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GIS-Based Analysis of Spatial Distribution of Medicinal and Herbal Plants in Arid and Semi-arid Zones in the North-west of Jordan

Jawad Taleb Al-Bakri[1]*, Dawud Al-Eisawi[2], Said Damhoureyeh[2] and Sawsan Oran[2]

[1] *Department of Land, Water and Environment, Faculty of Agriculture, University of Jordan, Amman, Jordan*

[2] *Department of Biological Sciences, Faculty of Science, University of Jordan, Amman, Jordan*

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Abstract: This study integrates geographic information systems (GIS) and ground surveys to map medicinal and herbal (MH) plants in a semi-arid and arid Mediterranean area in the north-west of Jordan. GIS layers of land use/cover, slope and aspects were created and different GIS functions were implemented to investigate the relationships between the number of MH plant species and land use types, altitude, slope and aspect. Statistical analysis was carried out to test the significance of the spatial distribution of the total number of plants and plant species among the sampled grids. Data from ground survey and GIS layers were then used to identify hotspots with high potential for conservation of MH plants. Results showed that more than 600 plant species, including 223 MH species, were recorded in the study area. The study area was characterized by intensive agricultural activities and urbanization, which affected spatial distribution of MH plants. The number of MH plant species tended to significantly ($P < 0.05$, $R^2 = 0.46$) decrease with altitude. The spatial distribution of MH plants was different from one species to another and was different from the distribution of all plant species (MH and non MH plants). Spatial distribution of hotspots, which was affected by different factors, including land use and global importance of MH plant species, recommended different sites for an *in-situ* conservation of MH plants. The study showed that anthropogenic factors were obviously impacting the spatial distribution of MH plants in this diverse semi-arid and arid area.

Key words: GIS, Jordan, arid, semi-arid, medicinal plants, Mediterranean.

Arid and semi-arid zones are the most dominant types of drylands in the eastern Mediterranean region. Arid zones are usually used as open rangelands and suffer from overgrazing which threatens biodiversity and accelerates desertification. The semi-arid zones are transitional steppes between the arid and hyper arid (deserts) and the dry sub-humid regions. These zones provide important sources of plant genetic resources that contribute to biodiversity and food resources. Unfortunately, many of the eastern Mediterranean arid and semi-arid lands have been suffering from increasing stresses of irrational land use and frequent droughts. Generally speaking, arid and semi-arid zones are characterized by low precipitation and highly variable rainfall patterns. Nevertheless, biodiversity of arid zones is significant in terms of endemism while semi-arid zones are very important in terms of both human livelihood and biodiversity (Blench, 2004).

Jordan, located in the eastern Mediterranean region between 29° 11′ to 33° 22′ N latitudes and 34° 19' to 39° 18' E longitudes, is dominated by arid and semi-arid climates (Fig. 1). The country encompasses a great diversity of unique habitats, flora and fauna and physical and geological features (GCEP, 2000; Disi *et al.*, 2004). Jordan has 18 distinguished vegetation zones (Albert *et al.*, 2003) and large volume of indigenous medicinal plants and herbs (MH) which are harvested from wild populations within Jordan and from the border areas of neighboring countries. The early studies of Zohary (1962; 1973) documented the country's flora as a part of that of the Middle East. Studies related to the flora of Jordan became prominent after 1972, when the recent collections of the flora of Jordan started accumulating in good numbers.

More than 2100 plant species were listed by Al-Eisawi (1982; 1985; 1996; 1998), who described the vegetation of Jordan in relation to biogeographic regions in the country and produced a small-scale vegetation map for the country. Detailed description of 488 species and their geographical distribution were included in the work of Al-Eisawi (1998) who added several new species of MH plants to the flora of Jordan. A survey of medicinal plants, as a total number of species with their brief uses was documented by Oran and Al-Eisawi (1998). Several studies in Jordan focused on the use of MH plants, phytochemical constituents, pharmacognosy, physiological effects, antimicrobial effects, antifungal effects, antitumor effects, food antioxidants and food additives

*E-mail: jbakri@ju.edu.jo

(Al-Eisawi and Takruri, 1989; Khalil *et al*., 2005; Khalil and Dababneh, 2007; Dababneh and Khalil, 2007; Dababneh, 2007; 2008).

Conservation of MH plants requires information on the spatial distribution and threats to these plants. The use of geographic information systems (GIS) to aid in conserving MH plants by assessing their distribution has been indicated in many studies (e.g. Mustalish *et al*., 1996; Schumaker, 1996; Sperduto and Congalton, 1996; Menon and Bawa, 1997; Debinski *et al*., 1999; Roy and Tomar, 2000; Porwal *et al*., 2003; Anderson *et al*., 2005; Roy and Behera, 2005; Yang *et al*., 2006). Most of the research indicated that GIS, along with remote sensing data, would provide effective methods for detailed vegetation mapping and analysis of data obtained from ground surveys. In mapping MH plants, remote sensing data could provide information on land use/cover; vegetation, terrain attributes and accessibility to area. On the other hand, GIS could be used to generate map layers and to build up comprehensive databases on physical, biological and environmental parameters which govern the spatial distribution and abundance of plants.

The use of spatial analysis within GIS showed to be effective in providing maps of spatial distribution of MH plants in relation to landscape and anthropogenic factors. Different functions of GIS could be used to generate digital layers of slope and slope aspect from topographic maps, or to create buffers of distances around sources of landscape disturbance. Intersection of these maps would enable the user to extract data from different layers and to export them for further statistical analysis and comparisons, which would save time and cost of analysis in these studies. Roy and Behera (2005) utilized those GIS capabilities to identify biological richness along different altitudes. The intersection of different GIS layers of vegetation, biogeographic and altitude zones enabled the identification of economically important medicinal and endemic species decreased with altitude and disturbance levels.

Another important contribution of GIS in studying spatial distribution of MH plants would be the implementation of different criteria to identify hotspots for *in-situ* and *ex-situ* conservation of these plants. The approach would be usually based on integrating different data of vegetation, botanical surveys, pharmacognosy and ethnobotany through user specified-criteria. An example of this approach was shown by Anderson *et al*. (2005) who integrated different vegetation, terrain and ethnobotany data to identify sacred MH plants in their study area.

In order to conserve the MH plants in the arid and semi-arid zones of Jordan, particularly those with global pharmaceutical importance, the questions of "how many MH plants?" and "where are the MH plants located?" should be answered. Spatial databases pertinent to these plants are urgently needed to identify hotspots where the potential of an *in-situ* conservation is high. This is particularly important in arid and semi-arid zones where human induced factors are adding more stresses on MH plants. Therefore, a national collaborative program "conservation of medicinal and herbal plants of Jordan", which involves several government and non-governmental agencies, is being implemented to support conservation, management, and sustainable utilization of MH plants in Jordan while ensuring effective *in-situ* protection of threatened habitats and eco-systems.

The research reported in this paper forms part of this program and explains how GIS and ground surveys are integrated to map MH plants in the upper slopes of the north-western parts of Jordan and to provide GIS layers for spatial distribution of important MH plants. The specific objectives of the research are: (1) to study the spatial distribution of the MH plants in relation to land use, elevation and slope, and (2) to incorporate GIS data and expert criteria to provide maps of hotspots where *in-situ* management and conservation would be possible to alleviate the anthropogenic stresses on MH plants. These objectives are in line with Jordan's international commitment to sustainable conservation of its natural resources and biological diversity within the framework of the Convention on Biological Diversity (CBD) (RSCN, 2000).

