Using medium-high spatial resolution satellite data to monitor biomass changes in the Dead Sea Basin[1]

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Abstract

The area of the Dead Sea Basin is about 47,000 square kilometers. Rainfall in the Basin is limited to winter months; it varies from about 500 mm/ yr in the northwestern highlands to less than 100 mm/ yr in the valley floor. The Dead Sea Basin has been affected by the political and demographic changes in the region. The land cover is mostly open with little vegetation; this is a fragile ecosystem vulnerable to anthropogenic impacts (e. g. grazing, tourism and expansion of built- up areas). Several areas in the Dead Sea Basin have become degraded through deprivation of freshwater, through expansion of human settlements, and through inappropriate land use. Water shortage and land degradation are a problem all over the Basin and these are likely to exacerbate with population growth and changes in consumption trends.

The aim of this work was to investigate the potential of using medium-high (LANDSAT TM/ETM+) spatial resolution satellite data to accurately map the changes in the spatial extent and abundance of green biomass in the Basin. Twelve spring and summer satellite images acquired on similar dates in years of similar climatic (precipitation and temperature) profiles were obtained so that changes in Green Biomass can only be attributed to long term processes and not to abrupt changes in precipitation and temperature profiles. The images spanned a period of 20 years; the earliest acquired in March 1985 and the latest acquired in March 2004. Results from the analysis indicated an overall decrease in green biomass. A similar trend was observed in the summer dataset. The loss of green biomass was higher in natural areas than in agricultural areas with greater losses than average observed in proximity to Wadis with stream flows. The role of nature as a legitimate water user of its own right was violated. Water diversion projects from the upper Jordan River Basin and the watersheds of the Dead Sea Basin have contributed along with overgrazing and other anthropogenic pressures to the observed overall loss in Biomass. Water will be needed to preserve vulnerable ecotones, corridors between biomes, natural vegetation at biodiversity hot spots and rangelands (semi- natural areas). The essential (minimum) water that nature requires to preserve key ecological processes was determined. This is imperative to conserve biodiversity and check further land degradation and desertification.

[1] This research was fully subsidized by funds available from the EU INCO-MPC funded project "A future for the Dead Sea Basin: Options for a more sustainable than today water management in the Dead Sea basin"

1. Introduction

The Dead Sea is the terminal lake of the Jordan Rift Valley. It is the lowest point on the surface of the earth, and the waters have the highest density and salinity of any sea in the world. The east and west shores of the Dead Sea are bounded by towering fault escarpments that form part of the African-Syrian rift system. The valley slopes gently upward to the north along the Jordan River, and to the south along the Wadi Araba.

The Dead Sea extends from 35°30'00 to 35°34'05 East and 30°58'01 to 31°46'01 North. Its total area is 634 km^2, while its perimeter is approximately 148 km. It lies some 1,357 feet (418 meters) below sea level-the lowest elevation and the lowest body of water on the surface of the Earth. The total surface area of the Dead Sea catchment is approximately 40,700 km^2. The major Wadis in the Dead Sea catchment are Wadi Mujib, Wadi Wala, Wadi Hasa, Wadi Draja, Wadi Arugot, Wadi Ze'elim, Wadi Zohar, Wadi Zin and Wadi Arava. The elevation ranges from 418 below sea level to 1,605 m (The mean elevation is approximately 440 m above sea level), and slopes range from 0 to 87 degrees (65% of the study area has a slope of less than 10 degrees). The coastal areas of the Dead Sea Basin exhibit complex relief characteristics with steep slopes. The highest point, the highlands around Al Tafila (1,605 m), lies near the South-eastern side of the basin.

The combinations of hot, dry summers and wet winters in the Dead Sea Basin satisfy the conditions required to classify the climate of the Basin as a Mediterranean climate. Furthermore, the Emberger (1971) method was used to define the subclasses of the Mediterranean bioclimate of the Dead Sea Basin. It was found to range from temperate and sub-humid (Al A'rrub Weather Station Readings) to hot and desert (Jericho Weather Station Readings).

The banks of the Jordan River and the Dead Sea Side Wadis, the marshes around the springs and the land depressions adorn the bare and desolate surroundings with evergreen meandering strips and Oasis. Soil moisture in these areas from springs, runoff or underground moisture compensate for the scantiness of atmospheric creating microhabitats booming with life forms. 1458 vascular plant species, 29 bats species, were recorded in the study area. In Wadi Mujib alone, 412 plant species, 40-50 aquatic invertebrates, 24 mammals, 3 amphibian, 150 birds, 21 reptile and 3 fish species have been recorded. Many of the plants in Wadi Mujib were recorded for the first time in Jordan; these are *Kickxia judaica , Ophioglosum polyphyllum , Withania obtusifolia, Polygomum argyrocoleum.*

The Dead Sea and its Basin are suffering degradation processes induced mainly by anthropogenic unsustainable development actions. In the last 30 years, the level of the Dead Sea has dropped more than 20 meters and its surface area has shrunk by 30%. The reasons for this are well known. Major water diversion projects of the waters of the Jordan River and of the Dead Sea side Wadis have reduced fresh water inputs from its pre-1985 annual average of 1,570 MCM to less than 560 MCM/yr of bad quality water (Average annual water inputs into the Dead Sea ranged between 419-559 MCM during the last 6 years). The drop in the Dead Sea water level has led to the opening up of sinkholes. 32 sinkholes opened up in recent years alongside the western coast of the Dead Sea (AIES, 2003) and the rate is has been increasing recently. The Dead Sea Basin is also living up to its name. Groundwater table levels have been dropping in several well fields at an alarming rate. The groundwater table in the Herodion Well Field is dropping at an alarming rate. The observed drop in certain wells exceeded 60 meters in the last 20 years. Groundwater quality is also degrading because of over abstraction and pollution. More than 90% of the generated industrial and domestic wastewater in the Dead Sea Basin is openly discharged without any prior treatment. Wadi Nar flows with more than 10 MCM/yr of untreated wastewater which has led to the degradation of the Wadi Bed ecosystem. Human ever growing needs for freshwater has led the riparian countries to harvest surface water thus depriving nature from its legitimate use of water. The Jordan River ecosystem suffered the most. It had a flow of 1,250 MCM of good quality water in the year 1957. Now it has a flow of less than 200 MCM/yr of Brackish and Wastewater. The banks of the Jordan River supported woodlands and underground vegetation of the Populion Euphraticae and Tamaricetum Jordanis alliance. The river banks were visited for their historic, cultural and religious values. In addition, several Dead Sea side Wadis with rainwater storm runoff and/or with permanent water from springs lost significant volumes of water due to diversion of water resources for agricultural purposes. Wadi Auja springs water was completely diverted for agricultural purposes. Ein Gedi spring water is partially used for agriculture and for industrial purposes, 35 MCM of fresh water is tapped in the Wadi Mujib Dam. The consequences of these actions were for some Wadis a striking loss of above ground green biomass and biodiversity. On the other hand, overgrazing is a problem in certain areas of the Dead Sea basin. Overgrazing has led to changes in vegetation structure in grazing areas. Annuals are being replaced with dwarf spiny vegetation with the consequences of land degradation, soil erosion and desertification.

The objective of this work is to assess the role of nature as a legitimate water user of its own right. The specific objectives are:

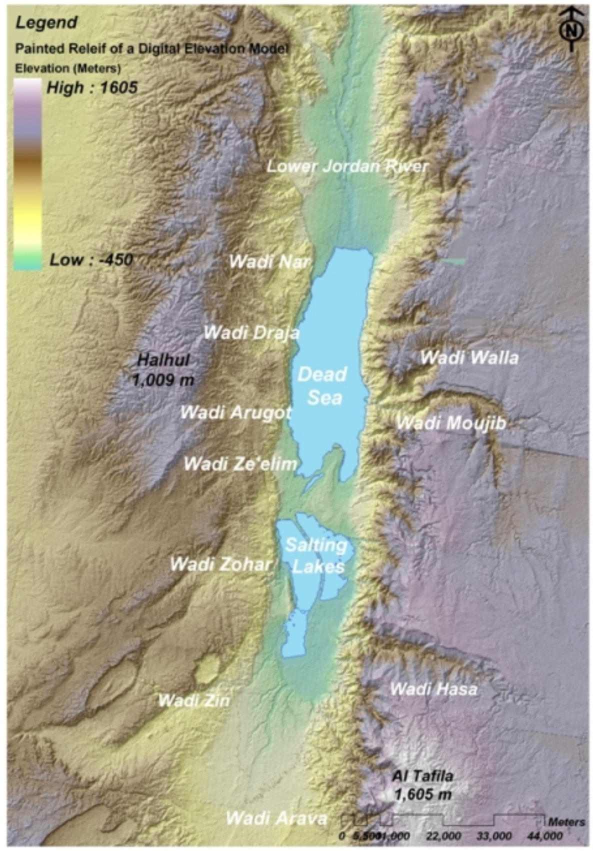
1. to quantify the overall change in above ground green biomass in natural landscape of the Dead Sea Basin;
2. to identify areas with significant losses of above ground green biomass;
3. to identify and delineate biodiversity hotspots and corridors between biomes;
4. to identify areas in need of immediate conservation and restoration;
5. to quantify water volume necessary for natural areas to maintain their unique flora, fauna and their ability to provide natural goods and services.

Satellite remote sensing provides the necessary means for gathering information of the earth's surface in a timely form. The periodic acquisition of data at a range of spatial resolutions from coarse to high provides an unlimited source of information (Chuvieco 1999). Actually, these data can contribute to a better, cost effective, objective and time saving method to quantify the location, aerial extent and intensity of land degradation processes. Satellite data from the present and the past was used to understand the spatial distribution and intensity of land degradation processes. Biodiversity record data was utilized to delineate biodiversity important areas such as marshes, land depressions and corridors between biomes. Quantitative analysis in a GIS was used to delineate the biodiversity important areas subject to land degradation processes. Biophysical models and climatic data were used to determine the minimum water requirements to maintain the delineated biodiversity important areas structural complexity and ecological functionality.

This report analyzes and describes the essential water and land needs for each unique ecosystem in the Dead Sea basin. It first describes the study area and assesses the data sets used in this study. It then describes the pre-processing measures used to geometrically, atmospherically and topographically correct the satellite images. Section 4 describes the methods used to derive the Land cover maps, to quantify the changes in above ground green biomass, and for quantifying the minimum water requirements for nature. Section 5 describes the results obtained from the analysis process and section 6 summarizes the findings and conclusions.

2. Study Area and Data sets

The Dead Sea extends from 35°30’00 to 35°34’05 East and 30°58’01 to 31°46’01 North. Its total area is 634 km^2, while its perimeter is approximately 148 km. It lies some 1,357 feet (418 meters) below sea level-the lowest elevation and the lowest body of water on the surface of the Earth. The total surface area of the Dead Sea catchment is approximately 40,700 km^2. The major Wadis in the Dead Sea catchment are Wadi Mujib, Wadi Wala, Wadi Hasa, Wadi Draja, Wadi Arugot, Wadi Ze'elim, Wadi Zohar, Wadi Zin and Wadi Arava (see Map 1). The elevation ranges from 418 below sea level to 1,605 m (The mean elevation is approximately 440 m above sea level), and slopes range from 0 to 87 degrees (65% of the study area has a slope of less than 10 degrees). The east and west shores of the Dead Sea are bounded by towering fault escarpments that form part of the African-Syrian rift system. The valley slopes gently upward to the north along the Jordan River, and to the south along the Wadi Araba. The highest point, the highlands around Al Tafila (1,605 m), lies near the South-eastern side of the basin.



Map 1 Topography of the Dead Sea Basin

The climate of the study area is highly variable. Average annual precipitation decreases along two geographical gradients; namely the latitudinal gradient as rainfall decreases from north to south and the altitudinal gradient as rainfall decreases along with the decrease in elevation. The maximum average annual rainfall of 594 mm/yr occurs in the north-western part of the study area (East Jerusalem) and the minimum average annual rainfall of 80 mm/yr occurs along a small hyper-arid longitudinal zone running along the Dead Sea coast. The mean annual precipitation in the study area is approximately 200 mm/yr (Map 3), of which approximately 60% falls in the three months of December, January and February (Figure 2).

