Full title: Sustainability assessment of flood mitigation projects: An innovative decision support framework

Short title: Sustainability assessment of flood mitigation projects

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Sustainability assessment of flood mitigation projects: An innovative decision support framework

Abstract

Sustainability assessment methods have been emerging around the world, mostly for national or regional level plans, but very few are related to flood mitigation projects. This article proposes a new innovative decision support framework for sustainability assessment (SA) of flood mitigation projects throughout the project life cycle, focusing on two main aspects: sustained flood mitigation by the project, and enabling of sustainable development of the floodplain. This study has employed a review of the life cycle of flood mitigation projects, a review of sustainability assessment methodologies, consultations with experts and case studies involving two flood mitigation projects in Australia. Conforming to the project life cycle, the decision support framework is developed incorporating five stages: 1) contextualizing the project with regard to floodplain sustainability, 2) SA during planning and implementation for integrating sustainability issues in the project, 3) SA during a flood event to assess the sustainability performance of the project 4) SA at periodic intervals, and 5) SA at the stage of modification or changing to a new project. The framework has adopted a multi-criteria analysis (MCA) approach using sustainability criteria and indicators to determine the sustainability index for the project. This paper describes the process of selecting indicators, defining the weightages and scores for indicators, and determines a sustainability index for various stages of the project. This framework will enhance decision making for sustainability of flood mitigation projects. Adapting this framework to projects in other development sectors is also envisaged.

Keywords: Flood mitigation projects; sustainability assessment; decision support framework; project life cycle; multi-criteria analysis.

1. Introduction

Sustainable development of the floodplains is one of the crucial development concerns around the world. Theoretically, sustainable development can be seen as a process of positive biophysical and socio-economic change or creating wealth (capital) that meets the needs of present generation and can be continued indefinitely without diminishing the natural systems upon which it depends or excluding the range of opportunities available to future generations. This is a continuous adaptation process to evolving environmental, economic, and social systems (Sadler et al. 2008; Sadler 2010). Floodplain development and community resilience to flood risk can be improved through landuse regulation and implementing adaptive flood mitigation measures in view of present and future scenarios of climate change impacts and socio-economic development (Dingman and Platt, 1977; López-Marrero and Tschakert, 2011; Schelfaut *et al.*, 2011). Sustainable development in floodplains largely depends on the way flood risks are managed because the flood risk reduction measures, mainly the structural flood mitigation projects (e.g. levee), affect the flood plain ecosystems and livelihoods of the people living in the floodplains. As ultimate goals, the flood mitigation measures should ensure flood risk reduction as well as contribute to the positive improvement of the environmental, social, and economic values of the floodplain. In most cases, structural flood mitigation projects are implemented in response to major flood events, usually

under a post-flood recovery program with funding from a national government or international development agencies. Sometimes these projects lack adequate planning and design as they are conducted in short timeframes due to social and political pressure, which may lead to the projects' failure to attain a desired level of flood risk reduction (DFID, 2005; Schipper and Pelling, 2006), the degradation of socio-economic and environmental conditions, and creating new risks due to unforeseen development (Wamsler, 2004; Luino et al., 2012; QRA, 2012; AAGD, 2013). Hence, planning, implementation and effective monitoring of flood mitigation projects are crucial for reducing flood risk and enhancing positive impact on environmental and socio-economic elements, which will finally contribute to achieve sustainable development of floodplains.

The current planning and implementation process of flood mitigation projects generally emphasizes on the mitigation structures only, and often considers some environmental and socio-economic aspects for selecting the suitable design. Monitoring of only the flood mitigation structures is usually continued over the years, without looking into other environmental and socio-economic aspects of the project area. Long term environmental, social, and economic aspects related to sustainable development in the project area and region are not adequately addressed in the planning process (Environment Agency, 2010; BWDB, 2014; DNRM, 2014; Shah *et al.*, 2015).

