LIFE CYCLE BASED DECISION SUPPORT FRAMEWORK FOR ASSESSING SUSTAINABILITY OF STRUCTURAL FLOOD MITIGATION PROJECTS

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ABSTRACT

Achieving sustainable structural flood mitigation remains crucial in floodplains with increasing flood risks due to rapid urbanisation and potential climate change impacts. A number of sustainability assessment methods has been developed, mostly applicable for national or catchment level plans, but none for individual flood mitigation projects. This paper illustrates a life cycle based decision support framework for assessing sustainability issues in structural flood mitigation projects, focusing on two basic aspects – how the project can ensure sustained flood risk reduction, and how suitably it can contribute to sustainable development of the floodplain. This research has employed an extensive review of existing sustainability assessment approaches, systematic analysis of life cycle of structural flood control projects, consultations with experts and detailed case studies of flood mitigation projects in Australia to develop the framework. This study has identified the sustainability issues of structural flood mitigation projects in terms of sustained flood risk reduction, environmental, social, economic and policy-oriented factors, and institutions related to the projects, which are integrated in the framework. Complying with the project management life cycle, the decision support framework is developed with five major stages, such as – a) setting contexts of the project with respect to regional sustainable development issues; b) sustainability assessment during planning and implementation for ensuring integration of sustainability concerns; c) sustainability assessment during flood event to evaluate the performance and identifying additional sustainability issues; d) sustainability assessment at regular intervals to check the achievement; and e) sustainability assessment at the time of modification/ changing to new project. The process of implementing the framework is also described herein that encompasses methods of analyses of sustainability indicators and multi-criteria analysis to generate conclusive outputs for decision making. This framework will facilitate better decision making for ensuring sustainability of the structural flood mitigation projects and sustainable development in the floodplains.

Keywords: Flood risk, structural flood mitigation, sustainability assessment, project management life cycle, Australia.

INTRODUCTION

Flood risk reduction is crucial for sustainable floodplain development. Among the flood management options, flood mitigation projects are taken as response to major flooding events, usually under emergency recovery programme with financial support from national government or international donors, without having adequate planning. Often these types of projects cannot attain desired flood risk reduction because of improper planning and design (DFID, 2005; Schipper and Pelling, 2006). Moreover, these projects may aggravate flooding problem, environmental and socio-economic degradation, and inefficiency of flood mitigation measures (DEFRA, 2007a; AAGD, 2013; QRA, 2012), and create new types of risks through facilitating unplanned development in the floodplain (Wamsler, 2004; O'Brien et al., 2006). Therefore, effective planning of flood mitigation projects is important for ensuring sustainable development of floodplains. Present planning processes of flood mitigation projects include feasibility study with multiple options in different flood scenarios, designing and implementing the selected option, and monitoring over the project period. Environmental, social and economic issues in the project area are considered in in the feasibility study for evaluating and selecting the suitable option. In some cases, environmental and social management plan are implemented to reduce the negative impacts (Environment Agency, 2010; BWDB, 2014; DNRM, 2014).However, long term sustainability issues of the flood mitigation projects are not adequately addressed in the planning process. There is no systematic approach in the planning and implementation process to assess the potential of sustained flood risk reduction by the flood mitigation projects as well as contribution of the project to sustainable development of the floodplain. This article presents a proposed decision support framework for assessing sustainability of structural flood mitigation projects, and the procedures for implementing the framework. The planners can use this framework as a decision making tool for ensuring sustainability of such projects.

REVIEW OF EXISTING SUSTAINABILITY ASSESSMENT APPROACHES

Sustainable development of a region depends on the collective outcome of the individual projects implemented in the region. In other way, if the individual projects are implemented sustainably, then sustainable development objective can be achieved at the regional and national level. Hence, sustainable assessment of the project is crucial. Sustainability assessment (or sustainability appraisal) is the process of evaluating the value, significance or status of a broad or specific course of development activity. This includes extensive professional analysis of economic, environmental and social impacts of the development project and its sustainability implications through integrated analytical approach *(*Sadler et al., 2008; Sadler, 2010*).* Sustainability assessment can be applied in micro, meso and macro level of policy making (Sadler 2004). A number of sustainability assessment approaches have been developed for the macro and meso-level policies and plans, such as Dashboard of Sustainability; checklist based ASSIPAC sustainability assessment framework for social initiatives (Devuyst, 1999); Sustainability appraisal (SA) guidance for the regional and local authorities of United Kingdom (ODPM, 2005); and Integrated Sustainability Assessment (ISA) developed by MATISSE project (Jager et al., 2008). However, the overall national sustainability objectives can be achieved effectively, if sustainability assessment process is implemented at the individual project level linking to the meso- and macro- level planning.