Temperatures vary from an annual average of 17 degree centigrade in the Western side of the Basin to 24 degrees centigrade along the Salting lakes coastal area. In the western part of the study area, the dry hot season (xerothermic period) starts in April and lasts for 6-7 months up to mid October whereas in the arid eastern part of the study area the dry hot season lasts for 10-11 months from February to mid November.

Based on the above, the combination of hot, dry summers and wet winters satisfy the conditions required to classify the climate of the Dead Sea Basin as a Mediterranean climate. Furthermore, the Emberger (1971) method was used to define the subclasses of the Mediterranean bioclimate of the Dead Sea Basin. It was found to range from temperate and sub-humid (Al A’rrub Weather Station Readings) to hot and desert (Jericho Weather Station Readings).

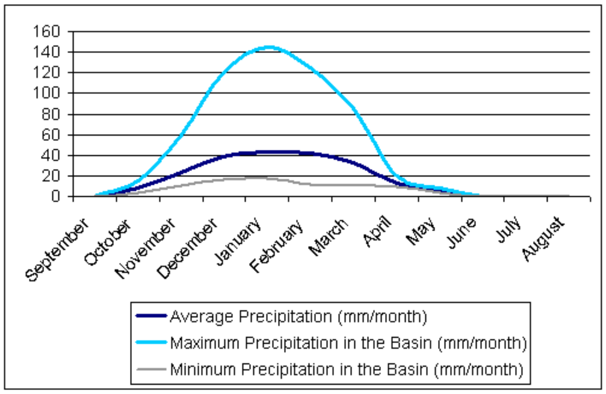
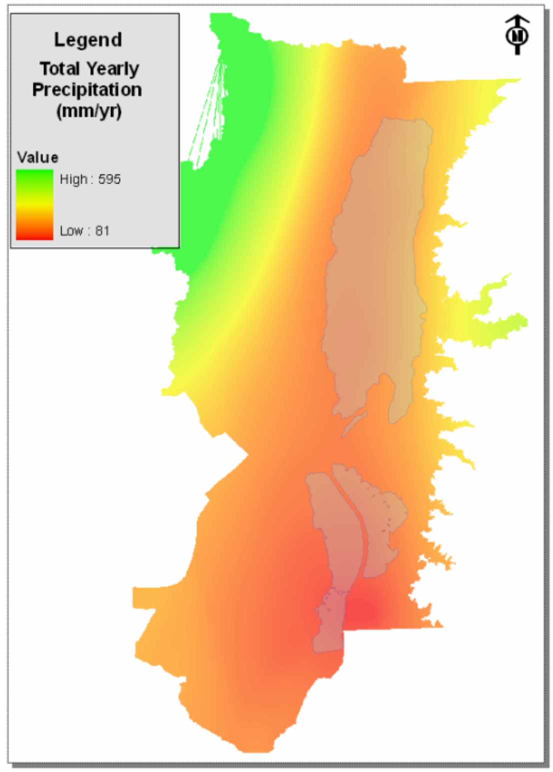


Figure 2 Monthly precipitation distribution in the study area showing precipitation patterns in the wet and dry areas of the Basin



Map 2 Average Annual Precipitation in the study area

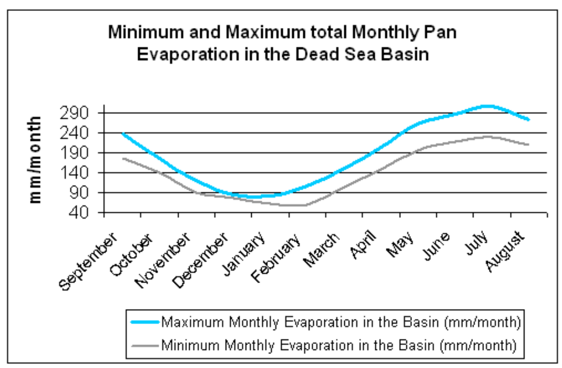


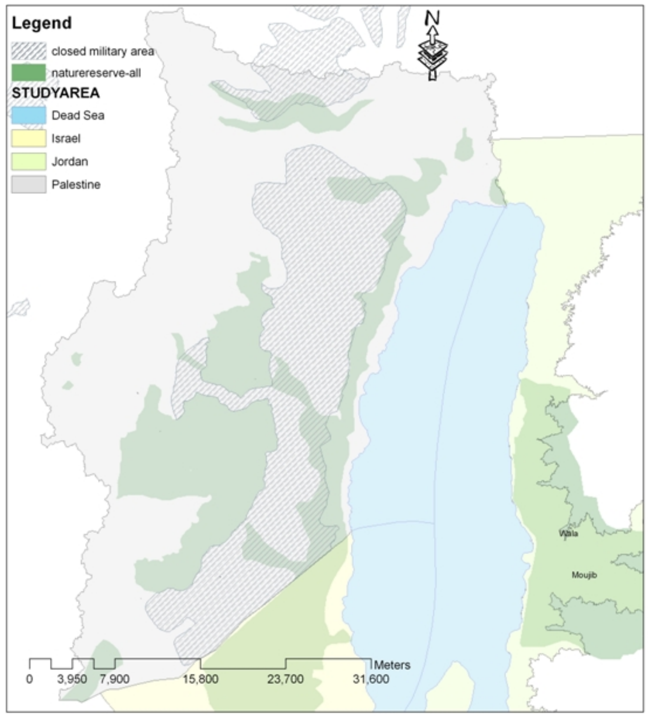
Figure 3 Minimum and maximum observed values of total monthly pan evaporation in different areas in the Dead Sea Basin

Potential evaporation (pan evaporation) in the study area varies from 1,700 mm/year in the north-western part to 2,300 mm/year in the northern Arava valley. Figure 3 shows the monthly values of potential evapotranspiration in the Dead Sea Basin. Average potential evaporation over the Dead Sea is approximately 1,980 mm/yr whereas average potential evaporation over the salting lakes is approximately 2260 mm/yr. Actual evaporation from the surface of the Dead Sea ranges between 1,300-1,600 mm/yr and depends on several climatic variable (e.g. wind speed, relative humidity, temperature) and surface water temperature and water salinity.

The land cover of the Dead Sea is mostly open with little or no vegetation. Natural vegetation in the Dead Sea Basin is mostly made of natural grasses and dwarf shrubs except in areas with a permanent water supply and in Wadis with storm water runoff. In these areas (e.g. around Lower Jordan River and water springs), the dominant vegetation are shrubs 2-3 meters high. Irrigated agriculture is concentrated in the lower Jordan River Basin around Jericho and South Shuna in Palestine and Jordan; respectively and along the Dead Sea coast in Israel. There are 109 Palestinian rural communities with a total population of 145,649, 24 urban communities with a total population of 350,123 and 4 refugee camps with a population of 16,466 (PCBS, 2002). Most of the communities are located in the Western part of the Dead Sea Basin whereas the eastern part is sparsely populated. The number of Israeli colonies and new outposts in the study area is 74 in which 164,523 Israeli colonists reside. Most of the larger Israeli colonies are as well located in the Western part of the Basin.

Approximately 240,000 grazing sheep and goats are found in the study area. These are mostly found within the West Bank of Palestine. Lower numbers of sheep and goats are found in the Jordanian side of the study area for two main reason, these are: (1) the relatively small surface study area in Jordan and (2) the difficult terrain. In Israel, sheep and goats are Sheep are kept in permanent farms with modern facilities and equipment and therefore not considered as grazing animals.

The large number of sheep and goats in the Palestinian side of the study area coupled with the restrictions on movement of herds in bucolic areas declared by Israel as closed military areas led to the deterioration of pastures accessible to Palestinian farmers (Map 3).



Map 3 Closed Military areas and Natural Reserves not accessible to the Palestinian Farmers

In the Palestinian part of the study area, the number of livestock is totally out of balance with the available grazing, which has suffered serious mismanagement. The impact of overgrazing on the vegetation is evident from the excessive uprooting of the green matter (grass and bushes), leading to reduced seeding, reduced regeneration, and the consequent loss of plant production in the next year. Also, there is a change in the floristic composition and a decline in volume and frequency of plants. This study area is ideal for addressing the problems of desertification and freshwater deprivation, because: (1) land degradation is induced by anthropogenic impacts most notably overgrazing, (2) several large scale water harvesting projects were recently completed which disturbed the ecological system and deprived nature of its minimum water requirements

The data set used in this study consists of: (1) twelve spring and summer satellite LANDSAT TM and ETM+ images acquired over a period of 20 years on similar dates in years of similar climatic (precipitation and temperature) profiles; (2) Climatological data which included precipitation, temperature, evaporation, solar incident radiation, wind speed and wind direction; (3) IKONOS very high resolution image captured in December 2003; (4) a digital elevation model (DEM) with 20 m pixels generated from a SPOT Stereo pair; (5) ground truth points of land cover types collected using a global positioning system and (7) planimetric maps.

3. Data Preprocessing

Prior to the analysis of satellite images to derive land cover and biomass data, the satellite images were pre-processed. Pre-processing of the satellite images included their atmospheric and geometric correction. The LANDSAT images were further corrected for topographic slope and aspect effects, a process most commonly known as topographic normalization. Meteorological data obtained from 30 rain gauge stations and from 12 full meteorological stations were utilized to derive climatic grids of the study area using stochastic interpolation method.

3.1. Atmospheric Correction

The objective of atmospheric correction is to reduce pixel Brightness Value (BV) variation caused by atmospheric attenuation so that variation in pixel BVs between images can be related to actual changes in surface conditions. In the case of Biomass mapping, atmospheric correction is necessary whenever more than one image is used to quantify biomass and to offer the potential of extending the reflectance-biomass algorithms produced for the year 2004 into images acquired over the same study area at any other time.

An absolute atmospheric correction method developed by Richter (1997) for sensors with a small swath angle was employed on the LANDSAT TM and ETM+ images. The method which is using the MORTRAN radiation propagation model first measures the optical depth (ground visibility) and then proceeds in the calculation of the ground reflectance for each pixel.

3.2 Geometric Correction

Geometric correction is essential in order to render the images and the auxiliary data sets geographically comparable. The DEM and the Meteorological data were referenced to the UTM WGS1984 coordinate system. Therefore, Ground Control Points were collected using a differential GPS. Since the transformation accuracy depends on the even distribution of the Ground Control Points over the image, an effort was made to space the points as widely as possible across the study areas. Characteristic features on the images such as road intersections provided excellent locations for the selection of data file coordinates. The LANDSAT images were orthorectified using a LANDSAT polynomial model that accounts for relief displacement. The modification in the LANDSAT polynomial model is that it also takes into account terrain elevation, local earth curvature, distance from nadir, and flying height above datum to get a polynomial transformation between the image and ground coordinates. It was found that the registration accuracy of the orthorectified LANDSAT image is higher than that obtained using a simple polynomial transformation. As topographic normalization will be further applied to the LANDSAT images, miss-registration between the LANDSAT images and the DEM can lead to unfavorable results.

3.3 Topographic Normalization

Several studies concerned with Land Cover mapping using LANDSAT TM reported confusion between agricultural areas and areas with natural vegetation located in topographically shadowed areas (Tanaka et. al. 1983, Milne 1986, Chuvieco and Congalton 1988, Parnot 1988, Pereira 1992, Caetano et. al. 1994, Lombrana 1995, Pereira et. al. 1997). In order to minimize the confusion, topographic normalization was applied to the LANDSAT TM and ETM+ images. Actually, the goal of topographic normalization is to remove topographically induced illumination variation so that two objects having the same reflectance properties show the same brightness value in the image despite their different orientation to the suns' position.

The topographic normalization model is derived from the algorithm

$$L_H = L_T * \cos e \,/\, [\, (\cos\theta)^{k} \,.\, (\cos e)^{k}\,] \quad (1)$$

Where

L_H = Normalized brightness values

L_T = Observed brightness values

$\cos_\theta$ = cosine of the sun incidence angle in relation to the normal on the pixel

$\cos_e$ = cosine of the exitance angle, or slope angle

k = Minnaert constant.

The Minnaert constant was empirically derived by: (i) logarithmically linearizing equation (1), (ii) obtaining a sufficiently large sampling size of pixels located on moderate to steep, east and west facing slopes (L_T Values) and on horizontal slopes (L_H Values) and (iii) estimating the value of the Minnaert constant using linear regression analysis. Actually, a Minnaert constant value ranges from 0 to 1 and is a measure of the extent to which a surface is Lambertian. Table 1 shows the values of the Minnaert constant for each band as well as their respective goodness of fit as obtained from the statistics of the regression analysis performed on the LANDSAT ETM+ 2004 image.

