IMPACTS OF LAND USE ON QUANTITY AND QUALITY OF URBAN RUNOFF (HERZLIYA AND RA'ANANA CASE STUDY)

J. Garzuzi[a], N. Goldshleger[b], E. Ben-Dor[c], L. Asaf[d], R. Ben-Yamin[b]

[a]The Porter School of Environmental Studies (PSES), Tel Aviv University, Israel, jamil.garzuzi@gmail.com

[b] Soil Erosion Research Station, Emek-Hefer, Israel, gold_n@macam.ac.il

[c]Geography and Human Environment Department, Tel Aviv University, Israel, bendor@post.tau.ac.il

[d] The Hydrology Department, TAHAL Group, lior.asaf@gmail.com

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ABSTRACT:

This study presents an analysis of the quantity and quality of urban runoff from various land uses by remote-sensing and GIS technology coupled with hydrological and chemical monitoring. The study areas were located in the cities of Herzliya and Ra'anana, in Israel's coastal plain, where extensive urbanization has taken place over the last 30 years. Different image-processing methodologies were developed to establish a relationship between the land-use maps and field measurements of runoff quality and quantity. The advantages of the abovementioned remote-sensing means, used separately and together, were analyzed for the generation of suitable maps for decision-makers from the research area. The obtained land-use maps provide an understanding of the influence of surface-cover information on facilitated analysis of runoff-land cover relationships and can serve as a tool in other urban environments.

1. INTRODUCTION

Urban hydrology has attracted a great deal of attention in the last two decades (Jens and McPherson, 1964; Massing et al, 1990), due to the environmental consequences of the global expansion of built-up areas. Some of these consequences are long-term, such as impaired recharging of ground water (Rogers, 1994) accompanied by salinization of wells. Coupling land-use/land-cover data from remote sensing with discharge/runoff information from urban catchments may help establish general relationships between land-cover/land-use parameters and runoff quality and quantity (Goldshleger, 2009). Such relationships could be instrumental in planning by allowing predictions of runoff intensities over wide regions (e.g., Bhaduri et al, 2000; Gill et al, 2005).

Over the past few decades, Israel has experienced intensive urbanization, especially in the coastal plain area, where one of the country's most important water resources—the coastal plain aquifer—is located. Many open and agricultural areas have been transformed into impervious (built-up) areas (Mazor, 1993). These changes impact the quality and quantity of water resources.

Research performed in the last decade indicates that the impervious area will double in the coastal plain by 2020, reaching 26% of the land area. At the same time, agricultural land is expected to decrease by two-thirds (Carmon and Shamir, 1997; Bromil et al, 2003).

Runoff quality and quantity in urban areas are affected by urban land uses, which include industrial areas, residential areas, roads, parking lots, public areas, airports and other results of human activity (Hermann et al, 1994; Marsalek and Torno 1994; Mikkelsen et al, 1994). In general, water from industrial areas and main roads is more polluted than that from residential neighborhoods and public parks. Various studies conducted worldwide have indicated the impact of urbanization on runoff quality (Mikkelsen, 1994; Bhaduri et al, 2000; Nativ et al, 2001; Asaf et al, 2002; Bromil et al, 2003; Shamir and Carmon, 2003). Several studies in Israel have explored these relationships using remote-sensing and GIS tools (Nativ et al, 2001; Bromil et al, 2003; Goldshleger et al, 2005, 2009).

The purpose of this study was to examine the influence of urban land use on the quality and quantity of urban runoff in two cities in Israel: Hertzlia and Ra'anana. The focus is on the use of remote-sensing and GIS means to study the relationship between land-use changes and runoff quality and quantity.

2. CASE STUDY

The research area and the location of the cities within the southern Sharon region are depicted in Fig. 1.

Both cities, located on the topographic plan, include a variety of urban land uses such as: parking lots, residential and commercial buildings, open areas (soil) and industrial areas. Results from studies by Nativ et al (2001) and Asaf et al (2002) on the cities of Ashdod and Rishon Lezion, which have the same soil and topographical conditions, were used for verification and comparison.

