

Assessment of Land Use Change Impact on Ecohydrological Parameters Using Remote Sensing in the Sub-Catchments of the Patish Watershed, Israel



MSc Thesis by Bart de Jong

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Assessment of Land Use Change Impact on Ecohydrological Parameters Using Remote Sensing in the Sub-Catchments of the Patish Watershed, Israel

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Abstract

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Discharge measurements in the Patish watershed in the Northern Negev region in Israel show a low stream flow, which cannot be explained by hydrological modelling. One hypothesis is that low discharge is caused by changes in land use in the watershed, which influence the rainfall/runoff ratio. This hypothesis was tested by assessing the impact of land use change on Ecohydrological parameters. Change in land use is determined by analysing Landsat images using Definiens®. Soil Ecohydrological properties were derived by field experiments, and taking samples to be analysed in the laboratory. Rainfall records were collected, and investigated for possible trends. Land use was analysed using three classes: natural, agricultural and urban. The class of natural open area decreased from almost 70% of the area to just more than 50%. Agricultural area increased from almost 30% to almost 40%, and the urban class increased from 5% to 10% of the area. In some natural areas forest with terraces and limans is established, but these developments could not be distinguished in the Remote Sensing analysis. Saturated hydraulic conductivity was found higher for the agricultural area. Rainfall shows a high variability, both temporal and spatial. Trend lines derived were horizontal or slightly decreasing, though uncertainty is high. The hypothesis could not be confirmed. Developments in the Patish watershed could decrease runoff, especially the increase in agricultural and afforested area. But with current data available they do not explain for the low amounts of runoff observed. Therefore more quantitative research is recommended.

Land cover change / Semi-arid area / Israel / Remote Sensing / Ecohydrological parameters

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1. Introduction

This first chapter gives some background of the research, and the research framework forming the basis of the research.

1.1 Background

The Patish watershed is located in the Northern Negev region of Israel, with the city of Be'er Sheva on its Eastern edge, and including the town of Ofakim in the West; it has an area of 255 km² (fig 1).



Figure 1 Patish watershed as located in the Northern Negev, Israel. Source: Google Earth, 2009

Discharge measurements over the last 20 years in the Patish watershed in the Northern Negev region in Israel show a low stream flow. And as compared to other comparable watersheds in the region, observed discharge quantities cannot be explained by hydrological modelling. Exemplary, model predictions are up to ten times higher than observed discharges.

To explain for these observations, two hypotheses were formulated by the researchers involved in this watershed. The first states that changes in land use in the watershed have influenced the rainfall/runoff ratio, resulting in lower than expected discharges. One of the land use changes in the area concerns afforestation activities by the Jewish National Fund (JNF), like the Ambassador forest and more recently in the Karkur sub-catchment. The second hypothesis is that vegetation in the river beds acts as a natural barrier to stream flow and obstructs discharge to reach the outlet of the catchment.

To get closer to the explanation for the hydrological behaviour of the Patish watershed, this report describes a research to get more insight in the processes active in the watershed, and their relationships. The hypothesis tested is the first as mentioned above: changes in land use in the Patish watershed have influenced the rainfall/runoff ratio, resulting in lower than expected discharges.

1.2 Research framework

1.2.1 Problem statement

Discharge amounts observed in the Patish catchment appear to be (far) lower than would be expected when looking to comparable catchments and model predictions. However, no comprehensive discharge data are yet available; hydrological monitoring stations are just being installed.

For changes in land use in the catchment a similar story can be told: changes have been reported, but no real data is available. Climate data was recorded for various research stations in the area, and in the larger Northern Negev region. Rainfall records are available for different periods dependent on the station, varying from the period 1934-2009 to in one occasion 2008-2011. In general, most data can be found for the more recent years.

To be able to test the hypothesis that the low amounts of discharge are caused by specific changes in land use in the watershed in this stadium of the research, one has to rely on data acquired by Remote Sensing and by measurements of soil properties and management practices in the field. Combining these types of data, one can apply the concept of 'Ecohydrological parameters', as is described below. Therefore, this concept will be applied combining Remote Sensed data and soil parameters collected in the field to be able to analyse the influence of land use change on soil surface parameters and subsequently on (potential) runoff in the Patish catchment.

1.2.2 Research Goal

The goal of this research is to “assess the impact of land-use change on Ecohydrological parameters, and subsequently on vertical water fluxes and potential runoff in the sub-catchments of the Patish watershed.”

1.2.3 Objectives

Based on this goal, three objectives were formulated, the first two being subdivided into two sub-objectives.

Objective 1

Collect available data for representative landscape units in two or three sub-catchments of the Patish watershed in a geo-database:

- 1.1 Collect available data on climate (especially rainfall), discharge, soil type, elevation and land use;
- 1.2 Derive information on land use and land use change from Remote Sensing data (including aerial photographs and grey scale images), combined with ground truth data.

Objective 2

Assess data on soil surface properties, land use, and land cover during field visits in the representative landscape units and add to geo-database – and upscale results to the sub-catchments of the Patish watershed:

- 2.1 Parameterise physical (and chemical) soil surface conditions influencing infiltration rate (like soil texture, bulk density and saturated hydraulic conductivity);
- 2.2 Upscale obtained information from landscape units to sub-catchments with comparable characteristics.

Objective 3

Analyse the relation between collected data for the landscape units and potential spatial water flow.

1.2.4 Research question

To reach the goal and objectives stated before, this research should find an answer to the following research question, and subsequent sub-questions:

“What is the combined impact of land use change, land management and Ecohydrological parameters on vertical water fluxes and potential runoff in the sub-catchments of the Patish watershed?”

Research sub questions:

1. How did land cover in the Patish watershed change over the last 25 years, and how can this be related to land management practices?
2. What are the physical (and chemical) properties of the soil surface in the various landscape units, and can these be linked to rainfall/runoff relations? And (how) can this be up scaled to the larger Patish watershed?
3. Which Ecohydrological parameters are characteristic for various landscape units, and is it possible to calculate and eventually model vertical water fluxes in the topsoil?

To answer these questions I first described in chapter two the main concepts and theory based on a literature research, after which the hypothesis is reformulated. Chapter three presents the methodology of this research, with subsequently the work flow, Remote Sensing analysis, field work and the rainfall analysis. The next chapter (four) gives the results of the research (again with Remote Sensing analysis, field work and rainfall analysis). Finally, in chapter five the results are discussed followed by the conclusion and recommendations (chapter six).

2. Theoretical background

To be able to answer the research question and test the hypothesis, in this chapter literature describing the main concepts applied and comparable research is analysed. Starting with 'land cover change' followed by 'Remote Sensing' because it is one of the main concepts applied in this research. Next the 'field water cycle' and the concept of 'Ecohydrology' to link the soil to the hydrological cycle. The fifth paragraph describes the 'influence of vegetation' to connect land cover to the soil and soil hydraulic properties, followed by the closely connected theme of 'afforestation', which focuses on one specific type of vegetation. Then the section 'modelling the effects of land use change' goes into the role of land use change in models, to distinguish important parameters and possible weaknesses. Also 'ephemeral streams' focuses on difficulties of catching semi-arid watersheds in a model, and finally the 'sampling of natural resources' is included to give some theoretical background to the field work. In the last paragraph a short analysis of this theoretical background is presented, with finally a reformulated, sharpened hypothesis.

2.1 Land Cover Change

Land cover change can be defined as "the change of the land cover and the associated properties for at least an annual time step" (Hörmann *et al.* 2005). Land use and land cover changes are known to influence watershed hydrology – for example in the case of deforestation which can affect the local water balance (Savary *et al.* 2009) – and soil hydraulic properties – as when bulk density increases by a change from forest to grassland or cropland (Bormann *et al.* 2007). According to Baldyga *et al.* (2008) land cover change affects hydrologic response at a range of scales. It alters both the balance between rainfall and evaporation and the runoff response of the area (Sahin and Hall 1996). And finally Ward and Trimble (2004) state that "urbanisation increases impervious land uses, reduces infiltration, and causes more runoff and higher peak discharges". Often a characteristic of urbanised land is a waterproof soil, because roofs, streets, sidewalks and parking lots are impermeable. Therefore the hydrologic effects of urbanisation can be significant (Ward and Trimble 2004).

Although land cover and land use often are used interchangeably, there is a difference. Land cover describes the physical attributes or characteristics of Earth's surface, whereas land use describes how the land is utilised. Without additional information, Remote Sensing detects land cover. In most cases, subsequently land use can be derived from land cover (Kiage *et al.* 2007). According to Hernández-Guzmán *et al.* (2008) do land use changes derived from human activities have the most significant impacts on hydrologic changes. Land cover changes affect evapotranspiration and surface runoff routing by altering the physical structure of vegetation and surface roughness (Savary *et al.* 2009). Land conversion alters the hydrologic characteristics of the land surface and modifies patterns and rates of water flow by determining the characteristics of runoff processes and altering the infiltration, erosion and evapotranspiration rates (Hernandez-Guzman *et al.* 2008).

Because land use affects many elements of the whole system, its representation is a key element of integrated models (Hörmann *et al.* 2005). It controls both the quantity and quality of water, and therefore land use is an essential input parameter for hydrological models (Hörmann *et al.* 2005).

To analyse and eventually model hydrological processes and dynamics, detailed information on geology, topography, land use, etc. is required (Helmschrot and Flugel 2002). And especially in semi-arid areas – characterised by a strong limitation of water while facing a remarkable increase of water demands – the impact of land cover changes on the runoff of a catchment is of large interest to water resources planners, managers and decision makers (Helmschrot and Flugel 2002). To support efficient water management, it is useful to be able to predict and demonstrate how diverse land uses compete and affect water resources (Jewitt *et al.* 2004). This can be conceptualised by the division between 'blue-water' and 'green-water'. Blue-water is water in liquid form, which is affected by physical processes like runoff, through flow and stream flow and eventually runs out of the catchment. Green-water is water that escapes the catchment in gaseous form, after it is transpired by vegetation or evaporated from open water bodies and other surfaces (Falkenmark and Lannerstad

2005). If the land use changes, the ratio between blue and green water may also change (Jewitt *et al.* 2004).

For the analysis of possible effects of land use change on runoff, one needs a reliable database of both factors for a long period – which is seldom available. Additionally, changes in precipitation and other climate factors may influence runoff, and should be taken into account (Hörmann *et al.* 2005). The mapping of land cover changes at regional scales is essential for a wide range of applications, including those dealing with landslides, erosion, land planning and global warming (Reis 2008). The influences of land use change are difficult to quantify, but recent developments in decision support systems based on geographical information systems (GIS), Remote Sensing (RS), and distributed hydrological models have led to practical and useful tools to assess potential hydrological responses of a watershed (Savary *et al.* 2009). Satellite RS techniques can play a crucial role in providing information on land cover change on local, regional and even global scales, especially for cases where aerial photographs are not available. These techniques have been applied to monitor change in various natural environments. Including semi-arid ecosystems, where they were proven useful for monitoring and assessing various phenomena as drought, land degradation and land cover change (Kiage *et al.* 2007). Nowadays, the integration of land use information into hydrologic models is primarily based on RS images (Hörmann *et al.* 2005).

2.2 Remote Sensing

Remote Sensing (RS) is broadly defined by Jin (2009) as "a collection of noncontact observational methods". Traditional techniques to measure hydrological variables rely on point sensors to collect information. This information is assumed to be representative for large areas, but in complex or heterogeneous environments this approach is not particularly helpful. Hydrological processes and the surface-atmosphere interface are heterogeneous and complex systems covering a wide range of scales in space and time. RS offers the potential to capture information on some of the spatial and temporal Ecohydrological processes. Next to this, RS is the only approach that has the potential to translate measurements from one scale to another (Jin 2009). The advantage of RS over traditional inventorial surveys is the greater information on the geographical distribution of land use, together with the temporal trends required for understanding and modelling the trajectory of land surface changes (Abdulaziz *et al.* 2009).

Many studies showed data derived from RS provide both actual and spatial distributed information for hydrological catchment modelling, especially in areas which are difficult to monitor when using conventional techniques (Helmschrot and Flugel 2002). RS appears to be a time- and cost-effective method to monitor changes in arid environments, which can detect and monitor landscape changes and degradation in arid and semi-arid regions. Therefore satellite data have become common in change detection studies in both urban and rural areas (Abdulaziz *et al.* 2009; Yuan *et al.* 2005).

The integration of information derived from RS data in GIS and their analysis can be considered as the primary tool for efficient acquisition of input parameters needed for distributed hydrological modelling, following Helmschrot and Flugel (2002). A lot of research predicts that hydrologic forecasts can be improved if (Remote Sensed) hydrological variables along with ground observations will be assimilated in hydrological models. The most interesting hydrological variables in this case include precipitation, evapotranspiration, surface water and river discharge volumes, soil moisture, groundwater storage capacity and ecosystems variables like vegetation cover (Jin 2009).

To complement satellite derived RS data, other data sources – like ground data and aerial photographs – are required for classification algorithm training and accuracy assessment. Of these, ground data collected *in situ* are most reliable, however not always available and often expensive to obtain. In any case, some types of reference data are essential for the evaluation of produced geospatial maps (Abdulaziz *et al.* 2009).

Also according Chehbouni *et al.* (2008) it is crucial to include other sources (sensors, platforms) of information for an effective control of hydrological models. For because of the complex character of the Earth-surface system with its various and interconnected processes, no single waveband can effectively characterise or constrain it. Understanding of a basin-wide hydrological system cannot be achieved without making full use of historical data and newly developed technology like GIS, ground instruments, numerical modelling, and data assimilation in addition to RS observations (Chehbouni *et al.* 2008).

2.3 Field water cycle

The water cycle in the field consists of the entry of water in the soil (infiltration), the temporary storage of water in the rooting zone, and the removal of water from the soil by drainage, evaporation or plant uptake (Hillel 1971). Infiltration can be defined as “the passage of water through the surface of the soil, via pores or small openings, into the soil profile”, following Ward and Trimble (2004). Other definitions used to describe the process of infiltration are infiltration rate (“the flux passing through the surface and flowing into the profile” (Hillel 1971)) and the infiltration capacity (or soil infiltrability) (“the flux which the soil profile can absorb through its surface when it is maintained in contact with water at atmospheric pressure” (Hillel 1971)).

Soil infiltrability depends on the following factors: time from onset of the rain (or irrigation); initial water content; hydraulic conductivity; soil surface conditions; and presence of impeding layers inside the profile (Hillel 1971). Important soil properties affecting infiltration are texture, structure, and organic material (Ward and Trimble 2004; Hillel 1971). The infiltration capacity of soils depends on many natural factors, but it is also the zone at which the human impact has a large role in influencing hydrologic processes as well as geomorphological change (Ward and Trimble 2004). When clay and silt-size particles dominate the upper soil materials, crusting can occur, inhibiting water movement into the soil matrix. Crusts are formed at the soil surface during the drying process. Also surface sealing – where the surface structure breaks down – may limit the infiltration of water into a soil (Ward and Trimble 2004). Water movement in soils is affected by soil texture, bulk density, heterogeneity, cracks and surface conditions (Ward and Trimble 2004). Another important soil property is hydraulic conductivity, which can be defined as “the ability of a soil to transmit water under a unit hydraulic gradient” (Ward and Trimble 2004).

“Surface runoff is the portion of rain which is not absorbed by the soil and does not accumulate on the surface, but runs down-slope and collects in gullies and streams”, according to Hillel (1971). It can only occur when the infiltration rate of the soil is exceeded by the rainfall intensity. However, it only really occurs when the excess rain also exceeds the surface storage capacity (amount of water stored in surface depressions) (Hillel 1971).

“Evapotranspiration is the process that returns water to the atmosphere and therefore completes the hydrologic cycle”. It consists of the two separate processes evaporation (from open water, soil or vegetation surfaces) and transpiration (removal of water from the soil via plants) (Ward and Trimble 2004), but because of the difficulty to distinguish between these processes, they are commonly treated as a single process (Hillel 1971). Evaporation from bare soil surfaces is either limited by the external evaporativity or the water-transmitting properties of the profile (Hillel 1971).

2.4 Ecohydrology

Ecohydrology can be defined as “the science which seeks to describe the hydrologic mechanisms that underlie ecologic patterns and processes”, (Rodriguez-Iturbe 2000) (as quoted in D’Odorico and Porporato 2006).

The main goal of Ecohydrology is twofold. First “to explain how hydrological processes influence the distribution, structure, function, and dynamics of biological systems” and secondly, “how feedbacks

from biological systems affect the water cycle" (Jin 2009). As a result, Ecohydrology is the discipline linking hydrology and ecology (Jin 2009).

Harper and Zalewski (2008) distinguish three subject areas in Ecohydrology. The first is focused upon plant-water dynamics on land, the second is connected with quantities in the water cycle and the impact of changes in quantity upon ecology in rivers and the third one advocates an integrated vision of physical and biotic processes driving the dynamic evolution of river basins. In this research Ecohydrology will deal with the first of these subject areas. Ecohydrological research is fundamental to the understanding of the linkages between ecosystem dynamics and the water cycle, in particular in arid and semi-arid environments, where water is an important limiting resource. Not only because of its scarcity, but also for its intermittent and unpredictable character (D'Odorico and Porporato 2006).

Organisms in arid lands have to concentrate and conserve resources such as water, nutrients and soils, and one of the mechanisms to resource concentration is the redistribution of resources to concentrated patches, resulting in heterogeneous soil properties. Physical and chemical properties exhibiting such heterogeneity are linked to maximising water and nutrient availability, and are therefore Ecohydrological properties, for they are a result of coupled hydrologic, vegetation and climate systems (Bedford and Small 2008).

2.5 Influence of Vegetation

Vegetation has a strong influence on its environment (including water recycling) (Gao *et al.* 2009), while the vegetation itself also is influenced by the environment. Vegetation can be regarded as an environmental indicator in water-limited ecosystems and can be linked to both the causes and consequences of land degradation in arid areas. Concerning the dynamics of soil moisture, runoff and stream flow the role of vegetation is acknowledged to be very important. One of the fundamental aspects of Ecohydrology is to understand the influence of vegetation on hydrological changes, and therefore studying the quantitative relationship between vegetation and water resources is a critical step in developing advanced Ecohydrological approaches (Jin 2009).

Arid and semi-arid ecosystems typically consist of vegetation patches and interpatch areas, also called a vegetation mosaic. The unifying feature of vegetation mosaics is that the physical, chemical and biologic properties between plant patches and interpatches are different. In general, microtopography, infiltration rates, organic matter, limiting nutrients and water holding capacity are higher in vegetation patches (Bedford and Small 2008).

Bedford and Small (2008) found that K_{sat} is significantly higher (up to 35%) under shrub canopy, that soil properties are strongly related to the pattern of the vegetation, and that the effect of vegetation on soil properties extends beyond vegetation canopy. They conclude that given similar soil characteristics, landform type and vegetation pattern are strong determinates of small-scale variability in soil properties. And according their observations, infiltration rates vary widely between sub-vegetation and non-vegetated interspaces (Bedford and Small 2008). Finally, Jewitt *et al.* (2004) found that both forestry and irrigated agriculture reduce the amount of blue water. An increase in forestry leads to a reduction in runoff, and an increase in irrigated agriculture will increase the amount of evaporation and thereby decrease the blue water flow (Jewitt *et al.* 2004).

When comparing evapotranspiration (ET) in a semi-arid area loess plateau in China, (Wang *et al.* 2008) found that ET for grassland is 60% of precipitation, while ET for shrublands accounts for 93% and ET for forest over 95% of the yearly precipitation. In Yatir forest (in the Northern Negev, like Patish) Yaseef *et al.* (2009) found an ET of 267 mm/yr for the forest, with a precipitation of 285 mm/yr (94%). Of this 267 mm/yr, 103 mm/yr was soil evaporation (Yaseef *et al.* 2009).

For crop ET it is difficult to find comparable data, but to estimate potential ET one can use the crop coefficient combined with the potential ET. For the area of the Northern Negev monthly mean daily potential ET is shown in table 1.

Table 1 Monthly mean daily potential evapotranspiration (mm) - Penman-Monteith model (Israel Meteorological Service 2012)

Region	Jan	Feb	March	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Northern Negev	1.7	2.1	2.9	4.5	5.6	6.1	6.2	5.6	4.8	3.4	2.5	1.8

Crop coefficients were found for some crops cultivated in the Patish watershed (table 2). Because actual ET is dependent on a scale of variables (like climate, cropping pattern) it was not possible to calculate actual ET for these crops. So these coefficients (combined with potential ET) only can give an indication of ET for various agricultural crops (as described in FAO irrigation and drainage paper 56).

Table 2 Crop coefficient for a number of crops under semi-arid conditions (Lazzara and Gainfranco 2010)

Crop	Kc				Country
	Initial	Middle	End	Season	
Watermelon	0.2	1.1	1		Spain
Potato				0.85	Portugal
Cotton	0.8	1.13			Turkey
Maize				0.91	Spain
Wheat	0.53	1.1	0.4		USA (Texas)

2.6 Afforestation

The earth's surface is affected by land degradation and desertification, and the semi-desert areas where biomass and soil cover are dramatically reduced or absent, are most severely affected. The productivity of these degraded drylands can dramatically increase by restoring natural grazing lands or the establishment of agroforestry projects (Rabia *et al.* 2008). Arid zones face increased runoff and erosion processes due to low vegetative cover, which results in excessive heat and inadequate, variable precipitation and convective rainfall cells (Merzer 2007).

On several sites within the Patish watershed, afforestation activities have taken place. Afforestation can be defined as "the introduction of trees to sites that never supported forest cover for a long period of ecologic time" following Nyland (1996) (as cited in Ginsberg 2006). Afforestation is one of the approaches to combat soil degradation and desertification (Merzer 2007), and afforestation of sandy areas is a widespread practice to prevent sand encroachment on cultivated and inhabited land. Vegetation growth and litter accumulation on the dune surface reduce the rate of sand transport, enhance the deposition of fine material, improve the nutrient balance, and improve the soil structure and the water holding capacity of the soil. And the shading provided by the cover together with the litter cover regulates the soil temperature and reduce evaporation (Arbel *et al.* 2005). Further is forestry management regarded as a sustainable measure in the struggle against desertification as it allows for timber production and pasture under the canopy of the trees (Arbel *et al.* 2005). In the second part of the 20th century, the objective behind many afforestation programs was socio-economic; to improve the livelihood of inhabitants of arid zones (Merzer 2007).

Much research has been done on the effect of afforestation on watershed hydrology. One of the first reviews of these researches was done by Hibbert (1967), who in his discussion makes three generalisations. First that a reduction of forest cover increases water yield, secondly that the establishment of forest cover on sparsely vegetated land decreases water yield and finally that the response to a treatment is highly variable and many times unpredictable (Hibbert 1967).

Bosch and Hewlett (1982) update the research of Hibbert, and reinforce the first two generalisations. Also Farley *et al.* (2005) find that runoff decreases consistently and substantially with afforestation.

When grasslands or shrublands are afforested, it will likely affect many other ecosystem processes, including the water yield from rivers and streams. The water yield is influenced by changes in interception, transpiration and evaporation. All these parameters tend to increase when grass or shrubs are replaced with trees (Farley *et al.* 2005; Huang *et al.* 2003).

According to various researches, coniferous and eucalypt forests have the most decreasing influence on the water yield (Bosch and Hewlett 1982; Sahin and Hall 1996), with eucalypt having the greatest impact following Farley *et al.* (2005). Additionally, eucalypts and pines have their greatest relative impact in lower rainfall regions (Farley *et al.* 2005).

For coniferous and eucalypt forest, a 40mm change in annual water yield per 10% change in forest cover was found (Bosch and Hewlett 1982). Farley *et al.* (2005) state the evaporation from a catchment planted with eucalyptus could be 40 to 250 mm higher than from grassland catchment. On average, afforestation of grasslands and shrublands can result in a loss of one-third to three-quarters of stream flow (Farley *et al.* 2005), or 35 to 70% in the arid and semi-arid areas of the Loess Plateau (Gao *et al.* 2009). Huang *et al.* (2003) found a cumulative reduction of 32 to 50%. Contrary, the afforestation of the Yatir area (not far from the Patissh) did not affect the local water balance (of small plots), because all stored water either transpired or evaporated direct form the soil surface (Merzer 2007).

Proportional losses in water yield seem to be higher in drier regions. And proportional losses in low flow are larger than proportional losses in annual flow, which suggests dry-season losses are more severe than total annual losses for afforestation situations (Farley *et al.* 2005; Gao *et al.* 2009). Afforestation has impact on all storm events that produce runoff, but impact on peak flow was found to be greater than on volume (Huang *et al.* 2003). However, Sun *et al.* (2006) find more uncertainty on the effect on peak flows than on annual water yield and base flows.

In arid and semi-arid regions, changes in low flow may be more important than changes in annual flow, for in the dry season a reduced water supply will have the most severe effects for users (Farley *et al.* 2005).

2.7 Modelling the Effects of Land Use Change

When runoff is generated, water is redistributed (from the location producing runoff to lower locations receiving runoff). Locations with a low infiltration rate and/or a low water storage capacity are potential sources for runoff. Contrary, locations with a higher infiltration rate and a larger water storage capacity are potential sinks for water. For example when comparing a bedrock surface with a loess covered surface. A bedrock surface area stimulates runoff; even at low precipitation events runoff forms and water is redistributed. Whereas with a (deep) cover of loess deposits a higher proportion of precipitation will infiltrate and no or less runoff is produced. The response of a catchment to precipitation is highly influenced by the depth of the soil (Buis and Veldkamp 2008). However, even more important than the depth of the soil, is the infiltrability of the soil.

To study environmental change, different model concepts are available to describe the hydrological processes on a physically basis or by conceptual approaches. In most cases physically based models are preferred because many of their model parameters are measurable at small scale, and also predictable if conditions change (Bormann *et al.* 2007). According to Wagener *et al.* (2008) dry catchments on the whole are more sensitive to the model structure and harder to model than wet catchments (as cited in Sharma *et al.* 2008).

This is caused by their stream flow series which stop abruptly or show periods of sustained but small stream flow. Such a stream flow record makes it difficult to calibrate a model. And secondly, for ephemeral (dry) catchments periods without stream flow offer no information on the soil moisture status of the catchment, which is required for most conceptual models applied in such catchments. And finally, the parameterisation of transmission losses is more critical in arid catchments. For the proportion of stream flow consumed by evaporation tends to be higher, and there is a higher possibility for reinfiltration of stream flow (Ye *et al.* 1997).

