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Discussions

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

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Abstract

Enhancing resilience is critical for coastal urban systems to cope with and minimize flood disaster risks. Global increases in the frequency of floods is a major concern for many areas in Africa. In this regard, urban planners need increasingly 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. Using three northern coastal municipalities, this study applied a composite index and geographic information system approach to measure and map resilience to floods. 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.*

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Introduction

Climate change represents a major challenge for development of African countries. Several studies highlighted the serious impact of global change in Africa (Bates et al., 2008).The pattern of precipitation (Born et al., 2008; Giorgi and 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 frequent occurrence of extreme events such drought and flooding (Ng'ang'a et al., 2016), especially in arid and semi-arid areas.

In this context, coastal zones situated in semi-arid are considered among the most threatened areas by a specific increase in the occurrence of flooding and rapid urbanization as well (Filho et al., 2018). In fact, population concentration impacts flooding. Consequently as population growth will likely increase, exposure to floods will be a real societal problem (Kundzewiczet al., 2014). Actually, 9642 peoples died out of 19,939,000 affected with floods in Africa between1993-2002(Conway, 2009).Moreover, it is excepted that coastal Africa will experience a higher rate of population growth and urbanization especially in the coastal zones 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 countries (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). It is therefore, urgent to assess resilience of these areas to flooding regarding the rapid urbanization.

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 (Bennani et al., 2001; Hoffman et Vogel, 2008; Schilling et al., 2012; Terink et al., 2013). The intensity of floods will increase over time (Barnett et al., 2005; Vicuña et al., 2011; Doocy et al., 2013; Roy et al., 2017).While the main economic activities are located in coastal zones, where 60 % of the total Moroccan population are living (Rohini, 2019). During recent years, several new behaviors policies have been implemented (Barthel and Planel, 2010; Ducruet et al., 2011; Kanai and Kutz, 2011).These, policies are mainly dedicated to improve the economic growth of these areas and reduce the negative effect of local migration. The main drivers of economy there are based on tourism and free zones industries. Which will impact the vulnerability of these zones to climate change (Perelli,2018). Adaptation to climate change is a key factor to achieve sustainability for such systems. Therefore, coping with combinations of environmental change, demographic growth and urban complexity challenges are putting urban environment under pressure (Marana et al., 2019). There are several ways to tackle adaptation issues limiting the input of climate related disaster and especially regarding flooding, which is considered as the most challenging disaster (UNDRR, 2019). The classical proposed methods to deal with such a problematic resides in implementing structural systems (Plate, 2002; Pender and Néelz, 2007; Papadopoulos et al., 2017; Bertilsson et al., 2019).Sizing these systems remain subject to ubiquitous uncertainty. In fact, climate variability will affect the reliability of such complex coastal areas systems. Therefore, adaptation should focus on resilience (Sustainable Development Goals), rather than structural measures.

Resilience approaches aim to understand and manage the capacity of a system to adapt, cope with,and shape uncertainty (Adger et al., 2005; Folke et al., 2002). Resilience has gained an increasing interest (Cretney, 2014; Weichselgartner and Kelman,2014; Patel et al., 2017;Kontokosta and Malik, 2018). It has been considered, in different manners, by various research fields: ecology (C.S.Holling, 1973; Folke, 2006), psychology (Westphal, 2007), geography (Pike, 2010; Cutter, 2010), archeology (Redman, 2005), and physics (Cohen, 2000). Recently including natural disasters, risk management, and climate change adaptation (Godschalk, 2003; Cutter et al., 2008; Gaillard, 2010; Nelson Adger&Brown, 2007; Serreet

Barroca, 2013), among others. However, a lack of consistent metrics to assess resilience is reported (Meerow et al., 2016, Asadzadeh et al., 2017; Rus et al., 2018).

Urban resilience is a broad and complex concept, difficult to express in quantitative terms (Bertilsson et al., 2019).Several tools in the literature have been successfully implemented: conceptual Model DROP (Cutter et al., 2008) and the operationalized version called BRIC (Cutter et al., 2010; Cutter et al., 2014). Composite indicators (Chillo et al., 2011; Cutter et al., 2010; Cutter et al., 2014 ; Joerin et al., 2014; Batica, 2015; Mugume et al.,2015 ; Hung et al., 2016; Kotzee et Reyers. 2016; Qasim et al., 2016; Mayunga, 2007) as one of the most applied frameworks on quantifying community disaster resilience in the literature.

The composite indicator provides a holistic overview of the resilience-building process and helps end-users to understand resilience as a multidimensional objective (Marana et al., 2019). The approach aims to provide a synthetic measurement of a complex, multidimensional, and meaningful phenomena through the aggregation of multiple individual indicators (Bapetista et al., 2014). Various indicators have been constructed during the last few years, to assess resilience and to compare their levels within particular geographical area (Cutter et al., 2010; Sharifi et al., 2016; Asadzadeh et al., 2017). Nevertheless, a knowledge gap has been identified at national and local levels in Morocco (Price, R.A. 2017).Furthermore, it is highly recommended to provide policymakers with information, simple approach and ways to enhance resilience to floods in local area (OCDE 2016).