Most literature has proposed different approaches for assessing sustainable development of a region or country, with few aiming to assess individual projects at the planning stage in order to choose an option with less negative environmental and societal impacts (Edjossan-Sossou *et al.*, 2014; Dalal-Clayton and Sadler, 2014; Uehara *et al.*, 2016). Some approaches have focused on integration of sustainable development principles and climate change adaptation into planning and implementation of flood mitigation projects (Swart et al., 2014; Huthoff et al. 2016). It is imperative to assess whether the flood mitigation projects are providing sustainable outcome throughout their project life, not only during the planning and implementation stage. Hence, a systematic approach is required to evaluate the potential of sustained flood risk reduction by the flood mitigation project as well as determining the project's influence on sustainable development of the floodplain in every stage of the project life cycle (DEFRA, 2007a). This article proposes a new and innovative decision support framework for sustainability assessment (SA) of flood mitigation projects, and outlines the methodological procedures for applying the framework to projects.

2. Literature review

Sustainability can be defined as the quality of the process of development that can be continued indefinitely for present and future generation. And, sustainability assessment is the process of evaluating the worth, significance or status of a work, an action or a broad or specific course of development activity. This is used to describe a broad field of professional analysis of economic, environmental, and social effects of the development and sustainability implications through integrated approach. The determinants of sustainability of development proposal may be highly approximated as achievements toward (or away from) pre-selected aims or criteria based on accepted principles of sustainable development (Sadler et al. 2008; Sadler 2010).

Sustainability assessment of development programs has been of interest to planners and scientists to determine how they can measure achievement towards sustainable development. An integrated decision making process, as urged by Sadler (2004), can be implemented at different levels of policy making such as micro-level integration (for individual projects), meso-level integration (for policies and programmes), and macro-level integration (national). Recently, several methods have been developed for sustainability assessment at the macro or national level such as an accounting-based approach (e.g. Genuine Progress Index (GPI)), a narrative assessment (e.g. World Bank's World Development Report) and indicator-based assessments (e.g. Dashboard of Sustainability) (Dalal-Clayton and Sadler, 2014). Also, some sustainability assessment tools are available for the meso-level such as a 'sustainability test' for appraising policies, plans and programs (Nelson, 2003), and capital stock based 'Telos' sustainability assessment tools used for provinces in the Netherlands (Knippenberg *et al.*, 2007). The UK government has pioneered an initiative through adopting meso-level sustainability appraisal guidance for regional and local authorities (ODPM, 2005). None of these macro- and meso-level sustainability assessment tools have been linked to the projects at the local level that have a huge impact on the outcome of those assessments.

A few researchers have recently proposed sustainability assessment methods for individual projects. For example, Varey (2004) has proposed an integrated sustainability assessment (ISA) model for appraising development proposals by managers of local government councils. The ISA model includes a simple one-page 'Thinking Tool' that generates a collective score of net benefit and impacts for determining whether the project is accepted or rejected. In case of large infrastructure projects like bridge, Ugwu *et al.*, (2006) have proposed an analytical decision model for sustainability appraisal in infrastructure projects (SUSAIP). This SA process includes a 'weighted sum model' technique in multi-criteria decision analysis (MCDA) and the 'additive utility model' in an analytical hierarchical process (AHP) for multi-criteria decision making. The model produces a "sustainability index" and ranking of alternative design options according to various sustainability indicators.

Similar to infrastructure projects like roads and bridges, most structural flood mitigation projects include large infrastructures such as levees and dams (Kundzewicz and Takeuchi, 1999). Aims of flood mitigation project planning are very different than that of other projects, and require integrated assessment considering present and future environmental, social, and economic issues in the floodplain. So, there must be SA tools explicit to flood mitigation projects. Few initiatives have already been taken to develop SA in the planning of regional flood mitigation projects. Kumar *et al.* (2012) describe a SA process for an urban river corridor re-development project in Sheffield, UK, in which a Bayesian belief network (BN) based integrated model was used to determine the best sustainable scenario. The UK government has recently developed sustainability appraisal guidance for evaluating flood and coastal erosion management related policies, plans and schemes (DEFRA, 2007a). In this approach, the sustainability tool and other several performance indicators such as environmental impact, operation and maintenance, health and safety, and cost risk evaluation have been used to evaluate alternative options for flood mitigation projects in the planning stage only. No further assessment in the post-implementation stages is reported (DEFRA, 2007b).

