type, traffic volume and alternative routes available.The figure 6 shows that the maintenance priorities according to Final ACS. The Odere khola Bridge with highest score gets highest priority for the maintenance whereas Madikhola Bridge gets lowest priority for the Mitigation Plan.The highest the score higher was the priority as shown in figure 6.

**Table 4:** Condition Score Rating for Bridges,DoR 2005

| Condition Score | Description |
|---|---|
| 4 | Serious condition with severe damage. The element or component is not functioning as designed. |
| 3 | Poor condition. The element or component shows numerous defects of structural significance which may soon prevent it from functioning as designed. |
| 2 | Below average. The element or component shows local defects of structural significance but functions as designed. |
| 1 | Fair condition. The element or component shows a few nonstructural defects |
| 0 | Good condition with no significant defects |
| N | Not applicable, or element not accessible for inspection. |

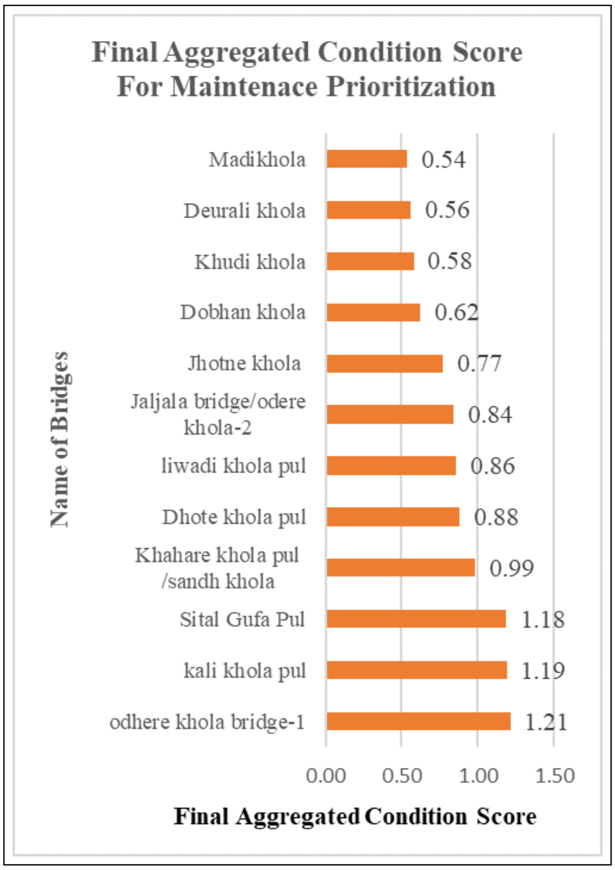


**Figure 6:** Final Aggregated Condition Score of Bridges

**Table 5:** Extent Rating for Bridges,DoR 2005

| Condition Score | Description |
|---|---|
| 4 | Extensive,most or the entire element affected. |
| 3 | Major, highly significant,more than 20% of the element affected. |
| 2 | Significant,5% to 20% of length or area of the element affected |
| 1 | Minor, less than 5% of length or area of the element affected |
| 0 | No defect or insignificant length or area of the element affected |
| N | Not applicable, or element not accessible for inspection. |

**Table 6:** Score Conversion and Mitigation Plan

| Condition 0-4 System | Condition 0-9 system | Proposed Mitigation Action |
|---|---|---|
| 4 | 0,1,2,3 | Investigation for rehabilitation |
| 3 | 4,5 | Major Repair |
| 2 | 6 | Minor Repair |
| 1,0 | 7,8,9 | Routine Maintenance |
| NA | NA,10 | Not Applicable |

## 4. Conclusion and Recommendations

The expert opinion survey through AHP was done to finalize the weightage of Criteria and Sub-criteria for Condition Rating of Bridges. It can be concluded that nine sub criteria grouped into four criteria can be used in condition assessment of Bridges to calculate aggregated score.The Multi-criteria Decision making process for condition rating of bridge was done with the help of AHP through pairwise comparison of criteria and sub criteria was established for ranking of bridge to have proper maintenance plan before the loss due to failure.The Aggregated Condition Score with Importance Factor was used to get Final ACS for Priority ranking of Bridges for Maintenance,Rehabilitation and Repair plan/Mitigation Plan.The serviceability and safety of bridge will be enhanced with such Management strategies as a part of BMS.Thus,The Practical based robust BREX for BMS was developed for proper management of bridges.

Beside these the structural aging,traffic volume ,increase in traffic load and environmental factors were inevitable factors for bridge deterioration causing damages.So proper planning for bridge management is must for considering the overall condition rating and their importance for maintenance purposes.It is suggested that the Final ACS is not only the factors to prioritized for the mitigation plan.Though owing the same value of Final ACS,bridge might be in critical as per the overall condition along with critical components of bridges.

