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Monitoring land use change in the Badia transition zone in Jordan using aerial photography and satellite imagery

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Detection of land use change makes a valuable contribution to the planning and monitoring of drylands. Land use changes at four sites within the Badia transition zone of Jordan were investigated and quantified over the period from 1953 to 1992 using black and white aerial photographs and SPOT PAN satellite imagery digitally merged with Landsat TM. Land use interpretation was checked in the field, and analysed using a Geographical Information System (GIS). Results indicated that land use changes have altered the character of the selected study sites. The important land use changes were from rangeland to rain-fed cultivation, irrigated fields and urban settlements. The increased agricultural activity was reflected in the land use maps through the 39-year period with the appearance of irrigated fields between 1978 and 1992. The land use changes are mainly attributed to the high population growth rate in Jordan and in the Badia, socio-economic change amongst Beduoin and farmers, the land tenure system and to a minor extent environmental factors.

KEY WORDS: Jordan, Badia, land use, GIS, remote sensing, socio-economic change

Introduction

Jordan is located in the eastern Mediterranean region between 29° 20′ to 32° N and 34° to 39° E. The climate of the country is arid to semi-arid and characterized by dry hot summers and mild wet winters with extreme variability in rainfall within and among years. More than 90 per cent of the country's land, known as the Badia, receives less than 200 mm average annual rainfall (Figure 1). The relatively high rainfall area in Jordan is limited and restricted to the western and northern highlands and gives rise to the most productive land agriculturally. However, this area has been affected by rapid urban developments and thus agricultural development is taking place on marginal lands, including the low rainfall zone (< 200 mm) (JAZPP 1997).

The agricultural expansion eastwards into the drier lands, population growth and unsupervised agricultural practices have started to impact the natural resources of the Badia (Taimeh 1989; Juneidi and Abu-Zanat 1993). Thus the University of Jordan and Jordan Ministry of Agriculture, supported by the European Union (EU), launched the Jordan Arid Zone Productivity Project (JAZPP) in 1994. The aim of this project was to develop sustainable methods of increased agricultural productivity in the 100 to 200 mm annual rainfall transition zone of the Badia through sound land use planning and technology transfer to farmers. Part of this process involved the determination of baseline land use change data and the reasons behind the changes seen, to provide the context for future planning.

The study of land use change requires a repeatable survey that is economical, sufficiently accurate and consistent with the objectives and scale of study. Remote sensing data within Geographical Information Systems (GIS) offers an alternative approach to conventional methods of field survey and can provide an effective means for establishing the rate and extent of land use change. The use of panchromatic, medium-scale aerial photography to

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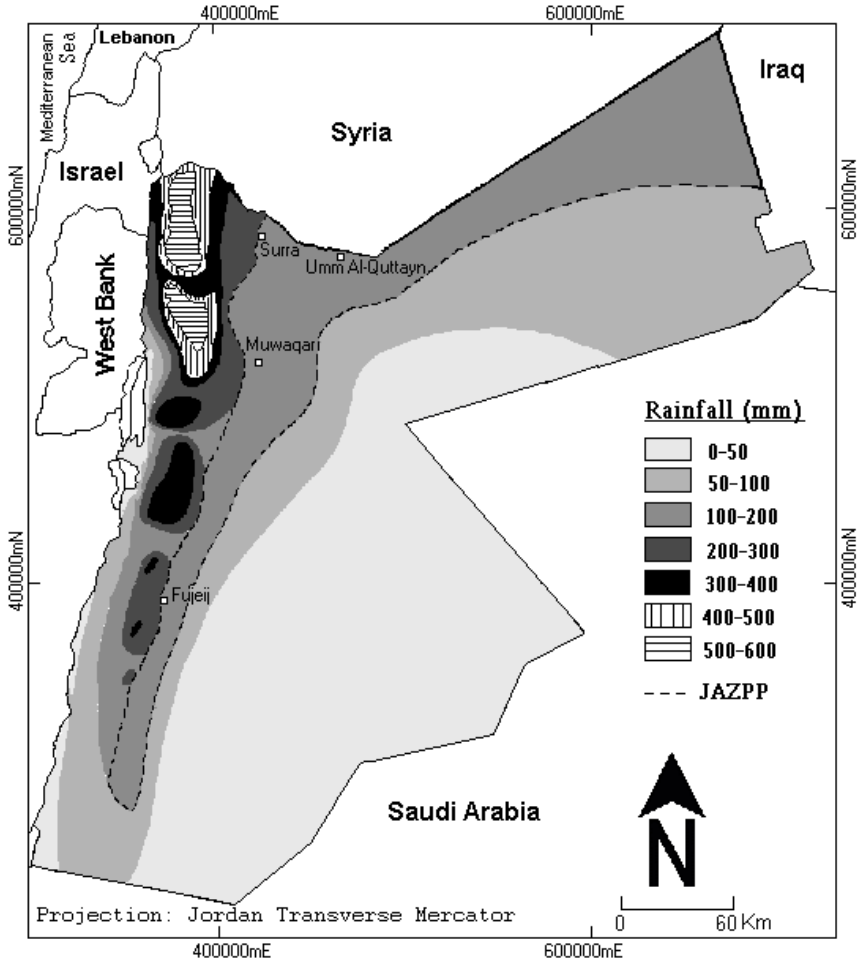

Figure 1 Locations of the study sites within the Badia transition zone

map land use has been an accepted practice since the 1940s and has proven to be a sufficiently accurate and rapid method of assessing land use change (Zobeiry *et al.* 1985; Virgo and Subba 1994; Ihse 1995). Physical changes of land use and land cover identified can be mapped, and inferences drawn as to underlying social and economic reasons for the changes seen.

Previous studies have adopted this approach and indicate that in the Badia region of Jordan the lifestyle of the Bedouin has changed towards a settled way of life that is reflected in the land use patterns seen today (JBRDP 1994; Dutton *et al.* 1996; Dutton 1998; Findlay and Maani 1999; Millington *et al.* 1999). Bedouin previously had a cycle of movements inside and outside the Badia controlled by the rainfall seasons. Their movements were mainly to sites where vegetation and water were available. In the last few decades improvements in infrastructure, sources of employment, health and education have changed this seasonal pattern of movement. In the northern Badia, the villages and hamlets have grown rapidly with new villages discovered in the 1993 census of the Badia Programme (Dutton *et al.* 1996). Expansion of cultivated areas (Millington *et al.* 1999) also concurs with a shift from nomadic pastoralism to farming-based systems.