In recent years, few sustainability assessment methods have been proposed for individual projects. For instance, Varey (2004) has developed a conceptual model for an integrated sustainability assessment (ISA) for evaluating development proposals by the municipal executives and managers of local government councils. This is a simple one-page ‘Thinking Tool’ that has been designed to reflect the psycho-dynamics involved in the integration of conflicting components of projects and various dimensions of sustainability including fundamental sustainability principles - inter-generational and intra-generational equity. This tool will generate a combined score of net benefit and impacts of the criteria compared to thresholds set out for the particular project, and the project will be selected or rejected based on the score. Relating to large infrastructure development such as bridge project, Ugwu et al. (2006) has proposed an analytical decision model for sustainability appraisal in infrastructure projects (SUSAIP). The ‘‘sustainability index’’ and ranking of alternative design options along the various main sustainability indicators were determined by the model.

The physical structures of some flood control projects (e.g. levee, floodwalls) are similar to other infrastructures (e.g. road, bridge); however the objective and planning considerations of the flood control project are very different than others. So, there should be sustainability assessment approach explicit to flood control projects. With respect to flood risk management, very few initiatives are taken to incorporate SA process in the development planning. Recently UK government has adopted sustainability appraisal approaches for flood and coastal erosion risk management (DEFRA, 2007a), which was based on the SA guidance for the regional and local authorities of United Kingdom (ODPM, 2005). This SA approach has been applied to Forres Scheme under the Moray Flood Alleviation programme as a case study. The sustainability tool, along with several other performance indicator assessments such as environmental impact, operation and maintenance, health and safety, and cost risk evaluation, has been applied to evaluate the alternative options (DEFRA, 2007a, b). Kumar et al. (2012) has illustrated a sustainability appraisal process for urban river corridor re-development project implemented in Sheffield, UK. This project has developed an integrated model based on Bayesian belief Network (BN) to integrate the sustainability indicators for comparing different alternative development scenarios and choosing most sustainable option.

It appears that the existing sustainability assessment approaches applied at the project level are aimed at selecting the best alternative option evaluating alternatives with respect to sustainability indicators; however, there is no mechanism to determine if the best selected option is truly sustainable, and whether the project will generate sustained outcome over the project life. Moreover, these SA approaches do not link the contribution of the overall outcome of the individual project to the regional and national level sustainable development goals. Further, the transformation of the project's objectives and outcomes throughout project life could be another issue to be addressed in the sustainability assessment in long term context.

RESEARCH APROACH

The research has applied a range of research methods including review of existing sustainability assessment approaches, consultations with experts and case studies. Detailed case studies of flood control levee projects of two regional councils (Lockyer Valley RC and Moreton Bay RC) in Queensland, Australia have been conducted for defining the current project planning and implementation process through consultation with practitioners of regional councils. Further, the sustainability issues and planning constraints for flood control projects have been revealed through the case studies and consultation with experts. Based on the initial findings, the sustainability assessment framework and implementation procedures have been developed.

RESULTS

Life cycle of flood control projects

In general, the project planning and implementation approach for flood control projects is similar to other engineering infrastructure projects like road, bridge. However, the project initiation and planning phase is quite complex for flood control structures than other similar project. Because the flood control projects often covers multiple purpose including flood mitigation as well as facilities for road communication or water reservoir for urban water supply. Also, flood control project are related to many environmental and social factors in addition to the economic and engineering factors. Based on literatures and case studies in Queensland, a typical life cycle of flood control levee project has been described here that will give a clear picture of complexities in such type of infrastructure projects (Fig. 1).

(a) Project initiation/ definition phase: The initiation of flood control levee projects is usually based on the legacy of the flood management efforts historically taken by experienced flood vulnerable community and the government. Generally government

authorities, either local or national, take initiative to implement the levee projects. Private land owners may also take initiative to construct levees to protect their large farmlands from floods.

Initial decision for levee project leads to conducting feasibility study or project appraisals of the project consisting of major investigations such as reviewing existing geographical and socio-economic condition of the area, analyzing flood characteristics, assessment of existing flood control schemes operating in the area, possible location of the levee, engineering design options, and assessment of flood damage reduction by the project. Feasibility study may include environmental impact assessment (EIA), social impact assessment (SIA), and probable impact on the flooding in other part of the catchment is covered in the feasibility study. Often, feasibility study may end up with establishing design criteria and planning concepts, preparing project layouts, engineering designs and drawings of relevant project components (DoWR, 2009; Environment Agency, 2010; BWDB, 2014; DNRM, 2014). The sustainability assessment of the levee project is still remained out of scope of feasibility study or project appraisal of flood control levee projects.

