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ASSESSMENT OF THE DEGRADATION STATE OF REINFORCED CONCRETE BRIDGES: AN AHP-BASED APPROACH

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Abstract

The main motivation for this research is to develop assessment and estimation tools for the degradation state of existing civil engineering structures. The longevity of a structure is influenced by a complex set of interconnected phenomena and parameters. Therefore, we adopt a multicriteria approach aimed at better identifying these elements, particularly the most influential ones. This study focuses on assessing the degradation of reinforced concrete girder bridges by developing a digital tool based on the Analytic Hierarchy Process (AHP). We have identified 30 factors impacting degradation, categorized as internal factors, such as the condition of structural elements, and external factors, such as age and environment. From these factors, we calculate a Global Bridge Degradation Index (GBDI) that reflects the overall condition of the bridge. This index allows us to establish a classification of the bridges, ranging from no danger to a critical state requiring immediate intervention. The innovation of our model lies in its ability to provide a quantified estimation of the degradation state while incorporating an unlimited number of factors and criteria. After applying this model to three bridges in Algeria, we observed satisfactory results. The ultimate goal is to provide managers with tools for reflection and comparison to assess the condition of bridges and consider the necessary actions for their maintenance, repair, or replacement, thereby contributing to the improvement of the management and safety of road infrastructures.

Keywords:

Reinforced Concrete Bridges;
analytic hierarchy process (AHP);
Degradations;
Influence Factors;
Case studies.

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1 Introduction

Bridges have a crucial impact on society, prompting engineers and researchers to improve their safety and efficiency. In Algeria, the transport infrastructure is relatively young compared to developed countries. Some bridges, although centuries old, remain in good condition, while others, more recent, show signs of deterioration. A large majority of these bridges were built in reinforced concrete. These structures are vulnerable to various degradation factors. An accurate assessment of their condition is essential for planning maintenance, but current methods, often subjective, lack systematization [1-2].

Most disorders appear after about fifteen years of operation, well beyond the end of the ten-year warranty period, which is often difficult to invoke for infrastructure works. These various processes, depending on the intensity and nature of the maintenance performed, impact the service life of the structures [3-4]. A structure can degrade due to factors related to its original quality of building materials or due to operational or environmental stresses. This encompasses a wide range of criteria: age, construction defects, traffic loads, foundation erosion, and chemical attacks [5]. Given the complexity of these phenomena and the diversity of influencing parameters, it would be appropriate to use a multicriteria analysis method that can consider most of these parameters.

This research presents a standardized numerical evaluation procedure for the degradation of reinforced concrete girder bridges. The developed method is based on the Analytic Hierarchy Process (AHP).

AHP, developed by Thomas L. Saaty in the 1980s [6-8] is a robust multicriteria decision-making method. It allows for the organization and analysis of complex decisions based on mathematical principles and the engineer's acquired experiences. This process is used in various fields, such as flood risk assessment [9-11], groundwater quality studies [12-14], infrastructure degradation modelling [15-16], seismic reliability of RC bridges [17] and Concrete technology in extreme weather conditions [18].

Complementary to these methodological approaches, research has increasingly addressed practical solutions for improving the durability and resilience of concrete infrastructure, as well as the strengthening of structures using innovative materials to enhance their resistance to bending or explosions [19–20].

The AHP method facilitates decision-making by breaking down problems into hierarchical criteria and enabling quantitative evaluation of alternatives.

The proposed model consists of six main steps. First, degradation factors, both internal and external, are identified in collaboration with experts. A hierarchical structure is then developed, organizing these factors from general to specific, thus facilitating the application of the Analytic Hierarchy Process (AHP). This allows for pairwise comparisons of elements at each level, calculation of relative weights, and verification of judgment consistency. A scoring system quantifies the impact of each sub-criterion on the bridge's condition. Finally, the Global Bridge Degradation Index (GBDI) is calculated, classifying the bridge into categories ranging from safe to critical which requiring immediate intervention.

This article proposes an innovative, systematic, and quantitative evaluation method for the degradation of reinforced concrete girder bridges, providing managers with a decision-support tool to guide intervention choices. The method allows for the prioritization of degradation factors, calculation of a synthetic index reflecting the overall condition of the structure, and guidance for maintenance decisions. Its application to real cases demonstrates its relevance and ability to identify intervention priorities, making it a valuable tool for managing RC bridges.

2 The evaluation procedure for assessing the degradation level of a reinforced concrete girder bridge

The main objective of this research is to create a numerical assessment tool based on the Analytic Hierarchy Process (AHP) to quantify the degradation level of reinforced concrete girder bridges. The evaluation process, illustrated by the flowchart in Figure 1, unfolds in six successive phases. The first phase involves identifying the factors that influence the degradation of the bridge. Next, a hierarchy of these factors and sub-factors is constructed. The AHP method is then applied to determine the relative weights of each element within this hierarchy. Afterward, scores are assigned to the criteria in the hierarchy, allowing for the calculation of a composite score that reflects the overall condition of the bridge. This score is subsequently used to establish a classification of the infrastructure's state

