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# The notions of resilience in spatial planning for drought - flood coexistence (DFC) at regional scale

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**Abstract.** The notions of urban resilience and resilient city has been developed in the 2000s [1], four decades since the first concept of ecological resilience was originally introduced in the 1970s by ecologist C.S. Holling [2]. However, they have attracted great attentions and interests, in both academia and urban governance, then in planning practice over recent years. The first two sections of this paper examine the term resilience in ecological systems, urban systems, in spatial planning and in urban design. Specific attention of the paper, introduced in the third part, is to investigate resilience in the context of drought-flood coexistence (DFC), revolving two key objects and their interactions: DFC and urban at regional scale. Flood and drought events, in their turns intertwine in natural correlation, which is also reviewed. These relationships are literally investigated, to prove that they interplay mutually with each other, and that once a city develops in relation with water cycle at a regional context, in arid zone, not only hydrological drought could be regionally decreased, but human-induced floods could be ecologically regulated.

The study concludes in the fourth, together with lessons from relevant case studies in America, China, with some principles on spatial planning, resilient/adaptive to DFC, which could be ecologically managed in correlation with urban development on a sustainable pathway.

*Key words: ecosystems, extreme weather events, drought - flood coexistence, sustainability, urban resilience, spatial planning, mitigate, adaptive cycles, adaptive capacity.*

## 1. Introduction

Human beings have experienced a very challenging phase since the industrial revolution early 17th century. From then, we have witnessed amazing advances in social, demographic, and economic development, which have strongly caused urban pattern changes [3][4]. What challenges our artifactual environment more over recent decades is threats from climate change.

On the one hand, the climatic impacts in general on human systems are remarkable, such as: melting snow, altered hydrological systems, shifting species, migrating patterns, etc. On the other hand, global warming has caused specified consequences with more frequent occurrences of extreme climate disturbances, such as heat wave, drought, extreme precipitation, inland and coastal floods, landslides, cyclones, and other weather extremes [5]. Among these, flood and drought is one of the hottest issues, both damage and loss of life. Moreover, desertification is becoming more and more severely in riverine, coastal and urban areas across the world and in Asian countries, which has caused a severe problem of DFC [6].

In a review of drought under global warming [6], Dai indicated that human have experienced a tough time of drought since the 1970s. Climate models have increased aridity in the 21st century over most of Africa, Southern Europe and the Middle East, most of the Americas, Australia, and South-east Asia. Compared to some similarly affected areas in the central region of Vietnam, where most of them



have been experiencing desertification ever since the 1970s [7], the similar findings show very high pressures of climate change impacts, such as: increased temperature, concentrated precipitation, flash flood in urban areas, coastal flooding, sea level rise, etc., particularly in Ninh Thuan province [8].

All impacts on human environment often come from natural systems, together with recent global changing climates. But more importantly, design is a very crucial task that would affect to the natural environment on either a good way or a bad way. Van Der Ryn and Cowan emphasized, in Ecological Design [9], that “*the current environmental crisis is caused by our design, which recently is just to serve human interest and ignore its relationships with other species*”. It is true that there is significant lack of preparedness and readiness as well, for a city to deal with hazardous threats and to rebound back after perturbation, in our current planning and design practice. There have been different conceptions of mitigation, adaptation, and currently resilience to cope with our naturally shaking and deteriorating environment, unknown disasters, and any climate change. However, these terms, particularly resilience is still ambiguous in planning practice. The concept will be explored in four parts of the paper in a purpose of seeking an appropriate way for resilient spatial planning in the context of DFC at regional scale, including: (i) from ecological science to urban resilience; (ii) resilience in planning and design; (iii) DFC, urban and their relationships; and (iv) spatial planning resilient to DFC, together with lessons learnt from relevant case studies.

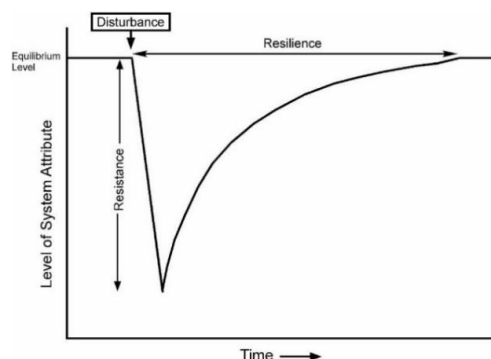
## 2. From ecological science to urban resilience

The prevalent notions of resilience, in theory and application over recent decades, is based on several concepts, including thresholds or tipping points, multiple stable states, regime shifts, complex adaptive systems, adaptive cycles, adaptive capacities, panarchy, etc., [10][11][12]. In this section, the definitions will be examined, firstly in ecological science, then interpreted in the context of understanding and managing social-ecological systems.

### 2.1. Ecological resilience

Originally, the concept of resilience was introduced by ecologist C. S. Holling in 1973 [2], where he defined as stability and the ability of ecological system to return to an equilibrium state after perturbations. Later on, it was defined as persistence or relationships within a system, and ability to absorb changes of state variables, driving variables, parameters, and still persist in its own basic structure and function, no need shifting into a different state. In some cases, a system can be very resilient, still fluctuate greatly and have low stability, or vice versa. Therefore, keeping balance between resilience and stability is a product of the evolutionary history of these systems in the face of the range of random fluctuations.

In an evolutionary literature relevant to the meaning from 1995 to 1997, many authors considered resilience as the time required for a system to return to a steady-state following a perturbation [13][14]. This conception implicitly means the system exists near a single or global equilibrium condition. Other authors considered the return time as a measure of stability. Among them, Holling described this return time as “engineering resilience” [2][15]. The figure 1 shows the engineering view of resilience, where a system deflected from an equilibrium point after a disturbance. After this emerging conception of resilience raised, most of the professional fields, including urban planning and design, adapt this concept through designing a system to be able to bounce back to stability.



**Figure 1.** Diagrammatic illustration of “engineering resilience”. A shock deflects a system from a steady state or an equilibrium point, to which a resilient system returns

Source: based on S. T. A. Pickett, B. McGrath, M. L. Cadenasso, and A. J. Felson, “Ecological resilience and resilient cities,” 2014.

The second movement, firstly termed ecosystem resilience [16], then broadly applied most interchangeable with the words ecological resilience [17][18][19] or resilience [2], has viewed

ecosystems operating with multiple or far from equilibrium state, (which noticed their flexible changes of a system into another regime). In this case, resilience is measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control their behavior. The term “ecological resilience” emphasizes on persistence, change, and unpredictability. It is contrast to “engineering resilience”, focuses on efficiency, constancy, and predictability [17]. The non-equilibrium resilience seems to be paradigmatic in ecological science, and results in a rich body of work at the socio-ecological interface [11][20] afterward.

The later concept of resilience, which was resulted from more human-induced impacts to the state changes in ecosystems, is adaptive capacities [18], which is less ambiguous, and more easily applicable for the design practice. The concept “adaptive capacities” could trace through the adaptive cycles, (social groups are active, resources are released or captured) and all plays out in spatially heterogeneous urban areas [21]. In the biophysical realm, which is more relevant to the study concerning spatial planning, adaptive processes are addressed in a variety of sources [19].