The majority of the studies analysing the effect of land use change on the catchment water balance do not consider that a change in land use or land cover may also effect in a change in other

landscape characteristics such as soil properties. These studies appear to be not aware of other studies that have systematically analysed and quantified the effect of land use change on soil hydraulic properties (Bormann *et al.* 2007). Therefore Bormann *et al.* (2007) state that soil property changes should be considered when analysing the effects of land use change in scenario studies. The effects of land use change and a change in soil properties induced by land use on the water flows are often in the same order of magnitude and therefore are equally important. Ignoring the effects of a change in soil hydraulic properties probably might cause relevant errors.

In their research Bormann *et al.* (2007) found that changes in the water balance were small (in the order of a few percent), but runoff generation mechanisms and flow components were considerably affected by the assumed changes in soil hydraulic properties. Therefore, a consideration of changes in soil properties as part of a land use change scenario analysis seems to be required.

Mean annual rainfall is one of the most important determinants of annual runoff and can have a strong influence on changes in runoff after vegetation change. It has the largest proportional impact on runoff and water supply in low-rainfall areas (Farley *et al.* 2005). Hughes (2008) agrees with the importance of adequately representative rainfall data, certainly in space and frequently in time, but emphasizes the very variable space-time distribution of rainfall (as cited in Sharma *et al.* 2008).

Yair and Kossovsky (2002) state that the assumed relationship between annual rainfall, geomorphic processes and environmental conditions (positive relationship up to rainfall amount of 300mm) is questionable in semi-arid and arid areas. Along a climate gradient, especially in the case of desert margins, changes are not limited to purely climatic variables such as rainfall and temperature. The spatial distribution of characteristic surface properties is not independent of the climate factor. The generation of runoff integrates a climatic factor (mainly rainfall) and a surface properties factor, which is only indirectly linked to climate. The (often soil-related) differences in infiltration rates will influence the runoff rate of rainfall, resulting in the spatial redistribution of water resources. Runoff generation is faster on relatively impervious, rocky surfaces than over soil-covered surfaces with a high porosity and a high water absorbing capacity. For this reason, a higher flow frequency and a higher runoff amount should be expected in rock-prevailing arid areas compared to semi-arid areas with more soil and vegetation cover. However, this could be compensated by the higher rainfall and storm amounts in the semi-arid environments. In their conclusions, Yair and Kossovsky (2002) state that of the two main factors (rainfall properties or surface properties), the surface properties represent the major role in runoff generation and runoff rate in semi-arid and arid areas. In their research at the Lehavim site East of Be'er Sheva they found almost negligible infiltration rates for bare and smooth rocky surfaces, rates in the order of 15 mm/hour for colluvial slope sections and 20-30 mm/hour over more extensive soil and vegetation covered areas (Yair and Kossovsky 2002).

2.8 Ephemeral Streams

In semi-arid climatic conditions ephemeral streams play a critical role in drainage and flood control, but also as habitat and open space. Ephemeral streams are more difficult to characterise than perennial streams, for which two reasons can be cited. First that the "spatially variable inputs (especially rainfall)" are difficult to represent, because of their variability in semi-arid areas. And secondly Hughes (2005) mentions it is because of "the dominance of in-channel processes that are either difficult to quantify or simply not understood sufficiently to incorporate into models" (as quoted in Tal *et al.* 2007). Further are these watersheds also characterised by flash floods, making it difficult to monitor and understand the process and the behaviour of the stream and the connected ecological system (Tal *et al.* 2007).

In a semi-arid channel system it is likely reductions in flow volume between upstream and downstream points occur. These transmission losses are caused by evapotranspiration and infiltration into the bed, the river banks, and possibly the floodplain. These losses reduce the discharge and can even dry up the channel completely (Cohen 2007).

2.9 Sampling of Natural Resources

For the collection of information on soil properties, it is important to think about the statistical implications of the sample scheme; which global quantity is most suitable, and which sampling method is appropriate.

The spatial mean is the most relevant global quantity in practice for sampling in space. And the Spatial Cumulative Distribution Function (SCDF) is the basic function from which all other global quantities can be derived (Gruijter *et al.* 2006). Therefore these global quantities are most suitable to collect during sampling.

To select an appropriate sampling method, the scheme as presented by Gruijter *et al.* (2006) was used. Following this scheme, Stratified Simple Random Sampling appeared the most appropriate method. Stratified Simple Random Sampling is a sampling method whereby the area is divided into sub-areas – called ‘strata’ – in each of which Simple Random Sampling is applied with the sample sizes chosen beforehand. The advantages to Simple Random Sampling are a higher efficiency and a better control of accuracy allowed for possible sub-areas of interest (Gruijter *et al.* 2006).

2.10 Analysis of literature review

The main conclusions derived from the literature with regard to the hypothesis are presented below.

Land cover change is known to influence watershed hydrology and soil hydraulic properties. Land conversion alters infiltration, erosion and evapotranspiration rates. Remote Sensing (RS) is a proven tool to monitor land cover change, but to complement RS data other data sources are required.

Infiltration is an important component of the field water cycle; important factors affecting infiltration are hydraulic conductivity, bulk density and soil surface conditions. Human impact plays a large role in influencing hydrologic processes. Ecohydrology links hydrology and ecology, and is a fundamental concept to understand the linkage between ecosystem dynamics and the water cycle, in particular in arid and semi-arid environments.

Vegetation has a strong influence on its environment; e.g. soil properties are strongly related to the vegetation pattern. Research found less runoff in both forestry and irrigated agriculture as compared to grasslands, and a higher evapotranspiration for shrublands and forests than for natural grassland. The interception, transpiration as well as evaporation tend to increase when grass or shrubs are replaced with trees. The afforestation of grasslands or shrublands can result in a loss of 35 to 70% of the stream flow. Proportional losses are higher in drier regions and for low flow.

According to literature, the effect of land use changes on soil hydraulic properties should be considered in models. The mean annual rainfall is one of the most important determinants of annual runoff, but in semi-arid areas surface properties may represent the major role in runoff generation. And finally, in models, ephemeral streams are difficult to characterise and incorporate.

When relating this information to the research question and the hypothesis presented, one can sharpen the hypothesis that ‘the low amounts of discharge in the Patish watershed are caused by specific changes in land use in the watershed’.

Therefore the hypothesis tested in the next chapters is: The low amounts of discharge in the Patish watershed are caused by an increased area of both agriculture and afforested land, increasing infiltration by affecting hydraulic soil properties.

3. Methodology

In this chapter the methodology will be described. First the research area and workflow (as displayed in a flow chart), followed by the various analyses in this research. Starting with the remote sensing analysis, and subsequently the field work, rainfall analysis, and hydrology.

3.1 Research Area

3.1.1 Geography

The Patish stream (nahal Patish) flows along the Grar watershed, which contributes to the Besor stream and therefore also is classified as part of the (larger) Besor basin (fig 2). The Besor drainage basin is the largest watershed in Israel and the Palestinian Authority (PA) draining to the Mediterranean Sea, and covers 3500 km² (Cohen 2007). In the area of this watershed maximum six to seven major flood events occur in a very rainy year with only a few days of flow. While in some (dry) years no floods occur. The average is 2 or 3 major flood events per year (Tal *et al.* 2007).

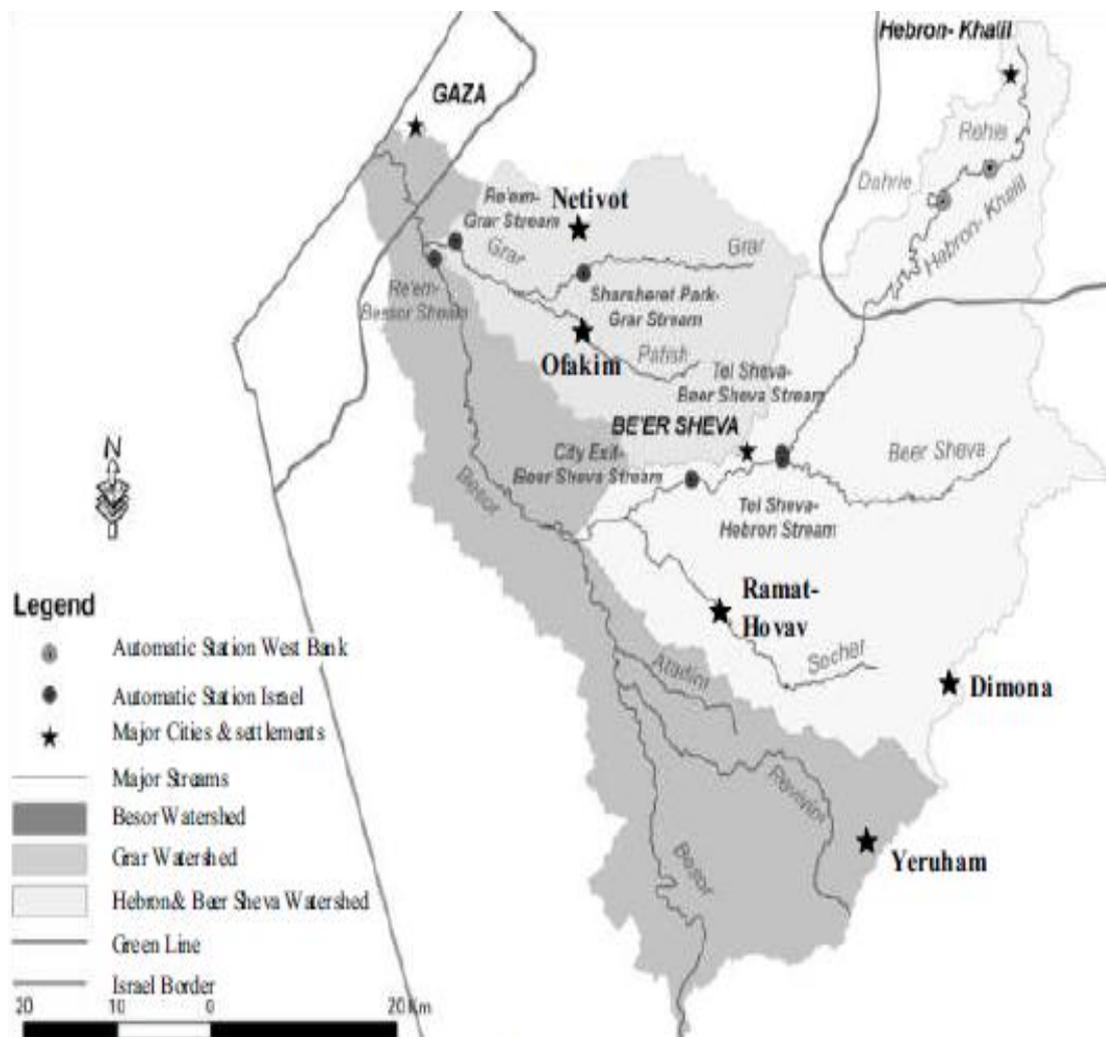


Figure 2 Map of the Besor Catchment (Cohen 2007)

In the semi-arid environment of the watershed the channel is hydrologically active for less than 2% of the time (about 7 days per year), why it is defined as an ephemeral stream (Cohen 2007; Tal *et al.* 2007). There are some small springs in the area, but these are not sufficient to generate an annual continual base flow. Part of the stream has continual stream throughout the year due to

anthropogenic activities, but the Grar (including the Patish) tributary is dry most of the year (Tal *et al.* 2007).

3.1.2 Soil

The Northern Negev covers 8850 km² from the Be'er Sheva region to Mizpe Ramon in the South, and can be subdivided in five different regions. One of these is the loess belt, stretching North-West of the city of Be'er Sheva (the Western part of the Besor basin). Loess soil formed during the Holocene period is the main soil type. The area shows an undulating landscape, with small gullies, loess-covered slopes, and only locally bedrock outcrops (Cohen 2007; Buis 2008). The nutrient-rich loess soil is valuable for agriculture, but because of the strong climatic gradient, large-scale agriculture is not possible because of insufficient precipitation in the more southern parts of the Northern Negev. If the loess is bare, (biological) crusts are easily formed, limiting the infiltration capacity (Buis 2008). According to Cohen (2007) the loess soils play an important role in generating runoff during storm events because their low infiltration rate.

Measured soil characteristics at the Gilat Research Farm in the Patish show a bulk density of 1.48 g/cm³, an Organic Matter content of 0.62% and a pH of 7.9 (Amir *et al.* 1991). Measurements of the loess soil of Kibbutz Alumim (about 20 km West of the Patish watershed) give values of 1.30 g/cm³ for bulk density, 1.44 for Electro Conductivity, 1.6 for Sodium Adsorption Ratio, 15.5 meq/100g for Cation Exchange Capacity and 7.9 for pH (Rawitz *et al.* 1983).

At the same location Rawitz *et al.* (1983) measured the infiltrability of various plots. The final infiltrability was 2 mm/hr for disked/ridged plots, and 4 mm/hr for ploughed plots. Initial infiltrability was much higher: 33 mm/hr at a freshly disked plot. The infiltrability of the loess soil decreased very rapidly with time. Sprinkler irrigation design at this location worked with a final infiltration rate accepted at about 8 mm/hr (Rawitz *et al.* 1983). In Sayeret Shaked a steady-state infiltration rate of 35.4 mm/hr was measured, after a biological crust was scalped from the surface. When compared to a crusted soil, infiltration rate was significant greater under the scalped soil (Eldridge *et al.* 2000).

3.1.3 Land use

The Patish watershed is characterised by a variety in land uses. There are urban (and industrial) areas (like Be'er Sheva and Ofakim), agricultural fields (managed by both Moshavs, kibbutzes and Bedouins), natural grazing lands, greenhouses, and natural open space. Boundaries between different land use units are not always clear to distinguish, and can be altered. Especially between agricultural fields, 'natural grazing lands' and natural open area (Argaman 2010; Tal *et al.* 2007).

In one of the natural open areas, the Jewish National Fund (JNF) established the Sayeret Shaked Park. It covers 12 ha, and the soil consists of sandy loess (Buis 2008). This park is one in a network of Israeli LTER sites (Long Term Ecological Research) (Boeken *et al.* 2001) and started with experimental plots some 20 years ago, and was later scaled up to the nearby (Ofakim) watershed. Livestock is excluded from the area since 1987 (Buis 2008).



Figure 3 Liman in Ambassadors Forest



Figure 4 Terrace in Ambassadors Forest

In another open area (Karkur watershed – North of Be'er Sheva) afforestation started in the Ambassadors Forest in 2005, and today trees reach up to 4.0 m with roots stabilising the soil. The forest is part of the so-called 'Green Belt' of Be'er Sheva, and stretches over 15 km². The trees were planted in limans and along bench terraces. A liman is a water harvesting system constructed in a gully; a flood dam stores runoff collected from the contributing slopes (fig 3). Terraces are constructed on a slope, to store rainfall runoff from a contributing area upslope (on a smaller scale than limans do) (fig 4). The terraces hold trees that are resistant to soil erosion and water stress (like Acacia, Eucalyptus and Tamarisk), where the limans hold (mainly) orchard trees (like Plum, Carob, Berries and Sycamore) (Argaman *et al.* 2009). The soil in this area is a loess and rendzina, and gullies are extending. No runoff from the planted forest area was observed (Argaman 2010).

3.1.4 Climate

The Patish area is situated in the Northern Negev Desert of Israel. Average annual rainfall in this region is 150 mm, but annual variability is high ranging from 60 to 250 mm. The rainy season is limited to the winter months, stretching from October to May, and rainfall is limited to 20 to 30 days a year. Daily average temperature ranges from 11°C in the winter to 25°C in the summer, and potential annual evaporation is 2300 mm (Arbel *et al.* 2005; Hillel and Tadmor 1962).

In Sayeret Shaked rainfall only occurs in winter between October and April, and has a long-term annual average of 200 mm (Boeken *et al.* 2001). According to Amir *et al.* (1991) mean annual rainfall at the Gilat Research Farm is 231 mm. The Northern Negev is classified as an arid to semi-arid area. Arid areas are defined by an average annual rainfall up to 250 mm, and semi-arid areas by an amount between 250 and 500 (or 600) mm (D'Odorico and Porporato 2006). Combined with sub-humid regions, arid and semi-arid regions occupy about 50% of the land surface of the earth (Jin 2009).

If the annual precipitation is less than annual potential evaporation, these regions and their environments can be defined as drylands. Drylands are water limited, drought-prone and experience conditions of permanent or seasonal soil water deficit (Jin 2009; D'Odorico and Porporato 2006). Obvious features are low precipitation amounts and a high variability and unpredictability of precipitation, which occurs in a discrete number of relatively infrequent events (D'Odorico and Porporato 2006). The cultivation of drought-resistant crops is possible (D'Odorico and Porporato 2006), but often these areas are sensitive and vulnerable because of low and highly variable precipitation, limited water resources and sparse vegetation (Jin 2009).

3.1.5 Vegetation

The native vegetation in the Negev is transitional between steppe and desert associations, and consists mainly of dwarf shrub communities (Arbel *et al.* 2005; Hillel and Tadmor 1962). Hillel and Tadmor (1962) distinguished between four natural habitats for the central Negev plain: Rocky slopes, loessial plains, wadi beds and sands. Nowadays, considerable areas are used for agricultural, residential or recreational purposes, or reserved for nature development.

3.2 Workflow

The research approach is represented in the flowchart on the next page (fig 5), subdivided according the three objectives. Because this figure shows the original, theoretical set-up of the research, the final outcome of this research may deviate from this framework.

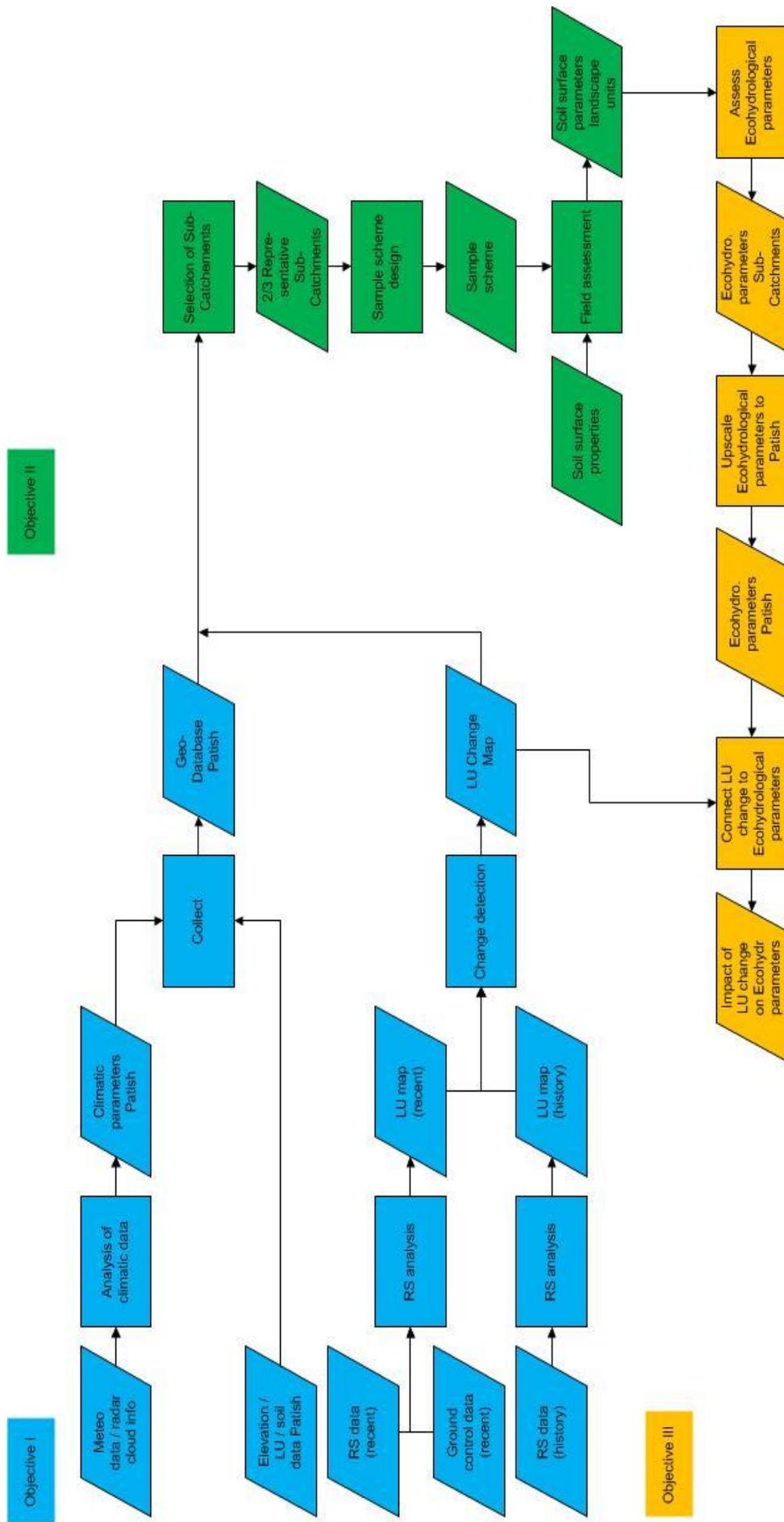


Figure 5 Flow chart representing research approach

3.3 Remote Sensing Analysis

Remote Sensing images were selected from the Landsat archive for the period between 1985 and 2010 (for five different years, as presented in table 3). Criteria for the selection were the availability of cloudless images and the period the images were created. Here for, two periods are selected. First period is between Julian Day 60-105 (March/April). This is the spring period, when natural and agricultural areas are green as a result of the winter rains. Vegetation is at its highest. The second period is between Julian Day 170-195 (June/July). This is the middle of the summer, when most crops (except irrigated crops) are harvested, and nature becomes dry (for practical reasons called 'fall' in this report, as opposed to spring). With these criteria, a number of years with suitable images were selected. These years are 1985, 1991, 1998, 2002 and 2009/2010.

Table 3 Overview of Landsat images used (TM = Thematic Mapper / ETM+ = Enhanced Thematic Mapper Plus)

Nr	Year	Julian Day	Date	Sensor
1	1985	60	March, 1	LandSAT TM 5
2	1991	69	March, 10	LandSAT TM 4
3	1998	80	March, 21	LandSAT TM 5
4	2002	67	March, 8	LandSAT ETM+ 7
5	2010	105	April, 15	LandSAT ETM+ 7
6	1985	172	June, 21	LandSAT TM 5
7	1991	181	June, 30	LandSAT TM 4
8	2002	195	July, 14	LandSAT ETM+ 7
9	2009	182	July, 1	LandSAT ETM+ 7

The Landsat Thematic Mapper is a multispectral sensor carried by Landsat 4 and 5, with seven spectral bands. The spatial resolution is 30m (120 m for band 6, the thermal band), and the spectral range is 0.45-12.5µm. The temporal resolution is 16 days, the image size is 185km x 172km and the swath is 185km (NASA 2012). The Landsat Enhanced Thematic Mapper Plus is a fixed "whisk broom" multispectral sensor carried by Landsat 7, with eight spectral bands. The spatial resolution is 30m (60m for band 6/15m for band 8), and the spectral range is 0.45–12.5µm. The temporal resolution is also 16 days, the image size is 183km x 170km and the swath is 183km (NASA 2012). For in this research only the bands with a resolution of 30m were used (band 1-5 and band 7), the images derived by both sensors can be compared.

These images were downloaded from the USGS Global Visualisation Viewer¹ (Path: 174/Row: 39). The study area (Patish watershed) was clipped from these images. For further analysis, digital numbers (DN values) were converted to reflectance values using the standard calibration tool in ENVI². This method is based on the following formulas:

$$L_{\lambda} = LMIN_{\lambda} + \left(\frac{LMAX_{\lambda} - LMIN_{\lambda}}{QCALMAX} \right) QCAL$$

where L_{λ} is the spectral radiance (mW/(cm²*sr*µm)), $QCAL$ is the calibrated and quantised scaled radiance (digital numbers), $LMIN_{\lambda}$ is the spectral radiance at $QCAL = 0$, $LMAX_{\lambda}$ is the spectral radiance at $QCAL = QCALMAX$, and $QCALMAX$ is the range of the rescaled radiance (digital numbers). And:

$$\rho_P = \frac{\pi \cdot L_{\lambda} \cdot d^2}{ESUN_{\lambda} \cdot \cos\theta_{\xi}}$$

where ρ_P is the exoatmospheric reflectance, L_{λ} is the spectral radiance (mW/(cm²*sr*µm)), d is the Earth-Sun distance (astronomical unit), $ESUN_{\lambda}$ is the mean solar exoatmospheric irradiance (W/µm³),

¹ www.glovis.usgs.gov

² www.exelisvis.com/language/en-US/ProductsServices/ENVI.aspx

and $\vartheta\xi$ is the solar zenith angle (degrees) (ENVI 2005). In the ENVI calibration tool the Landsat satellite (4/5/ETM+7), data acquisition month, data acquisition day, data acquisition year, sun elevation (degrees) and calibration type (radiance/reflectance) have to be entered. This data was extracted from the Landsat metafiles.

First it was attempted to make an analysis using an unsupervised ISODATA analysis in Erdas Imagine. A four-band combination (Principle Component Analysis / Tasseled Cap transformation / NDVI / band ratio LandsatTM band 5/band 1) was generated as input, but the results proved to be of an insufficient quality. After consultation, it was decided to abandon this method (which however is described in appendix I). Because of the complexity of the terrain (much variation both in spatial and in temporal aspect), it was deemed unlikely an ISODATA analysis would produce a result with a sufficient high quality.

Afterwards Definiens^{®3} was used to make a land cover classification. After experimenting with various classification techniques, a maximum likelihood decision rule based on sample areas was applied.

The input consisted of an eight-band combination. First the six (non-thermal, non-panchromatic) LandsatTM bands (1-5,7), followed by the NDVI index derived from band 3 and 4 to make a better distinction between vegetated and non-vegetated areas, and completed with the computed band ratio of LandsatTM band 5 and band 1, which was found to make a better distinction between urban and bare soil areas.