Overall, it seems that sustainability assessment approaches developed for projects are aimed at selecting the best alternative option; however, there is no instrument to justify whether the selected option will be really sustainable in the long term. It is urged that sustainability assessment should be an integral part of the project planning, implementation, and monitoring process (DEFRA, 2007a). The above discussed assessment methods do not link the contribution of the individual project's outcome to the sustainable development goals of the region or country. Moreover, the current sustainability assessment approaches (Ugwu et al., 2006; DEFRA, 2007a; Dalal-Clayton and Sadler, 2014) do not assess whether the project can fulfill its objectives (sustained outcome) over the project life as well as effect of any modification in the project.

3. Methodology

This study has employed a wide range of methods including a systematic review of current project planning processes and sustainability assessment approaches applied in various fields, a questionnaire survey and consultation with experts, and case studies involving two projects of two regional councils in Queensland, Australia. The case study projects were examined to determine their current planning and implementation process and sustainability issues. A series of consultation with the experts involved in the projects was carried out to explore the positive and negative aspects of the planning process and how sustainability concerns were integrated into the projects. A set of sustainability indicators has been developed through extensive literature review and case studies. These sustainability indicators were further validated by 15 experts working on flood management issues in local councils and consulting firms in Australia, through a structured questionnaire. Based on the project life cycle of flood mitigation projects and current practices, the proposed sustainability assessment framework has been developed. Additionally, a detailed procedure for implementing different stages of the framework has been outlined.

4. Flood mitigation projects: a whole life cycle

Understanding the whole life cycle of a project is essential to identify the sustainability concerns related to the project as well as to determine how sustainability assessment can fit in to the current planning process. Considering various aspects, the whole life cycle of a typical flood mitigation levee project has been delineated (Figure 1) based on relevant literature and the case studies. Some critical concerns in each stage of the project life cycle are illustrated here.

Initiation of project: Flood mitigation levee projects are usually initiated by the flood vulnerable community and the government through the historical legacy of flood management efforts in the floodplains. The project initiation phase may take one to several years (or even decades), depending on the flood damage, demands from the people, scale of the project, detail information on flood risk, and funding required. Private and/or community funded small projects can be initiated quickly. But complexities arise where funding and resources are required from the local and national government.

Figure 1: Whole life cycle of a typical flood mitigation levee project

After taking the initial decision, a feasibility study or project appraisal is carried out consisting of major investigations like flood characteristics analysis based on historical records, defining levee alignment and design options, and establishing the financial viability of the project. The feasibility study may also cover environmental and social impact assessment (EIA/ SIA), and extend to detailed designs of the key project components (DoWR, 2009; Environment Agency, 2010; BWDB, 2014; DNRM, 2014). Currently, a sustainability assessment has remained out of the scope of a feasibility study, project appraisal or any other assessments for flood mitigation levee projects.

The findings of the feasibility study establish the ground for issuing permits by state and/or national development control authorities such as the Integrated Development Assessment System (IDAS) in Australia (DNRM, 2014). Having the necessary permits and funding allocation, the detail planning and design phase starts.

Planning and detailed design: In the planning and design phase, detailed design and layouts of the levee and associated structures are prepared according to the standard design criteria (e.g. design level for flood of 1:100 Annual Recurrent Interval (ARI)) and construction guidelines. In addition to preparing detailed work plan, financial plan, and a draft of the operation and maintenance manual, emergency risk management plan including risk map, evacuation route are often prepared in this stage (Environment Agency, 2010; DNRM, 2014). This phase may take around one to two years depending on the size, location and complexities of the project.

Implementation: Project implementation may take between a few months to several years. Some projects are implemented phase by phase, which may face uncertainty of funding for completing the whole project. Land acquisition and resettlement of existing inhabitants along the levee site might be necessary, which may delay the implementation where there are many disputes. Any major modifications of the levee design (e.g. changing the levee height in consideration of mitigating climate change induced extreme flood events) may delay the implementation as well (CIRIA, 2013). Moreover, although the environmental and social management plan needs to be implemented in this phase (DoWR, 2009; Environment Agency, 2010), this is usually not implemented properly due to ignorance by the implementing agency, and a shortage of funds.