In the more recent papers, many authors noticed resilience as “specific adaptations” (i.e., high adaptedness) of a system to known threats and more generic adaptability [1]. Academia tends to view adaptability as synonymous with adaptive capacity, or flexibility necessary for confronting unexpected hazards [22].

In short, the development of the term resilience is quite long process. It was originally defined as stability, then as engineering resilience, or as ecological resilience, which have been explored in academia and urban governance over recent decades, yet seem to agree on a clear definition but a descriptive concept. For that reason, the notions of resilience could not be easily adapted in many practical disciplines. The theory has, therefore, been continuously studied and updated on the direction of a more normative concept, such as “adaptive cycles” or “adaptive capacity”. The latest concept appears as a step closer to what urban resilience would like to convey, which needs more applicable principles, with regard to planning practice, particularly with spatial planning.

## 2.2. *Urban resilience*

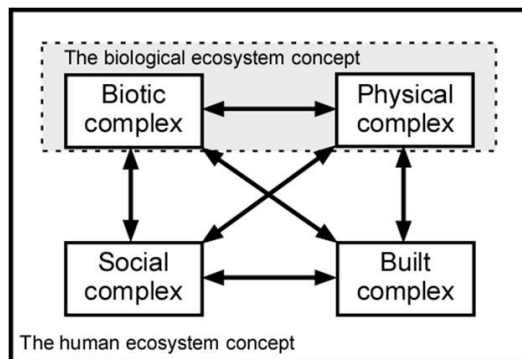
Since the first concept of resilience raised, it took four decades of development leading to the concept of urban resilience today.

To clearly understand urban resilience, it is necessary to first specify what is meant by ‘urban’, and how it is defined in ecological science. In a reviewing paper of the concept urban resilience, S. Meerow argued that most definitions of urban resilience are rather vague with respect to what constitutes an urban area of a city. Although there have been numerous definitions of urban, but she ended up with the holistic one: urban as a ‘conglomeration of ecological, social, and technical components’ [1][3]. In urban ecology, cities are often places where human and natural patterns and processes interact, evolving to form an “urban ecosystem” or an Social-Ecological-Systems SES [23] [24]. There have been two primary meanings of urban ecology [25]. One notices in designing human environment and prevalent in the urban planning field. While the other results from ecological science, which refers to studies of the distribution and abundance of organisms in and around cities, and on the biogeochemical inputs and outputs of urban areas [26].

Indeed, during the last decades, urban areas and their settlements have already been raised into another level in the discourse of ecological science [27], and city had been considered as ecosystem [28][29], at any scales, any levels. An ecosystem, based on ecological science, comprises a specified area or even size of the earth, in which the collections of organisms and the physical environment interact with each other [29][30]. In most ecosystems, some materials, nutrients or contaminants, will flow across boundaries. Therefore, it is important to know what flows will cross. According to ecosystem concept, the flow is metabolic transformations; while in landscape, spatial interaction in which organisms and fluxes engage is flowing. However, the contemporary ecology attempts to combine ecological approaches that had previously existed independently, to consider ecology of landscape and ecology of ecosystems reside on different special scales or organizational levels.

In the meantime, urban ecosystem also contains organisms, physical conditions and entities, and the interactions between them. Urban ecosystem, therefore, comprises not only human, institutional frameworks, their artifacts, but consisting of four dimensions: 1) biological, 2) social, 3) physical and 4) built components. They cannot be separated from one another, as shown on the figure 2 below [31]. “Urban systems” are conceptualized as complex, adaptive, emergent ecosystems composed of four subsystems - governance networks, networked material and energy flows, urban infrastructure and

form, and socio-economic dynamic that themselves are multi-scalar, networked, and often strongly coupled [1][3]. Furthering this point, the four major subsystems of the urban system are “governance networks,” “metabolic flows,” “built environment,” and “social dynamics.”



**Figure 2.** The human ecosystem concept was expanded from the bio-ecological concept of the ecosystem as originally proposed by Tansley (1935) in the dashed line. The expansion incorporates a social complex, which consists of the social and built environments.

Source: based on S. T. A. Pickett and J. M. Grove, “Urban ecosystems: What would Tansley do?,” *Urban Ecosyst.*, vol. 12, no. 1, pp. 1–8, 2009

Urban regions of cities have not only been as an isolated component separately from other natural components. Scholars in urban ecological science have taken a big progress in this concern. They have no longer consider ecology IN the city such as green areas and suburbs, but combined with other social and other natural sciences. From which, a new conception of city-suburban-exurban (CSE) complexes as integrated systems generated and emerged from urban designs. It is, therefore, nature can be ignored as outsider in the CSE realm. CSE ecosystems must be seen as comprising organisms, including human social structures and processes of soils, waters, air, and energy, along with built environment and infrastructure. Urban ecology is now an ecology OF the city [32].

Together with the movement of considering urban as SES, as noticed earlier, SES scholars tend to view adaptability as synonymous with adaptive capacity, or flexibility necessary for confronting unforeseen threats [22][3]. While leading SES scholars do not contrast adaptability or adaptive capacity and adaptedness, they do emphasize the importance of maintaining “general” resilience to unknown hazards in addition to “specified” resilience to known risks [12]. Scholars focusing on resilience to climate change argued that urban resilience should focus on adaptive capacity rather than specific adaptations.

To sum up with S. Meerow’s definition [1] “*Urban resilience refers to the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity*”, where city operates in non-equilibrium, is viewed as a desirable state because it recognizes multiple change pathways (persistence, transition, and transformation) and emphasizes the importance of adaptive capacity and timescales.

In reviewing 29 papers and researches on the term resilience, which was derived from ecological science. Several multi-discipline studies, developed continuously from the year of 1973 to 2016, related to notions of resilience shows that the science of earth, ecology, biology, etc. has been developed and persisted for a very long time. Although there have been some contrasts among the consulted papers in this section, but within the content of the topic, which focuses only on the two key objects (natural events of DFC and urban) and on the term spatial planning, the literature is therefore considered as high confident documentary.

### 3. Resilience in planning and design

The earliest author concerned about environmental matters and natural conditions in urban planning is McHarg, who emphasized in his book “*Design with Nature*”, published in 1969, that most cities in the world developed on their own processes and containing values, both natural and artificial [33]. However, the notions of resilience in relation to spatial planning just started in the late 1990s [34]. The main focus, nonetheless, was just on physical and infrastructure improvements to prevent disturbances.

Over recent years however, the challenges of climate change have become more prominent, the matter of mitigation, adaptation or resilience in planning, which quite coincides with a traditional approach to land use planning as a means of minimizing existing disturbances and reducing the risks

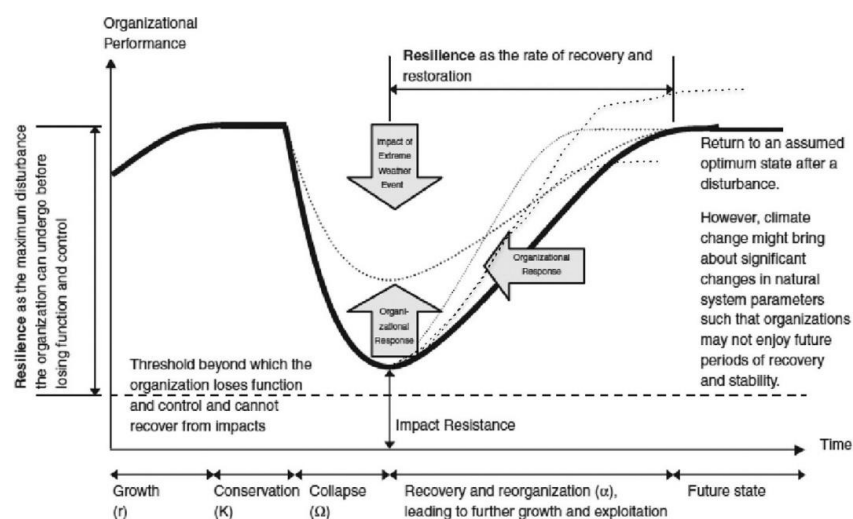


and negative effects of possible disturbances, have been critically important. Resilience in urban planning realm is building a city or a community that could physically resist with external shocks or disturbances by properly controlling their interactions. The section will therefore, focus on natural intertwined interactions between key objectives: urban settlements, natural events of drought and flood, in seeking relevant ecological principles in planning and design.