Methodology

Study area

The study area, located in the north-west of Jordan (Fig. 1), was geographically identified as the rectangle bounded by Northings 3535000 to 3615000 and Eastings 755000 to 770000, according to Universal Transverse Mercator (UTM) projection system for zone 36 north of equator. The study area, 15 by 80 km, extends from north of Irbid city (35°52′ E, 32°36′ N) to the south-west of the capital Amman (35°48′ E, 31°59′ N). The project aimed to cover this area as the first stage and to extend the survey to

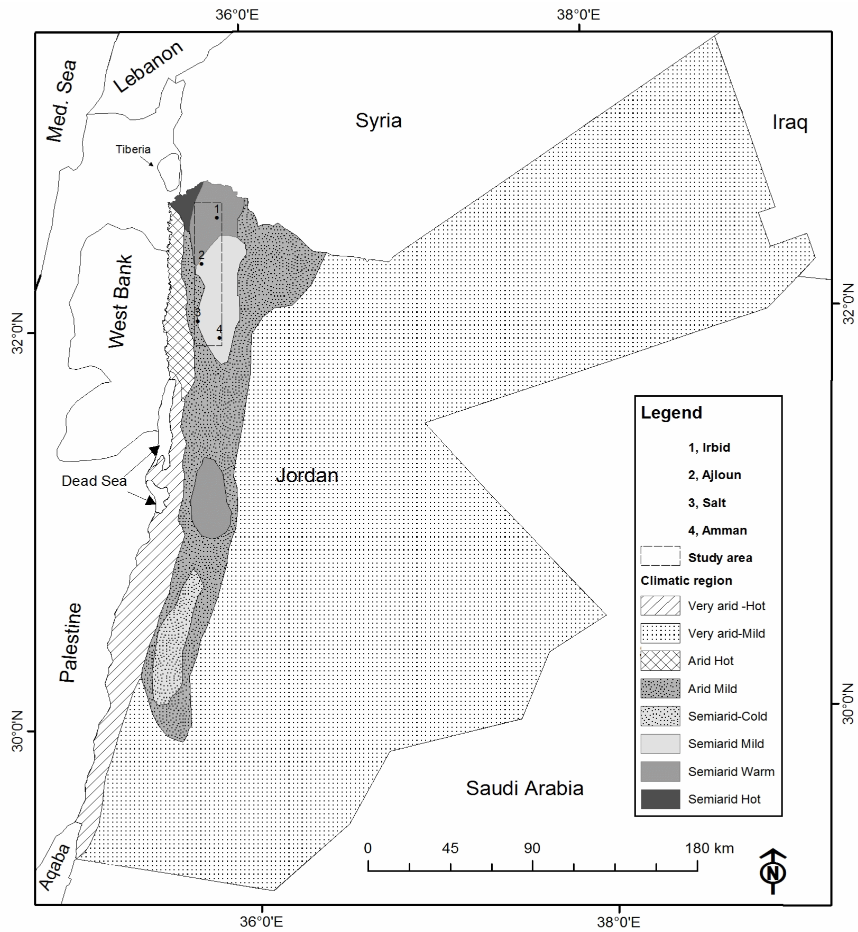

Fig. 1. Location of the study area and climatic zones of Jordan (After JNGC, 1984).

other areas in the country (eastern upper slopes of the Jordan rift valley). The area has a typical Mediterranean climate with precipitation ranging from 300 mm to more than 650 mm in Ajloun. The rainy season extends from November to mid of April and concentrates in December-February. The area is characterized by cool temperature in winter and mild temperature in summer; the mean maximum temperature is 34°C (occurring in August) while the mean minimum temperature is -4.2°C (occurring in January).

The region has xeric moisture and thermic temperature regimes. The reconnaissance soil survey of the Ministry of Agriculture (MoA, 1993) shows that the dominant soil subgroups, according to USDA-SSS (1990) classification system, are Typic Xerochrepts, Calcixerollic Xerochrepts, Lithic Xerochrepts, Xerothents, Vertic Xerochrepts and Haploxerolls. Soils of these subgroups have low content of calcium and include yellowish red silt clay and brown to strong brown clays of the same texture.

Intensive rainfed agriculture is practiced in the area, particularly cultivation of fruit trees of wild cultivars and olive groves. Cereals are sown in November on the undulating plateau remnants and in the larger valleys and are harvested in June. Description and analysis of existing and potential land use of this region was detailed by Al-Tamimi and Al-Bakri (2005) and Al-Bakri *et al*. (2008). Improper farming practices that accelerate soil erosion, woodland and forest cutting, land fragmentation and uncontrolled expansion of urban and rural settlements at the cost of cultivable land are the major causes of land degradation in the study area (Khresat *et al*., 2007; Al-Bakri *et al*., 2008). More than half of the country's population (5.6 million according to 2004 census) resides within this area.

Sampling scheme

The mandate of the study was limited by the available resources and the short growing season of MH plants. Therefore, a systematic sampling

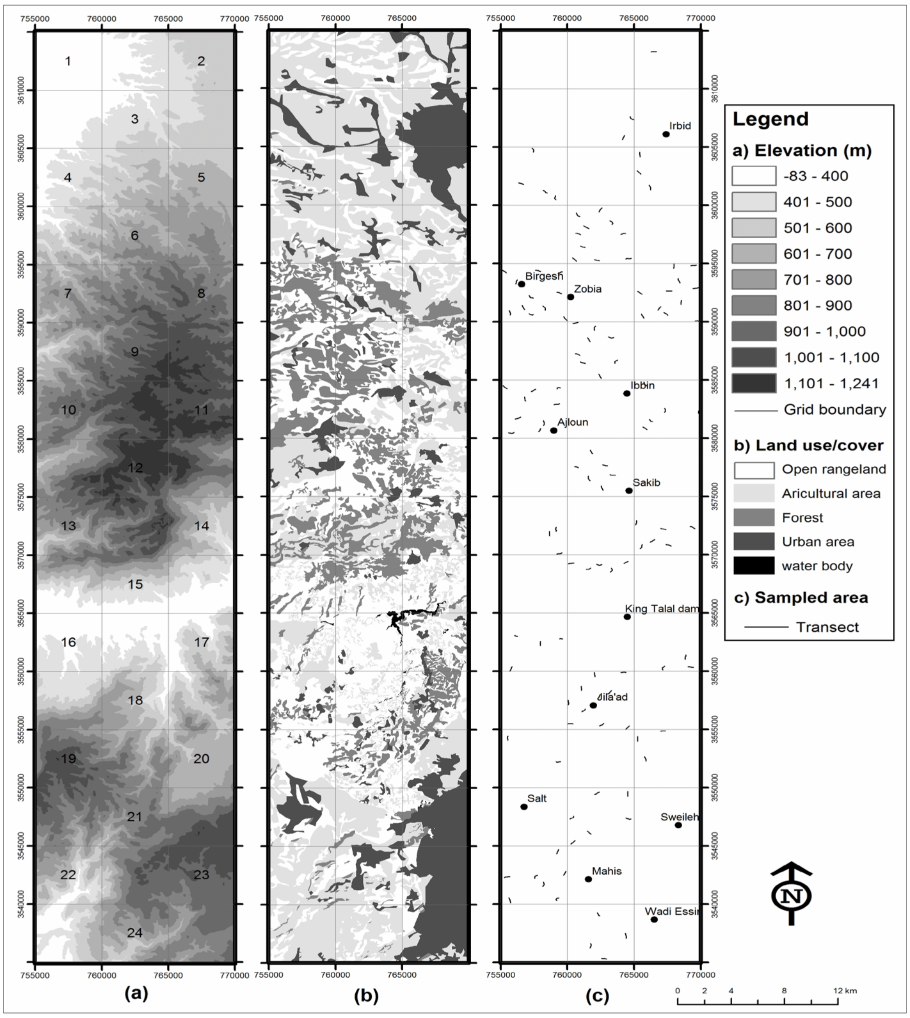

Fig. 2. Different GIS maps for the study area: a) digital elevation model; (b) existing land use/cover; (c) location of the sampled line and route transects.