The Normalised Difference Vegetation Index (NDVI) is a method to measure and monitor plant growth, vegetation cover and biomass production using multispectral data. NDVI is calculated by this formula: $NDVI = (NIR - Red) / (NIR + Red)$ (Weier and Herring 2011). In the visible red-light region of the spectrum chlorophyll absorbs a considerable part of the incoming sunlight, while in the near-infrared region the structure of the leaf reflects a considerable part. Therefore growing, healthy vegetation has a low red-light and a high near-infrared reflectance, and a high NDVI value. NDVI values range between 1.0 and -1.0. High values (close to 1.0) indicate high amounts of green vegetation. Low values (near and below 0) indicate non-vegetated surfaces (like rock, soil and water) (U.S. Geological Survey 2010). For LandsatTM bands: $NDVI = (band\ 4 - band\ 3) / (band\ 4 + band\ 3)$, which was calculated using Erdas Imagine⁴.

In LandsatTM band 1 is capable of differentiating soil and rock surfaces from vegetation. Band 5 is capable to separate forestlands, croplands and water bodies (Rahman 1997). Using band ratios (dividing one band by another) is a method to make spectral enhancements for Remote Sensing analysis. For example, it is applied to study lithological mapping or structural geology structures. One of the band ratios used in these studies, is dividing LandsatTM band 5 by LandsatTM band 1 (Gad and Kusky 2006; Inzana *et al.* 2003). By experimenting with band combinations, it appeared the band ratio 5/1 is able to distinguish between urban area and bare soil surface. Where the separate bands were not able to make a clear distinction, dividing band 5 by band 1 improved this ability. Urban area has a relatively high reflectance in band 1, and a lower reflectance in band 5. The natural area (mostly bare soil) has a low reflectance in band 1, and a relatively high reflectance in band 5. Because the soil is mostly dry, soil will have a higher reflectance. However, it should be noted both the urban and natural show a mixed pattern, making the result more complicated. But because the distinction between urban and natural area was found lacking in the analysis of the 'normal' bands and the NDVI index, this band ratio was calculated using Erdas Imagine, and added to the analysis.

³ Definiens[®] Professional 5. Copyright: 1995 – 2006 Definiens[®] AG

⁴ Erdas Imagine 2010 Version 10.1. Copyright © 1991-2009 ERDAS, Inc.

First a multiresolution segmentation was applied to create relatively homogenous segments to be used as input for the classification. The image weight was 1 for each layer, the scale parameter was 1, shape was set at 0.01, and compactness at 0.1. The other parameters were the default parameters.

Secondly, the various land cover classes were created in the class hierarchy, as listed below:

1. No data (area outside study area)
2. Agricultural (fields)
3. Natural open area (uncultivated / not built)
4. Town (urban areas + roads)
5. Water

These classes are defined by the (generated) nearest neighbour of the mean of all eight bands, based on the collected samples for each class.

Then, for each class a number of sample sites was collected, based on knowledge of the area. This was followed by executing the classification operation, and the result produced by these sample sites was assessed. If necessary, the number of sample sites was increased to improve the result. This sequence was repeated until increasing the amount of sample size stopped producing a visible increase in the quality of the classification.

Finally, the result was assessed, and where necessary the classification of incorrectly classified segments was adapted manually. Checking of segments was based on comparing the classification with the original data and aerial photographs (made available by the SERS⁵ and Google Earth⁶).

Classification in Definiens[®] was finished by merging all connected segments of each class (default parameters), and exporting the result as a shapefile.

At the end, a map of the result was made up in ArcMap⁷; the four classes were displayed in the legend, while the fifth class covers the area outside the watershed (displayed in white for that reason).

At the end, the areas of the various classes were derived from the maps, and processed in Microsoft Excel. To visualise the changes in land cover, the results of two different years were joined using the 'union' operation in ArcMap. The overlapping classes were compared, and classified according to the classes of the original maps. So if for example the class in the first year was agricultural, and in the second year was natural, the class for the map representing the land use change will be 'agricultural to natural'.

3.4 Field Work

Based on field visits, aerial photographs and the (provisory) remote sensing analysis, sub-catchments were selected for validation and further (physical) analysis. This further analysis consisted of doing measurements and taking samples in the field. Parameters measured are dry bulk density, saturated hydraulic conductivity, biomass, pH and Electro conductivity, texture, and various physical and chemical components like saturation point, sodium content, Sodium Adsorption ratio (SAR), Organic Matter (OM) content and Cation Exchange Capacity (CEC). Bulk density and saturated hydraulic conductivity were measured because of their large influence on the infiltration rate of the soil. Texture and OM content were measured for that reason too. Other parameters were determined to be able to investigate potential differences between various land cover types.

⁵ SERS = Soil Erosion Research Station (Midreshet Ruppim, Israel)

⁶ www.earth.google.com

⁷ ESRI © ArcMap TM 10.0. Copyright © 1999-2010 ESRI Inc.

First site is located in the Ambassadors Forest (fig 6), where an experimental site is located. Here measurements were done in the open natural area, both at (unaffected) open slopes, as well as (constructed) limans and terraces.

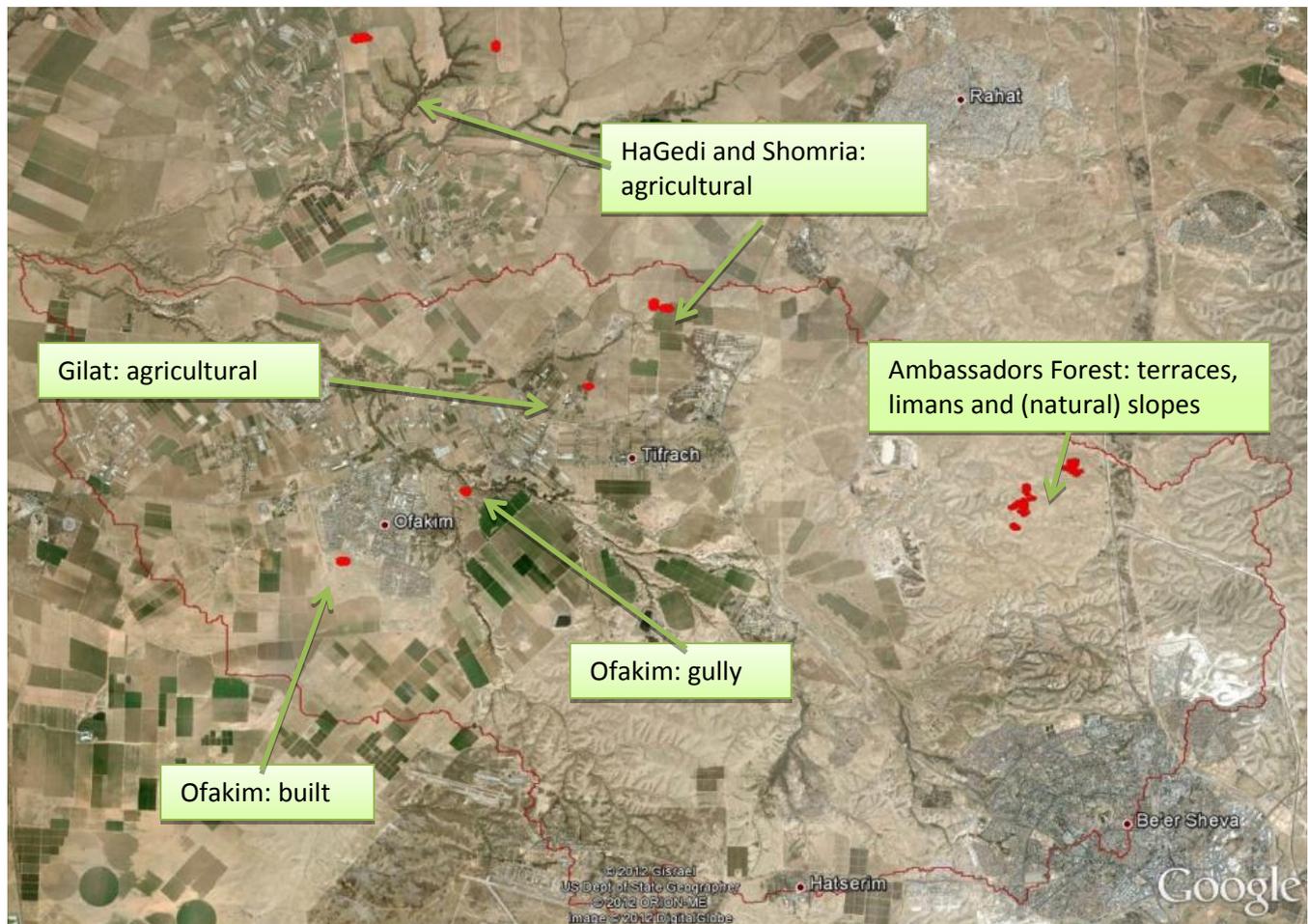


Figure 6 Field work locations inside (and nearby) the Patish watershed. Source background map: Google Earth, 2012

To represent other land cover types, several other locations were selected for research. Urban areas are represented by an area cleared for building in the town of Ofakim. Gullies are represented by an gully area East of Ofakim, and orchards by an orchard at the experimental farm of Gilat. For the (relatively large) area of agricultural land cover in the Patish watershed, various fields were selected in two different subcatchments. First the subcatchment of Shomria and secondly the HaGedi subcatchment. The latter is located outside (North of) the Patish watershed, but on a very close distance. It was selected because of the presence of a hydrological measurement station in the watershed (though these data was not used in the further analysis) (fig 5, table 4).

Table 4 Research plots in Patish watershed

Plot name	Treatments	Plot type
Shomria 1	Agricultural	Bare (harvested)
Shomria 2	Agricultural	Cotton
HaGedi 1	Agricultural	Grain (wheat)
HaGedi 2	Agricultural	Bare (tilled)
Ofakim 1	Cleared	Urban
Gully 2	Natural	Grass/Shrubs
Gilat 3	Orchard (irrigated)	Olives

Ambassadors 0	Planted, not sprayed	Terrace
Ambassadors 1	Not planted, not sprayed	Terrace
Ambassadors 10	Not planted, not sprayed	Liman
Ambassadors 11	Planted, not sprayed	Liman
Ambassadors 12	Planted, sprayed	Liman
Ambassadors 24 & 25	Already planted (old)	Terrace
Ambassadors 28 & 29	Not planted (empty)	Slope

3.4.1 Dry bulk density

The dry bulk density is a soil parameter, which is expressed by the ratio of the mass of dried soil particles to the total soil volume (Merzer 2007). This is calculated as such:

$$\rho_b = \frac{M_s}{V_T}$$

where ρ_b = bulk density (kg/m^3), M_s = mass of the soil (kg) and V_T = total volume of the soil (m^3). Samples were taken at the surface with a cone sampler (volume of 100 cm^3) (fig 7), stored in paper bags and oven dried for at least 24 hrs. at 105 degrees Celsius before they were weighted. For each subplot three repetitions (for some exceptions only two) were taken, where after the average and standard deviation of the measurements were derived using Microsoft Excel.



Figure 7 Cone sampling equipment



Figure 8 Mini disk infiltrometer

3.4.2 Saturated hydraulic conductivity

Hydraulic conductivity is the most important hydraulic property affecting water flow in soils. One method to determine hydraulic conductivity is to measure cumulative infiltration versus time and fit the results with the following function:

$$I = C_1 t + C_2 \sqrt{t}$$

where I = infiltration, C_1 ($\text{m}\cdot\text{s}^{-1}$) and C_2 ($\text{m}\cdot\text{s}^{-1/2}$) are parameters (related to hydraulic conductivity and soil sorptivity respectively). Consequently, the hydraulic conductivity of the soil is computed from:

$$k = \frac{C_1}{A}$$

with k = hydraulic conductivity ($\text{m}\cdot\text{s}^{-1}$), C_1 = the slope of the curve of the cumulative infiltration versus the square root of time, and A = a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of a infiltrometer disk. A can be computed using another formula (but

is also given in a table accompanying mini disk infiltrometers, where A is calculated for various soil texture classes and suction values (Zhang 1997; Decagon Services 2011).

To measure cumulative infiltration versus time a mini disk infiltrometer was used (Decagon Services 2011) (fig 8). Standard suction applied was -3 cm, but decreased (to -4 or -5 cm) in case of very conductive soils. C_1 was derived from the slope of cumulative infiltration over a time period, and A was taken from a table as mentioned above. With this information, k_{sat} was easily calculated. Again, three repetitions were taken for each subplot, and the average and standard deviations calculated in Microsoft Excel.

3.4.3 Biomass

For some plots, biomass samples were taken. For an area of 1.0 or 0.25 m² all biomass (above ground parts of vegetation) was collected. It was dried at 60 degrees Celsius for at least 24 hrs. Afterwards, the samples were sieved to remove the soil, and weighed. At the end, the average biomass and standard deviations were calculated (in g/m²) in Microsoft Excel (for each plot, three repetitions were sampled).

3.4.4 Analysis of soil samples

In the field, soil samples were collected to be analysed in the laboratory. However samples were taken at two depths (0-5 cm and 5-10 cm), only the samples taken from the surface (0-5 cm) were analysed. For the analysis, the soil was crushed in a mortar and sieved through a 2 mm sieve.

pH and EC

Soil pH is a measure of the soil acidity (or alkalinity), which influences the solubility of nutrients. Furthermore, it affects soil fauna activity and most chemical transformations in the soil. By these mechanisms, the pH influences the availability of several plant nutrients. For most plants, a pH range between 6 and 7 is most favourable (USDA 1998).

Soil Electrical Conductivity (EC) is the ability of a soil to transmit (conduct) an electrical current, which is commonly expressed in units of milliSiemens per meter (mS/m). EC is a measure that correlates with various soil properties affecting crop productivity (including soil texture, cation exchange capacity, drainage conditions, organic matter level, salinity, and subsoil characteristics) (Grisso *et al.* 2009).

To measure pH and EC, the crushed soil was dissolved in (distilled) water (ratio of 20 gram soil to 40 gram of distilled water), and left to rest for a while. Afterwards, the pH and EC were measured using measurement equipment from the Eutech company⁸ (fig 9).

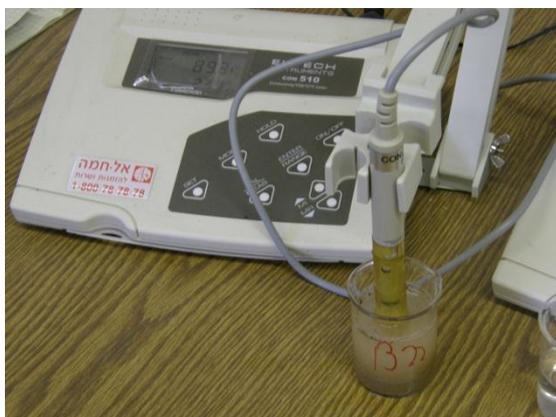


Figure 9 EC measurement equipment



Figure 10 Particle Size Analyser

⁸ <http://www.eutechinst.com/>

Texture

Soil texture is an important soil characteristic, which influences drainage, water holding capacity, aeration, and susceptibility to erosion (among others). Soil texture is determined by the percentage of sand, silt, and clay (Berry *et al.* 2007).

The crushed soil was dissolved in a small bottle with distilled water, and mechanically shaken for at least 24 hrs. Then, the dissolved samples were analysed using a Particle Size Analyser (PSA)⁹ (fig 10). By measuring the dispersion of two light sources (red and blue), the distribution of various particle sizes is determined. Knowing this distribution, one can derive the texture of the soil. In this analysis, the SPAW model¹⁰ was used to derive the soil class.

Because of the technique used, the PSA is known to underestimate the percentage of clay in a soil sample. The PSA measures the particles by the laser beams, and assumes all particles are spherical. But because this is not the case with soil particles, small particles can be classified as larger particles, for which reason the PSA overestimates (on average) the size of the particles. For this reason, soil classification results obtained by the PSA, cannot be compared with soil classification using other methods (Egozi 2010).

Laboratory analysis

Part of the samples was sent to the laboratory for further physical and chemical analysis. They were analysed to determine their saturation point (%), EC (dS/m), sodium content (Na, meq/l), calcium + magnesium content (Ca+Mg, meq/l), Ca content (meq/l), Chloride content (Cl, both meq/l and mg/l), Sodium Adsorption Ratio (SAR), Organic Matter content (OM, %), lime content (%), sand/silt/clay content (%), and Cation Exchange Capacity (CEC, meq/100 gram).

3.5 Rainfall analysis

A search was conducted to find meteorological stations in the Patish watershed. These were selected to provide actual and historical rainfall data, to compare with land use and land use changes in the area. Within the watershed, the following stations were found (table 5).

Table 5 Meteo(rological) stations inside Patish watershed

Station	Period	Coordinates (Lat/Lon, Dec.Deg.)	Source
Gilat Research Farm	1976-2009	31.3330 / 34.6650	MoAg Meteo ¹¹
Ben Gurion University	2000-2009	31.2736 / 34.8236	Ben Gurion University ¹²
Ambassadors Forest	2008-2011	31.2167 / 34.7667	SERS ¹³
Sayeret Shaked	2003-2010	31.2761 / 34.6528	SERS
Eshel Hanasi	1985-2009	31.3268 / 34.6975	MoAg Meteo
Hazerim	1985-2005	31.2670 / 34.7170	MoAg Meteo

To acquire a larger overview of the surroundings of the Patish watershed, additional meteo stations were selected for the larger Northern Negev area. For not enough stations in the direct environment of the Patish could be found, also stations at larger distances were selected. Because of the climatic gradient in the Northern Negev, the data of these stations will not give much information about the

⁹ <http://www.malvern.com/LabEng/products/Mastersizer/MS2000/mastersizer2000.htm>

¹⁰

<http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/drainage/?&cid=stelprdb104531>

1

¹¹ MoAg = Ministry of Agriculture (and Rural Development), Beit-Dagan, Israel

¹² Ben Gurion University weather station, Be'er Sheva,

http://www.epifdb.bgu.ac.il/Meteorologic/JSP_NoSecure_Eng/mainPage_Eng.jsp

¹³ Soil Erosion Research Station, Midreshet Ruppim, Israel

situation in the Patish watershed itself. However, they create the possibility to compare data from the Patish with other areas, and they can give information about climatic trends. The stations at a larger distance are displayed below (table 6).

Table 6 Meteorological stations outside Patish watershed

Station	Period	Coordinates (Lat/Lon, Dec.Deg.)	Source
Bsor	2002-2009	31.2730 / 34.3890	MoAg Meteo
Halutza¹⁴	2008	31.1570 / 34.3200	MoAg Meteo
Revivim	1934-2009	31.0471 / 34.7232	MoAg Meteo
Lachish	2000-2010	31.6061 / 34.7904	MoAg Meteo
Sde Boker	1976-2010	30.8500 / 34.9500	BGU Desert Meteo ¹⁵
Ramat Negev	1999-2009	30.9831 / 34.7083	MoAg Meteo
Barnea	1999-2009	30.9010 / 34.3944	MoAg Meteo

The composition, quality and length of the rainfall record are various. For some stations quite a long record was found (like Gilat and Revivim), but most periods are shorter (app. 10 years). For stations with more than one rainfall record available, the most complete and useful record was selected.

Data was available per day or month; to compare all data, daily data was summed per month. Because the region knows a clear rainfall season in the winter, yearly rainfall amount was analysed per rainfall season (July – June). These rainfall seasons were analysed in Excel, and an average was calculated for the most recent and complete period (counting back from the most recent rainfall season until the first season where data is missing) until the winter season 1985/1986. For some stations, longer periods were available, but to avoid too big differences in reference period, and because 1985 is also the start of the remote sensing analysis, the limit was set at 1985.

3.6 Hydrology

Because hydrological data is scarce for the Patish watershed, part of the larger project is to install measurement stations along various sections of the streams in the area. Some historical data is available, but only for one watershed inside the catchment and one just outside, and only for a limited period. Therefore, in the analysis no use was made of the hydrological data.

¹⁴ Only 1-year record; left out in further analyses (but displayed on maps)

¹⁵ Ben Gurion University Desert Meteorology, Sde Boker, Israel
<http://bidr.bgu.ac.il/bidr/research/phys/meteorology/index.html#top>

4. Results

In this chapter, the results of the analyses will be presented. Starting with the remote sensing analysis, followed by the field work, and finally the rainfall analysis.

4.1 Remote Sensing Analysis

For the spring period, five land cover maps were derived. The results are displayed below, beginning with 1985 (fig 11).

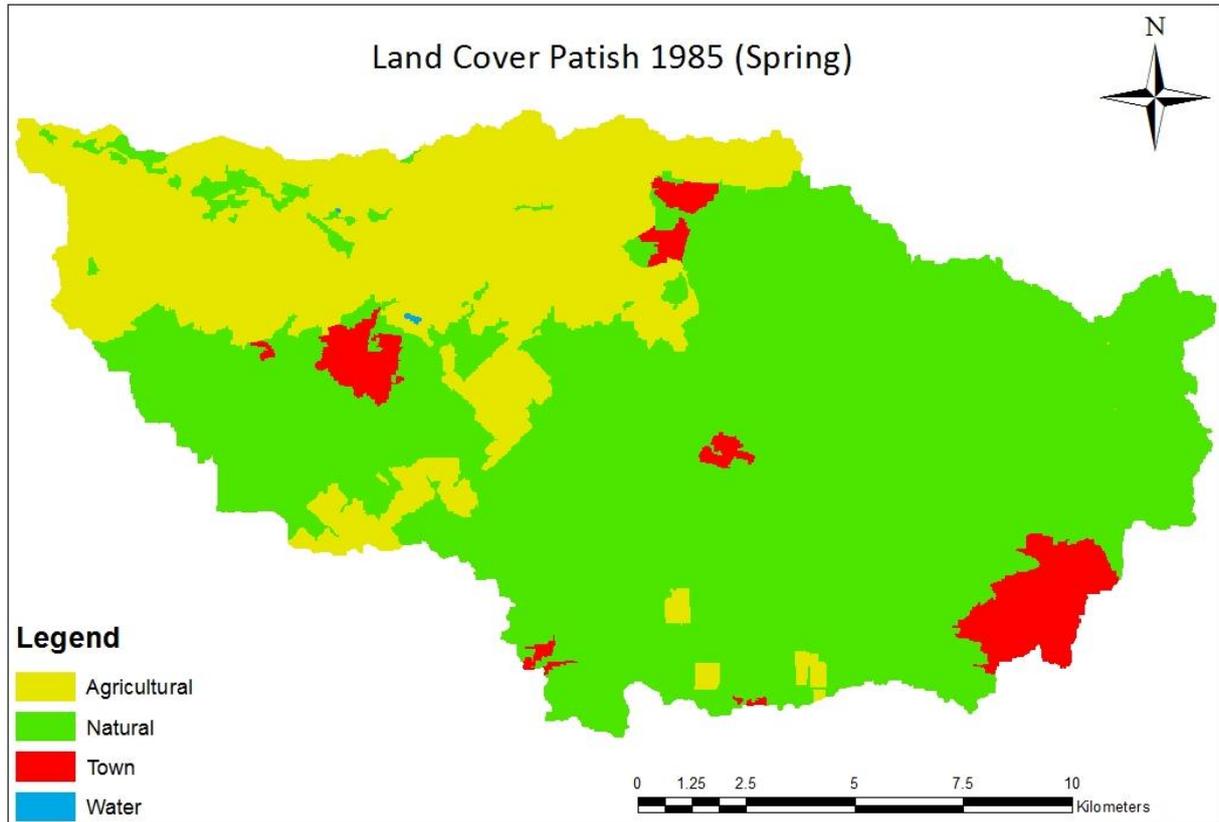


Figure 11 Classification results for the Patish watershed in the spring of 1985

The (South) East of the Patish watershed is characterised by natural open area, where the (North) West shows agricultural areas. In the natural area, some agricultural fields are cultivated. Whereas on the other side, in the agricultural area some natural open area is visible, existing of natural areas along the streams, or bare area being prepared for building.

Two major towns can be discerned; Be'er Sheva in the South-East, and Ofakim to the West. Further there are some smaller built areas spread over the area. The class 'water' is limited to a few basins, for there are no large water bodies in the area.

Below the results for the other four classified years are being displayed (fig 12-15).