The present study represents the first attempt to provide a methodological way to measure flood resilience for Northern coastal municipalities in Morocco: Martil, M'diq and Fnideq. In light of fact that 18 hot spots located there are highly exposed to floods (ABHL 2016) and the area is particularly highly vulnerable to different types of hazards : 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, index development

2.1.Martil, M’diq and Fnideq 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 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 andnon-climate hazards such as, erosion and morphological changes (Satta et al., 2016).

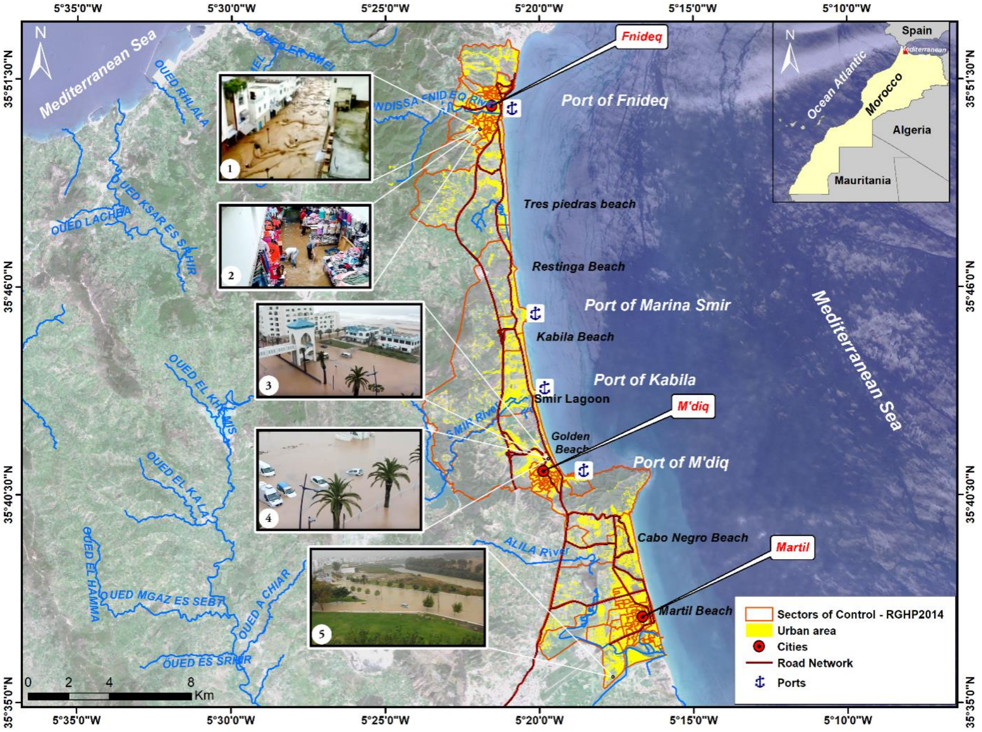

Figure 1: Location of the three studied municipalities : Fnideq, M'diq and Martil, in Northern Morocco and examples of the flooding (1: Photo of Fnideq Center in September,28th2008; 2: Photo ofAlmassira Commercial Center Fnideqin September, 27th2014; 3 and 4: Photo of M'diq in March, 06th 2010; 5:Photo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

2.2.Composite Indicator development

To produce an aggregate measure of resilience, through manipulation of individual variables, constructing a "Composite indicator" is often applied. It's 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 indicators as useful tools for decision-making and public communication. To simplify and communicate the reality of a complex situation (Freudenberg, 2003) and convey information that may be utilized as performance measures (Saisana and Cartwright, 2007).

For measuring flood resilience level, contracting composite indicators has been applied (Qasim et al ., 2016; Kotzee et Reyers. 2016). Although, through different geographical contexts and scales, measuring resilience is significant and encompassing many theoretical perspectives.

Through exploring and analyzing the relevant literature, the quality of the framework, the data and the methodology used influence, on the qualities of a composite indicator and the soundness of the messages that conveys. There is a need to explain the set of steps to taken to develop the Flood Resilience Index (FRI).

3. The theoretical comprehensiveness for primary indicator building

First of all a clear understanding of "flood Resilience", and measurement of multidimensional phenomenon are needed. In this case resilience is considered as both result and process oriented simultaneously (CDRI 2009, CoBRA2013, and BRIC 2014) (Asadzadeh et al., 2017). The assessments can be classified into measuring persistence (robustness), recovery (constancy), and adaptive capacity (transformative).

Explaining the basis for the selection and combination of variables is necessary to structure the various sub-components of the phenomenon. Flood Resilience Index (FRI) is divided into four sub-indicators: Social, Physical, Economic and Natural sub-indexes. Then, whether a sub-indicator will be included or not in the overall composite index will be identified (Fig.2).

