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

Narjiss Satour [1], Otmane Raji[2,] Nabil El Mmoceayd[3], Ilias Kacimi[1], Nadia Kassou[1]

[1] Geosciences, Water and Environment Laboratory, Mohammed V University,in Rabat, Morocco.
[2] Geology & Sustainable Mining, University Mohammed 6 Polytechnic, Benguerir, Morocco.
[3] International Water Research Institute, University Mohammed 6 Polytechnic, Benguerir Rabat, Morocco.

Correspondence to: Narjiss SATOUR (narjiss.satour@gmail.com)

1. **Abstract.** Enhancing resilience is critical for coastal urban systems to cope with and minimize flood disaster risks. The global increase in the frequency of floods is a significant concern for many areas in Africa. With this regard, 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 findings allowed 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 prioritization of 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 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 (Karanja et al., 2016), especially in arid and semi-arid areas.

In particular, 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). Population concentration impacts flooding. Consequently, as population growth increases, exposure to floods will be a real societal problem (Kundzewicz et al., 2014). Actually, 9642 persons died out of 19,939,000 affected by floods in Africa between1993-2002 (Conway, 2009). Moreover, it is excepted that

30 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 developed urban areas in Africa with residential, industrial, commercial, educational, and military opportunities (UN–Habitat, 2015).

Morocco, situated in the North West of Africa, reveals a trend towards a decrease in average annual rainfall, as well as an

35 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 the economic growth of these areas and reduce the negative effect of local migration. In this regard, the main drivers of the

40 economy are based on tourism and free zones industries, which 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 climate-related disaster and especially flooding, which is considered ~~as~~ the most challenging disaster (UNDRR, 2019). The

45 classical proposed methods to deal with such issues ~~a problematic~~ involve ~~resides in~~ implementing structural systems (Plate, 2002; Papadopoulos et al., 2017; Bertilsson et al., 2019). Sizing these systems remain subject to ubiquitous uncertainty. Climate variability will affect the reliability of such 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 the capacity of a system to adapt, cope with, and shape

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

Since the work of Holling~~,~~ (1973), 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).

55 Recently 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 ~~(Pelling, 2003; Pendall et al.,2007, IPCC, 2007;)~~ are focusing on the ability of 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

60 change (e.g. Pelling, 2003; Pendall et al.,2007, IPCC, 2007;). The bouncing back to the original state (equilibrium) after a disaster is undesirable (Klein et al. 2003), social systems are in a continuous state of change. Adaptation to some changing trends ~~new reality~~ (Paton &Johnston, 2006) or ~~a~~ several states of equilibrium (Walker et al., 2004; Pendall et al., 2007), becomes one of the main characteristics of resilience depending on being prepared for the ~~able to adapt to~~ unprecedented and

unexpected changes (Ahern,-2011). This is determined by the capacity of the system to organize itself, to learn from past disasters, in the Asian Cities Climate Change Resilience Network (ACCCRN) program, and to improve risk reduction measures (UNISDR, 2015). Some previous work (Meerow et al., 2016,) 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, adapting to change in the face of disturbance and quickly transform systems that limit current or future adaptive capacity. Resilience has a systemic property (Reghezza, 2015) and implies greater consideration of the time variable (Reghezza, 2015). Furthermore, some works (Chen N, & Graham P. 2011; Colding J., & Barthel S, 2013) describe the resilience of the system as the ability of short-term absorbing, self-organizing, and long-term learning and adaptation. The abundance of definitions shared makes it difficult to have a common definition concept (Carpenter et al., 2001). Therefore, it is important to set a resilience definition concept could be to form a- an appropriate basis (Carpenter et al., 2001).

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 where a coastal urban area will be able to absorb the disaster (at an acceptable level) and adapt to the changes. Besides, urban resilience is a complex and a 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) or 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 to the rivers are more sensitive to climatic flood disasters, which constitutes the natural component of resilience (Hung et al., 2016). Thus,Finally, institutions efforts aiming at coping with disasters through better planning, awareness programs prefer integrated approaches and by considering all integrating these dimensions in the evaluation of resilience. This may helps to have a global perspective general picture, which will lead to creating create suitable management tools that can be very useful in the decision-making process (Bertilsson et al., 2019). Supporting the this decision-making process on strategies, actions, and measures to be taken, planning for the long-, medium- and short-terms and assessing the progress, start with the assessment of the current and expected future status of resilience, to know where urban cities resilient areas are, and helping to identify their strengths and weaknesses (Cardoso et al.,2020).

Because of the its multidimensional aspect, it remains challenging to quantify resilience (Bertilsson et al., 2019). Many works have shown the need to have some metrics allowing to have some measure of resilience. Yet there is no consensus about a single metric of evaluation, and the literature (e.g. Meerow et al., 2016; Asadzadeh et al., 2017; Rus et al., 2018) refers to the need for measures. Furthermore, Making 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 are used through composites indicators providing provide a synthetic measurement of a complex, and mitigation measures should be considered

~~as the Institutional dimension (Changdeok et al., 2019).multidimensional).~~ multidimensional~~, and meaningful~~ phenomena (Changdeok et al., 2019. Those indicators are ~~schemed~~ 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 composites ~~indicators~~ indices to assess ~~urban~~ resilience of urban areas and to 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~~s~~ 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, ~~the~~ 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 ~~resilience in~~ "urban areas"~~,~~ as recently proposed also by ~~is similar to urban resilience (~~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, ~~(Miguez and Verol. (2016))~~ 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) ~~spatially explicit~~ using Geographic Information Systems (GIS) and stressing the need to move towards diversifying ~~measuring~~ resilience assessement approaches.

Regardless of several challenges associated ~~to~~ 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 ~~considerable~~ attention has been paid ~~given~~ to composite indicators (Heinzlef et al., 2019a), regarding ~~its~~ 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 ~~is revealed~~ was reported in a critical review by ~~(~~Sharifi, A., & Yamagata, Y. (2016).

~~Although, T~~the Mediterranean region ~~is a major climate change hot spot for the coming decades~~will suffer from severe impact due to climate change (Tuel and Eltahir, 2020). Particularly ~~and~~ Morocco ~~is figuring out~~ is mentioned as a hotspot for climate change in several works (Born et al. ,2008; Driouech et al. ,2009; Ouhamdouch & Bahir, 2017). Moreover, the seasonal distribution of the precipitation influence strongly 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 ~~of~~ in temperature and a decrease in precipitation (Driouech et al., 2010). Which 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).