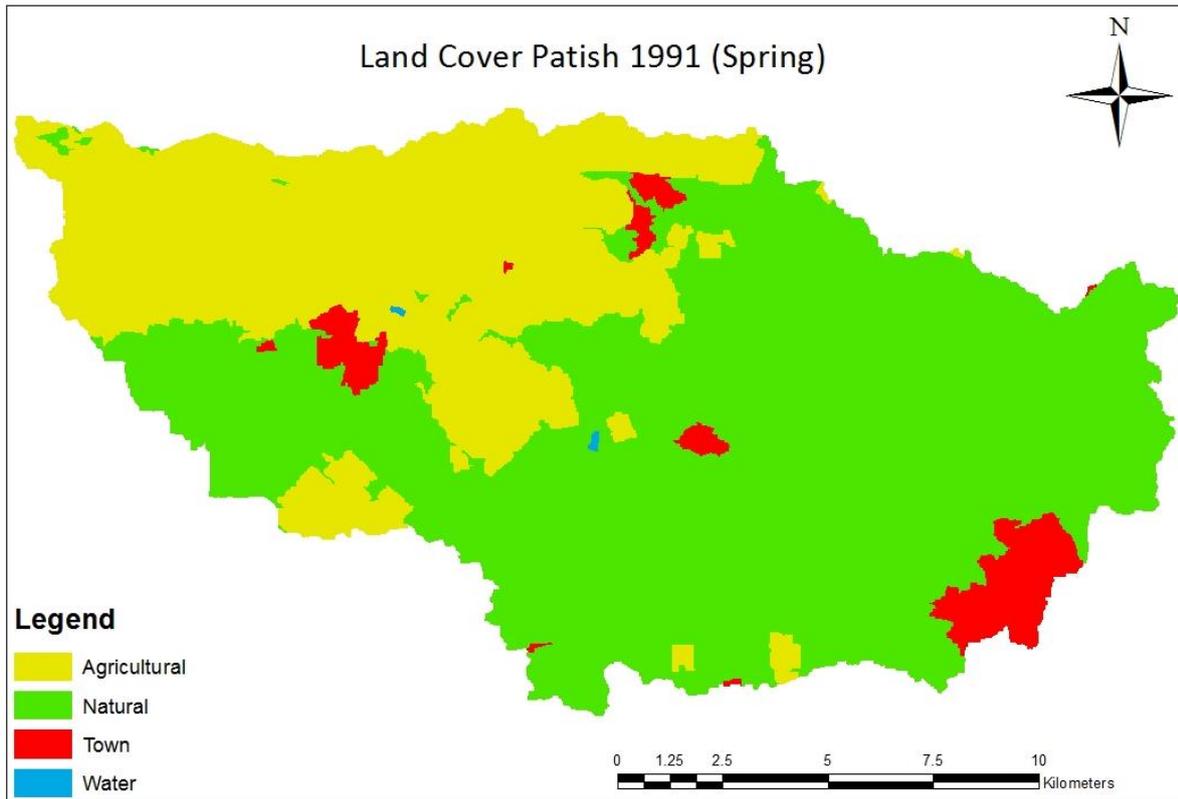


Figure 12 Classification results for the Patish watershed in the spring of 1991

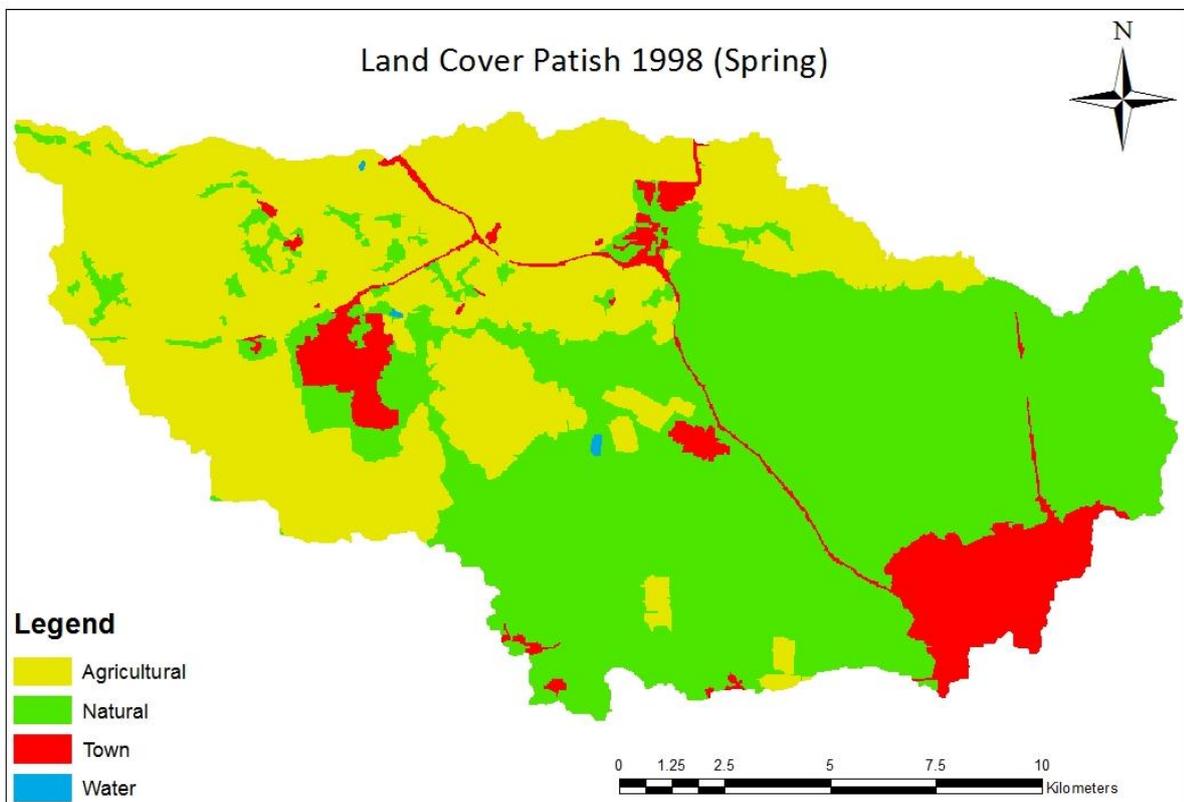


Figure 13 Classification results for the Patish watershed in the spring of 1998

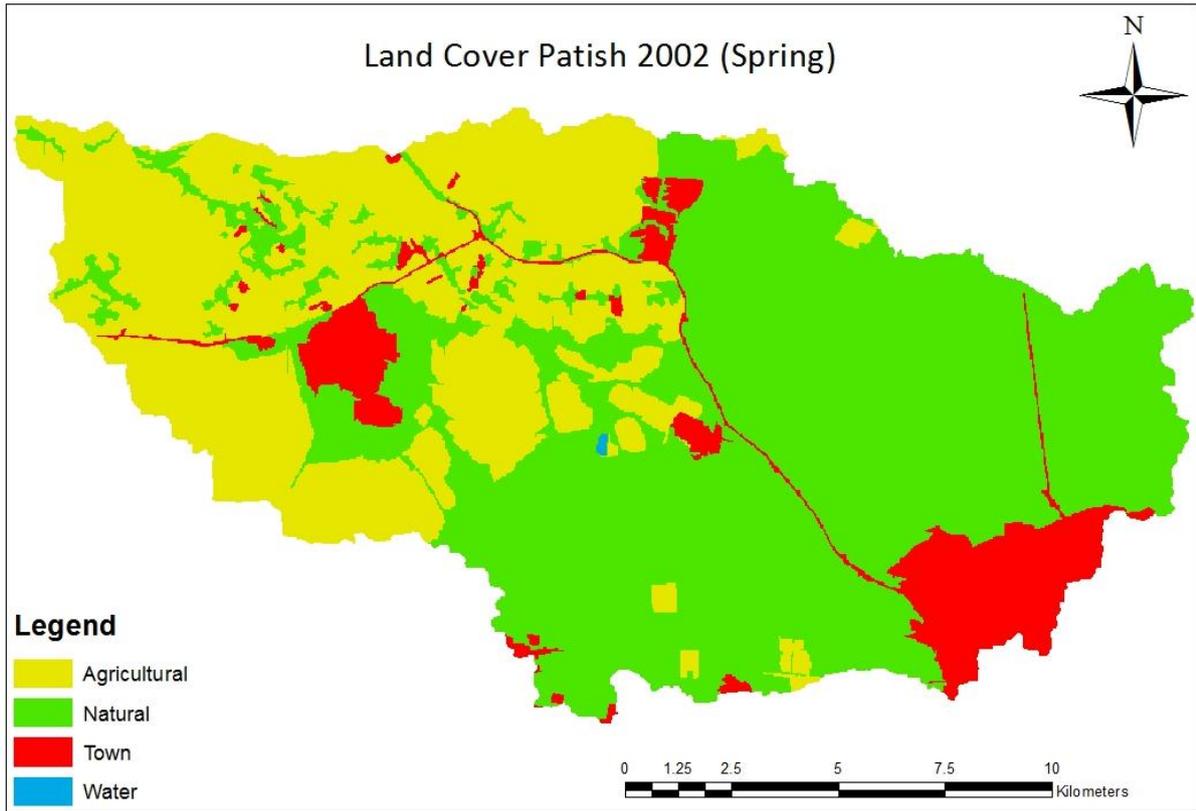


Figure 14 Classification results for the Patish watershed in the spring of 2002

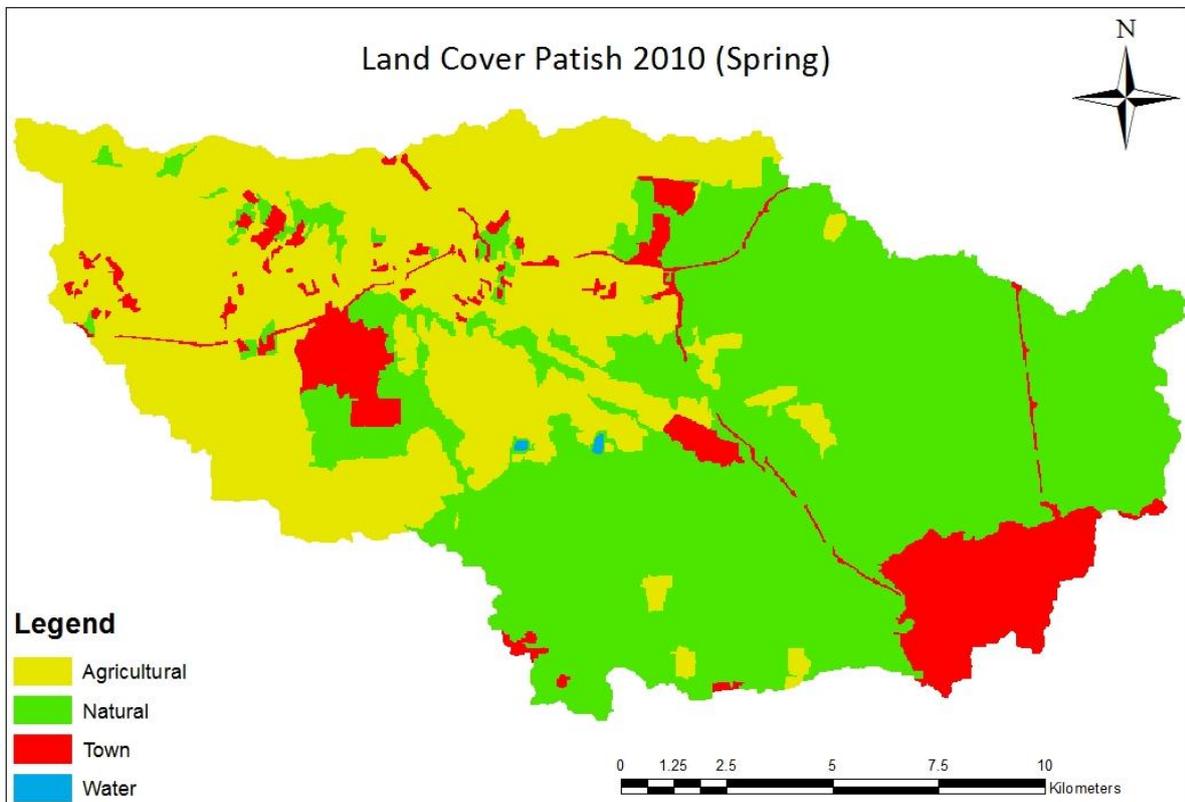


Figure 15 Classification results for the Patish watershed in the spring of 2010

For fall there are only four land cover maps (for 1998 is missing), closely resembling the maps derived for the spring period (fig 16-19).

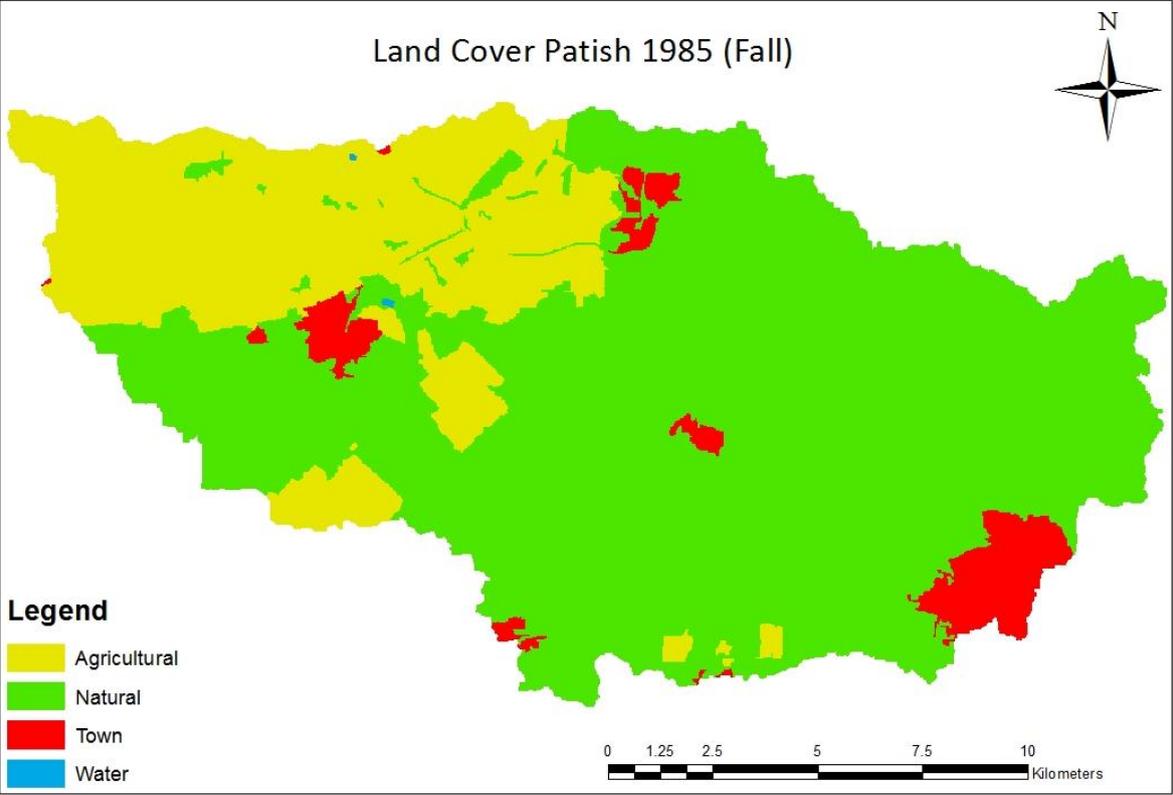


Figure 16 Classification results for the Patish watershed in the fall of 1985

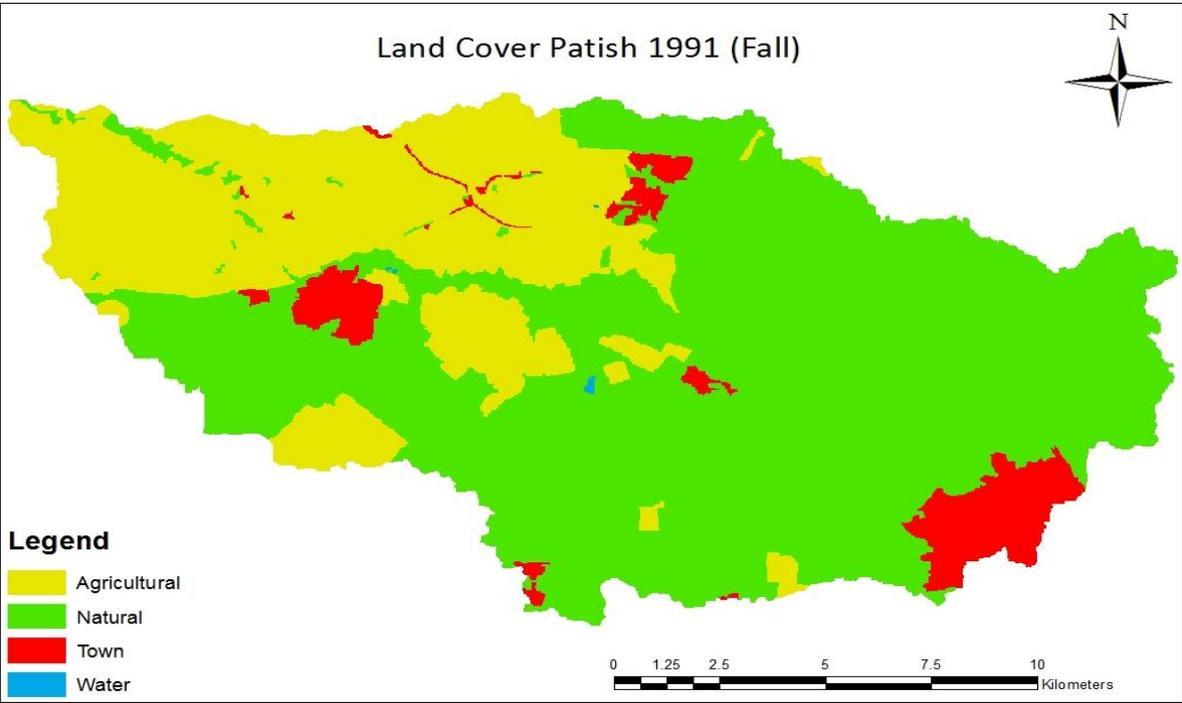


Figure 17 Classification results for the Patish watershed in the fall of 1991

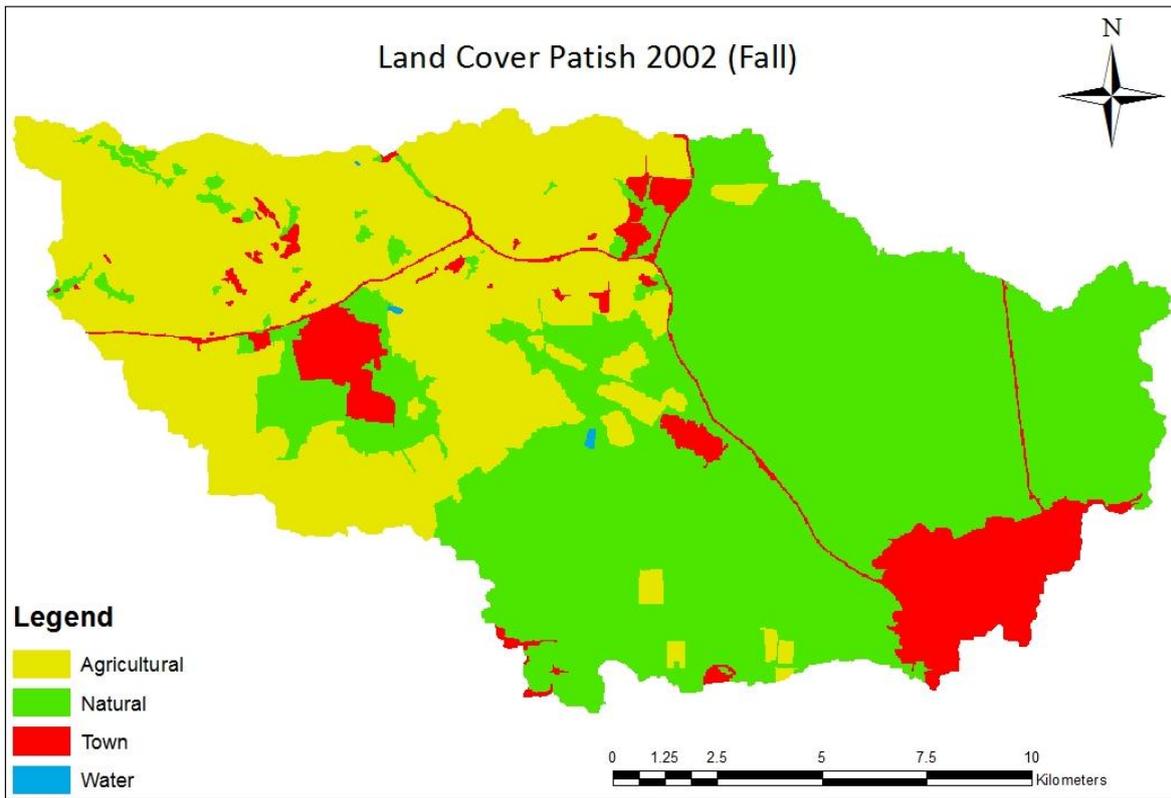


Figure 18 Classification results for the Patish watershed in the fall of 2002

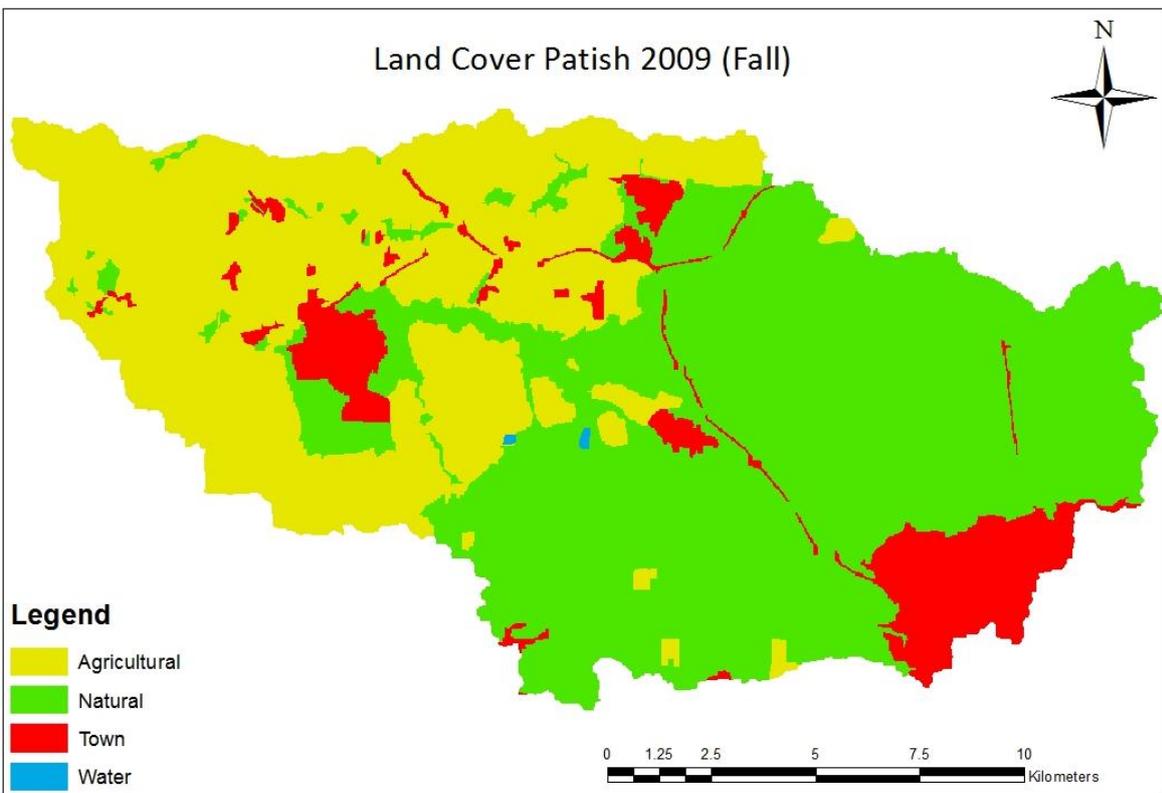


Figure 19 Classification results for the Patish watershed in the fall of 2009

Both the series for spring and fall show some gradual changes in land cover for the period between 1985 and 2009/2010. To analyse these changes in land cover, a land cover difference map was created for the period between 1985 and 2010 (for the spring period). In figure 20 one can see the largest area consists of natural open space, which remains natural area during this period. The second largest area is the area which remains agricultural, mainly located in the North-West. And the third stable area is the built area of the cities and settlements.

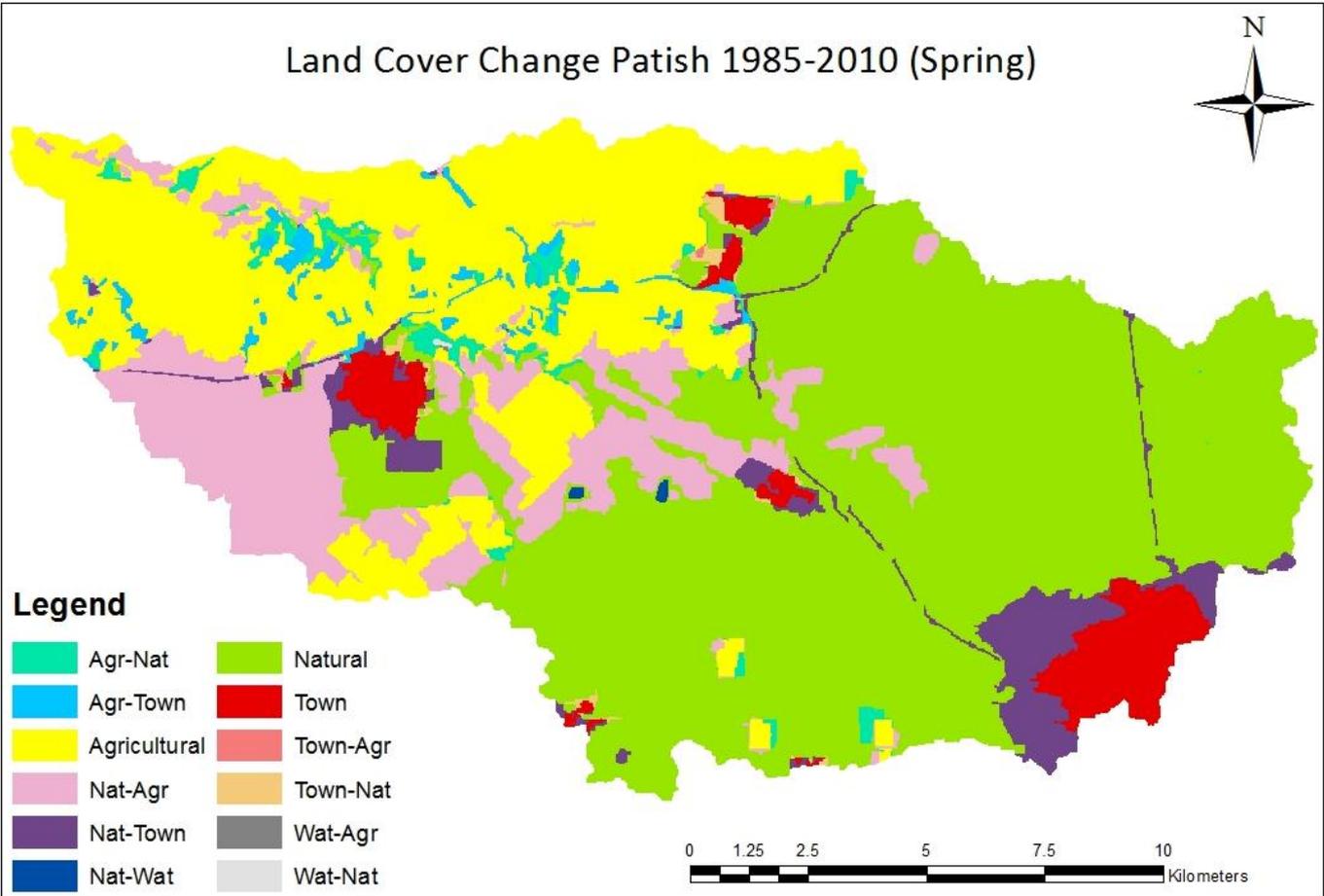


Figure 20 Land cover changes for the Patish watershed (spring)

Concerning areas with changes in land use, the largest is natural area becoming agricultural area, centred around Ofakim in the West of the watershed. And secondly natural open area turning into built area, mainly around Be’er Sheva, but also around Ofakim. And it applies for the roads, which could not be discerned in 1985, but are clearly visible in 2010. The other classes are quite marginal. There is some agricultural area becoming natural or built area, but the other classes are so small that they are hardly visible. And because of their small size compared to the uncertainty of the classification, they can be ignored. To quantify these land cover changes, some numbers (both absolute and relative) are presented in figure 21 and 22 and table 7.

