GIS-modelling of land-use trends: impact of drought in the Naghamish Basin (North Western Egypt)

S. Saïdi\textsuperscript{A}, G. Gintzburger\textsuperscript{B,E}, P. Bonnet\textsuperscript{C}, I. Daoud\textsuperscript{D} and V. Alary\textsuperscript{C}

\textsuperscript{A}International Consultant, Montpellier 34000, France.
\textsuperscript{B}Badia Consulting, Mariginiup, WA 6065, Australia.
\textsuperscript{C}IRAD, Montpellier 34000, France.
\textsuperscript{D}Governorate of Matrouh, Marsa Matrouh, Egypt.
\textsuperscript{E}Corresponding author. Email: badiaconsulting@gmail.com

Abstract. The basic features of the Naghamish Basin and agro-ecosystem in the North West Coastal Zone of Egypt (climate, soils and vegetation cover) are mapped to analyse the wear and tear of physical components of the environment of three tribes’ territories between 2006 and 2011 when a dry spell struck. Our land use mapping and results using RS and GIS indicate considerable and quick changes in the agricultural and biotic components in spite of an inter-annual long-term rainfall variability appearing standard for this low-rainfall desert region. After good rainy years (1985–1995), the impact of the following drought (1996–2011) perceived by the farmer and Bedouin communities is real and confirmed by our land cover mapping changes of the Nagamish watershed. The communities are correct in their perception of the drought and are deeply affected in their economy and social life.

Additional keywords: barley, Bedouin, climate change, landscape ecology, livestock systems, rangeland management, water harvesting, Sahara.

Received 1 July 2016, accepted 28 October 2016, published online 16 December 2016

Introduction

Droughts are a recurring and common occurrence in semiarid and arid Mediterranean zones where inter-annual and intra-annual precipitations are highly variable. With looming climate changes, droughts escalate in North Africa and the Middle-East (Le Houérou 1993) impacting not only farming systems and land use, welfare of farmers and Bedouins but also activities from governmental and international development agencies (Hazell et al. 2001).

In the North West Coastal Zone (NWCZ) of Egypt, a slow and relentless bedouins sedentarisation process started in the early 1920 with ensuing urbanisation, expansion of crop-tree-livestock systems over decades, and large tourist infrastructure developments (Bonnet et al. 2014). It lead to major long-term environmental degradation, desertification with large land clearing for hazardous rain-fed barley cropping, overgrazing, fuel wood harvesting predominantly on sandy soils and to a lesser extent, soil salinisation due to poor irrigation techniques. To remedy these adverse environmental trends and sustain the local agriculture and economy, numerous internationally and nationally funded agricultural and rangelands projects (WB, UNDP, FAO, GTZ, WFP, etc.) were implemented as early as 1960. In spite of all these efforts, local populations and experts noted accelerating trends land degradation (Ayyad and Le Floch 1983) along potential catastrophic ecological evolution foreseen for the Mediterranean Basin (Le Houérou 1993). These deleterious changes were even further exacerbated by droughts hitting the western coastal desert (Alary et al. 2012, 2014; Bonnet et al. 2014). El Sayed (2015) studied the native vegetation changes with conventional ecological vegetation surveys between 2004 and 2015 at Wadi ‘Umm Ashtan’ 20 km west of Marsa Matrouh. He demonstrated that drought, overgrazing, cropping and land use changes have negatively impacted biodiversity, vegetation cover, standing biomass and increased soil erosion.

Although conventional farm and field surveys, land and management mapping were carried out over years on the NWCZ (Ibrahim 1966; Van der Veen et al. 1968; El-Naggar et al. 1988; El-Miniaawy et al. 1992; Bartels and Moustafa 1991), geographic information system (GIS) techniques were first used in the Marsa Matrouh region (Delaroque 1998) to identify potential wadi sites for fodder shrubs plantations for the Qsar Range Development Project in collaboration and for the benefit of the livestock owners. Remote sensing (RS) combined with field surveys were only used recently at a large scale (Bonnet et al. 2014; Daoud 2015). Based upon most recent GIS and RS developments, our aim is to go further and illustrate land use and vegetation cover trends in relation to agricultural activities and
drought and its impact on agricultural systems practiced by three tribes living in the Naghamish basin. Populated with Bedouins and farming communities, this basin is an appropriate location to identify the land cover and land use spatial changes taking into account the recent worsening rainfall conditions and drought from 2006 to 2011. Processed Spot5 imagery combined with GIS were used to compare and describe land uses and vegetation cover changes between 2006 and 2011, taking into consideration rangelands areas, native vegetation, croplands, orchards and bare soil areas within the customary territories of these three tribes. This spatial approach was combined with farm surveys in the three locations of the wadi (from the coastal line in the North to the extreme arid zone in the south) to attempt understanding ongoing farm and tribal adaptation to drought in relation to environmental degradation or restoration over this period.