### 3.1. Urban complex adaptive ecosystems, a changing process and form

A decade or so after the first concept of resilience being realized in urban planning, our world has now been threatened by the extreme changing climate, the literature on resilience in planning has widened to encompass mitigation strategies such as reducing greenhouse gas emissions and other unpredictable disturbances. In a smaller scale, the literature also focuses on adaptation. To move on the right track toward urban resilience, with the above-discussed concept which considers city as ecosystems, four mentioned environments (biological, physical, social and built environments) constituting a city should be carefully understood by architects or planners before starting the planning process. Among these four, biophysics is originally derived from its own geological and biological evolution and artifacts demonstrates the consequence of cultural and social adaptations of the people into the plan of the city.

It coincides with Lu, in planning practice, that the use of the term resilience is limited in scope and often considered as synonym of adaptation [3]. Lu expressed the notion of resilience into the concept of the adaptive cycle [35], which passes through four characteristic phases, as illustrated on the figure 3: (r) growth and exploitation; (K) conservation; ( $\Omega$ ) collapse or release; and ( $\alpha$ ) renewal and reorganization, in terms of a system's robustness and rapidity. He considered a system's robustness being determined according to its 'strength' to carry and absorb uncertain disturbances, whilst its 'rapidity' refers to the flexibility to rearrange itself into a new stable state after a collapse occurs [3]. He gave an example of this interpretation in dealing with a flood prone area, a city's resilience performance is represented in terms of preparations (robustness) before the occurrence of floods (e.g., building types in vulnerable areas, flood control systems, administration of flood risk management) and its reaction (rapidity) to and management of the disturbances (e.g., city drainage systems, rapid response, damage repairs, rescue services, financial support and future improvements). The new condition of a city may not necessarily be the same as the state before a disturbance occurred. However, his interpretation focused much on urban governance and policy making. In planning and design, the preparations should focus on considering natural conditions at regional scale, such as river basin, geography, topography, soil, slope, etc., which interfere and interact with each other closely and mutually. Based on this concern, planning and design could minimize or even avoid disturbances. In the context of DFC, the occurring time could be in different seasons, but the preparations and actions are quite the same in meanings, just some of them are different in characteristics and attributes.



**Figure 3.** Resilience framework: a new stable state is not necessarily the same as the previous one.

Source: based on Linnenluecke and Griffiths (2010)

Also following McHarg's suggestions, objectives and method should be well defined to pursue urban resilience. While objectives focus on identifying locally discrete elements, the method will develop principles and, finally, principles should be constructed into policies for realization. It is practically proven that most of the memorable and sustainable cities in the world are planned and designed based on their own incorporations with dramatic sites. According to Jabareen [36], studies of urban resilience often overlook the importance of multidisciplinary and complex nature of within that notion, and/or use the term without a deep understanding. Focusing on limited number of relevant factors can easily lead a city to bad performance toward resilient end.

### 3.2. *Understanding river basin*

The 19<sup>th</sup> century western explorer and geographer - John Wesley Powell, defined the term watershed as "*That area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as human settled, simple logic demanded that they become part of a community*" [37], whilst McHarg emphasized river basin as a hydrological unit, an area of united water, and is permanent [38]. Both views are quite the same in defining boundary of water systems, which is an interacting process of diversified natural elements, as geography, topography, etc.

In the 1990s, the concept *Integrated Water Resources Management* (IWRM) with its emphasis on river basins as planning and management units was raised and encouraged, due to its failures in trying to intervene the unique natural system at large-scale river basin by building dams for the local context [39]. It reasoned out why McHarg emphasizing architects and planners should use river basin, for adequate understanding, to seek a more finite division of land, and designate appropriate land uses, and plan cities.

It is clear that, our world operates in its own rules, with its own interacting constituents, which reflects a half billion years of time in the interfaces of region, creating in its own local context. They are discrete, which is perfectly to investigate causes and effects between flood and drought events, and how to be affected by urban settlements growth.

### 3.3. *Intrinsic suitability for urban use*

As mentioned in the previous part about ecological knowledge on the nature of river basin system, McHarg stated that each ecological function within ecosystems will be compatible with an urban land use. For instance, subsurface geology, climate, soils, slope and thus drainage together with exposure, determine the appropriate types of agriculture that should be participated in the entire basin. There is the same logic for the functions of forest, grassland, wetland, and recreational areas. This concept coincides with Wenche E. Dramstad's [40] in proposing landscape ecology principles in landscape architecture and land use planning, of which the principles of landscape and regional ecology could be applied in any land mosaic, from suburban to agriculture and desert to human activity. Land mosaic will absolutely be a useful tool for planning and design a city toward resilience.

More importantly, defining sites for developing cities or urban settlements is much more complex. The number of assessment criteria should be set up. According to McHarg, the slopes must be less than five percent incline, not in the 50-year flood plain, and not in important aquifer recharge area. Adequate water supplies are logically a must. Similar to this concern, causes of flood in a city will be at first naturally controlled and then stored at conserved aquifer recharge areas. The context of DFC will be dealt with resiliently.

### 3.4. *Degree of urban compatibility, a step forward to resilient cities*

A defined system on intrinsic suitability for agriculture, forestry, recreation and urbanization indicates the values for each region and for the basin within each of the specified land uses. The system is not only defined for optimizing for a single urban land use, but for multiple compatible function [38].

Supporting the idea of considering river basin as a hydrological planning unit, subdividing into smaller units of watershed management [41][42], and studying aquifer recharge area and aquifers, flood plains [43] are also very fatal considerations for managing river basin ecosystem, a step forward to urban resilience. From theory to practice, there are many cases already applying principles of intrinsic suitability for urban use using GIS [44][45].

In 14 papers and researches collected and reviewed, that most of them are from urban planning field, some of them are from disciplines of environment, geology, ecology, and natural disasters. The oldest one published in 1992, and the newest in 2016, show that natural science is strongly developed.

