CLIMATE RISK ASSESSMENT FOR INFRASTRUCTURE: AN APPLICATION FOR CAI LON - CAI BE SLUICE GATES IN THE MEKONG DELTA

Duc Cong Hiep Nguyen[1(*)], Viet Minh Le[1], Duc Dung Do[1], Thi Minh Ngoc Nguyen[2], Benjamin HODICK[2], Katharina LOTZEN[2]

[1] Southern Institute for Water Resources Planning (SIWRP)

[2] German Cooperation Agency (GIZ)

(*) Corresponding author: hiepndc@yahoo.com; ngoctmnguyen@gmail.com

Abstract

In recent decades, Vietnam has invested millions of dollars into long-lived infrastructures, especially in the Mekong Delta. However, the risk to lose investments due to extreme weather events and slow-onset disasters like sea level rise requires decision makers to ensure the resilience of both existing but also new investments. In this context, climate risk assessments for infrastructure are recognized as an effective tool to identify and prioritise adaptation needs, and at the same time, serve as technical basis for developing appropriate climate change adaptation strategies. Such assessments are expected to support the development of solutions for climate-resilient infrastructure investment, especially as many new infrastructures are implemented without knowledge of the vulnerability of the planned infrastructure. In this study, a step-by-step methodology of climate risk assessment for infrastructure, namely the PIEVC Engineering Protocol (the "Protocol"), was used to assess the climate risk of the Cai Lon - Cai Be sluice gates. The project is in the basic design stage. The Protocol has been developed by Engineers Canada and is in use since 2008. The risk matrices obtained from this assessment provided a picture of the potential risks for the Cai Lon - Cai Be sluice gates under the impacts of climate and hydrological factors for both historical conditions and future projections. Some major recommendations were identified to support the decision-makers in the stages of the detailed design, construction drawing design, and operation and maintenance of the Cai Lon - Cai Be sluice gates. The study also revealed a high potential for the application of the Protocol for further climate risk assessment for both planned and existing infrastructures in Vietnam in the future, particularly in the Mekong Delta which is especially affected by sea level rise and more frequent and intense extreme weather events due to climate change.

Key words: climate risk assessment, PIEVC, Mekong Delta, Cai Lon - Cai Be, climate change adaptation, resilient infrastructure, climate risk management

1. INTRODUCTION

In recent decades, Vietnam has invested millions of dollars into long-lived infrastructures, where the Mekong Delta (MKD) accounts for 16.53% (around 8,346 million USD)[1] of the whole country in the period of 2016-2020. However, many new infrastructures are implemented without knowledge of the prevalent climate risk. At the same time, the impacts of climate change on infrastructures are more and more serious (IPCC, 2014). Not considering future climate conditions in the planning of such infrastructure may lead to ineffective decisions in planning infrastructure investments and engineering designs and consequently a high risk of negative societal and economic consequences under these circumstances.

According to the 2016 climate change - sea level rise scenarios of Vietnam, developed by the Ministry of Natural Resources and Environment (MONRE), the climate in the MKD is projected to change significantly in the coming decades. Among the most relevant changes, increases in total annual rainfall, heavy rainfall intensity, and the number of high temperature days are expected. These factors are anticipated to affect the

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[1] More information in http://daibieunhandan.vn/default.aspx?tabid=74&NewsId=421488

quality, function and operation of infrastructure in the region. Therefore, the analysis of these factors plays an important role in assessing the climate risks for infrastructure. Vietnam recognizes this challenge and has committed itself to strengthening the resilience of its infrastructure as part of its National Action Plan for the Implementation of the 2030 Sustainable Development Agenda (Prime Minister Decision No. 622/QD-TTg). The corresponding targets of Goal 13 "*Respond in a timely and effective manner to climate change and natural disasters*" highlight the importance of building adaptive capacity and incorporating climate change considerations into planning contexts.

Achieving these objectives requires mainstreaming climate change adaptation into the infrastructure investment cycle as well as making sure the necessary Climate Services for climate-risk-informed decision-making which are available and usable for planners and managers of infrastructure. Climate Services help translating climate data into guidance for adaptation decision by the development of tailor-made products for specific decision-making contexts. One such Climate Service which is key for making infrastructure more resilient are climate risk assessments. They help in identifying and evaluating climate risks and identifying and selecting appropriate adaptation options.

