Flood induced vulnerability in strategic plan making process of Riyadh city

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ARTICLE INFO

Article history:
Received 1 March 2015
Received in revised form
17 May 2015
Accepted 29 May 2015
Available online 20 June 2015

Keywords:
Flash flood
Social and physical vulnerability
Flood vulnerability index
Strategic plan

ABSTRACT

Riyadh, the capital of Saudi Arabia, is undergoing a critical transition when the conventionally thought desert climate has been witnessing ‘turning-to-be-regular’ flash floods. Since 2009, the city has been repeatedly hit by flash floods that has put further adverse consequences on the properties and even resulting in death tolls. Such critical transition has made the think-tanks seriously re-think about the resilient capacity of the existing infrastructure. Although the city has been attempted to plan, develop and expand under a number of master planning regimes, the ‘emerging-recurrent’ flash flood was not critically considered in the plan making process. However, the recent MEDSTAR comprehensive strategic development initiative has brought a new hope with re-conceptualizing the planning strategies in the plan making and revision processes. Thus, this study attempts to evaluate the credibility of master plans with an especial focus on MEDSTAR to find out the resilience power against flash flood driven adverse consequences. The evaluation is carried out with the lens of social and physical vulnerabilities of flash floods and associated risks of the proposed strategies for growth and land use of Riyadh until 2030. The evaluation suggests that many areas of Riyadh city, formally proposed with specific land uses, densification and expansion plan, are prone to both social and physical vulnerabilities of flood in the scale of ‘high’ to ‘moderate’ vulnerability induced risks. With the aid of composite flood vulnerability (social and physical) index, therefore, this study suggests MEDSTAR comprehensive development strategy to undergo another re-evaluation process that perhaps will strongly influence the current investment decision on infrastructure to make Riyadh resilient against the ‘emerging-recurrent’ flash floods.

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1. Introduction

With the increased pervasive consequence of climate change, the entire earth is witnessing recurrent and abnormal events, often turned into disasters, with a heightened frequency than ever before (IPCC, 2008; Schmidt & Wolfe, 2009). Such adversities also hit middle-eastern countries including Saudi Arabia. Although flood is understood as historically rare event in Arabian landscape, recent recurrent flash flood incidents put the contemporary landscape to a critical transition. As a result, the flash floods in large metropolises e.g., Jeddah, Riyadh, and Dammam has been occurring on a year interval, labeling it as a regular event, and cause extensive property damages and death tolls (Middleton, 2009). Essentially, such emerging and ‘turning-to-be-regular’ (ominous) events are making city planners seriously re-think about the city infrastructure and its adaptive capacity to the new transition. A series of consecutive floods, notably in 2009, 2010, 2011, 2012 and 2014 has already put a tremendous challenge on the existing infrastructure, urban planning process and questioned its adaptive capacity against such ‘turning-to-be-regular’ natural odds. However, keeping changing climate and its adversities in the forms of ‘newly-recurrent’ flash flood into consideration, the Saudi Arabian capital, Riyadh, aims to get prepared to achieve resiliency in the end (Craven, 2009; IPCC, 2008; Medstar Review, 2009). Therefore, the capital city underwent a number of master plans driven changes since 1971. While the revision is still ongoing, the latest structure plan, called Metropolitan Development Strategy for Arriyadh (MEDSTAR), has been drafted (2009 and 2012) in the aim to provide strategic planning and development guidelines until 2021, first, and then to 2030. Yet, one of the primary questions still co-exists about introducing adaptive approach in the strategic plan, which is capable of incorporating ‘newly-recurrent’ and
unforeseen event(s)-induced physical and social vulnerabilities and associated risks on the planning endeavors as it moves over time horizon. The socio-economic and climatic context against which MEDSTAR comprehensive plan making process was initiated, the city already started to experience adverse consequences of flash floods (Middleton, 2009). On that ground, the following question remains unanswered while flash flood has been an emerging-recurrent phenomenon for Riyadh and other metropolises: what is the adaptive capacity of the strategic plan to advocate city growth as well as land use policies and prepare for the unforeseen events? This, in turn, further encourages studying the strategic plan to see its potential adaptability to deal with the effects of unforeseen events and the options in which land use and growth policy might be altered with certain ‘adaptive-flexibility’. Therefore, with the aid of empirical evidence, this paper aims to scientifically review the comprehensive strategic plans of Riyadh city from flash flood induced social and physical vulnerability standpoints.