scheme was adopted to survey the area using line and route transects methods. According to the scheme, the target area was divided into grids of 5 by 5 km, with every other grid being included in the survey. The grids were sequentially numbered from 1 to 24 (Fig. 2). Each grid (25 km^2) was divided into smaller squares of 1 by 1 km, where every other square was surveyed. The squares were sequentially numbered from 1 (upper left square of the grid) to 13 (lower right square of the grid). Subsequently, the sampled transects were numbered according to the grid-square number. For example, the transect G2S1 would be located in the first square of the second grid. This system of numbering was used as a common field to join GIS maps with ground data.

Preparation of GIS data

Prior to field survey, it was important to prepare maps of the target area in order to identify locations where sampling is possible. According to the project tender, areas that had altitudes of 400 m or less and areas which were cultivated and/or urbanized should be eliminated from the survey. Therefore, GIS was used at the early stages to prepare a digital elevation model (DEM) to exclude squares with altitudes of less than 400 m, where another survey would take place. The DEM was created from a digital contour map, originally digitized from hardcopy topographic maps of the study area. The output map was rasterized and transformed into a DEM of 30 m resolution. The DEM was then classified to identify areas that have altitudes of less than 400 m. The output map (Fig. 2) showed that altitudes ranged from 83 to 1430 m. Areas with altitudes of less than 400 m were mainly located on the main streams of Zarqa River (Grids 15 to 18) and Wadi Shuaib (Grid 22).

In order to study the distribution of MH plants in relation to land use, a GIS layer was created

Table 1. The land use/cover (LUC) classification scheme and percent of each class in the study area

Class	Definition	Per cent of area
Open rangeland (OR)	Open shrub and herbaceous rangelands including bare rock and sparsely vegetated areas, cliffs, rock outcrops, exposed rocks and limestone.	33.6
Agricultural area (AA)	Rainfed wheat and barley, crops irrigated permanently or periodically. Areas of annual crops associated with permanent crops and orchards.	37.1
Forest (F)	Areas of deciduous and evergreen oak and pine forests, used mainly for recreation.	13.6
Urban area (U)	Continuous and discontinuous urban fabric used for residential, industrial and commercial purposes. Areas with an open-pit extraction (mainly quarries) and spaces under construction and development.	15.5
Water body (W)	Natural or artificial stretches of water including small pools and King Talal Dam.	0.2

from the visual interpretation of a high resolution (5 m) image of SPOT 5xS. The image, acquired on March 2007, was geometrically corrected using 25 well-defined and distributed ground control points (GCP's) collected by a global positioning system (GPS). The image was resampled with an error of less than one pixel using the Nearest Neighbour (NN) method and was registered in UTM projection system, zone 36.

An on-screen digitizing procedure was followed to delineate land use parcels from the satellite imagery. The interpretation was limited to six land use/cover classes (Table 1), which were visually interpreted and verified by several field visits prior to the ground survey. The output land use/cover map was analyzed in GIS to calculate the area of each class. Also, this map was used to derive the dominant land use of each sampled square and grid by rasterizing it to two raster maps with dimensions of 1 km and 5 km, respectively.

Both of the DEM and land use/cover maps were important to prioritize sampling locations prior to field survey. For example, the DEM enabled the team to identify areas with low altitudes where early growing season would be expected and field survey could be carried out in March-April. On the other hand, the land use/cover map was used to exclude squares which were totally urbanized or cultivated. Also, it was used to identify forested areas where climate is colder than in the open spaces and the growing season was longer, so that sampling would be carried out during May-June.

Implementation of ground survey

The line transect method was used to record the plants in the open areas while the route transect method was used to explore areas of rough terrain and wadis. Each route or line transect had a length of 400 m. The locations of transects were decided after traveling inside the square and locating the starting point that would lead into accessible paths of 400 m in mountains or wadis. A random selection of the starting point was followed when the topography of the area enabled more than one direction for sampling. The methods of line and route transects were selected within the systematic squares as it would contribute in interpolating the distribution of plants in the study area. Also, it would enable the long-term monitoring of different species. The theory behind determining the density and population estimates from transects would rely on knowing the area sampled on each transect. With multiple transects conducted in a region, an average density per unit area was determined and extended over the entire region to estimate the population.

For each sampled transect, plant species and their numbers (counts) were recorded for each quarter of transect using datasheets. The datasheets included information on plant species recorded, the number of plants (counts) for each recorded species and other information on the area. Coordinates of the transect (starting, end and several intermediate points) were recorded using a global positioning system (GPS) with an estimated accuracy of ±5 m. Ancillary data of topographic maps and satellite imagery were also used to allocate and trace the sampled transects. The high resolution images available on the web (http://earth.google.com/) were also very useful in exploring the sampling grids and in identifying routes to the sampling locations.

Identification of hotspots

The criteria and scores for identifying hotspots for possible conservation of MH plants are shown in Table 2. The final score for each sampled site was calculated by adding the score of each criterion.

Table 2. The criteria and the scoring system used for identifying hotspot

Criteria for hot spot selection	Explanation range, score
Global importance	The site contains one or more global important MH plant species 1 to 15 species, 5 16 to 30 species, 10 31 to 45 species, 15
Habitats and diversity	The site contains specific habitats with enough MH plant species that distinguish it from the surrounding 1 to 10 habitats, 1 11 to 20 habitats, 2 21 to 30 habitats, 3 31 to 40 habitats, 4 >40 habitats, 5
Naturalness	The level of human interference on the area and MH species. Very low, 1 Low, 2 Moderate, 3 High, 4 Very high, 5
Rarity	The site contains rare MH species 1 species, 1 (Very low) 2 species, 2 (Low) 3 species, 3 (Moderate) 4 species, 4 (High) > 4 species, 5 (Very high)
Fragility	The site contains sensitive species and fragile habitats Score (the same as rarity)
New species	The site contains new MH plant species that were not recorded in Jordan No species, 1 Up to 5 species, 2 Up to 10 species, 3
Threats	The site is under the threat of human activities and overgrazing Low, 1 Moderate, 2 High, 3
Land use	The different uses taking place in the site by the local people Score (the same as threats)
Accessibility	Easiness of the site to access Score (the same as threats)
Education potential	The potential for educational use which will promote conservation and raise awareness of the need for conservation of MH plants Score (the same as threats)
Tourism potential	Sites with potential for eco-tourism which can raise income for their protection, provide jobs for local people and raise visitors' awareness of conservation Score (the same as threats)
Ease of management	Land tenure, landholding size and number of surrounding villages Very difficult, 1 Moderately difficult, 2 Few difficulties, 3
Economical value	Sites or spot with a high potential for economical use Poor, 1 Moderate, 2 Good, 3

Sites with high scores were considered to have higher potential and priority for conservation than sites with lower scores and therefore were considered as hotspots. GIS was used to produce maps of spatial distribution for these hotspots (next section).