135   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, likewise urban resilience to floods. These areas were selected because they showIn light of the fact that 18 hot spots located there are 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

140   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 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

145   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

150   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 composite indicator 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

155   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. To They simplify and communicate easily the reality of a complex situations

160   (Freudenberg, 2003) and convey more precise information that may be utilized as performance measures (Saisana et al.,2005).

For measuring flood resilience level, contracting composite indices have been applied (Qasim et al ., 2016; Kotzee et Reyers,2016). However, through different geographical contexts and scales, measuring resiliencethese 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 the qualities of a composite index and the soundness of the messages that convey.

3. The theoretical comprehensiveness for primary indicator building

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 the its component weights. For Batica. (-2015) It has been built taking setting into account different spatial scales and focusing on urban functions. Using a 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. Limiting resilience definition to two phases event and recovery (Leandro et al., 2020) developed FRI for assessing climate change adaptation. 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.

In this study, Wwe adopt the specific Flood Resilience Index to quantify the resilience of coastal urban areas (Martil, M'diq and Fnideq) to floods. FRI was devided divided into four sub-indicators: Social, Physical, Economic, and Natural sub-indexes. , so as to enable sufficient flexibility to include or not each Then, whether a sub-index will be included or not in the overall global composite index will be identified (Fig.2). Three indicators were chosen for each sub-index (Tab1) based on data availability and its their contribution in to persistence, recovery, or adaptative capacity (the main components of the adopted resilience definition) : Households Density (HD), Illiteracy Rate (IR), and Vulnerable Individuals Indicator (VII) were 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), Stream Network Density (SND), and Distance from Depressions (DD) are the indicators selected to determine the natural resilience sub-index.

2.3. ~~3.1.~~ Selecting ~~variables~~ indicators: Scoring and classification

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

195 ~~data is an crucial factor that leads to realistic results (Fig.2.)~~

2.4. ~~3.2.~~ Normalisation

Indicators integration~~s~~ into sub-indicators ~~necessitate~~ needs ~~data transformation using~~ data normalization. Respecting the theoretical framework and the data ~~properties~~ characteristics, a ~~suitable~~ Min-Max normalization was ~~required; Min-Max Normalized were~~ applied. Subsequently. ~~o moralize the selected variable into one sub-index,~~ each variable was normalized

200 from 0 to 100 according to the following equations (1) and (2):

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

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

~~The e~~Equation (1) was applied for variables that positively influence resilience while ~~the~~ Eq. (2) was applied to those that are negatively correlated with resilience. When the scores are attributed, each of these indicators was gridded and then a

205 geodatabase was created ~~in order~~ to calculate the sub-indexes by using the GIS. Each sub-index is the mean value of all correspondent indicators.

2.5. ~~3.3.~~ Weighting and aggregation

The existing methods for determining weights are not always reflecting the priorities of decision-makers (Esty et al., 2005), ~~that~~ which are subjective (Cutter et al., 2010). Equal-weighting is the most common for composite indices with several sub-

210 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

215 corresponding composite ~~indicator~~ 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 ~~indicator~~ index at the local level, avoiding a large concentration of few indicators and making it is easy to communicate.

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

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

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.

2.6. ~~3.4.~~ Links to other indicators

To assess the ~~correlated~~ correlation between the composite ~~indicator~~ index ~~with~~ and ~~related~~ corresponding sub-indices/variables, a statistical ~~data~~ 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 ~~data~~ case-study sites. The significant differences 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 ~~that were significant~~ at a level of 0.05 are ~~presented herein~~ considered.

2.7. ~~3.5.~~ Visualization and validation

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

In our case, ~~T~~ the validation based on actual outcomes ~~in~~ of the municipalities is possible ~~here~~ using cross-validation type. It was performed to test and compare the reliability of FRI results ~~in use~~ using ~~with~~ the results of ~~another model~~ other studies

interested in ~~used to analyze risks of~~ hydro-climatic hazards ~~in the local zone~~as suggested by ~~(~~Satta et al., ~~(~~2016). This is possible~~T~~ ~~t~~hrough ~~exploring~~ 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. ~~4.~~ Results

3.1.~~4.1.~~ Sub-indices

Each sub-index was observed separately, to get additional insights about Flood resilience Index. For the social resilience (Fig.~~ure~~ 3D), produced based on the three indicators of social resilience (~~Figure~~ 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 term~~s~~ 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 level 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. ~~4.2.~~ 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. 4.3. 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. 5. 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 ranking and prioritization process (Chitsaz et al., 2015). Accordingly, the choice of a good methodology to assess and quantify the 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 in a 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 ~~on~~ 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 ~~the~~ people vulnerability, which affect ~~the~~ 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 ~~thing~~ result ~~as~~ given the characteristics of the wealthy residents living there (Tempelhoff et al., 2009; Kotzee Reyers. 2016). Unlike in 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 findings 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 ~~the~~ high incomes make a recovery after disaster quicker.

The overall picture of ~~the~~ 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 Reyers, 2016; Moghadas et al., 2019) showing that ~~the~~ 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.

Economic and 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. ~~Means~~ 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 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).

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 level in the municipalities.

340 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 ~~into~~ on the contingency plans in case of power or drinking water failure in the three municipalities.

Therefore, there is a need to incorporate disaster management education in college to explain hazards adaptation. Also, educate

345 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, 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).

350 **6. 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 the local contexts of Morocco, 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.

355 Flood resilience assessment was piloted using a composite index and a GIS. The spatial and statistical analysis gave further insights into the geographic distribution of FRI across Fnideq, M'diq and Martil municipalities. Moreover, clarify the presentation of a complex set of components linked in a reproducible 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

360 component could ~~In order to~~ advance our understanding ~~of the complex nature~~ of flood resilience, and provide useful results to suggest ~~a~~ floods adaptation strategies in a coastal area. The robustness of flood resilience indicator was tested by comparing the results against additional case studies and operationalized measures of resilience. ~~However, there is no question that recommendations to improve FRI development are suggest:~~ Some of the main limitation of the developed FRI are: starting with tackling the main limitations from considering real/simulate flood inundation maps, to integrating climatic data (flood

365 data or flood simulation data). Besides, for robust validation, 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 FRI in the same coastal area, to provide further insights about indicators assessments and the relationships among flood resilience and flood risk.

Mis en forme : Police :(Par défaut) Times New Roman, 10 pt, Police de script complexe :Times New Roman

Acknowledgments

370 The authors would like to thank the Office of the High Commission for Planning (HCP) and Hydraulic Basin Agency of Loukkos in Morocoo for making their data available for our study. ~~Once again, we thank reviewers for the time they allowed reviewing our paper, their inputs have been precious~~. We acknowledge the inputs from the reviewers (including Dr. Leandro) and the editor as they have been very helpful to improve the quality of the present work. Special thanks are to Dr Mohammed BEN-DAOUED, ~~and~~ Dr Mounir Ouzir and Mr Margaa Khalid for their meaningful insights provided.