Study area

Our case study is located between the coordinates N31.28°E27.38° and N31.10°E27.20° (Fig. 1) ~15–20 km south-east of the Marsa Matrouh town and ~220 km east of the Libyan border. It is part of the north-western coastal region and consists of four physiographic units, which are the wadi-bed and its small delta, the northern plateau and the southern plateau. The total area is ~89 km². The bioclimatic is a typically Mediterranean lower arid in the northern fringe along the shoreline and desert further south.

Materials and methods

On climatic trends

The wadi Naghamish basin is located ~10–15 km south-east of the Marsa Matrouh airport meteorological station monitored by the Egyptian Meteorological Authority providing the long-term rainfall data we used in our study. The rainy and growing season begins during the second half of October with a peak in January; hence the yearly annual rainfall taken into consideration is from September to August of the following year. In our study, we only considered the total annual rainfall and not the seasonal distribution within year.

The yearly amount of rainfall received by this station from 1944 to 2011 was assessed with a graphical analysis and smoothed with the moving average methodology reducing the inter-annual variability. This study period was used due to the fact that the wet and dry sequences are all less than 4 years long until 1995.

Statistical analyses

To interpret the curve difference observed graphically from the two periods: 1944–1985 and 1986–2011 of annual rainfall and to analyse if Marsa Matrouh station has been affected by a dry climate trend over the period 1995–2011, we used the z-score transformation test (Falissard 1998) to compare the average values of the two selected periods to the z-score transformation table with a 0.05 probability of error.

\[ Z = \frac{|\mu_1 - \mu_2|}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{n_1 + n_2}}} \]

Where \( Z = z \)-score transformation test; \( \mu_1 \) and \( \mu_2 \): rainfall averages for the two periods; \( \sigma_1^2 \) and \( \sigma_2^2 \): variances of two samples; and \( n_1 \) and \( n_2 \): the number of years of measurements.

Defining wet or dry years

To define a wet or a dry year, we may use the quantiles, the standard deviations or the percentage of annual rainfall from the median. In our study, we used the latter. A year is considered normal if the difference from the average value of annual rainfall time series does not exceed 10%. A year will be considered dry when the difference is below 10% and wet beyond (Le Goff 1985).

On vegetation cover

From a phytogeographic and floristic point of view, this region is referred to as Marmarica (Le Houérou 2004b). The flora belongs to the Ibero-Maghribian Mediterranean phytogeographic region with some Saharo-Arabian and Irano-Turanian elements (Long 1955; Ayyad 1976; Kassas 1979; Le Houérou 2004b). Human activities have slowly but surely eliminated nearly all tall shrubs and trees. Large quantities of fuel wood – probably from Pinus halepensis – were used during antiquity as witnessed by large pottery and glass-making kilns still visible along the coast near Marsa Matrouh. Human interference is the major ecological factor that shape the present rangeland cover condition and cropping (Bonnet et al. 2014).

The coastal plain, with its valleys and terraces is mainly formed of clean sandy loam alluvium and colluviums. It extends from 1 to 10 km inland and, generally, cultivated either with
cereals (mainly rain-fed barley) or with tree crops: fig-trees, olive, almond and grapes.

Mapping vegetation through remotely sensed imagery involves sophisticated processes and techniques. Various sources of imagery are known for their differences in spectral, spatial and temporal characteristics and thus are suitable for different purposes of vegetation mapping (Bonn 1996).

Estimation of PVI (Perpendicular Vegetation Index)

A set of Spot images Multispectral Sensor Xs, dated 30 May 2006 and 2011, with high spatial resolution (2.5 m) were used to estimate the PVI values (Richardson and Wiegand 1977), which were computed from the NIR (Xs3) and the Red (Xs2) channels brightness of the image. Geometric, radiometric and atmospheric corrections were required to estimate the herbage mass using satellite imagery. These pre-processing steps of satellite remotely sensed data are geometric correction of satellite images involved by modelling the relationship between the image and ground coordinate systems acquired through GPS device. The methodology used is described in details in Saïdi and Gintzburger (2013).

