Spatialised flood resilience measurement in rapidly urbanized coastal areas with complex semi-arid environment in Northern Morocco

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1. **Abstract.** Enhancing resilience is critical for coastal urban systems to cope with and minimize flood disaster risks. This issue is certainly more important in Africa where the increase in floods frequency is a significant concern for many areas. In this context, urban planners need accurate approaches to set up a standard for measuring the resilience to floods. In Morocco, this issue is still not fully covered by the scientific community, despite the obvious need for a new approach adapted to local conditions. This study applied a composite index and geographic information system approach to measure and map resilience to floods in three northern coastal municipalities. The approach is also based on a linear ranking of resilience parameters, offering a more optimal classification of spatial resilience variation. The results allowed us to identify specific areas with different resilience levels and revealed the relationship between urban dimensions and the flood resilience degree. This approach provides an efficient decision support tool to facilitate flood risk management, especially in terms of prioritising protective actions.

Keywords: Resilience, floods, composite index, Africa, Morocco.

2. Introduction

Climate change is a major challenge for the development of African countries. Several studies have highlighted the severe impact of global change in Africa (Bates et al., 2008). The pattern of precipitation (Born et al., 2008; Giorgi & Lionello, 2008; Paeth, 2011), temperature (Fisher, 2015), and evapotranspiration (Speth et al.,2010) are more likely to change, which will alter the hydrological cycle, in many regions causing a change in the occurrence of extreme events such as drought and flooding, especially in arid and semi-arid areas (Karanja et al., 2016).

The coastal zones situated in semi-arid are considered among the most threatened areas by the increase of flood occurrence and rapid urbanization (Leal Filho et al., 2018). The impact of these floods particularly affects population concentrations. Consequently, as population growth increases, exposure to floods will be a real societal problem (Kundzewicz et al., 2014). Between 1993-2002, more than 19 000 000 have been affected by floods, and 9642 persons have died in Africa (Conway,

30   2009). Moreover, it is excepted that coastal African cities will experience a higher rate of population growth and urbanization over the 21st century (UN–Habitat, 2008; Lutz & Samir, 2010; Neumann et al., 2015). The rapid coastal development will exacerbate the already high vulnerability of many African coastal areas (Hinkel et al., 2011) since coastal cities are the most densely populated taking advantage of residential, industrial, commercial, educational, and military opportunities (UN–Habitat, 2015).

35   Morocco, situated in the North West of Africa, reveals a trend towards a decrease in average annual rainfall, as well as an increase in average annual temperature (Hoffman et Vogel, 2008; Terink et al., 2013; El Moçayd et al., 2020). The intensity of floods will increase over time (Vicuña et al., 2011; Doocy et al., 2013; Roy et al., 2018) while the main economic activities are located in coastal zones, where 60 % of the total Moroccan population are living (Snoussi et al., 2009). During recent years, several new policies have been implemented (Barthel and Planel, 2010; Ducruet et al., 2011; Kanai and Kutz, 2011) to improve

40   these areas' economic growth and reduce the negative effect of rural migration. In this regard, the economy's main drivers are based on tourism and free zones industries, which regrettably will increase the vulnerability of these zones to climate change (Perelli, 2018). Adaptation to climate change is an important factor to consider in order to achieve sustainability in such areas. As the combinations of environmental change, demographic growth, and urban complexity challenges will put the urban environment under pressure (Marana et al., 2019), there are several ways to tackle adaptation issues limiting the impact of a

45   climate-related disaster especially flooding (UNDRR, 2019). The classical proposed methods to deal with such issues involve implementing structural systems (Plate, 2002; Papadopoulos et al., 2017; Bertilsson et al., 2019). However, climate variability has a very substantial effect on the reliability of complex coastal area systems. Therefore, adaptation should also focus on resilience (Sustainable Development Goals) (Chen and Leandro, 2019; Miguez and Verol, 2016), rather than only structural measures. Resilience approaches aim to understand and manage a system's capacity to adapt, cope with, and shape uncertainty

50   (Adger et al., 2005; Folke et al., 2002).

   Since Holling's (1973) work, where the resilience concept originates from the ecology field, the concept has gained increasing interest and recognition (Cretney, 2014; Weichselgartner and Kelman, 2014; Patel et al., 2017; Kontokosta and Malik, 2018). Resilience concept has been considered, in different ways, by various research fields: psychology (Westphal and Bonanno, 2007), geography (Pike, 2010; Cutter, 2010), archaeology (Redman, 2005), and physics (Cohen et al., 2000). Recently

55   including natural disasters, risk management, and climate change adaptation (Godschalk, 2003; Cutter et al., 2008; Gaillard, 2010; Nelson Adger& Brown, 2007; Serre et al., 2018, among others.

   Within the context of disasters and climate change, many definitions of the resilience concept have emerged. Some are focusing on the ability of the system, community, or city to absorb disturbances, retaining the same basic structures and normal ways of functioning, with self-organization capacity, and adaption to stress and change (e.g. Pelling, 2003; Pendall et al.,2007, IPCC,

60   2007;). The bouncing back to the original state (equilibrium) after a disaster is undesirable (Klein et al. 2003), knowing that social systems are in a continuous state of change. Adaptation to some changing trends or several states of equilibrium becomes one of the main characteristics of resilience depending on being prepared for the unprecedented and unexpected changes (Walker et al., 2004; Pendall et al., 2007; Paton &Johnston, 2006; Ahern, 2011). This is determined by system's capacity to

organize itself, learn from past disasters, and improve risk reduction measures (UNISDR, 2015). Some works (e.g. Meerow et
al., 2016) have linked the concept to the temporal and spatial scales, considering resilience as the ability of urban system
components (ecological and socio-technical) to maintain or rapidly return to desired functions.

Resilience has a systemic property and implies greater consideration of the temporal variability (Reghezza, 2015).Some works
describe it as the ability of short-term absorbing, self-organizing, and long-term learning and adaptation (e.g. Chen N, &
Graham P. 2011; Colding J., & Barthel S, 2013). The current diversity in definitions makes it difficult to have a common
concept (Carpenter et al., 2001). Therefore, set a resilience definition concept could be an appropriate basis.