375 **References**

ABH: Hydraulic Basin Agency of Loukkos, Typology and inventory of sites at flloding risk ABHL,2, www.abhloukkos.ma/abhl/index.php/fr/,2016.

Angeon, V., & Bates, S.: reviewing composite vulnerability and resilience indexes: A sustainable approach and application. World Development, 72, 140-162. https://doi.org/10.1016/j.worlddev.2015.02.011, 2015.

380 Anfuso, G., Martinez, J. A., & Nachite, D.: Coastal vulnerability in the Mediterranean sector between Fnideq and M'diq (North of Morocco). Co Ren de l'Aca bulgare des Sci, Géo. phy. Géomo. 63 (4), 561-570, 2010.

Andersson, E,: Urban landscapes and sustainable cities. Ecology and Society 11(1): 34. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art34/, 2006.

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström,: J. .Soc-eco Res.to. Coa. disa. Sc, 309(5737), 1036-
385 1039. DOI: 10.1126/science.1112122, 2005.

Ahern, J.: From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. Landscape and urban Planning, 100(4), 341-343. doi.org/10.1016/j.landurbplan.2011.02.021, 2011.

Asadzadeh, A., Kötter, T., Salehi, P., & Birkmann, J.: Operationalizing a concept: The systematic review of composite indicator building for measuring community disaster resilience, Inter J. of Dis. Risk Red, 25, 147-162.
390 https://doi.org/10.1016/j.ijdrr.2017.09.015, 2017.

Bahir, M., Ouhamdouch, S., Ouazar, D. & El Moçayd, N.: Climate change effect on groundwater characteristics within semi-arid zones from western Morocco. Groundwater for Sustainable Development, 100380. doi.org/10.1016/j.gsd.2020.100380 , 2020.

Barthel, P. A., & Planel, S., Tanger-Med and Casa-Marina, prestige projects in Morocco: new capitalist frameworks and local
395 context. Built environment, 36(2), 176-191. https://doi.org/10.2148/benv.36.2.176 ,2010.

Batica, J. Methodology for flood resilience assessment in urban environments and mitigation strategy development. Diss. Université Nice Sophia Antipolis, 2015.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds.,: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp. ISBN: 978-92-9169-123-4, 2008.

400   Bertilsson, L., Wiklund, K., de Moura Tebaldi, I., Rezende, O. M., Veról, A. P., & Miguez, M. G.: Urban flood resilience–A multi-criteria index to integrate flood resilience into urban planning. J of Hy, 573, 970-982. https://doi.org/10.1016/j.jhydrol.2018.06.052, 2019.

Born, K., Fink, A. H., & Paeth, H. . Dry and wet periods in the northwestern Maghreb for present day and future climate conditions. Meteorologische Zeitschrift, 17(5), 533-551. doi. 10.1127/0941-2948/2008/0313, 2008.

405   Cai, H., Lam, N. S., Qiang, Y., Zou, L., Correll, R. M., & Mihunov, V.: A synthesis of disaster resilience measurement methods and indices. International journal of disaster risk reduction, 31, 844-855. doi.org/10.1016/j.ijdrr.2018.07.015, 2018.

Cardoso, M.A.; Brito, R.S.; Pereira, C.; Gonzalez, A.; Stevens, J.; Telhado, M.J. RAF Resilience Assessment Framework—A Tool to Support Cities' Action Planning. Sustainability 12, 2349. doi.org/10.3390/su12062349, 2020.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N.: From metaphor to measurement: resilience of what to

410   what?. Ecosystems, 4(8), 765-781. doi.org/10.1007/s10021-001-0045-9, 2001.

Cariolet, J. M., Vuillet, M., & Diab, Y.: Mapping urban resilience to disasters–A review. Sustainable cities and society, 51, 101746. doi.org/10.1016/j.scs.2019.101746, 2019.

Changdeok Gim, Clark A. Miller, Paul W. Hirt: The resilience work of institutions Environ. Sci. Policy, 97, pp. 36-43, 10.1016/j.envsci.2019.03.004, july, 2014.

415   Chen, N., & Graham, P.: Climate change as a survival strategy: soft infrastructure for urban resilience and adaptive capacity in Australia's coastal zones. In Resilient Cities (pp. 379-388). Springer, Dordrecht, doi.10.1007/978-94-007-0785-6_38, 2011.

Chen, K. F., & Leandro, J.: A conceptual time-varying flood resilience index for urban areas: Munich city. Water, 11(4), 830. doi.org/10.3390/w11040830 ,2019.

Chitsaz, N., & Banihabib, M. E. Comparison of different multi criteria decision-making models in prioritizing flood

420   management alternatives. Water Resources Management, 29(8), 2503-2525. doi.org/10.1007/s11269-015-0954-6, 2015.

Cohen, R., Erez, K., Ben-Avraham, D., & Havlin, S. Resilience of the internet to random breakdowns. Physical review letters, PhysRevLett.85.4626 85(21), 4626. https://doi.org/10.1103/, 2000.

Colding, J., & Barthel, S.: The potential of 'Urban Green Commons' in the resilience building of cities. Ecological economics, 86, 156-166. https://doi.org/10.1016/j.ecolecon.2012.10.016, 2013.

425   Conway, G.The science of climate change in Africa: impacts and adaptation. Grantham Institute for Climate Change Discussion Paper, 1, 24. http://www.ask-force.org/web/Global-Warming/Convay-Science-Climate-Change-Africa-2008.pdf , 2009.

Cretney Raven. Resilience for Whom? Emerging Critical Geographies of Socio-ecological Resilience. Geography Compass 8/9 (2014): 627–640, 10.1111/gec3.12154, 2014.

430   CRED, E. EM-DAT. In: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels Belgium.www.emdat.be, 2010.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J.: A place-based model for understanding community resilience to natural disasters. Global environmental change, 18(4), 598-606. doi.org/10.1016/j.gloenvcha.2008.07.013, 2008.

435 Cutter, S. L., Burton, C. G., &Emrich, C. T. Disaster resilience indicators 517 for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1). doi.org/10.2202/1547-7355.1732, 2010.

Cutter, S. L., Ash, K. D., & Emrich, C. T: The geographies of community disaster resilience. Global environmental change, 29, 65-77. https://doi.org/10.1016/j.gloenvcha.2014.08.005, 2014.