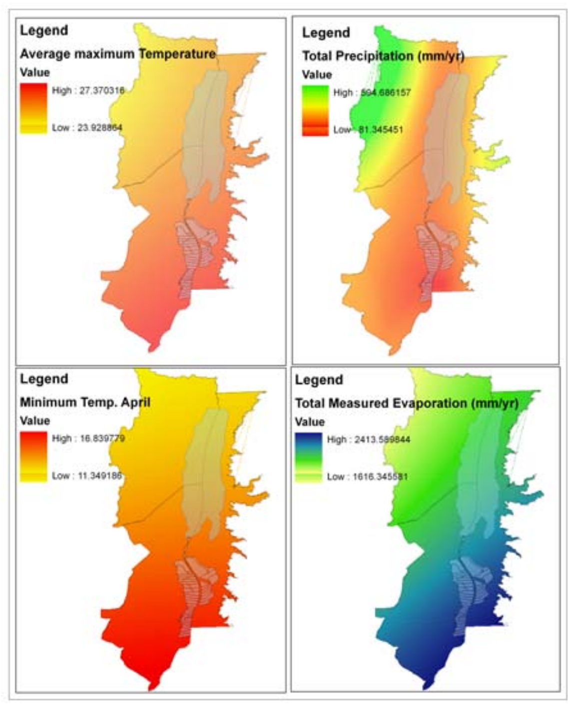
LANDSAT 2004	K	R	R^2
TM Band 1	0.651	0.811	0.606
TM Band 2	0.685	0.752	0.566
TM Band 3	0.681	0.733	0.537
TM Band 4	0.439	0.526	0.277
TM Band 5	0.544	0.722	0.521
TM Band 7	0.58	0.519	0.269

Table 1. The Empirically derived Minnaert constant (K), Pearson correlation (R) and goodness of fit (R^2) values per band for the LANDSAT ETM + scene.

It is interesting to note that R^2 values for bands 4 and 7 were less than those observed for the other bands, an indication that infrared bands are more severely affected by the topographic effect. However, the result of topographic normalization was an overall reduction in the illumination variation induced by topography.

3.4 Meteorological Data

Data from 75 rain gage stations in and around the Dead Sea Basin were collected. The temporal extent of data records differed significantly between stations. Stations with less than 10 years of information records were omitted from further analysis. Inconsistencies, spatial outliers and missing values problems were resolved using several statistical and visual data cleaning techniques. Information on precipitation from 60 rain gage stations was eventually utilized in a co-kriging stochastic model. In the co-kriging procedure, supplementary topographic and geographical information were utilized to enhance the accuracy of the derived precipitation grids. These included information on elevation, distance from the Mediterranean Sea Shore, Terrain Aspect and latitude. Unlike Ordinary Kriging methods, Co-Kriging utilizes both autocorrelation for precipitation and cross-correlations between precipitation and all the other variable types explained above to make better predictions. The mean prediction error for monthly precipitation grids was estimated at approximately 3 mm/month, and the root mean square errors was approximately 57 mm/month.



Map 4 average annual precipitation, average annual evaporation, average maximum annual temperature and average minimum April temperature.

13 meteorological stations are found in and around the study area. However, this is considered as a low number of Meteorological stations in an area with complex relief and elevation characteristics. To overcome the lack of Meteorological information, a co-kriging prediction model for the study area was developed using Israeli, Palestinian and Jordanian Meteorological station. The temporal extent of data records was significantly different between stations. Stations with meteorological record less than 10 years were omitted from further analysis. A total of 12 meteorological stations were used to derive the models (Map 4). Again, similar to the precipitation co-kriging method, supplementary topographic and geographical information were utilized to enhance the accuracy of the derived

relative humidity, evaporation, minimum and maximum temperature grids. These included information on elevation, distance from the Mediterranean Sea Shore, Terrain Aspect and latitude.

4. Methods

Land use and land cover are two approaches for describing land. Land use is a description of the way that humans are utilizing any particular piece of land for one or many purposes. Comparatively, land cover is the bio-physical material covering the earth's surface at any particular location. Together land use and land cover information provide a good indication of the landscape condition and processes that are occurring at a particular place. Time series of land use/land cover maps tell us how much of the landscape is changing, as well as what changes have occurred and where the changes are taking place. Accurate and timely mapping of land use/land cover provides vital information on the state of the environment, development trends and wildlife habitat among others. On the other hand, the assessment of changes in natural green biomass provides essential complimentary information as regards to the location and condition of the vegetation of pasture areas, of shrub lands and of forests. The assessment of pastureland productivity, predicting biomass and monitoring the vegetation health status (Reeves, 2001) in temporal and spatial scales is important for the proper management of pasturelands.

4.1 Land Cover Classification

Several methods have been developed and applied for the mapping of Land cover. These methods can be grouped into the following categories:

- Multitemporal thresholding of vegetation indices (Milne 1986. Chuvieco and Congalton 1988, Lopez and Caselles 1991, Viedma et. al. 1997)
- Multinomial logistic regression modeling (Koutsias and Karteris 1996, 1998, 2000)
- Linear and non-linear Spectral Mixture Analysis (Caetano et. al. 1994)
- Supervised classification of original bands, and/or Vegetation indices (Milne 1986, Jakaubauskas et. al. 1990) and ancillary information (Navarro et. al. 1997)
- Manual on Screen digitization of the satellite images; and
- Knowledge based classifiers (decision trees)

In this work, a supervised classification approach using the minimum distance classifier was utilized to derive the land cover classes observed in the Dead Sea Basin. Figure 1 shows the analytical framework of the image processing technique in order to derive the land cover classes.

- First: sample areas representative of each land cover type were located on the data layers and assigned a unique numerical value. The procedure resulted in a sample of cases for which the land cover type is known;
- Second: The spectral signatures of the different land cover types (sample cases) were evaluated to assess the level of spectral separability between the different land cover types. Ideally, the within land cover type spectral variance would be less than that of the between land cover types spectral variance.
- Third: The sample cases were redefined in an

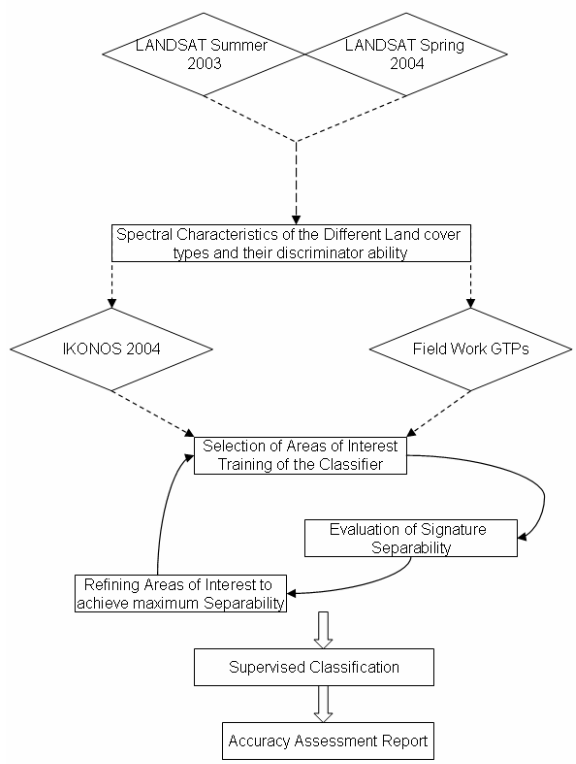


Figure 1 Analytical Framework for Land Cover Classification

iterative procedure in order to select sample cases that maximize the between land cover type spectral variance and minimize the within land cover type spectral variance.

- Fourth: A minimum distance classifier was applied using the sample cases (e.g. areas of interest) representative of each land cover type.
- Fifth: an accuracy assessment procedure based on a sampling of approximately 347 pixel comparisons between the classified image and the IKONOS image and field collected Ground Truth Points was determined. Given the complexity of digital classification, particular attention was given to assess the reliability of the results and an error matrix was determined. The error matrix was found to be a very effective tool to represent the accuracies of each category, together with both the errors of inclusion and the errors of exclusion always present in a classification (Congalton, 1991).

4.2 Quantification of Biomass

Time series information about photosynthetically active above ground biomass is one of the key elements for the effective management of Grazing land, assessment of vegetation health status in forests and for monitoring land degradation and desertification. Remotely sensed data derived from satellites have successfully being utilized for decades in assessment of pastureland productivity, predicting biomass and monitoring the vegetation health status (Reeves, 2001) in temporal and spatial scales and proved to be economically feasible measurements (Tueller 1989). Many researchers have studied vegetation growth and its productivity in two different directions. One is to establish empirical relationships between spectral reflectance and biomass (Tucker et al. 1983; Wylie et al. 1995) the other is the use of spectral reflectance to estimate the amount of absorbed photosynthetically active radiation (Choudhury 1987; Franklin 2001) for ecosystem modeling. The first method is mainly used to estimate active growing biomass and the estimated biomass is well correlated with remotely sensed vegetation indices (Tucker et al. 1983; Kennedy 1989; Thoma 1998). It should be noted that this method does not take the existing dry mass into account (Reeves 2001). The following methodological procedure was followed:

- First: Three vegetation indices were derived from each satellite image; namely the Normalized Difference vegetation Index (NDVI), the Modified Soil Adjusted Vegetation Index II and the Vegetation Reflectance (VR) model.
- Second: 20 plots (90x90 meters) were randomly selected in areas with natural vegetation. The selected areas were either pastoral areas or rangelands not accessible to farmers' herds. In each plot 2 to 4 quadrates were randomly selected. The number of quadrates in a plot positively corresponded to the degree of plant cover variability observed in the plot. The quadrate's dimensions ranged between 2 meter square quadrates to 4 meter square quadrates depending on the degree of plant species diversity observed in the quadrates.
- Third: The harvested above ground green biomass from the quadrates was dried for several days in the oven at 75 degrees centigrade and weighted.
- Fourth: Kriging stochastic interpolation was used to derive a continuous above ground green biomass surface for each plot.
- Fifth: The plots were stacked in a GIS over the vegetation indices to derive an empirical relation between NDVI and the measured biomass, between MSAVI II and the measured biomass and finally between the VR and the measured biomass. For the derivation of the empirical formulas, the vegetation indices of the spring 2004 LANDSAT image were used as the field experiments were accomplished in late February and March 2004.

- Finally: the derived empirical equations were extended in space and time to quantify above ground green biomass changes for all natural areas with low vegetation (grasses and dwarf shrubs) over the period from 1985 to 2004.

4.3 Quantifying the minimum water requirements for nature

The role of nature as a legitimate water user of its own right was assessed. Diverted water flows from the Upper Jordan River Basin and the contributory watersheds and the overexploitation of natural goods has contributed to land degradation and to the loss of biodiversity. Work focused on determining the essential (minimum) water that nature requires to preserve key processes. Water will be needed to preserve vulnerable ecotones, corridors between biomes, natural vegetation at biodiversity hot spots and rangelands (semi-natural areas). The latter is necessary to reduce the anthropogenic pressure on natural areas. The quantity of water required for natural and semi-natural areas was determined using biophysical models. This information can be synthesized with the current and future agricultural, Domestic, Industrial and tourism sector water needs in order to derive practical recommendations for the conservation of natural landscape and natural processes (Figure 2).