In this work, the resilience of the urban system to floods is the capacity of urban-flooded areas to maintain the activities during
and after floods. Simply put, a resilient coastal urban area will be able to absorb the disaster (at an acceptable level) and be
adapted to the changes. Besides, urban resilience is a complex and multidimensional concept (Sharifi, 2016), the resilience of
the urban system to floods includes several dimensions of an urban system: Social, economic, physical, natural, and
institutional dimensions equally important (Batica, 2015; Qasim et al., 2016). The social dimension explores flexibility, health
status, knowledge, while the economic dimension is related to the economic capacities, income resources, and connections
devices within the community. The physical dimension may include urban density, building materials, and infrastructure
(Qasim et al., 2016) and can be quantified based on physical indicators such as flood depth or flood duration extracted from
flood simulation data (Mugume et al.,2015; Chen and Leandro, 2019). Areas located at low elevations or near rivers are more
sensitive to flood disasters, constituting the natural component of resilience (Hung et al., 2016). Thus, institution's efforts aim
to cope with disasters through better planning, awareness programs prefer integrated approaches by considering all these
dimensions in the evaluation of resilience. This may help to have a global perspective, which will lead to creating suitable
management tools that can be very useful in the decision-making process (Bertilsson et al., 2019). Supporting this decision-
making process on strategies, actions, and measures to be taken, planning for the long-, medium- and short-terms and assessing
the progress starts with assessing the current and expected future status of resilience. This will highlight where urban resilient
areas are and identify their strengths and weaknesses (Cardoso et al.,2020).

Because of its multidimensional aspect, quantify resilience remains a great challenge (Bertilsson et al., 2019). Many works
have shown the need to have some metrics able to measure resilience. However, to date, there is no consensus about a single
metric evaluation, and the literature refers to the need for measures (e.g. Meerow et al., 2016; Asadzadeh et al., 2017; Rus et
al., 2018). Furthermore, making resilience tangible and practical for cities through a transition from theory to practice, is
challenging (Kontokosta & Malik, 2018; Meerow et al., 2016). Quantitative approaches through composites indicators provide
a synthetic measurement of a complex and multidimensional phenomenon (Changdeok et al., 2019. Those indicators are
developed based on the aggregation of multiple individual indicators (OECD, 2008). The choice of method to construct
composite indices dependent upon the type of problem, the nature of the data, and the goals (Nardo et al., 2005). Several
composite indices to assess the resilience of urban areas and compare their resilience levels within specific geographical
regions have been proposed in recent years (e.g. Sharifi et al., 2016; Asadzadeh et al., 2017). For example, the work of Cutter
et al. (2014) using BRIC (Baseline Resilience Indicators for Communities) as the first attempt to the operationalized version

of the conceptual framework "DROP model (Cutter et al., 2008). Within a socio-ecological approach, BRIC was calculated for multi-hazard context. Among other analysts, Joerin et al., (2014) state CDRI (Climate Disaster Resilience Index) gauges the different capabilities needed for communities in an urban system to regain an equilibrium state after climate-related disasters such as cyclones, droughts, floods, and heatwaves. Following the same holistic spirit, this index was adopted in Climatic Hazard Resilience Indicators for Localities (CHRIL) (Hung et al., 2016). (Mayunga.2007) also proposed a Community Disaster Resilience Index (CDRi). All of those previous indicators were applied to quantify community resilience to multi natural hazards. (Qassim et al.2016) determined community resilience to a particular hazard "floods", and specific community "urban areas", as recently proposed also by Cariolet et al., (2019). Although, many particular indicators were developed for a specific case of urban resilience to a specific hazard like floods.

Based on time-dependent characteristics, FResI was constructed to assess future resilience responses relative to the present situation (Miguez and Verol. 2016). Further, Chen and Leandro (2019) quantified the flood resilience of households in urban areas by FRI (Flood Resilience Index) as a time-dependent method. More examples of specific indicators are available (Kotzee and Reyers, 2016) using Geographic Information Systems (GIS) and stressing the need to move towards diversify resilience assessment approaches.

Regardless of several challenges associated with data quality and availability constraint (Moghadas et al., 2019; Cai et al., 2018), and standard procedure for composite indicator development (Asadzadeh et al., 2017), particular attention has been paid to composite indicators (Heinzlef et al., 2019a), regarding their ability to analyze the urban, social and technical resilience of a city. However, a lack of resilience measurement tools developed by local authorities and organizations in the developing countries was reported in a critical review by Sharifi.A., & Yamagata, Y. (2016).

The Mediterranean region will suffer from severe impact due to climate change (Tuel and Eltahir,2020). Particularly Morocco is mentioned as a hotspot for climate change in several works (Born et al. ,2008; Driouech et al. ,2009; Ouhamdouch & Bahir, 2017). Moreover, the the precipitation's seasonal distribution of strongly influences the Mediterranean river hydrology (Thornes et al., 2009). Assessing the intensity of the impact, Regional Climate Models (RCM) simulations over this area all agree that Morocco might experience an increase in temperature and a decrease in precipitation (Driouech et al., 2010). This will have a severe impact on water (Bahir et al., 2020), and natural hazards (Satta et al., 2016), among others. Consequently, increasing resilience against flooding is, therefore, of utmost importance to achieve sustainability (Snoussi et al., 2008). However, a knowledge gap for a better understanding of resilience has been identified at national and local levels (Price, R.A. 2017) in Morocco. It is highly recommended to provide policymakers with a simple approach and ways to enhance resilience to floods in the local area (OCDE 2016).

The present study is the first attempt to provide a methodological way to measure flood resilience for Northern coastal municipalities in Morocco: Martil, M'diq, and Fnideq. In this work, flood resilience refers to the resilience of these coastal urban areas (Martil, M'diq and Fnideq) to floods. These areas were selected because they show18 hot spots highly exposed to floods (ABHL 2016). Moreover, the area is particularly highly vulnerable to multi-hazards types, including floods (Karrouchi et al., 2016; Taouri et al., 2017), sea-level rise (Niazi, 2007; Snoussi et al., 2010), and coastal erosion (Satta et al., 2016;

Nachite, 2009). However, the littoral is nowadays very urbanized, and tourist activities are the main economic resources in the area (Anfuso et al., 2010).