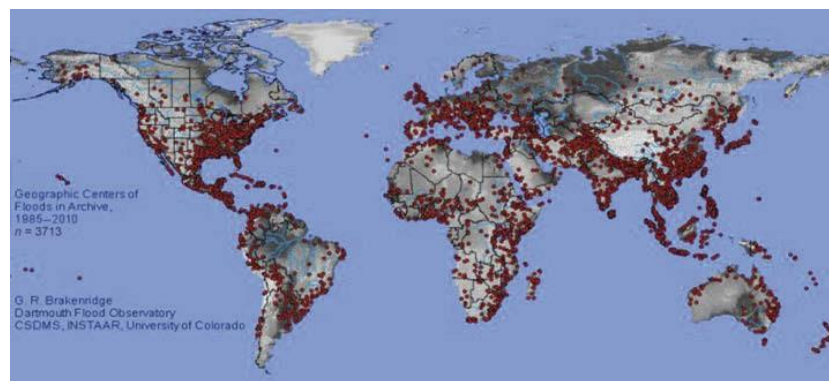
#### 4. DFC, urban settlements and their relationships

##### 4.1. Flood, drought, DFC and interrelationships

A natural hazard is a threat of a naturally occurring event that will have a negative effect on people or the environment. Drought and flood is one of the killing hazardous events.

##### 4.1.1. Flood, urban and relationships

Floods were the most devastating natural disaster of the twentieth century over the world, both damage and loss of life. Floods can occur at any regions, any seasons. Reasons of flood risk are caused by climate-related factors (water-containing capacity, characteristics of intense precipitation, etc.). Increased flooding can be attributed to two factors: 1) increased precipitation; and 2) changes in land use [46]. Inland floods are the result of storm water runoff that exceeds the capacity of their stream and river systems. The map below (figure 4) indicates the location of 3713 flood events during 1985–2010 recorded in the public global database maintained by G.R. Brakenridge at the Dartmouth Flood Observatory (<http://floodobservatory.colorado.edu>)



**Figure 4.** Geographic centers of large floods in the Dartmouth Flood Observatory archive.

The map illustrates 3713 events over the period 1985–2010.

Source: <http://floodobservatory.colorado.edu>

A number of current studies indicated that major floods around the world have raised the concern that river flooding is becoming more frequent and severe [49][50]. The frequency of major floods in many places around the world seems to be increasing; flash floods occurred throughout Europe in June 2016 [49]; the Elbe and Danube flooded in June 2013, just 10 years after the 2002 “millennium” flood; there was severe winter flooding in both 2013/2014 and 2015/2016 in England; and there are many more examples of fatal floods from all around the world [50]. River floods are affected by numerous processes and any changes in such processes may result in changes in the flood discharges. Merz et al. defined three groups of potential drivers related to the atmosphere, catchments, and the river systems [47].

Among flooding causes, natural flood plains are the most crucial driver. They are the most biologically productive and diverse ecosystems on earth. Globally, riverine flood plains cover more than  $2 \times 10^6$  km<sup>2</sup>, but they are the most threatened ecosystems. Its deterioration is closely link to the rapid decline in freshwater biodiversity; leads to habitat alteration, flow and flood control, species invasion and pollution. More than 90% of flood plains in Europe and North America are cultivated, functional extinction is unavoidable. In developing countries, the remaining disappearing at accelerating rate, due to changing hydrology. In 2015, increasing human population lead to further degradation of riparian areas, intensification of hydrological cycle, increase in the discharge of pollutants. In the future, South-East Asia will be the most threatened flood plains in the world [51].

Land use change is also among the major threats leading to floods to many countries worldwide [52], with more significant impacts on developing countries [53]. Land use change has, potentially, a very strong effect on floods as humans have heavily modified natural landscapes. Large areas have been deforested or drained, thus either increasing or decreasing antecedent soil moisture and triggering erosion. Hillslopes were modified for agricultural production, thus changing flow paths,



flow velocities, and water storage, and consequently flow connectivity and concentration times. The intensification of agricultural practices has resulted in the formation of platy dense soil horizons with preferential lateral flow which may reduce and/or retard vertical infiltration in the soils, but cause an intensification of lateral mass flow besides the reduced filter and buffer processes in deeper soil horizons. It is likely that hydrologically significant changes will continue in the next decades due to loss of agricultural land and forests [54]. In all of these processes, however, the exact role of land use change in modifying river floods is still elusive [50].

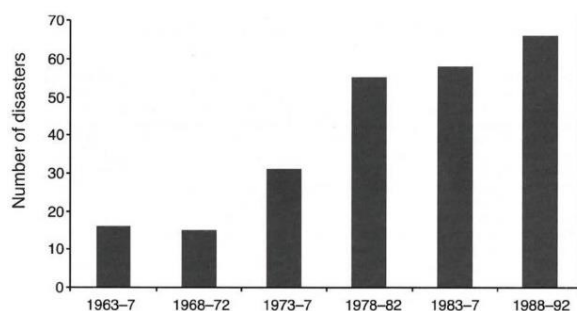
In addition, processes of urbanization also lead to increased occupation of flood plains and, often, inadequate drainage planning, that is for sure that flooding events increased [55]. Donald Watson indicated that in order to regulate ecosystem's service of water, we need to plan the watershed, or to plan urban areas sitting on it, planners should follow the water, water cycle, and should completely understand water supply, annual rainfall, extreme weather events and water storage [46].

A coincidence to the literature, McHarg had theoretically and practically illustrated, in chapter 'The River Basin' [38], that there is clear evidence when we deeply understand how a river system works through history of geology and climate interacted upon the its basin, we will know how to find suitable areas for developing cities. By investigating climate and lithology, urban morphology will definitely explain the patterns of rivers and streams, the distributions of groundwater. This kind of information on the movements of sediments, some by fluvial processes and others from deposition, will reveal the pattern, distribution and properties of soils. More importantly, where rivers and their tributaries start and run from the mountainous areas to coastal plain could help professionals seeking the areas fitting for cities, for urban land uses, and for their urban intrinsic compatibilities, by incorporating all relevant information. As consequence, not only river flooding, but urban flooding is also well regulated and prepared for human beings activities.

#### 4.1.2. Drought, urban and relationships

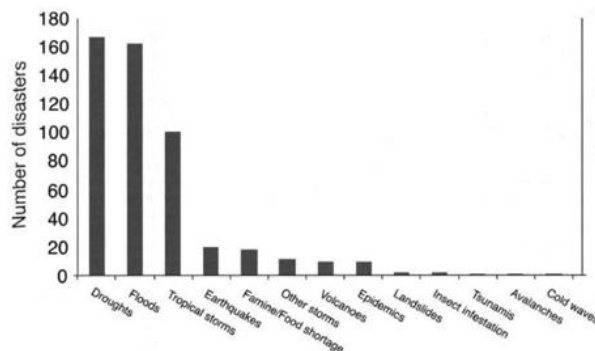
Among other natural events like flood or stormy surge, drought is one of the costly natural extremes to human system. Reasons for the occurrence of droughts are quite complex, since they depend not only in the atmosphere but also on the hydrologic processes, which feed moisture to the atmosphere. The lesser the relative humidity the less probable the rainfall becomes, as it will be harder to reach saturation conditions. Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid areas. Drought occurs over most parts of the world, even in wet and humid regions. This is because drought is defined as a dry spell relative to its local normal condition. On the other hand, arid areas are prone to drought because their rainfall amount critically depends on a few rainfall events [56][57]. That differentiated definitions between drought and aridity could explain why it is hard to visualize drought in Southeast Asia, Brazil, Western Europe, or the Eastern United States, the regions perceived by many to have a surplus of water.