A delicate balance exists in the natural systems of the Badia between its productivity and its susceptibility to degradation. The move to a farm-based system of agriculture has led to the ploughing of

Table 1 Characteristics of the study sites

Site	Mean annual rainfall (mm)	Range type	Altitude (m.a.s.l.)	Geomorphology/parent material
Umm Al-Quttayn	140–190	Steppe grassland mixed with basalt stones	1000 in north to 900 in south	Very gently undulating basalt plain with moderate colluvial/aeolian cover
Surra	180–250	Steppe grassland	750 in south to 650 in north	Hilly limestone terrain with shallow soils on the upper slopes to moderately deep soils on lower slopes
Muwaqar	110–180	Steppe grassland mixed with *Artemesia* brush	930 in east to 770 in west	Undulating limestone plain with shallow to moderately deep soils on lower slopes
Fujeij	175–225	Steppe grassland mixed with *Artemesia* brush	1400 in north to 1200 in south	Limestone escarpment with incised valleys in the west to gently sloping wadis dissecting aeolian plain in east

Source: MOA 1985

rangelands for the cultivation of cereal crops and asserting land ownership. The authors have observed this practice throughout the JAZPP region. Surface soil structure is destroyed through this process, giving rise to decreased infiltration and consequent reduction in productivity (Taimeh 1989; Juneidi and Abu-Zanat 1993).

Therefore, information about recent and current land use changes is needed for informed management and planning. Precise information about the extent and distribution of grazing lands, rain-fed cultivation, irrigated agriculture and urban development is required for future sustainable development of the fragile resources of the Badia.

Study sites

Four contrasting study sites within the JAZPP study region (Figure 1) were selected to detect and measure land use change. The selection of sites was constrained by the availability and quality of aerial photography and the need to include different geographical locations within the JAZPP study region in the research. The most important characteristics of the four study sites (Table 1) are the high variability of their limited rainfall, thin vegetation cover and the high rate of soil erosion by water and wind. Most of the rain in Jordan falls between December and March with high variability in intensity and duration of the individual showers. Prediction of a rainfall event is very difficult and therefore farmers prepare their land for cultivation in late summer in anticipation of rainfall (dry rain-fed cultivation known as *Afeer*). The soils of the four sites are dominated by aeolian material high in calcareous silt accumulated at the surface. They are compacted and characterized by a surface crust that results in low infiltration rates and low storage of rainfall, particularly at Muwaqar and Fujeij. In general, the soils of the study sites are sandy clay and sandy loam, high in carbonate and low in organic matter.

The Surra site has an old range reserve established in 1946 by the Ministry of Agriculture. Depending on the estimated carrying capacity, the reserve is usually opened in spring and early summer for a limited number of animals to browse grasses and shrubs. The University of Jordan Experimental Station at Muwaqar was established in 1985 and provides an enclosed area for agricultural experiments by the Faculty of Agriculture. Flocks of sheep and goats are excluded from the site. Fujeij is characterized by higher altitudes (1300 m.a.s.l.) and a colder winter season than the other study sites and has a protected marginal range reserve established in 1958. Umm Al-Quttayn is characterized by the presence of basalt stones and consolidated lava flows that restrict agricultural development in the north-west part of the study site.

Methodology

This study was based on the interpretation of aerial photographs taken from different dates using methods similar to that developed by Taylor *et al.* (1991). The methodology included acquisition of data, interpretation of aerial photographs from the different dates, field verification, digitizing and analysis using GIS software.

Stereoscopic black and white aerial photographic cover and topographic maps (1:25 000 and

Table 2 Summary of the aerial photography available for each of the study sites

Site	Date	Scale
Umm Al-Quttayn, Surra	1953, 1978	1:25 000
	1992	1:30 000
Muwaqar	1978	1:25 000
	1992	1:30 000
Fujeij	1953	1:25 000
	1990	1:60 000

1:50 000) were obtained from the Royal Jordanian Geographic Centre (RJGC). The selection was based on the scale and quality of aerial photographs available at different dates for each of the study sites (Table 2). In addition to aerial photography, hard copy geo-corrected satellite imagery and a derived 1:50 000 1992 land cover map, originally used in the National Soil Map and Land Use Project (NSMLUP) of Jordan (MOA 1995), were used to aid and verify the interpretation. The satellite imagery, 10 m resolution SPOT PAN digitally merged with Landsat TM (bands 4, 5, 3), was also used to derive the 1992 land use map of the Fujeij area where the most recent aerial photographs available, were for 1990 with a scale of 1:60 000. The false colour composite of the merged imagery, acquired in April 1992 when vegetative growth was at maximum, was also helpful in verifying the cultivated areas at all sites. The aerial photographs flown in November 1992, before the start of the 1993 growing season, still showed evidence of cultivated land from the 1992 growing season and could therefore be related directly to the 1992 satellite imagery.

The classification scheme used by the NSMLUP (MOA 1995) was adopted, with some modifications for the purpose of this study (Table 3). The most recent dates of aerial photography for each study site were interpreted first and two field checks were made to verify the photo interpretation, the first in October 1997 and the second in April 1998. The first field check verified the location of irrigated fields, urban settlements and rain-fed cultivation. The irrigated fields were detectable as crops were still growing or being harvested while the rain-fed fields were ploughed and prepared for cultivation. The second field visit verified and confirmed the presence of rain-fed cultivation, mainly fields of barley, which was at maximum growth. Owing to the time difference between the aerial photography and the two field checks, both checks were approximate verifications of the land use in 1992. This fact was kept in mind during the field survey, and therefore changes appearing after 1992 were not taken into consideration. Subsequently, aerial photographs of 1953 and 1978 were interpreted and land use maps derived for these dates. The 1953 and the 1978 interpretation was verified by interviews with the local farmers. The 1953 and/or the 1978 rain-fed cultivated areas were aggregated in the 1992 land use maps to represent the areas which have been put under cultivation in each of the study sites even if there was no evidence of cultivation at the 1953 and/or 1978 sites, in 1992. The reason for this was that visually the land cover appeared as bare ground on the aerial photography because no regeneration of rangeland species was evident on the photography.