2. Methods: study area and index development

2.1. Fnideq, M'diq, and Martil municipalities

Related to M'diq-Fnideq prefecture, Fnideq, M'diq and Martil municipalities have a population of "984hab/km²" (RGPH 2014). Precipitation regime characterized by seasonality, annual average rainfall of 679 mm (ABHL 2016). Rainfall variability is based on altitude and the geographic situation (Karrouchi et al., 2016). Rivers flowing into the Mediterranean Sea (Martil, Mellah, Smir, Negro and Fnideq) drain slowly during the rainy months and highly in a short time during flash floods (Niazi, 2007). While, the frequency of flood events and related damages increased gradually over time (e.g. on 26 December 2000, Martil Floods have invaded more than 2400 ha in the Martil plain) (Fig.1). Urbanization is concentrated in coastal zones and puts pressure on coastal ecosystems with high touristic value (Snoussi et al.,2010). It is pitiable that municipalities are also vulnerable to multiple climate and non-climate hazards such as erosion and morphological changes (Satta et al., 2016).

2.2. Theoretical comprehensiveness for composite index development

To produce an aggregate measure of resilience, through manipulation of individual variables, constructing a "Composite indicator" is often applied. It is a mathematical combination of thematic sets of variables that represent different dimensions of a concept that cannot be fully captured by any individual indicator alone (Nardo et al., 2008). An indicator is a quantitative or qualitative measure derived from observed facts revealing the relative position of the phenomena being measured. "It can illustrate the magnitude of change (a little or a lot) as well as the direction of change over time (up or down; increasing or decreasing)" (Cutter et al., 2010). Moreover, considerable attention is increasingly given to composite indices as useful tools for decision-making and public communication. They simplify and communicate easily the reality of complex situations (Freudenberg, 2003) and convey more precise information (Saisana et al.,2005). However, through different geographical contexts and scales, these indices may encompass many theoretical perspectives (Cutter et al.,2008). Also,the quality of the framework, the data, and the used methodology can significantly influence a composite index's qualities and the soundness of the messages that convey.

Flood Resilience Index is explored and calculated differently in several works. Kotzee and Reyers (2016) used PCA as a method to construct this index and define its component weights. For Batica (2015) It has been built taking into account different spatial scales and focusing on urban functions. Using time series indicators (event phase and recovery phase), Chen and Leandro(2019) computed FRI at time t as the product of the recovery factor and the FRI at the previous time step t-1. By defining resilience as time-dependent, based on two phases (event and recovery), Leandro et al., (2020) shown also the ability

of the developed FRI for assessing climate change adaptation. Despite the already existing studies on flood resilience assessment, there is still a need to develop methods for a specific case of study, where data availability remains a challenge, and the need for a tangible and simple way to better understand resilience is increasing.

165   In this study, we adopt the specific Flood Resilience Index to quantify the resilience of coastal urban areas to floods. FRI was divided into four sub-indicators: Social, Physical, Economic, and Natural sub-indexes, so as to enable sufficient flexibility to include or not each sub-index in global composite index (Fig.2). Three indicators were chosen for each sub-index (Tab1) based on data availability and their contribution to persistence, recovery, or adaptive capacity (the main components of the adopted resilience definition): Households Density (HD), Illiteracy Rate (IR), and Vulnerable Individuals Indicator (VII) were

170   taken into consideration as the mean indicators that affect the social resilience negatively and construct the social sub-index. The physical sub-index included the Old Buildings Rate (OBR), the Modernly Built Houses (MBH), and the Connection to Water Infrastructure (CWI). This sub-index is important because it improves the physical capacity of individual and common properties against floods, and thus minimizes their vulnerability degree. The Economic resilience sub-index also includes three indicators: Unemployment Rate (UR), Building Density (BD), and Communication Capacity (CC). Finally, Elevation (E),

175   Stream Network Density (SND), and Distance from Depressions (DD) are the indicators selected to determine the natural resilience sub-index.

2.3. Selecting indicators: Scoring and classification

Based on their relevance, analytical, representativeness, and accessibility, 16 indicators (variables) were selected (Tab.1). The data used was mainly drawn from the National Population and Housing Census (RGPH, 2014). The Arc Hydro and Line

180   Density modules of ArcGIS© were used to generate a stream network density from an ASTER digital elevation model (30 meters of spatial resolution), while Google high-resolution satellite imagery was used for digitizing the building area. This was converted firstly into points, and then their density was calculated using the ArcGIS© Point Density module.

2.4. Normalisation

Indicators integration into sub-indicators needs data normalization. Respecting the theoretical framework and the data

185   characteristics, a Min-Max normalization was applied. Subsequently, each variable was normalized from 0 to 100 according to the following equations (1) and (2):

$$V^+ = \left(\frac{\text{real value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \right) * 100 \tag{1}$$

$$V^- = \left(1 - \left(\frac{\text{real value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \right) \right) * 100 \tag{2}$$

Equation (1) was applied for variables that positively influence resilience while Eq. (2) was applied to those that are negatively
190 correlated with resilience. When the scores are attributed, each of these indicators was gridded and then a geodatabase was created to calculate the sub-indexes by using the GIS. Each sub-index is the mean value of all correspondent indicators.