Worldwide, economic damages attributed to natural disasters tripled from the 1960s (US\$40 billion) to the 1980s (US\$120 billion). The figures 5&6 below show economic, social, and environmental costs and losses associated with drought are also increasing dramatically, although it is difficult to quantify this trend precisely because of the lack of reliable historical estimates of losses [57]. The concerns about the trends in losses associated with natural disasters in developed countries are magnified when placed in the context of developing nations. Natural hazards result in significant loss of life and serious economic, environmental, and social impacts that greatly retard the development process.



**Figure 5.** Number of disasters causing significant damage, 1963-92, and affecting one percent or more of the total annual gross national product.

Source: based on D. Wilhite, 'Drought as a natural hazard: Concepts and definitions', 2000

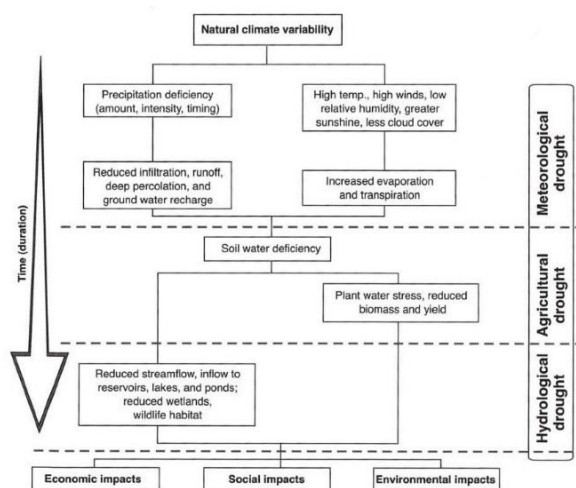


**Figure 6.** Disasters by type, affecting 1 percent or more of total population, 1963–92.

Source: based on D. Wilhite, 'Drought as a natural hazard: Concepts and definitions', 2000

Drought has a long-term history, that was examined by Dai in his review paper on drought under global warming challenge [6]. It reveals that large-scale droughts occurred many times during the past 1,000 years across the world: North America, Mexico, Asia, Africa, and Australia. In comparison to last multi-decadal droughts, the modern-day droughts in 1930s-1950s had similar intensity but shorter durations [58]. During this time particularly, the United States experienced one of the most devastating droughts in the last century, which covered almost two-thirds of the country, and parts of Mexico and Canada. S. Schubert et al presented that increased drought severity was caused by anomalous tropical sea surface temperatures and that interactions between the atmosphere and the land surface [58].

There have been several definitions of droughts. The more general one is as noted by the Intergovernmental Panel on Climate Change (IPCC), 'in general terms, drought is a 'prolonged absence or marked deficiency of precipitation', a 'deficiency of precipitation that results in water shortage for some activity or for some group' or a 'period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance [59]. But the one more specific and more theoretical is a classification of droughts by type, as indicated on the figure 7: meteorological, hydrological, agricultural, and socioeconomic [57]. Meteorological (or climatological) drought is defined on the basis of the degree of dryness and the duration of the dry period. Agricultural drought links various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration (ET), soil water deficits, and so forth. Hydrological droughts are correlated with the effects of periods of precipitation shortfall on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater) rather than with precipitation shortfalls [60]. Finally, socioeconomic drought associates the supply and demand of some economic good or service with elements of meteorological, hydrological, and agricultural drought. Some scientists suggest that the time and space processes of supply and demand are the two basic processes that should be included in an objective definition of drought [61].



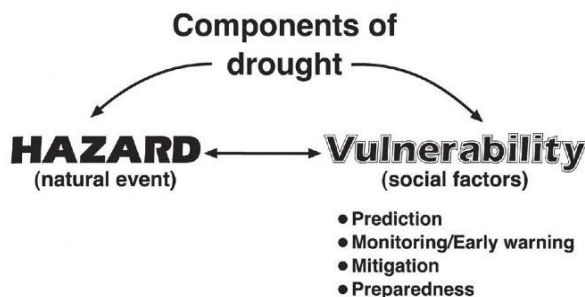
**Figure 7.** Relationship between various types of drought and duration of drought events.

Source: based on D. Wilhite, 'Drought as a natural hazard: Concepts and definitions', 2000

Natural drought events are increased under global warming pressure, that adds extra heat to the climate system and on land much of that heat goes into drying. It should therefore set in quicker, become more intense, and may last longer. Droughts may be more extensive as a result. Climate change may not produce droughts, but it could exacerbate them and it will likely expand their domain in the subtropical dry zone [62]. In another calculation, which was more realistic, based on the underlying physical principles<sup>8</sup> that take into account changes in available energy, humidity and wind speed, author suggested that there has been little change in drought over the past 60 years [63]. This confirmation was based on his/her study on previously reported increase in global drought is overestimated because the Palmer Drought Severity Indices (PDSI) [64] uses a simplified model of potential evaporation that responds only to changes in temperature and thus responds incorrectly to global warming in recent decades. Many other scholars were with this view point [63][65][66].

Drought is an insidious natural hazard that is a normal part of the climate of virtually all regions. It should not be viewed as merely a natural or physical phenomenon. Rather, drought is the result of an interplay between a natural event and the demand placed on water supply by human-use systems. Drought should be considered relative to some long-term average condition of balance between precipitation and evapotranspiration.

Drought is not only a natural or physical event, but social as well. While we can do a little to alter drought occurrence, but social factors can do much to reduce drought-influenced vulnerability by several solutions, like prediction, monitoring, mitigation, preparedness, as shown on the figure 8 [57].



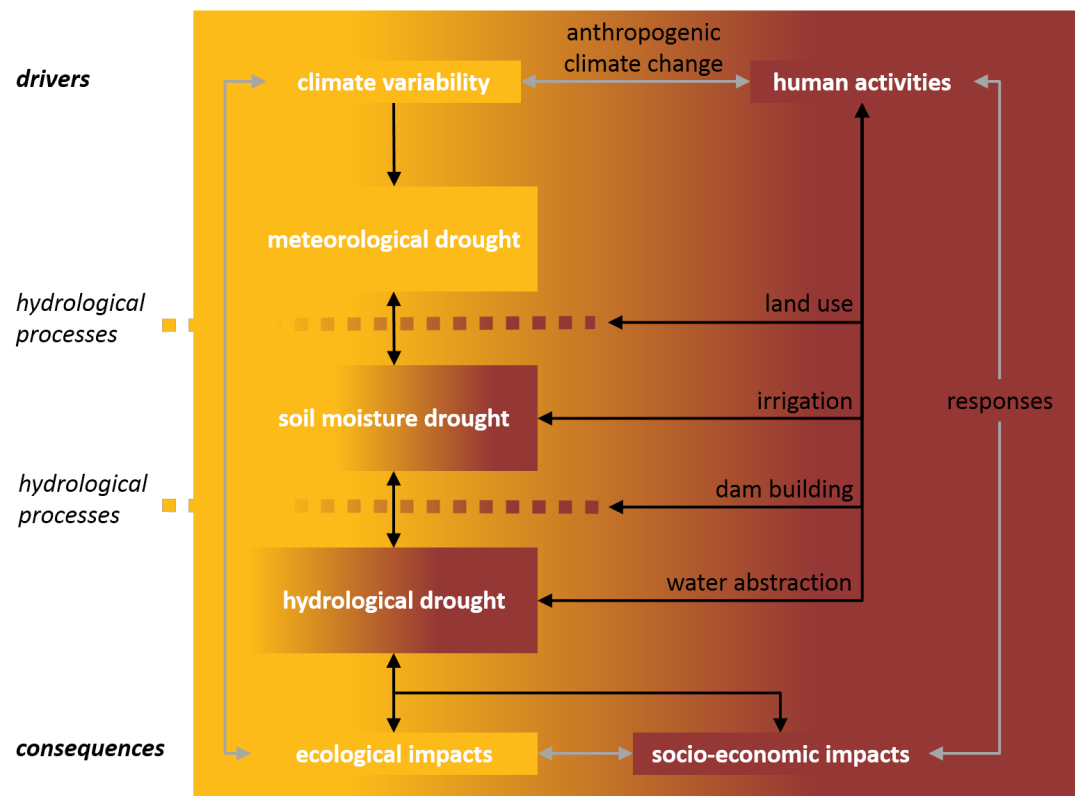
**Figure 8.** Components of drought.