Disse, M., Johnson, T. G., Leandro, J., & Hartmann, T.: Exploring the relation between flood risk management and flood
440 resilience. Water Security, 9, 100059. doi.org/10.1016/j.wasec.2020.100059, 2020.

Driouech, F., Déqué, M., & Mokssit, A.: Numerical simulation of the probability distribution function of precipitation over Morocco. Climate dynamics, 32(7-8), 1055-1063. doi.org/10.1007/s00382-008-0430-6, 2009.

Driouech, F., Déqué, M., & Sánchez-Gómez, E.: Weather regimes—Moroccan precipitation link in a regional climate change simulation. Global and Planetary Change, 72(1-2), 1-10. doi.org/10.1016/j.gloplacha.2010.03.004, 2010.

445 Doocy, S., Daniels, A., Packer, C., Dick, A., & Kirsch, T. D. The human impact of earthquakes: a historical review of events 1980-2009 and systematic literature review. PLoScurrents, 5.https://doi10.1371/currents.dis.67bd14fe457f1db0b5433a8ee 20fb833, 2013.

Ducruet, C., Mohamed-Chérif, F., & Cherfaoui, N.: Maghreb port cities in transition: the case of Tangier. Portus Plus, 1 (1), http://www.reteonline.org. ffhalshs-00553040f, 2011.

450 El Moçayd, Nabil, Suchul Kang, and Elfatih A. B. Eltahir. "Climate change impacts on the Water Highways project in Morocco." Hydrology and Earth System Science, 24, 3, 1467-1483. © The Author(s) https://hdl.handle.net/1721.1/125159, 2020.

Esty, D. C., Levy, M., Srebotnjak, T., & De Sherbinin, A.: Environmental sustainability index: Benchmarking national environmental stewardship. New Haven: Yale Center for Environmental Law & Policy, 47-60. doi:
455 10.1017/S1355770X05002275, 2005.

Fisher, M., Abate, T., Lunduka, R. W., Asnake, W., Alemayehu, Y., & Madulu, R. B. . Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. Climatic Change, 133(2), 283- 299 . DOI 10.1007/s10584-015-1459-2.2015.

Freudenberg, M. : « Indicateurs composites de performances des pays : Examen critique », Documents de travail de l'OCDE
460 sur la science, la technologie et l'industrie, n° 2003/16, Éditions OCDE, Paris, https://doi.org/10.1787/405566708255, 2003.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. : Resilience and sustainable development: building adaptive capacity in a world of transformations. AMBIO: A J of the human environment, 31(5), 437-440. dx.doi.org/10.1579/0044-7447-31.5.437,2002.

Gaillard, J. C. Vulnerability, capacity and resilience: perspectives for climate and development policy. Journal of International
465 Development: The Journal of the Development Studies Association, 22(2), 218-232. https://doi.org/10.1002/jid.1675. 2010.

GIORGI, Filippo et LIONELLO, Piero. Climate change projections for the Mediterranean region. Global and planetary change, vol. 63, no 2-3, p. 90-104.doi:10.1016/j.gloplacha.2007.09. , 2008.

Godschalk, D. R. Urban hazard mitigation: creating resilient cities. Natural hazards review, 4(3), 136-143. doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136), 2003.

470   Greco, S., Ishizaka, A., Tasiou, M., & Torrisi, G.: On the methodological framework of composite indices: A review of the issues of weighting, aggregation, and robustness. Social Indicators Research, 141(1), 61-94. , 2019.

HCP, Haut-Commissariat Au Plan. Monographie de la préfecture de M'diq-Fnideq, Direction régionale de Tanger-Tétouan-al Hoceima. Kingdoom of Morocco. 2018.

Heinzlef, C., Becue, V., & Serre, D.: Operationalizing urban resilience to floods in embanked territories–Application in
475   Avignon, Provence Alpes Côte d'azur region. Safety science, 118, 181-193. doi.org/10.1016/j.ssci.2019.05.003, 2019.

Hinkel, J. "Indicators of vulnerability and adaptive capacity": towards a clarification of the science–policy interface. Global Environmental Change, 21(1), 198-208. https://doi.org/10.1016/j.gloenvcha.2010.08.002, 2011.

Hoffman, T., & Vogel, C.: Climate change impacts on African rangelands. Rangelands, 30(3), 12-17, doi.org/10.2111/1551-501X(2008)30[12:CCIOAR]2.0.CO;2 , 2008.

480   Holling, C. S. Resilience and stability of ecological systems. Annual review of ecology and systematics, 4(1), 1-23. http://www.jstor.org/stable/2096802, 1973.

Hung, H. C., Yang, C. Y., Chien, C. Y., & Liu, Y. C. Building resilience: Mainstreaming community participation into integrated assessment of resilience to climatic hazards in metropolitan land use management. Land Use Policy, 50, 48-58. doi.org/10.1016/j.landusepol.2015.08.029, 2016.

485   Leal Filho, W., Balogun, A. L., Ayal, D. Y., Bethurem, E. M., Murambadoro, M., Mambo, J.,... & Mugabe, P. Strengthening climate change adaptation capacity in Africa-case studies from six major African cities and policy implications. Environmental Science & Policy, 86, 29-37. https://doi.org/10.1016/j.envsci.2018.05.004, 2018.

Leandro, J., Chen, K. F., Wood, R. R., & Ludwig, R.: A scalable flood-resilience-index for measuring climate change adaptation: Munich city. Water Research, 173, 115502, doi.org/10.1016/j.watres.2020.115502, 2020.

490   Leila Irajifar Neil Sipe Tooran Alizadeh: The impact of urban form on disaster resiliency: a case study of Brisbane and Ipswich, Australia, International Journal of Disaster Resilience in the Built Environment, Vol. 7 Iss 3 pp. http://dx.doi.org/10.1108/IJDRBE-10-2014-0074, 2016.

Lutz, W., & KC, S.: Dimensions of global population projections: what do we know about future population trends and structures? Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 2779-2791.
495   doi.org/10.1098/rstb.2010.0133, 2010.

Joerin, J., Shaw, R., Takeuchi, Y., & Krishnamurthy, R. The adoption of a climate disaster resilience index in Chennai, India. Disasters, 38(3), 540-561.https://doi.org/10.1111/disa.12058, 2014.

Kanai, M., & Kutz, W.: Entrepreneurialism In The Globalising City-Region Of Tangier, Morocco. Tijdschrift voor economische en sociale geografie, 102(3), 346-360 doi.org/10.1111/j.1467-9663.2010.00622.x,2011.