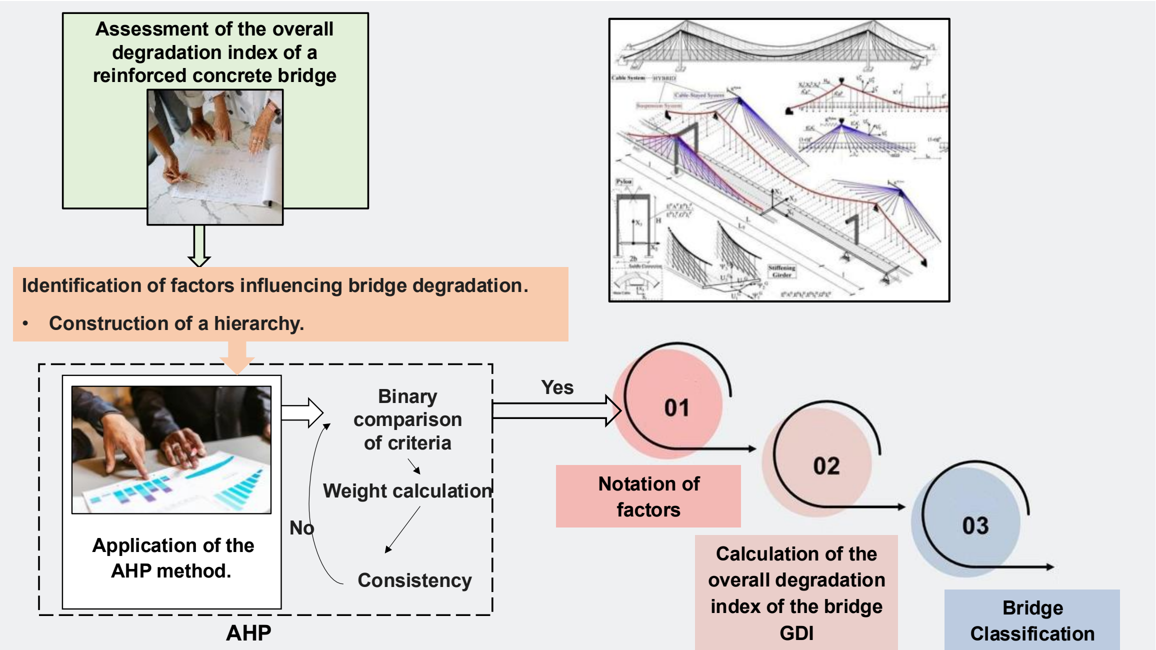


Fig. 1: Flow chart of the procedure for estimating the degree of degradation of a bridge.

2.1 Identification of degradation factors

A large number of factors and parameters can contribute to the degradation of a structure to varying degrees. It would be unrealistic to incorporate all factors into a single study. Most existing research focuses on the defects of structural elements or on external factors. In this study, we propose to define a Global Degradation Index (GBDI) for a bridge by simultaneously considering observable degradations of the structure, referred to as internal factors, as well as the adverse effects of certain parameters related to the age of the structure, its use, and its environment, which we call external factors. The elements impacting degradation were selected based on consultations and expert opinions in the field of civil engineering. Internal factors encompass the condition of various structural elements and equipment, while external factors include the age of the structure, its environment, external loads, and the influence of soil foundation and water. In total, this study identifies two main factors and 28 sub-factors which will be mentioned later (See Figure 2).

2.2 Development of the Hierarchical Structure

The second step involves developing a hierarchical structure, as illustrated in Figure 2. This structure organizes the identified factors into distinct levels, ranging from the most general to the most specific. At the top is the overall objective of assessing the Global Degradation Index (GBDI) of the bridge. The following levels group the main criteria and then the sub-criteria, forming a coherent decision tree. This hierarchical structure facilitates the visualization of the relationships between the different elements and enables the subsequent application of the AHP method.

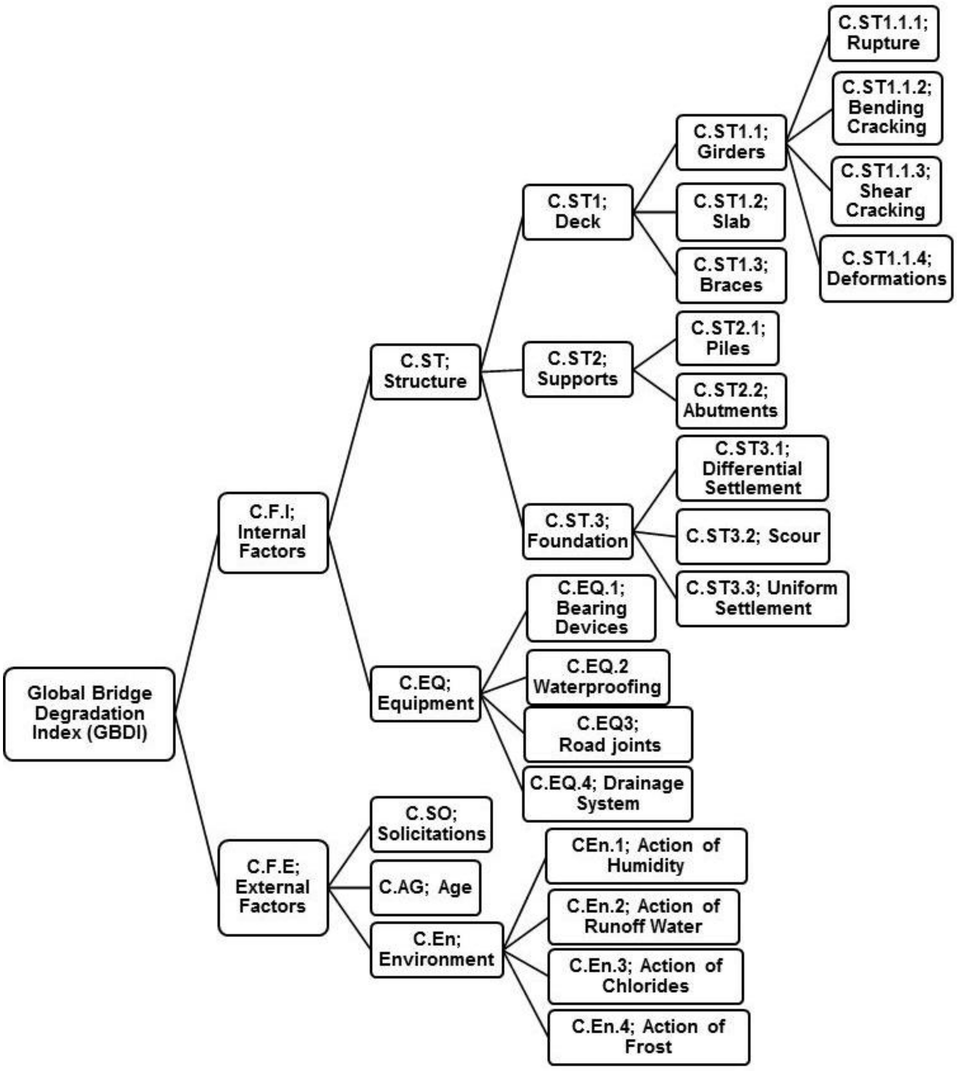


Fig. 2: The hierarchical structure of bridge degradation criteria.

2.3 The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that allows for the prioritization of elements based on various criteria. It consists of three steps:
First, the construction of a hierarchical structure, where the problem is decomposed into a hierarchical structure in the form of a pyramid, where the overall objective is at the top, corresponding to level 0. The lower levels consist of the criteria, which occupy level 1, followed by the sub-criteria, which are present at level 2 [21] (Figure 2).