On socioeconomic and tribes’ territories

In the entire NWoCZ, the population of the Nagamich basin is organised in tribes (Bonnet et al. 2014). Our study used socioeconomic information available from a survey based upon open questionnaires conducted between February and April 2012 among farmers and Bedouins of the Naghamish basin. The population interviewed consists of 17 families from the Gnashat and Mawalek tribes, 24 from the Hafian and Gbihat and nine from the Menfa (Daoud 2015).

The land is divided between these tribes and clans according to a complicated combination of tradition, size of the community, relative tribal power, and potential conflicts between tribes and sub-tribes. The main land use of the Naghamish Basin is a combination of rangeland grazing, water-harvesting techniques and rain-fed figs, olive, grapes, and barley cultivation, with rare intensive irrigated agriculture in the wadi (Bonnet et al. 2014). The land resources zones available for the farmers at various distances and times from settlements were computted for each tribe and defining their grazing territories. A GIS spatial analysis model based on geographical farmer’s dwellings location was used to identify these spatial tribes’ territories and characterise land use changes.

One way to visualise the grazing territories and explain the rangeland degradation around the farms settlements or wells of these tribes is to calculate the distance and time of a small ruminant flock led by a shepherd can travel from its base (usually the settlement) and return within a certain time. Various kinds of data were combined such as Digital Elevation Model and the geographical farmer’s dwellings locations to picture the tribes’ spatial territories. To compute the time necessary for farmer and his flock to reach any point on the Nagamich rangelands by the easiest track (avoiding too steep slopes, cliffs and other terrain constrains) and starting from their village position, we used the Pathdistance Grid Function available in GIS™ (Säidi and Gintzburger 2013).

Results and discussion

Long-term annual rainfall data analyses

Distribution of dry and wet years

According to the rainfall data provide by the Egyptian Meteorological Authority, the average annual rainfall calculated during the growing season on a series of 67 years (1944–2011) is ~142 mm (standard deviation: ± 67 mm). This station is representative of the lower-arid Mediterranean bioclimate with warm winter (i.e. 100–200 mm, no frost – Le Houérou 1982, 2004a, 2004b), with high inter-annual variability of rainfall and a rainfall coefficient of variation of ~45%. The moving average curve is a trend indicator reducing the inter-annual variability (Fig. 2).

Figure 2 shows the common discontinuities in the 1944–2011 time series with alternating dry and wet periods with variable durations not exceeding three successive years for dry and wet years and up to six successive normal years. Moving averages of annual rainfall show there is a difference between the two periods: 1944–1985 and 1985–2011. The yearly rainfall trend after 1985 indicates that the annual rainfall is above the average for 10 years (1985–1995). After 1995, the smoothed moving average curve does not exceed the average value over the period 1995–2011. This earlier 1985–1994 period displays a net increasing rainfall, followed by a noticeable yearly rainfall deficit from 1995 to 2011. However, the 1995–2011 smoothed curve remains above the median for most of the period considered. Yet, this rainfall deficit does not appear important enough. Although normal and dry years are succeeding at irregular intervals since 1995, our graph indicates that the Marsa Matrouh arid region may not be affected with a drier trend over years. This is in agreement with Le Houérou (1993) noting that the Global Circulation Models ‘do not provide any significant indication on change of rainfall (P) in the Mediterranean latitudes. We shall therefore assume no significant changes in the overall amount of rainfall, seasonal pattern and variability’, but admits that there could be a ‘lessening to the south’ by 2050 mostly due to relentless desertification process and anthropogenic pressure. The same Global Circulation Models predicts an average temperature increase of 3.0 ± 1.5°C for a doubling of CO2 in Mediterranean latitudes (30–45°N) by the year 2050. The overall temperature increase is already perceived by the farmers and Bedouins in the Naghamish basin (Daoud 2015).

With caution, Le Houérou (1993) speculates that this increase in average temperature would significantly increase the potential evapotranspiration (PET), in turn increasing water demand from crops, hence rain-fed crops yields expectancy could be further reduced (in spite of higher CO2 concentration), more so in subsistence farming zones below the average annual rainfall of 350 mm in North Africa and the Middle-East. Similarly, the native vegetation annual biomass productivity in these regions might slightly decrease because of a lower P/PET ratio. He comes to the conclusion that ‘Under the combined effect of a worsened soil water budget, erosion and a sharp increased pressure by man and livestock, most of steppic rangeland vegetation would give way to deserts…’

As for defining the wet or dry years, the 10% interval (Le Goff 1985) remains questionable as it is relatively low in
absolute term, so that, normal years are not the ‘majority’. However, it has the advantage of a better discrimination between dry and wet years in this arid environment where even a small reduction in yearly rainfall may lead to a drought period (Table 1).