One of the highlighted and useful tools for climate risk assessments for infrastructure is the PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate (the Protocol). "The observations, conclusions and recommendations derived from the application of this Protocol provide a framework to support effective decision-making about infrastructure operation, maintenance, planning and development" as part of climate risk management " (p. 9, Engineers Canada (2016)). Since 2008, the Protocol has been successfully applied to assess climate risks and vulnerabilities across a wide range of infrastructure systems in Canada and internationally (Engineers Canada (2018)).

This paper demonstrates the role of climate risk assessments for infrastructure in the MKD using the application of the Protocol for the Cai Lon - Cai Be sluice gates as case study example. This assessment is expected to support the decision-makers in planning infrastructure investments and adapting engineering designs in order to raise the resilience of infrastructures to climate change and related natural hazards. The case study was conducted in the context of the global project "*Enhancing Climate Services for Infrastructure Investment (CSI)*" funded by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) as part of the International Climate Initiative (IKI). The project is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in cooperation with Engineers Canada and the German Meteorological Service (DWD). CSI supports Vietnam in its efforts to make its infrastructure more resilient towards climate change.

In the following parts, a brief introduction of the Protocol is given in Section 2. This is followed by the case study, starting with a general description of the Cai Lon - Cai Be sluice gates project, followed by the risk assessment in Sections 3 and 4. And the results are presented and discussed in Section 5, prior to the conclusions and recommendations given in Section 6.

2. CLIMATE RISK ASSESSMENT METHODOLOGY - THE PIEVC ENGINEERING PROTOCOL

The PIEVC Engineering Protocol is a step-by-step process to assess the responses of infrastructure components to the impacts of a changing climate. The Protocol was developed by Engineers Canada, the national organization of the 12 sub-national engineering associations in Canada. Its role is regulation of the engineering profession as well as supporting the development of national policies, guidelines and positions. The development of the PIEVC Protocol was part of Engineers Canada's efforts to provide guidance to the engineering profession on sustainable infrastructure development. Specifically, the Protocol provides engineers with a flexible tool that allows them to evaluate climate risks while at the time being adaptable to different circumstances in terms of available information, resources and purposes. It serves to support "*practitioners in characterizing any gaps between additional duty loads*" [as potentially exerted by climate change] and the capacity of infrastructure "*to adapt to that challenge outside its original design*" (p. 29, Engineers Canada (2016)). Generally, the Protocol has five major steps as shown in Figure 1 (for more details refer to the Protocol Principles and Guidelines (2016)).

In the first step, general information about infrastructures (i.e. location, main infrastructure components, design standard, etc.), and climate and hydrological data (including parameters, trends, and events which may impact on the infrastructure) are collected and introduced for screening and scoping of the assessment work.

Based on the data collected in Step 1, Step 2 focuses on two main activities, including: (i) identifying the main infrastructure systems and their breakdown, and (ii) identifying any climatological and hydrological phenomena that may be relevant for the infrastructure and are hence to be considered in the assessment. The breakdown of infrastructures is what makes the PIEVC Protocol especially geared towards specific infrastructure projects. This components-wise approach allows to take into account different thresholds for different components and for the analysis to take into account the criticality of components for the infrastructure. In this step, the baseline climate and assumptions about climate change as well as first ideas about potential impacts on each infrastructure component individually and for cumulative effects of combined events are also stated to support climate data analysis in the next step.