Next, pairwise comparisons are conducted, where elements at each level are compared pairwise based on their relationship with the level above. To express the degree of relative importance of each element, a numerical scale is used (see Table 1). The results of these comparisons are then recorded in comparison matrices.

$$A=(a_{ij})_{nxn}, \quad (1)$$

where:

$$a_{ji}=\frac{1}{a_{ij}}, \quad (2)$$

and

$$a_{ii}=1, \quad (3)$$

n - is the number of criteria to be compared.

Table 1: Saaty's binary comparison scale [4].

Assessment	Degree of importance
Equal importance of two criteria	1
Low importance of one criterion in relation to another	3
Medium importance of one criterion in relation to another	4
High importance of one criterion in relation to another	5
Proven importance of one criterion in relation to another	7
Absolute importance of one criterion in relation to another	9

2, 6, 8; intermediate values between two judgments used to refine the judgment.

The third step is calculating weights and verifying consistency: The comparison matrices allow for the calculation of the relative importance of each criterion by determining the eigenvector Vmax=(W_1,W_2,…,W_n) associated with the largest eigenvalue λ_{max} . This vector Vmax directly provides the weights of our n criteria. At the same time, the consistency of the judgments is evaluated using the consistency index CI and the consistency ratio (CR), defined as follows:

$$CI=\frac{\lambda_{max}-n}{n-1}, \quad (4)$$

and

$$CR=\frac{CI}{RI}, \quad (5)$$

wehere *RI* is the random consistency index provided in the Table 2.

The RI values are sourced from the original work of T. SAATY, the founder of AHP, who computed these averages by generating thousands of random matrices [7]. If the consistency ratio is less than 10%, the judgments are considered sufficiently consistent. Otherwise, it is necessary to review the comparisons made.

Table 2: Random Inconsistency (RI) indices [7].

n	3	4	5	6	7	8	9	10	11
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

n is the number of criteria to be compared.

2.4 Notations

A scoring system has been designed to quantify and illustrate the impact of each criterion, at the end of the hierarchy, on the condition of the bridge. The results of this study, conducted in collaboration with RC bridges experts, are summarized in the Tables 3 to 8.

Table 3: Notations of Deck Factors.

Factor F	Findings	Notation N
Girders Rupture	None	0
	Rupture of a single girder.	44
	Rupture of multiple girders.	48
Girders Flexural Cracking	None	0
	Vertical and parallel cracks on the sidewalls and at the heel of the girder (flexural cracks) with an opening less than 0.3 [mm].	16
	Vertical and parallel cracks on the sidewalls and at the heel of the girder (flexural cracks) with an opening between 0.3 and 0.6 [mm].	24
	Vertical and parallel cracks on the sidewalls and at the heel of the girder (flexural cracks) with an opening greater than 0.6 [mm] affecting at least one central girder.	40
	Vertical and parallel cracks on the sidewalls and at the heel of the girder (flexural cracks) with an opening greater than 0.6 [mm] affecting an edge girder.	28
Girders Shear Cracking	None	0
	45° inclined shear cracks parallel on the walls of the girder with an opening less than or equal to 0.3 [mm].	22
	45° inclined shear cracks parallel on the walls of the girder with an opening greater than 0.3 [mm] affecting at least one central girder.	38
	45° inclined shear cracks parallel on the walls of the girder with an opening greater than 0.3 [mm] affecting an edge girder.	26
Girders Deformations	None	0
	Longitudinal downward deflection localized in the span	20
	Longitudinal downward deflection of the entire girder	22
Slab	No degradation	0
	Delamination, peeling in the lower surface of the slab (corrosion of reinforcement, concrete frost damage)	8
	Longitudinal cracks at the junction of the slab and the web of the girder (insufficient transverse tie reinforcement)	10
	Parallel longitudinal cracks at the lower level of the slab (transverse flexure of the slab).	14
	Deck rupture with total shear of the reinforcement.	32
Braces	None	0
	Deterioration of the cover, concrete spalling and corrosion of the reinforcement of the cross girder in the corners and on the lower surface.	8
	Vertical cracks at the cross girder-girder junction (insufficient tie reinforcement between girders and cross girders.	10
	Vertical cracking on the vertical faces and on the lower surface of the cross girder (flexural cracking).	14

Table 4: Notation of Pile Factors (Columns or Walls).

Factor F	Findings	Notation N
Pile Columns	No anomaly	0
	Cracks propagating from the bearing plinths (insufficient stirrups or bearing devices too close to the edge)	12
	Transverse cracks parallel on the upper surface of the cap girder (shrinkage)	12
	Transverse cracks on the upper part and lateral sides of the cap girder (excessive bending stresses in the cap girder)	19
	Horizontal cracks surrounding the cylindrical surface of the column (excessive combined bending stresses)	28
	Spalling, delamination, exposure of reinforcement (corrosion of steel)	22
	Vertical crack running along the column from bottom to top (Alkali-reaction or excess compression)	22
Wall Piles	No anomaly	0
	Localized cracks near the bearing plinths (insufficient stirrups)	12
	Narrow vertical cracks on the lateral walls of the pile propagating from the upper face (shrinkage)	12
	Wide open vertical cracks from the top downwards (insufficient tie reinforcement at the top of the pile)	19
	Vertical cracks rising from the foundation (soil settlement due to insufficient footing)	28
	Parallel horizontal cracks on the central part of the pile walls (excessive bending in the pile or poor concrete casting joint)	28

Table 5: Notation of Abutment Factors.

Factor F	Findings	Notation N
Abutments	No anomaly	0
	Wide open vertical cracks from the top downwards (insufficient tie reinforcement in the wall)	22
	Vertical cracks rising from the foundation (foundation soil settlement under the central part of the footing, insufficient reinforcement in the footing, restrained shrinkage of the wall)	30
	Parallel horizontal cracks on the central part of the wall (excessive bending)	30
	Narrow vertical cracks on the wing wall (concrete shrinkage)	5
	Horizontal crack along the lower edge of the wing wall (abnormal bending stress caused by the deck end coming into contact with the wing wall)	9
	Horizontal crack along the lower edge of the parapet wall (abnormal bending stress caused by the deck end coming into contact with the parapet wall)	5

Table 6: Notation of foundational factors.