2.5. Weighting and aggregation

The existing methods for determining weights are not always reflecting the priorities of decision-makers (Esty et al., 2005), which are subjective (Cutter et al., 2010). Equal-weighting is the most common for composite indices with several sub-
195 indicators (OECD, 2008). Thus, several arguments listed by Greco et al., 2019 ("i" simplicity of construction, "ii" a lack of theoretical structure to justify a differential weighting scheme, "iii" no agreement between decision-makers, "iv" inadequate statistical and/or empirical knowledge, and, finally "v" alleged objectivity). Moreover, the weighting method selection depends on the local factors where the method is applied (Mayunga, 2007; Reisi et al., 2014). Allocating equal importance across different indicators is better suited when no knowledge exists about the interactions among the sub-indicators/indices and the
200 corresponding composite index at the local scale (Cutter et al.2014; Asadzadehet al.2017). All variables are given equal weight (EW) in our case of study. The main reason is to allocate equal importance across indicators. Because of the lack of knowledge, and justification about the existing interactions among the sub-indicators and composite index at the local level, avoiding a large concentration of few indicators and making it is easy to communicate.

The simple method of aggregation supposed to be transparent and easy to understand, is a critical criterion for potential users
205 (Cutter et al.,2010). All individual indicators have the same measurement unit. Therefore, using linear aggregations is preferred over geometric aggregation. The linear aggregation formula of the FRI takes the following form Eq. (3).

$$FRI = \frac{SRI+PRI+ERI+NRI}{4}$$
(3)

Social Resilience Index (SRI); Physical Resilience Index (PRI); Economical Resilience Index (ERI); Natural Resilience Index (NRI); Zero is considered as low resilience level, 100 as high resilience level, and 50 medium resilience level.

210 **2.6. Links to other indicators**

To assess the correlation between the composite index and corresponding sub-indices/variables, a statistical analysis was performed, using the program SPSS 23. Data presented as a mean and standard deviation (st.dev) were statistically analyzed using multi-variance to confront data of natural, physical, economic, and social conditions with the Flood Resilience Index. Furthermore, to identify which variables differ significantly between the three case-study sites. The significant differences
215 were distinguished by posthoc Tukey's Honestly Significant Difference (HSD) test at p<0.05. The Spearman's rho coefficient was used for correlations between variables. Only significant correlation coefficients at a level of 0.05 are considered.

2.7. Visualization and validation

Particular attention has been paid to the visualization given its relevance in helping and enhancing interpretability. Maps facilitate further exploration of spatial data trends (Kotzee and Reyers, 2016). For that purpose, Geographic Information Systems (GIS) was adopted to visualize FRI and sub-indicators. After visualizing the composite index results, validation was the last step. Acting like a 'quality assurance', this step will highly reduce the possibilities to convey a misleading message (Saisana et al., 2005). Unfortunately such step is often skipped for the vast majority of the composite indices (OECD.2008). External validation has been the most used to validate several indicator results (CDRI 2009, BRIC 2012, CDRI 2013, and BRIC 2014).

In our case, the validation based on actual outcomes of the municipalities is possible using cross-validation type. It was performed to test and compare the reliability of FRI results using the results of other studies interested in hydro-climatic hazards as suggested by Satta et al., (2016). This is possible through the opposite correlation between risk and resilience (Cutter et al., 2014; Sherrieb et al.,2010). Seeking optimization by considering social and economic pathways, and combining flood resilience and flood risk, measures can be effective against a broader range of hazards than when considering either method alone (Disse et al., 2020).

3. Results

3.1. Sub-indices

Each sub-index was observed separately to get additional insights about Flood resilience Index. For the social resilience (Fig. 3D), produced based on the three indicators of social resilience (Fig. 3A, B and C). The highest values of social resilience are more related to a few urban areas than rural and less developed sectors ones. In terms of mean value, the social resilience sub-index was higher in Martil (69.03±11.24) followed by Fnideq and the coastal area of M'diq showing similar values (57.11±9.26 and 57.17±11.44 respectively).

Higher physical resilience scores (Figure 4A, B, C and D) are concentrated in the urban center areas with a spatial tendency towards the coastal area. Even though pockets of lower scores exist in the central area and some less developed sectors indicating low physical resilience levels. Therefore, the central area had a bit low level of physical resilience as compared to Fnideq, M'diq and Martil urban centres and the coastal zone (Fig.4 D).

Results (Fig.5D) show a concentration of the low and moderate levels of economic resilience in the three urban centers. However, this does not exclude that some coastal urban sectors showed high levels of Economic resilience sub-index.

The overall map of Natural Resilience Index shows a spatial variability between the lowest and the medium level of NRI in the whole study area (Fig.6 D). However, the high level of natural resilience is more prevalent in areas with high altitudes, such as Capo-Negro (Fig.6 AC).

3.2. Total Flood Resilience Index

The results reveal a marked spatial variability of resilience to floods (Fig.7). Overall, 31% of the study area varies from low to very low, which equals 45 km² (Fig.8a). 43% of the studied area, which equivalent to 52 km2, was classified as moderately resilient and only 17% of the studied area (17 km2) was classified as highly resilient and the remaining 3% with very high resilience. The central area shows the lowest levels of FRI, including sensitive coastal sites such as Smir Lagoon, Kabila beach, and Restinga beach. In contrast, M'diq and the North of Martil have relatively moderate to high values in terms of resilience to floods. However, the significant disparities between rural and urban areas, especially in terms of socioeconomics, highly influences the flood resilience index values.

In order to avoid any confusion related to flood management priorities between the rural and the urban areas. The resilience map corresponding to urban areas were extracted, and the index values using GIS were reclassified to have the priority areas without taking into account the rural part. Using this tool to overlay the spatial distribution of households (RGPH 2014) and FRI map, it turns out that 1151 households (around 2.4%) are in areas of very low resilience and more than 7800 households (about 16%) in low-resilience areas. On the other hand, 7402 households are in a high resilience situation, and only 177 can be qualified as very high resilient (Fig.8b).

3.3. Statistical analysis

In order to evaluate the contribution of the sub-dimensions (Social, Economic, Physical and natural dimensions) for the resilience analysis, the statistical relationship between the total Flood Resilience Index (FRI) and its sub-indices was estimated for each municipality (Tab.2).