It is important to mention that three indicators were chosen for each sub-index (Tab1): Households Density (HD), Illiteracy Rate (IR) and Vulnerable Individuals Indicator (VII) were taken into consideration as the mean indicators that affect negatively the social resilience, 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 includes also 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.

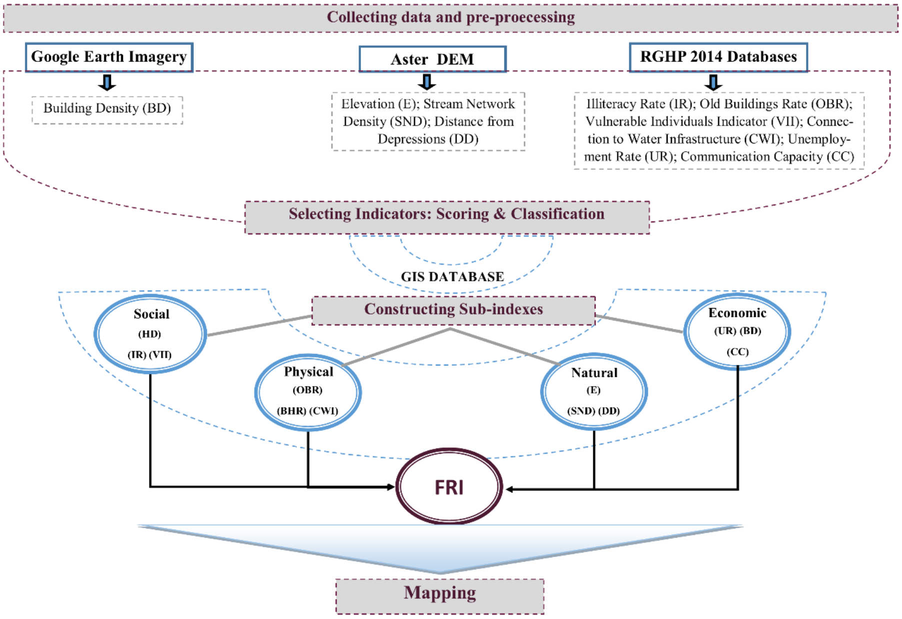

Figure 2: Procedure used to assess flood resilience in the three municipalities

3.1.Selecting variables: Scoring and classification

Based on their relevance, analytical, representativeness, and accessibility, 16 variables are 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 to digitize the building area. This was converted firstly into points and then their density was calculated using the ArcGIS© Point Density module. The quality of data is an important factor that leads to realistic results (Fig.2.)

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

Dimensions	Indicators	Description, effect on resilience &justification
Social (SD)	Households Density (HD)	Is the number of households per unit area, it also reflects the population density. It expresses the exposure of the population to floods and negatively influences resilience.
	Illiteracy Rate (IR)	The persons who have never learned to read. That can make the emergency and public awareness processes challenging.
	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 (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.

3.2.Normalisation

	Modernly Built Houses (MBH))	It reflects the percentage of modernly built houses (by Reinforced concrete and bricks with mortar) that will suffer less exterior damage during floods events in the local state (Cutter et al., 2010).
	Connection toWater Infrastructure (CWI)	The rate of connection to the sewage system and drinking water distribution strength resilience community (Cutter et al., 2010).
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, during, after and before flood hazards increases resilience (Cutter et al., 2010).
Natural ***(ND)***	Elevation (E)	It was selected basedon 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 including natural depressions of high flow accumulation, dam area and marine areas.

Integration of the selected indicators into sub indicators necessitates data transformation using data normalization. Respecting the theoretical framework and the data properties, a suitable normalisation was required; Min-Max Normalized were applied.

In order to moralize the selected variable into one sub-index, each variable was normalized from 0 to 100 according to the following equations (1) and (2):

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

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

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

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 are subjective (Cutter et al., 2010).In fact, the selection of weighting method depend on the local factors where the method is applied (Mayunga, 2007;Reisi et al., 2014). For this case of study, all variables are given equal weight (EW)for many reasons, the main one 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 at the local level. Moreover, to avoid 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, a very important criteria for potential users (Cutter et al.,2010).

All individual indicators have the same measurement unit. Therefore, using linear aggregations is preferred than geometric aggregation. The linear aggregation formula of the FRI takes the following form (3).

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

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.

3.4.Links to other indicators

To correlate the composite indicator with related variables, data statistical analysis was performed, using the program SPSS 23. Data presented as a mean and standard deviation (st.dev) were statistically analysed using multi-variance to confront data of natural, physical, economic and social condition with Flood Resilience Index. Furthermore, to identify which variables differ significantly between the three data sites. The significant differences were distinguished by post-hoc Tukey’s Honestly Significant Difference (HSD) test at $p<0.05$. The Spearman’s rho coefficient was used for correlations between variables. Only correlation coefficients that were significant at a level of 0.05 are presented herein.

3.5.Visualization and validation

Proper attention should be given to the visualization. It helps and enhances interpretability, thought to present information graphically. Graphics and maps facilitate further exploration of geographic trends in the data (Kotzee et Reyers. 2016). Hence, to visualize FRI and sub-indicators, results were expressed using Geographic Information Systems (GIS).