Analysis of data within GIS

GIS layers (known as "shape files") were created from the coordinates of the sampled transects. A nominal attribute representing the grid-square was appended with each sampled transect to enable joining of attributes from spreadsheets to GIS maps. At the same time, data of the recorded species were entered in spreadsheets; where the number of each recorded species was entered for each corresponding grid-square, using the same coding of the nominal attribute of GIS maps of transects. The data of spreadsheets were joined directly to the line and route transects within the GIS using the grid-square attribute as the "join-field". One big advantage of GIS is the ability to create a geo-referenced database, known as geo-database from the attribute table of GIS maps (Zeiler, 1999; Bolstad, 2008). To do so, two other fields representing the geographic coordinates were appended to the attribute table of the transect map of MH plants. By this, a geo-database for all MH plants was created for the study area and enabled the spatial query and export of data for further analysis in tabulated forms.

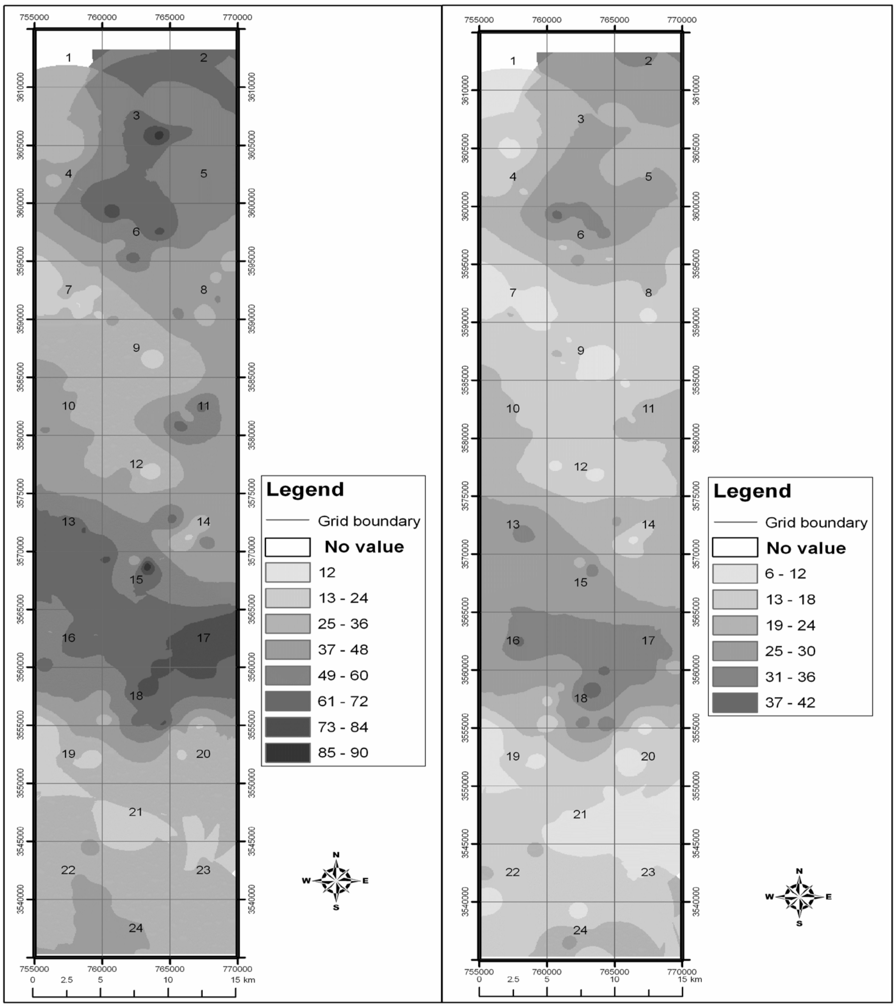

Fig. 3. Number of species for total plants (left) and MH plants (right), interpolated from the recorded plants on the 400 m transect.

Interpolation and reclassification of maps within GIS were carried out to generate the maps of locations of the sampled transects, number of species of all plants and of MH plants, distribution of MH plants and score of hotspots. The procedure of interpolation and classification of the output maps was carried out using the spatial analysis techniques of GIS. Interpolation was used to estimate the number of total plants and the number of each MH plant at unsampled locations. Also, it was used to generate a map of hotspots. The inverse distance weighted (IDW) method was used to interpolate unsampled areas as following (Bolstad, 2008):

$$Z_j = \frac{\sum_i \frac{Z_i}{d^n_{ij}}}{\sum_i \frac{1}{d^n_{ij}}}$$

where, Z_j is the estimated value for the unknown point at location j, d_{ij} is the distance from point i to unknown point j, Z_i is the value of the known point i, and n is a user-defined exponent (taken as 2). The radius of interpolation was 7 km which represented the possible distance between two transects in two successive grids. The IDW method was used to generate maps of: total number of plants (Fig. 3); distribution of each MH plant (Fig. 4); and distribution of global importance and hotspot scores (Fig. 5).

Finally, the map of transects was intersected with the layer of DEM and with maps of land use, slope and aspect. This was carried out to extract dominant land use, elevation, slope and aspect for the sampled transect. The output from this spatial join was appended in new columns of the attribute table and was exported in spreadsheets. Following this step, the relationships between the number of plants and plant species and those variables, for both MH and all plants, were examined using the data exported in the spreadsheets.

Statistical analysis

Although GIS maps would provide useful information on spatial patterns, statistical tests would be essential to interpret the significant differences among the sampled grids, in terms of the total number of plants and the number of species. This was carried out by applying student's *t-test* on the collected data after testing its normality. Within the statistical package (SAS, 2002), different tests were available. However, the normality test of Kolmogorov-Smirnov (K-S) was selected for this purpose as it was independent of sample size, which was different from one grid to another. The test was applied on the data of the total recorded MH and non-MH plants. Initial results showed that the data were not normally distributed. Therefore, the data were transformed using the natural logarithm function and the K-S test showed a normal distribution of the transformed data. Subsequently, means separation was carried out using student's t-test.

Statistical analysis also included the application of regression analysis on the data to investigate the relationships between altitude (independent variable) and the number of species and number of plants for MH and all plants (dependent variables). The same procedure was used with other independent variables of slope and aspect, which were extracted from GIS layers for the sampling transects.

Results

Land use/cover

Results of land use mapping showed that 37% of the area was cultivated and 16% was urbanized (Table 1, Fig. 2). Forests formed 14% of the total area, while 34% of the area was open spaces where cliffs and steep slopes were dominant. Urbanization resulted in excluding grid number 23 from sampling. Both urbanization and cultivation reduced the number of sampling locations.

Number of plants and plant species

Table 3 gives the list of sampled grids and the number of sampling transects. Also, it summarizes the number of recorded species and the total number of plants within each sampled grid. The total number of sampled transects was 123. Ten protected locations were not sampled while two squares were not accessible. Locations of the line and route transects are shown in Fig. 2.

Results of the statistical analysis showed that the number of plant species and the number of plants were significantly different ($P<0.05$) among the different grids (Table 3). The maximum number of MH plant species sampled by the 400 m transect was 46 (Fig. 3) while the average at grid level was 31. At the level of transect, the maximum number of MH plant species was 42 and was recorded in grid 18, near Jila'ad village. The minimum number of MH plant species was 6 and was recorded in grid 7.