Dry years represent the majority (at least 48%) compared with 30% of wet years. However, a dry year has a different effect on cropping and native vegetation depending on whether it follows another dry or a wet year (Rognon 1996). Furthermore, a dry year or a succession of dry years with annual rainfall less to 100 mm will have disastrous consequences on crop yields and fruit traditionally grown in the wadi collecting runoff water (Bonnet et al. 2014). To identify the average duration of dry sequences that will explain the drought perception of farmers, we calculated their distribution by class frequencies (Table 2). It shows that dry sequences vary between 1 and 3 years, with an average value of 1.7 years. During this studied period covering years, we noticed only four sequences of three successive dry years.

The z-score transformation results are presented in Table 3. The average rainfall recorded by the station increased by 16% (Table 3) between the two periods. However, the z-score transformation value is smaller than 1.96 (5% risk threshold) indicating that the difference between the two averages rainfall values for the two periods considered is not significant. According to this result, Marsa Matrouh station does not show a convincing dry climate trend. The rainfall fluctuations observed from this meteorological station fall well within the normal inter-annual rainfall variability in this lower-arid Mediterranean region.

The wet years and those called ‘normal’ are ~52% compared with 48% for dry years (Table 1). However, owing to the paucity of data relying on only one meteorological station, we must remain cautious about this final conclusion. These Marsa Matrouh rainfall data mainly reflects the climate of the coastal zone. The only significant difference is that the normal and dry years are occurring at irregular intervals over the period 1995–2006; this may explain the perception of drought by farmers relying rather on short-term memory. Moreover the

Table 1. Overview of wet, normal and dry sequences in Marsa Matrouh meteorological station (1944–2011)

<table>
<thead>
<tr>
<th>Wet</th>
<th>Normal</th>
<th>Dry</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of years</td>
<td>20</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>In (%)</td>
<td>30</td>
<td>22</td>
<td>48</td>
</tr>
</tbody>
</table>

Table 2. Frequency of dry sequence in Marsa Matruh meteorological station (1944–2011)

<table>
<thead>
<tr>
<th>Number of years by sequences</th>
<th>Frequency of dry sequences</th>
<th>Number of years observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Average number of dry years</td>
<td>1.7</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 3. z-score transformation test

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average values (μ1 and μ2)</td>
<td>133</td>
<td>155</td>
</tr>
<tr>
<td>Number of years observed (N)</td>
<td>41</td>
<td>26</td>
</tr>
<tr>
<td>Standard deviation (σ)</td>
<td>63</td>
<td>73</td>
</tr>
<tr>
<td>z-score transformation test (Z)</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Annual rainfall distribution at Marsa Matrouh meteorological station (1944–2011).
1995–2011 (i.e. 16 years) succession of drier years followed a 10-year period of relatively wet years between 1985 and 1995, therefore adding to the contrasting situation farmers may have in mind. Nevertheless, the statistical analysis and results obtained from the Marsa Matrouh station climatic database upon 67 years of rainfall observations would allow us to conclude that there is no drier climatic trend in the nearby region. It must be noted that such prolonged drought has always been a common occurrence in the arid Mediterranean zones, more so at the fringe of the desert as in the Marsa Matrouh region. Such disastrous droughts have been reported in Tunisia between 1846 and 1867 (Pélissier 1853; Kralik 1855; Guérin 1862; Mayet 1886; Doumet-Adanson 1887; Dupuy 1939), and also between 1918 and 1927 (Dupuy 1939). We must therefore be cautious identifying a long-term modification of the annual rainfall pattern and evidence of climate change in the Marsa Matrouh region. It nevertheless remains that the farmers used to customary 1–3 successive years of drought in the Marsa Matrouh region may have been deceived by the 10 wet years (1985–1995) followed by a severe and sustained drop in annual rainfall from 2006 to 2011.

Our rainfall data analysis only takes into consideration the total annual amount of rain received during the growing season. It does not analyse the impact of seasonal rainfall distribution and variability known to significantly affect crop yield and more so in semiarid and arid environments (Stephens and Lyons 1998).