Criteria	Factor F	Findings	Notation N
Foundations	Differential settlement	None	0
		H<L/350	20
		H>L/350	45
	Scour	None	0
		Erosion marks.	8
		Localized erosion up to half the height of the foundation.	16
		Total exposure (Strong erosion exceeding in places the entire height of the foundation).	43
	Uniform settlement	H < 5 [cm]	0
		5 [cm] < H < 10 [cm]	16
		H > 10 [cm]	40

With:
H - Settlement height [cm].
L - Span length of the bays [cm].

For medium-sized bridges, differential settlements can be tolerated provided that the H/L ratio remains below 1/350, which is approximately 4 cm for a span of 15 m [22].

Table 7: Notation of equipment factors.

Criteria	Findings	Notation N
Bearing devices	Good	0
	Deteriorated	16
	Very deteriorated	20
Waterproofing	Good	0
	Deteriorated	14
	Very deteriorated	18
Road joints	Good	0
	Deteriorated	14
	Very deteriorated	18
Drainage system	Good	0
	Deteriorated	14
	Very deteriorated	18

Table 8: Notation of external factors.

Factor F	Findings	Notation N	Factor F	Findings	Notation N
Action of runoff water	Absence of aggressiveness	0	Action of chlorides present in seawater	Structure located more than 5 [km] from the sea.	0
	Low aggressiveness	6		Structure located between 500 [m] and 5 [km] from the sea	6
	Medium aggressiveness	12		Structure located less than 500 [m] from the sea.	14
	High aggressiveness	18		Part of the structure submerged permanently in the sea	18
Action of frost	Weak or moderate frost without de-icing agent	2	Age	0 to 10	2
	Weak or moderate frost with de-icing agent	8		11 to 20	4
	Severe frost without de-icing agent	12		21 to 30	6
	Severe frost with de-icing agent	18		31 to 40	8
Action of humidity	Very dry environment (no risk of corrosion)	0		41 to 50	10
	Permanently dry or humid environment.	4		51 to 60	12
	Moderately humid environment	8		61 to 70	14
	Predominantly humid environment with infrequent drying periods	12		71 to 80	16
	Alternation of humidity and drying	18		81 to 90	18
Solicitations	Low (bridge class III)	12		More than 90 years	20
	Medium (bridge class II)	16			
	High (bridge class I)	20			

N.B.: We consider the effect of the environment based on the concept of "Exposure Class" in accordance with the normative texts related to concrete. These classes reflect the actions due to the environment to which the concrete and the reinforcements of the structure are exposed [23-24].

Table 9: Notation of equipment.

Factor F	Findings	Notation N	Factor F	Findings	Notation N
Bearing devices	Good condition	0	Pavement joints	Good	0
	Deteriorated	16		Deteriorated	14
	Very deteriorated	20		Very deteriorated	18
Waterproofing	Good condition	0	Drainage system	Good	0
	Deteriorated	14		Deteriorated	14
	Very deteriorated	18		Very deteriorated	18

2.5 Assessment of the Global Bridge Degradation Index (GBDI)

The Global Bridge Degradation Index (GBDI) numerically quantifies the degradation state of a bridge, which is closely linked to its performance, safety, and durability. This index is determined using the formula (12) which, if necessary, emphasizes any relevant cases and extreme cases of degradation.

To calculate this index, it is essential to determine two indices: the Calculated Degradation Index (CDI) and the Extreme Degradation Index (EDI), which are defined as follows:

$$CDI=\sum W*N, \tag{6}$$

Where W and N represent the global weights indicated in Figure 4, as well as the notations of the factors F illustrated in the Tables 3 to 8.

$$EDI=\begin{cases} DI_{max} & if\ DI_{max}>15 \\ 0 & otherwise \end{cases}, \tag{7}$$

with

$$DI_{max}=\max\left\{DI_{Deck}, DI_{Supports}, DI_{Foundation}\right\}, \tag{8}$$

and

$$DI_{Deck}=w_{C.ST1.1}\,[w_{C.ST1.1.1}*N_{C.ST1.1.1}+w_{C.ST1.1.2}*N_{C.ST1.1.2}+w_{C.ST1.1.3}*N_{C.ST1.1.3}+w_{C.ST1.1.4}*N_{C.ST1.1.4}]$$
$$+w_{C.ST1.2}*N_{C.ST1.2}+w_{C.ST1.3}*N_{C.ST1.3}, \tag{9}$$
$$DI_{Supports}=w_{C.ST2.1}*N_{C.ST2.1}+w_{C.ST2.2}*N_{C.ST2.2}, \tag{10}$$
$$DI_{Foundation}=w_{C.ST3.1}*N_{C.ST3.1}+w_{C.ST3.2}*N_{C.ST3.2}+w_{C.ST3.3}*N_{C.ST3.3}, \tag{11}$$

where w_F and N_F represent respectively the local weight (Figure 3) and the notation (Tables 3,…,8) of factor F.

Finally,
$$GBDI=max\{\,CDI,EDI\,\}, \tag{12}$$

2.6 Assessment of the Global

Once the GBDI index has been calculated, we propose to assign to the bridge a class according to the value of this index. Each class will induce the appropriate type of intervention.

After several meetings with experts (engineers, experts and academics) we arrived at the results presented in the Table below (see Table 9).

Table 10: Classification of the Bridge's Degradation State.

Class	GBDI	Degradation State	Intervention
C1	0 to 5	Degradation state with no current or potential danger	No intervention recommended
C2	5 to 10	Presence of signs of minor stable degradations with no consequences	Recommended but not major intervention
C3	10 to 15	Degradation that may evolve over time	Non-urgent intervention recommended
C4	15 to 20	Degradation causing dysfunction and potentially evolving dangerously	Urgent intervention recommended
C5	More than 20	Critical degradation state, deficiency, and severe damage	Immediate intervention recommended

3 Findings and discussion

3.1 Development of Binary Comparison Matrices and Weight Calculation

The comparisons (see Table 11) are made in consultation with expert engineers from the company specializing in the study and construction of civil engineering works in the west of Algeria (SEROR), as well as with mathematician academics and civil engineers. The binary comparison of two criteria aligns with the impact of these criteria on the parent criterion.

The calculations related to local weights (Figure 3) and consistency indices were performed using Excel software. The analysis of the consistency ratios (CR), all less than 10%, validates the consistency of the judgments provided by the experts.