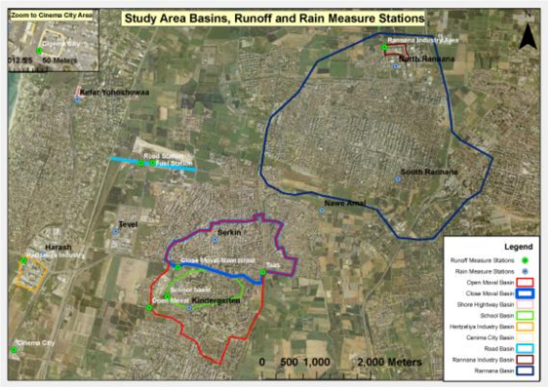

Figure 1. Map of the study area basins and measuring station locations.

3. METHODS

3.1 Mapping land use by remote-sensing and GIS data

The analysis focused on classifying urban land use that influences water quality and quantity into three main categories: industrial areas, urban roads and parking lots. This study used remote-sensing methods with three different spectral and spatial imaging resolutions:

1. Digital aerial photographs (RGB) of high spatial resolution (less than 1 m^2), covering the entire area.

2. Multispectral satellite imagery of intermediate spatial resolution (ATER)—multispectral imaging with 9 spectral bands and a low spatial resolution averaging 15 m, covering the entire area.

3. Hyperspectral satellite imagery (AISA) of high spatial resolution (1.6 m) and spectral resolution (198 bands), covering selected spots in the study area.

The processing methodologies were developed in different ways, according to the information content of each source, and they are therefore described separately.

Spectral-imaging correction, analysis and classification were performed with ENVI 4.6 software; spatial analysis of raster and vector data was performed with ESRI ArcMap 9.3.1 software.

3.2 The three methods of classification were:

3.1.1 Digital RGB photograph classification process:

1- Classifying the pixels by means of unsupervised classification (Isodata routine, ENVI 4.6). This process involved sorting pixels into a finite number of individual classes or categories based on their data file values. This method identifies multidimensional clusters representing minimum and maximum intergroup diversity. The classification was based on color characteristics (in the case of RGB channels). The number of groups, determined by the user, was 12.
2- Classifying the pixels by supervised classification (Mahalanobis Distance routine, ENVI 4.6).
3- Integrating information from the national GIS database (mostly updated for 2007), which served as a complementary source for improving the spatial definition of roads.

The results of the two classifications were compared and integrated for land-use mapping and area-size calculation by GIS. Accuracy was also checked through a confusion matrix.

3.1.2 Multispectral imaging classification process: Two ASTER multispectral photographic images covering the study area were received from the NASA website in VNIR (15 m), SWIR (30 m) and TIR (90 m) wavelength ranges; in this study we used only the VNIR-SWIR wavelength range (9 bands).

Preprocessing:

1- SWIR bands resized by half to 15 m.
2- Two-image mosaic by georeference function.
3- Calibration (empirical line calibration) performed to correct for atmospheric attenuation using a local spectral library.
4- Spectral angle mapper (SAM) classification by marking and selecting a land-use region of interest (ROI).
5- Post-classification function to improve the classification image.
6- Mapping land-use and area calculations by GIS functions.
7- Confusion matrix for accuracy rate estimation.

3.1.3 Hyperspectral imaging classification process: AISA airborne hyperspectral photograph covering a limited area, with high spectral resolution—198 bands with 1.6 m spatial resolution (pixel size).

Preprocessing:

1- Generating radiance by resampling sensor radiation flow reception (Modo IDL application) and producing spectral library.
2- EL calibration by Modo spectral library to fine-tune the radiometric data.
3- Distriping correction (spectral and geometry disturbances).
4- Atmosphere correction—ATCOR 4 IDL application.
5- EL calibration by ASD field measurements.
6- Spectral validation of received reflection (quality assurance (QA) was performed by ASDS factor).
7- SAM classification by selecting ROI for land-use components of interest.
8- Post-classification function to improve land-use mapping.
9- Land-use mapping and area calculation by GIS functions.
10- Accuracy rate estimation by confusion matrix.