Table 3 Land use classification scheme used in the study

Class	Description
Urban	Residential, built-up, industrial and commercial areas
Quarries	Gravel and stone quarries
Irrigated fields	Vegetable crops and orchards grown under drip irrigation
Rain-fed cultivation	Agricultural cropland mainly cultivated with barley
Rangeland	Shrub and brush rangeland, limestone outcrops and basalt stones
Basalt rock	Consolidated lava and volcanic ash
Range reserve	Grazing range reserve initiated by the MOA
Steep rocks and forest	Steep hilly areas, mainly found to the west of Fujeij

The results of the aerial photograph interpretation were photo overlays of land use for each study site at the different dates. The photo overlays were manually transferred onto drafting film overlays attached to the 1:25 000 topographic maps. These overlays were digitized and imported into the GIS software. Analyses of land use and land use change were carried out using the SPANS GIS software. The outputs from the GIS analysis included maps of land use (Figures 2 to 5) for the four sites and area cross tabulation tables.

Results

Generally, in all the sites, land use classes were easily recognized in the aerial photography. Few classes were identified in the 1953 and 1978 aerial photography. Analyses of land use and its change in

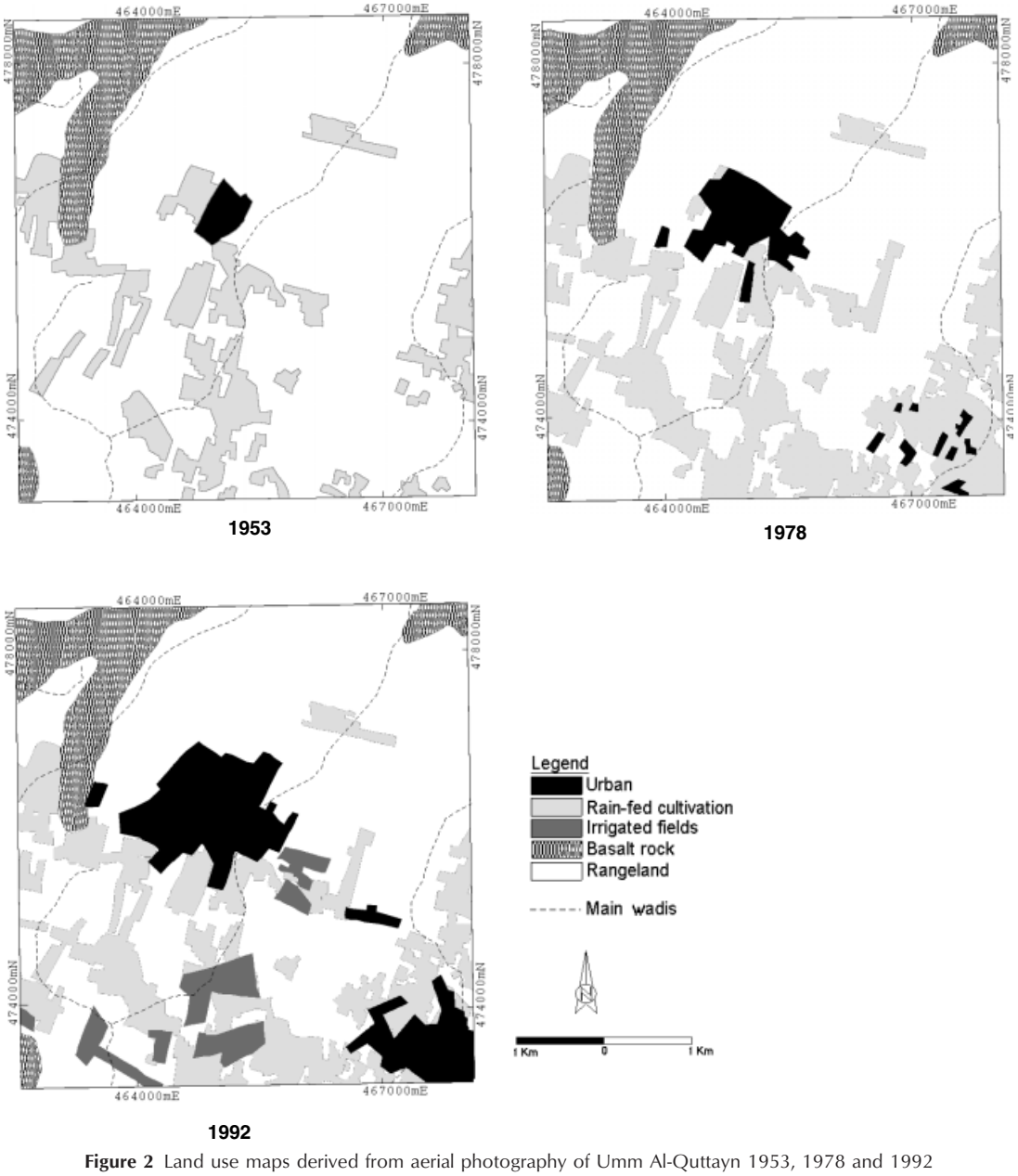

Figure 2 Land use maps derived from aerial photography of Umm Al-Quttayn 1953, 1978 and 1992

the four study sites are shown in Tables 4 to 7. These Tables result from the cross tabulation of the land use maps for each site where the column total represents the class proportion in 1992 and the row total represents the class proportion in 1953 and/or 1978. The intersection of the row and column for a particular class represents the unchanged proportion of that class in the land use maps for the two dates represented.

Land use changes at Umm Al-Quttayn

Three trends of change were observed at this site:

1 expansion of the urbanized area;