Last but not least step is the validity of results. Cross-validation was performed to test and compare the reliability of the results of FRI approach in use with the results of another model used to analyze risks of hydro-climatic hazards in the local zone (Satta et al., 2016).Through exploring the opposite relationship between risk and resilience (Cutter et al., 2014 Sherrieb et al.,2010).

4. Results

4.1.Sub-indices

Each sub-index was observed separately, to get additional insights about Flood resilience Index. For the ***social resilience*** (Figure3D), produced based on the three indicators of social resilience (Figure 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 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).

4.2.Total Flood Resilience Index

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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 show 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 major disparities between rural and urban areas especially in terms of socio economics, 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).

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 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 absente 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.

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

		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.

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 (Oumaet al., 2014). Producing flood resilience maps has thus become a crucial issue for the 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 major influence on the obtained results, and hence on the final decision making (Suárezet al., 2016).

In this paper, the adopted methodology is completely 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 provides also a more reliable and objective spatial comparison of resilience parameters 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 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 negatively the social resilience. However, the difference on SRI between municipalities may 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 because of the low population and urbanization (e.g. At the central area access to water infrastructure, as a 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 could be explained by the tourist and economic activities. An expected thing as the characteristics of the wealthy residents living there (Tempelhoff et al., 2009; Kotzee et Reyers. 2016). Unlike in the three urban centers having a 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 the recovery after disaster quicker.

The overall picture of the natural resilience shows that all the 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 the social resilience is strongly correlated to flood resilience degree. Moreover, the disparities highlighted between rural and urban areas revealed that rural areas displays the lowest resilience to floods.

Economic and natural resilience which is tightly linked in the sites are the second most statistically significant indicators linked to the total FRI. Disparities between municipalities are less significant. 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 confirm that the flood resilience index is relatively valid and can be adapted and tested in other geographical area. Moreover, this robustness analysis make the FRI in this case of study support the idea that areas with higher vulnerability levels examined have the lower resilience levels (H.-C. Hung et al., 2016).

There is a room for improvement within the three sites. 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.

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 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 people through communication devices, seminars and workshop 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 situation and as a decision support tool that offer an interactive use and continuing improvement (Oumaet al., 2014; Mayunga, 2007).

6. Conclusion

Building and enhancing resilience to floods becomes critical, as the urban development in 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 tangible approach to summarize and present complex components linked to resilience to floods.

The measurement of resilience to floods was piloted using a composite index and a GIS. The spatial and statistical analysis gives 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 indicates different factors can vary spatial patterns of resilience to floods. The robustness of flood resilience indicator was fully tested by comparing the results against additional case studies and operationalized measures of resilience.

The framework is flexible enough to allow the proposed index, in a future work, to take in consideration the institutional component. In order to advance our understanding of the complex nature of flood resilience, and provide a useful results to suggest a floods adaptation strategies in coastal area.