Spatial distribution of plant species

The spatial distribution of all plant species was different from that of the MH plant species (Fig. 3). The spatial distributions of average number of plants for each MH plant species, for the 400 m transect, showed differences among the different species (three examples are shown in Fig. 4). Maps of spatial distribution of plant species showed that grids 6, 13, 16, 17 and 18 were characterized by relatively high number of plant species for both MH and non-MH plants.

Results of the regression analysis showed significant linear relationships ($P<0.05$) between the total number of plants, plant species and altitude for all plants and for MH plants as well (Fig. 6). Generally, the number of plants and plant species tended to decrease with altitude. The maximum number of plant species were recorded at altitudes of 600 to 700 meters. Stronger significant correlation ($P<0.05$) with higher coefficient of determination (R^2), and relatively lower standard errors, were observed for MH plants than for all plant species. Results also showed that the number of species was neither correlated with slope nor with aspect. However, the aspect towards the west showed the lowest number of plant species in all sampled transects.

Results of sampling showed that the total number of plant species recorded in the study was 611, while the total number of MH plant species was 223. Two new genera to the flora of Jordan were recorded in the survey. The family Dioscoreaceae had also been added as a new family to the flora of Jordan. The study also recorded 11 new species to the flora of Jordan. These eleven species were recorded in eight different locations in the study area (Fig. 5). Results from field survey also showed that twenty rare species to the flora of Jordan were recorded in the study area. All of the new recorded genera, family, new and rare species are in the process of documentation and publication. The recorded MH species are listed in Table 4.

Table 3. *Summary of number of sampled transects (NT), average number of species (SP), minimum (Min), maximum (Max), and mean of total plants and the ratio of species of MH plants to all plants*

		All Plants						MH plants					
Grid	LUC	NT	SP*	Min	Max	Mean	log (mean) **	SP*	Min	Max	Mean	log (mean) **	Ratio
2	AA	1	62 abcde	1474	1474	1474	7.30 abcd	31 ab	581	581	581	6.36 abcdef	0.50
3	AA	2	69 ab	1136	2244	1690	7.43 ab	26 abc	106	812	459	6.13 a	0.38
4	AA	4	45 defg	568	1525	938	6.84 cdef	18 cdefgh	154	901	428	6.06 ghijk	0.40
5	OR	3	55 bcde	889	1518	1264	7.14 abc	22 bcd	330	828	564	6.34 abc	0.41
6	AA	10	59 bcd	648	1634	1029	6.94 bcd	27 ab	197	722	458	6.13 abcd	0.46
7	F	11	23 i	136	423	257	5.55 m	12 i	81	385	154	5.04 jk	0.51
8	F	11	41 efg	443	1601	749	6.62 efgh	16 defgh	49	453	261	5.56 fghi	0.40
9	F	8	32 ghi	97	420	268	5.59 m	13 fghi	61	196	133	4.89 k	0.41
10	F	9	40 efgh	283	496	365	5.59 jkl	20 cde	155	383	233	5.45 fghi	0.49
11	F, AA	5	47 cdef	290	870	565	6.34 ghij	18 cdefg	161	311	248	5.51 efghi	0.39
12	OR	6	30 ghi	227	404	331	5.80 klm	14 efghi	74	354	191	5.25 hijk	0.46
13	AA	3	65 abc	541	1356	912	6.82 bcdefg	29 ab	207	376	291	5.67 bcdefgh	0.44
14	F	6	39 efgh	324	1164	648	6.47 fghi	18 cdef	259	520	348	5.85 bcdefg	0.46
15	F, AA	5	61 abcd	408	1020	754	6.63 defgh	28 ab	263	573	391	5.97 abcde	0.45
16	OR	4	59 abcd	579	1599	1099	7.00 abcde	31 a	287	717	493	6.20 abcd	0.53
17	F	3	76 a	1186	2128	1615	7.39 a	29 ab	350	533	458	6.13 abcde	0.38
18	OR	10	60 bc	1082	1910	1382	7.23 a	29 ab	218	765	511	6.24 ab	0.48
19	OR	2	17 i	291	320	306	5.72 jklm	10 fghi	102	132	117	4.76 ijk	0.56
20	OR	3	24 hi	182	338	277	5.62 lm	10 ghi	100	185	144	4.97 hijk	0.42
21	OR	6	23 i	293	570	415	6.03 ijkl	11 hi	150	405	235	5.46 fghij	0.50
22	OR	7	34 fghi	375	1060	665	6.50 fgh	16 defghi	126	711	350	5.86 cdefg	0.46
24	AA	4	36 efghi	372	656	498	6.21 hijk	18 cdefghi	119	473	292	5.68 defghi	0.48

** For the same column, means followed by the same letter are not significantly different ($P < 0.05$) as indicated by the differences of least squares means.*
*** For the same column, numbers followed by the same letter are not significantly different ($P < 0.05$) as indicated by the differences of least squares means.*

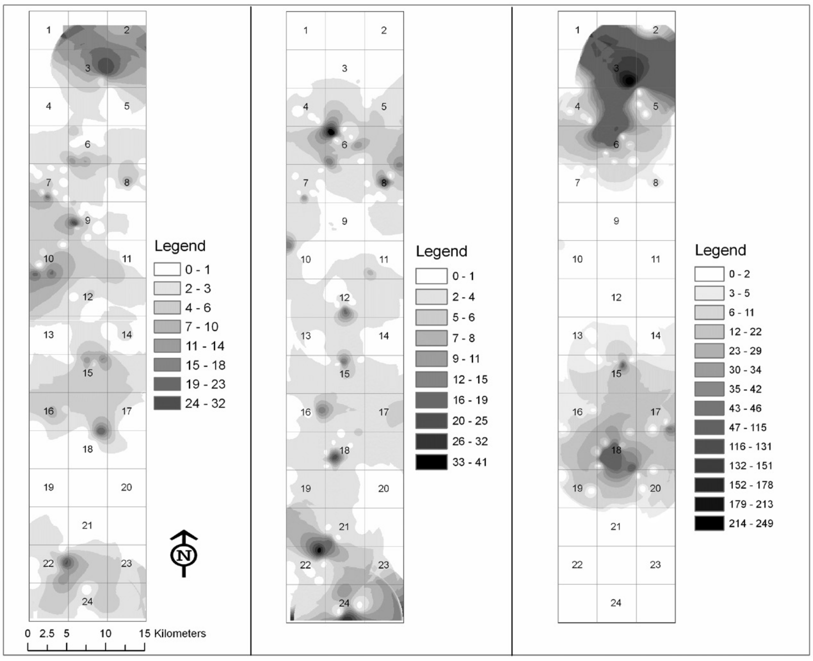

Fig. 4. Distribution and interpolated numbers of some MH plants: Teucrium polium (left); Varthemia iphionoides (middle); Urginea maritima (right). Note: Intervals are based on natural break of values.

Table 4: MH plants and their total numbers and the count of grids in which the plant was recorded.