2. Flood induced vulnerability and urban planning policy

Vulnerability due to flood fundamentally depends on two domains: intensity of flood and conditions of the built environment (i.e., types and density of infrastructure) and socio-demographic and politico-economic characteristics of the inhabitants (Mitchell, 1989; Cutter, 1996; Cutter, Carolina, Boruff, & Shirley, 2003; Cutter & Finch, 2008; Balica, Popescu, Beevivre, & Wright, 2013). Although researchers (e.g., Asare-Kyei, Kloos, & Renaud, 2015; Krellenberg et al. 2014; Koks, Jongman, Husby, & Botzen, 2015; Rojas, Feyen, & Watkiss, 2013; Romero-Lankao et al., 2014; etc.) attempt to understand, identify and operationalize, flood-induced ‘vulnerability’ is commonly grounded on and defined by nature and intensity of flood, its associated risks and exposure. This study, therefore, adopts fundamental nexus of vulnerability, which is the function of flood-induced risks and exposure that largely relies on population characteristics of the district residents in Riyadh and availability of the essential infrastructure.

Environmental hazards have always been a threat for the city infrastructure. Hence, it poses a consistent challenge and, at the same time, derives experiential knowledge that feeds into formulating sustainable planning framework, which, in turn, brings resiliency against e.g., floods that could be recurrent, discreet or unpredictable in nature (Smith & Petley, 2009). The increasing frequency of flood throughout the world is perceived to be one of the pervasive consequences of climate change (Satterthwaite, 2013). Thus, growing concern of the city governments on development plans to deal with the mounting consequences of recurrent disasters (e.g., floods) become a regular day-to-day task (Downtown & Pielke, 2001). Many city governments including in the third world nations (e.g., India, Sri Lanka, China, Thailand, Philippines, Peru, Argentina, etc.) have become more proactive in taking effective actions to improve governance in order to reduce disaster risk and vulnerability (Johnson & Blackburn, 2014). These local governments have been persistently investing on (Johnson & Blackburn, 2014).

- expanding capacities emphasizing on local indigenous knowledge, and experience;
- building partnerships between the local communities, private actors, Non-government organizations (NGOs), academic institutions and other stakeholders;
- prioritizing needs of the most vulnerable groups including women, elderly, children, etc. by insuring their participation in the local plan making process; and
- insuring participation of the city governments in national disaster risk reduction planning and framework.

Often, the challenges of planning policies and regulatory legislations are rooted to the unpredictable nature of flood and, thus, lies on city’s adaptive capacity to cope with it. Therefore, UNISDR (2013) identifies ‘10 essentials’ for making cities resilient among which building essential infrastructure and its upgradation are considered to be the vital steps for built-environment resilience. Moreover, financing and allocating resources for necessary infrastructure, and enforcing building and land use regulations are equally appraised as the supporting pillars towards achieving resiliency against (e.g.,) flood (Kelly, 2010; UNISDR, 2013). Nevertheless, the investment decision on building infrastructure depends on the ability to ‘knowing possible risks’ – understanding the nature of exposed risk and state of vulnerability. This is why, researchers (e.g., Cutter et al. 2008; Johnson & Blackburn, 2014; Silva, Moench, Kernaghan, Luque, & Tyler, 2010; Winsemius et al., 2013; Ward et al., 2013, etc.) fundamentally stress on the risk assessment exercise – ‘multi-hazard risk assessment’ to maintain updated data on hazards and vulnerabilities, assess risks and use these as the foundation for urban development (re-)plans and resilient (re-) framework. Many city governments, notably Mumbai, Cape Town, Vancouver, Johannesburg and San Francisco (Philippines) carry out regular disaster risk assessments by drawing communities’ indigenous knowledge and experiences into account. Evidently, such risk assessment strongly influences the preparation of a city development plan (Johnson & Blackburn, 2014; UNISDR, 2012).