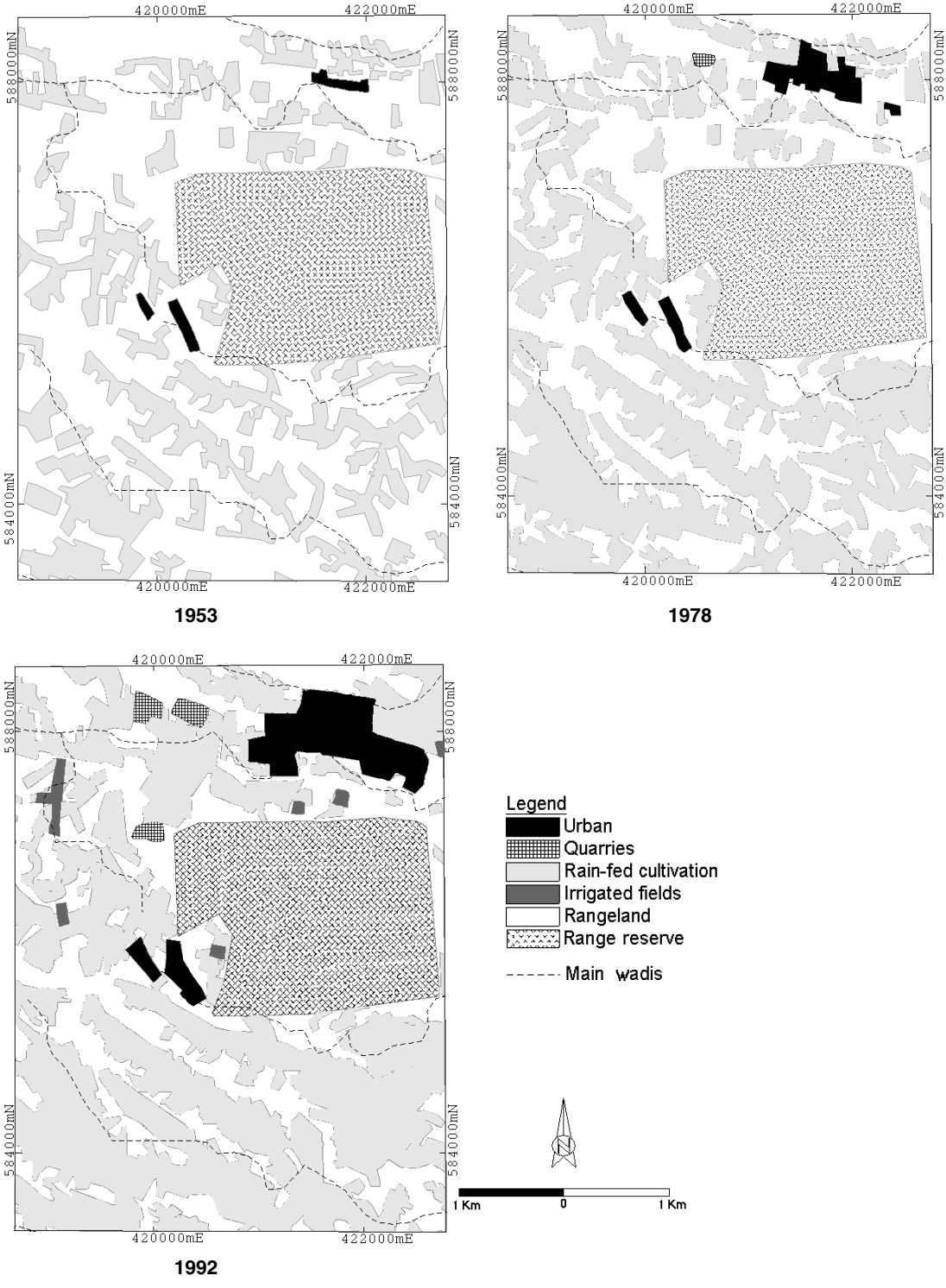

Figure 3 Land use maps derived from aerial photography of Surra 1953, 1978 and 1992