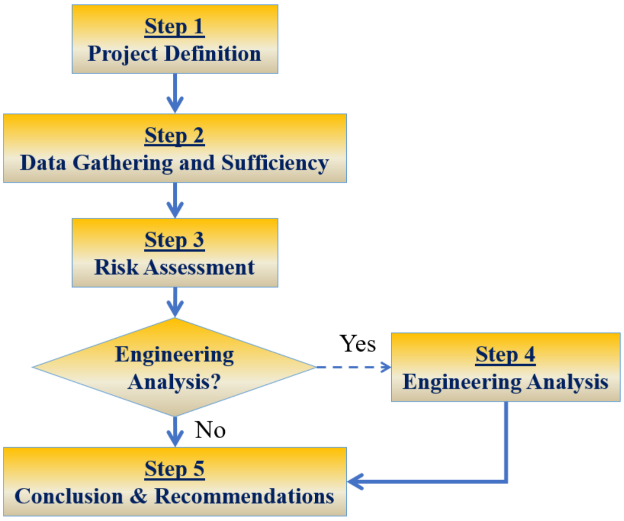


Figure 1. Five major steps of PIEVC

As the heart of the PIEVC process, the main goal of Step 3 is to implement the actual assessment of risk based on the interaction between the identified components and climate and hydrological parameters. This includes analyzing cumulative effects of two phenomena occurring at the same time. The interactions are then evaluated in terms of frequency and severity of impact. While frequency is represented by probability scores (P) of climate and hydrological factors, severity of impact is represented by severity scores (S) of infrastructure components under the impacts of climate and hydrological factors. Both the probability and severity scores are valued in specific ranges, where the minimum value (e.g., 0) means negligible or no negative consequences, and the maximum value means highly probable or extremely negative consequences. These scores are identified based on the data analysis and professional judgement if the available data is limited. All the activities are usually implemented at risk assessment workshops with the attendance of experts in different aspects (e.g., climate, hydrology, water resources, civil, etc.) and other stakeholders. In the Protocol, risk scores (R) are calculated by the following formula:

$$R = P \times S \qquad (1)$$

For the risk assessment, most commonly two scenarios are used (though the use of more is possible). One is the baseline scenario, where risks are evaluated based on historical conditions. The other is the future scenario, where it is analyzed how the probability scores and consequently risks change if projections on future climate conditions (based on the emissions scenario selected by the assessment team) are used.

The risk matrices are analyzed to decide if an engineering analysis (Step 4) is conducted or not. Step 4 is an optional step that is only conducted if for any of the interactions the available information is insufficient to determine the severity of impact. If Step 4 is implemented, the total load on the infrastructure and its total capacity for both current and future conditions will be calculated to identify whether there is a vulnerability (i.e., total projected load exceeds total projected capacity) or whether sufficient adaptive capacity exists (i.e., total projected load is less than total projected capacity). In the context of Cai Lon – Cai Be sluice gates project Step 4 was excluded as it was not deemed necessary in the context of the assessment. Finally, the assumptions, limitations and recommendations from the assessment process are elaborated in Step 5, on the basis of interpretation of the risk matrices and actual conditions for adaptation.

3. CASE STUDY

In this study, an application of the PIEVC Protocol was carried out to assess current and future climate risks for the Cai Lon - Cai Be sluice gates project, which was classified into Group A of new construction works in Vietnam with a total state investment of 3,300 billion VND (around 142 million USD, exchange rate July 2019). The project was first proposed in 2006, and recently approved for investment by the Prime Minister and managed by the Water Resources Investment and Construction Board No. 10 under the Ministry of Agriculture and Rural Development (MARD). As the Cai Lon - Cai Be sluice gates project was in the stage of basic design when this climate assessment was conducted, the information and data on this infrastructure for this climate risk assessment were extracted from the design version as of December 2018. In this study, the assessment followed steps 1-3 and 5 of the PIEVC Protocol. Step 4 was excluded from the assessment as it was judged that a more detailed analysis would be more appropriate at a later stage of project implementation.

The Cai Lon and Cai Be sluice gates are located 2.1 km and 1.9 km, respectively, upstream from the Cai Lon and Cai Be bridges (Figure 2). The Cai Lon sluice gate has a total width of 470 m, consisting of 11 sluice gates of 40.0 m width (elevation threshold of -3.5÷-6.0 m) and 2 ship locks of 15 m width and 100 m length (elevation threshold of -5.0 m). In a smaller scale, the Cai Be sluice gate has a total width of 85 m, consisting of 2 sluice gates of 35 m width (elevation threshold of -5.0 m) and 1 ship lock of 15 m width and 100 m length (elevation threshold of -4.0 m height). Both sluice gates are designed with a crest elevation of +2.5 m. The suggested construction material is steel. The gates are designed as a vertical lift system to be operated by a hydraulic cylinder system. The sluices also have an integrated bridge with a width of 9.0 m (Figure 3). For the assessment described in this paper, the focus were the sluice gates themselves.