Table 11: Binary Comparisons of Criteria.

Criteria	C.ST 1.1.1	C.ST 1.1.2	C.ST 1.1.3	C.ST 1.1.4	Weight	CR%	Criteria	C.ST3.1	C.ST3.2	C.ST3.3	Weight	CR %
C.ST1.1.1	1	2	2	3	0.4	5 <10	C.ST3.1	1	1	2	0.4	0<10
C.ST1.1.2	0.5	1	1	4	0.25		C.ST3.2	1	1	2	0.4	
C.ST1.1.3	0.5	1	1	4	0.25		C.ST3.3	0.5	0.5	1	0.2	
C.ST1.1.4	0.33	0.25	0.25	1	0.09		**Criteria**	**C.ST1**	**C.ST2**	**C.ST3**		
Criteria	**C.En.1**	**C.En.2**	**C.En.3**	**C.En.4**			C.ST1	1	1	1	0.33	0<10
C.En.1	1	1	2	3	0.36	2 <10	C.ST2	1	1	1	0.33	
C.En.2	1.0	1	2	2	0.32		C.ST3	1	1	1	0.33	
C.En.3	0.5	0.5	1	2	0.19		**Criteria**	**C.ST1.1**	**C.ST1.2**	**C.ST1.3**		
C.En.4	0.33	0.5	0.5	1	0.32		C.ST1.1	1	3	6	0.67	0 <10
Criteria	**C.EQ.1**	**C.EQ.2**	**C.EQ.3**	**C.EQ.4**			C.ST1.2	0.33	1	2	0.22	
C.EQ.1	1	2	3	2	0.42	5 <10	C.ST1.3	0.167	0.5	1	0.11	
C.EQ.2	0.5	1	2	2	0.26		**Criteria**	**C.F.I**	**C.F.E**			
C.EQ.3	0.33	0.5	1	2	0.18		C.F.I	1	1		0.5	
C.EQ.4	0.5	0.5	0.5	1	0.14		C.F.E	1	1		0.5	
Criteria	**C.SO**	**C.AG**	**C.En**				**Criteria**	**C.ST**	**C.EQ**			
C.SO	1	1	1		0.33	4.63<10	C.ST	1	3		0.75	
C.AG	1	1	0.5		0.26		C.EQ	0.33	1		0.25	
C.En	1	2	1		0.41		**Criteria**	**C.ST 2.1**	**C.ST 2.2**			
							C.ST2.1	1	0.5		0.33	
							C.ST2.2	2	1		0.67	

N.B.: For the comparison of two criteria, the consistency of judgments is evident, (the CR is not checked).

The Figure 3 presents a sun diagram that illustrates the local weights (w_i) obtained from the consistency tests. This diagram highlights that the parameters "Structure" (75%) and "Environment" (41%) are the most significant. Furthermore, the parameters "Girders," "Piers," and "Abutments" are the dominant criteria within the "Structure" criterion. In contrast, the parameter "Equipment" is considered the least important, contributing only 25% to the degradation of the bridge.

Fig. 3: Local weights (w_i) of criteria and Sub criteria.

The application of the hierarchical model also allows for the determination of the global weights Wi of the factors by multiplying the local weights by those of their lower-level parent criteria. The Figure 4 summarizes these global weights of the different factors. The analysis of the sun diagram presented in this Figure reveals significant discrepancies between the global weights of the various sub-factors. These variations illustrate the unequal importance and influence of these factors on the degradation of the bridge.

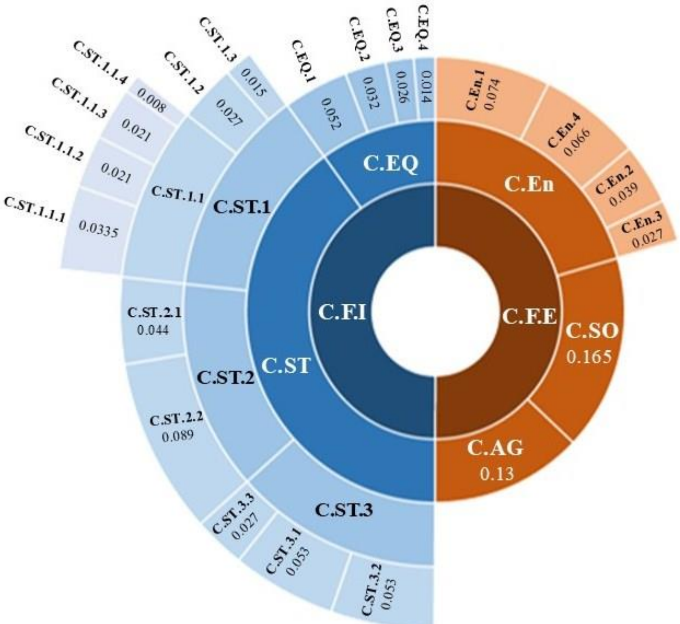


Fig. 4: Global Weights W_i of Factors F.

4 Case Studies

The developed model is used to evaluate the degradation state of two bridges located in west of Algeria. The locations of these structures are illustrated in the Figure below.