The SRI is positively correlated to the FRI index in the three municipalities ($p<0.001$), particularly in the urban areas where it is proven to be important as an FRI component. Regarding the ERI sub-index, it shows a moderate correlation at the Fnideq and Martil municipalities ($p<0.01$), or even a low correlation at the M'diq level ($p<0.05$). Unlike SRI and ERI, the correlation to the PRI sub-index is different from one municipality to another. It is strong at the level of Martil ($p<0.001$), weak at the level of Fnideq ($p<0.01$) and absent at the level of M'diq. In the case of the NRI sub-index, it displays a strong correlation at the level of Fnideq and moderate at the level of Martil and M'diq.

4. Discussion

Within the current context of global climate change associated with an increase of flood damage, the efficient use of available data is, in most cases, the primary source of judgment control decision-making for flood risk management (Ouma et al., 2014). Producing flood resilience maps has thus become a crucial issue for local flood management planners (Godschalk, 2003). However, these products require generally detailed knowledge about all resilience components in time and space to be effective. They should be designed in such a way that can help the decision-making by using the ranking and prioritization

process (Chitsaz et al., 2015). Accordingly, the choice of a good methodology to assess and quantify resilience attains its utmost importance and relevance. Indeed, the adopted methodological approach as well as the quality of the data has a significant influence on the obtained results, and hence on the final decision making (Suárez et al., 2016).

In this paper, the adopted methodology is adaptable according to the study case and the available data. Moreover, the adapted ranking process is based on linear scoring, which offers the advantage to be more sensitive to changes compared to the usual methods based on assigning scores according to intervals (e.g. Angeon et al., 2015). It also provides a more reliable and objective spatial comparison of resilience parameter values which will finally allow obtaining effective prioritization of resilient areas.

It should be noted that significant components for the resilience analysis have been considered and the obtained resilience map allowed to classify the study area according to four resilience degrees to floods: very low, low, moderate, and high.

The difference in the social resilience sub-index between urban and rural areas could be explained by the fact that human development indicators are generally lower in rural and less developed areas, especially those related to school attendance and people vulnerability, which affect social resilience negatively. However, the difference in SRI between municipalities may occur because of the great growth rate of Martil municipality rather than Fnideq and M'diq (HCP, 2018)

The low physical resilience in the central area and the less developed sectors may exist because of the low population and urbanization (e.g. At the central area access to water infrastructure, as basic service is still low (Figure 4C). Unlike in the case of the urban centers with high physical resilience scores.

Meanwhile, the high level of Economic resilience sub-index in some coastal urban sectors may be explained by tourism and economic activities. An expected result has given the characteristics of the wealthy residents living there (Tempelhoff et al., 2009; Kotzee et Reyers. 2016). Unlike the three urban centers having low and moderate economic resilience that could be explained by the high unemployment rate "17.9 %"(HCP, 2018) and the high urban density. These results support our hypotheses and the suggestions from Cutter et al. (2010) and H.-C. Hung et al. (2016). Further, the results of (Irajifar et al. 2016) show that the association of high population density and high incomes make a recovery after disaster quicker.

The overall picture of natural resilience shows that all three municipalities have lower natural resilience. Martil had a bit low level of the NRI as compared to Fnideq and M'diq. This is because of the lowest values of elevation indicator and distance from depressions. The findings are fully corresponded to the existing literature (H.-C. Hung et al.,2016), supporting the relationship between elevation, flood-prone areas, and the least resilience.

The areas with very low and low Flood Resilience Index seem to be generally associated with the areas showing unstable socials conditions. This observation is confirmed by the statistical analysis, and studies (Godschalk, 2003; Cutter et al., 2010; Kotzee et Reyers, 2016; Moghadas et al., 2019) showing that social resilience is strongly correlated to flood resilience degree. Moreover, the disparities highlighted between rural and urban areas revealed that rural areas display the lowest resilience to floods.

310 The natural resilience which is tightly linked in the sites is the second most statistically significant indicators linked to the total FRI. Disparities between municipalities are less significant. This means that areas having low or moderate resilience to floods need equal attention (Qasim et al., 2016).

The risk and vulnerability-oriented studies (Niazi, 2007; Snoussi et al., 2010; Nejjari, 2014; Satta et al., 2016) in the coastal area were used for validation. The results are consistent, showing that coastal sites such Restinga plain, kabila beach, Smir

315 lagoon and Martil-Alila plain having a low resilience are highly vulnerable to the flash floods and sea-level rise impacts (Snoussi et al., 2010; Niazi, 2007; Satta et al., 2016). Considering all the output, this confirms that the flood resilience index is relatively valid and can be adapted and tested in other geographical areas. Moreover, this robustness analysis makes the FRI in this case of study support the idea that areas with higher vulnerability levels examined have lower resilience levels (H.-C. Hung et al., 2016).

320 In this context, there is a need to prioritize the actions contributing to enhancing the social and economic communities' levels. Providing support and strengthen actions promoting social and economic levels in the municipalities.

Further, the statistical analysis shows a significant link between the natural characteristics and resilience degrees. In that situation, it is recommended to establish best practices and measures to avoid urban development in flooded areas and to provide more efforts to manage the risk of floods in urbanized areas, with a strong focus on the contingency plans in case of

325 power or drinking water failure in the three municipalities.

Therefore, there is a need to incorporate disaster management education in college to explain hazard adaptation. Also, educate people through communication devices, seminars and workshops involve citizens to be aware of the damages and the climate change effects.

The obtained results highlight the importance of using a multidimensional approach to assess flood resilience. Furthermore,

330 GIS is also highly recommended as a solution to complex situations and as a decision support tool that offers an interactive use and continuing improvement (Ouma et al., 2014; Mayunga, 2007).

5. Conclusion

Building and enhancing resilience to floods becomes critical, as the urban development in a coastal area in Africa is increasingly stressed. Especially, for the coastal zones situated in semi-arid threatened areas. Nevertheless, in Morocco's local

335 contexts, where this study is the first attempt focusing on enhancing the understanding of resilience to floods highlighting the application of the tangible approach to summarize and present complex components linked to resilience to floods.

Flood resilience assessment was piloted using a composite index and Geographic Information Systems. The spatial and statistical analysis gave further insights into the geographic distribution of Flood Resilience Index across Fnideq, M'diq and Martil municipalities. Moreover, the index clarifies the presentation of a complex set of components linked in a reproducible

340 way.