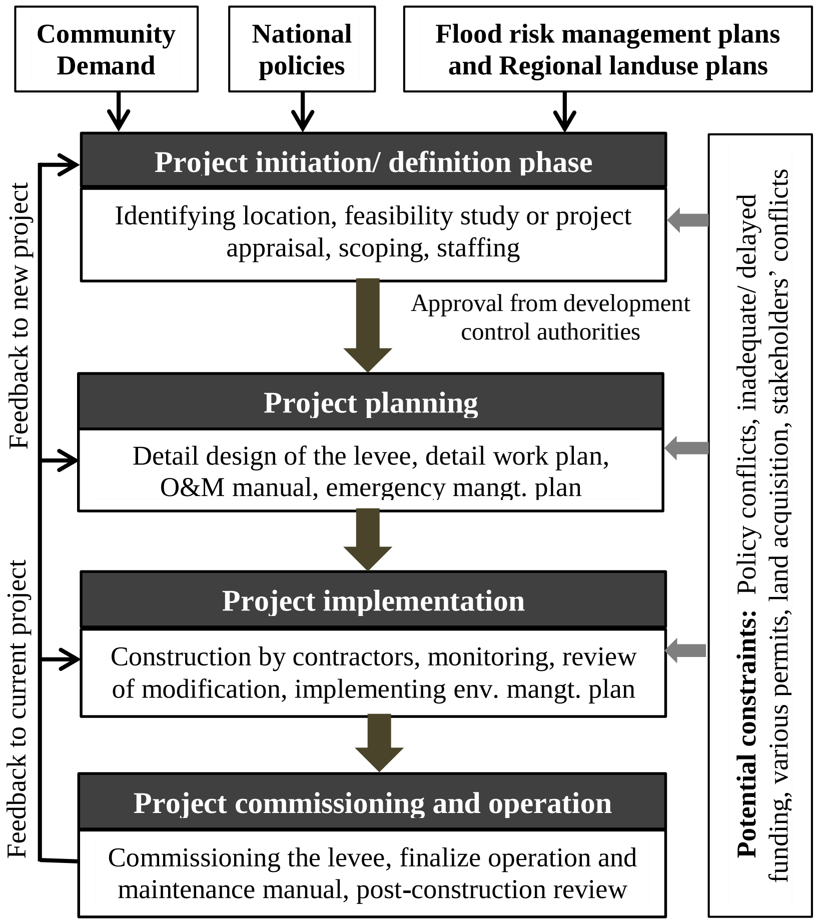

Figure 1: Life cycle stages of a typical flood control levee project

The results of the feasibility and other assessments provides basis for issuing clearance permits by the development control authorities, as for example, the levee projects are approved by the IDAS system in Australia depending on the size and category of the levee (DNRM, 2014). Completing necessary permit procedures, funding arrangements as well as establishing project team for the project in the initiation phase, the project enters into planning phase.

(b) Project planning phase: In the project planning phase, detail design of the levee and associated structures is prepared following engineering construction guidance and standard practices. According to the detail design, task scheduling, resource plan, financial plan, risk management plan are prepared. An operation and maintenance manual for the project can be drafted at this stage, and finalized at the closing stage of the project. Further, since there is chance of levee failure, an emergency management plan need to be prepared for the community detailing potential risk map, emergency warning communication, resource requirements, evacuation route, shelters, and health and safety risks (DNRM, 2014).

(c) Project implementation: The implementation of the projects starts with appointing contractors for constructing the levee. Monitoring and quality control of the construction is carried out by the consultants appointed by the implementing agency. Any modification or changes in the design or construction materials are reviewed and approved by the implementing agency. In addition to the construction, the environmental and social management plan should be implemented at this stage (DoWR 2009), which is often ignored by the implementing agencies due to lack of funding and inappropriate project plan.

(d) Project commissioning and operation: Like other infrastructure projects, after implementation of the project, the levee and associated structures are commissioned and project documents are handed over to the implementing agency. The operation and maintenance manual is also finalized at this stage. The levee and associated structures operates when there is flood. Post-implementation review of the levee projects is very important, which is rarely done, as it depends on the next flood event. After a flood event, damage and maintenance requirement for the levee to withstand future flood load is assessed rather than assessing the effectiveness of the levee to reduce present and future flood risk. Feedbacks from the post flood evaluation are incorporated in maintenance of the current project as well as designing new projects.