Flood induced risk assessment entails physical, socio-demographic, cultural and economic dimensions and the state of vulnerability relies on resistance, coping, recovery and adaptive capacity of a city (Cutter et al. 2008; Silva et al. 2010). Hyndman and Hyndman (2010) attempt to integrate the physical and social sciences dimensions to identify and describe general principles that can enhance the understanding of physical, social, and economic forces inherent in natural disasters, including flash flood. Physical vulnerability of flash floods is an obvious and widely witnessed phenomenon. Therefore, it is essential that the physical characteristics of flood and prevailing perceptions around (e.g., magnitude, duration, and frequency, the individual and community perceptions) need to be thoroughly explored, appraised and recorded. On the same thread, social vulnerability is somewhat undermined during the assessment of overall flood-induced vulnerability at the household level (Linnekamp, Koedam, & Baud, 2011). Contrarily, reducing overall flood risk significantly depends on the adaptive capacity of the individual households, which is associated with the demographic structure of the household, education, age, gender, ethnicity, and income level, among others (Cutter et al., 2003; Kienberger, Contreras, & Zeil, 2014; Koks et al., 2015). Thus, composite vulnerability score incorporating physical and social vulnerabilities has been effective in actual assessment of potential risks posed by floods and resulting damages. Use of composite score values as input-decisive variables in the master plan making process has been quite an established practice in North America, European Union and far eastern countries including China, South Korea, Japan, and Australia (Kim & Rowe, 2013; Viegas, Saldanha, Bond, Ribeiro, & Selig, 2013). Specifically, investment decision on city’s infrastructure to make it resilient against the natural disasters including flood is largely influenced by the estimated vulnerability score of the city neighborhoods (Melgarejo & Lakes, 2014; Saraswati, 2014).
3. Study area — Riyadh, the Saudi capital

Riyadh is strategically located at a major crossroads of the continents of the Kingdom and the eastern part of the Arabian Peninsula. Until 2012, the total (developed) area in Riyadh city was 1297 sq. km (ADA, 2013). The area allocated for urban development is expected to reach 3115 sq. km in 2029 (Medstar Review, 2009). The core city consists of 153 neighborhood districts, which are the habitats of majority (98%) residents and includes 13 municipalities in addition to Addiriyah governorate that accommodates 209 quarters (Qahtani & Al Fassam, 2011). Notably, the expansion beyond its original walls has resulted in Riyadh city becoming one of the three largest metropolitan areas in the Kingdom, together with Makkah and Jeddah in the West and Dhahran, Dammam and Khobar in the Eastern Province. In the current land use setting, the housing neighborhood represents the major share i.e., about 17.8% of the city area, and the allotment for other uses is as follows: industrial — 1.88%; transport services — 3.12%; commercial — 1.97%; health government and educational — 10.66% (Qahtani & Al Fassam, 2011).

Riyadh as a rapidly expanding multi-cultural city hosts a blend of 65% Saudi and 35% non-Saudi populations. The conventional city climate is featured by hot dry summer while the winter enjoys cool moist weather with mean annual rainfall ranging between 85 and 116 mm (Al Saleh, 1997; Alyamani and Sen, 1992; Subyani, 2004). However, in the recent past, the rainfall pattern has changed resulting hours to days of downpour causing high volume of surface run-off (ADA, 2013).