Table 7 Land cover areas Patish watershed during spring for classified years (km2)

Land Use	1985	1991	1998	2002	2010
Agricultural	71.2	82.4	102.4	86.3	96.9
Natural	172.3	162.1	131.8	146.2	133.0
Town	11.5	10.4	20.8	22.5	25.0

Table 7 shows the calculated areas for three distinguished land covers for the different years during spring (water is left out, because of the relatively small area). Agricultural area increases with 35%, and town with more than 100%. Natural open space loses over 20%.

Figure 21 displays the relative areas for the Patish watershed; town shows a steady increase, but remains a relative small area. Natural open area declines between 1985 and 1998, but remains steady since then. Agricultural area mirrors this picture; increase until 1998, and almost stable between 1998 and 2010.

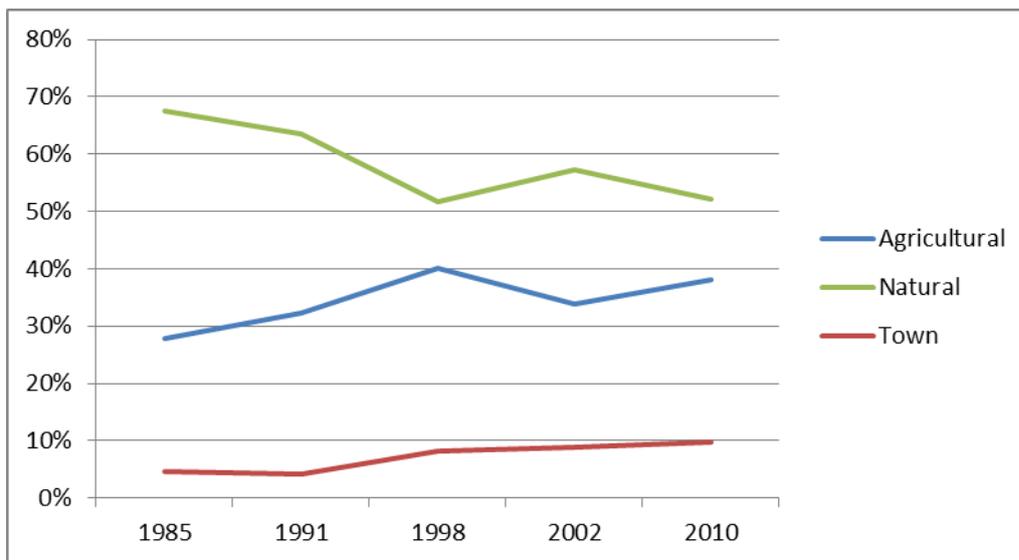


Figure 21 Relative land cover areas Patish watershed during spring for classified years

Finally, figure 22 shows the relative land cover mutations as derived from figure 20. Natural open area is the main class with 50%, followed by agricultural (25%). The other large class is natural area changing into agricultural area (13%). Town and natural area changing to town form about 4% of the area, and agricultural changing to natural and to town both form something more than 1% of the area. The other classes covered less than 1% of the area, and were left out of the graph for that reason.

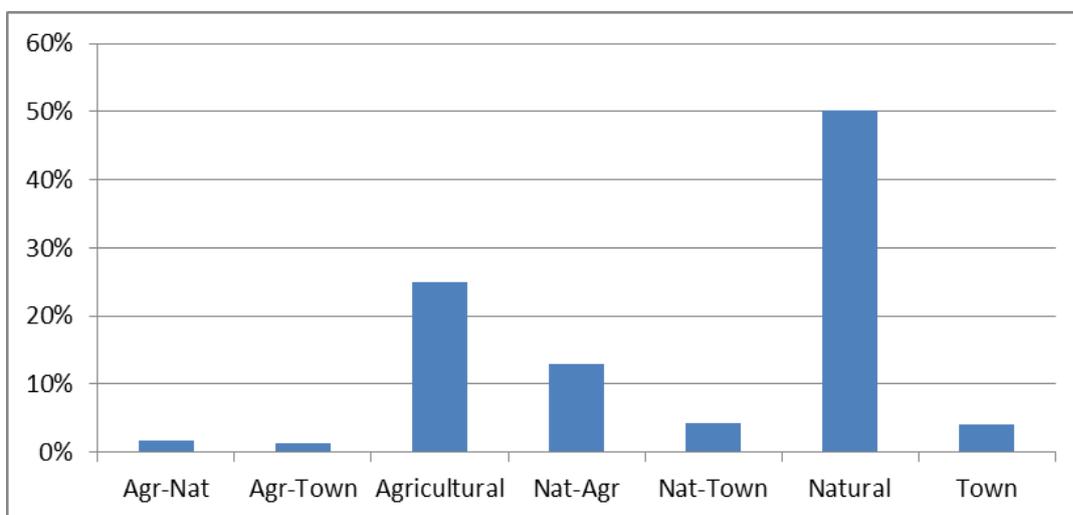


Figure 22 Relative land cover mutations for the Patish watershed between 1985 and 2010 (spring)

The difference map for the fall period in the Patish watershed gives a pretty similar picture (fig 23). A large natural area in the South-East, with an agricultural area in the North-West. And the same pattern of natural area becoming agricultural area or town.

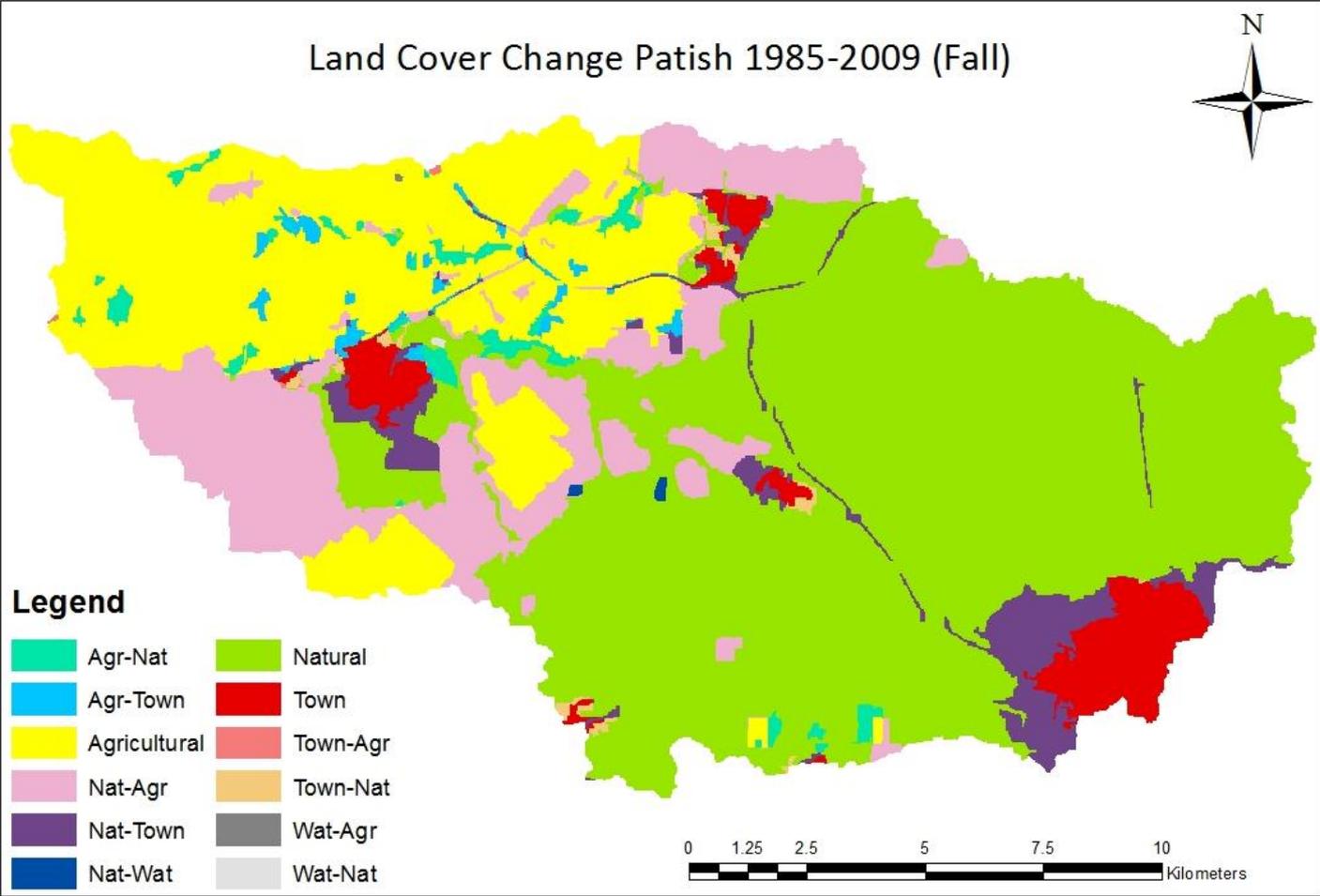


Figure 23 Land cover changes for the Patish watershed (fall)

The derived land cover areas for the Patish watershed during fall show the same pattern as for the spring period (table 8). Agricultural area and town grow (with 30km² and 11.5 km² respectively), at the expense of the natural area (which shows a decrease of almost 42 km²). However, the numbers shows some differences with the spring period, especially for 1985 and 1991. The area classified as agricultural is smaller in the fall, where the natural area is larger.

Table 8 Land cover areas Patish watershed during fall for classified years (km2)

Land Use	1985	1991	2002	2009
Agricultural	63.6	73.3	92.9	93.8
Natural	179.8	167.5	139.8	138.1
Town	11.6	14.5	22.3	23.3

This is confirmed by the relative size of the land cover classes (fig 24). Again, the agricultural area increases at the expense of natural area between 1985 and 2002 (in this case). But now the relative

area of agricultural lands does not reach the 40%, and the natural area remains above the 50%. The class of town does not show much differences; again a steady increase up to 10% in 2009.

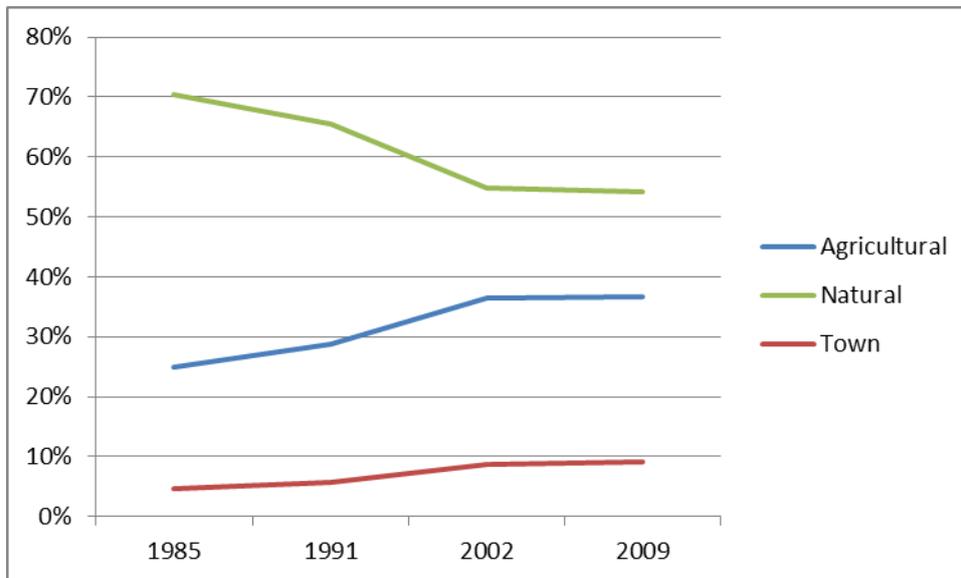


Figure 24 Relative land cover areas Patish watershed during fall for classified years

The relative land cover changes (fig 25) show by far the largest area is continuous natural area (over 50%). Agricultural is the second again (though a bit less than the 25% for spring), with natural area turning into agricultural is third in size (14%). The relative sizes of the classes ‘natural to town’ and ‘town’ are about 4% again, and ‘agricultural to natural’ and ‘agricultural to town’ are the smallest classes being displayed. For the other classes were also in the fall less than 1%, and not displayed for that reason.

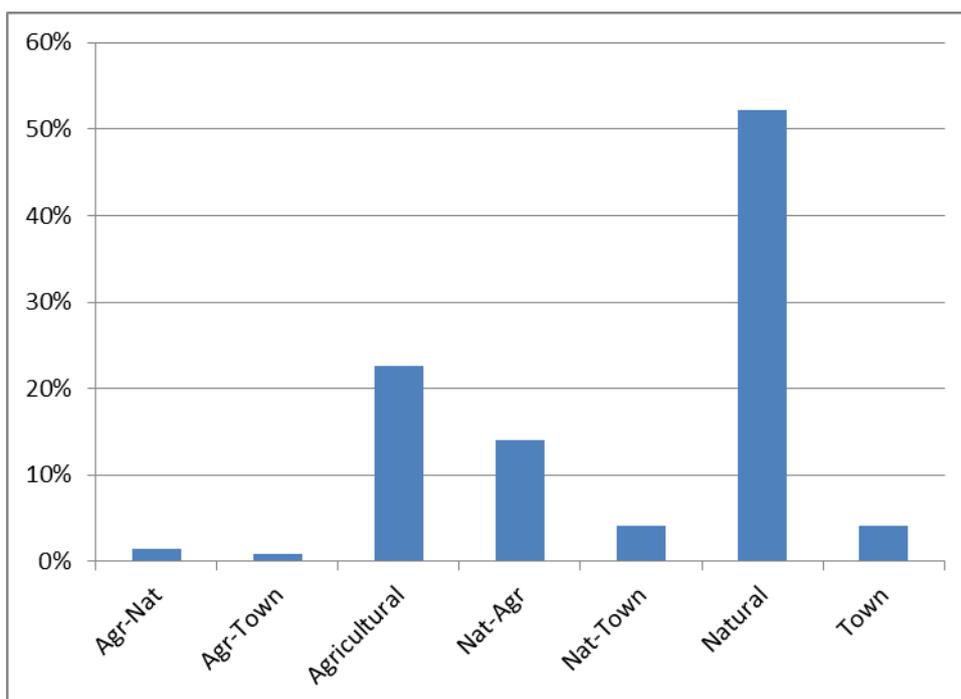


Figure 25 Relative land cover mutations for the Patish watershed between 1985 and 2010 (fall)

4.2 Field work

The results for the field work will be presented below, beginning with dry bulk density analysis, followed by saturated hydraulic conductivity, biomass and finally the analysis of the soil samples.

4.2.1 Dry bulk density

Values for dry bulk density measured vary between 1.28 grams/cm³ and 1.73 grams/cm³ (fig 26). Average values for terraces and limans are close to equal, with higher values for the slopes. Standard deviations vary between 0.01 and 0.20 (for three [or two] repetitions per subplot).

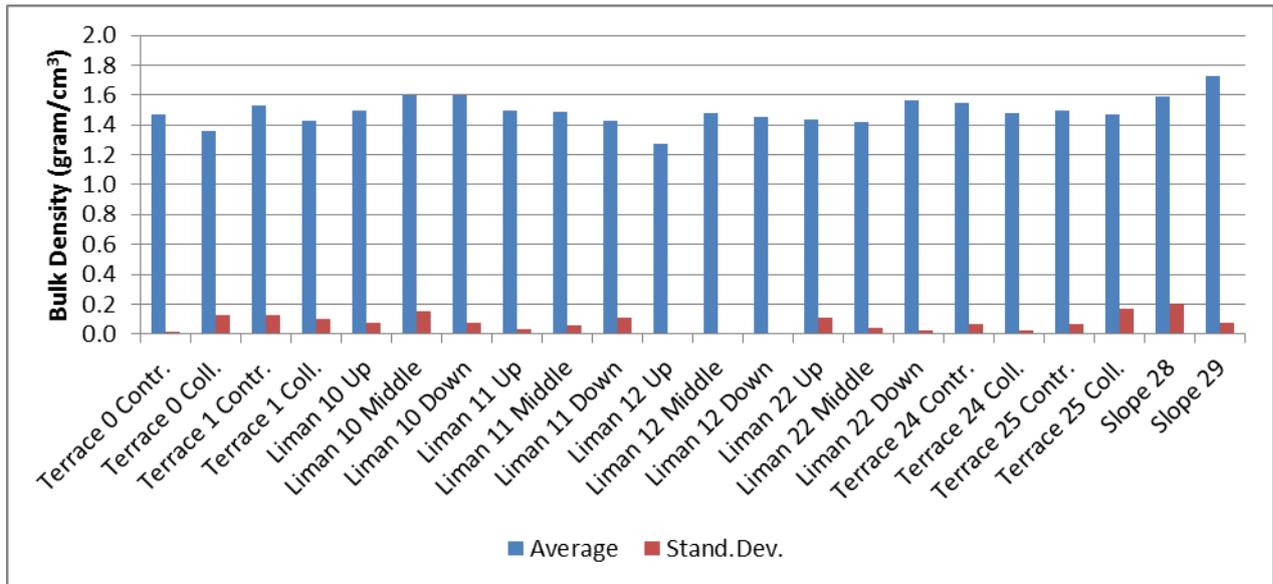


Figure 26 Average dry bulk density (of three measurements) with standard deviation for plots in Ambassadors Forest. For liman 12, only one measurement was available (so no standard deviation could be calculated)

For the non-natural plots, values range from 1.29 grams/cm³ to 1,70 grams/cm³ (with standard deviations between 0.02 and 0.08) (fig 27).

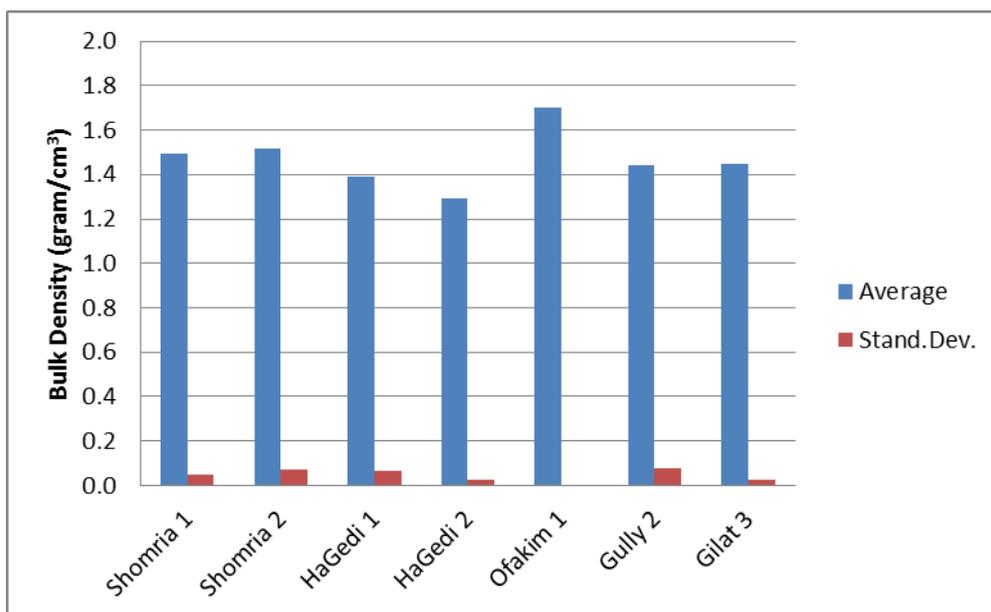


Figure 27 Average dry bulk density (of three measurements) with standard deviation for plots in the Patish watershed

4.2.2 Saturated hydraulic conductivity

Measured hydraulic conductivity shows a high variation (fig 28) as shown by the high standard deviations. On average, the average value is highest for the slopes, followed by terraces and limans. However, inside classes different values can be observed, and standard deviations are high (between 0.1 cm/hr and 2.6 cm/hr). For each subplot ('Terrace 0 contributing' is a subplot of the plot 'Terrace 0') three repetitions were taken.

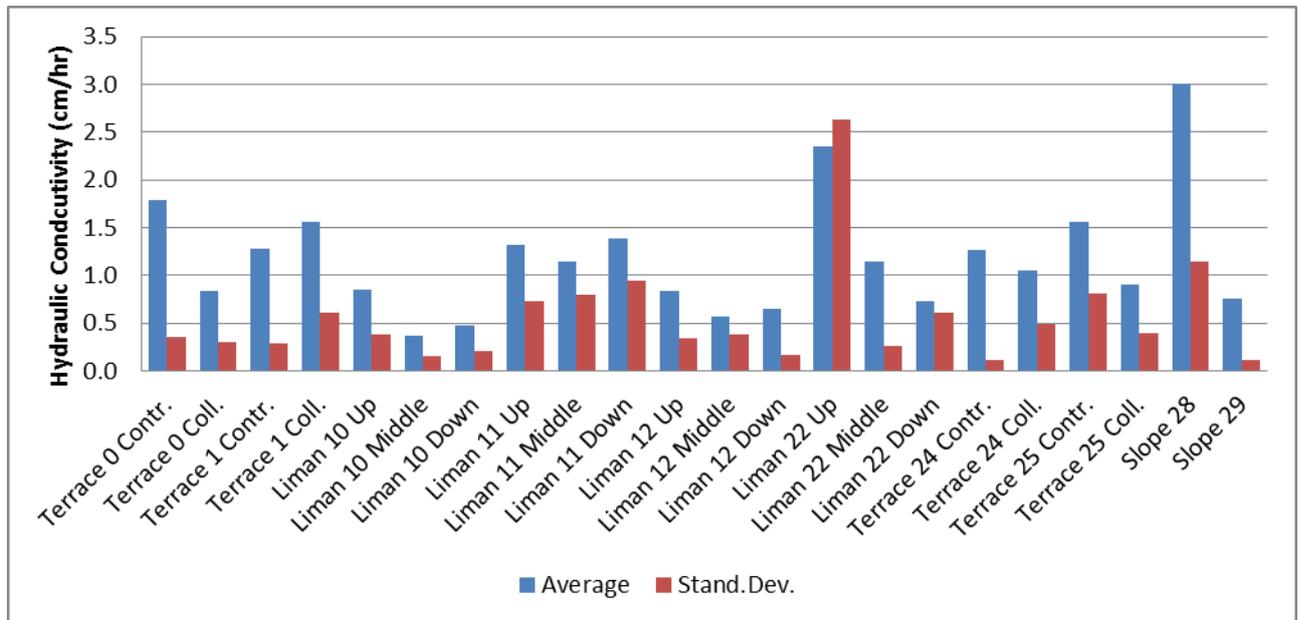


Figure 28 Average hydraulic conductivity (of three measurements) with standard deviation for plots in Ambassadors Forest

The other plots give higher values for the saturated hydraulic conductivity, however values for HaGedi 1 (2.9 cm/hr) and especially Ofakim 1 (0.9 cm/hr) are lower (fig 29). Again, standard deviations are high, showing a large variation between various measurements.

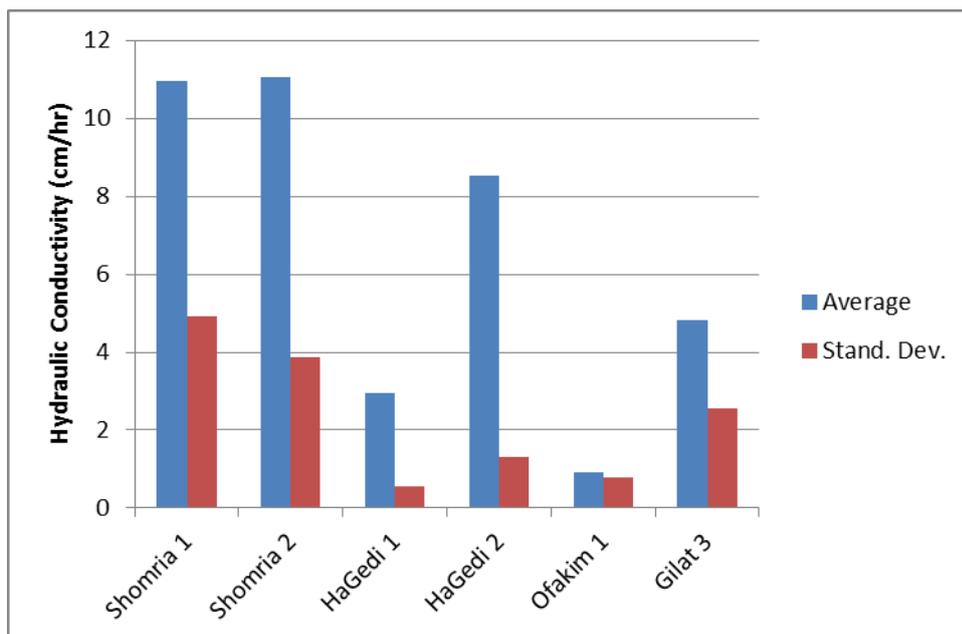


Figure 29 Average hydraulic conductivity (of three measurements) with standard deviation for plots in the Patish watershed

4.2.3 Biomass

Biomass was only measured for a limited number of plots in the Ambassadors Forest (main reason was the absence of biomass in other plots, and next the fact biomass collection was not included in the research goals). The terraces show a big difference between the (bare) contributing areas and the (grown) collecting areas (fig 30).