Commissioning, operation and maintenance: At the commissioning stage, like other infrastructure projects, it is important to do a post-implementation review of the levee projects to see their performance; however, this is rarely carried out because it is dependent on the flood event. Operation and maintenance of the levee and associated structures usually continue throughout the project life and beyond, especially after every flood (Environment Agency 2010; BWDB 2014). Currently, post flood evaluation only focuses to the levee structures (Environment Agency, 2010; DELWP, 2015); little or no focus on the flood risk prevails in the floodplain at the time of evaluation.

5. The decision support framework (DSF) for sustainability assessment of flood mitigation projects and the implementation process

The major sustainability issues in flood mitigation projects could be sustained flood mitigation, environmental, social, economic, and policy and institutional aspects (Carter *et al.*, 2009). Some of these have been considered in the planning of flood mitigation projects in recent years in the name of strategic environmental assessment (SEA), EIA and SIA (Varey, 2004). These types of assessments clearly highlight the sustainability concerns of flood mitigation projects, how long the project can provide sustained flood risk reduction to the area and whether the project can enhance the sustainable development of the area or not (DLPE, 2000; IBWC, 2007).

Considering the aforesaid sustainability aspects, this proposed decision support framework for sustainability assessment of flood mitigation projects has been developed with two major focuses: 1) sustained flood risk reduction by the project and, 2) enabling of sustainable development of the floodplain. The proposed framework has been illustrated in Figure 2, which includes components of sustainability assessment at each stage of the project as discussed below. This framework would be applicable to assess

the flood mitigation projects (e.g. levee) in riverine and coastal floodplains. It considers all the environmental, social, and economic elements in the project impacted area, and emphasizes proportionately according to their importance. The framework supports the transformation of objectives and revision of indicators (i.e. adding a new assessment indicator or removing a previous indicator) at different stages of the project life cycle.

Figure 2: Overall layout of the DSF for sustainability assessment of flood mitigation projects

Stage 1: Contextualising the project

At the beginning of the sustainability assessment, we need to contextualize the flood mitigation projects within the floodplain and their linkage to regional development programs. Several studies conducted at the initial stage of the project such as the flood risk management study including hydrological and morphological impacts, project feasibility study, EIA and SIA can be useful for characterizing the flooding pattern and potential impacts of the project (e.g. vulnerable population, flood damage) in the floodplain. The proportion of total flood risk reduction by the proposed flood mitigation

project should be determined as well (Smith, 2013). The uncertainties in the flood events, impacts and flood risk estimation should be taken into account while determining the specific flood characteristics and impacts to be considered for the proposed alternatives of the project (Olbrich *et al.*, 2009; Su and Tung, 2014). Regional floodplain development policies and plans should be reviewed to define the sustainable development objectives, indicators and targets for the region; and these should be related to the main objective of the proposed project. Also, the potential for future development in the project area such as an urban township, agriculture should be identified. Further, the policy and institutional provisions required for planning, implementation and operation of the project should be identified as well. All the above information will help to determine the status of the proposed project with respect to how much flood risk reduction it can provide, and how much it can contribute to the sustainable development of the floodplain.

In addition, a comprehensive list of criteria and indicators for SA of the project throughout the life cycle should be aligned under two sustainability objectives – sustained flood risk reduction and contribution to sustainable development of the floodplain. In this study, a list of important SA criteria and indicators has been developed (Table 1) through verification with the existing literature, case studies of two levee projects in Australia, data availability for the indicators, and consultation with experts. National/ state sustainable development objectives and indicators were given special emphasis to link the project to regional sustainable development. The achievable reference or target value of each indicator should be set at this stage as well, so that the effect of the project on the indicators can be compared quantitatively or qualitatively (Tugnoli *et al.*, 2008). Each indicator can have target value in the form of lowest to highest limit, and the range can be sub-categorized into one of five classes: highly positive impact, positive impact, neutral, negative impact and highly negative impact. Then, a score of 1 to 5 can be assigned to each indicator according to its impact on the project. The scoring would help to generate ordinal numerical values that facilitate aggregation and simplification of the assessment of both the quantitative and qualitative values of parameters (Gafsi and Favreau, 2013). A generic form of scoring the indicators is given in Table 2. The selected indicators at this stage should be used for determining the sustainability index (SI) for the proposed project in the next stages of sustainability assessment.