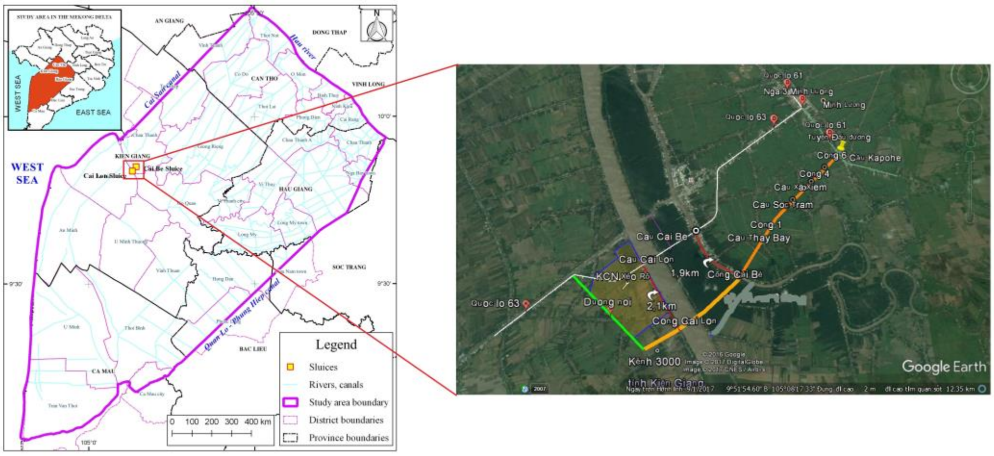


Figure 2. Location of Cai Lon – Cai Be sluice gates (Adapted from PMU-10, 2018)

The design life of the planned infrastructure is 100 years. Accordingly, with regards to the potential impacts of future climate, the climate change scenarios for Vietnam (MONRE, 2016) corresponding to the period of 2080-2099 were used. The time milestone of sea level rise projections is every 10 years from 2030 to 2100. Generally, it has to be kept in mind that though the overall infrastructure has a design life of 100 years, the components vary in design life. For example, the control and monitoring systems have a design life of 10 years while the physical structures have a design life of 70 – 100 years (Reference to PIEVC report). Keeping this in mind is important for Step 5 of the assessment, the recommendations, as for components of a shorter lifespan the implementation of adaptation measures later in the life of the infrastructure is much easier. On the other hand, for components with very long lifespans it is even more important to anticipate climate change impacts as well as possible as later retrofitting is often costly.

Figure 3. Overall perspective of Cai Lon – Cai Be sluice gates (Source: PMU-10, 2018)

In order to identify the interactions between the infrastructure and climate events, the structure of the Cai Lon and Cai Be sluice gates was grouped into thirteen main infrastructure systems and their breakdown (Table 1). Based on the functions and characteristics, the components of the Cai Lon – Cai Be sluice gates are divided into four main groups: (A) Operation and maintenance staff; (B) Primary infrastructure components (*consisting of sluice gate structure, ship lock, gates, and retaining walls and connected embankment*); (C) Operation systems (*consisting of power supply, operation and control system, monitoring system, fire extinguishing system, and communication system*); and (D) Ancillary infrastructure components (*consisting of bridge, operation house and park*).

Table 1. Main infrastructure systems and their breakdown

No.	Main system	Components	Group
1	Operation and maintenance	Personnel Transportation/Supplies Delivery	A
2	Sluice gate structure	Pile foundation Waterproof pile foundation Pillar footing Bottom beam Pillar Gate tower (gate hanger)	B
3	Ship lock	Lock chamber Lock head Filling and discharge culverts Leading jetty	
4	Gates	Hydraulic Cylinder Gates (large and small) Water tight gasket	
5	Retaining walls and connected embankment	Retaining walls Gabion Connected embankments Rip-rap embankments sections Stilling basin	
6	Power supply	Transmission Lines Power Supply Standby Generators	C
7	Operation and control system	Control Systems Operation systems	
8	Monitoring system (e.g. SCADA)		
9	Fire extinguishing system	Fire warning system, extinguisher…	
10	Communication system	Computers, phones, fax machines…	
11	Bridge	Bridge Surface Hand Rail Lighting System Traffic Sign Post	D
12	Operation houses		
13	Park		

In addition to the climate factors required by the Protocol, for this case study the assessment team also assessed the impacts of hydrological factors and salinity intrusion on the Cai Lon – Cai Be sluice gates, as they are the significant features impacting infrastructures in the MKD. The climate and hydrological data used for the risk assessment were collected from 6 climate stations, 10 rainfall stations and 10 hydrological stations around the study area. The dataset periods are 29 years (1988 - 2017), except for the salinity data, where only 21-year datasets were available (1996 - 2017). To consider the impacts of climate change and hydrological factors on the infrastructure, the assessment team selected 9 climate factors (high temperature, heat wave, drought, heavy rain, heavy 5-day total rainfall, high wind, tropical storms/depression, tornado, and thunderstorms/lightning corresponding to Columns 1 to 9 in Figure 4), 2 hydrological factors (water level and salinity intrusion corresponding to Columns 10 to 11 in Figure 4), and 2 cumulative effects (salinity intrusion and high temperature, and high water level and heavy rain corresponding to Columns 12 to 13 in Figure 4). These factors were selected because their impacts on the similar infrastructures were recorded in the MKD and their available data is sufficient for assessment.