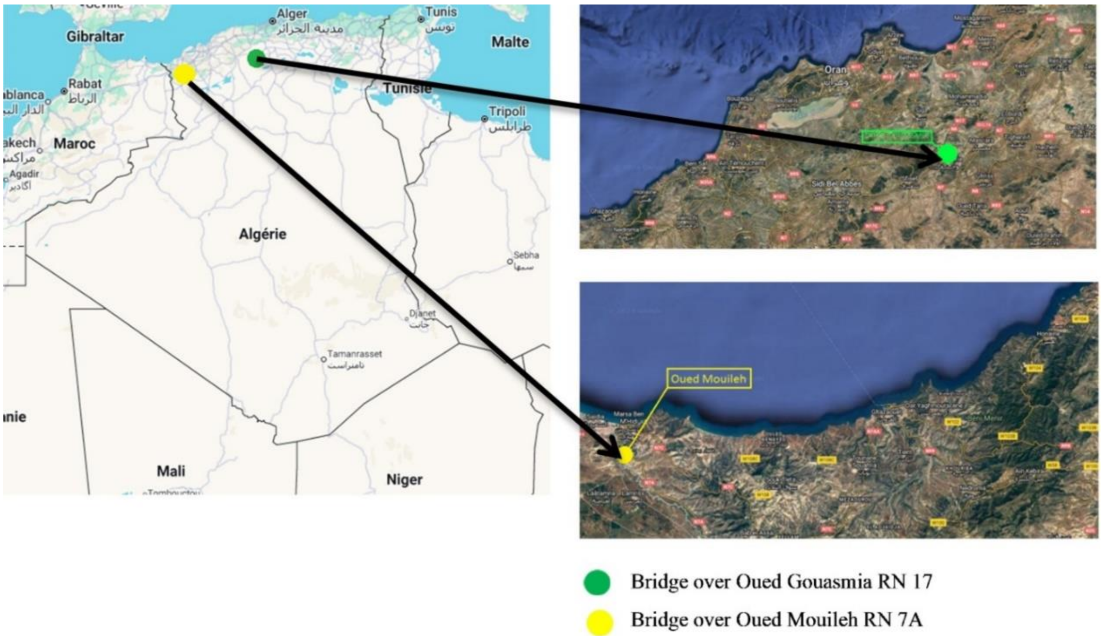
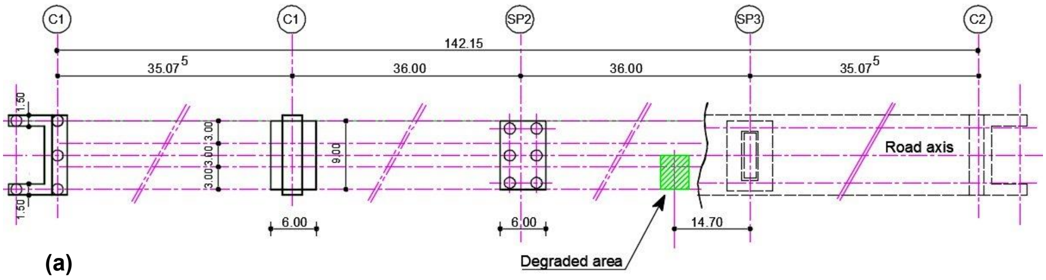


Fig. 5: Overall location of case studies on the map of Algeria. Source: © OpenStreetMap contributors, accessed on March 17, 2025. Available at: https://www.openstreetmap.org.

4.1 Bridge over Oued Gouasmia RN17

The first case studied concerns the road bridge located on National Road No. 17 in the Wilaya of Mascara (coordinates: 35.2872306250305, -0.14250877056492023). This bridge, constructed in the 1980s by the Algerian public works company "SEROR," is a prestressed concrete structure composed of four spans, each 36 m long, crossing the Oued Gouasmia at kilometer point 87+781 of the RN17, on the section connecting the town of Bouhanifia to that of Sfisef. Each span consists of four girders topped with a 20 cm thick cast-in-place reinforced concrete slab. The distribution of forces within the deck is ensured by a properly reinforced slab, which provides bracing between the girders for improved rigidity. The deck rests simply on its supports via neoprene support pads. The piers consist of reinforced concrete walls topped with a rigid cap girder. The abutments consist of a rigid cap girder resting directly on 1.20 m piles anchored in the ground (Figure 6).



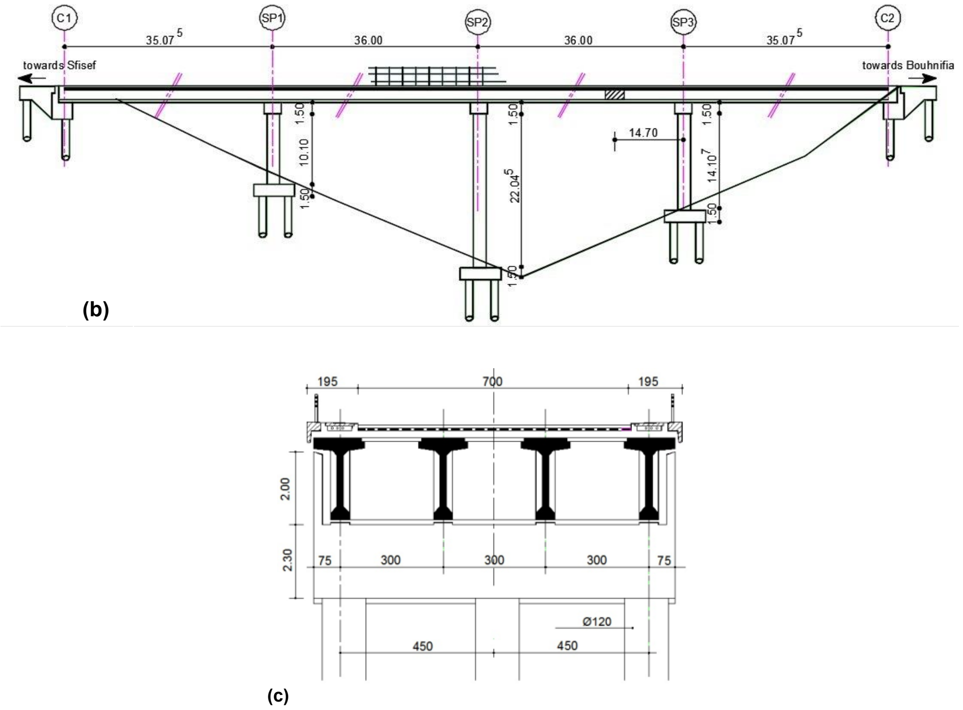


Fig. 6: Schematic drawings for the Bridge over Oued Gouasmia RN 17, (a) Longitudinal section, (b) Plan view, (c) Cross-section of the abutment.

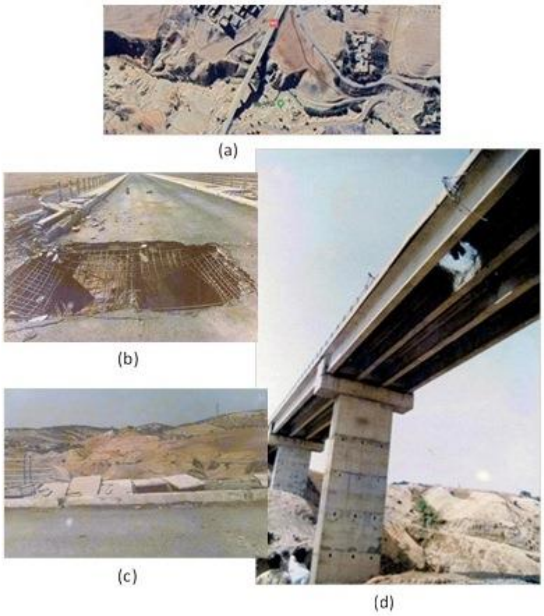


Fig. 7: Bridge over Oued Gouasmia RN 17, Source: Authors, (a) Satellite image (b) Extent of disorders on the deck (c) Extent of disorders on the sidewalk and guardrail (d) Damaged span (girder and slab).