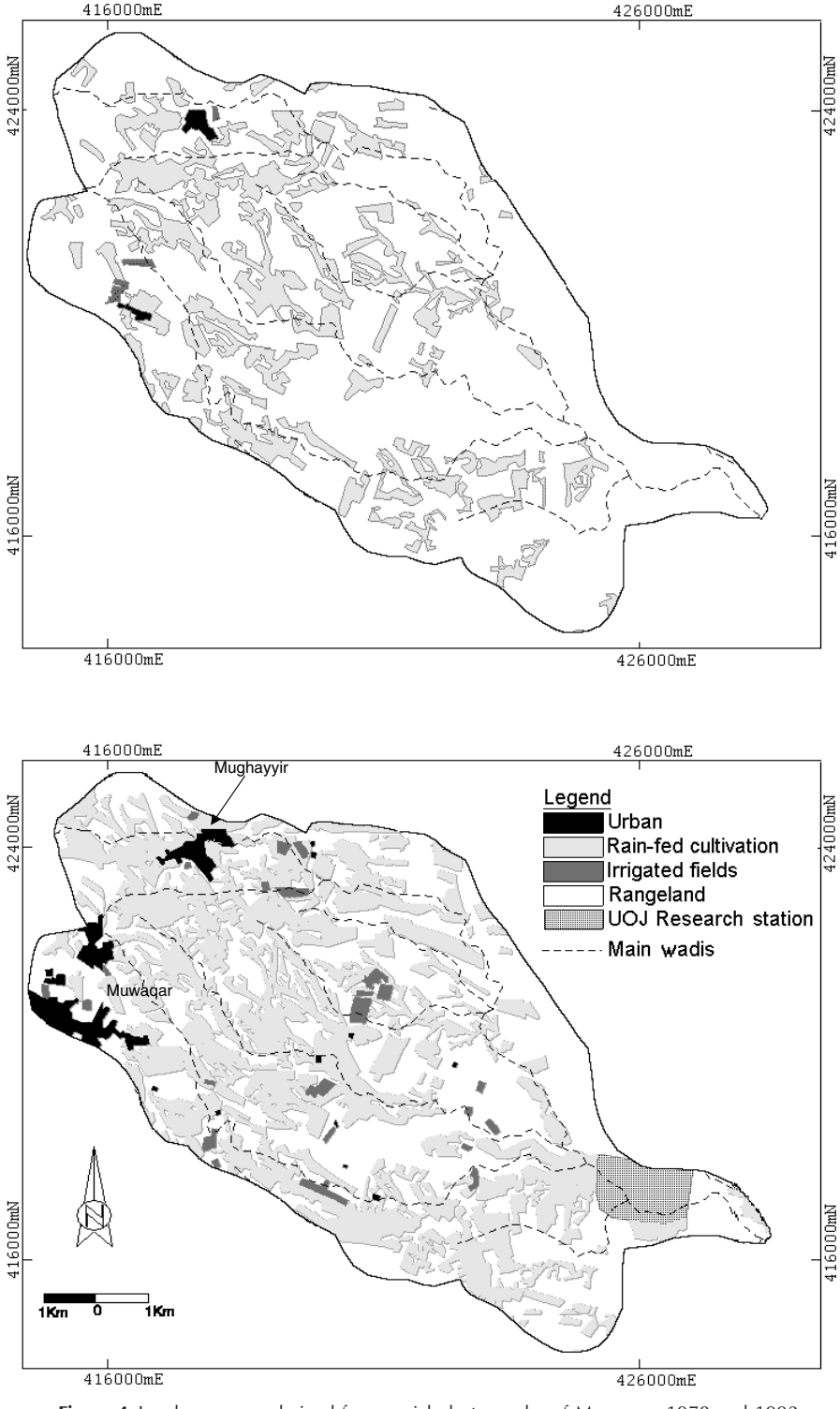

Figure 4 Land use maps derived from aerial photography of Muwaqar: 1978 and 1992

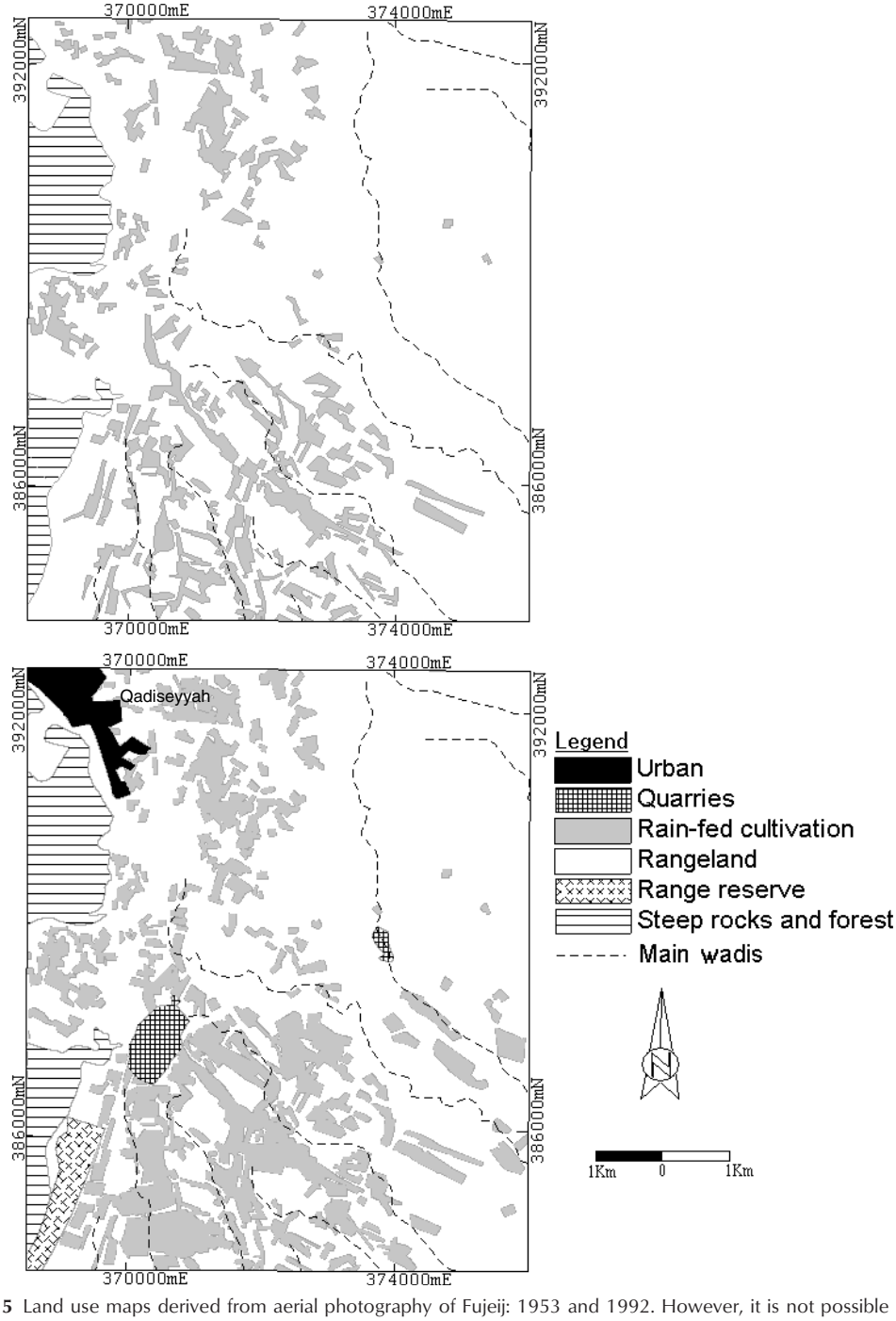

Figure 5 Land use maps derived from aerial photography of Fujeij: 1953 and 1992. However, it is not possible to show the location of all the farms as area features on this Figure due to the scale of the map

Table 4 Percentage land use change, Umm Al-Quttayn+

		1992					
		Urban	Rain-fed cultivation	Irrigated fields	Basalt rock	Rangeland	Total
1953	Urban	0.9	—	—	—	—	0.9
	Rain-fed cultivation	1.3	11.3	1.6	—	—	14.2
	Basalt rock	0.1	—	—	7.9	0.4	8.4
	Rangeland	7.7	7.6	2.5	0.2	58.5	76.5
1978	Urban	3.9	—	—	—	—	3.9
	Rain-fed cultivation	2.3	18.9	1.8	0.1	—	23.1
	Basalt rock	0.5	—	—	7.8	0.7	9.0
	Rangeland	3.3	—	2.3	0.2	58.2	64.0
	Total	10.0	18.9	4.1	8.1	58.9	100.0

+ Total area of Umm Al-Quttayn = 28.3 km^2

Table 5 Percentage land use change, Surra+

		1992						
		Urban	Quarries	Rain-fed cultivation	Irrigated fields	Rangeland	Range reserve	Total
1953	Urban	0.6	—	—	—	—	—	0.6
	Rain-fed cultivation	0.9	0.2	23.4	0.3	—	—	24.8
	Rangeland	3.1	0.5	23.2	0.5	29.3	—	56.6
	Range reserve	—	—	—	—	—	18.0	18.0
1978	Urban	1.8	—	—	—	—	—	1.8
	Quarries	—	0.1	—	—	—	—	0.1
	Rain-fed cultivation	0.8	0.1	37.3	0.5	—	—	38.7
	Rangeland	2.0	0.5	9.3	0.3	29.3	—	41.4
	Range reserve	—	—	—	—	—	18.0	18.0
	Total	4.6	0.7	46.6	0.8	29.3	18.0	100.0

+ Total area of Surra = 22.0 km^2

2 a shift from rangeland into rain-fed cultivation; and
3 an incremental loss of rain-fed cultivation and rangeland into irrigated fields (Table 4 and Figure 2).

