A State-of-the-Art Review of Flood Risk Assessment in Urban Area

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Abstract. Flood risk management has become more significant in the face of rapid urban development and the climate change. Many governments and the decision makers have recognized the requirement of resilient flood management policies and strategies for sustainable urban development. During the recent decades, various conceptual framework of flood risk assessment and management emerged and they in turn questioned the characterization of resilience in flood risk management. More recently, research on flood risk management and spatial planning have demonstrated a common discussion platform appreciating the concept of flood resilience in policy and strategy making. However, assessment and operationalization of flood resilience is often questionable due to its conceptual vagueness. The present work is a review of the plurality views of flood resilience. Resilience thinking has moved the focus of flood risk assessment towards vulnerability. Flood resilience embeds the incorporation of spatially distributed land use policies and regulations which are a must for the management of flood vulnerability. Spatial planning reflecting flood resilience becomes vital when managing the uncertainty incorporated with flood risk management. However, the operationalization and legitimacy of the importance of the combined role of spatial planning and flood risk management with stakeholder acceptance still remains implicit and weak.

1. Introduction

Flood damages are consistently rising, and flooding is a significant and a worsening disaster for many societies. Climate change predictions forecast an increase of extreme events in the future. Every government annually allocates large amounts of public funds for flood control structural measures. Recently, many parts of Asia experienced an extreme flood damage that hinted the structural flood control measures are insufficient to provide a resilient solution. Thus, there is a worsening stake with respect to floods, which demands early attention of decision makers for a resilient solution [1,2,3]. The main objective of the resilient flood management system is to enable a region to function sustainably at present, and in the future, despite the disturbances of flood occurrences. Thus, the flood management strategies should focus on improving the floodplains for greatest benefits of society, considering the socio-economic development in long term perspectives. Therefore, flood risk assessment should provide a rational basis for decision making in flood risk management and planning [4, 5]. The understanding of resilience in flood assessment and management has improved over the years. Still, there is a knowledge gap with respect to the assessment of flood resilience and hence its operationalization [6, 7].

2. Objective and the methodology of the review

This article reviews how the general notion of resilience has evolved over the period of time and the current knowledge gap in the flood risk assessment. The application of resilience in the traditional and contemporary flood risk assessment was critically evaluated by considering the conceptualization of flood risk in order to propose a way forward. The peer reviewed publications in the past decades which covered the subjects of flood risk assessment, flood risk management and spatial planning had been evaluated.

3. Review

This review is mainly focused on understanding how the uncertainty associated with flood risk has been considered in the assessment process, and how the consideration factors of flood risk assessment have changed over the period of time. Accordingly, the paper examines how segmented planning and flood management has focused towards the amalgamation of flood management and spatial planning with time. Moreover, it examines how spatial planning, as a collaborative planning tool has become vital when managing the uncertainty incorporated with flood risk.

4. Segmented flood management and spatial planning

4.1 Flood management

Before 70s, most often, floods have been framed solely in terms of the water system. However, the vulnerability perspective shifted the attention towards consideration of interactions between both physical and social systems for flood risk assessment

4.1.1 Tradition of urban flood management and role of spatial planning. In the early periods, the central governments focused on controlling flood losses by reducing the flood hazard, mainly with flood control infrastructural measures. Urban flood management systems were designed mostly in a 'technical way' with an emphasis on getting rid of water from urban areas as soon as possible. Flood managers were focused on increasing the efficiency of flood protection and did not consider the values and the potentials of the floodplain conservation. The floodplain land use development mainly relies on flood control infrastructure which was poorly prepared in the case of extreme floods. Around 1950s, it was realized that the structural measures were not fully effective in the face of flooding episodes. As a result, spatial planning controls were also incorporated in the flood management [8]. Spatial planning policies and strategies were also designed to reduce the flood hazards by controlling the behaviour of community, by mainly restricting the development of floodplains. However, during the earlier periods, the policies and regulations of water sector and spatial planning sector functioned in fragmented and disconnected government frameworks [9]. Flood management had been the responsibility of water managers who held a dominant position in the state water management administration [10].