Source: based on D. Wilhite, 'Drought as a natural hazard: Concepts and definitions', 2000.

Severe droughts in human-dominated environments, as experienced in recent decades in many parts of the world, cannot be seen as purely natural hazards. Anthropogenic changes to the land surface alter hydrological processes including evapotranspiration, infiltration, surface runoff, and storage of water and in this way affect the development of drought [67].

The sharp decreases in the PDSI and soil moisture from the late 1970s to the early 1990s mainly result from precipitation decreases in Africa and East Asia [6]. The recent drought in Africa is related to changes in the Atlantic and steady warming in the Indian Ocean. The warming in the Indian Ocean is likely related to recent global warming, which is largely attributed to human-induced GHG increases [59]. L. D. Rotstayn and U. Lohmann also suggested on their study that increased aerosol loading over the Northern Hemisphere may have played an important role in the recent drying over the Sahel and other tropical precipitation changes [68].

Traditionally, most definitions have viewed drought as a natural phenomenon and regarded human-made water shortage as a separate process. And the impacts of drought to socioeconomic and ecological systems are the result of this lack of water that is caused by the complex interaction of natural and anthropogenic processes [67]. In order to manage drought effectively in our profoundly human-influenced era, the Anthropocene, Jamie Hannaford suggested on her paper that we need to acknowledge that human influence is as integral to drought as natural climate variability [67].



**Figure 9.** Drought propagation of Anthropocene.

Source: based on Jamie Hannaford, 'Drought in the Anthropocene', 2016

#### 4.1.3. Drought - flood coexistence (DFC), urban and relationships

Many considers drought and flood are independent natural disasters, they still interrelate with each other, and exist in an interactive cycle. A cause in to drought as investigated by Ekwurzel, in the case occurred in Bonita Canyon in the Santa Catalina Mountains north of Tucson, Southwest of America, that during high temperature fires in the forest, organic debris in the top level soil vaporize, condense and block the soil pores to create a hydrophobic layer that reduces the permeability of the soil. This results in an increasing erosion and water runoff during a rainstorm [69]. Some studies before Ekwurzel's also suggested that accumulated fuel loads and drought created conditions favorable not just for the Aspen Fire, which happened in Bonita Canyon, but for post-fire flash flooding, and this situation is typical for most fires in the semi-arid Southwest. Flash flooding is always a danger in a desert. A drought, in turn, becomes a cause to flood.

In addition to Ekwurzel's analyses, Li also studied the occurrence of drought-flood coexistence in the middle and lower reaches of the Yangtze River [70]. The result shows that the frequency of DFC occurrence has increased remarkably in the past 50 years, especially since the 1980s. According to Li, there exists a significant correlation between DFC phenomenon and the intensity of East Asian Summer Monsoon, which could cause flood and drought in the same area.

The phenomenon exists in the central regions of Vietnam as well, where L. Sam defined four ecosystems spreads in a very thin strip along the complex topographic coastal zones, as indicated on the table 1 below [71]. The area suffers flash flood and storm annually, in addition to increasingly desertification.

**Table 1** Four ecosystems in the central of Vietnam. Source: based on L. Sam,

Ecosystem of coastal sandy land	Ecosystem of central lowland	Ecosystem of central midland	Ecosystem of central highland
<ul style="list-style-type: none"> <li>- Connect to the sea</li> <li>- No surface runoff</li> <li>- Sandy area</li> </ul>	<ul style="list-style-type: none"> <li>- Narrow area between sandy and midland</li> <li>- Flat, 5-100m high</li> </ul>	<ul style="list-style-type: none"> <li>- Large ecosystem, 35% of natural area.</li> <li>- Hilly, 100-500m high</li> </ul>	<ul style="list-style-type: none"> <li>- 40-45% of natural area</li> <li>- High mountains, belong to East Truong Son,</li> </ul>

- Tough drought	- Affected by flash-flood down poured from highland	- High precipitation, receives high runoff volume from highland	- High (> 500m high), slope, high precipitation
	- Tough drought, desertification due to storm water runs directly to the sea	- High water storage for the area	- Water storage/reservoir for lower land

The discourse of typical DFC cases is unlimited across the world recently, whereas the world we are living now is not only in the era of extreme weather-induced hazards, but human-dominated era as well.

#### 4.2. DFC, urban and relationship

Drought, flood and DFC have been identified not only natural events, but human-induced. Once water is hydrologically managed, drought could naturally be alleviated. However, the lack of freshwater in our current era is not only natural hazards, it is triggered by human interference as well, as it is resulted from extreme manipulation of urban aquatic systems and from changes of land-use patterns at large scale, particularly from land uses for urban settlements.

The study of Hualou Long about the correlation between drought-flood disasters and land use changes in West Jilin, China [72] has shown that the conversion rate of land use types (e.g. amongst forested land, grass land, wetland, and arable land) does not have much impact on the occurrence of drought-flood disasters, while the land use pattern changes do influence them. It is also proven in the research that the changes in landscape pattern affect floods more than droughts. Therefore, the land use pattern characteristics can be taken into account to mitigate the disaster or damages [72].

With holistic considerations of the two key objects (DFC, urban settlements), they interact with each other in environmental and ecological concerns. The analytical results will be a foundation for creating principles of resilient urban design.

In conclusion, by reviewing 29 studies and papers related to natural events of drought, flood, DFC, urban and their interrelationships, the multi-discipline literature ranged from earth science, climate, biology, hydrology, water resources, disasters, urban planning, etc., has a quite long history. The findings might not be collected adequately. However, the limited sources of literature indicate very remarkable results of natural extremes of drought, flood, DFC in their relations with human activities, particular in urban areas. From the oldest document prepared by W.C. Palmer in 1965, who suggested general methodology for evaluating the meteorological anomaly in terms of an index which permits time and space comparisons of drought severity, there have not been many additional or supporting studies in the next two decades, until J. A. Dracup's 'On the definitions of droughts' in 1980. From 2000 to 2017, there have been numerous papers on the natural events. Since 2007, the problems of rapid urbanization and changing climates have been raised to an alarming level, that have taken great interests and attentions from scholars, that are shown on table 2 below.