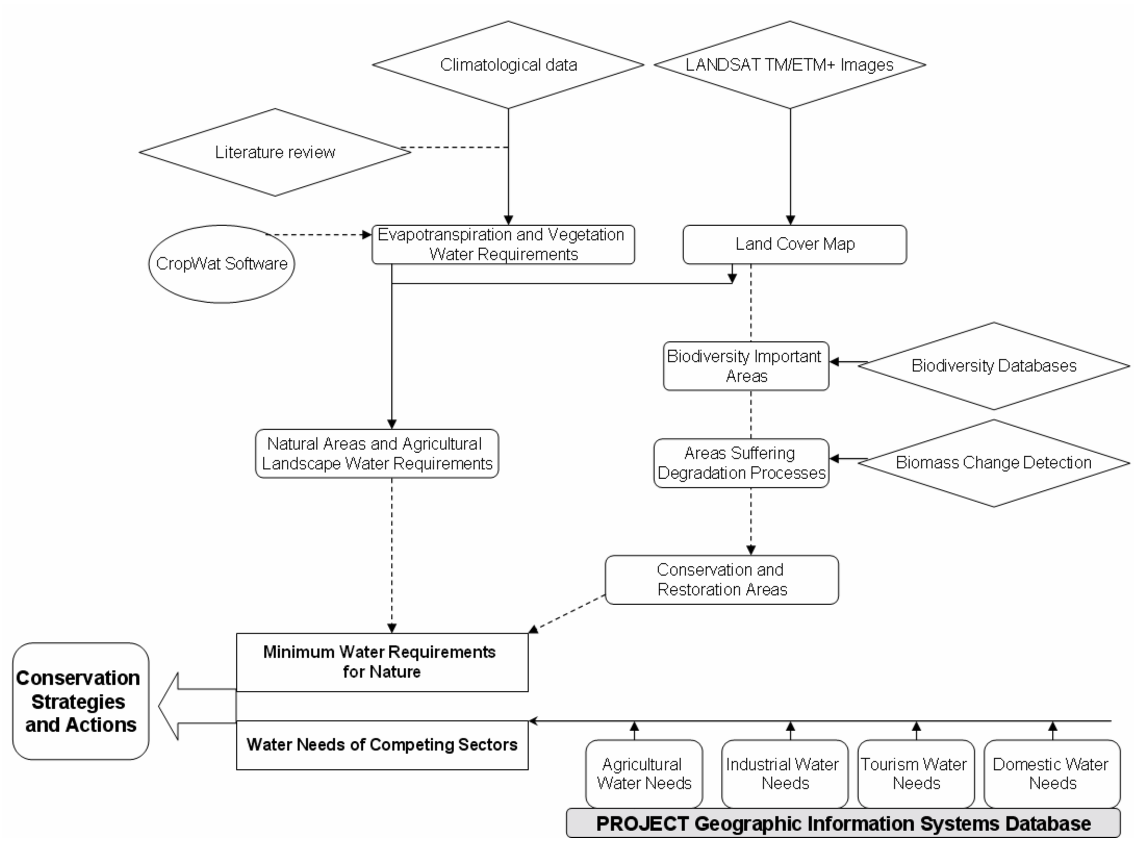


Figure 2 Analytical Framework for assessing the minimum water requirements

First: A literature review of all available Biodiversity databases were harmonized and integrated into a GIS and a biodiversity index map was derived. The Hebrew University Databases provided a useful source for understanding the distribution of recorded plant and animal species in the study area. ARIJ flora and Fauna database listed the IUCN classification of the species into threatened and endangered species and both Feinbrun's 1991 Analytical Flora and Zohary's

Flora Palestina provided information on the abundance of the different plant species found in the Dead Sea.

Second: The biodiversity index map was used to delineate the biodiversity important areas and the corridors, located in valley floors, connecting the biodiversity important areas were as well delineated. Attention was made that the delineated biodiversity important areas contained most of the habitats where the endangered, threatened and rare species were recorded. Zoological and botanic information on the range of these species was also taken into consideration.

Third: Information on above ground green biomass changes from the year 1985 to the year 2004 was integrated into the Land cover maps. Natural areas showing a trend of biomass loss were identified as areas subject to land degradation processes.

Fourth: Evapotranspiration values for the study area were calculated. Evapotranspiration are two processes that cannot be separated over land areas. These are (1) evaporation which is defined as the change of water state from liquid to vapor. Sunlight aids this process as it raises the temperature of liquid water. The rate of evaporation is highly variable and depends of factors such as temperature, humidity of the air mass, wind speed and amount of solar radiation and (2) Transpiration which is a biological process whereby plants pull water from the soil and loose it through evaporation from their tissues through the stomata of the leaves. Rates of transpiration would be affected by, temperature, wind speed, humidity, plant type, amount of cover and the amount of water in the soil. Transpiration proceeds almost entirely by day under the influence of solar radiation. At night the pores or stomata of plants close up and very little moisture leaves the plant surfaces. Evaporation, on the other hand, continues as long as heat input is available (Wilson, E.M., 1990). The Penman-Montieth method was used for estimating reference evapotranspiration in the study area after modification by the Food and Agriculture Organization (FAO) of the United Nations; The FAO modified the Penman Montieth method and developed the CROPWAT software to estimate the reference evapotranspiration. The Modified Penman- Montieth equation can be simplified as follows:

$$ET_0 = [0.408\ \Delta\ (R_n - G) + \gamma\ (900/\ (T + 273))\ U_2\ (e_a - e_d)]\ /\ \Delta + \gamma\ (1 + 0.34\ U_2)$$

Where:

ET_0	:	reference crop evapotranspiration (mm/day),
R_n	:	net radiation at crop surface (MJ /m²/ day),
G	:	soil heat flux (MJ /m²/ day),
T	:	average temperature (C°),
U_2	:	wind speed measured at 2m height (m/s),
$(e_a - e_d)$	:	vapor pressure deficit (Kpa),
Δ	:	Slope vapor pressure curve (Kpa/ C°),
γ	:	Psychometric constant (Kpa/ C°) and
900	:	conversion factor.

Fifth: In order to calculate the actual water requirements of natural plant species, the plant species coefficient should be determined. Different natural plants use varying amounts of water. Little research has been done to valuate the plant species coefficient (KC) in the Mediterranean Basin. Accordingly the water needs of plants per species could not be determined. However, few studies (e.g. Kite et al, 2000) has estimated the Kc values of Mediterranean plant categories. Ever green trees native to the Mediterranean climates have a Kc values between 0.4-0.6. Evergreen shrubs have Kc values range from 0.25-0.5 and native plants from arid zones Kc values average approximately 0.25. Soil characteristics as well as vegetation association types and plant abundance category were used to determine whether the lower or upper range of Kc should be used. The water needs were determined using the following equation:

Water Needs = ET_0 * Kc

5. Results

5.1 Land cover classification

The land cover types identified in the Dead Sea Basin were urban areas, road network, palm trees, banana trees, olive trees, vineyards, citrus plantations, other unclassified fruit trees, vegetables, wheat, natural trees (forest), shrubs land, Natural grass land, open space with little vegetation, open space with little or no vegetation, bare soil & rocks and fallow agricultural land and water bodies. Several sampling points were collected for each of the aforementioned land cover types. The spectral properties of the land cover types on the LANDSAT ETM+ image were inter-compared. The results can be summarized as follows:

- The three visible bands were not particularly useful for the discrimination between mixed fruit trees, olive grooves and banana plantations, these three classes had very low reflectance values which overlap in the visible bands (Figure 3).
- The near infrared (NIR) and the mid infrared (MIR) were the best spectral regions for the discrimination between vineyards and the other fruit tree classes found on the image. The NIR and MIR values of vineyards were significantly higher than the NIR and MIR reflectance values of other fruit trees; however, there is still some overlap between vineyards reflectance values in the NIR channel and the Palm trees reflectance values (Figure 3). These findings were also verified by the Euclidean-Distance separability index. The within land cover averaged Euclidean Distance was similar to the between land cover types Euclidean distance for the different fruit trees classes (table 2).
- The LANDSAT ETM+ reflectance bands did not provide sufficient separability between all fruit trees classes except for the vineyards class which is spectrally separable from the other fruit trees.
- Wheat and irrigated vegetables had similar reflectance values in all bands.

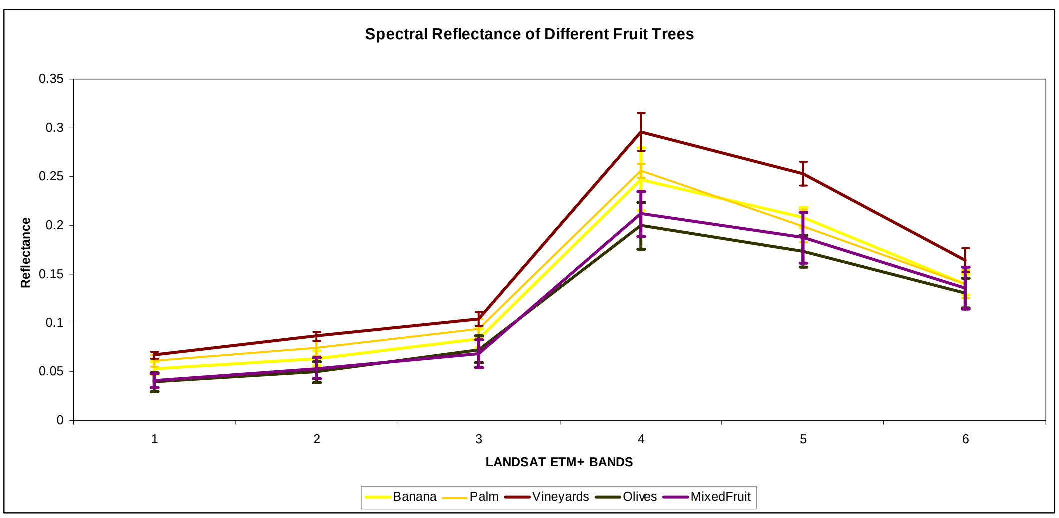


Figure 2 Spectral profiles of the different fruit tress types found in the Dead Sea Basin

Table 2 Averaged Euclidean Distance Separability Matrix the different fruit tree types found in the Dead Sea Basin. In yellow are the within group spectral variances. In orange are the between groups (fruit tree types) spectral variance with values similar to the within group spectral variances

	Wheat	Vineyard JV	Palm	Banana	Citrus	Olives	Fruit Trees
Wheat	0.1896177	0.2571188	0.2337757	0.2731029	0.2652369	0.2248768	0.2150513
Vineyard JV	0.2571188	0.162351	0.1335741	0.1665519	0.1733696	0.1597859	0.1538814
Palm	0.2337757	0.1335741	0.0682509	0.1445995	0.1324819	0.1312762	0.1320755
Banana	0.2731029	0.1665519	0.1445995	0.1567811	0.1919255	0.1995885	0.1913182
Citrus	0.2652369	0.1733696	0.1324819	0.1919255	0.1395421	0.185455	0.1902085
Olives	0.2248768	0.1597859	0.1312762	0.1995885	0.185455	0.1154179	0.1146862
Fruit Trees	0.2150513	0.1538814	0.1320755	0.1913182	0.1902085	0.1146862	0.1011312

An iterative process of refining the sampling areas in order to maximize the between land cover types separability was followed. This included deleting the sampling areas with high within group variance values and adding new sampling areas with low within group variance values. The procedure resulted in a 10% average increase in between groups' Euclidean distance. Table 3 provides information as regards to the are of each land cover class in the Dead Sea Basin.

Table 3 Areas of land cover types in the Dead Sea Basin

CLASS NAME	AREA SQ KM
Banana Grooves	20
Citrus Plantations	2
Olive Trees	67
Vineyard	55
Palm Trees	31
Fruit Trees Unclassified	129
Total fruit Trees	304
Fallow Irrigated Ag Land	97
Irrigated Ag Land at time of Image Acquisition	14
Wheat and barely	2
Total Irrigated Ag Land	113
Grass Land	97
Natural Shrubs	49
Natural Trees and Shrubs	13
Open Space With Little Vegetation	865
Open Space With Little or No Vegetation	1,392
Bare Rocks	630
Total Natural and Semi-Natural Areas	3,046
Water Bodies	886

Accuracy assessment was applied to evaluate the classification results and the overall accuracy for the classification process. An error matrix was determined and the Producer's (a measure of omission error), User's Accuracy (a measure of commission error) and the Kappa coefficient of agreement were calculated for each class and for the overall map. The Kappa coefficient measures the agreement between the classified and reference data corrected for chance agreement (Congalton and Green, 1999). A value greater than 0.80 represents strong agreement and a value between 0.40 and 0.80 represents moderate agreement. A minimum sample size of thirty points per class is generally recommended for a valid accuracy assessment for that particular class.