The findings on this structure reveal a rupture at the level of a single girder, with vertical and parallel cracks on the lateral walls and the heel of the girder (flexural cracks with an opening greater than 0.6 mm. A rupture of the slab with complete shearing of the reinforcement is observed over an area of approximately 10 m². In contrast, the piers and abutments show no significant anomalies. Additionally, signs of erosion are visible at the foundation level, while the waterproofing, road joints, and drainage system are degraded. The structure, aged between 30 and 40 years, is subjected to moderate loading, with alternating humidity and drying. The runoff water has low aggressiveness, and the structure is located more than 5 km from the sea. The effect of frost is mild to moderate without de-icing treatment.

The different notations for the criteria considered in this case are reported in Table 12.

Table 12: Notations of the different criteria for the two case studies.

Criteria	**C.ST1.1.1**	**C.ST1.1.2**	**C.ST1.1.3**	**C.ST1.1.4**	**C.ST1.2**	**C.ST1.3**	**C.ST2.1**	**C.ST2.2**	**C.ST3.1**	**C.ST3.2**	**C.ST3.3**
Bridge over Oued Gouasmia	44	40	0	0	32	0	0	0	0	8	0
Bridge over Oued Mouilah	0	0	0	0	0	0	12	0	0	16	0

Criteria	**C.EQ.1**	**C.EQ.2**	**C.EQ.3**	**C.EQ.4**	**C.En.1**	**C.En.2**	**C.En.3**	**C.En.4**	**C.SO**	**C.AG**
Bridge over Oued Gouasmia	0	14	14	14	18	6	0	2	16	8
Bridge over Oued Mouilah	16	18	14	18	18	18	0	2	16	8

The bridge over Oued Gouasmia is classified in category C5 with a GBDI of 25,53 (Table13). Therefore, the structure is in a critical state of degradation, exhibiting deficiencies and severe damage that require immediate intervention.

4.2 Bridge over Oued Mouilah RN 7A

As a second case study, we examined the bridge crossing the Oued Mouilah at kilometer point 7+800 on the RN 7A, on the section connecting the city of Maghnia to Marsa Ben Mehidi in the Wilaya of Tlemcen (Coordinates: 34°51'14" N, 1°51'27" W). This is a reinforced concrete girder bridge with a total length of 60 m, divided into three spans of 20 m each. The deck consists of six rectangular girders (40 cm wide and 120 cm high) topped by a 20 cm thick reinforced concrete slab. The intermediate supports are composed of piers formed by three columns with a diameter of 1.0 m, surmounted by a rigid cap girder. The abutments consist of a front wall and return walls, extended by a high retaining wall (Figure 8).

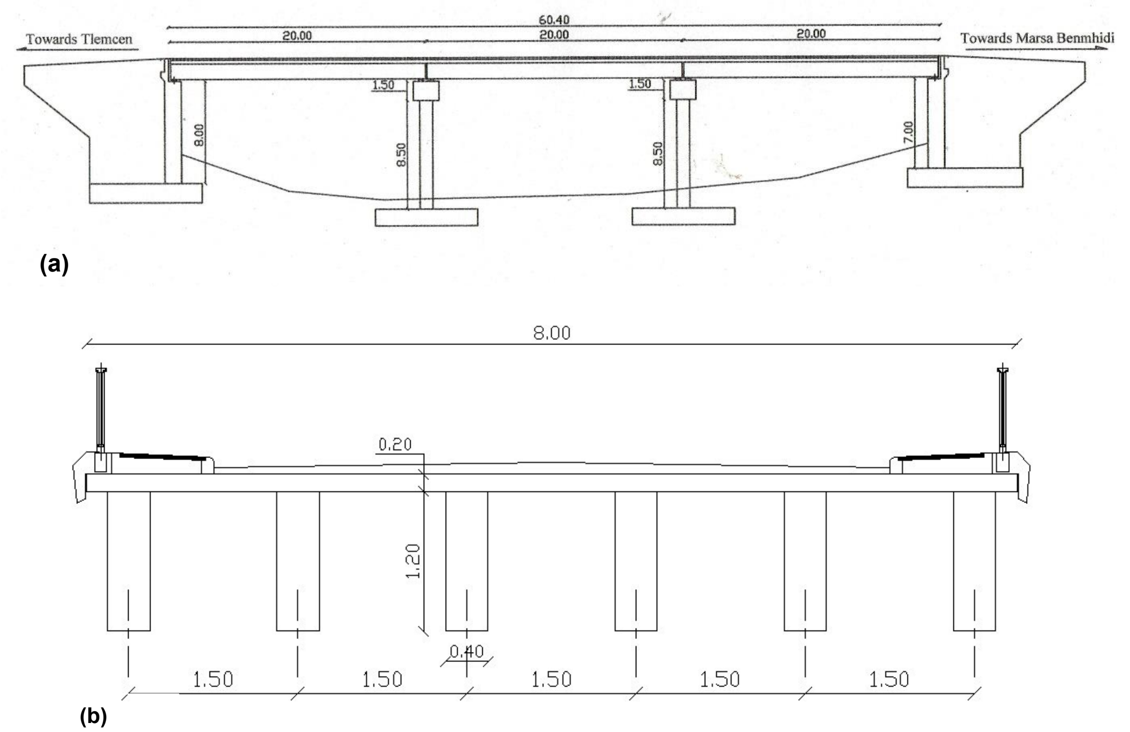
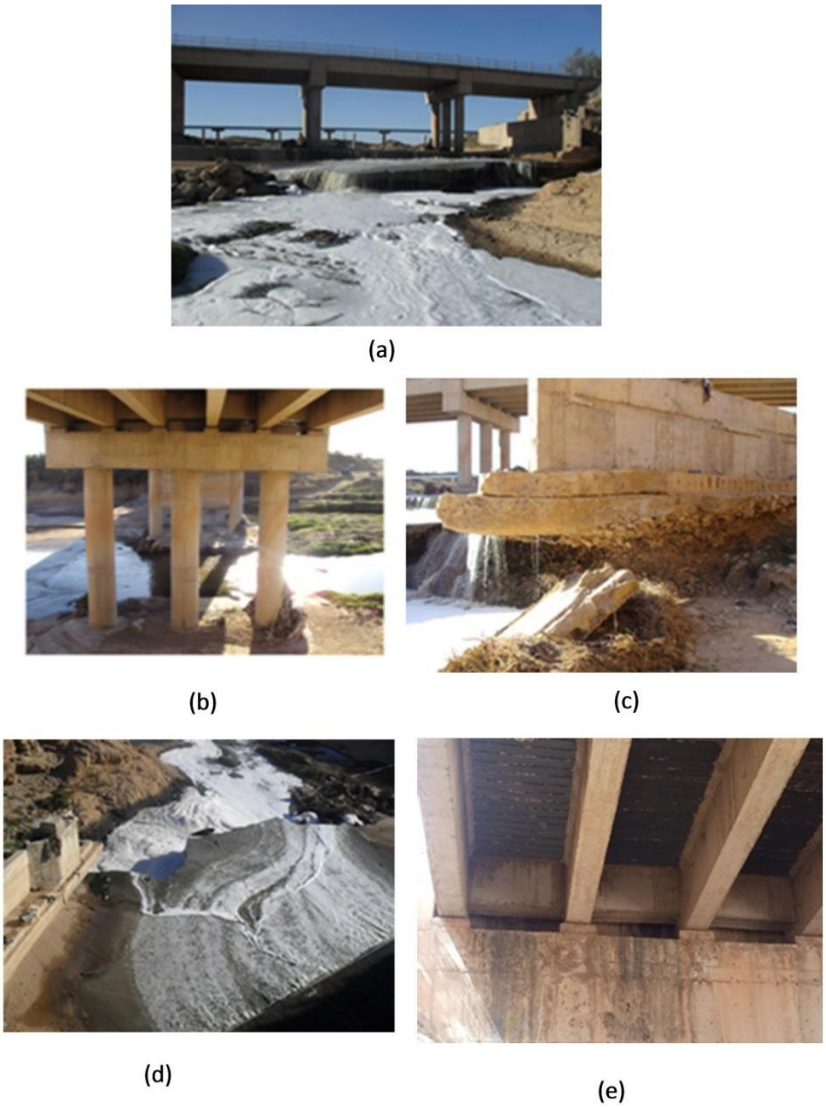