Stage 2: SA in planning and implementation stage

The actual process of sustainability assessment of the flood mitigation project will start from this stage. Sustainability assessment, at this stage, can be sub-divided into three important phases of the project life cycle (Figure 1) as explained below.

Table 1: Sustainability assessment criteria and indicators

Sl.	Sustainability criteria and indicators	Measuring parameter	Linked to national/state sustainable development
Objective 1: Sustainable flood risk reduction			
Criteria-A. Flooding characteristics change			
A1	Design Flood Level	ARI (e.g. 1:50, 1:100)	
A2	Change of flood level and velocity outside project area in future	Increase/ Decrease (% of flooded area)	
A3	Create new type of flooding (by different causes) in future (e.g. due to heavy rainfall instead of river overflow)	Yes / No	
A4	Change of river morphology due to sedimentation	Change of river bed level (m)	
Criteria-B. Flood damage reduction			
B1	Reduction of damage to critical infrastructures (e.g. hospital/clinic, police, fire service, educational institutes, etc.)	Rehabilitation cost saved (\$)	X
B2	Reduction of residential property damage	Value of properties saved (\$)	X
B3	Reduction of damage to roads and railways	Rehabilitation cost saved (\$)	X
B4	Reduction of damage to utility services (water, power, etc.)	Rehabilitation cost saved (\$)	X
B5	Reduction of agricultural damage	Value of agri-production saved (\$)	X
B6	Reduction of commercial/ industrial damage	Value of production (\$)	X
Objective 2: Contribution to sustainable development of the floodplain			
Criteria-C. Environmental improvement (in the project area)			
C1	Extent of land used for the levee construction	Area (km ²)	X
C2	Use of natural landform to manage flooding in the project area	% of total project area	
C3	Loss (or enhancement) of floodplain habitat (aquatic and terrestrial)	Area (km ²)	X
C4	Creation of new landscape feature other than the levee (e.g. park/ walkway)	Area (km ²)	
C5	Diversion of natural water flow from the flood channel	m ³ /s	
Criteria-D. Social affairs (in the project area)			
D1	Safety of life	No. of flood victims (death)	X
D2	Displacement of people due to levee project	No. of people	
D3	Highly vulnerable population (Child, elderly and autistic)	% of total population	X
D4	Community preparedness for floods	% of HH taken preventive measures	X
D5	Acceptance by the stakeholders	No. of complaints/ conflict raised	
D6	Population growth	% per year	X
D7	Property development areas	Total area of properties (km ²)	X
Criteria-E. Economy (in the project area)			
E1	Project life cycle cost	Total amount (Million \$)	
E2	Resettlement cost of people	Total amount (\$)	
E3	Agricultural production	Value of production (\$) in flood season per year	X
E4	Commercial/industrial production	Value of production (\$)	X
E5	Share of funds from local government	% of total project life cycle cost	
E6	Contribution of local community to O&M cost	% of total O&M cost	
Criteria-F. Policy and institutions (in the region)			
F1	Existence of updated regional and local flood mitigation plan and planning scheme	Yes / No	
F2	Ensured community participation	Yes / No	X

SI.	Sustainability criteria and indicators	Measuring parameter	Linked to national/state sustainable development
F3	Engagement of local professionals in both project implementing agency and the contractors	% of staffs	
F4	Separate institutional unit for the project	Yes / No	
F5	Engagement of local contractors	% of total work	

Table 2: Setting target value and score for each indicator

Sustainability indicators (I_j)	Value of parameter due to impact of a project design option (L_i)	Target value range at baseline scenario	Class of impact	Score for a project design option (L_i)
I_1	$Imp(I_1)$	Tb_1	C_1	$L_{i,1}$
I_2	$Imp(I_2)$	Tb_2	C_2	$L_{i,2}$
I_3	$Imp(I_3)$	Tb_3	C_3	$L_{i,3}$
I_n	$Imp(I_n)$	Tb_n	C_n	$L_{i,n}$

Note: $j = 1, 2, 3, \dots, n$;

$C_1, \dots, C_n$ = one of the five impact classes (highly positive, positive, neutral, negative, and highly negative)