The urbanized areas, Umm Al-Quttayn and Mukayfita, increased from less than one per cent in 1953 to reach ten per cent of the total area mapped in this part of the Badia in 1992. Part of the urbanized area of 1992 was previously cultivated, in 1953 and 1978, but most of it was originally shrub rangeland with scattered basalt stones. Similar land use changes between rangeland and cultivated areas have been indicated by previous research in the northern Badia (Millington *et al.* 1999). The shift from rangeland to cultivation has increased with time as farmers have cleared basalt stones from the soil surface to create small fields for rain-fed barley cultivation. These are commonly used for forage production as the lack of rainfall often prevents grain from developing. In many cases, the cleared basalt stones are used to define the boundaries of cultivated land. Part of the

Table 6 Percentage land use change, Muwaqar+

		1992					
		Urban	Rain-fed cultivation	Irrigated fields	Rangeland	Research Station	Total
1978	Urban	0.4	—	—	—	—	0.4
	Rain-fed cultivation	0.3	18.9	0.5	—	<0.1	19.7
	Irrigated fields	<0.1	0.1	—	0.1	—	0.2
	Rangeland	2.4	21.4	1.5	51.9	2.4	79.6
	Total	3.1	40.4	2.0	52.0	2.4	100.0

+ Total area of Muwaqar = 78.8 km^2

Table 7 Percentage land use change, Fujeij+

		1992						
		Urban	Quarries	Rain-fed cultivation	Range reserve	Rangeland	Steep rocks	Total
1953	Rain-fed cultivation	0.2	0.3	11.5	0.1	—	—	12.1
	Rangeland	1.5	0.9	8.8	1.3	68.8	—	81.3
	Steep rocks	—	—	—	—	—	6.6	6.6
	Total	1.7	1.2	20.3	1.4	68.8	6.6	100.0

+ Total area of Fujeij = 67.3 km^2

rain-fed cultivated lands and rangeland have changed into irrigated fields. These occupied more than four per cent of the study area in 1992. These fields are usually irrigated from wells drilled by wealthy landowners and cropped with fruit trees and vegetables.

Land use changes at Surra

The expansion of rain-fed cultivation and urbanized areas are the major land use changes at this site. The rain-fed cultivation area increased from less than 25 per cent in 1953 to approximately 47 per cent of the total area in 1992 (Table 5). The rain-fed cultivated fields (mainly barley) have irregular shapes and are aligned along the valley sides (Figure 3) as farmers have cultivated the areas at the foot of slopes near the wadis where water is stored in the relatively deeper soils. However, cultivated areas are also found along the ridges. Irrigated fields, mainly five farms for olive production, appeared between 1978 and 1992 and comprise less than one per cent of the total area at Surra in 1992. Irrigation at this site is supplementary during summer; and water is usually brought from wells drilled at sites other than Surra.

Overall urban development at this site increased from less than one per cent in 1953 to approximately five per cent of the total area in 1992. One quarry was detected in 1978 to the north of Surra but it only occupied a very small proportion of the total area. In 1992, two additional quarries were detected, thereby increasing the proportion of quarries to approximately one per cent. The area of Surra's range reserve did not change between 1953 and 1992 and constituted a constant 18 per cent of the total study area. The natural vegetation inside the reserve was mainly shrubs of *Artemisia herba alba* and *Salsola vermiculata* and *Atriplex* spp.

Land use changes at Muwaqar

Expansion of rain-fed cultivation over a 14-year period was noticed at Muwaqar as a considerable part of Muwaqar study area changed from rangeland in 1978 to rain-fed cultivation in 1992 (Table 6). The rain-fed cultivation was mainly for barley. The fields are characterized by their small

size, reflecting the pattern of land fragmentation in this area (Figure 4). Irrigated fruit trees, orchards and vegetable fields with small poultry or livestock units, started to develop between 1978 and 1992. These comprised two per cent of the total area in 1992. The poultry or livestock units were easily identified on the 1992 aerial photography due to their characteristic building shapes, patterns and sizes. In addition to this agricultural expansion, a small proportion of rangeland has changed to urban land use that includes 11 scattered poultry and livestock farms. Furthermore, part of the study site has changed into a research station since 1978. This was founded by the University of Jordan (UOJ) in 1985 to develop practices for integrated farming and rangeland management in the low rainfall zone.

Land use changes at Fujeij

This site has less intensive agricultural activity than the other sites reported on. The cultivated areas were mainly small, fragmented barley fields (Figure 5) constituting approximately 12 per cent of the total area in 1953 and more than 20 per cent in 1992 (Table 7). In 1953, no settlement was detectable on the aerial photography but a few Bedouin tents were sparsely distributed in the north of the study area. Qadiseyyah town was identified in the 1990 aerial photographs and the 1992 satellite imagery, though it represents less than two per cent of the area. The Fujeij marginal range reserve (Figure 5) is included in the study site and forms a rectangular strip in the south-west. The reserve, established in 1958 by the MOA for the purpose of rangeland research, is a good example of the potential of semi-arid vegetation to recover when protected. Field observations showed relatively high vegetation cover inside the reserve (30 to 50%) compared to a very low vegetation cover (0 to 5%) in the open, overgrazed range outside the reserve (Abu-Swai 1998). The thick vegetation cover inside the protected reserve and the thin vegetation cover of the open range clearly indicate the extent to which human influence is a major cause of landscape change in this part of the Badia.

Discussion

The observed trends of land use change at the four sites were mainly the expansion of cultivated and urbanized areas. These changes are related to land colonization in the Badia which are affected by demographic, socio-economic and environmental factors (Maani *et al.* 1998; Findlay and Maani 1999; Millington *et al.* 1999).