500   Karrouchi.M, Ouazzani.M, Touhami.M, Oujidi.M, and Chourak.M. : "Mapping of flooding risk areas in the Tangier-Tetouan region: Case of Martil Watershed (Northern Morocco)," International Journal of Innovation and Applied Studies, vol. 14, no. 4, pp. 1019–1035. http://www.ijias.issr-journals.org/, 2016.

Kontokosta, C. E., & Malik, A: The Resilience to Emergencies and Disasters Index: Applying big data to benchmark and validate neighborhood resilience capacity. Sustainable cities and society, 36, 272-285.https://doi.org/10.1016/j.scs.2017.10.025, 2018.

505   Kotzee, I., & Reyers, B. Piloting a social-ecological index for measuring flood resilience: A composite index approach. Ecological Indicators, 60, 45-53.https://doi.org/10.1016/j.ecolind.2015.06.018, 2016.

Kundzewicz, Z. W., Kanae, S., Seneviratne, S. I., Handmer, J., Nicholls, N., Peduzzi, P., ... & Muir-Wood, R. Flood risk and climate change: global and regional perspectives. Hydrological Sciences Journal, 59(1), 1 28.https://doi.org/10.1080/02626667.2013.857411. 2014.

510   Marana P, Eden C, Eriksson H, Grimes C, Hernantes J, Howick S, Labaka L, Latinos V, Lindner R, Majchrzak T, Pyrko I, Radianti J, Rankin A, Sakurai M, Sarriegi JM, Serrano N, Towards a resilience management guideline—Cities as a starting point for societal resilience, Sustainable Cities and Society , doi.org/10.1016/j.scs.2019.101531, 2019.

Mayunga, J. S. Understanding and applying the concept of community disaster 603 resilience: a capital-based approach. Summer academy for social vulnerability and resilience building, 1, 16.
515   www.ucursos.cl/usuario/3b514b53bcb4025aaf9a6781047e4a66/mi_blog/r/11._Joseph_S._Maynga.pdf, 2007.

Meerow, S., Newell, J. P., & Stults, M. : Defining urban resilience: A review. Landscape and urban planning, 147, 38-49. http://dx.doi.org/10.1016/j.landurbplan.2015.11.011,2016.

Miguez, M. G., & Veról, A. P.: A catchment scale Integrated Flood Resilience Index to support decision making in urban flood control design. Environment and Planning B: Urban Analytics and City Science, 44(5), 925-946.
520   doi.org/10.1177/0265813516655799, 2016.

Moghadas, M., Asadzadeh, A., Vafeidis, A., Fekete, A., & Kötter, T. A multi-criteria approach for assessing urban flood resilience in Tehran, Iran. International Journal of Disaster Risk Reduction, 35, 101069. doi.org/10.1016/j.ijdrr.2019.101069, 2019.

Mugume, S. N., Gomez, D. E., Fu, G., Farmani, R., & Butler, D. A global analysis approach for investigating structural
525   resilience in urban drainage, Water Research . doi.org/10.1016/j.watres.2015.05.030, 2015.

Nachite, D. : Le developpement touristique du littoral de la region Tanger-Tetouan: une evolution vers des scenarios non desirables ? In: Domínguez Bella, S., Maate, A.(Eds.), Geología y Geoturismo en la Orilla Sur Del Estrecho De Gibraltar. MCN - UCACadiz, ISBN 978-84-9828-224-5, pp. 59e78. 2009.

Nardo, M., M. Saisana, A. Saltelli and S. Tarantola: Handbook on Constructing Composite Indicators: Methodology and User
530   Guide. Paris,France: OECD Publishing, citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.958.2519&rep=rep1&type=pdf 2008.

Nejjari..A Abdelkader,: Vulnérabilité environnementale et planification urbaine, états des lieux : cas du littoral M'diq-F, Revue AFN Maroc, N° : 12-14, 2014.

Nelson, D. R., Adger, W. N., & Brown, K. Adaptation to environmental change: contributions of a resilience framework.
Annu. Rev. Environ. Resour., 32, 395-419. https://doi.org/10.1146/annurev.energy.32.051807.090348, 2007.

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J.: Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. PloS one, 10(3), e0118571.doi.org/10.1371/journal.pone.0118571, 2015.

Niazi. S. Evaluation des impacts des changements climatiques et de l'élévation du niveau de la mer sur le littoral de Tétouan (Méditerranée occidentale du Maroc) : Vulnérabilité et adaptation, Phd thesis. Mohamed V, Rabat, Maroc http://toubkal.imist.ma/handle/123456789/1774, 2007.

Karanja Ng'ang'a, S., Bulte, E. H., Giller, K. E., McIntire, J. M., & Rufino, M. C.: Migration and self-protection against climate change: a case study of Samburu County, Kenya. World Development, 84, 55-68, doi.org/10.1016/j.worlddev.2016.04.002, 2016.

Klein, R. J., Nicholls, R. J., & Thomalla, F. : Resilience to natural hazards: How useful is this concept?. Global environmental change part B: environmental hazards, 5(1), 35-45. doi.org/10.1016/j.hazards.2004.02.001, 2003.

Lutz, W., & Samir, K. C: Dimensions of global population projections: what do we know about future population trends and structures? https://doi.org/10.1098/rstb.2010.0133, 2010.

OCDE, Organisation de coopération et de développement économiques, 'Rapport sur la gestion-des-risques-maroc-principaux-résultats.http://www.oecd.org/fr/gov/risques/gestion-des-risques-maroc-principaux resultats.pdf, 2016.

Ouhamdouch, S., & Bahir, M.: Climate change impact on future rainfall and temperature in semi-arid areas (Essaouira Basin, Morocco). Environmental Processes, 4(4), 975-990. doi.org/10.1007/s40710-017-0265-4, 2017.

Ouma, Y., & Tateishi, R.: Urban flood vulnerability and risk mapping using integrated multi641 parametric AHP and GIS: methodological overview and case study assessment. Water, 6(6), 1515-1545. https://doi.org/10.3390/w6061515, 2014.

Paeth, H., Hall, N. M., Gaertner, M. A., Alonso, M. D., Moumouni, S., Polcher, J., .. & Gaye, A. T. : Progress in regional downscaling of West African precipitation. Atmospheric science letters, 12(1), 75-82. doi.org/10.1002/asl.306. 2011.

Pagano, A., Pluchinotta, I., Giordano, R., & Vurro, M.: Drinking water supply in resilient cities: Notes from L'Aquila earthquake case study. Sustainable cities and society, 28, 435-449. doi.org/10.1016/j.scs.2016.09.005, 2017.