**Table 2.** Synthesis of reviewed literature on Drought, Flood, DFC, Urban and their relationships  
Source: author

No	Authors	Disciplines	Year	Findings
5	M. Roger et al.	Water Resources	2017	... fatal floods partly caused by land use change ...
19	L. Alfieri et al.	Earth science	2017	... Natural drought events increased under global warming pressure ... exacerbate them and it will likely expand their domain in the subtropical dry zone ...
24	J. Hannaford, G. Di Baldassarre, A. J. Teuling, and L. M. Tallaksen	Hydrology Water Resources	2016	... Anthropogenic changes to the land surface alter hydrological processes: evapotranspiration, infiltration, surface runoff, and storage of water and affect the development of drought ...
8	M. G. Míguez, A. P. Veról, M. M. De Sousa, and O. M. Rezende	Sustainability	2015	... significant impacts on developing countries ...



- |    |  |                 |      |   |
|----|--|-----------------|------|---|
| 4  | J. Hall et al.   | Hydrology       | 2014 | ... frequency of major floods in many places around the world increased ...   |
| 7  | W. Su, G. Ye, S. Yao, and G. Yang  | Sustainability  | 2014 | ... Land use change is among the major threats leading to floods worldwide ...  |
| 10 | Z. W. Kundzewicz et al.  | Hydrology       | 2014 | ... processes of urbanization lead to increased occupation of flood plains and, often, inadequate drainage planning, ... flooding events increased ...  |
| 27 | J. Li  | Climate         | 2014 | ... exists a significant correlation between DFC phenomenon and the intensity of East Asian Summer Monsoon ...  |
| 3  | Z. W. Kundzewicz, I. Pińskwar, and G. R. Brakenridge                           | Hydrology       | 2013 |   |
| 1  | D. Watson and M. Adams   | Urban Planning  | 2012 | ... two factors increase floods: 1) increased precipitation; and 2) changes in land use ... Inland floods are the result of storm water runoff that exceeds the capacity of their stream and river systems ...  |
| 2  | B. Merz, S. Vorogushyn, S. Uhlemann, J. Delgado, and Y. Hundecha               | Hydrology       | 2012 | ... river flooding is more frequent and severe ... three groups of potential drivers: atmosphere, catchments, and the river systems   |
| 20 | J. Sheffield, E. F. Wood, and M. L. Roderick,                                  | Nature          | 2012 | ... little change in drought over the past 60 years ...   |
| 29 | L. Z. Wang, H. L. Long, H. Q. Liu, and G. H. Dong,                             | Disasters       | 2012 | ... the conversion rate of land use types ... does not have much impact on the occurrence of drought-flood disasters ...  |
| 14 | A. Dai   | Climate         | 2011 | ... land use pattern changes do influence them  |
| 9  | C. J. A. Bradshaw, N. S. Sodhi, K. S. H. Peh, and B. W. Brook                  | Biology         | 2007 | ... Land use change has, potentially, a very strong effect on floods as humans have heavily modified natural landscapes ...   |
| 12 | Y. Sun, S. Solomon, A. Dai, and R. W. Portman                                  | Climate         | 2007 | ... arid areas are prone to drought because their rainfall amount critically depends on a few rainfall events ...   |
| 16 | IPCC   |                 | 2007 | Drought: 'prolonged absence or marked deficiency of precipitation', a 'deficiency of precipitation that results in water shortage for some activity or for some group' or a 'period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance' ... |
| 15 | S. D. Schubert, M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister | Science         | 2004 | ... increased drought severity was caused by anomalous tropical sea surface temperatures and that interactions between the atmosphere and the land surface ...  |
| 26 | B. Ekwurzel,   | Climate         | 2004 | ... drought causes fires in the forest ... > flash flood ...  |
| 6  | K. Tockner   | Water Resources | 2002 | ... natural flood plains are crucial drivers and the most threatened ecosystems ...   |
| 25 | L. D. Rotstayn and U. Lohmann  | Climate         | 2002 | ... increased aerosol loading have played an important role in the recent drying in Northern Hemisphere ...   |
| 13 | D. A. Wilhite  | Climate         | 2000 | ... Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid areas  |
| 11 | I. McHarg  | Environment     | 1992 | ... understand river system through history of geology and climate interact upon its basin,   |

				will know how to find suitable areas for developing cities ...
17	J. A. Dracup, K. S. Lee, and E. G. Paulson	Water Resources	1980	... Hydrological droughts correlated with the effects of periods of precipitation shortfall on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater) rather than with precipitation shortfalls ...
21	W. C. Palmer	Weather	1965	... Drought considered as a strictly meteorological phenomenon. ... evaluated as a meteorological anomaly characterized by a prolonged and abnormal moisture deficiency ...

## 5. Spatial planning resilient to DFC

As many other natural-caused disturbances like heat wave, drought, extreme precipitation, inland and coastal floods, landslides, cyclones, and other weather extremes, that have emerged over the last decades, DFC has been the most prevalent phenomenon. Although its impacts cannot be considered as disruptive as other disasters like storm surges, cyclones, tsunami, etc., but it has caused gradual impacts on both societies and ecosystems, that really need our proper attentions, including in urban governance realm, and planning discipline, on the way to urban resilience and sustainability.

In the notions of emerging ecological resilience, which have gained high attentions from most of professional disciplinary, spatial planning and urban design take a critically important role in designing and creating resilient cities [59]. Beside specified resilience (predictable and foreseen disturbances), defined for a concrete context, generic resilience (unknown and unpredictable threats) should be put at high consideration, in parallel with adaptive capacity [3].

Within the current climate awareness on spatial planning, it is a matter of course, raising it for DFC is also a critical task, and must be in accordance with the notions of resilience, includes: (i) considering urban regions as ecosystems, complex adaptive systems, that should be planned resiliently across scale, (ii) designing city or community adaptively, and (iii) accepting all unpredictable external and internal changes and disturbances.

### 5.1. Resilience in spatial planning

Urban area as a socio-ecological system, which is supported by ecosystem services, including: (i) provisioning services such as food and water; (ii) regulating services such as regulation of floods, drought, and disease; (iii) supporting services such as soil formation and nutrient cycling; and (iv) cultural services such as recreational, spiritual, religious and other nonmaterial benefits [73].

Regarding to indigenous approaches on city planning, South East Asia is quite an expertise in regulating water systems in urban areas. Chengde, China is a typical case [74], of which small-scale irrigation systems and terraced fields was originally created, with flood was fully controlled. However, in the current of coexistence of indigenous and modern techniques of water management, the distribution of water is highly imbalanced – both geographically and seasonally. The consequence, subsequently, is more frequent occurrences of drought and flooding events, and other social impacts. The reinvented waterscape urbanism in Chengde was developed to cope with new challenges of deteriorating ecosystems. The urban water landscape with a clear connection with the locally natural conditions, such as topography, hydrology and soils, fundamentally structures foundation of urban morphology. All urban water landscape becomes green infrastructures, which is less expensive and more ecological. More importantly, river basin boundary is considered for city physical planning and regulation.

In addition to the most prevalent concerns on natural events of flood and drought, which focus on how to mitigate situation at regional scale and to adapt at urban scale, a recent study from A. Buyantuyev has shown an interesting result. According to the study, urbanization of cities in arid environments can increase net primary production substantially [75], in the condition of introducing highly productive plant communities and weakening the coupling of plant growth to naturally occurring cycles of water and nutrients. The study stated that urbanization may not only increase regional net primary production and disrupt the coupling between vegetation and precipitation, but also increase spatial heterogeneity of NPP in this arid region.