4.1.2 Governing Factors, Assessment and Methods. Traditionally, the flood risk has been characterized based on the probabilistic approach. The extreme events have been considered as arise from a serially independent time series with a probability distribution pattern and therefore, the parameters of flood events are considered as fixed over the design life of infrastructure measures [11, 12, 13]. The probabilistic approach has considered that the flood events in the future are predictable, based on the experience of the past. The probabilistic approach has defined the flood risk under the stationary hydrologic conditions. However, there was a widespread acceptance that most of the hydrologic processes exhibit nonstationary behavior due to changes in land uses, climatic conditions, and water management infrastructure [14]. Traditionally, flood risk assessments had focused on the direct damages which can easily measurable with monetary terms [5,15,16]. Nevertheless, there had been awareness on damages which occurred beyond the actual event of flooding which affected in a wider area, in space and time than those directly involved in a hazard zone [17, 18]. Flood risk assessment poses difficulties when accounting secondary economic impacts such as long term intangible disruptions to economic chains, which are elusive to quantification [19]. The traditional flood risk assessment did not recognize all damage dimensions including the social, political, economy and environmental characteristics of the flood impacts. Therefore, it could not obtain a comprehensive picture of flood damage [5].

Flood control structural measures were designed to resist to the flood consequences from specific flood events. Traditional flood risk assessment had treated both low-probability and large consequence risk as well as high-probability and small-consequence risk are as equals in monetary terms [20]. There had been awareness that at any given time, flood impacts cannot be predicted with certainty because of the uncertainty in both hazard as well as the consequences [21]. Thus, reducing the probability of flood risk with structural measures incorporated with rules of thumb designs was inadequate in the face of event uncertainties [22, 20]. Moreover, effectiveness of the traditional flood risk assessment has been questioned in the face of climate change and the fast changing socio economic systems in urban areas. Thus, reducing the probability of flood risk with structural measures incorporated with rules of thumb designs was inadequate in the face of event uncertainties [22]. Moreover, flood control structural measures were criticized by decision makers due to the ill consideration of natural and social system dynamics and hence creating of false sense of security [23].

Further, the traditional flood damage assessments had not been adequately addressed the interests of all the stakeholders. Flood damage assessment did not address the entire range of human responses. There was a difficulty to accommodate social needs and social justice in the decision making of flood risk due to the absence of a clear interpretation of the uncertain information that is related to its probabilities and consequences. Therefore, traditional flood risk assessment had been labelled as biased and incomplete due to neglect of public perception on different thresholds, inadequacies in handling the spatial distribution of flood risks and the benefits from mitigatory measures [24, 25,26]. There had been awareness that at any given time, flood impacts cannot be predicted with certainty because of the uncertainty in both hazard as well as the consequences. There was a difficulty to accommodate social needs and social justice in the decision making of flood risk due to the absence of a clear interpretation of the uncertain information that is related to its probabilities and consequences.

4.1.3 Need for spatial planning and stakeholder concerns in flood risk assessment. The potential of flood damage arises due to the increase of floodplain development and increasing the ownership of properties on floodplains [27]. It has been recognized that the magnitude of the flood consequence is influenced by the inherent vulnerability of the receptor and their value which places by the society. Consequently, it has highlighted the importance of understanding the characteristics of the environment and society, that makes them susceptible to flood damage rather than investigating the nature of hazards. Moreover, the decision makers have questioned the reasons for the actual flood damage or the role of vulnerability in determining natural hazard risk levels. In this alterative conceptualization, vulnerability of exposed elements of the socio economic and ecological system became considered as the keys to determine whether the hazard would be converted into a disaster ([28].

Further, flood vulnerability has been considered as an evolving phenomenon and the physical nature of floods and the socio-economic factors are important for deciding the vulnerability of flood prone populations, properties, etc. Flood vulnerability of a community or a location, is considered as a complex which is governed by multi-dimensional factors such as economic, social demographic, political, etc and processes which are influenced at multiple scales and levels [29, 30]. Therefore, management of flood vulnerability has commenced the discussion with a holistic approach considering the dynamics of complex interactions between social and physical systems. Assessment of flood vulnerability faces difficulties due to its multi-faceted and dynamic nature. It has been recognized that the flood vulnerability is difficult to understand and model, mainly due to the complex and dynamic interactions of social, ecological and physical processes [31]. Many frameworks have been proposed to assess vulnerability of physical structures assuming a homogeneous social vulnerability and coping capacity for the entire population as well as place. Moreover, flood vulnerability was mainly assessed quantitatively using the multiple attributes and have neglected the inhomogeneity of multiple attributes. In addition, the flood vulnerability assessment greatly hinders, from making a reasonable assessment due to the neglect of high dimensional, nonlinear relationships among land water and people [32]. Moreover, it has been recognized that the historical experiences and knowledge have become less valuable when attempting to predict those complex interactions related with flood vulnerability [33, 34]. Therefore, assessment and management of flood vulnerability has been also recognized as a challenging task.