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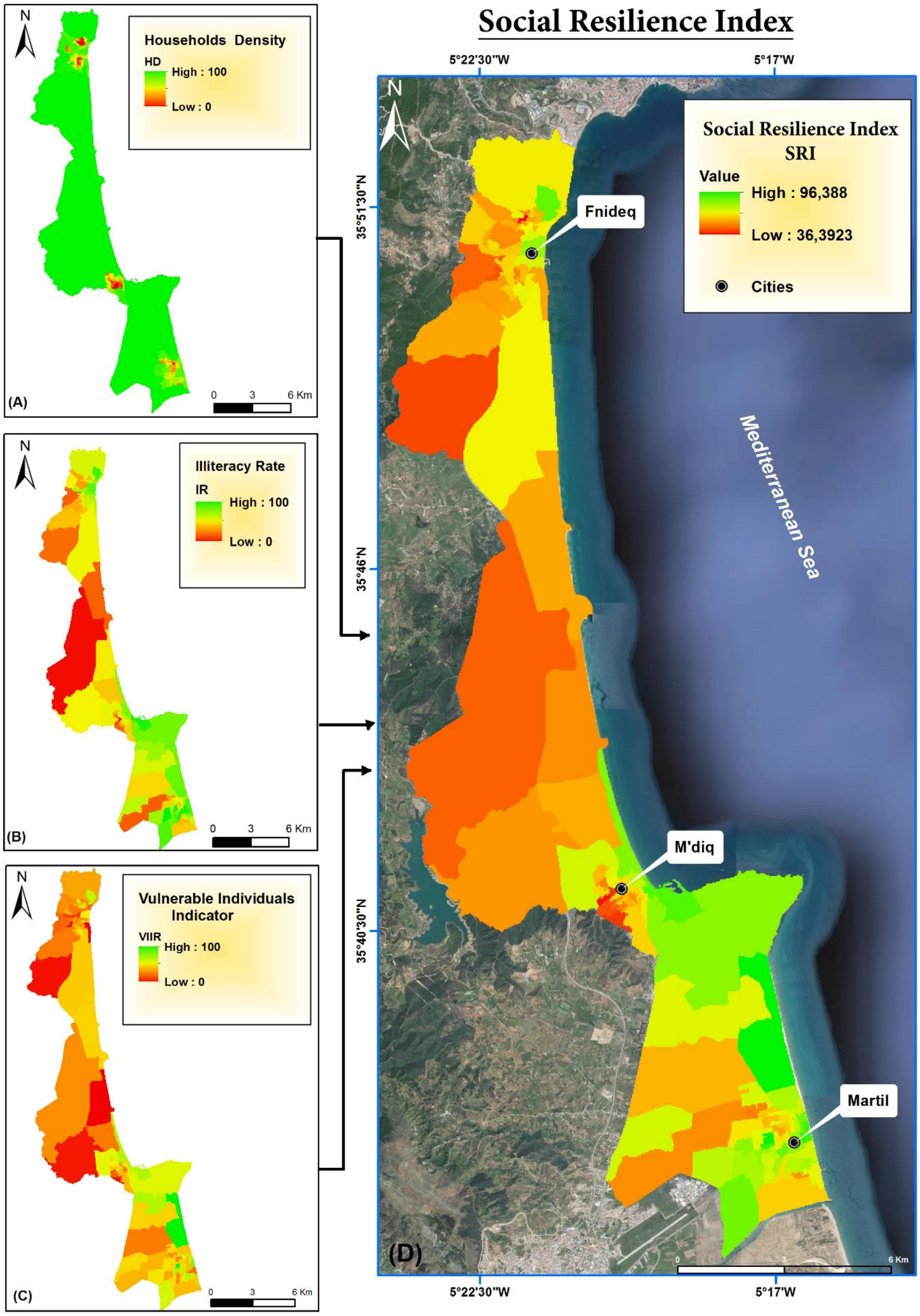
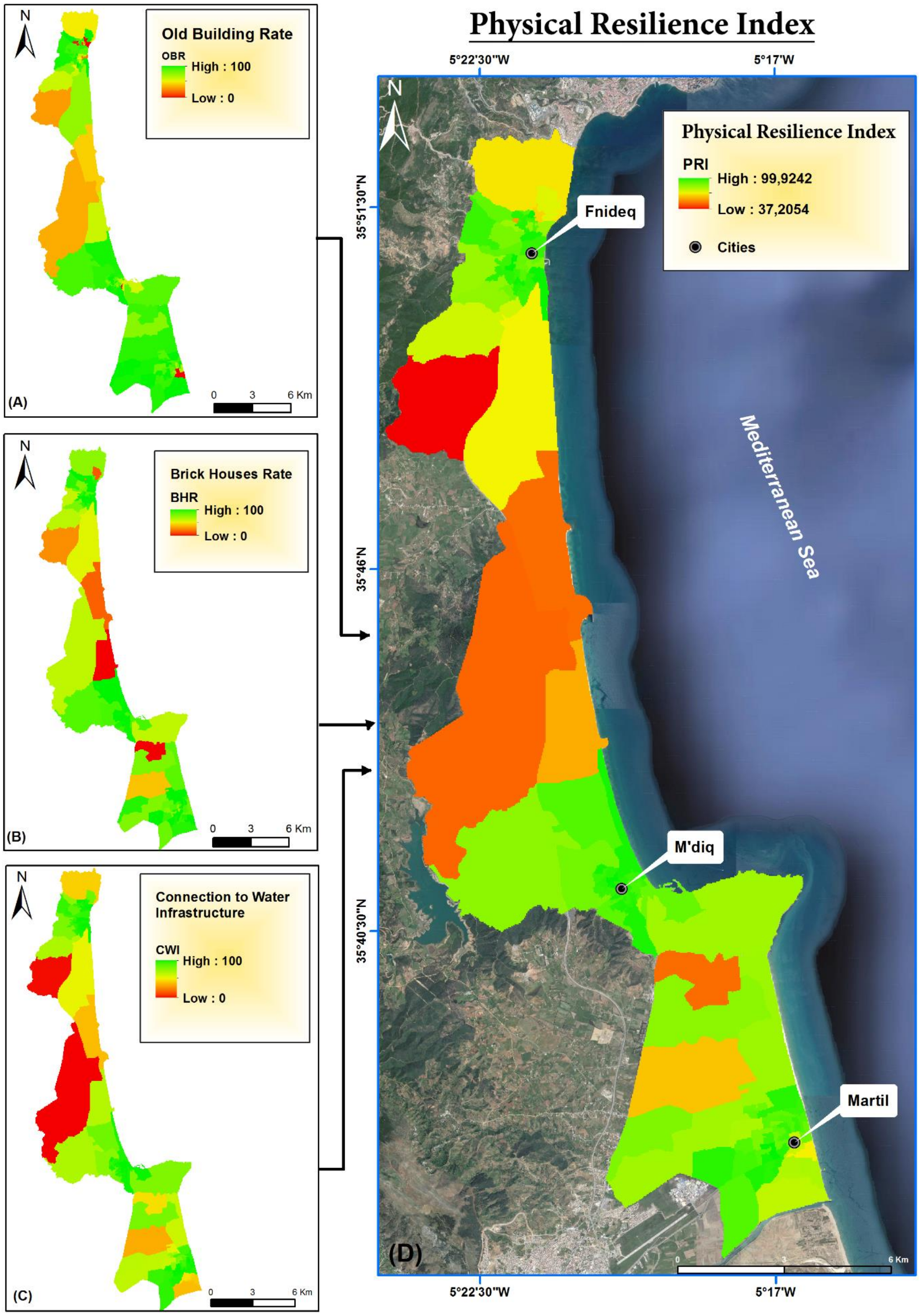