3.3 GIS data process

The buildings, roads and drainage net were taken from the national GIS system. These data were also integrated into the analysis of land-use classification and impact on water quality and quantity.

3.4 Rain and runoff measurements

Automatic tipping-bucket rainfall recorders with a resolution of 0.1 mm were installed at three stations (Fig. 1) to accurately represent the spatial and temporal distribution of precipitation in the city.

Five runoff stations were installed at the outlets of five stormwater drains (four in Herzliya and one in Ra'anana). In 2007/2008, one station was moved from a school basin to a road basin (Fig. 1).

Each station included a pressure transducer (with a resolution of 10 mm) and a data logger. The area draining into each of the stations was estimated using an ESRI GIS (ArcInfo 9) aerial orthophoto map, topographic and infrastructure data and drainage network provided by the local municipalities. Because the drains channeled water from areas of different sizes and land uses, the impact of these characteristics on the quantity and quality of storm water could be evaluated.

Stormwater samples were collected both manually and automatically. Automated samplers were installed next to the stormwater gauges at the three stations draining relatively large areas (Fig. 1), whereas samples were collected manually from the other drains. The runoff gauges provided information about the discharge and cumulative runoff that could be matched for each sample. The sampler was programmed to start sampling at the beginning of each flow event, then at 10-min intervals during the first hour, followed by 30-min sampling intervals thereafter.

4. RESULTS AND DISCUSSION

4.1 Land-use classification and measurements

According to the results of the land-use analysis, the impervious area reached 30 to 40% in the residential areas and 60 to 75% in the industrial areas. The road fractions in residential areas reached 13 to 16%, 20% in the industrial areas (Table 1 and Figs. 2, 3, 5). Herzliya basin was made up of several basins.

Land-Use classification	Open Moval		Closed Moval		Hertzliya Industrial Area		Ra'anana Industrial Area	
	%	KM^2	%	KM^2	%	KM^2	%	KM^2
Vegetation Cover	19	0.79	20.7	0.37	9.6	0.02	4.9	0.004
Open Area	26.4	1.09	22.9	0.41	18.8	0.04	8.0	0.01
Built-up Area	39.2	1. 62	40.9	0.73	63.9	0.14	75.6	0.065
Roads	15.4	0.64	15.5	0.28	7.7	0.02	11.5	0.01
Total	100	4.11	100	1.79	100	0.22	100	0.086

Table 1. Example for land-use classification after ISO Data classification on RGB orthophoto

1. Herzliya's industrial area was composed of mostly impervious (roads and buildings) areas—about 70% (Table 1), and therefore up to 80% (0.8 runoff coefficient) of the rainwater flows as runoff.

2. Herzliya basin (Open Moval) includes another two basins: Closed Moval, and the school basin. These three basins were characterized by mostly impervious residential area (40-60%) (Table 1, Figs. 2, 3, 5). Closed Moval's impervious area made up almost 57% of the basin area and the runoff coefficient was found to be about 0.46, 0.45 in the school basin; 18% of this basin land-use composition was road and the other 38% was built-up area.

The Ra'anana basin was process into only one land-use classification: the industrial area covers about 100 dunams, 75% of which was impervious area (Table 1), and the runoff coefficient was about 0.42 (Fig. 2, 4).