4.2 Spatial Planning

Decision makers have realized that the exact prediction of flood damage is impossible due to uncertainties associated with the hazard variabilities. The perspective of resilience has shifted the flood risk assessment from technical flood protection towards more holistic flood risk assessment, emphasizing spatial planning as a mean to reduce the vulnerability.

4.2.1 Tradition of role of spatial planning in flood risk management. In the early periods, water was considered as a technically controllable and adaptable element in spatial planning, and hence the flood control infrastructure measures became the key factor which strongly contributed to the concerns of a built environment. The measures of spatial planning were not recognized for management of flood vulnerability [35]. In many countries, spatial planning was a component in the sector planning hierarchy. This compartmentalization has mainly prevented the integration of spatial planning and flood management [9].

4.2.2. Governing Factors, Assessment and Methods. Traditionally, spatial planners were also continued to assume that the flood conditions with certainty. The flood control planning measures were also based on the engineering considerations of flood events and systems. Hence, the designing of spatial planning measures was also based on static limits of floodplain development, and such measures could cope up with only certain flood events [36]. Spatial planning practices were discouraged incompatible land uses in flood prone areas by applying these controlling measures [37]. The flood risk was mainly assessed using the economic criteria and most often, the priority was given for the economic uses of floodplain instead of conservation of environmental values of flood plains such as the reservation of large areas for water retention. By examining the performance of land use management programs in protecting flood plains, it has argued that the factors which stimulate the adoption of flood plain land use management programs, also stimulate the encroachment on the hazard area, which in turn limits the effectiveness of flood management programs [38].

4.2.3. Component of Flood Management in Spatial Planning. Meantime, the flood management approach focused towards alteration of all three factors of flood risk such as the hazard, exposure, and vulnerability. This emphasis in flood risk management is upon reducing harmful outcomes, rather than prescriptive approaches in responding to particular flooding mechanisms. This understanding has highlighted the organization of floodplain land uses according to the hazards levels of floodplain, and coherence with the natural environment [39]. Operationalization of flood resilience means the ecological integration and the utilization of synergies between land and water It has been underlined that the flood management strategies should not stand alone and that should be considered in broader socio-economic development [40] and the context of other river functions [41].

Thus, the flood risk management should highlight the performances of whole system rather the merely considering each part in isolation. The importance of consideration the consequences of certain measures for various flood events instead of specific probability of return period highlighted [42]. Accordingly, they have pointed the consideration of uncertainty about external pressures, specifically climate change for designing of sustainable flood risk management policies and strategies in urban areas. In the beginning, spatial planners misconstrued the complex and dynamic nature of flood risk. However, in 1990s, spatial planning process also started to transform, showing a high emphasis on spatial integration, which means creating an added value or coherent outcome on a space by joining different spatial claims of stakeholders, land uses and functions [43]. In this circumstances, spatial planning has transformed as a process that organizes the physical space, coherent from both sector and multi-sector points of views, and can withstand the unexpected circumstances [44]. Accordingly, spatial planning process focuses to ways which can mitigation as well as adaptation of floods [45]. Moreover, spatial planning focuses for the alteration of the physical landscape and the activities that take place in the physical landscape, based on the demands and requirements of the diverse stakeholders of the society highlighting the sustainable development. Thus, spatial planning has become a process which controls the spatial transformation considering the concerns and objectives of diverse groups in the society. Accordingly, consideration of assessment and management flood risk became main components of spatial planning process.

4.2.4 Need to incorporate Stakeholder Concerns. The notion of resilience has pointed that the social systems of floodplains are evolved with the natural system rather than separately, and therefore it has highlighted the ecosystem services in managing the flood risk. This thinking of socio ecological systems, contributes to avoid the artificial division between a physical and a social system, is emphasized in flood risk assessment [46. 47,48]. Further, this understanding promotes to conceptualization of the unique characteristics of floodplains which can enable the urban development to thrive in a sustainable manner, in flood risk management. Hence, flood risk management has demanded the acknowledgement of co - evolutionary nature between land and water, and maintaining more flexible boundaries in flood risk assessment [49]. As a result, the understanding of flood management options has broadened within the boundaries of the land and water systems [50, 51].