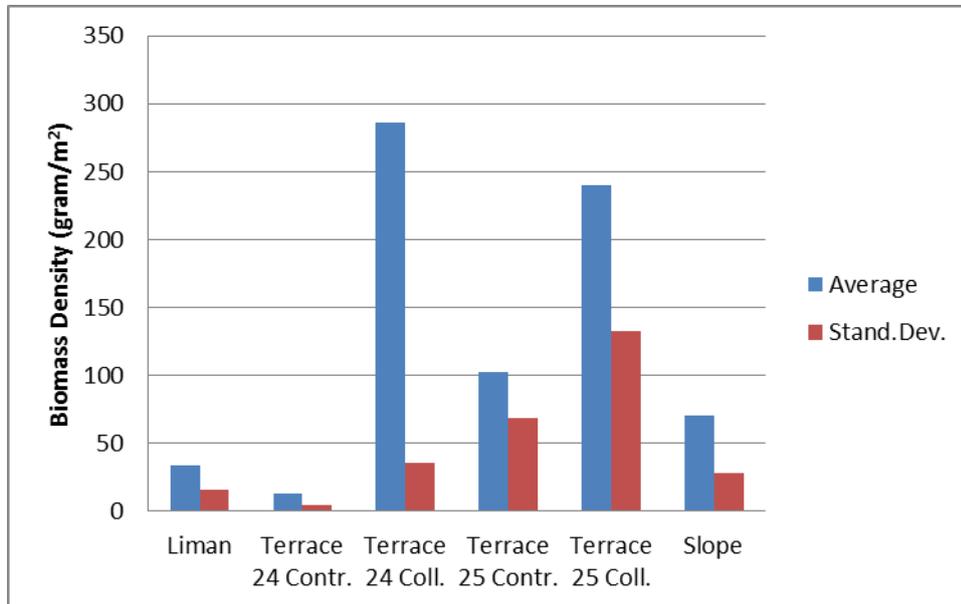


Figure 30 Average biomass density (of three measurements) with standard deviation for plots in Ambassadors

4.2.4 Analysis of soil samples

The saturation point of the soils in the selected plots varies between 35.4% and 43.8%. The values for the agricultural fields (as well as the gully) are almost equal, with lower values for the building site at Ofakim and in a smaller degree for the orchard at Gilat (fig 31).

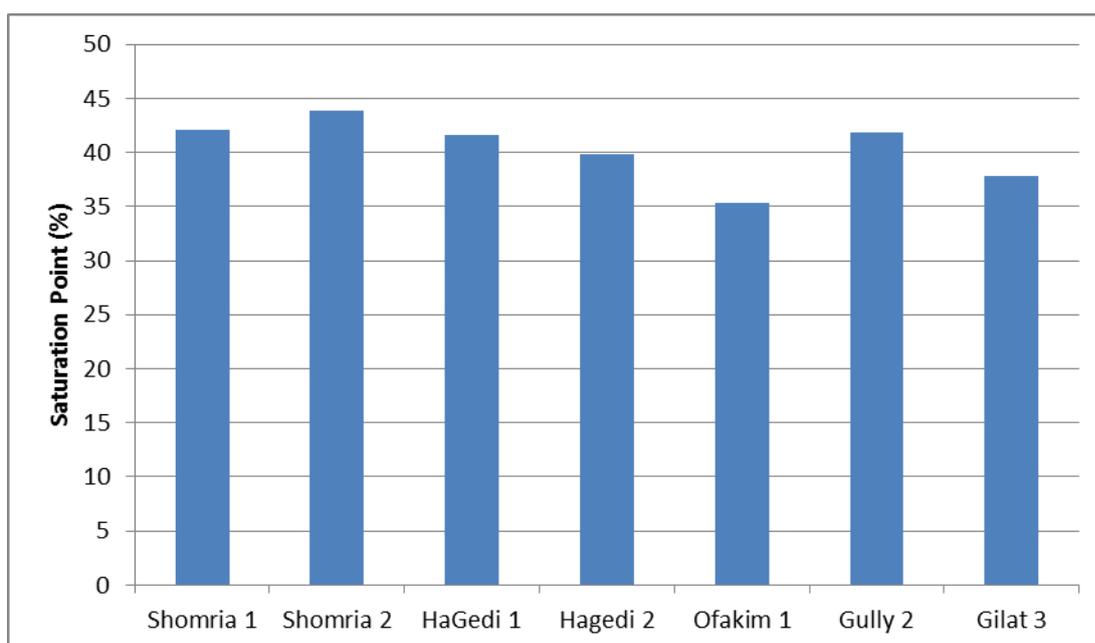


Figure 31 Measured Saturation Point for plots in the Patish watershed

The irrigated plots of Shomria 2 and especially Gilat 3 show larger concentrations for all measured elements. The other plots show no significant variation (fig 32). For Chloride, also the concentration measured in mg/l was measured, but left out this graph because of the clearness of the graph, and the fact this information doesn't add to what is given by the concentration in meq/l.

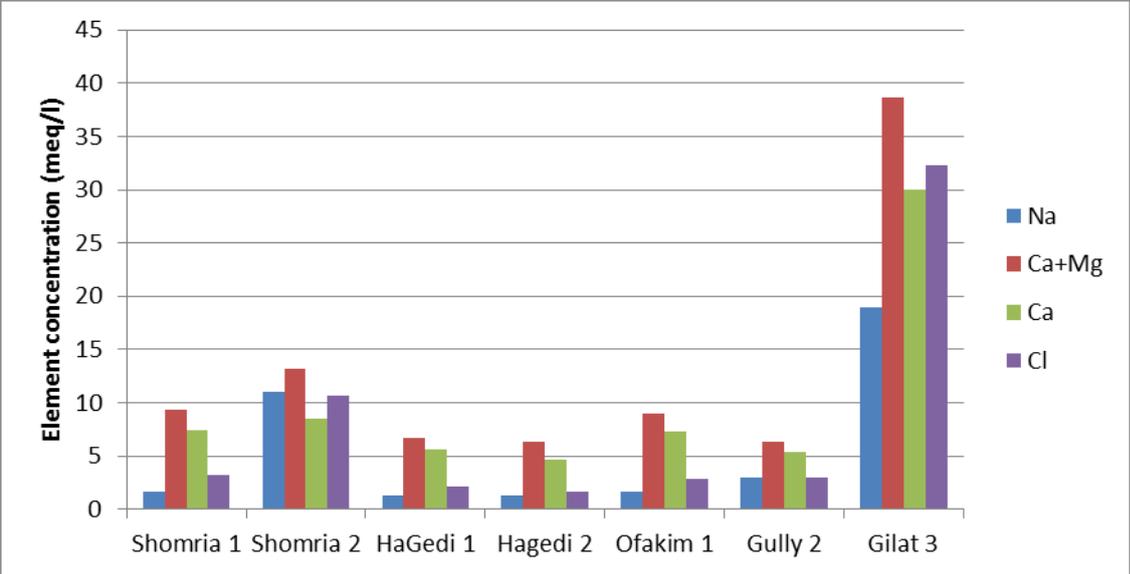


Figure 32 Measured Sodium, Calcium + Magnesium, Calcium and Chloride content for plots in the Patish watershed

Also for the Sodium Adsorption Ratio (SAR), the plots of Shomria 2 and Gilat 3 show the highest values. Where values for the other agricultural plots are approximately 0.70/0.80, the SAR for Shomria 2 and Gilat 3 is above 4.0. The SAR for the gully is in between (1.79) (fig 33).

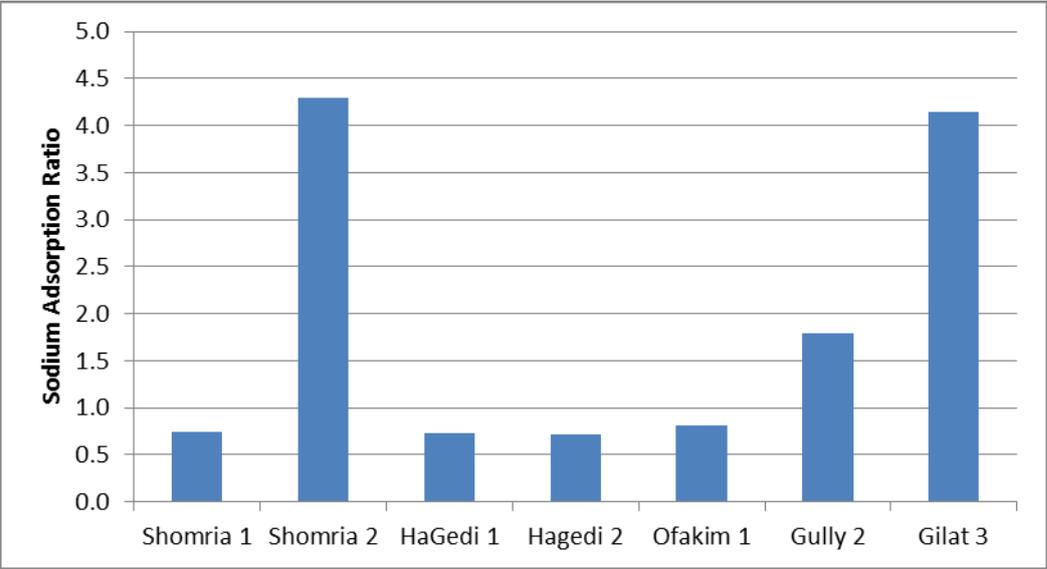


Figure 33 Measured Sodium Adsorption Ratio (SAR) for plots in the Patish watershed

The organic matter (OM) content of the soils is quite low in general. The (by far) highest value of Ofakim is still below the one percent (fig 34).

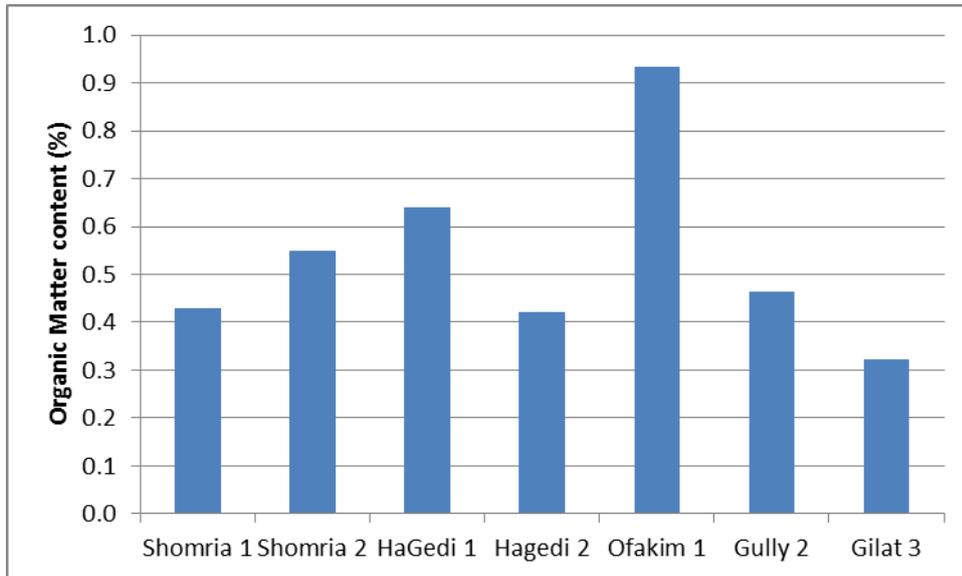


Figure 34 Measured Organic Matter (OM) content for plots in the Patish watershed

The Cation Exchange Capacities (CECs) are in line with the expectation for this type of soil. The values for Ofakim and Gilat are the lowest measured (fig 35).

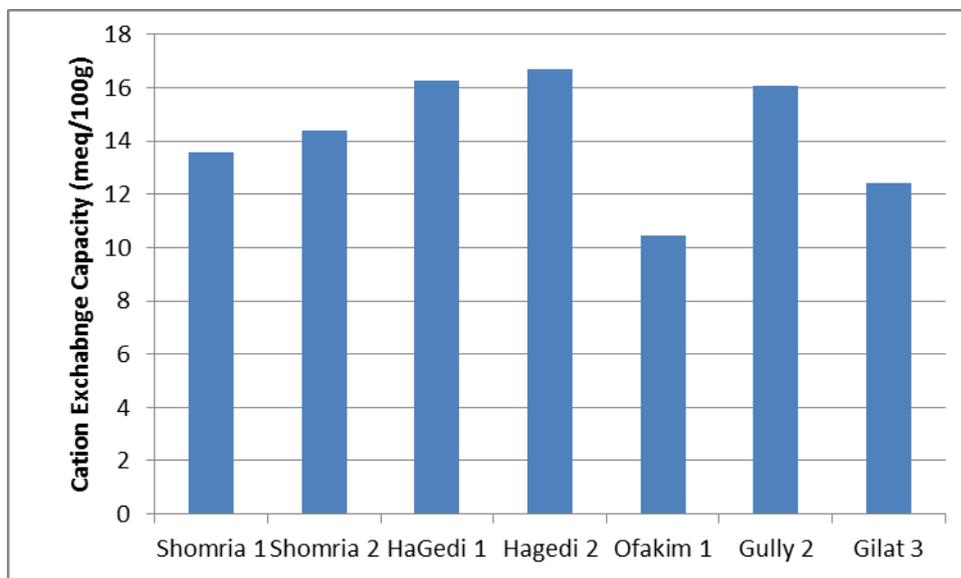


Figure 35 Measured Cation Exchange Capacity (CEC) for plots in the Patish watershed

The pH of the soils varies between 7.9 for Ofakim and 9.1 for Terrace 24 (contributing) (fig 36). In general, the pH is higher for the natural plots in the Ambassadors Forest (and the gully), than for the agricultural plots in Shomria and HaGedi. Inside the Ambassadors, the pH for limans is lower than for terraces.

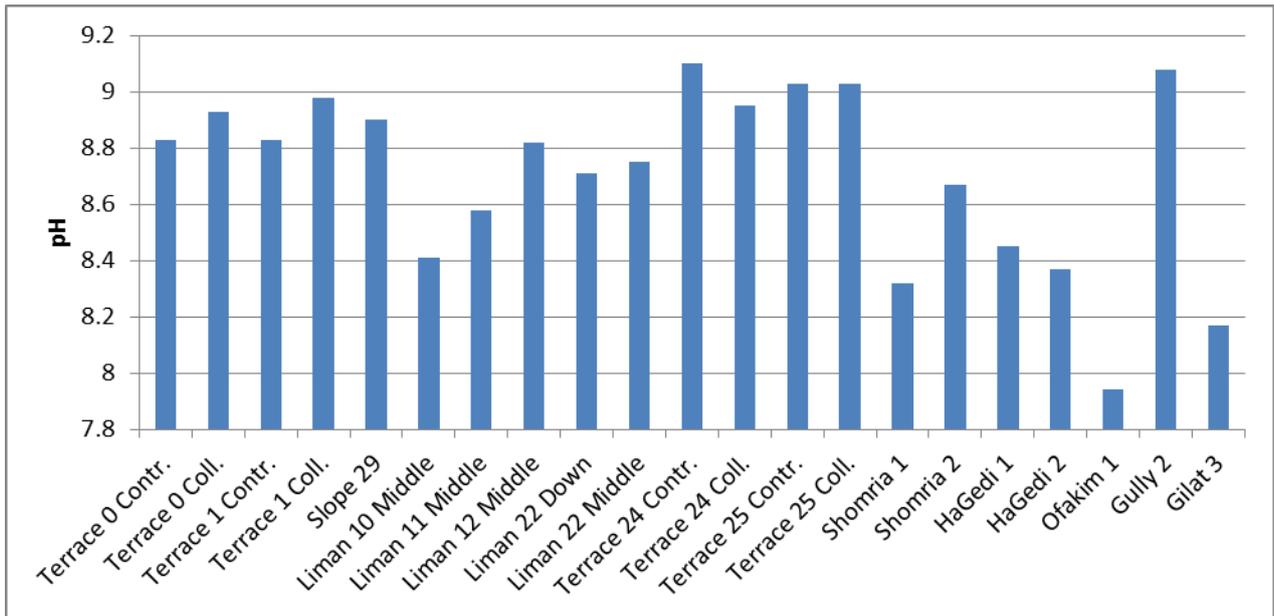


Figure 36 Measured pH for plots in the Patish watershed

The measured Electro Conductivity (EC) mostly is around the 100 $\mu\text{S}/\text{cm}$ (fig 37). However, there are a few outliers. First are limans 10 and 11, which are the only ‘natural’ plots with higher values. The other outliers are Shomria 1 and 2, Ofakim 1 and especially Gilat 3. The latter are all agricultural plots, with the irrigated plots (again) showing the highest values.

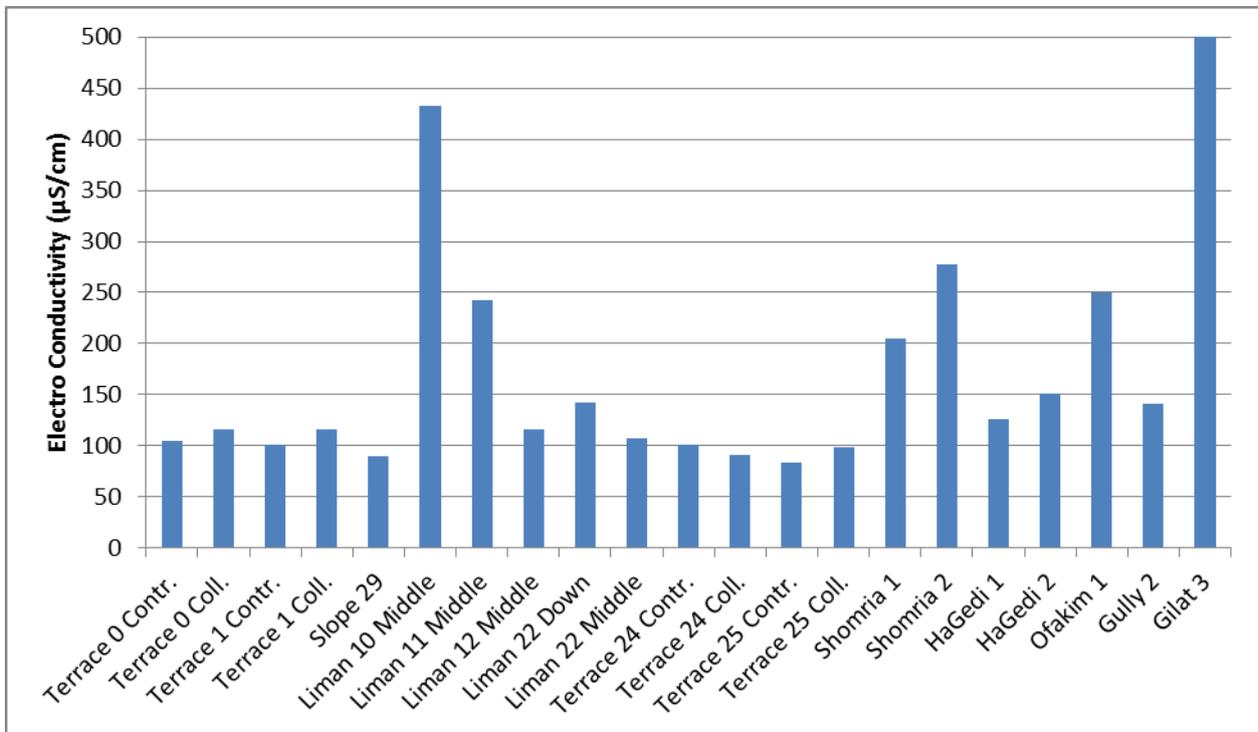


Figure 37 Measured Electro Conductivity (EC) for plots in the Patish watershed. Value for Gilat 3 is 838 $\mu\text{S}/\text{cm}$, exceeding the range of the graph

The final measurements conducted in the laboratory concerned the lime content, as well as the division of the soil over the various soil texture classes. The lime content lies between the 10 and 20 % (fig 38). The percentage of sand fraction according to the laboratory analysis ranges from 37.9 to 53.7 %, with silt ranging from 24.4 to 37.7 % and clay from 22.0 to 29.4 %. When classifying according to the USDA classification, the texture varies between sandy clay loam (Ofakim 1) and clay loam (Shomria 2 and HaGedi 2). The other four plots are classified as loam.

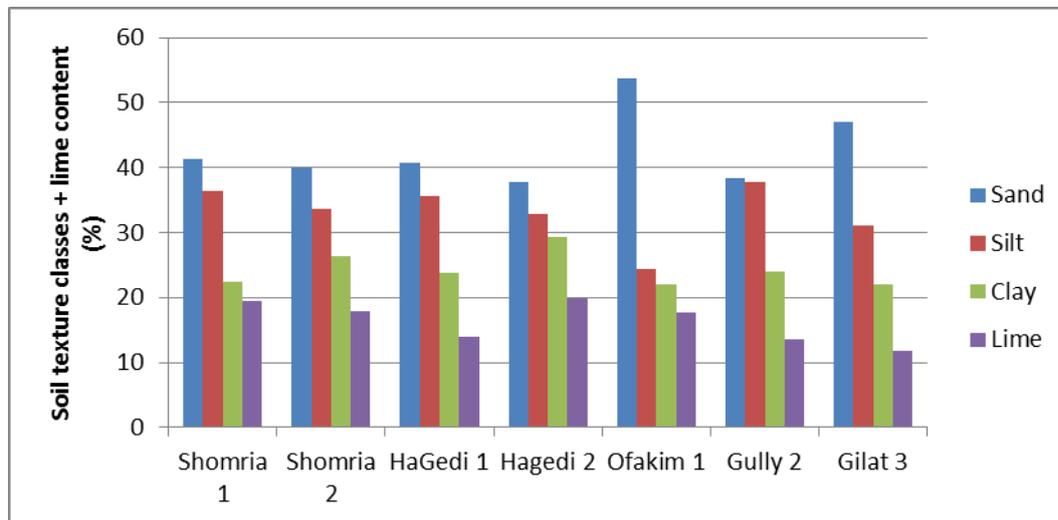


Figure 38 Size of soil texture classes and lime content for plots in the Patish watershed, as determined in the (external) laboratory

Soil texture analysis was also conducted using the Particle Size Analyser (PSA) for all investigated plots both in the Ambassadors Forest as well in the other plots in the Patish watershed (fig 39).

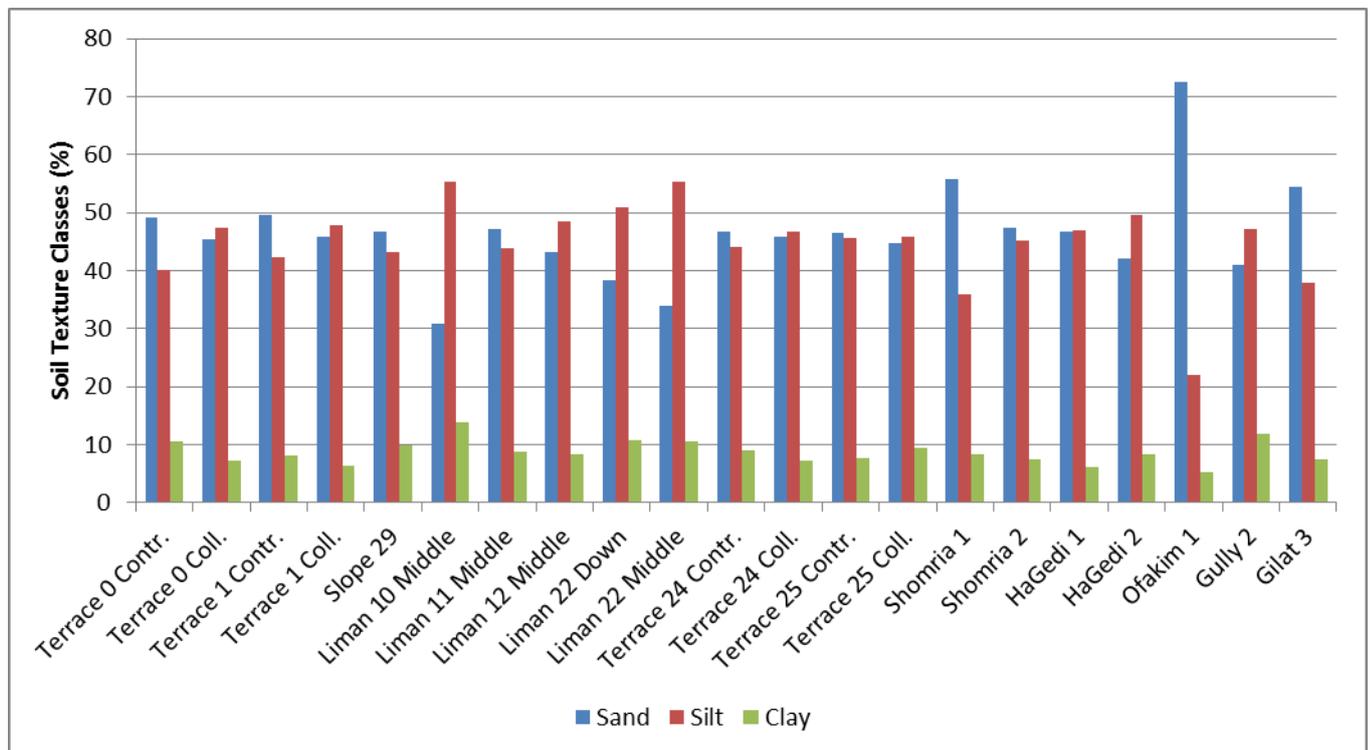


Figure 39 Size of soil texture classes for plots in the Patish watershed, as determined by measurements with a Particle Size Analyser (PSA)

Using this analysis, soil texture types varies between sandy loam, loam and silty loam. Percentage of sand fraction varies between 30.8 and 72.6 %, of silt fraction between 22.1 and 55.4 %, and of clay fraction between 5.3 and 14.0 %.

To give an impression of the soil types in the Patish watershed, an overview is given for the two different analysis types (table 9).