4. CLIMATE RISK ASSESSMENT

As mentioned above, this section is a core step in the Protocol as it embodies the assessment of the risk climate change to an infrastructure. To achieve this, an assessment team of climate, hydrology, water resources, and civil experts specified infrastructure components, values of climate parameters and other factors, and minimum performance goals before coming to a professional judgment and assessment. This judgment was based on the combined skills, advice and training provided by Canadian experts as well as expertise and experience of the entire team. It was to evaluate the interactions. The infrastructure components identified are likely to be sensitive to variations of the assessed climate and hydrological parameters. In this step, a risk assessment workshop was organized to consult with the infrastructure project owner, infrastructure designers, engineers in charge of operations and other relevant stakeholders. This workshop allowed the assessment team to work as a multidisciplinary group combining different areas of expertise. In this manner the team was able to jointly arrive at professional judgements under circumstances of limited availability of data on the severity and (in some cases) probability of a given impact.

Based on the PIEVC guidelines, the probability scores were ranged from 0 to 7, where 0 means that the climate and hydrological event is negligible in terms of frequency and 7 means that the event is highly probable. The probability scores were estimated based on the data analysis and professional judgement of the climate and hydrological experts. In addition to the traditional statistical methods used for the analysis of historical data, this study applied the Climate Change Hazards Information Portal (CCHIP) tool (https://go.cchip.ca/) provided by Engineers Canada and Risk Sciences International (RSI) to support climate and hydrological data analysis for both, deriving historical trends and projections.

Similar to the probability scores, the severity scores were also standardized in a range of 0 to 7, where 0 means no negative consequences and 7 means failure of the infrastructure. Under the PIEVC guidelines, the severity scores for each infrastructure component of Cai Lon - Cai Be Sluice Gate under the impacts of each climate and hydrological factor (including cumulative effects) in both the past and future cases were determined. In order to determine the severity scores, the risk assessment team relied on the following sources of information:

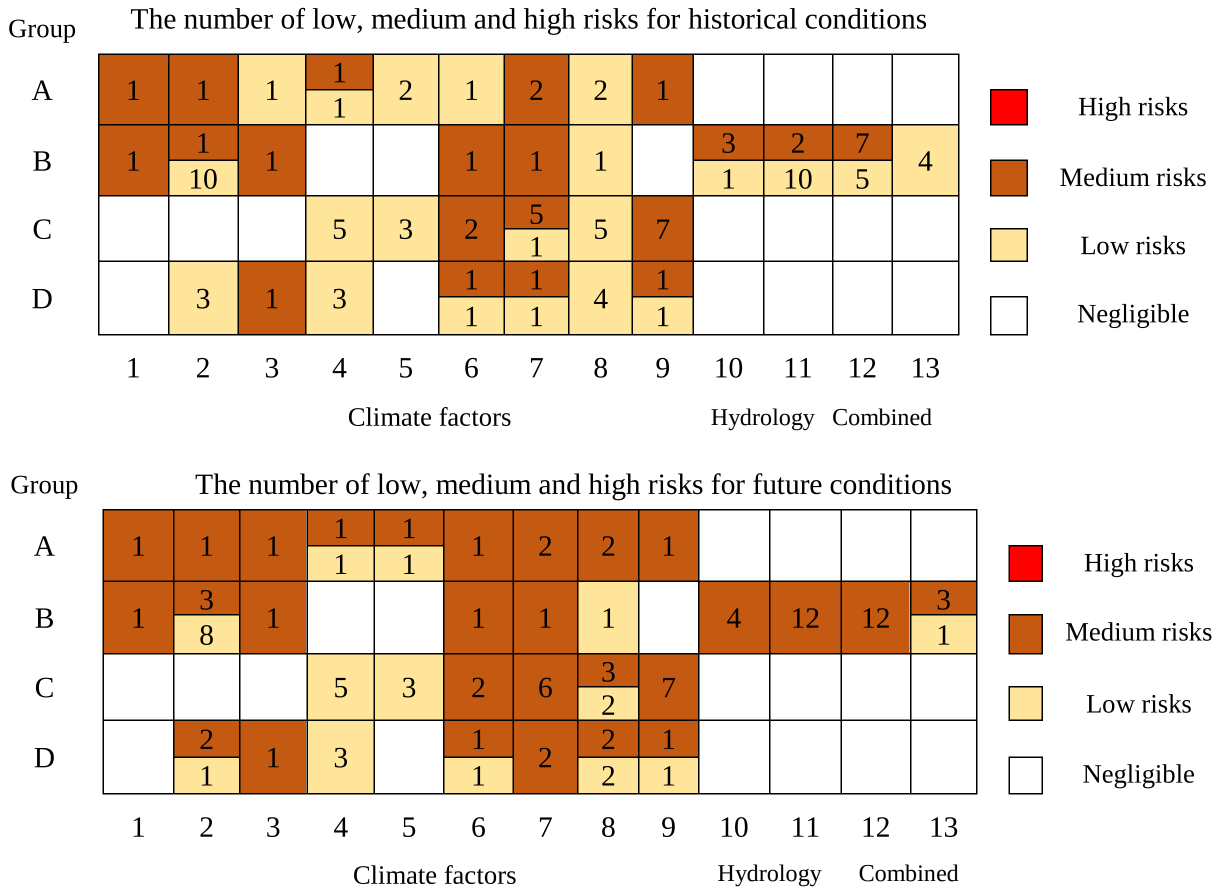
- Design standards and regulations for the Cai Lon - Cai Be sluice gates;
- Characteristics of the Cai Lon - Cai Be sluice gates as specified in the basic design documents;
- Historical data, trends and projections of the climate-hydrological factors;
- Knowledge of administration and operation staff on the impacts of past events on similar infrastructures such as the Ba Lai sluice gate (Ben Tre), Lang The sluice gate (Tra Vinh);
- Documentation on the administration and operation of the similar infrastructures such as the Ho Phong sluice gate, Lang Tram sluice gate (Bac Lieu) and Can Chong sluice gate (Tra Vinh);