Plant	Total	Count
Acanthus syriacus	217	8
Achillea aleppica	5	2
Achillea biebersteinii	86	8
Achillea santolina	52	2
Adiantum capillus-veneris	1	1
Adonis aestivalis	59	6
Adonis palaestinus	3	1
Ajuga chia	139	16
Ajuga orientalis	1	1
Alcea acaulis	51	13
Alcea setosa	13	4
Alkanna orientalis	2	1
Alkanna tinctoria	16	5
Allium erdelii	2	1
Allium neapolitanum	45	6
Allium orientale	1	1
Allium pallens	1	1
Allium stamineum	62	8
Allium truncatum	15	2
Amygdalus communis	37	9
Anagallis arvensis	1159	14
Anchusa aegyptiaca	324	10
Anchusa italica	1	1

Plant	Total	Count
Anchusa strigosa	126	9
Anchusa undulata	10	1
Androcymbium palaestinum	56	1
Anemone coronaria	842	8
Anthemis bornmuelleri	102	2
Anthemis palaestina	736	10
Apium graveolens	1	1
Apium nodifolium	1	1
Arbutus andrachne	230	7
Aristolochia billardieri	1	1
Aristolochia parvifolia	11	5
Arum hygrophilum	8	1
Arum palaestinum	15	2
Arundo donax	1	1
Asparagus aphylla	77	11
Asphodelus aestivus	3021	19
Asterolinon linum-stellatum	67	6
Astragalus annularis	1	1
Astragalus beershabensis	4	1
Astragalus bethlehemiticus	2	1
Astragalus callichrous	26	2
Astragalus cruciatus	12	5
Astragalus deinacanthus	3	1

Plant	Total	Count
Astragalus fruticosus	1	1
Astragalus oocephalus	1	1
Astragalus palaestinus	15	3
Astragalus sanctus	4	1
Ballota undulata	463	15
Bifora testiculata	238	4
Blepharis ciliaris	2	2
Bryonia cretica	4	4
Bryonia syriaca	36	8
Calamintha incana	2	1
Calendula palaestina	584	10
Calendula tripterocarpa	291	8
Calycotome villosa	86	6
Capparis spinosa	8	4
Capsella bursa-pastoris	334	3
Centaurea iberica	1032	14
Ceratonia siliqua	11	3
Chrysanthemum segetum	10	1
Cichorium pumilum	909	14
Cistus creticus	1047	8
Cistus salvifolius	554	6
Clematis cirrhosa	64	9
Consolida scleroclada	4	2
Convolvulus scammonia	2	1
Coronilla scorpioides	48	9
Crataegus aronia	322	16
Crocus hyemalis	7	1
Cupressus sempervirens	7	2
Cyclamen persicum	852	6
Cynodon dactylon	4	1
Cynoglossum creticum	14	6
Cyperus longifolium	1	1
Daucus carota subsp. maximus	24	2
Delphinium peregrinum	23	4
Ecballium elaterium	1	1
Echinops polyceras	1495	20
Eminium spiculatum	1	1
Ephedra alte	2	2
Ephedra campylopoda	24	4
Eremostachys laciniata	31	2
Erodium acaule	38	2
Erodium malacoides	338	11
Erodium moschatum	41	1
Eruca sativa	6	3

Plant	Total	Count
Eryngium creticum	1577	20
Eryngium glomeratum	419	12
Erysimum crassipes	1	1
Euphorbia aleppica	62	5
Euphorbia helioscopia	9	3
Euphorbia hierosolymitana	11	3
Euphorbia macroclada	15	1
Euphorbia oxyodonta	40	7
Euphorbia peplis	170	9
Ficus carica	1	1
Foeniculum vulgare	1	1
Fumaria densiflora	11	3
Fumaria parviflora	6	4
Galium aparine	1	1
Geranium dissectum	4	1
Geranium molle	346	12
Geranium tuberosum	3	2
Glaucium arabicum	1	1
Gundelia tournefortii	454	10
Helichrysum sanguineum	118	11
Heliotropium europaeum	51	7
Herniaria hirsuta	2	1
Hyoscyamus aureus	1	1
Hypecoum imberbe	1	1
Hypericum triquetrifolium	15	4
Inula viscosa	3	2
Lactuca serriola	7	2
Lactuca tubersoa	16	6
Lagoecia cuminoides	1358	21
Lamium amplexicaule	30	8
Lamium moschatum	1	1
Lonicera etrusca	6	4
Mandragora autumnalis	6	4
Marrubium vulgare	5	2
Matricaria aurea	15	1
Melilotus indicus	1	1
Mentha longifolia	1	1
Mercurialis annua	312	9
Micromeria nervosa	239	12
Myosotis uncata	3	1
Nasturtium officinale	1	1
Nepeta curviflora	2	1
Nerium oleander	1	1
Neslia apiculata	4	3

Plant	Total	Count
Nigella ciliaris	6	5
Olea europaea	4	2
Ononis natrix	1290	19
Ononis spinosa subsp. antiquorum	152	12
Onopordum alexandrinum	39	4
Onopordum cynarocephalum	1	1
Onopordum macrocephalum	71	9
Ophrys carmeli	4	2
Orchis anatolica	5	2
Origanum syriacum	8	4
Osyris alba	40	5
Papaver subpiriforme	25	7
Papaver syriaca	12	2
Paronychia argentea	275	14
Paronychia sinaica	10	3
Phagnalon rupestre	334	18
Phoenix dactylifera	1	1
Phragmites australis	1	1
Pimpinella cretica	911	19
Pimpinella eriocarpa	62	2
Pimpinella olivieri	8	2
Pimpinella peregrina	48	6
Pinus halepensis	778	12
Pistacia atlantica	3	1
Pistacia palaestina	223	10
Plantago afra	514	16
Plantago lanceolata	1	1
Plantago major	1	1
Plantago ovata	701	8
Plumbago europaea	1	1
Polygonum equisetiforme	1	1
Polygonum lapathifolium	1	1
Psoralea bituminosa	41	5
Punica granatum	1	1
Quercus coccifera	3874	16
Ranunculus asiaticus	884	12
Reseda lutea	7	3
Retama raetam	89	5
Rhus coriaria	5	2
Rhus tripartita	10	1
Ridolfia segetum	3	1
Roemeria hybrida	3	1
Rubus tomentosus	1	1
Rumex crispus	1	1

Plant	Total	Count
Rumex cyprius	1	1
Rumex pulcher	16	5
Ruta chalepensis	8	2
Salix acmophylla	1	1
Salix alba	1	1
Salix pseudo-safsaf	1	1
Salvia dominica	79	6
Salvia multicaulis	7	1
Salvia triloba	1	1
Sanguisorba minor	45	5
Sarcopoterium spinosum	3055	15
Scrophularia xanthoglossa	63	15
Scutellaria subvelutina	14	5
Scutellaria tomentosa	6	1
Sedum nicaeense	2	1
Senecio vernalis	845	13
Silybum marianum	13	2
Sinapis alba	2	1
Sinapis arvensis	510	10
Smilax aspera	53	6
Solanum dulcamara	1	1
Solanum luteum	1	1
Sonchus oleraceus	6	3
Stellaria media	87	6
Styrax officinalis	9	4
Symphytum palaestinum	13	4
Taraxacum officinale	68	3
Tetragonolobus palaestinus	20	5
Teucrium polium	387	16
Tordylium aegyptiacum	100	5
Trigonella foenum-graecum	2	1
Tulipa agenensis	3	1
Typha domingensis	1	1
Urginea maritima	1282	12
Urtica pilulifera	1	1
Vaccaria pyramidata	13	3
Varthemia iphionoides	376	18
Verbascum fruticulosum	8	3
Verbascum sinuatum	1	1
Veronica anagallis-aquatica	1	1
Veronica syriaca	102	6
Vicia sativa	34	8
Xanthium spinosum	1	1
Ziziphus lotus	1	1
Ziziphus nummularia	8	1