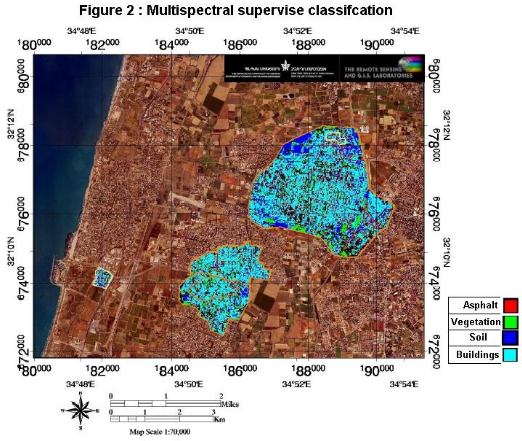

Figure 2. Multispectral Supervise Classification

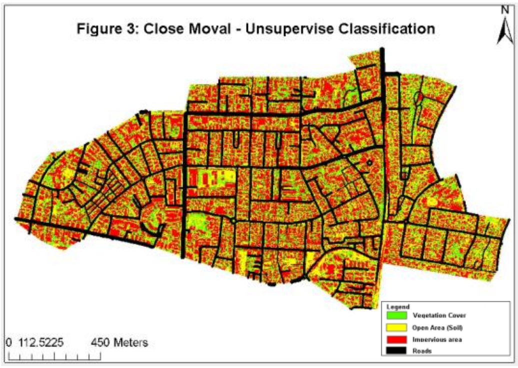

Figure 3. Close Moval - Unsupervise Classification

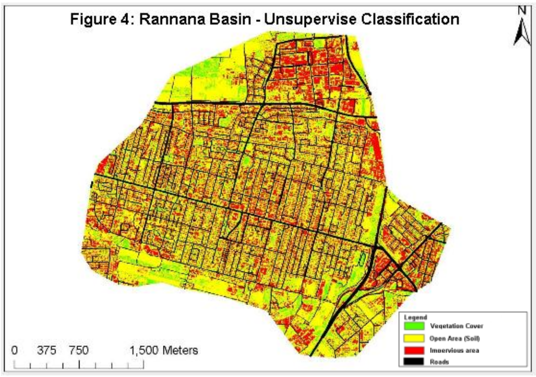

Figure 4. Close Moval - Unsupervise Classification

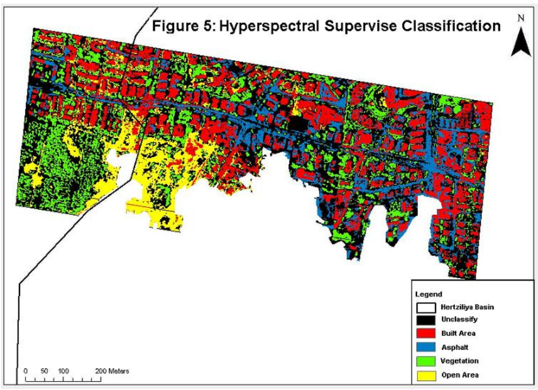

Figure 5. Hyperspectral supervise classification

4.2 Runoff coefficient

Runoff coefficients were calculated for all basins, and compared to those measured previously for Ashdod (Asaf et al, 2002). A good correlation was found between impervious area and runoff quantity/coefficient size (Fig. 6). The trend of rising runoff percentage with increasing impervious area was also verified by matching trends from the Ashdod data.

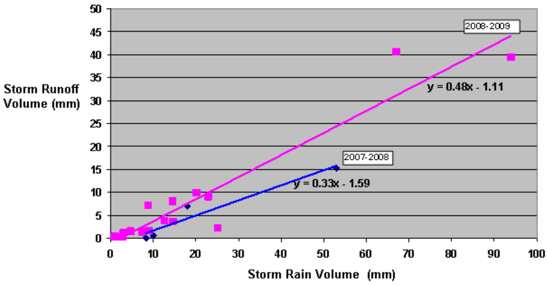

Figure 6. Relation between rain and runoff in Open Moval (2007-2009)

4.3 Runoff quality according to different land uses

Runoff was characterized by a low level of salts and suspended materials. Salt concentration in the runoff from residential areas was lower than that from industrial areas. Average chloride and nitrate concentrations in the runoff from the residential area (30 mg and 5 mg, respectively) were lower than the Israeli drinking water standards (250 mg and 70mg, respectively).

The concentrations of total suspended solids (TSS), sulfate and potassium in the storm water from the Ra'anana industrial area were lower than the Israeli freshwater standards but still higher than the Herzliya industrial area.

The concentration of heavy metals was low except for lead, manganese and iron in the industrial area, and lead in the residential area. In general, the values were below freshwater standards (Fig. 7). The main contributors to the high concentration of lead were transportation and lead-based paint. Results similar to those from Herzliya were obtained previously in Rishon Lezion (unpublished data) and in Ashdod (Asaf et al, 2002), confirming the high quality of the urban storm water in the coastal plain of Israel.