Population growth

This has resulted in the expansion of both urbanized and cultivated areas. The increase in the urbanized area over time was expected and can be explained by the high rate of population growth in Jordan (3.4% in 1997) (JNIS 1999). The total population of Jordan, including the Badia, increased from 586 000 in 1952 to 2.13 million in 1979, and reached 4.14 million in 1992 (JNIS 1999). The increase has been enhanced by international events: e.g. the immigration of Palestinians from the West Bank in 1967, and the return of Jordanian labour from the Gulf countries after 1990. The same trend is seen in the Badia where the population increased from 56 000 in 1974 to 146 000 in 1991 (FAO 1991). The total population of Umm Al-Quttayn and Mukayfita, for example, increased from 451 in 1976 to 4100 in 1993 (Maani *et al.* 1998). Detailed studies (Maani *et al.* 1998; Findlay and Maani 1999; Millington *et al.* 1999) on demographic trends and population projections indicate that population growth is the main 'push' factor affecting the land use, particularly the expansion of urbanized and cultivated areas.

Socio-economic factors

Changes in farming systems In the past, Bedouins were animal-oriented by occupation and tradition. Pastoralism was a way of life more than just a source of income. Herds of camels and sheep were regarded as the only form of wealth, and nobility and prestige were equated with the ownership of these animals (Juneidi and Abu-Zanat 1993). The nomadic pastoralism included east–west movements from the Badia to the steppe rangeland where vegetation and crop residues were available during the lower rainfall season. In winter the animal herds were mainly concentrated in the eastern desert to browse the natural vegetation of the Badia. Studies by Al-Sharafat (1996) and Harb (1994) indicate that this form of transhumance applied to more than 70 per cent of the sheep flocks in Jordan. As a result of the socio-economic development of the western part of the country, particularly the development of urban infrastructure on traditional grazing lands, the Bedouin have lost access to the steppe rangelands. This has exerted more pressure on the natural resources of the transitional zone of the Badia and resulted in more rangelands being put under cultivation to support the grazing herds.

In addition to the changes in the nomadic pastoralism system, the livestock owners have started to shift from subsistence to commercial production. This change has resulted in the increase of livestock numbers in Jordan from 607 000 in 1950 to 1.32

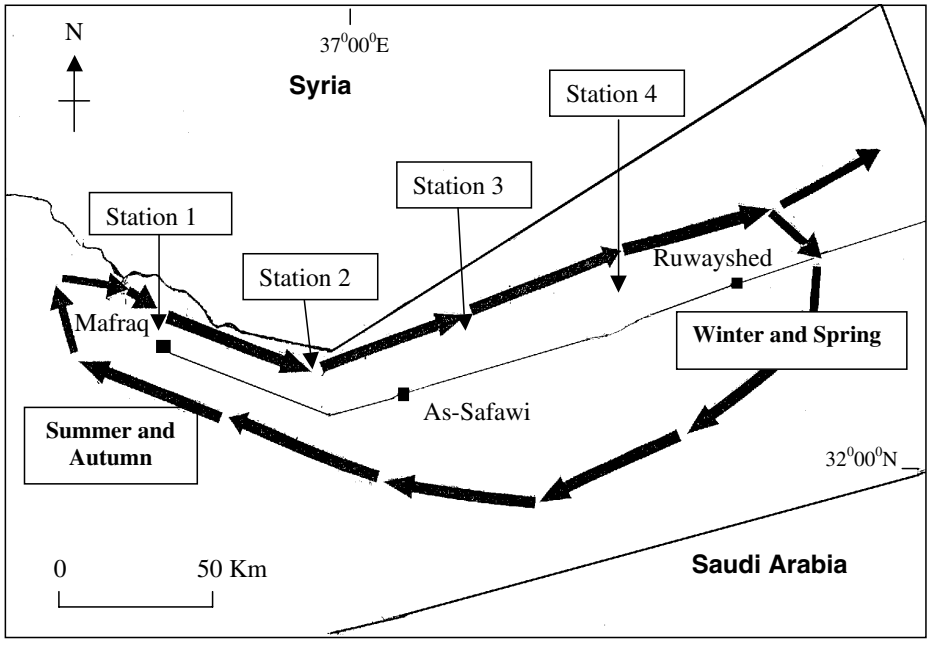

Figure 6 Pattern of seasonal movements by Bedouin in the northern part of the Badia transition zone

millions in 1980 and 2.04 millions in 1990 (DOS 1991). The viability of these increased flock sizes depends upon the implementation of forage subsidies, the availability of veterinary services and the prices of live animals on the export market. During the cycle of movement, the Bedouin have stations (Figure 6) where veterinary services, markets and feed (concentrates and residues) are available. The feed resources of the transhumance system are divided as follows:

45 per cent concentrates;
15 per cent barley;
25 per cent crop residues; and
15 per cent rangeland vegetation (Al-Sharafat 1996).

These percentages, however, are changeable depending on the season, and feed and water availability; and in addition, the policy of feed subsidy might influence these percentages. After 1992, for example, the lifting of the feed subsidy forced the Bedouin to adopt intensive cultivation of barley (Abu Zanat 1995). Its high flexibility and the easy management of the crop (USAID 1986) also enhanced the cultivation of barley on native rangelands.

In good years, (that is years when above average rainfall is evenly distributed throughout the season) a grain crop is produced and the straw is stored for use later in the winter. In dry years, sheep graze the non-harvested barley. Therefore, variations in rain-fed cultivation and, consequently, on production are to be expected. In 1992, an above average rainfall year, the total production of barley in Jordan was approximately 69 000 tonnes, while from 1993 to 1997, below average rainfall years, it was around 30 000 tonnes annually (JNIS 1999). The flexibility of barley and the lack of subsidized forage, therefore, have resulted in increased rain-fed cultivation in the four study sites.

Access to capital Access to capital is another factor that has enhanced the shift to commercial production and increased the area under cultivation. It has enabled the wealthy local landowners to drill wells to shift their farming systems from rain-fed cultivation dominated to irrigation-dominated agriculture. This shift is obvious at the Umm Al-Quttayn and Muwaqar sites, while at Fujeij and Surra the greater depth of the ground water aquifer raises the cost of water abstraction (approximately JD10 – 20 000 and JD50 000, respectively) and restricted the expansion of irrigated agriculture. The investment in irrigation inside the Badia and the JAZPP regions is not only restricted to the local landowners but it has also been established by wealthy absentee landowners who generally live in cities in the western parts of the country (Millington *et al.* 1999). This can be attributed to the cheaper price of land in the Badia and the ability of absentee landowners to obtain licences for groundwater

drilling. Therefore, the irrigation developments inside the Badia have been mainly 'pushed' from outside the area. This can be attributed to the high investment costs which are beyond the means of many traditional farmers, who in the past shifted from rangeland to rain-fed cultivation with lower capital input.