The findings indicate that different factors can vary spatial patterns of resilience to floods. The framework is flexible enough to allow the proposed index, in future work, to take into consideration the institutional component. Including the institutional component could advance our understanding of flood resilience and provide useful results to suggest floods adaptation

strategies in a coastal area. The robustness of the flood resilience indicator was tested by comparing the results against
345 additional case studies and operationalized resilience measures. Some of the main limitations of the developed Flood Resilience Index are: starting with tackling the main limitations from considering real/simulate flood inundation maps, and integrating climatic data (flood data or flood simulation data). Besides, for robust validation, the date of resilience assessment and validation tool date should be highlighted to take the specific changes in land covers between the two periods of time. Further work will use other methodologies developing Flood Resilience Index in the same coastal area to provide further
350 insights about indicators assessments and the relationships among flood resilience and flood risk.

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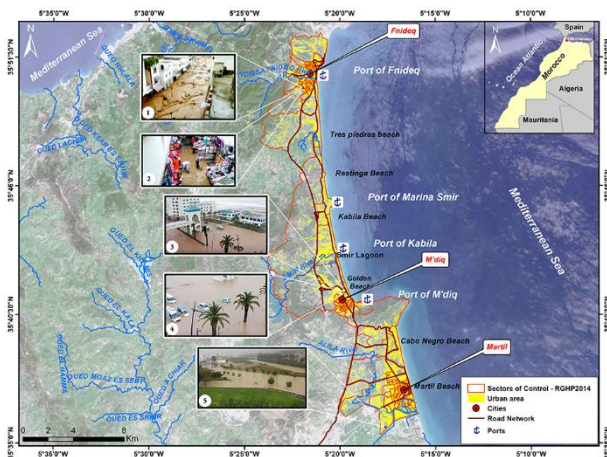


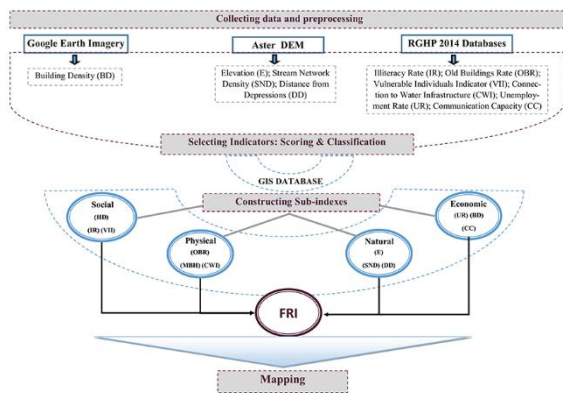
Figure 1: Location of the three studied municipalities: Fnideq, M'diq and Martil, in Northern Morocco and examples of the flooding (1: Photo of Fnideq Center in September,28th2008; 2: Photo ofAlmassira Commercial Center Fnideqin September, 27th2014; 3 and 4: Photo of M'diq in March, 06th 2010; 5:Photo of Martil River in March, 02nd 2018). (©Copernicus data (2017).

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Figure 2: Procedure used to assess flood resilience in the three municipalities

Dimensions	Indicators	Description, effect on resilience &justification
Social *(SD)*	Households Density (HD)	Cities with higher building density in developing countries tend to be densely populated, with many areas that have grown fast, (Andersson, 2006), often with insufficient infrastructure, resulting in environmental degradation and high damaging floods. Studies have found that high resilient sites had low population density (Sanabria-Fernandez et al., 2019).
	Illiteracy Rate (IR)	The persons who have never learned to read. That can make the emergency and public awareness processes challenging. (Cutter et al., 2010)
	Vulnerable Individuals Indicator (VII)	It refers to all vulnerable people (0-14 year olds, 60 year olds and disabled people) who can creates hindrances in mobility during floods and operations of evacuation (Hung et al., 2016; Qasim et al.,2016).
Physical *(PD)*	Old Buildings Rate (OBR)	Is the percentage of buildings that are over 50 years old, it expresses the fragility that increases with building materials age.
	Modernly Built Houses (MBH))	Based on the building material factor (by Reinforced concrete and bricks with mortar) modernly built houses will suffer less exterior damage during floods events in the local state (Cutter et al., 2010).
	Connection to Water Infrastructure (CWI)	The rate of connection to the sewage system and drinking water distribution strength resilience community (Cutter et al., 2010).

		A not being guaranteed access to water during and after emergency (Pagano et al., 2017) will aggravate the situation.
Economic ***(ED)***	Unemployment Rate (UR)	It expresses the decrease in the individual economic capacity. Unemployed people are faced with difficulties related to their disability to recover or rebuild their damaged property (Cutter et al., 2010; Sherrieb et al., 2010).
	Building Density (BD)	It reflects the concentration of building per area. People are more concentrated in low quality urban housing, infrastructure and services the impact of natural disaster is higher (Pallard et al., 2009).It was selected based in the fact that an area with high building density is less resilient to floods.
	Communication Capacity (CC)	Is the rate of persons having communication devices (Television, Mobile phone and Internet).It express communication facilities availability , during, after and before flood hazards. strengthen resilience (Cutter et al., 2010).
Natural ***(ND)***	Elevation (E)	It was selected based on the fact that lands with low elevation, are more risked to flooding and exposed to damages compared to high elevation areas.
	Stream Network Density (SND)	It describes the degree of drainage network development and was recognised to be significantly linked with the formation of flood flows (Pallard et al., 2009).
	Distance from Depressions (DD)	It expresses the distance from flood-prone areas or flood risk areas (ABH databases 2016) including natural depressions of high flow accumulation.