**Land Cover Change 2006–2011 – impact on crops, livestock and population**

To analyse the Land Cover Change due to human activities, the land cover of Naghamish area in 2006 and in 2011 is mapped.

The PVI radiometric threshold were investigated, based on adequate field sampling data, and compared with produce the final land cover map (Fig. 3).

Human activities impact on landscape was assessed and quantified through the comparison of the 2006 and 2011 land cover maps to reveal the temporal changes of land cover categories. However, the first comparison between 2006 and 2011 maps for the wadi land cover displays less apparent production capacity and embedded diversity in 2011, be it for crop and rangelands associated with the north to south rainfall-based stratification of the wadi, or embedded in the complex network of wadi tributaries (in wadi bed and slopes).

As a matter of fact, land use and changes in land cover are directly related to the type of crops and farmers’ agricultural practices. The central stream of the wadi bed with deep soils is used for orchards and some market gardening when irrigation is available for the latter; the use of the plateau and slopes close to the wadi depression is assigned to rain-fed barley cropping with some water harvesting, and to some extent to grazing rangelands. Remote rangelands on the plateau with shallow or rocky soils are strictly assigned to small ruminants and camels grazing with flocks roaming there for a day or more (Fig. 4).

**Cultivated areas in the Naghamish basin**

Cropping and especially rain-fed barley cropping is essential to sustain the small ruminants flocks when they are not grazing rangelands in low rainfall/sub-desert region. From Fig. 3, we extracted the cultivated areas for each of the three tribes for 2006.
and 2011. The Gnashat had ~45% of their territory cultivated in 2006 and only 23% by 2011 clearly showing an impact by the post-2006 accentuated drought, retreating from the depressions with shallow soils on the plateau with poor water harvesting potential and cropped with rain-fed barley to the main wadi bed with deeper soils and better water harvesting capability. As seen from Fig. 3 and on Fig. 4, the lower and most fertile part of the wadi bed and tributaries are predominantly assigned to fruit trees with little barley cropping. Therefore, the Gnashat lost most of their rain-fed barley between 2006 and 2011 as they could not crop barley where the fruit trees were grown. The Hafian maintained their cultivated areas ~15% throughout from 2006 to 2011 mostly and carefully sticking to the most favourable wadi bed and tributaries with fruit trees. The impact of this change in barley cultivation location and drought was spectacular with barley grain yield average dropping from ~1200 kg/ha before the drought to ~620 kg/ha in 2012 (Daoud 2015) when drought struck. The Menfa have no cultivated areas at all (no barley, no fruit trees), as their territory is mostly located on the southern arid plateau without water harvesting potential or appropriate deep soils. This is confirmed with the results of Naghamish basin farm survey (Daoud 2015) indicating that two-thirds of the 50 farmers and Bedouins interviewed in spring 2012 noticed negative change in the soil quality mostly affected by wind erosion, as well changes in extreme temperature. All the interviewees perceive the desertification threat as real since 1996 when drought strike, reporting that they believe that 5–10 cm of soil has been wind eroded at the time of the interview due to loss of native vegetation and crop failure.

Livestock numbers trends in the Naghamish basin

Small ruminants and especially small ruminants are regarded in the region as the mainstay of livestock rearing and main income in normal conditions. The livestock data (Table 4) were gathered through interviews (Daoud 2015) in the three tribes
according to years of reference and converted into Sheep Unit Equivalent (SUE).

Considering the size of each tribal territory and respective SUE over the period 1995–2001, we extracted the stocking rates (SR) trends (Fig. 5).

All these SR are quite high for their very sub-desert rainfall zone. Proper practice would consider SR of a minimum of 8–10 ha/SUE for such a region. The Gnashat and the Hafian tribes stocked moderately (nevertheless still high) their land (~1–3 ha/SUE), having other feed resources available like barley grain. Quite stunning is the extremely high SR practiced by the Menfa tribe with 1/3 ha/SUE in 1995. We assume that this tribe was encouraged to increase its flock with the good rainfall episodes from 1985 to 1995 (Fig. 2) but then, when the 1995–2011 dry spell struck, had to drastically readjust to lower SR. Most livestock owners interviewed by Daoud (2015) claim negative changes affecting the grazing period, 90% – the mating period, 84% – the rate of lambing and 68% the overall animal production. As for the feed calendars for small ruminants, on wet years, the supplemental period for the three tribes is on average 6.4 months, 2.2 months on barley crop residues and 3.4 months of rangeland grazing, whereas in dry years and after drought strike, supplementation was provided during the whole year as no crop residues or grazing remains available. This led many livestock owners of the wadi Naghamish abandoning small ruminant rearing for more lucrative poultry production in spite of the risk due to summer hot temperature and scarcity of water supply (Daoud 2015).