4. Study method

As far as physical indicators are concerned, the most common choice set includes the following to create a physical vulnerability index (PVI): geomorphology, flood heights, tidal wave distances, as well as rainfall data (Gornitz & Kanciruk, 1989; Gornitz, White, & Cushman, 1992; Mclaughlin & Cooper, 2010). This study takes into account a set of context-specific indicators relative to Riyadh that also comply the required input variables to run simulation through the Watershed Modeling Systems (WMS): surface elevation, rainfall intensity and duration. At the outset, the geographical areas of interest in Riyadh city are identified that have been repeatedly hit by flash floods in the recent past. In other words, these are the areas that are potentially prone to flood vulnerability. Thus, PVI is created studying those areas using the WMS. In the simulation, gridded surface subsurface hydrologic analysis model of WMS is used to calculate rainfall event (before, during and after) for each grid cell and then the response from individual grid cells are integrated to produce a comprehensive watershed response map. A 30 m ASTER digital elevation model (DEM) is fed as the input data into WMS where aforementioned indicators are analyzed to determine the depth of flooding throughout Riyadh city. The model was executed under a ‘worst flood scenario’ (60 mm/h and 6 h of continuous rainfall) to simulate maximum depth and volume of water that may accumulate over the study area. Afterwards, the flood depth map was converted into a 30 m raster grid layer and the water depth was reclassified to a scale score of 1 to 5 to measure flood induced physical vulnerability of the city. Areas with a score of 1 corresponds to have ‘very low’ vulnerability while score of 5 were identified as ‘highly vulnerable’ to flash floods.

Besides politico-economic factors (e.g., land ownership and property values, etc.), a number of demographic attributes, including population density, population growth, age, gender, family size, race, ethnicity, etc., and social indicators, such as housing conditions, per capita GDP, urbanization, household income, etc. are commonly taken into account to create social vulnerability indices (Balica, Wright, & Meulen, 2012; Cutter & Finch, 2008; Rygel, O’Sullivan, & Yarnal, 2006). Nevertheless, the

Fig. 1. Location of Riyadh in the Kingdom of Saudi Arabia.
choice of variables is adaptive to the context, which differs based upon the socio-economic and political characteristics of the urban geographies in focus (Cutter et al., 2003; Zhang & You, 2014). Riyadh is characterized by higher mix of foreign populations and differentiated socio-economic status (Aldosary & Nahiduzzaman, 2010; Middleton, 2009), which makes the choice of variables relatively critical. Therefore, after a due consideration of the social, economic and demographic (understood as ‘socio-economic’) composition, total 7 variables are chosen to create social vulnerability index (SVI) where presence of Arabs (non-Saudi) and Asians are duly accounted because of their varying exposure to flash flood-induced risks. An SVI of the city’s residents (both Saudis and non-Saudis) to flash flooding is computed accounting the following variables: (1) average family income; (2) percent of population below 7 years and over 65 years; (3) population density; (4) land use; (5) percentage of Arabs (non-Saudi); (6) percentage of Asians; and (7) percentage of people unemployed in each neighborhood. The rank scores for all seven indicators were summed and averaged to compute the social vulnerability index (SVI) for each neighborhood. By multiplying physical and social vulnerability scores, composite flood overall vulnerability index (FVI) for each neighborhood of Riyadh city is computed using the following equation: FVI = SVI × PVI. Finally, based on FVI, this study attempts to review the prescribed growth policy, land use settings as well as the investment decision about building infrastructure in all master plans with an emphasis on the latest comprehensive strategic plan of Riyadh i.e., MEDSTAR.

5. Urban planning practices and natural disaster induced vulnerability

The need for (strategic or comprehensive) urban planning in Riyadh does not necessarily stem to build adaptive capacity to cope with the unforeseen or ‘newly-recurrent’ natural disasters such as flood and its associated risks. Traditionally, the urban development practice has been a direct result of the urban decisions made at that time on case by case (e.g. Almalaz, old airport etc.) (ADA, 2003). For example, Arriyadh development authority (ADA) realized the need for establishing control over the urban development process by only relying on popular regulatory tools such as land subdivision plans (Middleton, 2009).