Fig. 8: Schematic drawings for the Bridge over Oued Mouilah RN 7A, (a) Longitudinal section., (b) Cross-section of the deck.


(a)

(b) (c)

(d) (e)

Fig. 9: Bridge over Oued Mouilah RN7A, Source Authors, (a) Overview of the structure (b) Underside View (c) Breakage of the protective slab, degrees of water pollution (d) Extent of scour (e) Defect in the drainage system.

The bridge does not present any major anomalies on the girders, slab, or webs. However, several issues have been detected at the level of the piles, including scours, delamination, as well as exposure of the reinforcement with corrosion of the steel. Additionally, localized erosion has been observed up to mid-height of the foundation.

The bearing devices and road joints are degraded, while the waterproofing and drainage system are severely degraded. The bridge, which is between 30 and 40 years old, is subjected to medium-level stresses. It is located in a moderately humid environment, but the runoff water exhibits significant aggressiveness. Situated more than 5 km from the sea, the bridge is exposed to climatic conditions characterized by light to moderate frost without the use of de-icing agents.

Table 12 presents the notations assigned to these criteria.

This bridge is classified in category C2 with a GBDI of 9.59 (Table 13). The structure shows signs of minor, stable degradation without significant consequences. A minor intervention is recommended.

Table 13: Results of the model application for the different case studies.

Case studies	CDI	EDI	GBDI	CLASS
Bridge over Oued Gouasmia	10.06	25.53	25.53	C5
Bridge over Oued Mouilah	9.59	6.4	9.59	C2

5 Conclusion and perspectives

In this study, we applied the Analytic Hierarchy Process (AHP) to evaluate the overall degradation state of reinforced concrete girder bridges by introducing a Global Degradation Index (GBDI) that we defined.

Our model has proven to be a reliable and effective method for addressing the issue of divergence in expert evaluations. We developed a six-level hierarchical structure incorporating 28 sub-criteria, demonstrating that a bridge's health primarily depends on the condition of its load-bearing structure (foundation, piles, abutments, and deck), followed by external factors (age, stresses, and type of environment), and finally by factors with lesser impact (equipment and non-structural elements).

Additionally, we employed a method that prioritizes extreme degradation situations that correspond to an obvious danger in the operation of the structure. Based on the calculated degradation index (GBDI), we categorized the structures into five distinct classifications, each reflecting the condition of the bridge and the suitable type of intervention. This classification is crucial for prioritizing interventions and efficiently allocating the necessary resources for bridge maintenance.

This methodology was applied to two existing RC bridges in west of Algeria: the bridge over Oued Gouasmia was classified in category C5 with a GBDI of 25.53 indicating a critical state requiring immediate intervention, while the bridge over Oued Mouilah was classified in category C2, showing minor signs of degradation.

This model proves effective in reducing uncertainties during bridge assessments, and we recommend its use for rationally evaluating their condition and planning appropriate interventions. This research paves the way for better management of reinforced concrete bridges, emphasizing the importance of an integrated and multidisciplinary approach to the evaluation and maintenance of infrastructures.

The prospects of this research are promising and open several avenues for further exploration. It would be beneficial to extend the study to different regions to test the model’s robustness across diverse geographical contexts while enriching the database with degradation factors from multiple case studies to enhance its reliability. Furthermore, reducing the subjectivity of weightings could be achieved by integrating alternative multi-criteria methods or artificial intelligence tools, while incorporating an economic dimension would allow for the assessment of the financial feasibility of proposed interventions. The integration of advanced technologies such as sensors, drone imagery, remote sensing, and automated analysis systems would improve the accuracy and objectivity of diagnostics by providing real-time data. Finally, adapting the methodological framework to other infrastructures, such as tunnels, roads, or railways, would enable a comprehensive and sustainable management of assets, thereby supporting more targeted and effective interventions.

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