Various constraints like policy conflicts, inadequate/ delayed funding, delayed permission, delayed land acquisition, and conflicts among the stakeholders may interrupt timely planning and implementation of the project (DoWR, 2009).

Proposed decision support framework (DSF) for sustainability assessment of flood mitigation projects and implementation procedures

Sustainability of flood control projects are closely linked to various environmental, social and economic factors in the project area (Carter et al., 2009). Although sustainability assessment has not been applied yet, key aspects of sustainability (environmental, social and economic components) has been considered in the planning, implementation and monitoring of flood control projects in the past in the name of strategic environmental assessment (SEA), environmental impact assessment (EIA) and social impact assessment (SIA) (Varey, 2004). All these assessments highlight the sustainability issues of flood control projects, and how the project can contribute to enhance the sustainable development in the floodplain (IBWC, 2007; BWDB, 2013; MAFWM, 2014). It is also important to assess how long the flood control project can provide sustained flood risk reduction to the area. The key sustainability issues in flood control projects could be aligned in the following aspects: (a) sustained flood mitigation (e.g. functioning of flood control infrastructures); (b) environmental aspects (e.g. reducing loss of floodplain habitats); (c) social aspects (e.g. employment); and (d) economic aspects (e.g. reduction of flood damage). Considering the sustainability issues, the proposed decision support framework (DSF) for sustainability assessment of flood mitigation projects has been developed focusing on two main aspects – sustained flood risk reduction and contribution to sustainable development of the floodplain. The following sections have broadly outlined the proposed framework

(Fig. 2) including components of sustainability assessment for all stages of the project life cycle.

Step-1: Setting contexts of the project

The sustainability assessment process begins with setting the context of the flood mitigation projects within regional floodplain development programmes. Flood risk management study, feasibility study, environmental and social impact assessment conducted for the proposed projects can be used for defining flooding pattern and potential impacts in the project area. For example, baseline information like flood vulnerable population living in the project area, agricultural production, recent flood damage occurred, and potential flood damage that can occur in different flood scenario should be in the baseline context of the project. The proportion of total flood risk reduction by the proposed flood mitigation project should be determined. The sustainable development objectives, indicators and targets for the region should be defined through reviewing the regional development policies and plans; and should be related to the main objective of the proposed project. Also, the future development potential for township, commercial area, agricultural, and environmental protection should be identified in the project area. Adequate information on the above concerns will assist to set the context of the proposed project with regards to flood risk reduction and contribution to sustainable development of the floodplain within local and regional perspectives.