Table 9 Soil type of plots in the Patish watershed according to texture analysis (two analysis methods)

Plot	Classification PSA	Classification Laboratory
Terrace 0 Contributing	Loam	
Terrace 0 Collecting	Sandy Loam	
Terrace 1 Contributing	Loam	
Terrace 1 Collecting	Sandy Loam	
Slope 29	Loam	
Liman 10 Middle	Silty Loam	
Liman 11 Middle	Loam	
Liman 12 Middle	Loam	
Liman 22 Down	Silty Loam	
Liman 22 Middle	Silty Loam	
Terrace 24 Contributing	Loam	
Terrace 24 Collecting	Sandy Loam	
Terrace 25 Contributing	Loam	
Terrace 25 Collecting	Loam	
Shomria 1	Sandy Loam	Loam
Shomria 2	Sandy Loam	Clay Loam
HaGedi 1	Sandy Loam	Loam
HaGedi 2	Silty Loam	Clay Loam
Ofakim 1	Sandy Loam	Sandy Clay Loam
Gully 2	Loam	Loam
Gilat 3	Sandy Loam	Loam

According to the classification with the PSA, loam and sandy loam are the most frequent occurring soil types. When compared with the laboratory analysis, most sandy loam soils from the PSA will be analysed as loam soils in the laboratory.

Figure 38 and 39 show (expected) differences in soil texture analysis between the laboratory and the PSA. To visualise this, the texture classes of the plots with a double analysis are plotted in the same graph (fig 40).

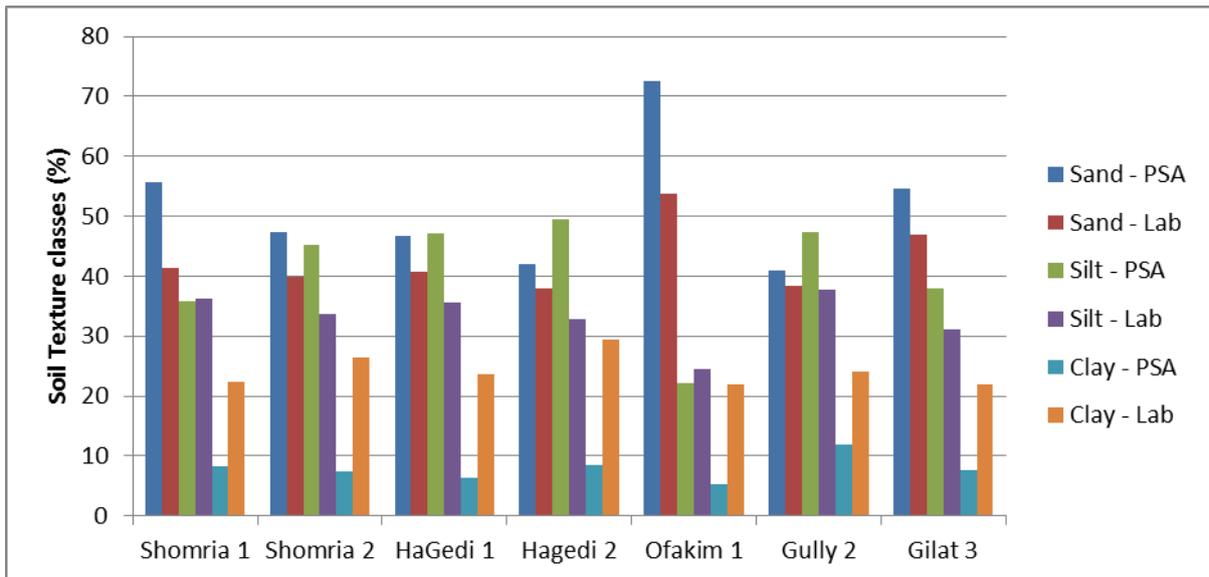


Figure 40 Size of soil texture classes for plots in the Patish watershed, both as determined by an external laboratory as by measurements with a Particle Size Analyser (PSA)

The graph shows a higher percentage of sand fraction for the PSA, while the percentage of clay fraction is lower. For silt the picture is mixed; in most cases the silt fraction is larger for the PSA analysis (except for Shomria 1).

4.3 Rainfall analysis

For the rainfall analysis, the average rainfall was analysed for various stations for the most recent (available) years (fig 41). As the blue dots correspond with the (calculated) average rainfall amounts, one can see a decrease from North (Negba) to South (Sde Boker).



Figure 41 Meteorological stations in the Patish watershed and its larger environment. Size of the blue dot corresponds with calculated average rainfall. Source background map: Google Earth, 2012

This degree in rainfall amount is better visualised in this map below, derived by a (simple) Kriging operation (fig 42). Because of a low density of measurement points, accuracy is low, especially along the edges of the map.

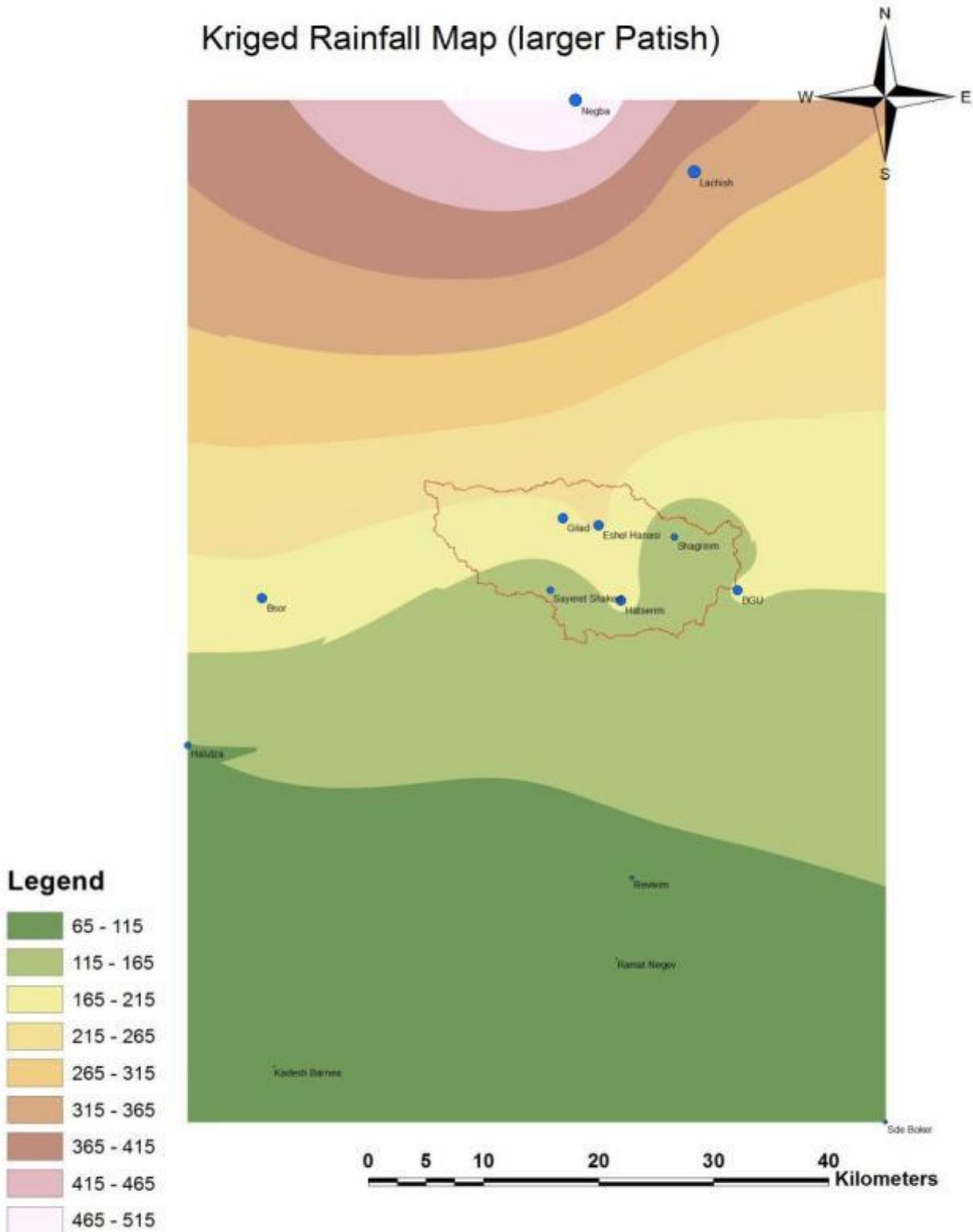


Figure 42 Rainfall zones for the Patish and its larger environment, derived by a kriging operation of average rainfall amounts. Values in legend are in mm/year. Negba (Northern edge) is not included in other analyses.

The average rainfall for the stations within the Patish watershed varies between 125.0 mm (Ambassadors Forest) and 206.8 mm (Gilat), where should be noted the record for Ambassadors is very short (table 10).

Table 10 Average calculated rainfall for meteo stations inside Patish watershed

Station	Period	Average rainfall (mm)
Gilat Research Farm	1985-2009	206.8
Ben Gurion University	2000-2009	168.0
Ambassadors Forest	2008-2011	125.0
Sayeret Shaked	2003-2010	130.6
Eshel Hanasi	1985-2009	203.6
Hazerim	1985-2005	171.9

In the larger environment of the Patish, variability is larger. Lachish (Northwards) shows an average of 344.9 mm, while (Kadesh) Barnea in the South only yields 65.3 mm (table 11).

Table 11 Average calculated rainfall for meteo stations in larger environment of Patish watershed

Station	Period	Average rainfall (mm)
Bsor	2002-2009	199.1
Revivim	1985-2009	103.5
Lachish	2000-2010	344.9
Sde Boker	1976-2010	94.1
Ramat Negev	1999-2009	76.1
Barnea	1999-2009	65.3

When plotted over the last 25 years, the high rainfall variability in the Patish watershed is clearly distinguishable (fig 43). Rainfall varies between 60mm (1998/99 and 1999/00) and more than 300mm (1994/95). Besides temporal variability, also spatial variability can be observed. The shape of the various graphs is quite similar, but for some stations and periods the gap is over 100mm. For the various (station)lines in the most recent years should be noted that for some stations (like Sayeret Shaked and Ambassadors Forest) only a few records are available, which doesn't allow for much conclusions concerning convergences.

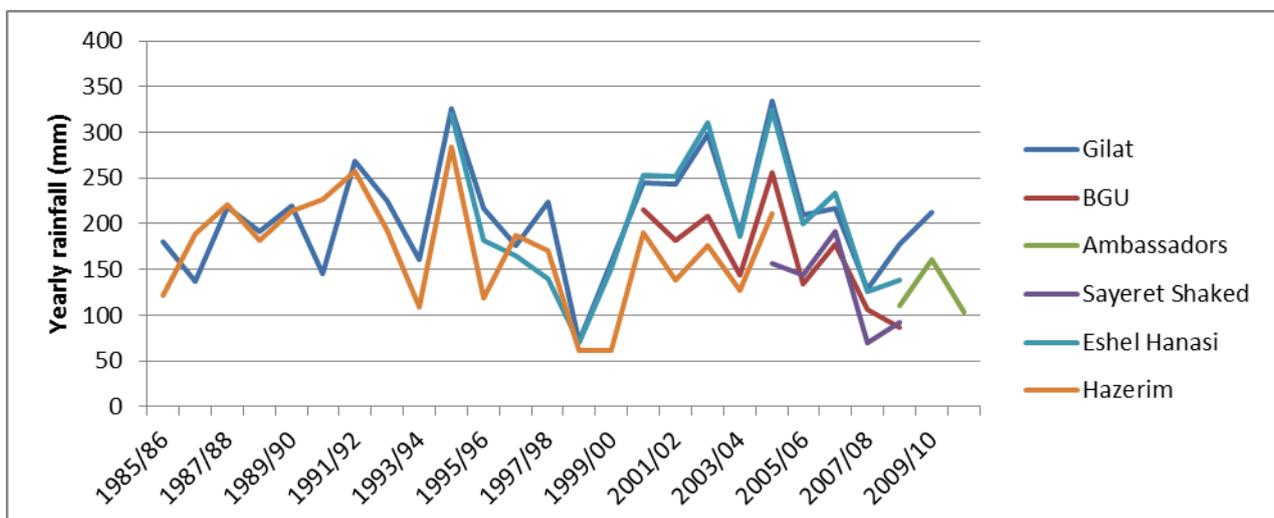


Figure 43 Yearly (winter) rainfall for meteo stations inside the Patish watershed

The long term view for the stations in the larger surrounding shows few information regarding historical developments. Only Revivim and Sde Boker (both in the South) show long term records, which are almost identical. Here variation is less than can be observed inside the Patish watershed (especially absolute, but also relative). For the most recent years, when also the Northern stations (Lachish and Bsor) are included, variation is higher, but this variation is (almost) only spatial variation (fig 44).

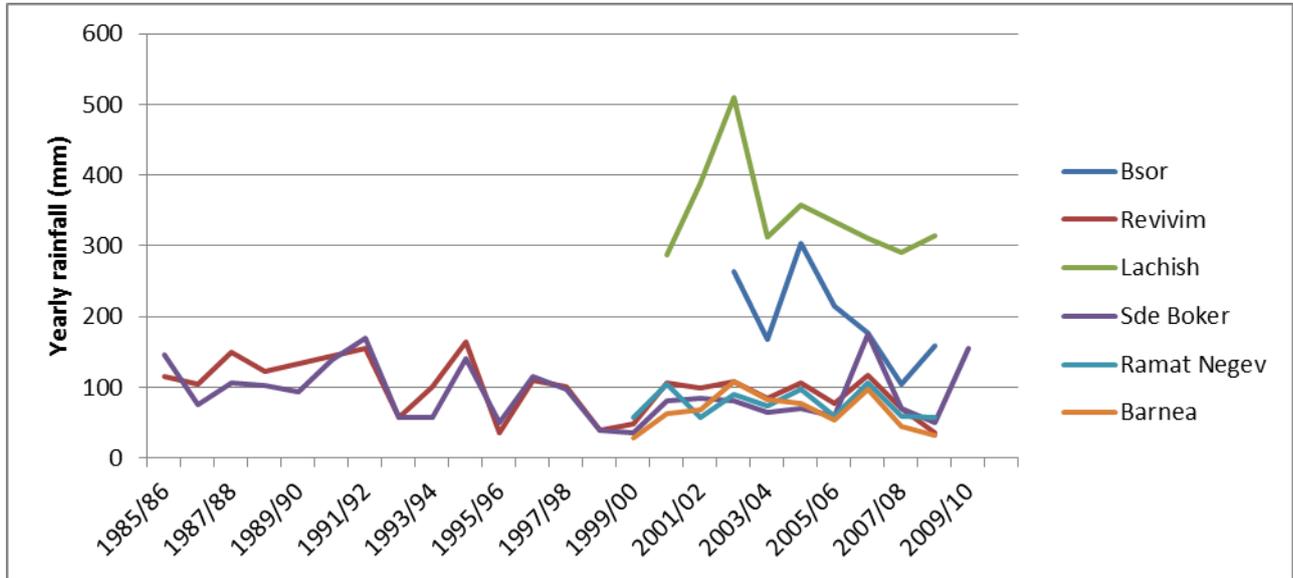


Figure 44 Yearly (winter) rainfall for meteo stations in larger environment of Patish watershed

To analyse long term developments, a trend line was added for stations with a long term record (fig. 45). Gilat and Eshel Hanasi show almost horizontal trend lines. The trend line for Hazerim is decreasing, but because the rainfall record for Hazerim stops after 2004/2005, the trend line cannot be compared one-to-one with the others. In general the trend lines represent little agreement, considering the low to very low R^2 values for the trend lines.

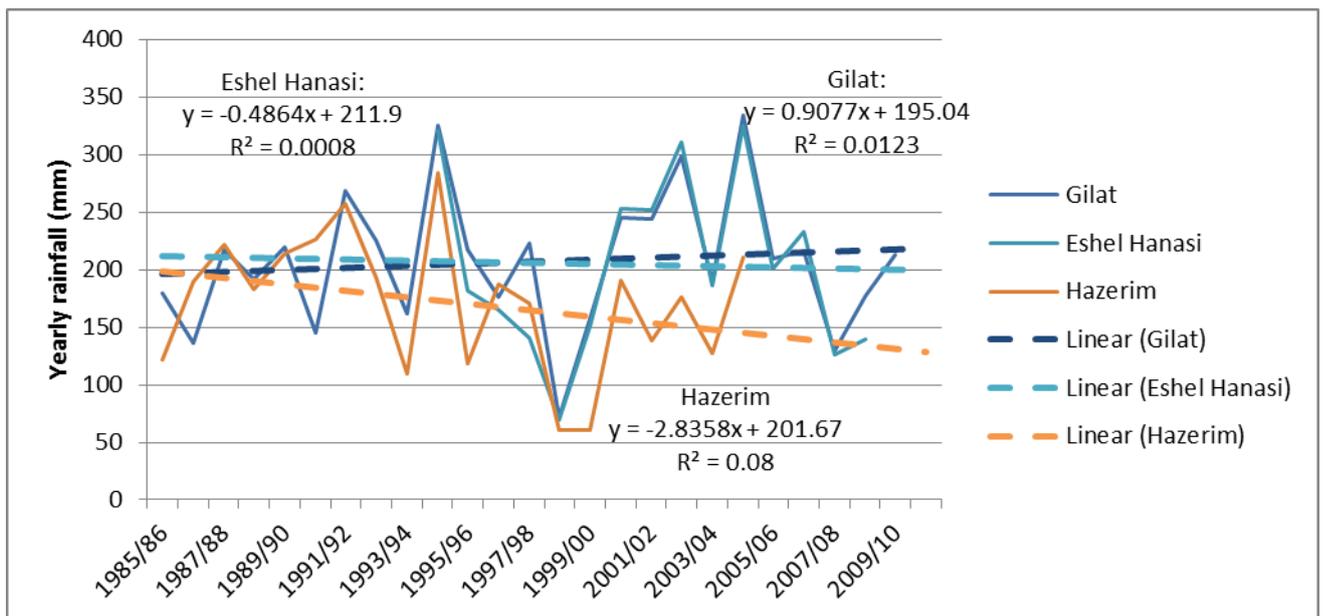


Figure 45 Yearly (winter) rainfall for selected meteo stations inside the Patish watershed with trend lines

For the other stations, only for Revivim and Sde Boker a trend analysis could be made (fig 46). Both show a decreasing trend, with Revivim having the highest R² value of all.

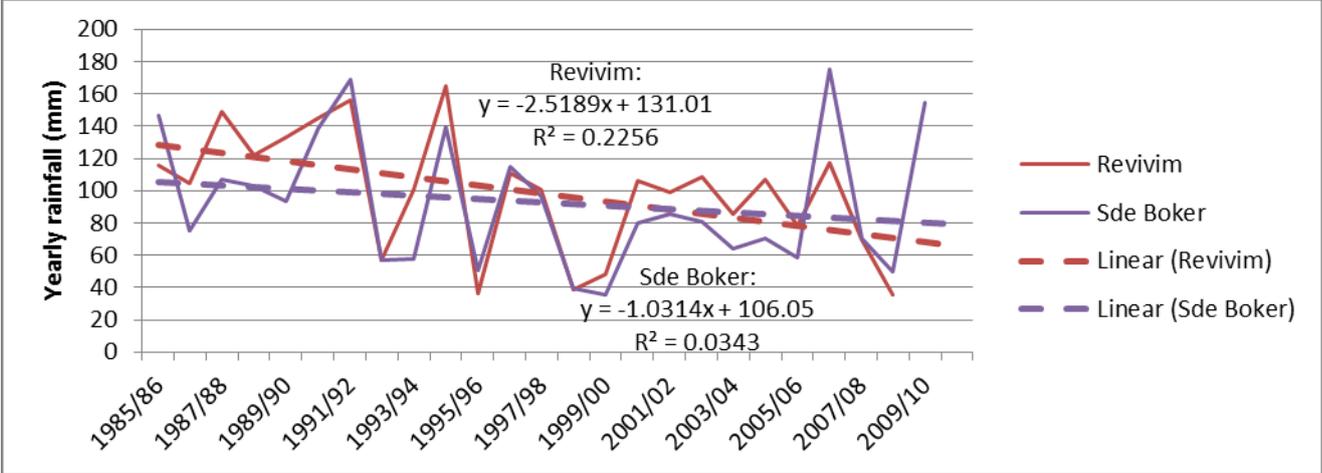


Figure 46 Yearly (winter) rainfall for selected meteo stations in larger environment of Patish watershed with trend lines

5. Discussion

In this chapter the results of the various analyses of this research will be discussed; following the objectives, and where possible by comparing the results with information found in literature. At the end a critical analysis of the methods applied is included.

Results

The analysis of rainfall data shows no or just a small decline in rainfall for the last 25 years. The analysis makes clear variation (both temporal and spatial) is high, where periods with low rainfall in general are followed by periods with higher rainfall. Average yearly rainfall varies from 125.0 mm and 130.6 mm (only short records of recent years) to between 168.0 and 206.8 mm (for longer periods). This corresponds with the 150 mm found by Boeken *et al.* (2001), and is somewhat lower than the 231 mm mentioned by Amir *et al.* (1991). The higher amount found by the latter could be explained by the fact his records stopped in 1991, and the records in this research mostly started in 1985.

The soil type in the Patish varies between sandy (clay) loam and clay loam, which is in line with expected results from literature (loessial soils).

The Remote Sensing analysis shows the area covered with agriculture and town in the Patish watershed increased, at the expense of natural open area.

For soil properties affecting the hydraulic character of the soil, no clear conclusion can be drawn for the relation between land cover and dry bulk density. Values for dry bulk density range from 1.28 g/cm³ to 1.73 grams/cm³. This is in line with the 1.48 g/cm³ found by Amir *et al.* (1991) for Gilat research farm, and on average slightly higher than the 1.30 g/cm³ as measured by Rawitz *et al.* (1983). The relatively high values for the unaffected slope and near Ofakim suggest a lower infiltrability for these locations.

Saturated hydraulic conductivity gives higher values for the agricultural plots. Near 11 cm/hr for Shomria 1 and 2, over 8.0 cm/hr for HaGedi 2, almost 5 cm/hr for Gilat 3 and almost 3 cm/hr for HaGedi 1. While almost all values found for natural areas are below 1.5 cm/hr (except Liman 22 up and Slope 28). The hydraulic conductivity for Ofakim is low (below 1.0 cm/hr). The infiltration rates for agricultural plots are higher than measured by Rawitz *et al.* (1983), who mention rates of 0.2 cm/hr (2 mm/hr) and 0.4 cm/hr (4 mm/hr) for freshly disked and ploughed plots respectively. On the other side, it is more in line with the initial infiltrability of 3.3 cm/hr (33 mm/hr) measured by them. And with the 3.54 cm/hr (35.4 mm/hr) measured by Eldridge *et al.* (2000) for a scalped soil in Sayeret Shaked, or the 1.5-3.0 cm/hr (15-30 mm/hr) found by Yair and Kossovsky (2002). However, the values of 11 cm/hr and 8 cm/hr remain remarkably high.

Measured elements (like Sodium and Calcium) in the soil samples show higher values for the irrigated plots of Shomria 2 and Gilat 3. Same is the case for Sodium Adsorption Ratio (SAR), with high values for Shomria 2 and Gilat 3 (more than 4.0). The value of SAR measured is low for the other agricultural plots (around 0.7), which is also lower than the 1.6 as found by Rawitz *et al.* (1983).

Organic Matter content is between 0.3 and 0.95 %; pretty low, but similar to the 0.62% found by Amir *et al.* (1991) at Gilat. Cation Exchange Capacity is equal to or somewhat lower than the 15.5 meq/100g measured by Rawitz *et al.* (1983) on a comparable loess soil. Most remarkable is the low CEC for Ofakim, despite the (relatively) high OM content (fig 35). But because CEC is also strongly influenced by soil texture, this result is not very surprising. pH in general is higher than the 7.9 found by Rawitz *et al.* (1983), except for Ofakim (also 7.9). Electro Conductivity is high again for the agricultural plots, especially for the irrigated plots. Other values are in line with the 144 µS/cm given by Rawitz *et al.* (1983).

The shift in land cover is likely to affect the local water balance of the watershed, as was found in the introduction (e.g. Savary *et al.* 2009; Bormann *et al.* 2007; Baldyga *et al.* 2008; Sahin and Hall 1996; Hernández-Guzmán *et al.* 2008). Jewitt *et al.* (2004) found that both forestry and irrigated agriculture reduce the amount of blue water by reducing runoff and/or increasing evapotranspiration (ET).

Also for the Patish, one can expect agricultural land increases infiltration and evapotranspiration. As found in the literature, crops cultivated in the Patish like wheat, maize, potato and especially watermelon and cotton have a relatively high evapotranspiration. And with regard to soil properties, measured infiltration rates for agricultural plots are higher than for natural plots.

However concerning higher ET it should be mentioned not all water consumed by the crops is extracted from the watershed. Water used for irrigation can be 'imported' by a pipe system from other (wetter) parts of the country, or from waste water treatment plants.

Although afforestation activities in the Patish watershed could not be discerned by the Remote Sensing analysis (as discussed below), they are likely to influence the hydrology of the watershed. According to the literature, the establishment of forest cover on sparsely vegetated land decreases the water yield (Hibbert 1967; Bosch and Hewlett 1982; Farley *et al.* 2005; Huang *et al.* 2003). Both Wang *et al.* (2008) and Yaseef *et al.* (2009) found considerable higher ET values for forests as compared to grasslands. On the other hand, Merzer (2007) found the afforestation of the Yatir did not affect the local water balance (of small plots), because all stored water either transpired or evaporated directly from the soil surface. Because of the relatively young age of the trees planted, it is difficult to estimate their impact on the hydrological soil properties. And therefore the soil properties measured in the locations with afforestation activities at his moment should not be seen as belonging to an afforested land cover.

The increase in urban area is difficult to analyse when looking to soil properties. Often, urban area is covered by impermeable surfaces (like tarmac, paving or roofs), so no soil is exposed to rainfall and/or rainfall runoff. And generally, urban areas show quick discharge rates with low infiltration, resulting in high amounts of runoff delivered to the drainage system (Ward and Trimble 2004). However, in arid cities as Be'er Sheva and Ofakim, the area of bare soil appears to be relatively high. Therefore it would make sense to have a look at the soil properties measured. These properties show a high bulk density and low hydraulic conductivity, so also uncovered soil will have low infiltration rates, resulting in a higher than average runoff.

Methodology

The character of the research area makes it difficult to distinguish between natural open area and agricultural area, especially in dry periods. When the soil is bare, the spectral signatures of these land use types are almost similar, so one has to rely on the shape of fields and other less specific characteristics.

The gully area surrounding the streams is easily classified as agricultural area. Because this area is relatively wet, there is more vegetation than in other natural areas. Therefore the chance is high it has spectral characteristics closer to agricultural area than to natural area.