- Professional judgement of the assessment team, experts from the different sectors (i.e., construction, climate, hydrology and water resources), and the Canadian experts.

The risk scores (R) were then calculated and categorized into high, medium and low risks as stated in the Protocol guidelines. It is noted that high risks ($R > 36$) require a considerable response in the detailed design phase, while a low risk level ($R < 12$) needs not immediate actions. Medium risks ($12 \leq R \leq 36$) should also be concerned during the detailed design phase. The determination of the risk thresholds is usually done by the assessment team, as it depends on the risk tolerance of the owner of the infrastructure. However, in case of this assessment, the team decided to follow the default thresholds given in the PIEVC Protocol.

5. RESULTS AND ANALYSIS

As a part of the climate risk assessment, the interactions between the infrastructure components and climate and hydrological factors were identified and analyzed. Totally, there were 468 interactions considered. Of those, only 106 interactions had the potential of negative impacts (i.e. performance responses) and were hence scored in terms of severity and probability. A summary of risk matrices obtained from the risk assessment process for both historical conditions and future projections is shown in Figure 4.



The number of low, medium and high risks for historical conditions

Group	1	2	3	4	5	6	7	8	9	10	11	12	13
A	🟫 1	🟫 1	🟨 1	🟫 1 🟨 1	🟨 2	🟨 1	🟫 2	🟨 2	🟫 1				
B	🟫 1	🟫 1 🟨 10	🟫 1			🟫 1	🟫 1	🟨 1		🟫 3 🟨 1	🟫 2 🟨 10	🟫 7 🟨 5	🟨 4
C				🟨 5	🟨 3	🟫 2	🟫 5 🟨 1	🟨 5	🟫 7				
D		🟨 3	🟫 1	🟨 3		🟫 1 🟨 1	🟫 1 🟨 1	🟨 4	🟫 1 🟨 1				

Climate factors (1–9) · Hydrology (10–11) · Combined (12–13)

🟥 High risks
🟫 Medium risks
🟨 Low risks
⬜ Negligible

The number of low, medium and high risks for future conditions

Group	1	2	3	4	5	6	7	8	9	10	11	12	13
A	🟫 1	🟫 1	🟫 1	🟫 1 🟨 1	🟫 1 🟨 1	🟫 1	🟫 2	🟫 2	🟫 1				
B	🟫 1	🟫 3 🟨 8	🟫 1			🟫 1	🟫 1	🟨 1		🟫 4	🟫 12	🟫 12	🟫 3 🟨 1
C				🟨 5	🟨 3	🟫 2	🟫 6	🟫 3 🟨 2	🟫 7				
D		🟫 2 🟨 1	🟫 1	🟨 3		🟫 1 🟨 1	🟫 2	🟫 2 🟨 2	🟫 1 🟨 1				