Figure3: Spatial distribution of A: HouseholdsDensity, B: Illiteracy Rate; C: Vulnerable Individuals Indicator and D: Social Resilience Index (obtained from © Google map image in 2018).



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403 **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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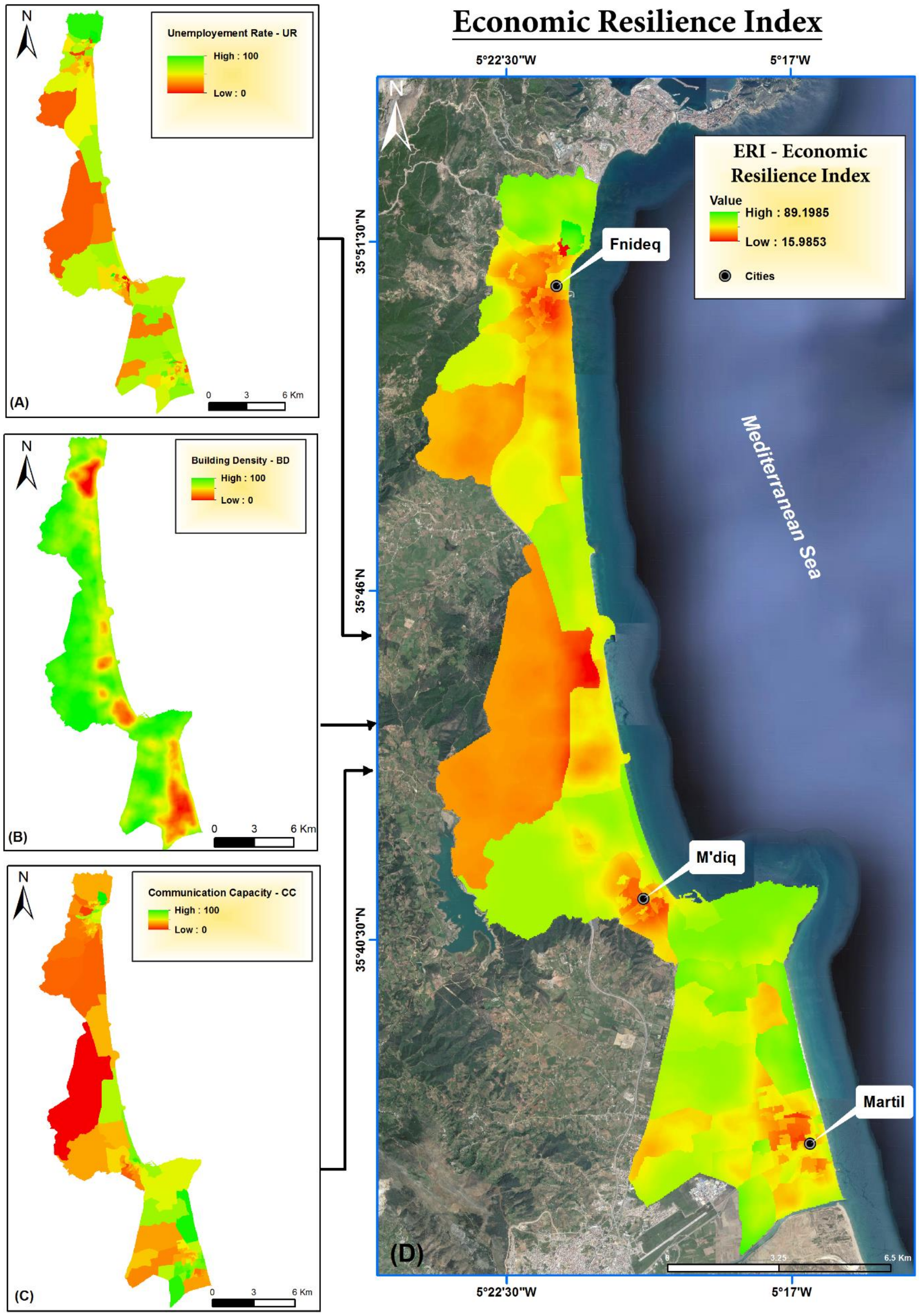