The Table 8 provides the overall condition and Maintenance priorities with their mitigation plan according to their Final ACS and condition score respectively.Finally, the results of case study from table 8 ,was carried out selecting 12 bridges of kaski district and concluded that the Odere khola Bridge-1 got the highest Final ACS with Major repair plan and hence gets the first priority among 12 bridges for urgent maintenance purposes. Priority was suggested as per table 6 with overall condition rating of bridges so as to done among the bridges with bridges having same overall condition rating according to Final ACS with the same level of Mitigation Plan.As an Example the Priority of Minor Repair plan can be done by ranking the Final ACS of bridges with overall condition rating 2,and finalized with reference to the condition value of critical elements i.e., higher weightage criteria from AHP. Similarly for the Routine Maintenance priority ranking from highest to lowest priority from Dobhan khola, Khudi Khola, Deurali khola and Madi Khola bridge according to Final ACS value.

This Simplified BMS will be more useful to implementing offices for Bridge management and Maintenance like local Governments,Provincial Office and Divisional Office for ranking bridges for Maintenance,Rehabilitation and Repair plan with a proper inventory record. The deterioration model and cost-based model for the bridges could be a best part for the future study so that decision makers could make right decision with better alternatives.

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**Table 7:** The Final Aggregated Condition Score of Bridges

| S.N | Name of Bridge | Aggregated Condition Score(ACS) | Road Type(RT) | Detour Time(DT) | Traffic Index(TI) | Importance Factor(IF) | Final ACS |
|---|---|---|---|---|---|---|---|
| **Weightage** | | | **0.40** | **0.10** | **0.50** | | |
| 1 | Sital Gufa Pul | 0.35 | 3.00 | 2.00 | 4.00 | 3.40 | 1.18 |
| 2 | Khahare khola pul | 0.29 | 3.00 | 2.00 | 4.00 | 3.40 | 0.99 |
| 3 | Madikhola | 0.16 | 3.00 | 1.00 | 4.00 | 3.30 | 0.54 |
| 4 | Dobhan khola | 0.19 | 3.00 | 1.00 | 4.00 | 3.30 | 0.62 |
| 5 | Khudi khola | 0.18 | 3.00 | 0.00 | 4.00 | 3.20 | 0.58 |
| 6 | Deurali khola | 0.18 | 3.00 | 0.00 | 4.00 | 3.20 | 0.56 |
| 7 | Jhotne khola | 0.23 | 3.00 | 2.00 | 4.00 | 3.40 | 0.77 |
| 8 | Jaljala bridge | 0.25 | 3.00 | 2.00 | 4.00 | 3.40 | 0.84 |
| 9 | odere khola bridge-1 | 0.36 | 3.00 | 2.00 | 4.00 | 3.40 | 1.21 |
| 10 | Dhote khola pul | 0.26 | 3.00 | 2.00 | 4.00 | 3.40 | 0.88 |
| 11 | liwadi khola pul | 0.25 | 3.00 | 2.00 | 4.00 | 3.40 | 0.86 |
| 12 | kali khola pul | 0.33 | 4.00 | 0.00 | 4.00 | 3.60 | 1.19 |

**Table 8:** Final Ranking with Mitigation plan of Bridges

| S.N | Name of Bridge | Overall Condition Score(0-4) | Aggregated Condition Score(ACS) | Final ACS | Ranking | Maintenace,Repair and Rehabilitation Plan(Mitigation Plan) |
|---|---|---|---|---|---|---|
| 1 | odhere khola bridge-1 | 3 | 0.36 | 1.21 | 1 | Major Repair |
| 2 | kali khola pul | 2 | 0.33 | 1.19 | 2 | Minor Repair |
| 3 | Sital Gufa Pul | 2 | 0.35 | 1.18 | 3 | Minor Repair |
| 4 | Khahare khola pul | 2 | 0.29 | 0.99 | 4 | Minor Repair |
| 5 | Dhote khola pul | 2 | 0.26 | 0.88 | 5 | Minor Repair |
| 6 | liwadi khola pul | 2 | 0.25 | 0.86 | 6 | Minor Repair |
| 7 | Jaljala bridge | 2 | 0.25 | 0.84 | 7 | Minor Repair |
| 8 | Jhotne khola | 2 | 0.23 | 0.77 | 8 | Minor Repair |
| 9 | Dobhan khola | 1 | 0.19 | 0.62 | 9 | Routine maintenace |
| 10 | Khudi khola | 1 | 0.18 | 0.58 | 10 | Routine maintenace |
| 11 | Deurali khola | 1 | 0.18 | 0.56 | 11 | Routine maintenace |
| 12 | Madikhola | 1 | 0.16 | 0.54 | 12 | Routine maintenace |

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