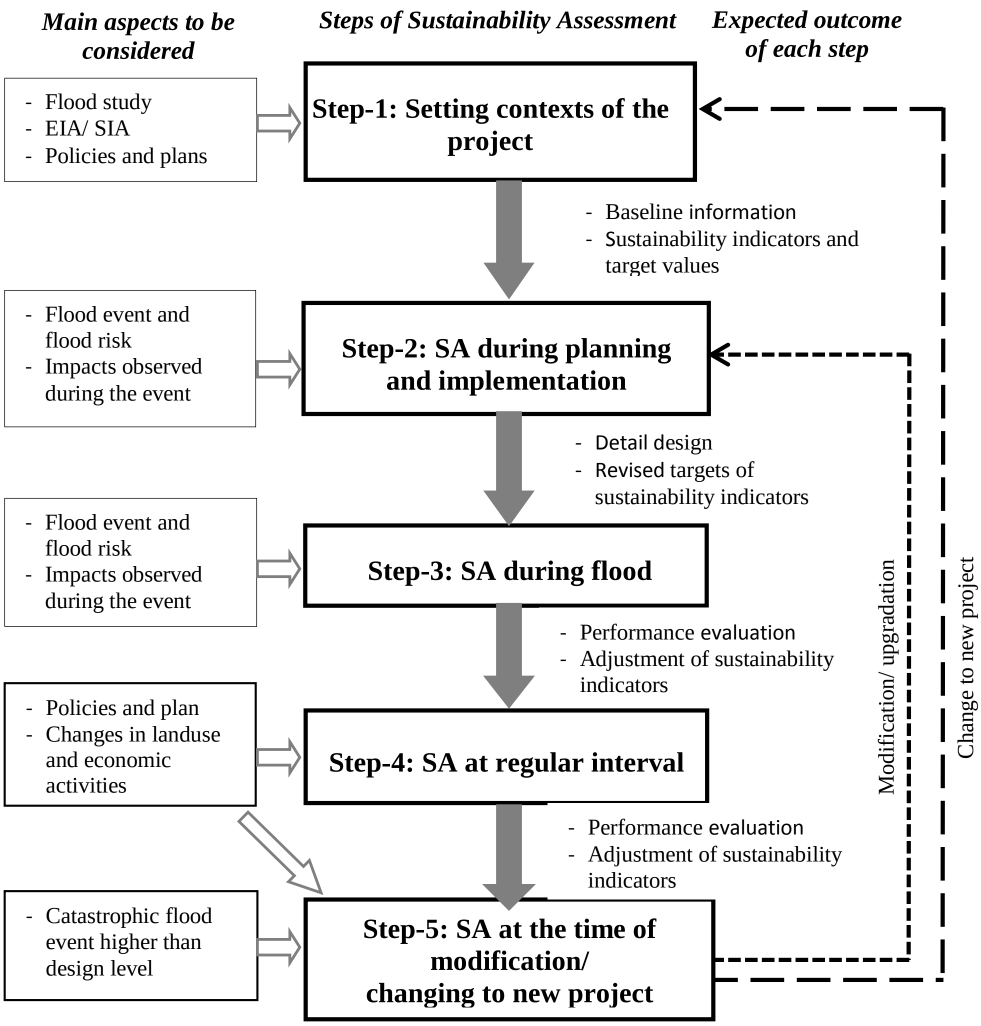

Figure 2: DSF for sustainability assessment of flood control projects

Considering the important aspects of the project, a set of sustainability assessment criteria, indicators and their target values should be defined. An example of the sustainability assessment criteria and indicators, developed through case studies, literatures and consultation with experts, is outlined in Table 1. The criteria and indicators were selected in line with three pillars of sustainable development (environment, social affairs and economy) along with sustained flood risk reduction objective. These indicators will be used for multi-criteria analysis in next steps of sustainability assessment.

Table 1: Sustainability assessment criteria and indicators

Sl.	Sustainability criteria and indicators	Sl.	Sustainability criteria and indicators
Objective 1: Sustainable flood risk reduction			
A	**Flooding pattern**	**B**	**Flood damage**
A1	Flood level	B1	Agricultural damage
A2	Change of flooding outside project area	B2	Commercial/ industrial damage
A3	Creating new type of flooding	B3	Residential property damage
Objective 2: Contribution to sustainable development of the floodplain			
C	**Environment**	**E**	**Economy**
C1	Loss of habitat for aquatic life	E1	Project life cycle cost
C2	Loss of habitat for terrestrial animals	E2	Cost for EMP
C3	Fragmentation of habitats	E3	Employment rate
C4	Construction waste generation	E4	Agricultural production
C5	Facilitating env. pollution (air/ water/ noise)	E5	Commercial production
D	**Social affairs**	E6	Property value
D1	Displacement of people (direct/ indirect)	**F**	**Policy and institutions**
D2	Safety of life	F1	Regional and local plans
D3	Property development areas	F2	Institutional unit for the project
D4	Population density	F3	Fund allocation for the project
D5	Occupation diversity	F4	Ensured community participation
D6	Housing density		

Step-2: Sustainability assessment during planning and implementation

Sustainability assessment should be conducted during planning, construction/ implementation and commissioning of the flood control projects. Sustainability assessment at planning stage is similar to the approach applied by DEFRA (2007b), but the assessment indicators are different. At the project planning stage, different design options will be assessed with sustainability assessment indicators, such as flood risk reduction (present and future), impacts on environment, society and economy, possibility of modifying the project objective (e.g. levee to levee cum road), etc. Multi-criteria analysis (MCA) techniques (Ness et al., 2007; Dalal-Clayton and Sadler, 2014) will be used for integrating the quantitative and qualitative indicators for comparing the alternative project designs in different scenarios. The process of sustainability assessment of different design alternatives includes three steps: (i) determining the relevant sustainability indicators and alternative design options, (ii) assigning numerical values (i.e., weights) to measure the relative importance of these indicators for a given alternative design option, and (iii) processing the numerical values to determine the ‘‘sustainability index’’ and ranking of alternative design options along the various sustainability indicators. The general sustainability assessment decision matrix that could be applied in this method is given in Table 2.