$L_{i,1}, \dots, L_{i,n}$ = a value between 1 to 5 depending on the class of impact.

a. Planning and design phase:

Usually in the planning and design phase, various design options are evaluated considering economic, social, and environmental aspects, and the best alternative design option is selected. Integrating all those aspects, a sustainability assessment of each design option should be carried out using the indicators selected in the previous stage. Every sustainability indicator should be attributed with both spatial (local and regional) and temporal (inter- and intra-generational) aspects of sustainable development. The SI for each alternative design option should be determined using multi-criteria analysis (MCA) techniques (Edjossan-Sossou *et al.*, 2014; Ness *et al.*, 2007) integrating the sustainability indicators.

The process of sustainability assessment of the design alternatives includes three major steps: (a) determining the relevant indicators commonly applicable to all the alternative design options, (b) assigning a numerical weightage value to each indicator to measure the relative importance of the indicators for achieving the sustainability objectives, and (c) computational analysis to determine the SI for each alternative, and ranking of the alternatives. The numerical representation of the sustainability assessment decision matrix is given in Table 3 showing the weightage of indicators for various alternative design options.

The sustainability index (SI_i) of alternative L_i will be estimated using the following formula adapted from the seminal works of Fishburn (1967).

$$SI_i = \sum_{j=1}^n l_{ij} W_j \quad (\text{here, } i = 1, 2, 3, \dots, m; \quad j = 1, 2, 3, \dots, n)$$

The design alternative with the highest SI score will be chosen as the best suitable design option. In addition, the minimum and maximum scores of the SI for the chosen

best option should be determined as limits of SI for the project. The assessment results can be presented graphically as shown in Figure 3. The baseline situation of the chosen best design and its positive and negative impacts should be determined in this phase, which will help to monitor the achievement of the project in future.

Table 3: Decision matrix for sustainability assessment of a levee project

Alternative design options for proposed levee	Sustainability indicators			
	I_1	I_2	I_3	I_n
	W_1	W_2	W_3	W_n
L_1	$l_{1,1}$	$l_{1,2}$	$l_{1,3}$	$l_{1,n}$
L_2	$l_{2,1}$	$l_{2,2}$	$l_{2,3}$	$l_{2,n}$
L_m	$l_{m,1}$	$l_{m,2}$	$l_{m,3}$	$l_{m,n}$

Note: I_j – Sustainability indicator j , W_i – Weight assigned to I_j , L_i – Levee design option i , $l_{i,j}$ – user assigned utility (scalar value) that measures the performance of L_i to achieve/ maintain target of a given I_j .

Figure 3: Conceptual representation of sustainability index of alternative design options

Note that, in the sustainability assessment process, the internal uncertainties related to subjective human judgement for weighing and scoring the indicators should be analyzed to examine on the possible variation and reliability of estimation of SI score for the project design alternatives (Su and Tung, 2014). In addition, sensitivity analysis should be performed for assessing the influence of the indicators to the final SI scores (Edjossan-Sossou et al., 2014). These analyses will help the planners to choose the better alternative design with higher confidence.

b. Construction phase:

In the construction phase, there should only be monitoring of whether the sustainability indicators are in compliance with the SA in the planning phase. The execution of environmental and social management plans should be monitored as well, since these management plans can greatly influence the sustainability of the project. This compliance and the achievement of the project design targets should be reported. If any

changes occur in the sustainability indicator targets because of any modification of the project design, that should be recorded.

c. Commissioning phase:

Sustainability assessment is important in the commission stage because many things can change within or outside the project during implementation, particularly for large projects. Socio-political and administrative changes may greatly influence the project implementation. At present, project completion reports are usually prepared showing the ‘design as constructed’ and some operation and maintenance guidelines. No detailed review or further study is usually done after completion of the project to compare the variation with assessment results found in the planning phase. A detailed post-implementation review of the project needs to be done to specify the finally constructed design, and to determine their influence on the sustainability indicators. Residual flood risks of the project in case of worst case scenarios like flooding higher than the design flood level or failure of the existing levee (by various mechanisms) and its impact on sustainability indicators should also be assessed.