In another research paper, Foster firstly reviewed and redefined resilience literature at regional scale as the ability of a region to anticipate, prepare for, respond to and recover from a disturbance, then proposed A Framework for Assessing Regional Resilience and a system of four stage criteria, including assessment, readiness, response, and recovery [76]. In addition to two key points of the study, he suggested another crucial element (i) consisting of two different connected types: preparation and performance, (ii) applies not only to a system, but to system elements (e.g. infrastructures, information, and physical environments), (iii) resilient on one element not necessarily resilient on another, and (iv) that resilience can be developed.

In regard to spatial planning, in particular with DFC, the service of regulating becomes the most critical one, whilst others become supporting factors. In urban ecosystems, the land used for natural conservation such as: forest, grassland, wetland, etc. take less attention than other economically-drawn beneficial land uses. To avoid deteriorating our ecosystems, such imbalanced and one-faceted thinking should definitely be put away from spatial planning. Additionally, to physically design a city resilient to DFC, defining river basin as a studying boundary is a must. Socio-economically, exploiting anthropogenic during urbanization, rather natural land covers, to increase net primary product.

### 5.2. Adaptive capacity

City as an ecosystem [29][77], and a complex adaptive system which consists of four basic environments. Adaptive solutions for city-scale resilience must follow natural flows from regional level and keep them interconnected (water, air, information, material, etc.), besides keeping ecology protected and intertwined in their mutual interactions.

The lesson from the Water Urbanism across scales in China, to solve the water crisis, is an integrative and adaptive solution. The key is to build an 'ecological infrastructure' based on water processes across scales, from the national and continental scale to the local and specific sites. Four ecosystem's services are accordingly provided in this water-based ecological infrastructure [42].

To achieve urban resilience, Siavash identified key urban planning and design principles and interventions that contribute to increasing as city's level of urban resilience [78]. A system of four key morphological elements consists of streets and spatial structures, green, blue and open space networks, building typologies and density, and patterns of uses. Whereas the first two elements (streets and spatial structures, green, blue networks and open spaces) she suggested on her article is kind of green infrastructures, which is quite similar to cross-scale ecological infrastructure project in China in solution. They, the street and overall spatial structures according to her consideration, are the most permanent components. Therefore, decisions relating to these structures should have long-term foresight, accounting for sufficient capacity and flexibility that can last for generations, and requiring adequate understanding of ecological knowledge.

In regarding to the concerns of DFC, based on a concrete context, adaptive solutions should be taken into account, aiming at achieving urban resilience.

### 5.3. Prepare for uncertainties and unforeseen threats

As defined by various scholars in ecological science, urban ecosystem going toward resilience could change its structure and functions, and lead to another stable state. Where fluctuations could be harsher or more disruptive, the system still exists and withstands with new equilibrium state. However, we really need ecological knowledge to accept all unknown threats and disturbances, and to adequately understand it as a process of four phases. The process is always moving as cycles, adaptive cycles. After the last cycle, another cycle will continue. After collapse, recovery is needed.

In short, 8 papers and researches have been collected and reviewed for the term spatial planning resilient to DFC as shown on the table 2. The figures show that there have not been many studies related to the spatial planning resilient to DFC. The findings are only limited from the year 2005 to 2014, which indicates that the topic is still open for coming studies.

**Table 3.** Synthesis of reviewed literature of spatial planning resilient to DFC. Source: author

No	Authors	Disciplines	Year	Key Findings/Concepts/Definitions
8	J. Ahern, S. Cilliers, and J. Niemelä,	Landscape/Urban Planning	2014	... A system of four key morphological elements consists of streets and spatial structures, green, blue and open space

				networks, building typologies and density, and patterns of uses ...
2	P. Lu and D. Stead	Urban planning	2013	
7	S. T. Pickett,	Urban Ecology	2012	
5	A. Buyantuyev and J. Wu	Environment	2009	
4	Bruno De Mulder, Kelly Shannon	Urban planning	2008	... urban water landscape with a clear connection with the locally natural conditions, such as topography, hydrology and soils, fundamentally structures foundation of urban morphology ...
1	IPCC		2007	
6	K. a. Foster,	Urban planning	2006	... ability of a region to anticipate, prepare for, respond to and recover from a disturbance ... ... four stage criteria, including assessment, readiness, response, and recovery ... (i) consisting of two different connected types: preparation and performance, (ii) applies not only to a system, but to system elements (e.g. infrastructures, information, and physical environments), (iii) resilient on one element not necessarily resilient on another, and (iv) that resilience can be developed.
3	A. K. Duraiappah and S. Naeem,	Biology	2005	

## 6. Conclusion

The world is a capsule [79], consisting of different ecosystems and being able to self-organize and actively adjust to cope with both internal and external changes and disturbances. City or community, according to ecological science, has been considered as an ecosystem as well [29], because of their dynamics and complexities in adaptive systems. Both are changing quickly in the pace of our rapid civilization over recent decades. Changes have currently not attributed to natural conditions, but have been caused by increasing human-induced activities. Global warming is one of the consequences of such activities. Some changes could be known and predictable, while others unforeseen and unpredictable. In addition to the changing problematic situation, increasing desertification across the world has become more and more severe [6]. All changes must be dealt with actively on their own adaptive cycles in order to create an environment designed and built to be resilient and sustainable.

As discussed, the two properties of resilience are in sharp contrast. The traditional equilibrium state presumes homogeneity, predictability, and inherent stability of ecosystems, focusing on keeping it at stasis. Meanwhile, the most contemporary resilience focuses on the multiple stable states with hierarchical patch dynamics paradigm, heterogeneity, nonlinearity, and concerning natural flows [80]. The ideas of the latter are not only essential in the theory of ecological resilience, but also crucial in applying them so we could understand and manage socio-ecological systems, including spatial planning and urban design.

Based on the utmost meaning of the term resilience, spatial planning and urban design professions must take crucial roles in the process to achieve success in building an ecologically resilient system. However, a deep consideration in ecological resilience is a must. Hence, our emphasis should be on creating and maintaining urban resilience – the ability of a city to persist without changing its structure and function when facing perturbations. Essentially, we could design urban regions or cities resilient to any changes, including coexistence of drought-flood, as mentioned earlier, only by considering them as complex socio-ecological systems with dynamics, cross-scale interactions, etc.

In the context of DFC within at regional scale, such as the central provinces of Vietnam, situating in specific characteristics of meteorology, geography, topography, etc., beside drought caused by local context, and worsen by desertification, it faces flash floods caused by deep slope in highland area, narrowness in lowland, in addition to high precipitation and n as well [71]. The areas suffer twice as hard. A possible solution is that the human systems' water supply could be regulated at the regional

scale to avoid flash floods during rainy season and cope with drought during dry season [20]. The focal point of resilience perspective on spatial planning and urban design is proactively changing the situation of drought and flood, and possibly even dealing with the problem of rising sea level, instead of stasis – “to withstand change with adaptive change” [20]. Based on that theory, under carefully exploring local context at cross-scale interactions, all nature’s services could be easily regulated and managed, resulting in urban resilience - a threshold toward to sustainable development.

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