In this context, the main focus of flood risk assessment should be to select the options which optimize the multiple objectives of stakeholders, in the face of uncertainties associated with floodplain land uses and urban floodplain functionality. Stakeholders have commenced to question the trade-offs between the interactions related to land and water in decision making. Recognition of different spatial claims voiced by different stakeholders at different scales has become a pressing challenge in flood risk assessment. As a result, decision makers raise the requirement of a common understanding of flood resilience, in flood risk assessment. The notion of resilience underlined the need of having a desired common goal to stakeholders on floodplain land uses with a long term perspective [51]. Moreover, the assessment of uncertainty incorporated with flood risk, has become a challenging task in resilient flood management. Therefore, when resilience is used to analyse socio ecological systems, three main questions have been raised, (1) what are the objectives of the flood management system?', (2) who should be considered, and (3) what are their roles? [52]. As a result, the practical meaning of the "flood risk management system" has been questioned.

5. Amalgamation of flood management and spatial planning

5.1 Evolution of an Amalgamated Concept

The natural and social systems related with flood risk are coevolved together means that these two systems are interdependent rather independent. Small change on either natural system including the hydrological or ecological system as well as social system in a flood risk system, results in a non-proportional change in the dependent variable, or threshold effects occur. The boundary conditions of the flood risk system, change temporally and spatially. As a result, it is difficult to analyse these dynamics, their thresholds of transformations [53]. Moreover, the prediction of emergent properties of the flood risk system is difficult, due to inevitable uncertainties which incorporate with both hydrological, ecological and social system [54, 55]. Therefore, the presence of different perceptions among stakeholders is unavoidable in flood risk management. Moreover, the uncertainties connected with flood risk is provided a platform for framing of 'flood risk management system' including the objectives, strategies, stakeholders and their roles in different ways. In this circumstances, the decision making process demands integration of stakeholders in order to facilitate the co-production of knowledge for coping with these uncertainties. Further, integration of different knowledge of stakeholders or the combination of technical views together with social views in flood risk assessment and management have been highlighted. Due to this understanding, the role of spatial planning has changed and has become more significant in the face of flood resilience. There is a growing recognition of the application of spatial planning in flood risk managements. However, operationalizing of flood resilience and the cooperation between water managers and spatial planners, is still not a common practice.

5.2 Spatially Distributed land use Policies and Regulations

Traditionally, the frameworks developed for flood risk assessment were not recognize these nonlinear dynamics among social and natural systems, and spatial temporal relations [56]. As a result, the spatial planning policies and the regulations could not accommodate the safeguarding of the wellbeing of the particularly urban poor, and failed to break vicious cycles of flood risk which is common in most of cities in the global south. Therefore, most often the environmental costs are remained external to the developers and created the tension between floodplain conservation and floodplain urban development. The societies have undergone rapid spatial transformations without improving, their capacities to manage the environmental feedbacks [57]. However, intensification of the flood risk, urban areas will increase at a higher rate in the coming decades. The majority of the population growth will take place in urban areas. This rapid urban population growth will increase the land demand for the growth of residential areas, infrastructure, industries and recreational areas. This increase of the development pressure and rapid spatial transformation will increase the overuse of the floodplains due to the land scarcity in urban areas in future scenarios. The impacts of the flood, vulnerability including resilience capacity are unevenly distributed over the catchment areas. Deficiencies of understanding these interactions, and their spatial dimensions, may lead towards preconditions for experiencing flood vulnerability. Designing of spatial policies and regulations process requires to foreseeing these social, hydrological, ecological interactions, as well as their interdependencies which are unique to each geographical location. Therefore, the flood resilience is an inherent characteristic of a particular social system or their decision-making system.

5.3 Concept of Resilience in Flood Management

Along with the system thinking, resilience entered in the field flood risk management. Multiple meanings of this concept have been emerged in literature since 1960s. Resilience is increasingly used as an approach for understanding the dynamics of natural disaster. Decision makers have viewed resilience as a property of the system that describes the system response to changes and recover quickly to the same, or an equivalent state, or to adapt to an uncertain change. Therefore, flood resilience has pointed the importance of develop diverse strategies for coping with uncertainty associated these different scenarios. The notion of evolutionary resilience also emphasized that the capacity of a socio ecological system is not only to return it to a state that existed before the disturbance, but also to advance the state through learning and adaptation [58, 59]. It has been further stressed that the flood management system need to encompass integrated and flexible governance solutions that have the ability to respond the complex feedback. Furthermore, flood resilience could be considered as an internal capacity of social systems for the adaptation of socio ecological changes. Hence, evolutionary resilience demands the assessment of flexibility of the decision-making process which considers the multiple possible changes of social and ecological system.