Table 4 Accuracy Assessment results of the classification procedure

Classified Data	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
	----------	----------	-------	---------	-----
Wheat & Vegetables	32	27	18	56.25%	66.67%
Fruit Trees	53	63	27	50.94%	42.86%
Forests and Shrubs	38	22	15	39.47%	68.18%
Deep Water	37	37	37	100.00%	100.00%
Shallow Water	45	53	45	100.00%	84.91%
OSWLV	67	77	64	95.52%	83.12%
OSWLNV	41	40	40	97.56%	100.00%
Natural Grass L	15	9	7	46.67%	77.78%
Bare Rocks	22	22	22	100.00%	100.00%
Total	350	350	275	78.57%	

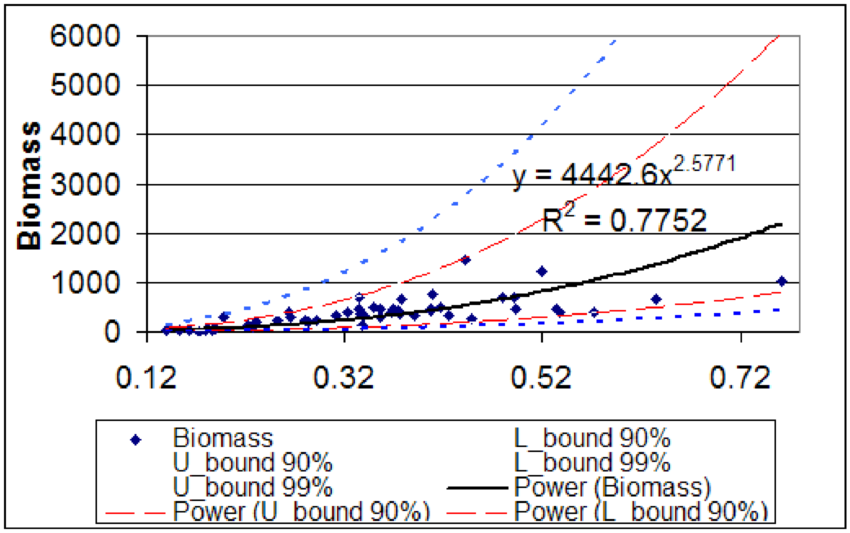
Overall Classification Accuracy = 78.57%

5.2 Quantification of Biomass

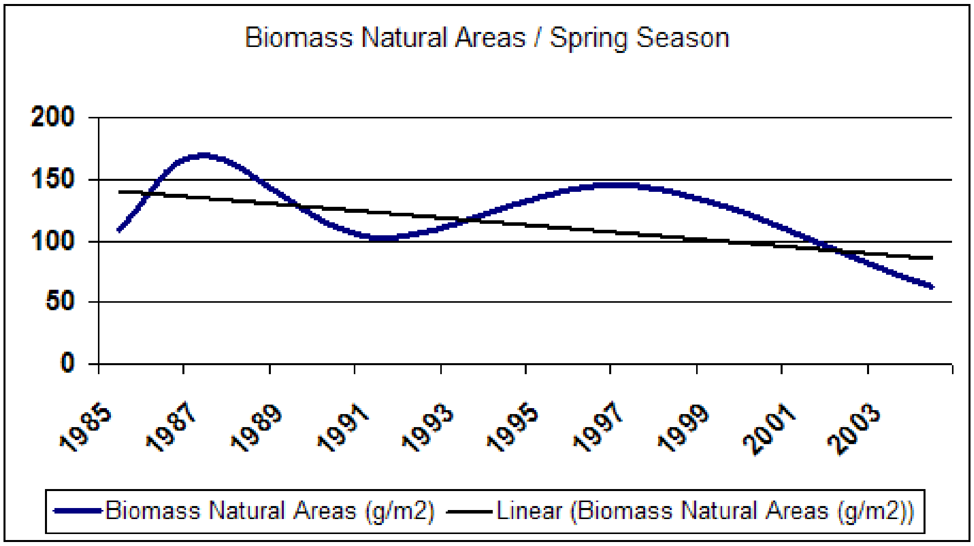
Following the atmospheric and geometric correction of the satellite images, the images were analyzed. Several spectral indices were derived that are indicators of green biomass relative abundance but not measures of Biomass. These were the Normalized Difference Vegetation Index (NDVI), the Modified Soil Adjusted Vegetation Index II (MSAVI II) and the Vegetation Reflectance Model (VR).

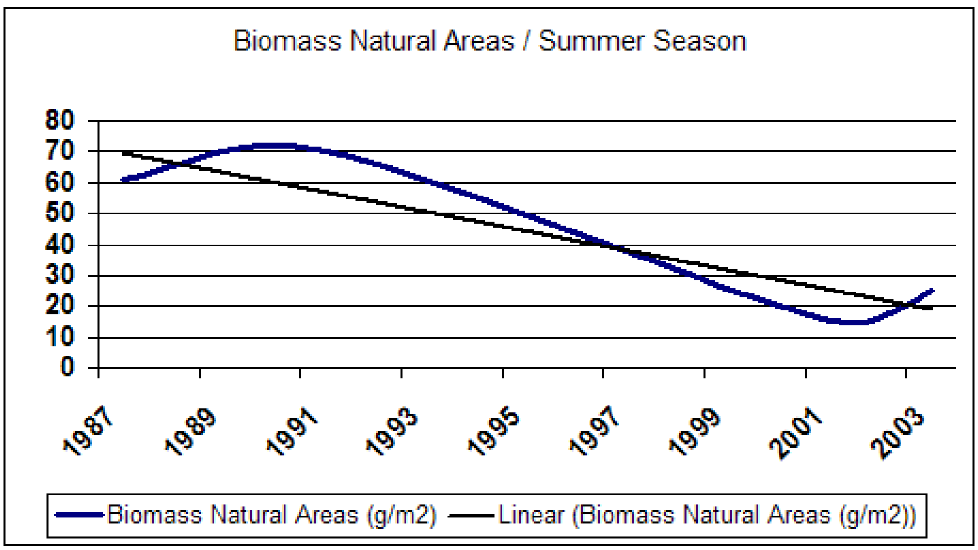
In order to measure biomass, the indicators of biomass relative abundance were regressed against a set of field biomass observations. Figure 3 shows the regression results between the 55 plots and the Normalized Difference Vegetation index values obtained from the spring 2004 image. Regression coefficients were significant at the 99% confidence level and the goodness of fit values for the regression model was 0.77.

Figure 3 to the right represents the regression equation between NDVI values and observed biomass (g/m2) for the training locations



Comparing the results from natural biomass analysis obtained from the multi-temporal set of satellite images has revealed a significant drop in average natural biomass in the study area. Figures 4a and 4b respectively show the drop in biomass as observed in spring and summer seasons over the years from 1985 to 2004.





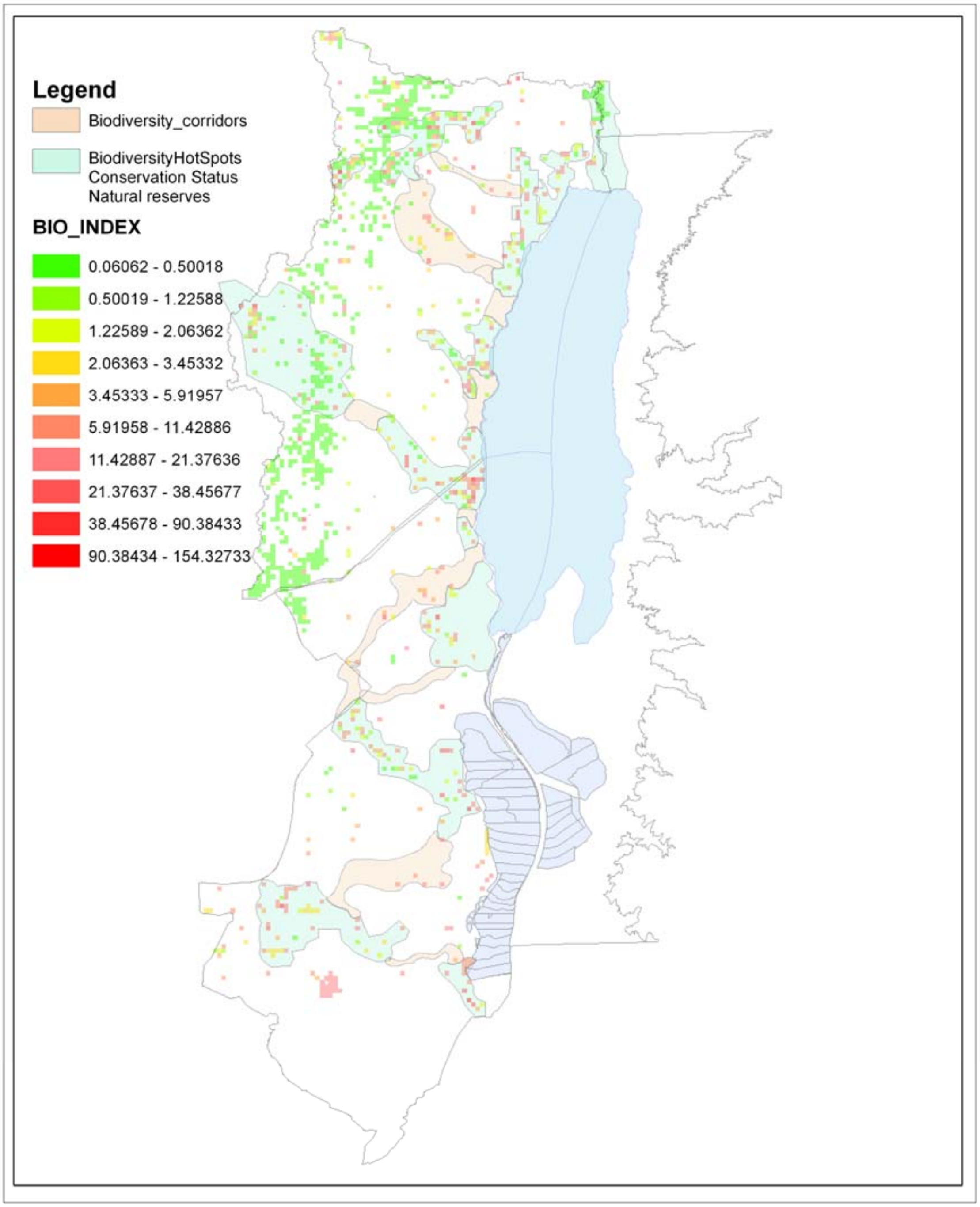
Figures 4.a and 4.b show the changes in average natural biomass in gram per square meter for the study area for the spring and summer seasons respectively.

5.3 Quantifying the minimum water requirements for nature and agricultural landscape

An index of biodiversity important areas was derived. Each record of endangered species (ES) was assigned a weight of 10, records of very rare species (VRS) was assigned a weight of 7, records of rare species (RS) was assigned a weight of 5, and records of other species (OS) was assigned a weight of 3. The measured above ground green biomass was as well integrated in the calculation of the biodiversity index map. The biodiversity index map was generated using the following equation:

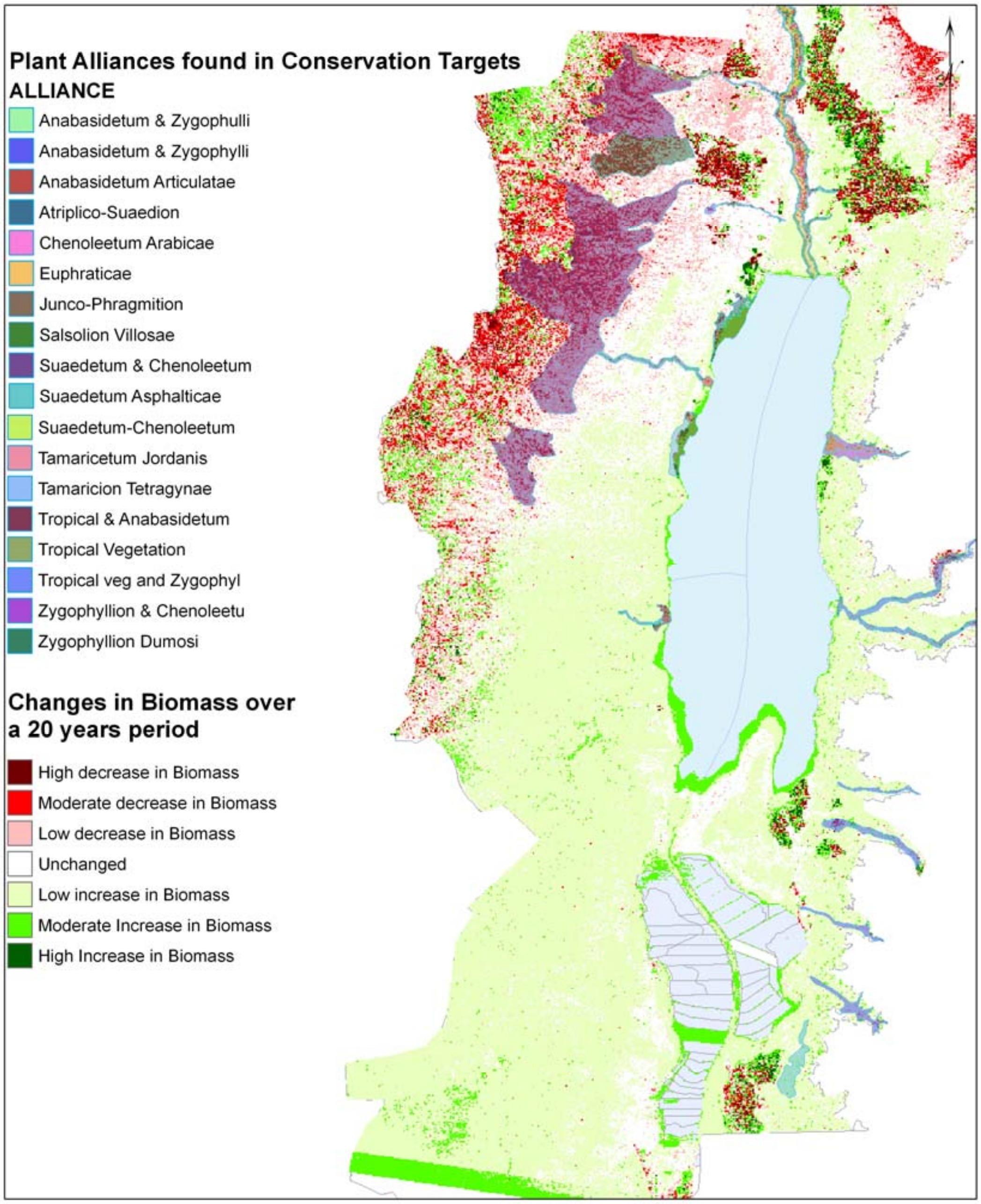
Biodiversity Index = 10*ES + 7*VRS + 5*RS + 3*OS + 0.05*Biomass

This resulted in a map highlighting natural areas with high biomass and species records (Map 5). The index map was used to delineate biodiversity hot spots and animal and plant corridors (Map 5). The criterion used for delineating hotspots was the inclusion of 95% of endangered species, very rare species and rare species habitats. No data was available for the Jordanian part of the study area, accordingly the declared natural reserves were observed for the purpose of this study as biodiversity hot spots and biodiversity corridors.



Map 4 Biodiversity Index map, biodiversity hotspots and biodiversity corridors

Map 5 shows the changes in above ground green biomass between mid 1980s and mid 2000. It was apparent that the eastern slopes of the West Bank were most hit by degradation processes. This was mainly due to (1) urban expansion and (2) overgrazing as these areas are accessible to farmers' herds. The eastern slopes closer to the Dead Sea either had no changes in Biomass or a low-moderate increase in above ground green biomass. This is mainly due to the fact that most of these areas are declared Israeli natural reserves or military closed areas inaccessible to farmers' herds.



Map 5 Biomass change detection between an averaged biomass for the years 1985 and 1978 and an averaged biomass for the years 2000 and 2004. Areas with the most negative change are delineated in blue.

In order to identify primary conservation targets, the biodiversity hot spots and corridors (Map 4) were overlaid over the aboveground green Biomass change layer and primary conservation and restoration sites were delineated (Map 5). Of all the Biodiversity hot spots and biodiversity corridors; the lower Jordan valley was the most hit by degradation processes. This is mainly due to the continuous reduction of water flow through the Jordan River as more surface runoff is tapped behind dams and (2) the increased level of pollutants and salt concentrations in the Jordan River which degrading water quality. Other biodiversity important areas that require immediate attention and restoration are (1) Wadi Zarqa Main; (2) Wadi Wala; (3) Wadi Al-Karak; (4) Wadi David (Ein Gedi

Area); (5) Al-Fashkha Springs and Wadi Nar. The latter receives 2.4 MCM/yr of surface runoff but also receives more than 10 MCM of domestic and industrial wastewater. It should be noted that the above ground green biomass increase on the Dead Sea shores cannot be attributed to improved ecological conditions. Indeed, the positive change in Biomass is due to the recession of the Dead Sea shores. These areas were covered by water and had an NDVI value of zero.

5.4 Quantifying the minimum water requirements for nature and agricultural landscape

Water flow in the lower Jordan River has been reduced from its natural flow of 1,200 MCM/yr to approximately 150 MCM/yr of poor quality water. This has resulted in a continuous degradation of the Jordan River Landscape including but not exclusive to the loss of above green biomass and biodiversity. Restoring the natural vegetation of the Jordan River Valley would first require partially restoring a minimum water flow in the Lower Jordan River and restoring the flood events on its banks. Flood events are an integral part of many river bank ecosystems with the Jordan River banks being no exception. Flood events are important for (1) irrigating natural vegetation such as evergreen broadleaf trees and shrubs that would otherwise be replaced by less water demanding vegetation such as dwarf and succulent shrubs and (2) supporting endemic forms of vertebrate and invertebrate animals. Water requirements for the endemic natural vegetation of the Jordan River Basin was determined by calculating reference evapotranspiration for the study area and evaluating the natural vegetation water requirements by multiplying reference evapotranspiration by the plant coefficient. A similar procedure was carried for Wadi Zarqa Main, Wadi Wala, Wadi Al-Karak, Ein Gedi, Wadi Nar and Wadi Qilt.

The Penman-Montieth method was used after modification by the Food and Agriculture Organization (FAO) of the United Nations; The FAO modified the Penman Montieth method and developed the CROPWAT software to estimate the reference crop evapotranspiration. The reference crop evapotranspiration was calculated for the entire Dead sea Basin. Map 6 shows monthly Reference crop evapotranspiration for the months of June, July, August and September.

The actual amount of water needed by a certain Plant association, or Plant evapotranspiration (ET_{plant}), was calculated using the plant evapotranspiration coefficient. Halophytic vegetation is common in the study area. The banks of the Jordan River and the tributaries pouring into the Jordan River and the Dead Sea were populated by Populion Euphraticae and Tamaricetum Jordanis alliances that formed dense and even impenetrable woods. They adorn the bare and desolate surroundings with an evergreen meandering strip. *Populus* occupied the frontal part of the bank while *Tamarix jordanis* was situated behind it. In the shade of these trees –Zohari described (1962) - one often encounters several species including *Lycium europaeum, Atriplix halimus, Asparagus palaestinus,* and others. These plants can tolerate fairly high soluble salt contents, which used to accumulate in summer on the dried up river sides. Kc values for these evergreen plants were estimated to average approximately 0.7. Around the Jordan River Banks, in the Lower Jordan River Valley and around the Dead Sea, Zohari (1962) described the plant life to be inhabited by halophytic vegetation occurring in confluence with brackish springs and high water table salines. These Marshes are abundant in the Dead Sea region in areas like Ein-Fashkha. The vegetation in these areas belongs to the Suaedetea Deserti Class mainly formed of the Junco-Phragmition alliance, the Tamaricion Tetragynae alliance, Atriplico-Suaedion Palaestinae alliance and the Salsolion Villosae alliance. The Junco-Phragmition alliance vegetation is found in permanently open water bodies of brackish water. The Tamaricion Tetragynae alliance vegetation is found in areas inundated during winter. The Atriplico-Suaedion alliance vegetation is mesohalophytic and found in areas where groundwater tables are close to the surface. Finally, the Salsolion Villosae alliance vegetation is found in dry areas forming the outermost belt of all halophytic vegetation and can be classified as xerohalophytes. The Junco-Phragmition alliance vegetation is mainly Reed and Rush vegetation with high to very high Kc values of 0.7-0.8. The Tamaricion Tetragynae alliance is less water demanding and has Kc values of approximately 0.4-0.5. The Suaedetum Forskalii occupies broad belts along the Banks of the Jordan River at the Back of *Tamarix jordanis* and on the elevated foreshore of the Dead Sea. These have spiny leaves and relatively low evapotranspiration coefficient (Kc) of approximately 0.25-0.35. The Salsolion Villosae alliance vegetation is mostly dwarf shrubs with Kc values of 0.25 or less.

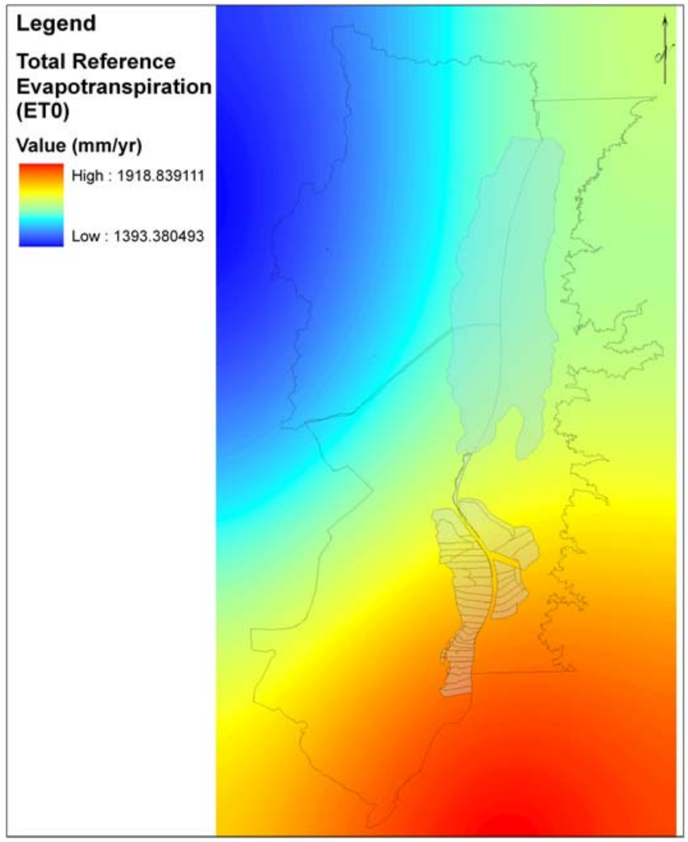
Further from the coastal areas of the Dead Sea are the Saharo-Sindian hammada deserts of Transjordan (Zohari, 1962) consisting mainly of the following plant alliances: Anabasidion Articulatae, Zygophyllion Dumosi, Chenoleion Arabicae and Suaedion Asphalticae. The former belongs to the Anabasidion Articulatae order and the others belong to the Zygophyllion Dumosi order. The Zygophylletum persists only in the low lands where the scantiness of atmospheric moisture is compensated for by runoff or underground moisture. The order comprises of winter annuals which appear only in rainy season. The plant coefficient of these annuals is relatively high (Kc 0.5-0.8; average 0.65). The perennials are mainly succulent chamaephytes which replace their larger winter leaves by minute summer leaves which reduce transpiration by 87%. The two communities of Suaedetum Asphalticae and Chenoleetum Arabicae accompany Zygophylletum. These are mainly dwarf shrubs with small succulent leaves, shallow root systems, and high osmotic values. The Kc values for these dwarf shrubs is approximately 0.25. The Anabasidetum Articulatae Typicum species are confined to Wadis, runnels, and depressions. Moisture conditions in these sites are more favorable for a richer flora and the salts are leached. The species are annuals, Tamarix or Acacia trees and Retama bushes. On average, the Kc value Anabasidion Articulatae species is 0.7.

The tropical vegetation in the Lower Jordan valley and in the Arava valley are relics of a Tertiary tropical flora which after the decline of Pliocene, took refuge mainly in the lower Jordan and the Arava Valleys occurring in the outlets of permanent and ephemeral watercourses (tropical oasis) such as in Ein Gedi, Jericho, Wadi Farah, etc. The most common trees are Acacia spp.; Zizyphus spina-christi among others. Accacia trees have a Kc of approximately 0.35 and Zizyphus trees have a Kc of 0.4. The average Kc values for these trees is approximately 0.4.

Table 5 shows an aggregation of the plant evapotranspiration coefficients for the different plant associations found in the study area.