The sustainability indicators used in the planning phase may need to be revised if there is any modification of the project or a greater understanding of them is reached during construction of the project (Table 4). New indicators may be added or existing indicators may be removed. The target and scores for sustainability indicators determined in the planning phase (e.g. Tb_n , $L_{m,n}$) need to be adjusted in the post construction phase (e.g. Tp_n , $PL_{m,n}$), which could mean they are equal or different to the values set in the planning phase. The sustainability index should be re-estimated with the adjusted indicators and scores in the post-construction phase (SI_i at post cons), thus these may also vary from the sustainability index at the planning phase (SI_i at planning) (Table 4). Ideally, it is expected that the SI_i at post construction should be greater than the SI_i at planning phase, as the implementing agency should have the intention to enhance the sustainability aspects of the project during its implementation. The finally established sustainability indicators at the commissioning phase will be used for further SA in the project operation phase (i.e. during a flood event, at periodic assessment) and at the time of modification or changing to a new project (Figure 2).

Table 4: Sustainability index (SI) in planning and post-construction phase

SA indicators	Weightage	Target & Score in planning phase		Target & Score in post-construction review phase*	
		Target	Score	Target	Score
I_1	W_1	Tb_1	$l_{m,1}$	Tp_1	$Pl_{m,1}$
I_2	W_2	Tb_2	$l_{m,2}$	Tp_2	$Pl_{m,2}$
I_3	W_3	Tb_3	$l_{m,3}$	Tp_3	$Pl_{m,3}$
I_n	W_n	Tb_n	$l_{m,n}$	Tp_n	$Pl_{m,n}$
I_{n+1} (new indicator, if any)	W_{n+1}			Tp_{n+1}	$Pl_{m,(n+1)}$
		SI_i (at planning phase)		SI_i (at post-construction phase)	

Note: * New indicators may be added to the SA indicator's list.

$Tp_1, Tp_2, \dots, Tp_{n+1}$: Adjusted target value of indicators in post-construction phase

$Pl_{m,1}, Pl_{m,2}, \dots, Pl_{m,(n+1)}$: Adjusted score of indicators in post-construction phase

Stage 3: SA during flood event

As the actual performance of the flood mitigation project can be observed during a flood event, sustainability assessment should be conducted during such an event starting from the beginning to end of the flood. Presently, only the engineering performance of the flood mitigation structures (e.g. levee and ancillary structures) is assessed in terms of whether they need repair or improvement. However, SA considering all sustainability aspects can give more details of the project performance. The assessment should evaluate the performance of the project during a flood event with respect to targets of sustainability indicators, mainly flood risk reduction (how much damage was avoided) as well as the performance of mitigation measures undertaken to minimize negative environmental and social impacts of the project. This will act as monitoring of the project's sustainability. This assessment will provide a statement of the performance of the project compared to the assessment done in the planning and post-construction phase. Sustainability indicators may need to be adjusted incorporating new or modified indicators into the SA process, considering additional benefits and negative impacts of the project observed during flood. Based on this assessment, additional enhancement and mitigation measures may be included in the project.

Stage 4: SA at periodic intervals

As with periodic monitoring of the project regardless of a flood event, sustainability assessment should be carried out at regular intervals, usually at every five years or ten years matching with the regional development planning cycle. This is because the regional development plan will influence the land use and economic activities in the project area in future. Therefore, in the periodic assessment, how much risk reduction is provided by the project should be estimated. In addition, the positive and negative impacts of the project and changes of environmental, social, and economic issues in the floodplain including the project area (e.g. trend of changing economic activities such as fisheries to agriculture to industrialization, value of properties) should be assessed. It is also important to determine whether the project has facilitated creation of new types of risk (e.g. pollution, internal drainage congestion) in the project area. This periodic SA should deliver a comparative statement of the performance of the project with respect to the SA results in the post-construction phase, and, if required, adjust sustainability indicators based on the impacts observed. It may also suggest revision of the objectives and target of the project, linking it to upgraded sustainable development objectives of regional development plans, if needed.