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Table 1: Indicators descriptions selected to assess the flood resilience in Fnideq, M'diq and Martil area; (compiled from different sources)

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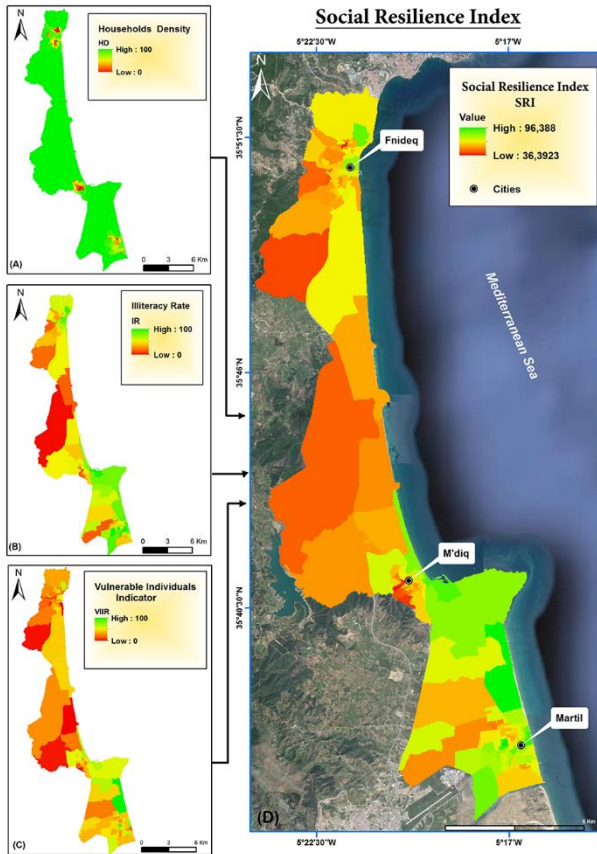


Figure3: Spatial distribution of A: Households Density, B: Illiteracy Rate; C: Vulnerable Individuals Indicator and D: Social Resilience Index (obtained from © Google map image in 2018).

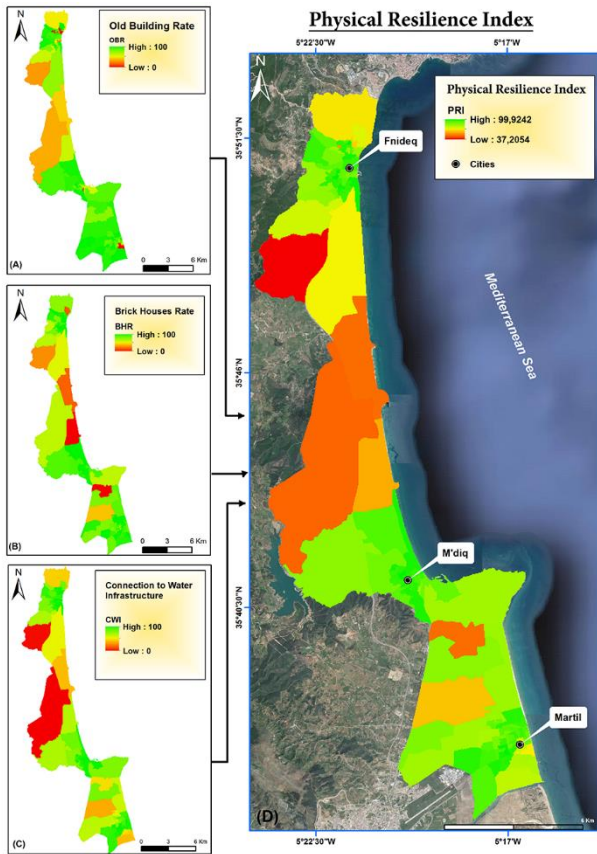



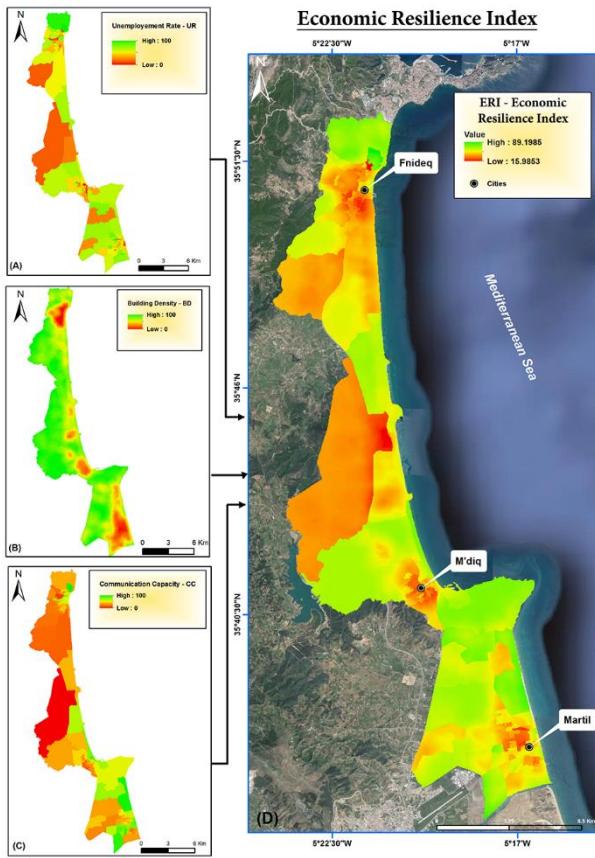
Figure 4: Spatial distribution of A: Old Buildings Rate, B: Brick Houses Rate, C: Connection to water infrastructure and D: Physical Resilience Index (obtained from © Google map image in 2018).