Climate factors (1–9) · Hydrology (10–11) · Combined (12–13)

🟥 High risks
🟫 Medium risks
🟨 Low risks
⬜ Negligible

Figure 4. Summary of risk matrices between 4 groups of components (Rows 1 to 4) and climate factors (Columns 1 to 9), hydrological factors (Columns 10-11) and combined factors (Columns 12-13)

5.1. Interactions between the infrastructure components and climate and hydrological factors

It can be seen from Figure 4 that only the primary infrastructure components (Group B) are affected by the hydrological factors and cumulative effects. The increase in water level (B10) due to sea level rise, tidal regimes and storm surge is expected to not only affect the functionality of pillars, gates and ship locks if overflowing, but also increase the instability risk of slope and embankment in the front of and behind the sluice. Although the severity scores for these interactions are low (from 1 to 4), the corresponding probability scores are 7 for both historical and future conditions. As a result, the risk scores are medium (up to 21 and 28 for historical and future conditions, respectively), i.e., the stability, function and operation of the Cai Lon – Cai Be sluice gates may be reduced significantly. Furthermore, water level also indirectly causes physical abrasion and chemical corrosion for concrete as recorded in some sluices in the MKD.

On the other hand, high salinity concentration of saltwater and vapor (B11) is expected to reduce the lifespan of the watertight gasket and increase the chemical corrosion, leading to faster erosion of the gates, cracked concrete, and cylinder. The negative impacts on these interactions are also expected to be reinforced under the cumulative effects of salinity intrusion and high temperature (B12), as well as high water level and heavy rain (B13).

In addition, the components of Group B are also impacted by some climate factors. High temperature, heat waves, drought (B1 to B3) may increase the cracking and the corrosion of concrete, increase the likelihood of embankment erosion due to the change of the soil texture, and reduce the lifespan of the water tight gasket. Tropical storms/depression, tornado, and high wind (B6 to B8) can lead to a rising water level, increasing the risk of overflowing the sluice and thus causing instability, especially when the drain is open.

In contrast to other component groups, Group A (operation and maintenance staff) is affected by all the climate factors in this assessment. While tropical storms/depression, tornados and lightning (A7 to A9) can cause injury to the operators and even endanger their lives during work, other factors such as high temperature, heat wave, heavy rainfall or high wind can cause fatigue and affect their performance outdoors.

For Group C, interactions were identified with heavy rain, 5-day total rainfall, tropical storms/depression, high wind and lightning (C4 to C9). Whilst lightning could completely destroy the system, other factors can damage the wires and sensors, cause electric shock, and interrupt the signal transmission.

Finally, though the damages of ancillary infrastructure components (Group D) do not directly impact on the function and operation of the sluices, it can cause loss of property and restrain the working ability of the staff.

5.2. Potential risks for infrastructure components

A picture of the potential risks for the components of the Cai Lon - Cai Be sluice gates under the impacts of climate and hydrological factors is presented in Figure 4. It can be seen that there were no high-risk interactions for both historical and future conditions.

In reference to the colors representing the risk levels, it can be observed that the coverage of low and medium risks was fairly equal under the historical conditions, but the medium-risk coverage dominates under the projected future conditions. In terms of values, historical conditions are dominated by the low-risk interactions (64 compared to 42), while the majority of interactions for future projections are of medium risk (76 compared to 30). This indicates that risks are going to increase under the influence of a changing climate. The increase of the medium-risk interactions from historical to future conditions mainly came from Group B (from 17 to 38 interactions). Thus, these risks need to be taken into account during the detailed design phase of the primary infrastructure components.

Furthermore, the medium-risk interactions for historical conditions were mainly affected by tropical storms/depression, lightning, and high wind. The corresponding variables for future projections were tropical storms/depression, lightning, high wind, drought, water level, salinity intrusion, and salinity intrusion combined with high temperature. As lightning had average probability scores (from 3 to 5) and a significant impact (i.e., the severity scores were mainly from 5 to 7), the measures to mitigate its impacts should be considered in the next phases (i.e., the detailed design, construction drawing design, and operation and maintenance). Besides, salinity intrusion and salinity intrusion associated with high temperature affected the components made of metal and concrete at medium level (from 2 to 4) but had high probability scores (equal to 7). Thus, it is necessary to consider these components at the detailed design phase.