Impact on the social fabric of the Naghamish basin

Other consequences of lower agricultural production following the drought years were that many farmers and family members migrated to the city seeking a better life, work in the city and better education options for their children (Daoud 2015). This land abandonment trend was further accelerated with the lack of available agricultural manual labour, increased labour costs and unpredictable market products prices. From field surveys (Daoud 2015) it is clear that the barley areas cropped by the Gnashat (and associated Mawalek clan) and by the Hafian (and associated Gbihat clan) dropped by ~53% between 2006 and 2011. This boosts agricultural land abandonment and consequently turned cropped lands into bare lands. All the above changes have severely impacted the Naghamish basin agricultural landscape with rainfall reduction over years.

Delimiting the spatial tribes’ territories

To evaluate the impact of some types of farming management on the structure and functions of ecosystems, a GIS spatial analysis model was developed. The land resources zones available for the farmers and Bedouins at various distances and times from settlements were computed for each tribe and defined their grazing territories (Gintzburger et al. 2005; Saïdi and Gintzburger 2013).

When each shepherd with his flock starts from his settlements and usually comes back at night, this is described as land use in ring 1 (maximum distance from settlement is 1.8 km or equivalent to a 1-h walk, and back to his settlement). Ring 2 represents 3.6 km (up to a 2-h walk, with coming back). Ring 3 represents the maximum distance of 5.4 km from settlement (3-h walk, with coming back). Usually the shepherd would return to his settlement for the night, hence, while leading his flock, he would go to a maximum distance of 5–8 km (3–4 h) and return back home for the night (Fig. 6).

Land use and land cover changes affecting the Gnashat tribe

This tribe is located in the best rainfall area of the Naghamish basin close to the shoreline. Its main and traditional economic activity is based on rain-fed barley cropping clearly impacting the tribe’s land use. Barley is the dominant crop due to its drought resistance, and its short life cycle, which makes possible its cultivation between December and April when the water balance is favourable on sandy soil. Fig trees are generally grown in areas receiving runoff; other trees are also present as olives and almonds. We note that the rangelands with low vegetation cover (23% in 2006) have changed in 2011 into bare soil around settlement by 6% around the settlement, 4% at 1-h distance and 3% at 1.5-h distance (Fig. 7). This could be due to land abandonment. However, a notable decrease to bare soil is observed in 2011 indicating more cropping concentrating close to the settlement. The bare soil reduction appears important around settlements at less than 30 min (7%) and at 1-h distance (4%). In contrast, the area with rangelands with dense vegetation cover (5% in 2006) appears to remain fairly similar in 2011 reflecting little grazing occurring.

One should note that the vegetation cover without overall change accounted for 50.5% of the area in the three first rings.
Fig. 6. Spatio-temporal rangelands territory of the Nagamish tribes while grazing during any single day.
Out of the remaining 49.5% of the land displaying cover change, rangeland areas with low vegetation cover in all three rings that were 23% in 2006 turned in 2011 into bare soil for 13%, 1% to crop land and 1% to dense vegetation cover. The former 13% can be desegregated into change in the settlement area by 6% around the settlement (ring 1), 4% at 1-h distance (ring 2) and 3% at 1.5-h distance (ring 3) indicating either increase grazing or increase cropping on this low vegetation cover land category. However,
12% of crop land turned into bare soil between 2006 and 2011. This cropland area reduction appears important around settlements (ring 1: 7%) and at 1-h distance (ring 2: 4%) pointing to a possible increased grazing pressure on the two closest rings near the Gnashat settlement. It is difficult to explain this result as livestock number collected during field survey indicates that the Gnashat SUE shrink by ~22% between 2006 and 2011. We hypothesise that the drought between 2006 and 2011 seriously impacted the Gnashat tribe economy, leading to diminishing barley cropping and yields, hence less grain available to feed the tribe’s flock, the latter relying more on rangeland feed, in turn putting more grazing pressure on low vegetation cover near the Gnashat settlement. Less barley grain available from the Gnashat for sale on market would also be an added reason leading the neighbouring tribes to reduce their flocks’ sizes, rangeland SR and rangeland utilisation.