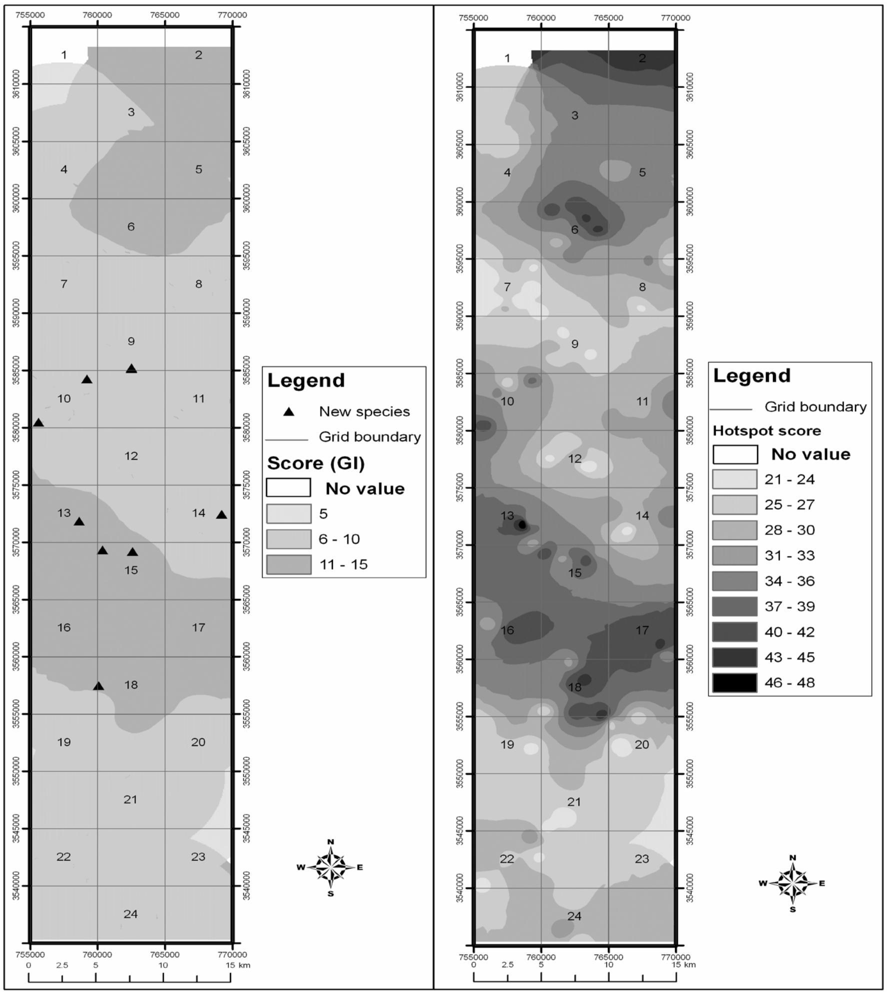

Fig. 5. Map of sites with the new recorded species and the score of global importance (GI) (left) and the map of interpolated hotspots scores (right).

Spatial distribution of hotspots

Spatial distribution of hotspots (Fig. 5) showed that some grids had high potential for conservation of MH plants. These were: Grid 6 at the area between al-Mazar al-Shamaliah and Zobia (North-west of Ibbin); Grid 13 to the south-west of Ajloun and north of Burma; and grid 18 to the north-east of Salt and centered at Jala'ad. To less extent, a lower potential for conservation was obtained for grid 10, to the northwest of Ajloun and the area between near grids 16 and 17. The area near grid 2 could be excluded as it contained only one sampled transect.

Discussion

Intensive human activities were reflected in the land use map (Fig. 2) which showed that rainfed cultivation is taking place in different parts of the study area. Scattered forests were dominating the high altitude areas in the middle parts of the study area. The pattern of the forested area indicated deforestation and replacement of forests with rainfed crops, as forests were discontinuous and formed elongated patches in the study area. Generally, both arid and semi-arid zones were utilized for urban use, rainfed farming and as open rangelands. Forests were mainly concentrated in the semi-arid zone while urbanized areas were scattered in nearly all parts of the study area. These patterns of land use would indicate intensive utilization of the study area which was threatening plant biodiversity. Also, it emphasized the importance of *in-situ* conservation for the MH plants which would disappear in the near future.

Results indicated that the study area was rich in MH plants, although its total area was relatively small. Nearly one-third of the country's plant species were recorded in this area. The ratio of MH plants to the total plant species was relatively high in most sampled grids (Average = 0.45). The new

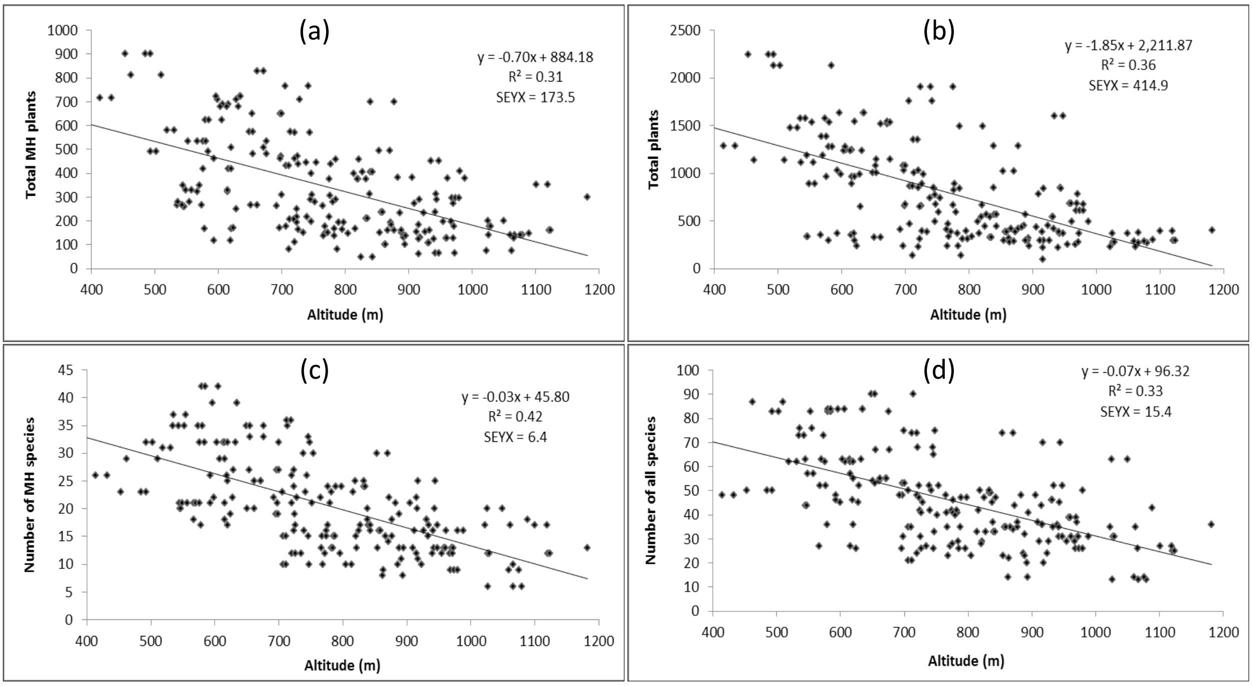

Fig. 6. Relationships between altitude and total number of MH plants (a), total number of plants (b), number of MH species (c) and number of all species (d).

recorded genera and species also emphasized the richness of this study area. However, intensive cultivation, urbanization and deforestation were seen as main land use practices that threaten MH plants in the study area, as indicated by the land use maps and the observations during the field visits. This confirmed the findings of previous studies (Al-Tamimi and Al-Bakri, 2005; Khresta *et al.*, 2007) which indicated high levels of land degradation in the study area. Generally, the area was heavily utilized for rainfed cultivation and many forests were cleared for this purpose, although the potential land use of the area might not suit land capabilities (Al-Bakri, 2005; Al-Bakri *et al.*, 2008). The agricultural intensification and land use shifting was observed in many Mediterranean ecosystems (Al-Bakri, 2005; Lasanta *et al.*, 2006) and resulted in replacement of landraces with agricultural crops.