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Figure 5: Spatial distribution of A: Unemployment Rate, B: Building Density 2017, C: Communication Capacity and D: Economic Resilience Index (obtained from © Google map image in 2018)

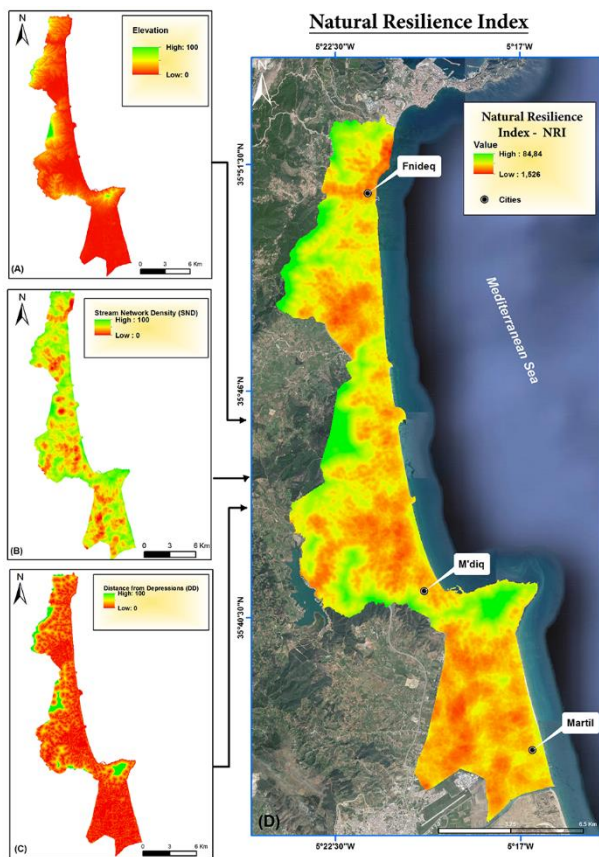
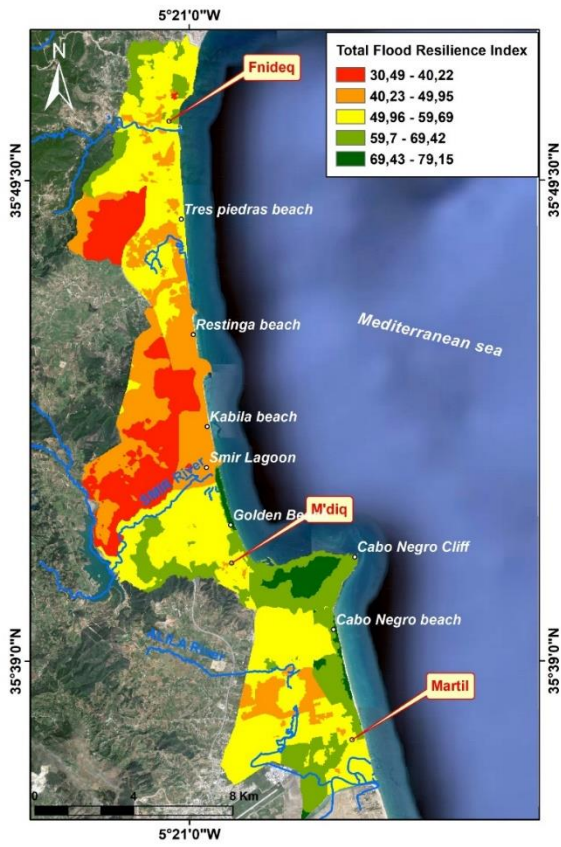



Figure 6: Spatial distribution of A: Elevation, B: Stream Network Density, C: Distance from Depressions and D: Natural Resilience Index (obtained from © Google map image in 2018)

		SRI	ERI	PRI	NRI
FRI	**Fnideq**	0.643***	0.441**	0.378*	0.650***
	Martil	0.764***	0.425**	0.589***	0.470**
	M'diq	0.800***	0.408*	-	0.544**

*p<0.05; **p<0.01; ***p<0.001.

Table 2: Spearman's rho Correlation between the total Flood Resilience Index (FRI) and its dimensions.

690   **Figure 7: Distribution of Total Flood Resilience Index. (obtained from © Google map image in 2018)**

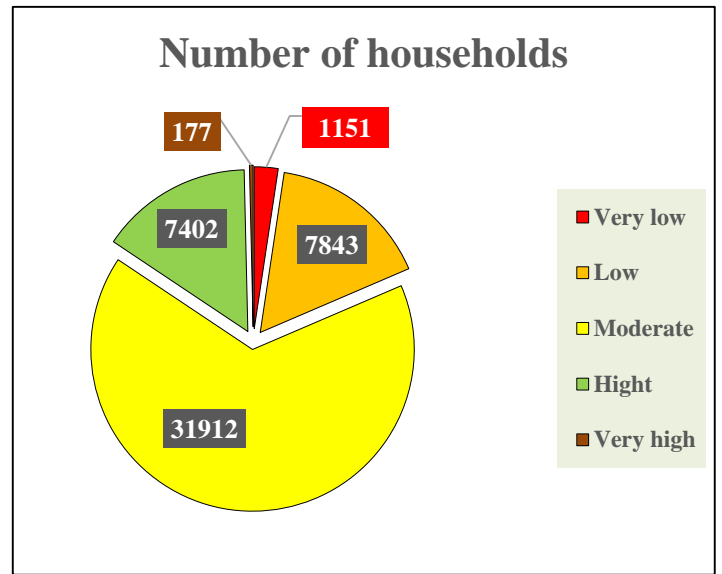
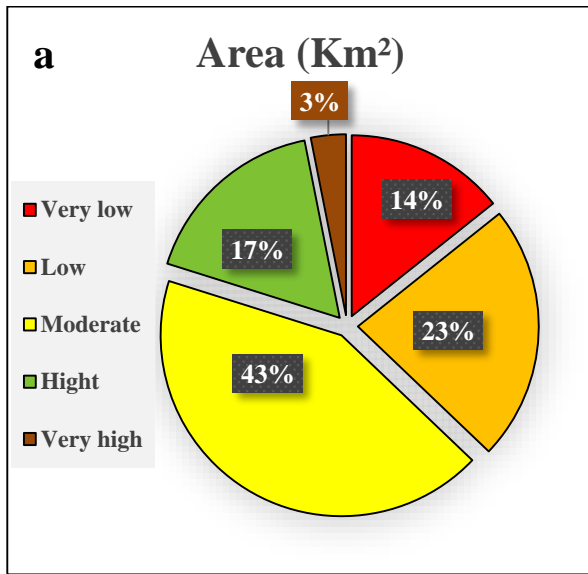



Figure 8: a) Total Flood Resilience scores distribution according to the surface of the study area; b) Total Flood Resilience scores distribution according to Households numbers in the study area.