Pallard, B., Castellarin, A., &Montanari, A.: A look at the links between 645 drainage density and flood statistics. Hydrology and Earth System Sciences, 13(7), 1019- 1029.https://doi.org/10.5194/hess-13-1019-2009, 2009.

Papadopoulos, T., Gunasekaran, A., Dubey, R., Altay, N., Childe, S. J., &Fosso-Wamba, S. : The role of Big Data in explaining disaster resilience in supply chains for sustainability. Journal of Cleaner Production, 142, 1108 1118.https://doi.org/10.1016/j.jclepro.2016.03.059, 2017.

Patel, S. S., Rogers, M. B., Amlôt, R., & Rubin, G. J.: What do we mean by "community resilience"? A systematic literature review of how it is defined in the literature. PLoS currents, 9.https://10.1371/currents.dis.db775aff25efc5ac4f0660ad9c9f7db2, 2017.

Pelling, M.: The vulnerability of cities: natural disasters and social resilience. Earthscan, ISBN 1853838306 , 2003.

Code de champ modifié

Code de champ modifié

Perelli, C. A. R. L. O : Case Study Morocco: Mediterranean Morocco, a Vulnerable Development Called into Question. In Global Climate Change and Coastal Tourism. Recognizing Problems, Managing Solutions and Future Expectations. CABI International, ISBN 9781780648453 (ePDF), 2018.

570 Pendall, R., Foster, K. A., & Cowell, M.: Resilience and Regions: Building Understanding ofthe Metaphor. Retrieved from https://escholarship.org/uc/item/4jm157sh , 2007.

Pike, A., Dawley, S., & Tomaney, J.,: Resilience, adaptation and adaptability. Cambridge journal of regions, economy and society, 3(1), 59-70. doi.org/10.1093/cjres/rsq001, 2010.

Plate, E.J.:. J.:Flood risk and flood management. Journal of Hydrology, 267(1-2), 2-11. https://doi.org/10.1016/S0022-
575 1694(02)00135-X, 2002.

Price, R.A.: Climate change and stability in North Africa. K4D Helpdesk Report 242. Brighton, UK: Institute of Development Studies. https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/13489, 2017.

Qasim, S., Qasim, M., Shrestha, R. P., Khan, A. N., Tun, K., & Ashraf, M.: Community resilience to flood hazards in Khyber Pukhthunkhwa province of Pakistan. International Journal of Disaster Risk Reduction, 18,
580 100106.https://doi.org/10.1016/j.ijdrr.2016.03.009, 2016.

Redman, C. L. Resilience theory in archaeology. American Anthropologist, 107(1), 70-77. doi.org/10.1525/aa.2005.107.1.070, 2005.

Reisi, M., Aye, L., Rajabifard, A., & Ngo, T.: Transport sustainability index: Melbourne case study. Ecological Indicators, 43, 288-296. https://doi.org/10.1016/j.ecolind.2014.03.004, 2014.

585 RGPH, Recenssement Géneral de la Population et de l'Habitat. https://rgph2014.hcp.ma/downloads/Publications-RGPH-2014_t18649.html, 2014.

Reghezza-Zitt, M., Lhomme, S., & Provitolo, D. : Defining Resilience: When the Concept Resists. In Resilience Imperative (pp. 1-27). Elsevier. doi.org/10.1016/B978-1-78548-051-5.50001-2, 2015.

Roy, P.T., El Moçayd, N., Ricci, S. et al.: Comparison of polynomial chaos and Gaussian process surrogates for uncertainty
590 quantification and correlation estimation of spatially distributed open-channel steady flows. Stoch Environ Res Risk Assess 32, 1723–1741, doi: 10.1007/s00477-017-1470-4, 2018.

Rus, K.Kilar, V., &Koren, D. Resilience assessment of complex urban systems to natural disasters: a new literature review. International journal of disaster risk reduction.https://doi.org/10.1016/j.ijdrr.2018.05.015, 2018.

Sanabria-Fernandez, J. A., Lazzari, N., & Becerro, M. A.: Quantifying patterns of resilience: What matters is the intensity,
595 not the relevance, of contributing factors. Ecological Indicators, 107, 105565. doi.org/10.1016/j.ecolind.2019.105565, 2019.

Saisana, M., Saltelli, A., & Tarantola, S.: Uncertainty and sensitivity analysis techniques as tools for the quality assessment of composite indicators. Journal of the Royal Statistical Society: Series A (Statistics in Society), 168(2), 307-323. doi.org/10.1111/j.1467-985X.2005.00350.x, 2005.

Satta, A., Snoussi, M., Puddu, M., Flayou, L., &Hout, R.: An index-based method to assess risks of climate-related hazards in coastal zones: The case of Tetouan. Estuarine, Coastal and Shelf Science, 175, 93 105.https://doi.org/10.1016/j.ecss.2016.03.021, 2016.

Serre, D., Barroca, B., Balsells, M., & Becue, V.: Contributing to urban resilience to floods with neighbourhood design: the case of Am Sandtorkai/Dalmannkai in Hamburg. Journal of Flood Risk Management, 11, S69-S83. doi.org/10.1111/jfr3.12253, 2018.

Sharifi, A., & Yamagata, Y. :On the suitability of assessment tools for guiding communities towards disaster resilience, Inter J of Disr Risk Re, 18, 115-124. http://dx.doi.org/10.1016/j.ijdrr.06.006, 2016.

Sherrieb, K., Norris, F. H., & Galea, S.: Measuring capacities for community resilience. Social indicators research, 99(2), 227-247.doi 10.1007/s11205-010-9576-9, 2010.

Suárez, M., Gómez-Baggethun, E., Benayas, J., &Tilbury, D.: Towards an urban resilience Index: a case study in 50 Spanish cities. Sustainability, 8(8), 774.https://doi.org/10.3390/su8080774, 2016.

Snoussi, M., Ouchani, T., Khouakhi, A., & Niang-Diop, I.: Impacts of sea-level rise on the Moroccan coastal zone: quantifying coastal erosion and flooding in the Tangier Bay. Geomorphology, 107(1-2), 32-40. doi.org/10.1016/j.geomorph.2006.07.043, 2009.

Snoussi, M., Niazi, S., Khouakhi, A., &Raji, O. Climate change and sea-level rise: a GIS694 based vulnerability and impact assessment, the case of the Moroccan coast. Geomatic Solutions for Coastal Environments Book. Nova Publishers, ISBN 978-1-61668-140-1, 2010.

Speth, P., Christoph, M., & Diekkrüger, B.: Impacts of global change on the hydrological cycle in West and Northwest Africa. Springer Science & Business Media. Doi.10.1007/978-3-642-12957-5, 2010.