Vegetation Types	**Habitat**	**Density**	**Kc**
Halophytic Vegetation			
Suaedetea Deserti Class	Marshes of springs or High Groundwater Tables		
Junco-Phragmition alliance	permanently open water bodies of brackish water	High	0.75
Tamaricion Tetragynae alliance	areas inundated during winter	Medium-High	0.45
Atriplico-Suaedion Palaestinae alliance	areas where groundwater tables are close to the surface	Medium	0.3
Salsolion Villosae alliance	dry areas forming the outermost belt of all halophytic vegetation	Low	0.2
Euphraticae and Tamaricetum Jordanis alliances	Banks of Jordan River	Very High	0.7
Hydrophilic vegetation			
Zygophyllion Dumosi Alliance	Low Lands in Wadis or close to surface ground water table	Annuals/Medium High	0.65
Zygophyllion Dumosi Alliance	Low Lands in Wadis or close to surface ground water table	Perennials / Medium	0.25
Suaedetum Asphalticae	Low Lands in Wadis or close to surface ground water table	Low	0.25
Chenoleetum Arabicae	Low Lands in Wadis or close to surface ground water table	Low	0.25
Anabasidetum Articulatae Typicum species	Wadis, runnels, and depressions	Medium	0.7
Tropical Vegetation (oasis)			
Acacia spp	Ein Gedi, Jericho, Wadi Fara'h, Wadi Qilt, Wadi Auja	Medium	0.35
Zizyphus spina-christi	Ein Gedi, Jericho, Wadi Fara'h, Wadi Qilt, Wadi Auja	Medium	0.4

In order to calculate the minimum water requirements for the plant alliances found in the study area, monthly reference evapotranspiration grids were calculated using Penman-Montieth method after modification by the Food and Agriculture Organization (FAO) of the United Nations. Map 6 shows the annual average reference evapotranspiration values for the entire study area. Reference evapotranspiration values ranged from approximately 1,400 mm/yr to 1920 mm/yr with the lowest values occurring in the northwestern tip of the study area and the highest values occurring in the southernmost tip of the study area. Monthly average Reference evapotranspiration for each of the conservation targets was evaluated and multiplied by the plant alliance Kc factor in order to estimate the volume of water that would evapotranspirates from the vegetated surface.



Map 6 shows the annual average reference evapotranspiration

It is important to note that this does not represent the minimum volume of water that needs to be supplied to nature in order to conserve the natural habitats but the fraction of water from that supplied that would evapotranspirates. Another significant volume of water would infiltrate through the soil. The volume of water infiltrating is variable and depends on several factors; these are: (1) the water-holding or storage capacity of the soil; (2) the permeability of the soil to the flow of water and air; (3) the physical features of the soil like the organic matter content, depth, texture and structure; and (4) the soil's chemical properties such as the concentration of soluble salts, nutrients and trace elements. For example, the crop water requirements of 1 hectare of Palm trees planted in Silty loam soil are approximately 10,000-12,000 CM/yr whereas that for the same crop in sandy soils ranges between 22,000-27,000 CM/yr. Unfortunately, there is a serious lack of information on soil texture, physical and chemical properties, only general descriptions exist.

5.4.1 Minimum Water Requirements for the Lower Jordan River

Prior to the year 1955, the Jordan River discharged an annual flow of 1,200 MCM/yr into the Dead Sea. In the early 1950's, Israel began draining the Huleh marshes (north of the Sea of Galilee). It built the National Water Carrier between 1953 and 1964: a complex of new and existing canals, pipelines and tunnels to convey water from the Sea of Galilee to the coastal plain of Israel and the Negev Desert. In 1961 Jordan began operating the East Ghor Canal in the Jordan Valley to use Yarmuk waters for irrigation further south. Jordan also built the King Talal Dam on the Zarqa River to store water for irrigation. These, in addition to smaller Jordan River valley dams are diverting approximately 120 MCM of fresh water to agricultural uses. Accordingly, the Jordan River system discharge into the Dead Sea is reduced to less than 150 MCM of domestic and industrial sewage and agricultural runoff drain. Indeed salt concentrations prior to 1958 averaged 500 mg/l, in April 1959 salt concentrations reached 2,050 and in June 1960 salt concentrations reached 2,473 mg/l. In 1958, the banks of the Jordan River and the tributaries pouring into the Jordan River and the Dead Sea were populated by Populion Euphraticae and Tamaricetum Jordanis alliances that formed dense and even impenetrable woods. These plants utilized the lightly brackish water of the Jordan River and were tolerant to salt deposition on the Banks of the Jordan River in summer months. However, Populion Euphraticae and Tamaricetum Jordanis distribution has been greatly reduced due to the diversion of water and to high increases in salt concentration by more than 500%.

The volume of water evapotranspirating from Populion Euphraticae and Tamaricetum Jordanis alliances was estimated at 130 MCM/yr. Evaporation from the Jordan River course was estimated at approximately 4.5-6.5 MCM/yr. In the Jordan River Basin, the texture of the soil changes from north to south, from fine-textured soil to silt loam and sandy loams immediately north of the Dead Sea. Water infiltration and percolation rates in saturated fine textured clay soils can be as low as 0.01 cm/hr and can increase to approximately 0.25 cm/hr in the saturated sandy loams. Deep percolation of water through soil increases natural vegetation water needs as the water becomes inaccessible to vegetation. Percolation rates in the southern part of the Jordan River are higher than percolation rates in the northern part of the Lower Jordan River Basin. Infiltration and percolation from the water course was estimated at 41 MCM/yr. Infiltration and percolation from the inundated banks was estimated at 45 MCM. The water requirements for the natural vegetation of the lower Jordan River Basin were therefore estimated at approximately 222 MCM/yr of good quality water with a total salt concentration less than 600 mg/l. Technical methods are needed to move water from the Jordan River bed to the Banks in order to provide natural vegetation with water. Another option would be to restore the natural flow of the river that floods the river banks in the winter season.

5.4.2 Minimum Water Requirements for the Dead Sea

In 1947, the total evaporation from the surface of the Dead Sea was approximately 1,650 MCM/yr. This was balanced by the discharge from the Jordan River (1,350 MCM/yr), by lateral discharges from several Wadis along the Dead Sea Shore (220 MCM/yr) and by underground lateral water and spring discharges (60-100 MCM/yr). Major water diversion projects and abstraction of groundwater drastically reduced the total volume of water discharged into the Dead Sea. This has led to dramatic changes in the Dead Sea water level and surface area. Indeed, the level of the Dead Sea dropped by 19 m in the last 25 years and its surface area shrunk from 1031 square kilometers in 1947 to 634 square kilometers in 2004 (Table 6).

Table 1: Changes in the surface area of the Dead Sea and evaporation ponds as observed from Satellite Images.

Year	Surface Area Dead Sea	Surface Area Evaporation Ponds/Israel	Surface Area Evaporation Ponds/Jordan	Total Surface Evaporation Area
1947	1,031	0	0	1,031
1965	973	16	0	989
1973	925	26	0	951
1985	676	139	105	920
1987	665	139	92	895
1991	655	139	101	894
1997	651	150	105	906
2000	640	144	116	900
2004	634	152	103	888

Average total yearly evaporation from the surface of the Dead Sea between the years 1998-2002 was estimated to range between 1,100 and 1,240 MCM/yr (Actual evaporation range between 1,250-1,380 mm/yr) of which approximately and approximately 311-351 MCM of water was pumped to the salting lakes for industrial and recreational purposes. This resulted in an average drop in the water level of the Northern Basin of 1.06 cm/yr, the equivalent of 681 MCM of water per year. Total water inputs from all sources into the Dead Sea ranged accordingly between 419-559 MCM/yr.

Accordingly, the minimum water requirements to conserve the Dead Sea water level is an increase in inputs by approximately 680 MCM/yr or by increasing water inputs by some 350 MCM/yr and drying up the evaporation ponds.

5.4.3 Minimum water requirements for the Swamps and Marshes

The marshes of Ein-Fashkha and Ghwair-Turba springs are occupied with the Suaedetea Deserti Class vegetation mainly formed of the Junco-Phragmition alliance, the Tamaricion Tetragynae alliance, Atriplico-Suaedion Palaestinae alliance and the Salsolion Villosae alliance (See Map 7 on page 23). Ein-Fashkha was declared a natural reserve by the Israeli authorities. Evapotranspiration from Ein-Fashkha was estimated at 8 MCM/yr and deep soil percolation was estimated at 10 MCM/yr. The historic discharge from Ein-Fashkha averaged 34 MCM/yr. However, two problems face the long term sustainability of Ein-Fashkha; these are the continuously declining water discharge due to over abstraction from groundwater in the Herodion well field and due to the retreating Dead Sea shores. Analysis of satellite images from 1985 – 2004 has shown that the vegetation of Ein-Fashkha is being slowly moving eastwards as the Dead Sea shores are retreating and the vegetation of the Western boundary of Ein-Fashkha is degrading. Ghwair and Turba marshes are facing similar problems. Again, it appears that vegetation is being displaced to the east and the Western Vegetation boundary is degrading. Historic water discharges from Ghwair and Turba springs combined averaged approximately 26 MCM/yr. Water discharge volumes are being also reduced due to over abstraction of ground water. The minimum water requirements to sustain the vegetation of Ghwair-Turba marshes were estimated at 15 MCM/yr.

5.4.4 Minimum water requirements for major side Wadis

These Wadis include Wadi Zarqa Main, Wadi Wala, Wadi Mujib, Wadi David-Arugot and Wadi Nar. Only Wadis with observed loss of above ground green biomass were considered for analysis. It should be noted that no vegetation degradation was observed in Wadis with little or no anthropogenic impacts. All of the Wadis discussed here are associated with different levels of anthropogenic influence such as the building of large water diversion projects (Wadi Wala and Wadi Mujib), agricultural and industrial development such as Wadi David-Arugot (Ein Gedi), and discharge of domestic and industrial waste such as Wadi Nar.

These Wadis are occupied with Hydrophilic and Tropical vegetation Alliances. The Zygophyllion Dumosi Alliance can be found in the low lands where the scantiness of atmospheric moisture is compensated for by runoff. The Zygophyllion Dumosi Alliance is usually accompanied with plants belonging to Suaedetum Asphalticae and Chenoleetum Arabicae alliances. Wadis with a permanent source of water from springs are also occupied with Anabasidetum Articulatae Typicum species. These are larger trees and bushes that occur in runnels such as in Ein-Gedi, Wadi Draja and Wadi Nar. Tropical vegetation of Accacia trees and Zizyphus Spina-Christi were observed in Wadi David-Arugot (Ein Gedi), in Wadi Draja and in Wadi Nar. Populus Euphraticae was also observed in these Wadis (See Map7).

5.4.4.1 Al-Auja Wadi

Of all Wadis in the study area, Wadi Auja suffered the highest rate of above ground green biomass loss between the years of 1985 and 2004. This is a loss of natural biomass mostly from Anabasidetum and Zygophylletum alliances. The water required by vegetation to conserve the natural vegetation in the Wadi bed and banks was estimated at 4.1 MCM/yr. Deep percolation beyond the root zone was estimated at 3.8 MCM/yr. The total water requirement by vegetation is 7.9 MCM/yr. The discharge from the Auja spring averaged 10 MCM/yr and surface water runoff was estimated by CH2MHILL (2002) to be approximately 4.6 MCM/yr. Recently, the entire volume of water from Al-Auja was diverted for agricultural uses. This has dramatic impacts on the Anabasidetum alliance vegetation. Overgrazing is another problem around Al-Auja Wadi bed which has severely degraded the Zygophylletum vegetation.

Surface water runoff in Wadi Nar is estimated at 2.4 MCM/yr. An additional 10 MCM of domestic and industrial untreated wastewater are also discharged into Wadi Nar which has degraded water quality in Wadi Nar and polluted the runnel. This has led to an overall observed degradation of the ecosystem and a loss in above green biomass. Treatment of wastewater prior to its open discharge into the Wadi is important to reverse the degradation process.