5.3. Recommendations

Based on the analysis in Sections 5.1 and 5.2, the major recommendations for the stages of the detailed design, construction drawing design, and operation and maintenance of Cai Lon - Cai Be Sluice Gate were proposed as shown in Table 2.

Table 2. Proposed measures for climate proofing the infrastructure

Order	Climate risk on infrastructure components	Proposed measures for climate proofing the infrastructure
1	Pillars, ship locks, etc.	To refer to the materials that have been applied for reducing concrete corrosion in Vietnam; for example, using sulphate resistant cement, anti-corrosion additive mixture, or high grade concrete (M50);
2	Hydraulic cylinders, gates, etc.	To study on mechanisms and causes of metal corrosion in the MKD to have the suitable prevention measure such as using a stainless steel as applied to bridges;
3	Pillars, ship locks, hydraulic cylinders, gates, etc.	To consider the use of the high-quality paintings for concrete and metal to prevent corrosion, such as epoxy painting method as recommended by Vietnam Academy for Water Resources and US Army Corps of Engineers (USACE).
4	Operation systems (Group C)	To consider underground wiring designs to ensure safety under thunderstorms/lightning, tornado or in the rainy season, and no splices/cable junctions at risk (i.e. wet) areas;
5	The whole infrastructure	To design lightning protection systems for the whole infrastructure as applied for Rach Chanh sluice gate in Long An Province;
6	Monitoring system	To select SCADA system (sensor) with high tolerance, as experienced in the sluices gate in Tra Vinh Province;
7	Operation and maintenance staff	To have trainings for staff about the climate/hydrological risks on the infrastructure, and how to cope with the extreme events with the low probability scores (e.g., tropical storms and tornado);
8	Operation and maintenance staff	To use protective equipment and clothing as working outdoors under the high temperature, heavy rain, tropical storms, high wind, tornado or thunderstorms/lightning;
9	Operation and maintenance staff	To use the automatic operation mode or choose the time of proper maintenance in the condition of heat wave, for example, in the afternoon when the temperature is reduced.

6. CONCLUSION

This study has completed a climate risk assessment for the Cai Lon - Cai Be sluice gates (basic design phase) using the PIEVC Protocol. This assessment has identified historic and projected representations of climatic variables and phenomena and their interactions with infrastructure and operations associated with the Cai Lon - Cai Be sluice gates. The identified interactions have formed the basis for quantification of probability of occurrence and severity of outcome estimates which has led to the identification of vulnerabilities affected by climate change and the quantification of risk.

Steps 1, 2, 3 and 5 have been included in this assessment. Although Step 4 has not been included in the assessment, the risk matrices obtained from the assessment process present a picture of the potential risks for the Cai Lon - Cai Be sluice gates under the impacts of climate and hydrological factors for both historical conditions and future projections. The commendations to support the stages of the detailed design, construction drawing design, and operation and maintenance of Cai Lon - Cai Be Sluice Gate were proposed based on the analysis of the interactions between the infrastructure components and climate and hydrological factors, as well as their potential risks.

The results of this study are based on applying professional judgment to the assessment of the most current information available within the scope of the Protocol and thus can be used as a guide for future action to inform the detailed design of the Cai Lon - Cai Be sluice gates and similar studies. As this is the first application of the Protocol in Vietnam, the assessment was challenged by some limitations in terms of information and data (e.g., storm surges, waves, water temperature and sediment transport). To allow for analyses like this in the future, which are highly relevant for infrastructure in the Mekong Delta, one vital step would be to increase monitoring and observation activities, making available the required information and data for future studies. This goes beyond climate and hydrological data but also includes the monitoring of impacts extreme climate events are having on infrastructure. Generally, further research into the impacts of climate change and the efforts of Vietnam to enhance its Climate Services will allow future climate risk assessments to provide an even more comprehensive insight into potential climate risks.

In general, the study results proved that the PIEVC Protocol has high potential to apply for climate risk assessment of infrastructures (both planning and existing) in Vietnam, particularly the MKD in the context of climate change - sea level rise. However, the Protocol needs to be adjusted and supplemented to match the actual conditions in Vietnam, as is the case of Cai Lon – Cai Be Sluice Gate to consider the impacts of changing water level and saline intrusion.

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