Figure 5: Spatial distribution of A: Unemployment Rate, B: Building Density 2017, C: Communication Capacity and D: Economic Resilience Index (obtained from © Google map image in 2018)

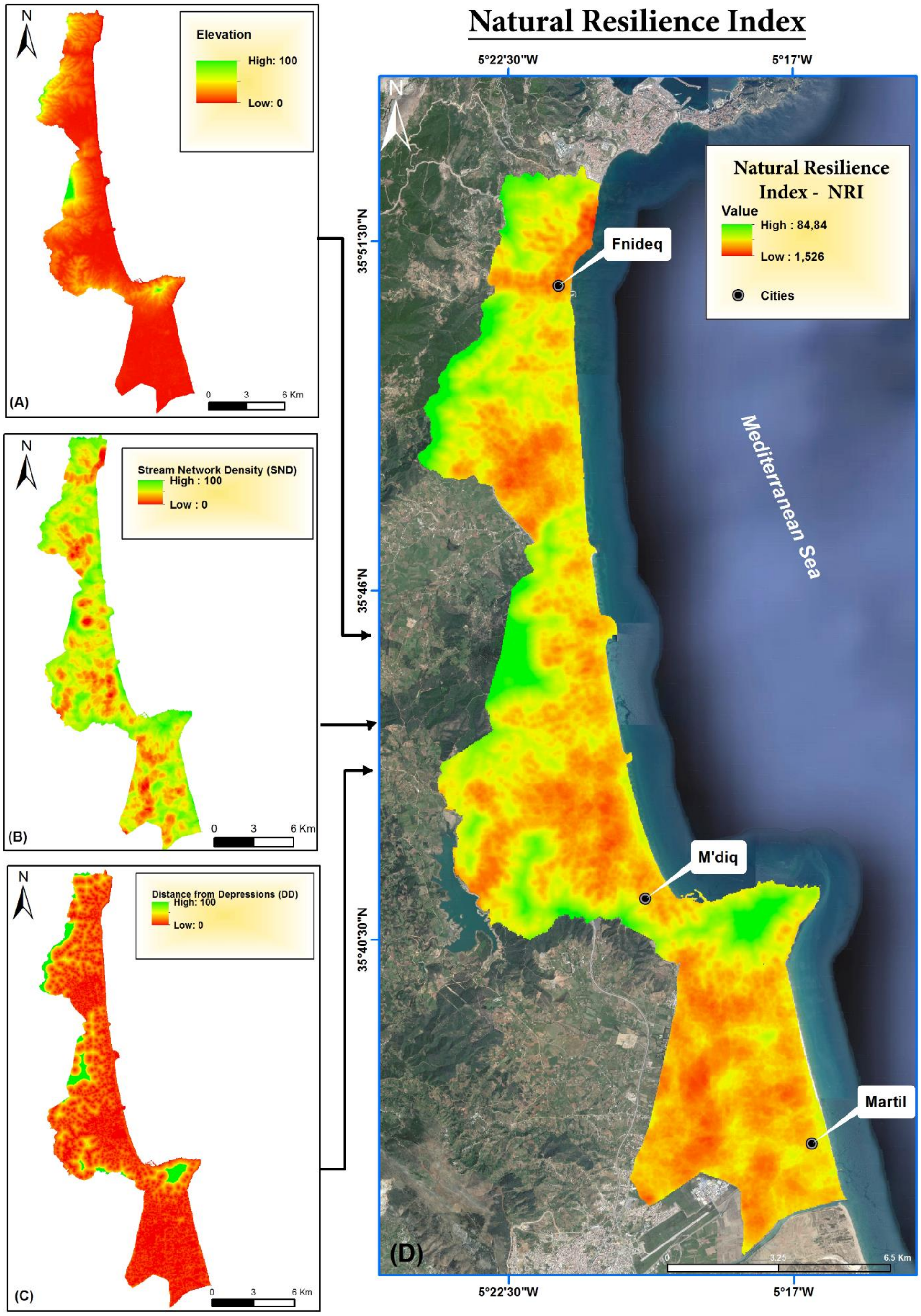
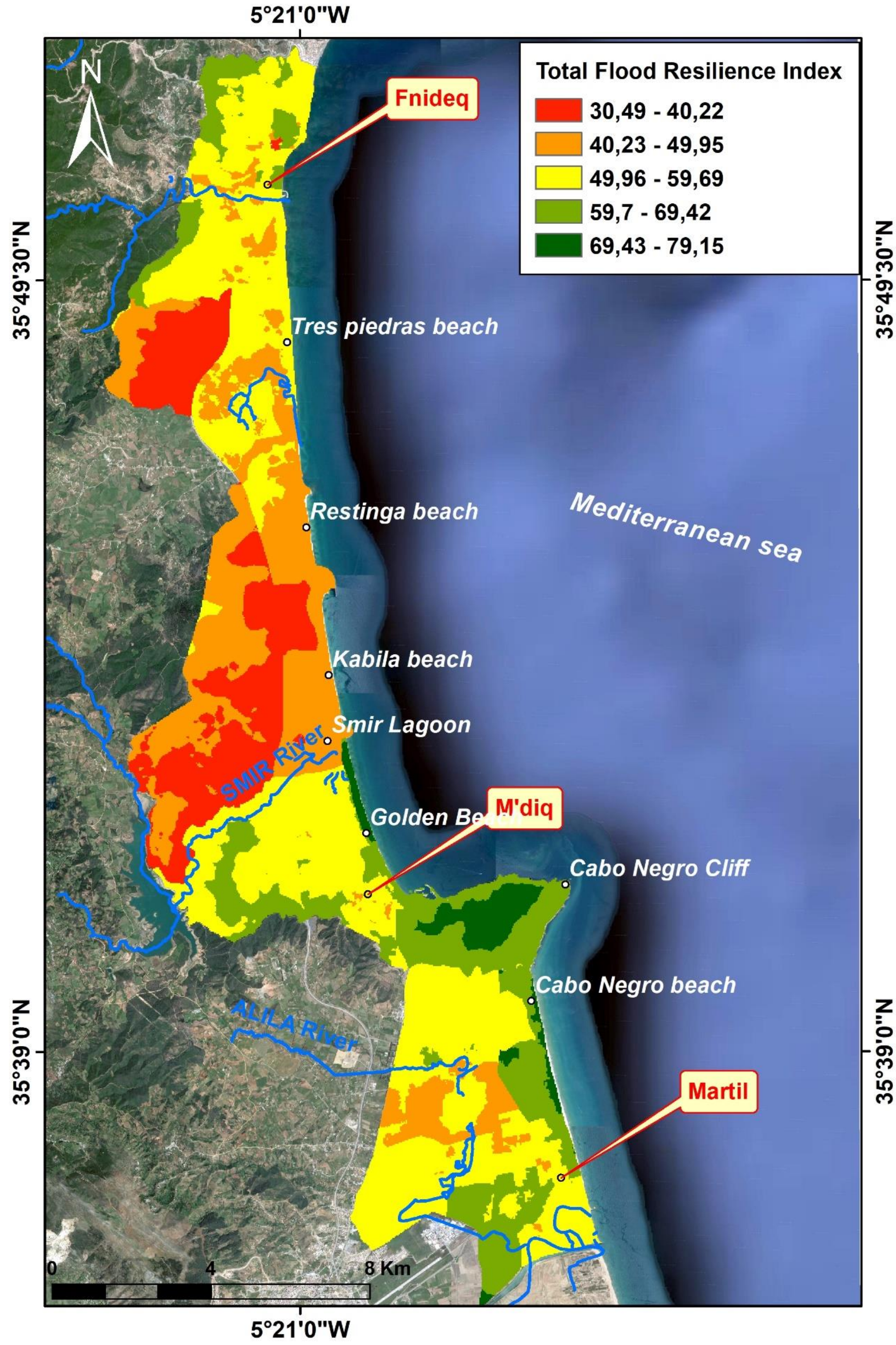