Taouri.O , El Ghammat.A , HILAL.I,. stitou. J , Hassani Zerrouk. M, Drraz. C.: Flood management: Case of the city of M'diq and Fnideq. JOWSET, (02), N°02, 259-264, htt p:/ / revues.imist.ma/?journal = JOWSET, 2017.

Tempelhoff, J., Hoag, H., Ertsen, M., Arnold, E., Bender, M., Berry, K., ... & Ur, J.: Where has the water come from? 10.1007/s12685-009-0003-6, 2009.

Terink Wilco,Walter Willem Immerzeel and Peter Droogers ,: Climate change projections 715 of precipitation and reference evapotranspiration for the Middle East and Northern 716 Africa until 2050. Int. J. Climatol. 33: 3055–3072 (2013). doi: 10.1002/joc.3650, 2013.

Thornes JB.: Land degradation. In: Woodward JC (ed) The physical geography of the Mediterranean. Oxford University Press, Oxford, pp 563–581, 2009.

Tuel, A., & Eltahir, E. A. B.: Why Is the Mediterranean a Climate Change Hot Spot?. Journal of Climate, 33(14), 5829-5843. doi.org/10.1175/JCLI-D-19-0910.1, 2020.

UNISDR, Sendai Framework for Disaster Risk Reduction https://www.unisdr.org/we/coordinate/sendai-framework/ 2015, (Accessed: 28-Jan-2016).

UN-Habitat , "Cities at risk from rising sea levels", in UN-Habitat, State of the World's Cities 2008/2009, Earthscan, London , 224 pages, pages 140-155. 2008.

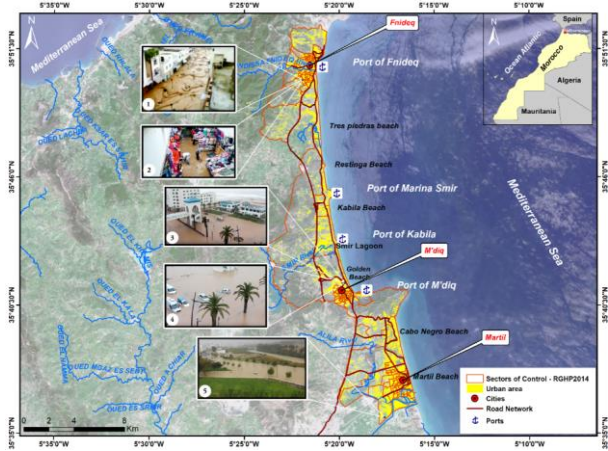
UN-Habitat , Habitat III, U. N.: Issue papers 22–informal settlements. In United Nations Conference on Housing and Sustainable Urban Development. New York. 2015.

UNDRR. Global Assessment Report on Disaster Risk Reduction; United Nations Office for Disaster Risk Reduction (UNDRR): Geneva, Switzerland, 2019

Vicuña, S., Dracup, J. A., & Dale, L.: Climate change impacts on two high-elevation hydropower systems in California. Climatic Change, 109(1), 151-169. doi.org/10.1007/s10584-011-0301-8, 2011.

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A.: Resilience, adaptability and transformability in social–ecological systems. Ecology and society, 9(2). http://www.ecologyandsociety.org/vol9/iss2/art5 , 2004.

Weichselgartner, J., & Kelman, I.: Challenges and opportunities for building urban resilience. A/Z ITU Journal of the Faculty of Architecture, 11(1), 20-35. https://discovery.ucl.ac.uk/id/eprint/1437000, 2014.

Westphal, M., & Bonanno, G. A.,: Posttraumatic growth and resilience to trauma: Different sides of the same coin or different coins? Applied Psychology, 56(3), 417-427. doi.org/10.1111/j.1464-0597.2007.00298.x, 2007.

670 **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).**

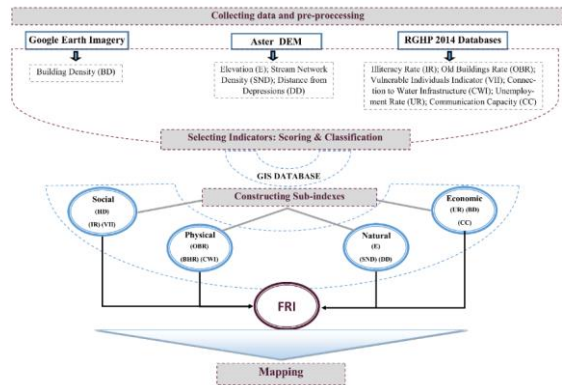



Figure 2: Procedure used to assess flood resilience in the three municipalities

675

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).

	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.
Natural *(ND)*	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.

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

680

685

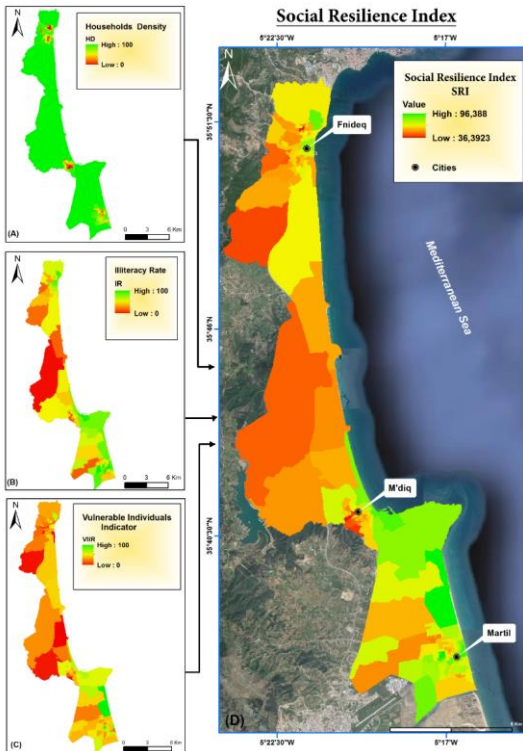



Figure3: Spatial distribution of A: Households Density, B: Illiteracy Rate; C: Vulnerable Individuals Indicator and D: Social Resilience Index (obtained from © Google map image in 2018).