Availability of markets Accessibility to the markets of major cities (Amman, Zarqa, Irbid and Mafraq) has encouraged the farmers to expand rain-fed and irrigated cultivation. One good example from the study sites is the establishment of poultry and livestock farms at Muwaqar. The relatively short distance and good road connection between Muwaqar and Amman, the main market in Jordan, have enhanced this development. This means transportation costs area relatively low and it gives the farmers at Muwaqar a competitive advantage over farmers from Umm Al-Quttayn and Surra who have to transport their goods much further. An additional benefit is better access to veterinary services from the MOA and private sector companies: an important consideration when rearing livestock and poultry intensively.

Services and sources of employment The improvements to infrastructure, health and education have encouraged the Bedouin to depend on goods, services and sources of employment inside and outside the Badia. Official Figures (JNIS 1999) have shown that the Jordanian labour force has increased from more than 405 000 in 1979 to more than 1.18 million in 1997. As expected more Bedouin have settled inside the JAZPP region and resulted in the appearance of new urban settlements and the expansion of older ones, as observed in all four study sites. The availability of new sources of income has affected the land use in selected areas of the JAZPP region. For example, the establishment of the Rashadyyeh Cement Factory (slightly to the north of the Qadiseyyah) in the early 1980s had two main impacts on the land use at Fujeij. It attracted the local labour force away from agricultural development and led to the development of quarries to meet part of the factory's needs. The establishment of a tomato processing plant at Al-Sa'adiyaah in Mafraq in 1993, on the other hand, has had a significant influence on the decisions of many farmers to move into irrigated farming and to grow tomatoes as their main summer crop (Millington *et al*. 1999).

Land tenure system

According to *Agricultural Law No. 20* (1973), the government owns all the rangelands of the Badia. In reality, the actual rangeland tenure is different and most of the area is privately owned and cultivated by Bedouin for erratic cereal production (FAO 1991; Juneidi and Abu-Zanat 1993). According to USAID (1986), Bedouin establish the right to use and develop state land by fencing, planting, ploughing or developing a water supply. This has been enhanced by governmental strategies that encouraged people to settle inside the Badia and to show their loyalties as Jordanians rather than moving between countries (Dutton 1998). The land ownership is then transferred and usually split unequally between the heirs after the death of the tenant. Existing laws give an individual the right to own a minimum of one dunum (0.1 ha). Outside the city or village, the minimum landholding size is one hectare (Qasem 1985). Available data indicate that the average size of a landholding in the dry areas is about 3.3 hectares (Jaradat 1988). Previous research (El-Hourani and Duwayri 1986) revealed that the number of landholdings with an area of less than two hectares was 18 000 in 1975 and had increased to 23 000 by 1983, an increase of 28 per cent. This fact is reflected in the fragmentation of landholdings seen in the Badia today.

In this study most of the cultivated fields were relatively small and fragmented. A land tenure map of Muwaqar (Makhamreh 1996), for example, shows that about 60 per cent of the landholdings are less than five hectares. The land use maps of Muwaqar (Figure 4) and Fujeij (Figure 5) show relatively small fields dominating both sites – this is a result of land fragmentation. Generally, the wish of the heirs to have their share near roads usually results in splitting the land into rectangular elongated fields that may hinder the use of modern farm machinery and enhance the use of inappropriate agricultural practices. As a result, most of the lands are ploughed without regard to the direction of the slope. Consequently, soil erosion by water is accelerated. This situation calls for urgent action to improve the land tenure system in the Badia to prevent this type of land degradation through fragmentation. If the existing land tenure system is not modified, then more land fragmentation is to be expected in the future.

Environmental factors

These factors are related to climate and the site topography. Both rainfall amount and distribution impact on rain-fed cultivation. However, the rainfall amount might be interrelated, or overridden by other influences, e.g. topography. The effect of topography on land use is obvious to the northwest of Umm Al-Quttayn and in the western and north-eastern parts of Fujeij. At Umm Al-Quttayn

the agricultural activity is restricted by bare basalt rocks, parts of the consolidated lava flows of the Harrat Ash-Shaam basaltic super group (Ibrahim 1993) extending from Syria into Umm Al-Quttayn. The absence of agricultural activity in the western part of Fujeij, on the other hand, is attributed to the fact that it is a steeply sloping and rocky area while the undulating mountains in the north-east of Fujeij restrict agricultural activity in that area.

In addition to rainfall and topography, the depth to the aquifer is an important factor related to land use and its change at the four study sites. This factor is expected to influence the existence and the distribution of irrigated fields at the four study sites and in the Badia as a whole. In the northern Badia, variation in depth to the water aquifer is one major factor that influences the distribution of irrigation in that area (Millington *et al.* 1999). In Fujeij, for example, the deep-water aquifer raises the cost of drilling wells (2 to 5 times the cost of drilling at Umm Al-Quttayn) and therefore irrigated farms are absent at this site.

Conclusions

The results from this study show that land use at the selected sites altered in the last half century and that this corresponds closely to changes in socio-economic and environmental factors influencing the Badia region. An increased amount of rangeland has been brought into rain-fed and irrigated cultivation. Expansion of the urbanized areas, a process that is still taking place in the Badia, has occurred at all the sites studied. The patterns of land fragmentation that are reported by other authors are clearly evident in the four study sites. The land use changes can be attributed to the high rate of population growth, increased livestock numbers and socio-economic change in the agricultural sector. The rapid population growth in Jordan as a whole and the Badia in particular is believed to override the other factors and is expected to exert more pressure in the future on the natural resources of the Badia by expansion of the urbanized and cultivated areas. This fact is recognized by the JAZPP, and different alternatives (Mazahreh 1998; Al-Shoubaki 1999; Al-Rashdan 1999) are being proposed for appropriate land use and management of the region. Alternative land use approaches will require good data regarding the current and the expected future changes in the factors discussed in this paper and their relations with the socio-economic and demographic factors. A comparison between the potential and the current land use is also required to map the extent of land misuse and accelerated degradation. Thus, the applications of this study for the whole project area is required and should be investigated further to enable such mapping.

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