5.1. First master plan (1971)

Perhaps merely from the preservation point of view, Doxiadis assumed a linear development along the spine extending in a north-south direction of Riyadh, parallel to the Wadi Hanifa while the growth was proposed to be limited against the traditional development corridor of towards east-west direction (ADA, 2003). Due to high economic boom, Riyadh experienced a heightened magnitude of urbanization causing the city to grow outside the pervasive boundary that superseded this master plan. Due to loosened-control over the actual development, the strong pressure of the east-west direction development along the traditional corridors had countered the concept of north-south direction development. As a result, many of the natural drainage outlets towards the Wadi either started to disappear or experience blockages while the urbanization process continued (Middleton, 2009).

5.2. Second master plan (1976–81)

While the first master plan underwent revision, a new master plan was proposed with an expansion of 850 sq. km, until 1990 to accommodate increased population of 1.6 million. However, the growth strategy was hindered by the advent of new projects that attempted to fit into the proposed urban settings in an unsuitable manner. In the process of economic boom, the planning focus was predominantly diverted to building financial infrastructure and supporting amenities with a diminished priority to execute what has been proposed on the development and preservation of green infrastructure in the master plan. As a result, the development proposed for Wadi Hanifa, as a main green belt and drainage outlet, in order to integrate in the park system at the city level and promote natural drainage system, was not fully implemented (ADA, 2003) (Fig. 2 around here).

However, under the ‘urban limits policy’ while the attempt was made to concentrate the development within a certain urban cordon and restrict sprawl development, city expanded more than 632 sq. km and the vacant land decreased from 50% to less than 30% putting a further pressure on the natural drainage outlets (Middleton, 2009).

5.3. Comprehensive strategic plan (MEDSTAR): 1996–2021

Comprehensive strategic plan (Metropolitan development strategy for Arriyadh – MEDSTAR) is considered to be one of the important milestones of planning endeavors in Riyadh to accommodate future requirements, adapt to upcoming changes and avoid the negative dimensions of city growth, particularly those resulting from fast growth leading to urban sprawl and resultant consequences. Under the comprehensive strategic plan, structural plan defines and specifies the environment protection zones, open areas, directions and boundaries of urban development along with land use regulation, and city transportation system, among others. The structural plan covers all parts of Riyadh city within the protected boundaries of development having an area of 4900 km² and projected population of 7.2 million by 2024 (Ministry of Economy and Planning, 2010). On that note, following key features of the strategic plan requires a reiteration in order to understand the urban growth policy taking ‘emerging-recurrent’ flash flood into consideration, which, however, has been existed in the desert climate of Riyadh in varying magnitude:

The revised zoning regulations and land use plan, understood to be effective executive tools for development plans, defines the current and future land use regulations until 2021. While the zoning regulation aims to set control on population and building density, height (FAR), use and other terms to ensure privacy and protection of property and environment, it attempts to regulate the construction of city infrastructure, which intends to serve the desired number of population in a sustainable manner. Transportation plan has always been a top agenda to accommodate current and future demand, taking into consideration the need for an increased population, urban growth policy and land use settings. Thus, the urban growth is highly encouraged and stimulated by the financial investment decisions to diversify the economic base. On this continuum, the strategic plan still encourages horizontal expansion of the city boundary simulating to ‘urban sprawl’.

In the strategic plan, environment management and protection plan gets a serious attention to achieve a sustainable environment while attempting to preserve natural resources and improve overall city environment. This is strongly connected to the provision of public utility plan that includes electricity, water, tele-communication, sewerage, sanitary waste and rainwater drainage. The current rainwater drainage does not adequately drain rain-water owing to the fact that the network covers only about 26% of the total developed areas, mainly the central drainage area of the Wadi Hanifa, Bat’ha and Al Aisín area (ADA, 2003; ADA, 2013). Thus, rainfall with relatively intensified rates in a short time span
leads to acute flooding problem in the main streets and low land areas. This is partly caused by poor design of the drainage system and that many of the ducts crossing the roads were closed by the developers in the areas to which water was planned to drain out (Middleton, 2009). Moreover, lack of thoughtful consideration for an appropriate use of the natural Wadi courses and flood drains at the time of planning further contributes to exacerbating flood situation in those areas.