5.4.4.2 Nahal David, Nahal Arugot and Ein-Gedi Oasis

There is some loss of above green Biomass along the water courses of Nahal David and Nahal Arugot but more significantly in Ein-Gedi Oasis. While the loss of above green biomass along the water courses is due to the loss of natural vegetation, that of Ein-Gedi Oasis is most probably due to abandonment of Palm plantations. Sinkholes are opening in the palm plantations of Ein Gedi and more water is being allocated to nature. Both reasons combined have resulted in the partial abandonment of Palm plantations in the area. The two other sectors competing for water resources in Ein-Gedi are the domestic sector and the industrial sector. The industrial, domestic and agricultural water consumption was reduced from 1.4 MCM in the year 2000 to 1.2 MCM in the year 2003. Most of the water comes from the natural discharge of Ein-Gedi springs. More recently, small quantities of water are being harvested from the surface runoff of the Wadis and are being used for the domestic sector (field visit to Ein Gedi). The estimated volume of surface water runoff in Nahal David and Nahal Arugot combined is 7.9 MCM/yr and the total discharge of Ein-Gedi Springs is approximately 2.9 MCM/yr. Two factors jeopardize the sustainability of Ein-Gedi reserve; these are the opening of sinkholes and the development of groundwater wells in Beni Neim which can significantly reduce spring discharges in Ein-Gedi. Evapotranspiration from the palm plantations and natural vegetation in areas facing loss of vegetation biomass in Ein Gedi, Nahal David and Nahal Arugot was estimated at 3 MCM/yr. However, water courses in Nahal Arugot and Nahal David are laid down with coarse gravel which results in very high infiltration and percolation rates. The volume of water deeply percolating and cannot be used by vegetation was estimated at 6.9 MCM/yr (percolation rate of 3.8 cm/hr during flood events). Accordingly, the total water requirements for the conservation of vegetation are approximately 9.9 MCM/yr. In addition, further drop of the Dead Sea water level should be stopped in order to prevent further opening up of sinkholes in the reserve.

5.4.4.3 Zarqa-Main Wadi

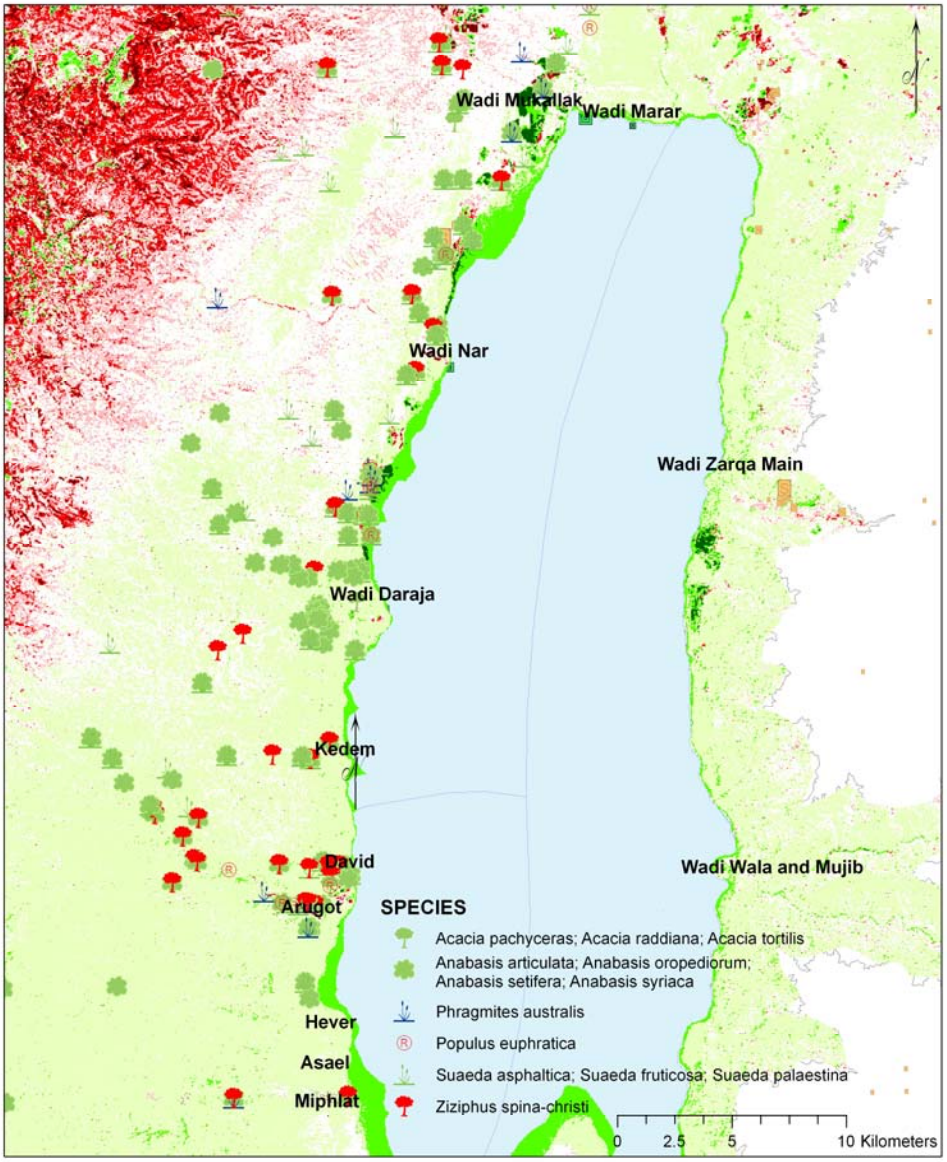
The estimated annual water flow in Wadi Zarqa-Main is 20 MCM/yr. 12 springs in the Zarqa-Main watershed discharge approximately 16 MCM of water annually and contribute significantly to water flow in the river bed. The average Chloride concentration of these springs is 420 mg/l and the total dissolved salts average 1,150 mg/l. From water quality data of the springs, one might assume that the vegetation in Wadi Zarqa-Main is mesohalophytic. There is a significant loss of above green biomass along the river bed of Wadi Zarqa-Main. The drivers of the loss of biomass are not well understood to the author. Evapotranspiration in Zarqa Main river bed located inside the study area (See Map 7) is estimated at 5.6 MCM/yr.

5.4.4.4 Wadi Wala and Wadi Mujib

No loss of above ground green biomass was observed in Wadi Wala and Wadi Mujib. It appears that the trapping and diversion of some 30 MCM/yr of water by Wadi Mujib Dam had no effect on the volume of Biomass in the Wadis. No information exists on whether the Dam had any effect on plant composition and animal biodiversity in Wadi Mujib and Wadi Wala. However, plans exist to increase the maximum capacity of the Dam to 42 MCM. Another Dam with a maximum capacity of 5 MCM/yr is planned in Wadi Wala. These combined will reduce the flow of Wadi Mujib and Wadi Wala from its pre-1995 level of 66.5 MCM/yr to 24.5 MCM/yr. Although this figure exceeds the Water requirements of plant life in the Wadis' beds and Banks estimated at 10 MCM of evapotranspiration and 10 MCM of infiltration, the disturbance of the flood regime might have adverse impacts on biodiversity in the Wadis. Indeed, these Wadis have been recognized as biodiversity hot spots and have been declared natural reserves by the Jordanian authorities since 1987. 412 plant species, 40-50 aquatic invertebrates, 24 mammals, 3 amphibian, 150 birds, 21 reptile and 3 fish species have been recorded in the reserve.

5.4.4.5 Wadi Numeira, Wadi Assal, Wadi Al-Karak and Wadi Ibn Ahmad

Wadi Numeira, Wadi Assal, Wadi Al-Karak and Wadi Ibn Ahmad all suffered low-moderate losses in above ground green biomass. As many other Wadis in Jordan, these areas are subject to overgrazing. Rangeland management is important to conserve the natural flora of these Wadis.



Map7 the distribution of selected plant species in the Dead Sea Basin

6. Conclusions and Recommendations

Detailed and current information concerning the location and extent of land degradation processes, as well as the level of loss of above ground green biomass is important to target actions aimed at conservation and restoration of biodiversity important areas and corridors between biomes. Land degradation, the loss of biodiversity and the consequent loss of ecosystems structural complexity and ecological functionality would result in the loss of ecosystems' goods and services essential for the well being of the human residents of the Basin. The objective of this work was to assess the minimum water needs that nature requires to preserve key processes. The specific objectives were:

Objective 1: to quantify the overall change in above ground green biomass in natural landscape of the Dead Sea Basin

The analysis of a time series satellite images from 1985 to 2004 have revealed an average loss of above ground green biomass of 70 g/m^2 in the spring season and of 35 g/m^2 in the summer season. However, the loss of biomass is a symmetrical in the Dead Sea Basin. The North Western side of the Dead Sea Basin suffered the most in terms of loss of biomass. These are areas accessible to Palestinian farmers and grazing in these areas is extensive. Approximately 240,000 grazing sheep and goats are found in the study area grazing 270 square kilometers of land. Overgrazing in these areas has resulted in the reduction of the abundance and diversity of annual herbaceous species and an increase in dwarf spiny shrubs. The closed military areas, the southern and the Eastern parts of the Dead Sea Basin did not suffer a loss in above ground green biomass in general except in some runnels, Wadis and Oasis. In runnels, Wadis and Oasis, water diversion project and anthropogenic uses of water resulted in a loss of above ground green biomass. The Jordan River also suffered a sharp decrease in biomass due to the continuously reduced flow of water and the degradation of water quality in the river.

Objective 2: to identify areas with significant losses of above ground green biomass

Areas with significant loss of above ground green biomass are the following, ranked from high losses to moderate losses:

i. Wadi Al-Auja: the discharge of Al-Auja spring was completely diverted to agricultural use. This coupled with overgrazing has led to very sharp losses in biomass and destruction of natural vegetation.

ii. Grazing areas in the north western part of the Basin: Grazing by some 240,000 small ruminants in that area has led to land the loss of annual herbs and their replacement by dwarf spiny shrubs.

iii. The Jordan River Bed and Banks: The ecosystem of the Jordan River was reduced from a healthy association of Euphraticae and Tamaricetum Jordanis alliances to a degraded ecosystem with short shrubs. The diversion of some 1,250 MCM/yr of good quality water from the Jordan River was the main reason for the degradation of the ecosystem.

iv. Wadi Nar: Pollution of Wadi Nar with more than 10 MCM of untreated wastewater is the main reason of the degradation observed in Wadi Nar.

v. The marshes of Ein-Fashkha and Ghwair-Turba: The main reason of degradation is the retreat of the Dead Sea shores and the declining water level. While vegetation is spreading eastwards as more land is drying up, the vegetation forming the Western belt of the marshes is degrading.

vi. Major Wadis: All major Wadis with anthropogenic impacts of either overgrazing or diversion of water resources are suffering differing levels of biomass loss with the exception of Wadi Mujib where the construction of the Dam did not have an adverse impact of biomass. However, the same cannot be told of biodiversity as there is a serious lack of records of changes in biodiversity available to the project team.

Objective 3: to identify and delineate biodiversity hotspots and corridors between biomes

The biodiversity index has identified several biodiversity important areas. These were mostly concentrated in runnels, Wadis and marshes and Oasis. The important areas were Ein-Gedi, Wadi Mujib, Wadi Wala, Wadi Zarqa Main, Wadi Draja, Wadi Nar, Wadi Auja, the southern pat of the lower Jordan River and marshes of Al-Fashkha Springs and Turba-Ghwair.

Objective 4: to identify areas in need of immediate conservation and restoration
These were Wadi Auja, Jordan River bed and Banks, Wadi Nar, the Dead Sea, Ein Gedi and Wadi Zarqa-Main.

Objective 5: to quantify water volume necessary for natural areas to maintain their unique flora, fauna and their ability to provide natural goods and services
Monthly Reference evapotranspiration grids were produced. These were multiplied by the natural vegetation water needs factor (Kc) reviewed from literature to produce the actual evapotranspiration for the different land cover types in the study area. Watering requirements for the natural vegetation was assumed to be equal to actual evapotranspiration plus the volume of water that will deeply percolate in the soil layers beyond the plants root zones. In order to accurately assess deep percolation, several physical and chemical soil characteristics needed to be available. However, only a general description of soil texture was found in the literature and was used to provide a general estimation of water volume that would deeply percolate in soil. It was found that natural vegetation in several biodiversity important areas was deprived of its minimum water requirements. These areas, ranked according to the level of water deprivation, were Jordan River ecosystem, Wadi Nar, Wadi Arugot-David and Ein-Gedi Oasis. For example, the vegetation on the banks of the Jordan River requires a minimum of 222 MCM/yr of good quality water (Overall salt concentration of approximately 500 mg/l) to restore the ecosystem. It should be noted however that increasing the flow of the Jordan River by 222 MCM/yr would not be sufficient as would not reach the root zone of the targeted vegetation. Technical solutions have to be found to deliver water to the root zone of natural vegetation.