On aerial photographs (with higher resolutions), the activities regarding the creation of terraces and limans and afforestation are visible, while they do not appear in the Remote Sensing analysis. Because of the scale of these activities compared to the scale of the images (30x30m), they are ignored in the classification results. While at least the terraces and limans will have a considerable impact on the hydrology of an area, and also the trees once they have grown to a certain size.

The edges of built area (towns etc.) are not always sharply distinguishable, making it difficult for the program to define the edges of the segments. This has as result in the classification the edges of some built areas vary over the years, while it is unlikely this happens in reality (it is unlikely some area is built in 1985, not built in 1998 and built again in 2002).

An extra difficulty is the presence of some military bases in the area; these have a more flexible character, and because of security reasons no aerial photographs are available.

Roads are not classified in the first two years (1985/1991), however most of them are already present at that moment. Probably they are too small, and become visible after having increased in the more recent years.

Another complication for the class of built area is the appearance of houses and greenhouses in the agricultural area in the North-West. Because of the scale of the images (30x30m), they are difficult to distinguish. Often this results in mixed segments, being classified as natural (bare) area, or as town.

Like mentioned about the land cover change maps, some classes are very small and can be ignored. This is especially true for the classes 'town to agriculture' and 'town to nature', because such land cover changes are unlikely, as explained above.

The graphs and tables with the (relative) area of the different land cover classes in the Patish show some different between the spring and fall period. Area of town for fall 1991 probably is classified too low; when comparing the maps especially Be'er Sheva in the South-East is small as compared to the spring. Spring 2002 shows too few agriculture as compared to the fall period, so probably the 'dip' between 1998 and 2010 is not correct. And finally, in general the area classified as agriculture in the fall is smaller than as classified in the spring (vice versa for natural area). As mentioned above, the fallow (bare) agricultural lands are difficult to distinguish from natural open area, especially in the dry season when the winter crops have been harvested.

Despite these probable errors, are the graphs of the land cover mutations pretty similar; classified land cover changes for spring and fall are in the same range.

A concluding remark on the Remote Sensing procedure; contrary to the initially applied ISODATA analysis, is the current analysis not really automated, but very reliant on knowledge based input from the user. This makes it more difficult to repeat, and less applicable for other (comparable) areas. Another consequence is no statistics on the quality of the classification results could be derived; the segments were checked and if necessary reclassified manually. So there was no classification on pixel scale, and because of the adaptations made an accuracy assessment afterwards would not make much sense.

The measured hydraulic conductivity is remarkably high (when compared to values given in literature). A possible reason could be a difference in methods applied; most analyses found did not use a mini-disk infiltrometer. This suggests the method used overestimates the infiltration rate.

The effect of crusting of the soil under rain storms is not included in the analysis. The soils in the area are prone to crusting (according to literature), which can have a large influence on infiltration and runoff characteristics.

When comparing the soil type as derived by the PSA, some variation within the watershed (even at plot scale) can be observed. But this variation appears to be throughout the whole watershed, and is in line with the soil map available of the area. And in general, soil texture measurements using the PSA turn out to be less reliable (as expected).

Because the forest was not really developed, no comparison could be made between forest and open natural area. According to literature, the development of a forest on natural open area will affect the soil properties. These effects could not be included in the research, because of the early development stage of the forest.

Measurement of biomass, element concentrations, Sodium Adsorption Ratio, Saturation Point, Cation Exchange Capacity, pH, and Electro Conductivity did not really contribute in achieving the research goals. They give some general information on the soil, which could be used to check for irrigation or other management practices, but these characteristics are not really soil hydraulic characteristics.

For the rainfall analysis only a few long term rainfall records were available, making it difficult to make a reliable long term analysis. Further causes the irregular rainfall pattern in this area for a high variation in rainfall amounts, which adds to the difficulty of deriving trends from the data.

The stations inside the Patish show a considerably similar pattern; however even on this scale the spatial variability can be pretty high. Outside the watershed the stations in the North are of low value for a long term analysis, because of the short period covered by the record. The stations in the South show remarkably few variation, both spatially and temporal. However, even for these stations the value of R^2 is not so high, emphasising the difficulty to create a good trend line.

6. Conclusion & Recommendations

To come to the conclusion of this research, the research question will be answered. Before reaching there, first an answer to the research sub questions will be sought. At the end some recommendations for further research will be given. For clarity, each (sub)question will be repeated before the answer found in this research is given.

1. How did land cover in the Patish watershed change over the last 25 years, and how can this be related to land management practices?

Land use changes from almost 70% natural open area, almost 30% agricultural area and 5% urban area in 1985 to just more than 50% natural open area, almost 40% agricultural area and 10% urban area in 2010. Over 10% of the area of the Patish watershed changed from natural to agricultural area, and 4% of the natural area changed to town. In the natural area the land surface partly changed by the creation of terraces and limans, and afforestation practices. These latter changes could not be quantified by the Remote Sensing technology applied in this research.

2. What are the physical (and chemical) properties of the soil surface in the various landscape units, and can these be linked to rainfall/runoff relations? And (how) can this be up scaled to the larger Patish watershed?

Soil properties are examined for various plots in the Patish watershed. Most striking differences were found for the saturated hydraulic conductivity; by measuring with a minidisk infiltrometer higher infiltration rates were measured for the agricultural area, as compared to the natural area. For the chemical analyses, the effect of irrigation applied could be distinguished.

Rainfall amounts for the last 25 years were analysed for both the Patish and the larger area surrounding the Patish. For some rainfall records trends could be derived, showing an almost horizontal or slightly decreasing trend. But uncertainty is high; in general rainfall variability is high, both in spatial and temporal aspect. Amounts measured for the Patish do not seem to be out of line with the amounts measured in the surrounding area. It can be concluded the rainfall amounts do not explain for the low discharge perceived in the Patish watershed.

3. Which Ecohydrological parameters are characteristic for various landscape units, and is it possible to calculate and eventually model vertical water fluxes in the topsoil?

When comparing parameters for different land use areas, it is suggested infiltration rates are higher for the agricultural areas than for the natural areas. For the built areas, infiltration appears to be low, which would result in higher runoff during high intensity rain storms. With regard to the natural area, developments like creating limans and terraces and planting trees as in the Ambassadors Forest will affect the hydrology of these areas, probably decreasing runoff.

Concluding: What is the combined impact of land use change, land management and Ecohydrological parameters on vertical water fluxes and potential runoff in the sub-catchments of the Patish watershed?

The results found suggest there is an impact of land use change affecting Ecohydrological properties in the Patish watershed. But by lack of quantitative data no final verdict can be given on the hypothesis tested, so we cannot say that “the low amounts of discharge in the Patish watershed are caused by an increased area of both agriculture and afforested land, increasing infiltration by affecting hydraulic soil properties”. With current data available one cannot say which development will have the largest impact. Increase in agriculture seems to decrease runoff, as does the (not quantified) establishment of a forest with terraces and limans. The increase in built area meanwhile could increase the amount of runoff generated. And even in case these developments do decrease the amount of runoff, with current data available they do not explain for the low amount of runoff observed as compared to other watersheds.

Recommendations

At the end of this report, some recommendations for further research are given. Based on experience of this research, it is expected this could improve the result of this or comparable studies.

It is recommended to measure discharge for the various sub-catchments of the Patish watershed, to be able to determine runoff for the various land use units. This is currently practiced in the research conducted by Dr. Naftali Goldshlager.

More detailed Remote Sensing analysis (higher resolution) could reveal more land use classes, as this research distinguishes only four (three major classes, and the small class of 'water'). It would improve the quality of the analysis as classes like 'natural area with terraces' and 'gully area' could be separated from the other classes. However, it might be difficult to obtain such images, especially for the beginning of the research period.

It would be better if all analyses were made for all measured plots; so that also for the plots at the Ambassadors at least also the soil texture and Organic Matter content would be derived.

And it is recommended to repeat the measurements in the Ambassadors forest when the forest has been more established, and has reached a stable state with its environment. For then soil characteristics would be really representing an afforested area.

To improve the validity of this research, a better analysis of the rainfall/runoff ratio in the urban areas could be made. This should not only include soil properties, but also try to measure or estimate the area of impermeable surfaces.

Finally, the general validity of the model applied to estimate discharge for the Patish watershed could be reviewed, taking into account the comments made on the difficulties faced when modelling ephemeral streams and arid watershed in general. Besides that, the other hypothesis as mentioned in the introduction (reduction of stream flow by vegetation in the gully) could be tested.

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Appendix I: ISODATA analysis in Erdas Imagine

Originally, the Remote Sensing analysis was conducted in Erdas Imagine¹⁶. In this appendix the workflow of this analysis is described. However the results turned out to have a too low quality, it was included to show a potential analysis for other situations.

By trying various band combinations for the best result, it was decided to make use of the Principal Component Analysis (PCA), Tasseled Cap transformation (TCT), and the NDVI index, combined with the band ratio of band 5 and band 1. More detailed explanation for each procedure follows below.

Principal Components Analysis (PCA) can be used as a method of data compression. It is a technique to reduce the dimensionality of the data, by compacting redundant data into fewer bands. PCA rotates the axes of the spectral space, changing the coordinates of each pixel in the spectral space (and also the data file values). The first principal component measures the highest variation within the data (in spectral space). In n dimensions, there are n principal components – but the first few bands account for a very high proportion of the variance in the data (ERDAS 2009). Therefore, in this analysis the first principal component is selected for the analysis, however 6 components were derived. PCA was applied using Erdas Imagine, using the six selected LandsatTM bands (band 1-5, 7) as input file.

The Tasseled Cap Transformation (TCT) is another way to optimise the viewing of data, most specific for vegetation studies. By a linear combination the data space is rotated to present a specific axis. Because the principal axes of the data structure are not necessarily aligned with the axes of the data space, it is advantageous to rotate the data space in such way that one or two of the data structure axes are aligned with the viewer (X and Y) axes. By doing this, you could view the axes that are largest for the data structure of special interest for the application. In Remote Sensing applications, three data structure axes are defined that give the most information. First TC axis is brightness (most information on soil reflectance), second is greenness (strongly related to amount of green vegetation) and the third is wetness (related to canopy and soil moisture). For this transformation, linear transformations with specific coefficients (statistically derived) are available in e.g. Erdas Imagine (ERDAS 2009; Watkins). For all TC transformations the Landsat 5TM sensor was selected, with the TC coefficients as supplied by Erdas Imagine. For the input consisted of six comparable bands, it was chosen to apply the same transformations, to be better able to compare the results. Because canopy can be recognised very well by the NDVI index, for this analysis just the brightness component was selected.

The Normalised Difference Vegetation Index (NDVI) is a method to measure and monitor plant growth, vegetation cover and biomass production using multispectral data. NDVI is calculated by this formula: $NDVI = (NIR - Red) / (NIR + Red)$. In the visible red-light region of the spectrum chlorophyll absorbs a considerable part of the incoming sunlight, while in the near-infrared region the structure of the leaf reflects a considerable part. Therefore growing, healthy vegetation has a low red-light and a high near-infrared reflectance, and a high NDVI value. NDVI values range between 1.0 and -1.0. High values (close to 1.0) indicate high amounts of green vegetation. Low values (near and below 0) indicate non-vegetated surfaces (like rock, soil and water) (US Geological Survey 2010). For LandsatTM bands: $NDVI = (band\ 4 - band\ 3) / (band\ 4 + band\ 3)$, which was calculated using Erdas Imagine.

In LandsatTM band 1 is capable of differentiating soil and rock surfaces from vegetation. Band 5 is capable to separate forestlands, croplands and water bodies (Rahman 1997). Using band ratios (dividing one band by another) is a method to make spectral enhancements for Remote Sensing

¹⁶ Erdas Imagine 2010 Version 10.1. Copyright © 1991-2009 ERDAS, Inc.

analysis. For example, it is applied to study lithological mapping or structural geology structures. One of the band ratios used in these studies, is dividing LandsatTM band 5 by LandsatTM band 1 (Gad and Kusky 2006; Inzana *et al.* 2003). By experimenting with band combinations, it appeared the band ratio 5/1 is able to distinguish between urban area and bare soil surface. Where the separate bands were not able to make a clear distinction, dividing band 5 by band 1 improved this ability. Urban area has a relatively high reflectance in band 1, and a lower reflectance in band 5. The natural area (mostly bare soil) has a low reflectance in band 1, and a relatively high reflectance in band 5. Because the soil is mostly dry, soil will have a higher reflectance. However, it should be noted both the urban and natural show a mixed pattern, making the result more complicated. But because the distinction between urban and natural area was found lacking in the analysis of the 'normal' bands and the NDVI index, this band ratio was calculated using Erdas Imagine, and added to the analysis.

After applying these transformations/calculations, the (four) bands produced were stacked in a new output file. This raster file was used as input for an unsupervised ISODATA classification. The number of produced classes was 60, with a convergence threshold of 0.950. Maximum iterations was set at 15 (which was never reached). Other settings remained in default (Skip factors for X and Y were 1). The 60 produced classes were manually clustered in three land cover classes (+ one extra for 'no data'). This was done changing the column 'class name' into one of the following numbers (representing the different classes).

0. No data (Area outside of study area)
1. Agricultural
2. Natural open area (including water / gully areas)
3. Town (Urban areas + roads)

The output was saved and analysed.

The final step of the classification is the post classification process. Subsequently, the 'recode', 'clump', 'eliminate' and 'neighbourhood' operations were carried out using Erdas Imagine.

By applying 'recode' the 60 created classes are reduced to three land cover classes (plus one for 'No data').

The 'clump' operation identifies clumps of the different classes (based on 8 connected neighbours), after which 'applying eliminate removes clumps smaller than 20 pixels, and backfills the created open ware with surrounding classes. And finally the 'neighbourhood' operation simplifies the picture some more; by applying a majority filter class values are based on the surrounding class values.

Finally, the result is shown below (fig 47); the three classes are as displayed in the legend, while the fourth class covers the area outside the watershed (displayed in white for that reason).

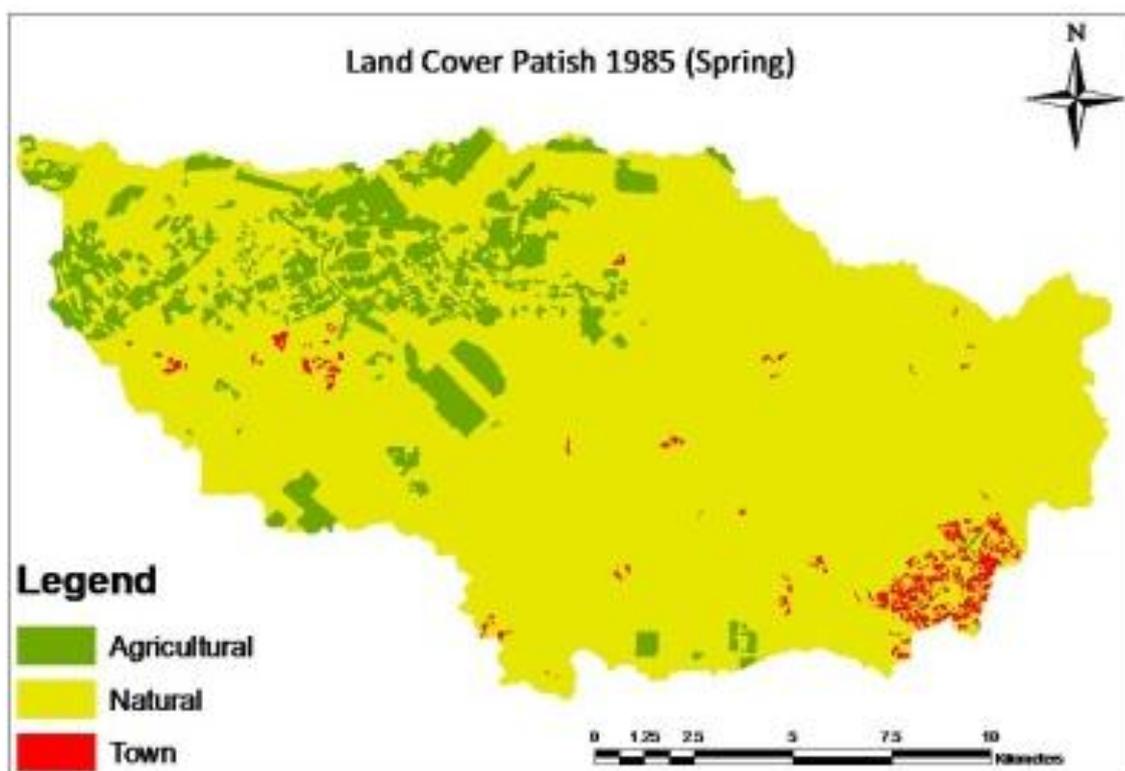


Figure 47 Land cover of the Patish watershed; spring 1985

Afterwards, an accuracy assessment was carried out (using Erdas Imagine). 200 stratified random points were added, with a minimum of 50 points for each of the three classes. These points were shown in the viewer, and subsequently checked (manually) by comparing them with the original data and aerial photographs (made available by the SERS¹⁷ and Google Earth¹⁸). With this information, an accuracy report was calculated. An example is shown below (fig 48).

¹⁷ SERS = Soil Erosion Research Station (Midreshet Ruppim, Israel)

¹⁸ www.earth.google.com

ERROR MATRIX

Classified Data	Background	Reference Data		
		Class 1	Class 2	Class 3
Background	0	0	0	0
Class 1	0	40	15	0
Class 2	0	14	73	8
Class 3	0	0	6	44
Column Total	0	54	94	52

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Class 0	0	0	0	---	---
Class 1	54	55	40	74.07%	72.73%
Class 2	94	95	73	77.66%	76.84%
Class 3	52	50	44	84.62%	88.00%
Totals	200	200	157		

Overall Classification Accuracy = 78.50%

----- End of Accuracy Totals -----

KAPPA (K[^]) STATISTICS

Overall Kappa Statistics = 0.6627

Conditional Kappa for each Category.

Class Name	Kappa
Class 0	0.0000
Class 1	0.6264
Class 2	0.5631
Class 3	0.8378

Figure 48 Error Matrix for the classification of spring 1985

The producers' accuracy shows what percentage of a particular class is correctly classified. It is calculated by dividing the number of correct pixels by the actual ground truth pixels for that class (Natural Resources Canada 2005).

The consumers' accuracy shows what percentage of a particular class corresponds to the ground-truth map. It is calculated by dividing the number of correct pixels by the total amount of pixels assigned to that class (Natural Resources Canada 2005).

The Kappa coefficient is a statistical measure of the agreement between two maps (e.g. a classified map and a ground-truth map), where coincidental agreement is taken into account. Because pixels can be assigned correctly by chance, the kappa value accounts for this random portion (Natural Resources Canada 2005).

For the spring period, the following five land cover maps were derived (fig 49).

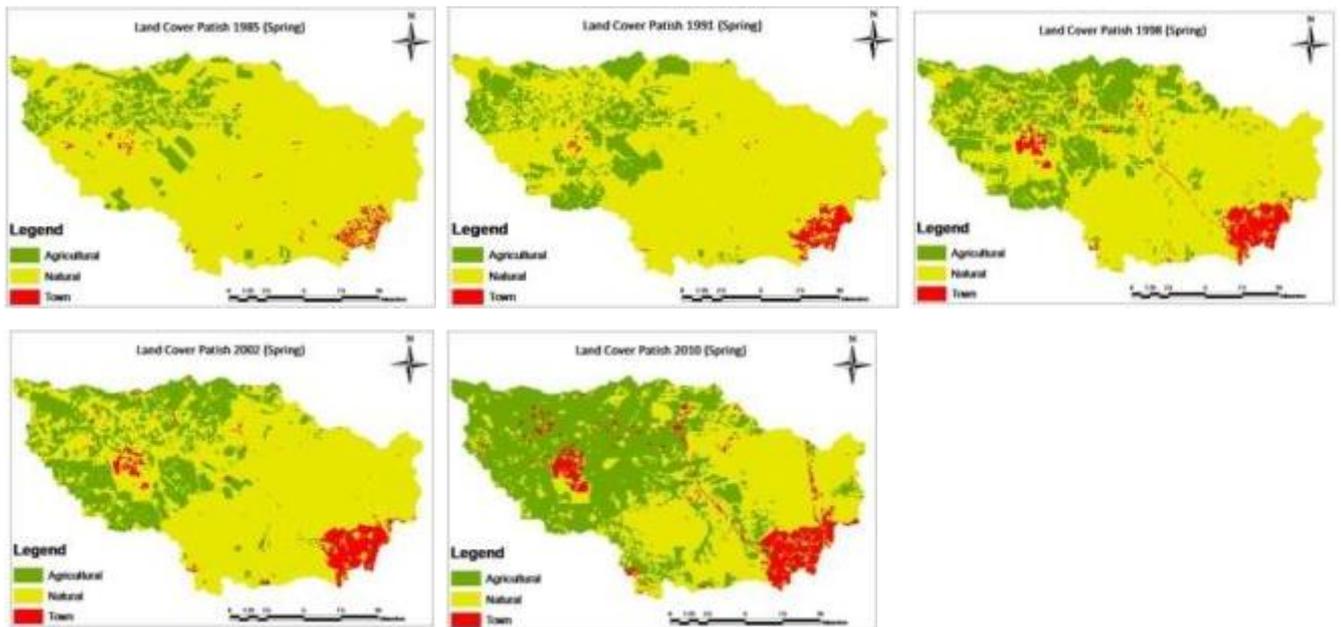


Figure 49 Classification results for the Patish watershed in the spring period

The (South) East of the Patish watershed is characterised by natural open area, where the (North) West shows agricultural areas. Over the years, these agricultural areas increase in the West. Two major towns can be discerned; Be'er Sheva in the South-East, and Ofakim to the West.

For fall there were only four land cover maps (fig 50).

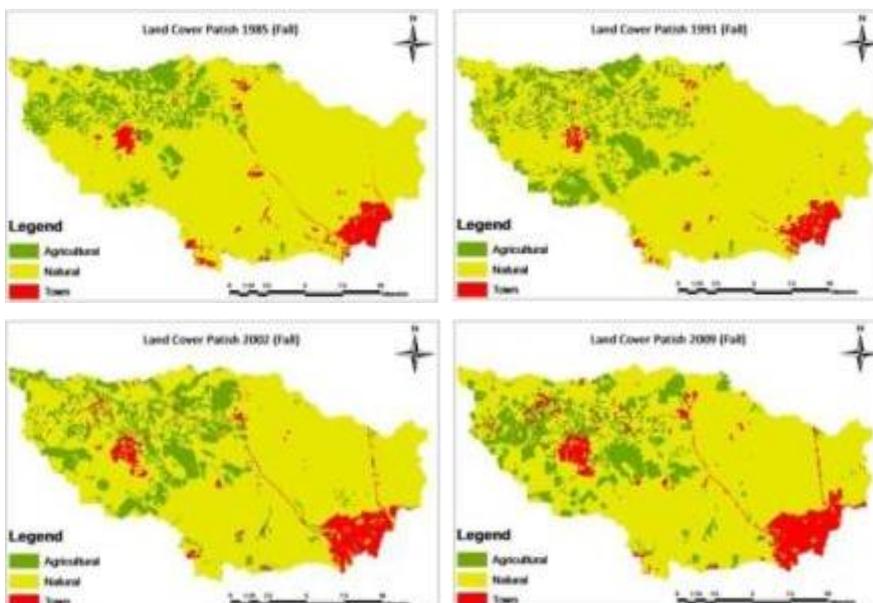


Figure 50 Classification results for the Patish watershed in the fall period

In general, the picture is the same as for the spring; natural area in the East, and more agriculture in the West, with clearly (even better) visible the town of Be'er Sheva and Ofakim. But agricultural area seems to be smaller than during spring.

To assess the accuracy of the classification, the results of an accuracy assessment are presented. Producers' accuracy varies between 70% and 90% for spring, and between 56% and 96% for fall. Users' accuracy varies between 65% and 96% for spring, and between 53% and 94% for fall. Overall classification accuracy ranges from 78.50% till 83.50% for the spring classification, and from 71.50%¹⁹ till 83.50% for the fall period. Overall Kappa statistics are between 0.6627 and 0.7475 for spring, and between 0.5560²⁰ and 0.7549 for fall (table 12 and 13).

Table 12 Classification accuracy assessment for spring classification

Classified image	Producers Accuracy			Users Accuracy			Overall Accuracy ²¹	Kappa Statistics ²²
	Agric. ²³	Natural	Town	Agric.	Natural	Town		
Spring 1985	74.07%	77.66%	84.62%	72.73%	76.84%	88.00%	78.50%	0.6627
Spring 1991	72.58%	80.72%	83.64%	77.59%	72.83%	92.00%	79.00%	0.6771
Spring 1998	77.46%	86.30%	85.71%	87.30%	72.41%	96.00%	83.00%	0.7422
Spring 2002	83.05%	85.54%	81.03%	79.03%	80.68%	94.00%	83.50%	0.7475
Spring 2010	89.09%	70.33%	81.48%	65.33%	85.33%	88.00%	78.50%	0.6736

Table 13 Classification accuracy assessment for fall classification

Classified image	Producers Accuracy			Users Accuracy			Overall Accuracy	Kappa Statistics
	Agric.	Natural	Town	Agric.	Natural	Town		
Fall 1985	80.33%	83.51%	92.86%	90.74%	84.38%	78.00%	84.50%	0.7549
Fall 1991	76.36%	78.22%	95.45%	73.68%	84.95%	84.00%	81.50%	0.7072
Fall 2002	56.60%	72.53%	83.93%	53.57%	70.21%	94.00%	71.50%	0.5560
Fall 2009	68.52%	81.72%	83.02%	67.27%	80.00%	88.00%	78.50%	0.6633

Because it turned out the area of natural land was overestimated, and the variations between the different classes were higher than could be expected (or even be possible), this analysis was reviewed, and discussed.

Because the results could not be improved by staying with this analysis, it was decided to apply another analysis, which is included and described in the regular part of this thesis.

¹⁹ Caused by the low score for fall 2002; if this is neglected, value will be 78.50%, which is equal to the spring

²⁰ 0.6633 if 2002 is neglected

²¹ Overall classification accuracy

²² Overall Kappa statistics

²³ Agric. = Agricultural