Table 2: Sustainability Assessment decision matrix

Design options for proposed levee	Sustainability assessment 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	$l_{m,1}$	$l_{m,2}$	$l_{m,3}$	$l_{m,n}$

Key: I_i – Sustainability indicator *i*, W_i – Weight assigned to I_i, 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_i.

The sustainability index (SI_i) of alternative L_i was calculated using Equation 1, adapted from the seminal works of Fishburn (1967).

$$SI_i = \sum_1^n l_{ij} W_j \quad \text{(for i = 1, 2, 3….. m; j = 1, 2, 3……n)} \qquad (1)$$

The sustainability index (SI_i) for each alternative will be compared to the possible maximum SI score, estimated with the maximum target value of indicators. The best suitable design option of the project, having highest SI score, will be selected for implementation. The baseline of the best design and expected benefits, that are to be monitored in future, will be determined in this stage. Monitoring construction of the project, and execution of environmental and social management plan should be carried out with respect to the sustainability indicators.

A post-implementation review will set the design specifications of the finally constructed project and level of potential flood risk reduction. Residual flood risks in worst case scenario and its' impact to sustainability indicators should be assessed as well. The list of sustainability assessment indicators may be revised due to modification or detail understanding during construction of the project (Table 3). The target and scores for the indicators in the planning phase (Tb_n, $l_{m,n}$) can be equal or different to those of the post construction phase (e.g. Tp_n, $Pl_{m,n}$). Accordingly, the sustainability index may also vary from planning phase (SI_i at planning) to post construction phase (SI_i at post-construction) (Table 3). Ideally, the SI_i at post-construction should be higher than the SI_i at planning phase, which would indicate achievements towards sustainability. The final set of indicators will be used for further sustainability assessment in project operation phase.

Table 3: SA indicators and 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	$Pp_{m,3}$
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)	

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

Step-3: Sustainability assessment during flood event

Actual performance of flood mitigation project is effectively visualized during flood events. Therefore, sustainability assessment should be conducted during flood event to evaluate the performance of the project with respect to targets of sustainability indicators, mainly flood risk reduction (how much damage avoided) as well as the performance of mitigation measures undertaken to minimize negative environmental and social impacts of the project. This assessment will provide comparative statement of the performance of the project as well as recommend for improvement of the project.

Step-4: Sustainability assessment at regular intervals

Since the socio-economic development of the project area will change over time, sustainability assessment should be carried out at regular interval, regardless of occurrence of flood event. The interval could be every five or ten years, matching with the regional development planning cycle to include the changes of potential flood risk due to changes of the landuse and economic activities in the project area. The benefits and negative impacts of the project, change in environmental, social and economic issues, particularly whether the project has facilitated creation of new risks (e.g. internal drainage congestions) in the project area should be assessed. This periodic assessment will provide comparative statement of the performance of the project, as well as revised objectives and target of the project with respect to upgraded regional development plans.

Step-5: Sustainability assessment at the time of modification/ changing to new project

There may be modification of the flood mitigation project due to upgrading the project to prevent higher flood, or, adding new component to the current project (e.g. transforming levee to road-cum-levee project). Therefore, the main objective of the project will be changed and more extended outputs will be expected. This stage of the existing flood control project could be termed as ‘end of project’ or ‘transition point’ to new project. The contribution of the project to regional sustainable development will be further enhanced and therefore, new assessment should be carried out. In case of upgrading the existing project, the SA process can start again from Step 2 to 4. Otherwise, while adding new component to the existing project, the SA process will start from the Step 1 to 4.

CONCLUSIONS

Sustainability assessment of flood mitigation would be necessary to integrate the impact of such projects on the river basin and regional developments for ensuring regional sustainable development. The proposed decision support framework for sustainability assessment presented here will assist the planner for better decision making considering the local and regional sustainability issues. The framework has been developed conforming to the existing project management cycle practiced in development projects, and therefore, the framework could easily integrated to the current project management process. This framework will benefit the planners for tracking and evaluating the flood control projects throughout its life as to its compliance with the sustainable flood management. It will enable well-informed decision making for ensuring sustainability of the flood mitigation projects and sustainable development of the floodplains for present and future generations. The proposed framework is applicable to the flood control levee projects to be implemented in riverine and coastal floodplains. Finding appropriate measurable indicators and their values could be challenging, and this could limit the reliability of the expected outputs of the sustainability assessment. This conceptual framework will be further developed through practical implementation to case study projects. Further research is required how to integrate the findings of the project level sustainability assessment to the regional catchment level floodplain management. This framework can be further developed to make it applicable to all type of projects.

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