5.4 Flood Management and Resilience

Resilient flood management requires more flexibility to address the diverse values of society, economy and environment which are related with flood risk management. Accordingly, integration encompasses incorporation among stakeholders, actions, places, policies and sectors. Operationalization of flood resilience depends on the level of coordination between these characteristics of the water system (natural – physical), and the institutional structure of that particular context [60, 61]. Flood risk management has highlighted integrated governance and paradigm shifts from "top-down" and "command and control" approaches towards the recognition of bottom-up community- based efforts in flood risk management. The governance mechanism should be flexible enough to accommodate even with small scale transformations of the socio-ecological system. Therefore, the analysis of the stakeholders, their discourses, rules and resource distributions are considered as important parameters should be considered in flood risk assessment. In addition, the operationalization frameworks of flood resilience should be legitimized. However, legitimacy has received comparatively less attention when considering the context of flood resilience [62].

5.4.1 Managing of flood resilience with spatial planning. Therefore, decision makers questioned the capacity of spatial planning to cope up with these uncertainties which are associated with flood risk [52, 63]. Currently, spatial planning plays a minor role in flood risk management and this will guide the operationalization of flood resilience through spatial planning. Adequately dealing with uncertainties has been considered as a primary concern for flood resilience. Therefore, it is necessary to explore the factors which are related with spatial planning in order to complement the flood risk assessment.

5.4.2 Challenges for Flood Resilience strategy. Integration of stakeholders in decision making is varied greatly according to main three factors such as (1) context of planning (institutional culture, level of political decentralization and the fashion for public consultation (2) the planning process and (3) the expected planning outputs [64, 65]. One of the major obstacles, is the shared governance dilemma where the higher level of government has a strong stake in promoting risk based policies but the lower governing bodies are unwilling to become partners. As a result, there are standalone hazard mitigation plans and the spatial plans at local level does not often contribute to disaster management. Thus, flood resilience becomes a context-specific characteristic and hence, it generally depends on aspirations of the local community. Many local officials, politicians and the community often give a low priority to spatial planning as a strategy to reduce flood risk. Public indifference to natural disasters is another major impediment to operationalization of flood resilience. Further, the cost of mitigation measures is immediate, but the benefits are long-term and uncertain and cannot occur during the term of elected officials. Moreover, the physical manifestations of increased public security are not visible. As a result, the flood management has a weak public constituency.

6. Voids in the present setting

The notion of resilience has challenged the goals, objectives, measures and the organizational structure of the traditional flood risk management system. The level of operationalization of flood resilience primarily indicates how floodplain land uses are organized to cope up with the uncertainties associated with flood risk. Further, it has pointed that the flood risk is increasing, particularly in urban areas due to the ill conceptualization of nonlinear interrelations between land, water and people. Evolutionary resilience has underlined the need of changing the floodplains in order to support functionality of socio ecological systems under the constantly changing socio-economic and climatic conditions. Flood resilience depends on the stakeholders' understanding of coevolution, and coproduction nature of land and water systems. Assessment of flood risk is a challenging task due to the availability of limited knowledge to understand these nonlinear interdependencies, thresholds and their spatial variations. Therefore, the flood risk assessment should focus to identify the factors which caused to common frame following the plural views among stakeholders. In this context, the decision making process should provide opportunities to derive integrated strategies through sharing the negative and the positive impacts equally to each stakeholder at different sectors, different scales and multiple scenarios. There should be opportunities in strategy making process for the integration of diverse views of these stakeholders which are focusing towards sustainable functions of considered socio ecological systems. Therefore, spatial planning, as a collaborative decision making tool requires the providing of opportunities to stakeholders to find out the integrated and adaptive strategies for operationalization of flood resilience.

7. Conclusions

The notion of flood resilience has moved flood vulnerability assessments towards the measuring of resilience capacities of the socio ecological system. Flood resilience is based on the understanding nonlinear feedbacks between land and water. Flood resilience embeds the incorporation of spatially distributed land use policies and regulations which are a must for the management of flood risk. Therefore, the present meaning of flood management system including the objectives of flood risk management, the capacities of flood management strategies, stakeholders in the management process and their roles have been questioned. It is largely evident that as at present, the role of spatial planning in flood risk management remains inadequate mainly because of the absence of a common framework for implementation and legitimization of flood resilience. Therefore, it is of utmost important to initiate an action to establish a framework to assess the capacity of spatial planning process for dealing with uncertainties incorporated with flood risk and to institutionalize as appropriate.

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