During field visits, signs of high level of vegetation disturbance were observed in locations where settlements and rainfed cultivation were dominant. This resulted in relatively low number of plant species in some grids where these land uses were dominant. Although GIS was implemented to create buffers around the sampled transects to correlate the number of MH species with distance from roads and urban settlements, no obvious trends were observed. These findings disagreed with Anderson *et al*. (2005) who indicated that the distance to village was one of the main factors that distinguished the sacred medicinal plants. In our

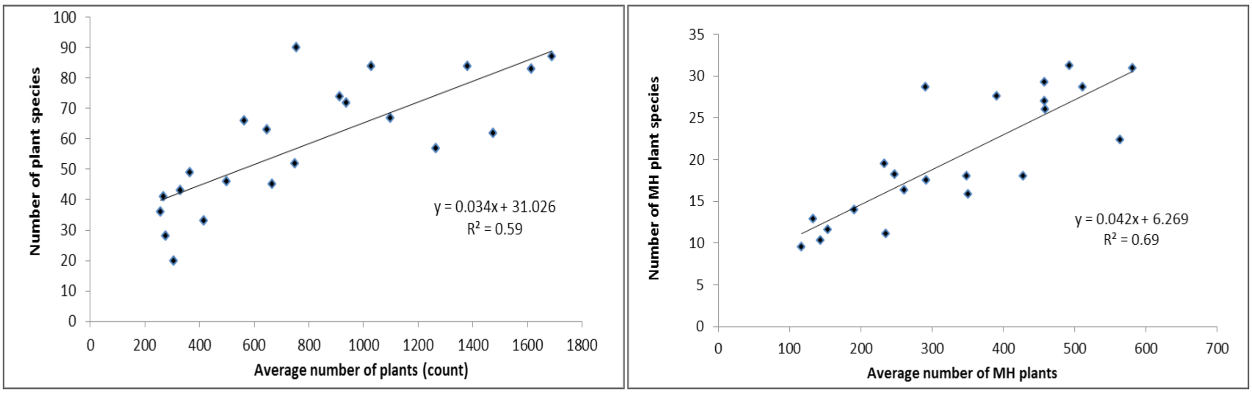

Fig. 7. Relationships between number of plant species and average number of plants for the sampled grids for all plants (left) and for MH plants (right).

study area, the interaction between human-induced and landscape factors could explain the variations among the different grids. This was reflected by the high numbers of plant species in the protected forests and in some areas with rough terrain. Generally, sites which were close to the main cities were characterized by high levels of disturbance and hence low number of plant species.

Human induced factors also included overgrazing and deforestation. The impacts of overgrazing were obvious in the southern parts of the study area, where grids 18 to 22 were characterized by relatively low number of plant species. Deforestation was obvious in the northern parts of the study area where a land use shift between forests and agricultural areas was taking place, as indicated by Khresat *et al.* (2008). Furthermore, in areas of Birgesh and Zobia (grids 7 and 9) human activities included the use of forests for recreation and tourism and hence the number of MH plant species was significantly lower than in other locations of the study area. These anthropogenic factors and land use activities were very important in identifying hotspots for conservation of MH plants, and therefore they were given similar weightage and scores in the approach followed in this study (Table 2).

Generally, the only landscape factor which was correlated with the number of total plants and plant species was altitude. Results from the study showed that the number of plants and MH plant species was inversely correlated with altitude. These results were in agreement with previous research in other ecological zones (e.g. Gaston, 2000; Roy and Behera, 2005). In our study, the maximum number of MH plant species was found at altitudes around 600 m and decreased with altitudes. High numbers of MH plant species were also strongly correlated with average number of plants (Fig. 7) which also indicated that both MH and non-MH plants had similarities in the levels of abundance and disturbance.

Results also emphasized that the usefulness of GIS was not only limited to the maps of spatial distribution of sampled grids and transects, but it also provided useful maps for every MH plant species. This was reflected in some maps of the spatial distribution of key MH plants in Jordan (e.g. *Teucrium polium, Varthemia iphionoides*), which showed that some locations were rich in particular MH species and poor in others (Fig. 4). Also, GIS provided maps of the spatial distribution for globally important species which were new to the flora of Jordan, particularly in grids 9 and 10.

The map of hotspots (Fig. 5) was consistent with the map of spatial distribution of globally important species and the map of spatial distribution of MH plant species (Fig. 3). This showed that the map of hotspots compiled the most important layers in the criteria of identifying important sites for conservation. The hotspot of grid 6 was characterized by high number of MH species and high levels of threats as it was surrounded by 5 urbanized areas. The hotspots in grid 10 were mainly attributed to the existence of new recorded MH species. The remaining hotspots in grids 13, 17 and 18 were characterized by globally important species and high levels of threats which included cultivation and overgrazing, particularly in Jala'd. These findings indicated the uniqueness of these hotspots and the potential for the implementation of *in-situ* measures and interventions that sustain diversity of MH plants in these sites. Taking into consideration the different threats and the possible expansion of urbanized and rainfed areas, alternatives and options of conservation should be selected and implemented. These options were summarized by previous studies (GCEP, 2000; RSCN, 2000; UOJ, 2003; Blench, 2004) and would serve the purpose of biodiversity conservation. The use of GIS maps and the GIS database of this study would facilitate the selection of options, even at the level of MH plant species.

Conclusions and Recommendations

Results from this study showed that arid and semi-arid zones in the north-west of Jordan were rich in MH species. In these zones, the number of plant species was significantly correlated with altitude. Generally, the number of MH plants tended to decrease with altitude, with maximum number of MH plants being found at altitudes of 600 to 700 m. A significantly strong correlation ($R^2 = 0.69$) was also found between the number of plants and the number of MH plant species. At the level of 400 m transect used in the sampling, the number of MH plant species ranged between 6 in the highly disturbed sites to 42 in areas that were relatively far from the main urbanized cities.

The use of GIS in this study was useful in identifying the most threatened areas that would serve as hotspots for possible conservation of MH plants. The map of hotspots was consistent with the map of spatial distribution of globally important species and the map of spatial distribution of MH plant species, particularly the new recorded species to the flora of Jordan. Since conservation of the medicinally important species is of prime concern, the areas identified as hotspots should be made protected habitats for *in-situ* conservation and preservation as rich genetic resources of MH plant species. A future plan for the conservation of the study area, particularly the sites which were considered as hotspots, is strongly recommended. The use of GIS as a spatial database for MH plants shall be a target future objective, particularly when the survey will be extended to other areas of the country.

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