Stage 5: SA at the stage of modification/ changing to new project

The flood mitigation project may be modified because of failure of the structures or upgrading to withstand extreme flooding. In such case, the sustainability assessment process can again begin from Stages 2 to 4. Often, the current project may be transformed to serve multiple purposes, for instance transforming a levee project to road with levee project. Consequently, the original objectives of the project set in the planning and implementation phase will be changed. This stage of the project could be defined as a 'transition point' to a new project. The project might have a further contribution to flood mitigation and sustainable development of the floodplain. In this case, the SA should be done starting from Stage 1 and continuing to Stage 4 inclusive as if considering a new project.

6. Discussion and conclusions

While integration of the principle dimensions of sustainable development is warranted in every policy and strategy, it is practically unachievable until these are integrated in the decision-making process of individual projects at a local level. Particularly for flood mitigation projects, which might have a local and regional as well as inter- and intra-generational impact, sustainability concerns become crucial (Carter *et al.*, 2009). Decision making for achieving sustainability at the project level is not merely a one-time exercise (as done in the planning phase for most plans and projects); rather it should be a continuous process throughout the life of a project (DEFRA, 2007a). Currently available sustainability assessment approaches have focused on choosing the best suitable alternative strategies or project design with the most positive impact on the environmental, social, and economic dimensions of sustainable development, without detailing further whether the selected alternative could be really sustainable or not (DEFRA, 2007a,b). To overcome these limitations, the proposed decision support framework for sustainability assessment has been developed considering the whole life cycle of a flood mitigation project. The framework can be integrated easily into present project management practices. A similar approach was attempted by DEFRA (2007a,b), however, that was only developed up to the planning phase of flood control schemes.

This study has delineated the sustainability assessment process for every stage of the life cycle of flood mitigation projects, which can assist planners to evaluate the flood mitigation projects throughout their lives as to their compliance with sustainable flood management. As of current practices, the performance of the flood mitigation projects is evaluated based on the level of flood prevention as per construction design (Environment Agency, 2010; DELWP, 2015), without looking into its influence on the environmental and socio-economic condition of the floodplains. The values of sustainability indicators and sustainability index obtained in different stages of the proposed framework can not only provide information on how the project is giving sustained flood mitigation service itself but also indicate how the project is contributing to the sustainable development of the region for present and future generations. The impacts of the project on flood mitigation as well as environmental and socio-economic development in the floodplain will be clearly determined and will help the planners/policy makers in taking decisions for further improvement of the floodplain with a great deal of confidence. In addition, since the framework includes continuous assessment process throughout the project life, the information produced in every stage of assessment will help both present and future generation to rectify any project deficiency and develop adaptive flood mitigation measures in the floodplain for ensuring sustainable development and improving community resilience to flood risk.

This framework has adopted an indicator-based multi-criteria analysis (MCA) method for determining the sustainability index (SI) for the project, as similar methods applied by many researchers (Edjossan-Sossou *et al.*, 2014; Ness *et al.*, 2007). The set of indicators identified in this study could be different for different projects based on where a project is located and what political and social system plays a role in the project. Similarly, the weightage and score for indicators are case specific, subject to change by the decision makers (Mitchell, 1996). This proposed framework does not necessarily provide the best set of indicators and criteria, but rather a credible set which

could readily be used by decision makers. No methodological framework for this kind of multi-criteria based decision making can capture all the complex relationships of the social, environmental, and economic dimensions and all possible project impacts (Helming *et al.*, 2011; Edjossan-Sossou *et al.*, 2014). Therefore, this study proposes a prototype framework that includes simple calculations for planners through an easily accessible conceptual approach. It is up to the decision makers how they will fit in the project purpose and link to sustainable development through incorporating appropriate criteria and indicators. Careful selection of indicators, weightage and score would enhance the reliability and acceptance of the sustainability assessment results. Sensitivity analysis of the weightage and scores of indicators should be performed as well (Edjossan-Sossou *et al.*, 2014), addressing uncertainty of the system dynamics (Olbrich *et al.*, 2009).

Further research is being carried out to implement the framework for case study projects. This methodological framework can be aided by a GIS-based computer program to make it user friendly. Although the proposed framework is developed for the levee projects, it can be introduced to all types of structural and non-structural flood mitigation projects. This framework can even be developed further for projects like road infrastructure, power development and other works.

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