6. MEDSTAR 1996–2021 & revised 2030: new urban strategy

The current MEDSTAR comprehensive plan reflects a major shift on how the spatial form of Riyadh is conceptualized, developed and governed. The new planning approach is a comprehensive value driven action strategy that integrates urban governance, economic development, urban identity, regional development, urban growth and infrastructure. The first MEDSTAR 2021 draft regional strategic plan was finalized in 1997 with 2009 MEDSTAR revision, which extended with further development option to 2030 (Middleton, 2009). The objective is to formulate phase wise implementation plan with an adaptive inclusive approach so that the plan would be updated at regular intervals: 50-year vision; 25-year strategic framework; and 10-year comprehensive implementation plan.

Under MEDSTAR comprehensive plan, the planning program took into account the traditional planning concerns emphasizing ecological and environmental projects, which increasingly were addressing ‘emerging problems’ of flash flood and the Wadi Hanifa watershed (Middleton, 2009). Topography along with water originally viewed as the limiting resource that would limit the city growth and development potential turned out to be an unexpected planning problem due to the increasing incidence of rainfall and flash flooding and a growing problem of continuous high ground water throughout city districts (Qahtani & Al Fassam, 2011). Moreover, since 1996 the net national in-migration to Riyadh from other regions in the Kingdom decreased to more than half — less than 37,000 persons per annum. As a result, the anticipated growth rate for Riyadh had reduced from 8 percent to 4.2 percent per annum (Medstar Review, 2009). In spite of that, Riyadh’s revised structure plan 2030 reveals the growth strategies for urban land use and infrastructure and presents policies strongly encouraging physical expansion and development of the city and entire region (Fig. 3 around here).

To regulate and diversify the financial investment, the major commercial center at the heart of the city is proposed to be supplemented by a number of metropolitan sub-centers, which, in turn, would cluster commercial and public activities in proximity to sub-regional populations. As shown in Fig. 3, high-density spines will be supported by the sub-centers, and terminate at two new cities shown in yellow color to accommodate 50,000—100,000 persons with gross residential densities in the range of 10—20 dwellings per hectare in district groupings. This means, sub-urbanization will be encouraged with relatively high population density in the south-west, south-east and north-east regions of the city while high density development will be promoted with mixed of commercial and residential development at the city core (see Fig. 3) (Medstar Review, 2009). Thus, the development of urban nodes (shown in red (in web version)) are planned to be high density and mixed-use which, will reflect hierarchical concept of centers to serve community needs (Middleton, 2009). Notably, the ecological remediation of the Wadi Hanifa highlighted as key urban projects, exhibits the notion of
preserving natural heritage. However, it awaits further clarification that how this is going to contribute to the emerging flash flood induced drainage problem and associated risks.

Urban limits have been revised in the MEDSTAR 2030 plan with the majority of lands to be released for development are concentrated along the northern axial spine and to the south west of the city center. Doxiadis prescribed growth along the north-south corridor to maintain natural water flow in the Wadis and at the same time safeguard the future development initiatives from being vulnerable to potential water logging and flooding. However, the density proposed for the south-west region of Riyadh is relatively high (Fig. 4 around here). Therefore, new development and urban expansion to the west side of the Wadi Hanifa will potentially pose a major challenge for the installation of infrastructure services, requiring substantial infill due to the Wadi geography and topographical features.