Figure 6: Spatial distribution of A: Elevation, B: Stream Network Density, C: Distance from Depressions and D: Natural Resilience Index (obtained from © Google map image in 2018)



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

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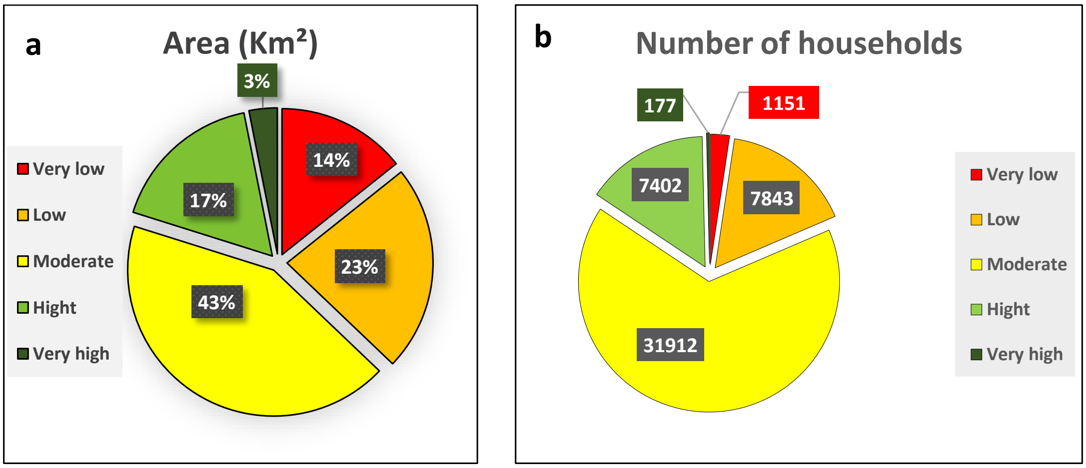

Figure 8: a) Distribution of Total Flood Resilience scores according to the surface of the study area; **b)** Distribution of Total Flood Resilience scores according to Households numbers in the study area.

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