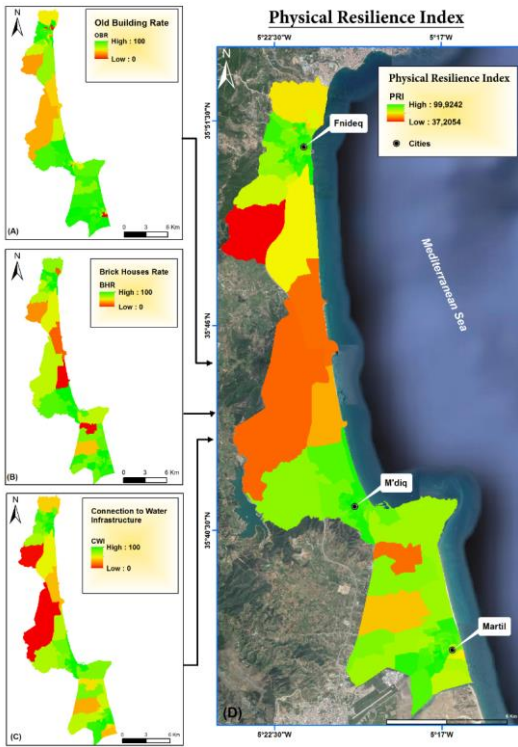
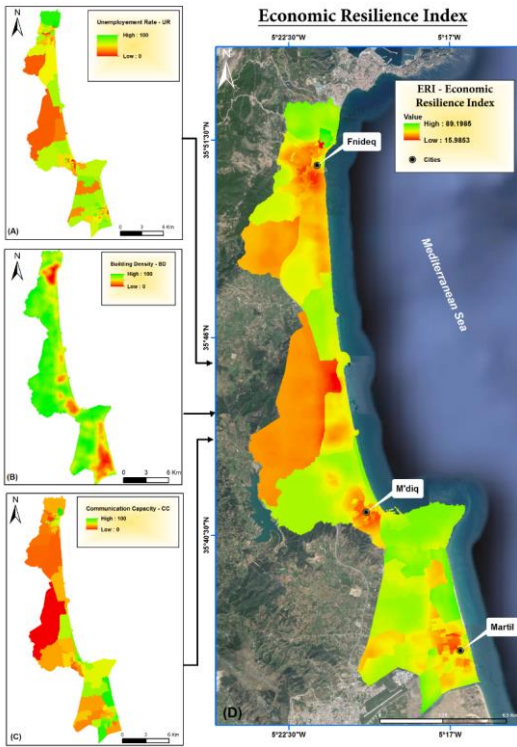



Figure 4: Spatial distribution of A: Old Buildings Rate, B: Brick Houses Rate, C: Connection to water infrastructure and D: Physical Resilience Index (obtained from © Google map image in 2018).

695 **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)**

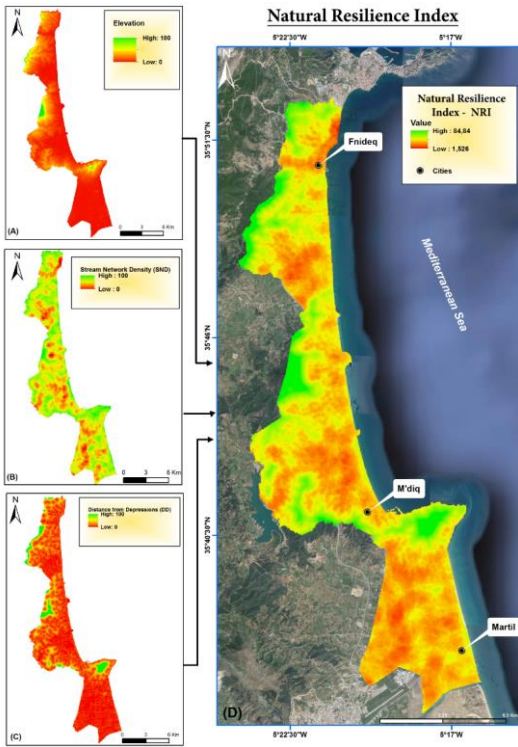
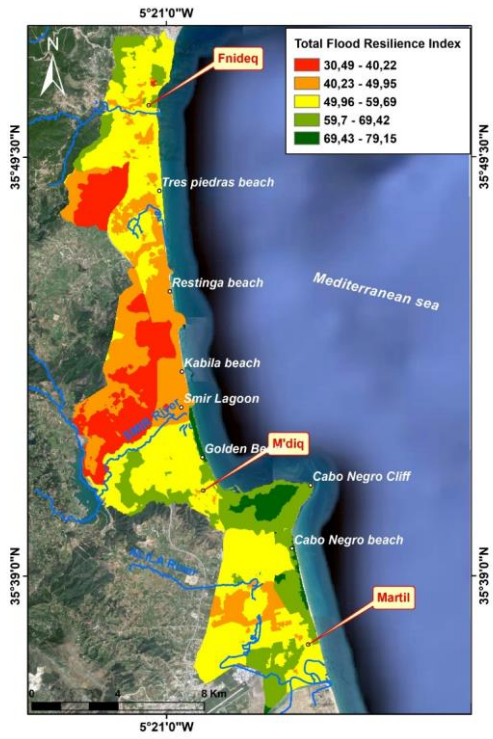



Figure 6: Spatial distribution of A: Elevation, B: Stream Network Density, C: Distance from Depressions and D: Natural Resilience Index (obtained from © Google map image in 2018)

700

		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.

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

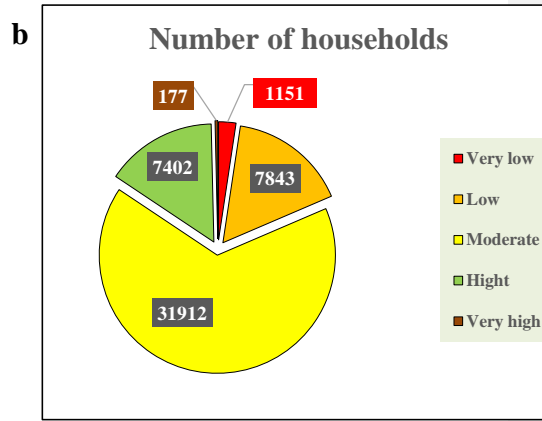
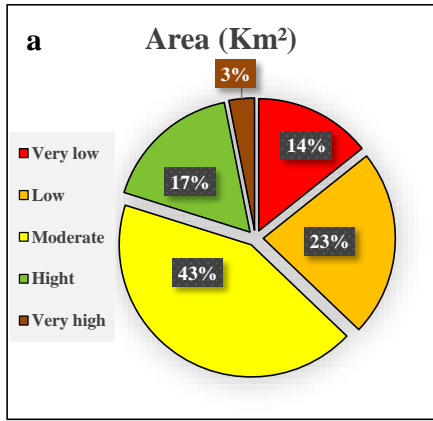



Figure 8: a) Total Flood Resilience scores distribution according to the surface of the study area; b) Total Flood Resilience scores distribution according to Households numbers in the study area.