7. Comprehensive strategic plan and flood-induced socio-physical vulnerability

The comprehensive structure plan (MEDSTAR) suggests the north and south-west axial spine of Riyadh to be considered for future urban expansion in 3 different phases. The flood water depth values suggest that the core and suburb areas have low to moderate flood depth, which at its current state does not pose any risk of flooding to the settlements (Fig. 5 around here). However, as per the MEDSTAR development guidelines, both the core and suburbs would be promoted with moderate to high-density development (see Fig. 4). In that case, the question remains to be answered onto the nature and type of infrastructure to be instilled, which would enable the flash-flood water to be drained out at a faster rate. Otherwise, the proposed moderate to high density core and suburbs will be subject to high vulnerability against flooding and further adverse consequences.

In terms of physical vulnerability, this study suggests that areas in the north-west, part of north and southeast regions are high to moderately vulnerable to flash floods (Fig. 6 around here). This also inscribes a further challenge on ArRiyadh Development Authority (ADA) to promote high density mixed use development along with options for transport corridors while building necessary infrastructure that must be resilient against the recurrent flash flood driven consequences.

Although the urban planning regimes of Riyadh city has been undergone several revisions and changes, no attempts has been made yet to assess current flood-induced risks and associated vulnerability while prescribing future guidelines and regulations for the metropolitan city. While MEDSTAR proposes for expansion in almost all directions, except to the west, of Riyadh, a diversified land use settings are prescribed that is expected to bring financial investment and promotes desired threshold population density (see Fig. 3). However, the study results find that with the current infrastructural conditions, majority of the built-up areas are prone to risks and highly vulnerable of recurrent flash floods (Fig. 7 around here).

Riyadh being the diverse cultural and socio-economic-centric city is very likely to witness differential effects of flood at the

![Fig. 3. The Riyadh Metropolitan Structure Plan 2030 (Medstar Review, 2009).](image-url)
household level in each districts. Having a high mix of foreign population with diversified ethnic backgrounds even makes the magnitude of vulnerability to a critical state. On the contrary, MEDSTAR strategic plan doesn't seem to pay attention on flash flood driven social vulnerability emanating from the following key socio-economic attributes: population density, income level, ethnicity, age (proportion of children and elder), and employment status. This study attempts to evaluate social vulnerability of Riyadh city based on scores generated from the combined effects of these variables. The result suggests that central part (core downtown and adjacent areas), part of south-east, south-west, and north-east regions of Riyadh are prone to socially most vulnerable to flooding while the adjoining areas would have moderate to low vulnerabilities (Fig. 8 around here).

This study further portrays that in the composite flood vulnerability index (FVI), combining social and physical vulnerability scores, the following areas of Riyadh city are potentially found to be ‘very high’ vulnerable to flash flood and associated risks while the adjoining areas are high to moderately vulnerable: south-west, south-east, central core and part of north-east (Fig. 9 around here). Moreover, MEDSTAR strategic plan aims to encourage the growth of residential and commercial development to the areas that are found to be high to moderately vulnerable to future flash floods, as the results suggest. Furthermore, there is a concern about high-density mixed-use development in the city core where chances of experiencing potential adverse effects by flood are be very high. Again, advanced preparation (mitigation plan) in the form of (re-)construction of essential infrastructure would help reduce the overall ‘vulnerability’ situation in the future city of Riyadh, from ‘very high’ to a ‘low’. Nevertheless, at its current state and proposed urban planning and growth policies, it is much is needed to take into consideration the flood induced potential vulnerabilities against which a resilient plan can be made to tackle the possible adversities.

**Fig. 4.** Current and future (proposed) population distribution (in thousand) for the year 2021 (MEDSTAR Review, 2009).

**Fig. 5.** Distribution of simulated flood water depth across Riyadh city.
Fig. 6. Physical vulnerability scores across Riyadh city (1 indicates low and 5 indicates high vulnerability).

Fig. 7. Vulnerability rank scores assigned based on percentage of the built-up areas.
Fig. 8. Distribution of social vulnerability scores across the study area.