Fig. 8. Spatio-temporal changes on the territory of the Hafian tribe.
We also note that the changes to bare soil inside all the rings from all land cover units are ~28.5% in 2011. Taking into account areas that remained unchanged between 2006 and 2011, bare soil represents in 2011 up to 47% of the Gnashat spatial territory (22% are situated at 0.5-h distance, 18.5% at 1-h distance and only 7% at 1.5-h distance).

In conclusion, in this coastal zone of the Gnashat territory, the increased sedentarisation, and reduction in barley cropping areas, the introduction of aggressive technologies for fruit tree plantation and rain-fed cropping (more tractors and disc plough on sandy soils), have had an obvious damaging effect on soils and native vegetation cover through water and wind erosion with new...

Fig. 9. Spatio-temporal changes on the territory of the Menfa tribe.
sand dunes development. The Gnashat territory is becoming highly sensitive to environmental degradation due to changing agricultural activities, urban development and recent drought.

**Land use and land cover changes affecting the Hafian tribe**

Rainfall is one of the most important elements in the dynamics of the Hafian tribe agricultural system mostly based on pastoralism. It affects directly rangelands production, hence feed production. So this factor may force this tribe to diversify their activities and exploit other sources of income. Generally, this tribe associates different types of combination of agriculture and non-agricultural activities with livestock breeding and also off-farm jobs in and out of agriculture sector.

On normal climatic years, their herds graze native vegetation on rangelands after the first autumn rains until mid to end of spring. Then, when rangeland feed is depleted by the end of spring, they move onto stubble and crop residues after harvesting from June to October–November. Barley grain (produced or bought) from neighbours is used to make traditional bread as well as used as a major source of animal feed during summer months. The rest, if any, is sold to the market.

Over the period 2006–2011, the most important environmental change in this tribe territory is that the low vegetation cover areas, which represented 51% in 2006, changed to dense vegetation cover in 2011, increasing by 5% around settlement by 11%, at 1-h distance and by 10% at 1.5-h distance (Fig. 8). This may indicate that cereal cultivation and tree plantation are limited only to suitable areas with low/medium vulnerability affecting natural plant cover and with soil and areas where the topography allows for water harvesting and rain-fed barley cropping. Furthermore, bare soil areas in 2006 (17%) changed around settlements to a low vegetation cover by 1%, by 4% at 1-h distance and by 7% at 1.5-h distance reflecting a change for the better in their range management and SR allowing minimal but noticeable biological recovery. Regarding areas remaining unchanged between 2006 and 2011, it clearly appears that these territories display a factual decrease of degradation processes. The native flora and vegetation are not been damaged and display good regeneration capability.

We may conclude that the Hafian tribe land-users have been struck by the regional drought. It appears that, de facto, they adjust to climatic change and are properly managing their territory and rangeland resources taking into account the environmental consequences of their actions, especially those having long-term effects on rangeland biological recovery.

**Land use and land cover changes affecting the Menfa tribe**

Pastoralism is the only agricultural activity of this tribe and their main source of income. They have no barley cropping area as their territory is located at the head and driest part of the wadi Naghamish basin with poor shallow desert soils. They do rely upon barley feed bought from the local market and from other tribes and on rangeland gazing. It is clear that the Menfa capitalised on the good rainy 1985–1995 years to augment their livestock heads due to large availability of barley grain produced by the Gnashat and Hafian tribes and high market price for the meat they produce. But the drought struck the region, the barley grain became rare and expensive and the rangelands produced less. This inflicted a dire blow to Menfa’s ‘s grazing systems and practices based on the abundance of native vegetation cover around settlements and on the north-west of the tribe territory. Sheep and goats grazed all areas with dense vegetation covering ~37% of the tribe territory in 2006. By 2011, the area with dense vegetation rangeland cover has significantly decreased to low vegetation cover around settlements by 9%, by 13% at 1-h distance and by 15% at 1.5-h distance (Fig. 9).

However, the changes affecting rangelands with low vegetation cover (60% in 2006) appears to be insignificant by 2011. This low vegetation cover may eventually regenerate if it receives good rain, and if it has not lost its potential productivity and native seed stock. The area with bare soils did not change much between 2006 and 2011. However, by 2011 the Menfa shepherds have drastically reduced their SR and avoid grazing on rangelands with low vegetation cover providing minimal and poor feed supply in this desert environment. They may also take into account the overgrazing risk and empirically, are able to identify rangeland areas having different levels of productivity. The drought consequences on barley grain availability, more than for the other two tribes, forced the Menfa to considerably reduce their animal number, and adjust their SR (Table 4 and Fig. 5) to moderate to low level to avoid overgrazing and ensure plant cover recovery, hence making sustainable use of their essential natural resources. Despite the fact that some tall shrubs in the area are seasonally harvested for cooking and heating (such as the unpalatable *Thymelaea hirsuta*, *Lycium europaeum*, *Rhus tripartita* and *Periploca angustifolia*) the Menfa rangelands are not systematically damaged in spite of having less vegetation cover than the two other tribal territories.