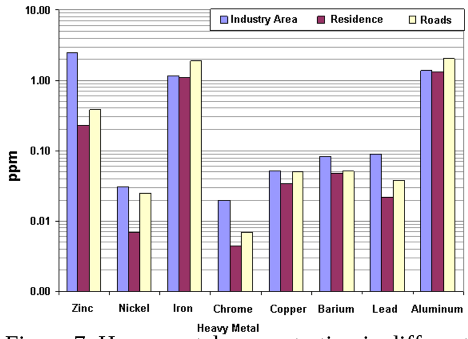

Figure 7. Heavy metal concentration in different land-use areas.

A high concentration of microbes—*Escherichia coli* and coliforms (about 10^3-10^5 cfu/100 ml), was observed in the runoff from all land uses (Table 2), similar to in the previous Ashdod data (Nativ et al, 2001). This high biological contamination stems from sewage leaks which flow into the drainage lines, and from the presence of animals and peat in urban areas.

General Court Cfu/1ml	Escherichia coli MGG Cfu/ 100ml	Escherichia coli Cfu/ 100ml	Coliforms Cfu/ 100ml	Examination Date	Sample Code
57000	Covered Plate	Covered Plate	Covered Plate	14/3/2007	R1
222000	ND	32000	81000	15/3/2007	R2
450000	ND	65	83000	15/3/2007	R3
60000	ND	<1000	5000	15/3/2007	R11
130000	ND	<1000	3000	15/3/2007	R12
590000	ND	Covered Plate	Covered Plate	15/3/2007	R21
240000	ND	28000	Covered Plate	15/3/2007	R22
150000	ND	3000	4000	15/3/2007	R23
60000	ND	2000	4000	15/3/2007	R15
480000	ND	Covered Plate	Covered Plate	15/3/2007	R25
290000	ND	9700	Covered Plate	15/3/2007	R4

Table 2. General count (cfu/100 ml) of microbes (coliforms, E. coli) in the runoff from different land uses.

5. Conclusions

1. Land-use classification and mapping can be achieved by remote-sensing and GIS tools.

2. Digital high-resolution RGB is the recommended method for land-use classification, due to its high resolution (1 m) and low cost.

3. ASTER low-spatial-resolution imaging classification can be used to draw conclusions on general land-use composition.

4. AISA imaging classification is the best method to classify land use in small areas, but its high cost, sizeable time investment and low availability make it useful only for limited study areas. Nevertheless, the resultant classification can be used to calibrate and correct classifications made from more highly available low-quality imaging.

5. The different remote-sensing methods can be combined for optimal results (Table 3).

	RGB	Multispectral	Hyper spectral
Spatial Resolution	High – 1m	Low-15m	High – 0.5m (Up to 2,000 m high)
Bands Number	3	9-13	198
GIS layers Match	80%	60%-80%	85%-95%
Max Classification classes	Up to 5	Up to 8	All materials
Processing Time (days)	1-2 days	5-7days	5-7days
Availability	Cover the entire area Update every year	Cover the entire area Update in every few yea	covering selected spots Available by order
Classification rate Level	65%-75%	88%	95%

Table 3. Compression between different RS methods

6. Runoff coefficients in the different basins ranged from 0.3 to 0.55, similar to data from other built-up areas worldwide.

7. A high concentration of microbes was found with all types of land use, calling for the requisite treatment of runoff before reuse.

8. Concentrations of the major elements were low relative to freshwater standards. Lowest concentrations were found mainly in the residential areas.

9. Iron and lead concentrations were higher in industrial areas, similar to the data generated previously from Ashdod and Rishon Lezion (Asaf et al, 2002).

Runoff from urban centers in the Israeli coastal plain is not currently being utilized. Large amounts of runoff, estimated at about 30% of rainfall (80-100 MCM), flow into the sea each year, a scarcity of water in the Israeli coastal plain aquifer calls for the reuse of runoff water. Use of the new remote-sensing and GIS methods to characterize runoff quality and quantity can help assess their potential for reuse.

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