Fig. 9. Distribution of composite flood vulnerability index (FVI) values across Riyadh city.
8. Concluding thoughts

MEDSTAR attempts to offer a new spatial direction for Riyadh, which infuses the strategy-making effort with predominantly project-oriented development and conceptualize modes of urban spatial change, governance of development in unconventional ways. It reveals a model of urban governance where land use planning and implementation attempted to (re-)define socio-spatial processes to re-activate the sense of place, and considering the environmental change(s) (Middleton, 2008). However, on the plan making and revision process, recurrent floods and its foreseeable consequences were not taken into account to scientifically justify the expansion strategy and land use propositions. Thus, the study findings, in many ways, put a ‘concern’ mark both on what has been proposed in MEDSTAR and its ongoing revision effort. Therefore, a sense of urgency has emerged to re-evaluate the entire plan making strategies and urban planning growth policies by employing the vulnerability measures – in the form of index based scores as presented in this study.

Flash flood has turned out to be a ‘recurrent-regular’ phenomenon in the Saudi physical and social landscape. The criticality lies on the fact that ADA needs to be flexibly adaptive to (re-)build infrastructure and allocate resources accordingly based on area-specific state of vulnerability and from that ground, whether the future propositions for growth and land use settings will bring any sustainable solutions to make Riyadh resilient against regular flash flood driven adversities. Thus, urban planning think-tank(s) for Riyadh city will have to be adaptive enough to tackle its vulnerability and make sure about the optimum use of its future investment (resources) on infrastructure that will potentially reduce socio-physical vulnerability and bring citywide resiliency.

In the light of the above, this study attempts to suggest the following to bring resiliency into the plan making (or revision) process for Riyadh city:

- essential infrastructure, notably drainage network needs to be developed with prescribed population density. On the same view, construction for other infrastructure (e.g., road network, bridge, tunnel, etc.) must be seriously monitored so that it does not continue to block the natural (or existing built-up) drainage system, which the current practice has turned out to be;
- While a specific set of guidelines must be prepared and enforced to preserve and maintain the natural flows of the Wadis, it must be reinforced when actual development will take place as proposed by MEDSTAR comprehensive strategic development;
- The land use decision, growth policy and densification strategy must be developed based on ‘vulnerability’ analysis where socio-economic and physical vulnerability scores need to be combined for critical justification. Based on the score, a contingency plan also needs to be in place showing how it is going to reduce development induced ‘vulnerability’ against ‘emerging-recurrent’ flash floods driven risks. Incorporating this in the development code for Riyadh city, actual practice might further be enforced. On that ground, the current MEDSTAR comprehensive development strategy stems the need to undergo another critical (re-)evaluation.

The composite vulnerability based index (i.e., FVI) would not only guide the concerned local governments in Riyadh but also lead the research and planning practices towards establishing resilient frameworks by taking due consideration of adaptive, resistive, coping and recovery capacity of the city. Like many local governments in the developing and developed nations, ADA is currently in advantageous position to infuse resilient components while considering further revision of the strategic plan.

The appropriate approach and means to engage communities and incorporate their indigenous knowledge and experiential thoughts into building vulnerability index is important and critical for the future of Riyadh. However, this study did not account these inputs in preparing vulnerability scores due to limitation of resources to access to the communities.

The flood simulation in WMS is run on 30 m (DEM) resolution imagery, which is freely available for the researchers. A finer resolution (e.g., 5 m, 10 m, etc.) might have produced better index scores for Riyadh, which the researcher(s) might want to further investigate in the future. Furthermore, while running simulation ‘worst flood scenario’, the rainfall is evenly considered throughout Riyadh to identify the flood depth for each district. In reality, some of the districts might not experience the same amount of intensity of rainfall, which adds another dimension of future research to assess flood depth by accounting district specific rainfall information of Riyadh.

Acknowledgment

The authors acknowledge and appreciate the support provided by King Abdulaziz City for Science and Technology (KACST) through the Science & Technology Unit at King Fahd University of Petroleum & Minerals (KFUPM) for funding this work through project number 11-ENV1646-04 as part of the “National Science, Technology and Innovation Plan (NSTIP)”.

References


Development (IED), 26(1), 1–24.