All in all, the Menfa have been economically more affected by the 2006–2011 drought than the two other tribes but have managed or were forced to rapidly adjust to the new climatic conditions by reducing their flocks size. Once the drought over, and possibly barley cropping resuming in the region with better rain, they will be able to quickly rebuild their flocks having spared their rangeland resources.

**Conclusions**

Wadi Naghamish is diverse in its agricultural and rangeland use, close to Marsa Matrouh, at the upper limit of the western Egyptian coastal desert close to the Libyan border. This wadi watershed and surrounding plateau is traditionally used by the Gnashat, the Menfa and Hafian tribes with Gbihat and Mawalek associated clans. The agricultural economy of these communities is traditionally based upon rain-fed barley cropping providing grain and crop residues to their small ruminants, and complemented with fruit production from orchards (olives, figs, almonds) supplemented with runoff and waste water. The communities reported and insisted that the drought (1996–2011) they perceived affected drastically their livelihood and changed their environment and economy.

A long-term rainfall data (1944–2011) statistical analysis on the Marsa Matrouh meteorological data does not reveal a clear
drying pattern over years and especially during the past 30 years in spite of the better annual rainfall (1985–95) and the apparent drought (1996–2011). The high inter-annual rainfall variability observed is quite common and normal in arid regions receiving a mean annual rainfall of 100–150 mm at the margin of the desert. However, when mapping the land cover changes affecting rain-fed crop and rangeland, the drought impact is clear and real. It mostly and drastically reduces the rain-fed barley areas especially on the Gnashat and Hafian territories hence reducing the grain supply to small ruminants of all tribes and more so to the Menfa tribe having no cropped barley on their most arid rangelands. The consequence is first that all tribes had to reduce their small ruminant numbers after 1995 hence considerably reducing the small ruminants SR on rangelands. When drought stroke, barley fields were abandoned on the Gnashat and Hafian territories, leaving large tracks of barren – poor rangelands as seen on our maps as the native vegetation does not regenerate easily and fast on long-cultivated ex-barley field in this low rainfall – sandy desert areas. Abandoned cropped, overgrazed and denuded sandy soils on the Gnashat and Hafian territories are rapidly subject to wind erosion discouraging native seedlings emergence and establishment, hence inducing rapid native seed stock depletion and productivity loss. Concurrently, reducing SR on uncultivated rangelands as on the Menfa territory allows native vegetation regeneration as seeds stock remains unaltered.

After the good rainy years (1985–1995), the impact of the following drought (1996–2011) is confirmed with our land cover mapping changes in the Naghamish watershed. The communities are right in their perception of the drought affecting and disrupting their economy and social life. Our long-term rainfall statistical analysis clearly does not reflect the field truth. It remains at the best a partial interpretation that requires further refining with studying in particular the relationship between seasonal rainfall distribution and crop yield. The reality of the drought impact remains with the farmers perception supported with reliable field agricultural surveys and data collected confirmed by our GIS and RS land cover changes analysis and mapping. These techniques may be put at good use by national and international development agencies to carefully plan and lessen the burden on local populations of the steppe and the margin of the desert. Past droughts in the Mediterranean regions were common over centuries but the present condition with unsustainable anthropogenic and livestock pressure is now drastically changing the game. All in all, the prospect of an ecological and economic catastrophe will emerge in the horizon if drought occurrences would continue in arid Mediterranean regions, with increasingly poorer farmers and Bedouins in search of better life moving to nearby settlements and towns. The impact of a similar 2006–2011 drought in Eastern Syria catapulted the region into dire long-term economic and human consequences (Gleick 2014). Le Houérou’s (1993) early premonition warned in his conclusion that ‘...Unless strong and determined actions are taken between now and the year 2025, the catastrophe is arithmetically unavoidable. Social unrest and all sorts of extremisms would flourish. European countries would undergo extreme pressure from the hungry multitudes to the south. Such pressure could in turn lead to social unrest...’

References


