Urban Planning and Design Research (UPDR), Volume 3, 2015 www.seipub.org/updr
doi: 10.14355/updr.2015.03.003

On-line Evaluation of Earth Observation Derived Indicators for Urban Planning and Management

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Abstract

Extensive urbanization and growth of population density have acquired a paramount interest towards a sustainable urban development. Earth Observation (EO) is an important source of information required for urban planning and management. The availability of EO data provides the immense opportunity for urban environmental indicators development easily derived by remote sensors. In this study, the state of the art methods were employed to develop urban planning and management relevant indicators that can be evaluated by using EO data. The importance of this approach lies on providing alternatives for improving urban planning and management, without consuming time and resources in collecting field or archived data. The evaluated urban indicators were integrated into a Web-based Information System that was developed for online exploitation. The results for three case studies are therefore available online and can be used by urban planners and stakeholders in supporting their planning decisions.

Keywords

Urban Indicators; Urban Planning; Earth Observation; Web Information System

Introduction

Cities attract the interest of world scientific and planning community due to their accelerating growth of residential population. In 2007 the urban population outnumbered the rural population for the first time in history and two thirds of the world's population is estimated to be living in cities by 2030 (UNPF, 2008). Cities have become the centers of cultural, economic and political development and therefore, any expert intervention for a sustainable living experience would improve the quality of life. Earth Observation (EO) is one of the main fields of research, which can provide powerful tools for urban management and planning. Nowadays, EO can be used to area-widely analyze urban surface structure, physiognomy, traffic, land use/land cover (LULC), building density and urban environmental quality, quickly and accurately. This information can be used as a valuable input to urban management and planning, which requires data methods and tools for evaluating alternatives in decision making (Chrysoulakis et al., 2013).

EO data derived from spaceborne and airborne systems have become promising sources of geoinformation, valuable in many urban applications (Masser, 2001; Bhatta et al., 2010; Esch et al., 2010). Data from a large number of sensors are available to urban studies. These data are acquired in different spatial, spectral and temporal resolutions. The different characteristics of EO data allow different applications such as land cover mapping and change detection, urban morphology characterization, surface energy balance estimation, air quality and thermal stress assessments. According to different spatial resolution, the following categories can be specified: a) at low and medium spatial resolution (MR), global urban maps are generated by using imagery collected from optical sensors such as MODIS (Moderate Resolution Imaging Spectroradiometer) (NASA, 2013a), DMSP-OLS (NOAA, 2013a), AVHRR (NOAA, 2013b), MERIS (ESA, 2013a) and SPOT-4-VEGETATION (CNES, 2013), b) at city to local scale, high spatial resolution (HR) data are typically used for regional analyses including thematic characterization of major urban types; both optical (e.g., Landsat TM and ETM+ (NASA, 2013b), SPOT (CNES, 2013), IRS LISS and AWiFS (ISRO, 2013), as well as radar sensors (e.g., TerraSAR-X (DLR, 2013a), TanDEM-X (DLR, 2013b), RADARSAT (CSA, 2013), ALOS-PALSAR (JAXA, 2013), Cosmo SkyMed (UGS, 2013) are generally employed with a spatial resolution ranging from 10 to 50 m, and c) local-scale analyses are carried out by means of very high resolution data (VHR) (spatial resolution up to ~0.4 m) acquired by optical systems - e.g., RapidEye (RapidEye, 2013), CARTOSAT (ISRO, 2013), IKONOS (DigitalGlobe, 2013), QuickBird (DigitalGlobe, 2013), WorldView 1 and 2 (DigitalGlobe, 2013), GeoEye 1 and 2 (DigitalGlobe, 2013) - or radar satellites such as TerraSAR-X (DLR, 2013a), TanDEM-X (DLR, 2013b), or RADARSAT (CSA, 2013). Furthermore, using digital surface models derived from stereo imagery of VHR optical sensors such as CARTOSAT-1 or WorldView II, it became even possible to map complex urban environments in 3D. New perspectives with respect to the characterization of building volumes, although at a coarser resolution, are expected by the TanDEM-X (DLR, 2013b). Future missions will continue the path defined by current missions or even enlarge the capabilities for urban remote sensing to develop and provide key geo-information products. In this context, most relevant missions include Sentinel 1, 2 and 3 (ESA, 2013b) to be operated by ESA, EnMAP (EnMAP, 2013) to be operated by DLR and HyspIRI (NASA, 2013c) to be operated by NASA.

EO urban indicators are powerful tools in describing the urbanization process. They belong to a wider category, called urban sustainability indicators, the aim of which is to understand the urban sustainability performance within an environmental, social and economic framework (Briassoulis, 2001; Shen et al., 2011). The great importance of EO urban indicators is based on its ability of low cost, easy and quick retrieval by EO data. Therefore, urban environmental indicators are valuable means in planners' hands, because of their contribution to analyzing and characterizing urban form and shape, urban dynamics and urban microclimate. A framework of EO-based indicators for urban planning and management was recently given by Chrysoulakis et al. (2014). In this framework the proposed EO-based indicators have the potential to provide useful tools to urban planners and decision makers by saving time, reducing costs and providing higher adaptability. The objective of our recent article (Chrysoulakis et al., 2014) was to set the theoretical framework for indicators selection and development, as well as to identify the optimum methods for their evaluation for Earth Observation (EO) data. The objective of the present work is to present the web-based system that was developed in the framework of the GEOURBAN project for the on-line evaluation of the developed/selected indicators. This is an important difference, because the present manuscript describes how this tool makes possible the evaluation of such indicators by non-experts in the domain of EO, such as urban planners and local authorities who have direct access to the system via internet. The involvement of the end-users through the on-line system adds to the present manuscript new relevant content to the already published materials. Furthermore, the on-line tool has the potential to directly transfer the GEOURBAN methodology to any city, therefore to set the basis for the development of a fully operational tool in the future by exploiting also the capabilities and the improved data quality of the forthcoming Copernicus Sentinels. This study presents the development and evaluation of EO-based urban indicators in the framework of the GEOURBAN (ExploitinG Earth Observation in sUstainable uRBan plAnning & maNagement) project (Chrysoulakis et al., 2013; Esch et al., 2013). The evaluation of the developed indicators was performed in three cities with different typologies and planning systems (i.e., Basel, Switzerland; Tel Aviv, Israel and Tyumen, Russia), according to: a) routine urban planning and management requirements (including requirements for natural disaster risk mitigation and urban security); and b) urban planning requirements for adaptation to climate change. The above requirements were identified after consultation meetings with the urban planners and stakeholders in each city, as it is described by Chrysoulakis et al. (2014).

Study Areas and Datasets

The study areas (Figure 1) include: Tyumen (Russia), Tel Aviv (Israel) and Basel (Switzerland). The selected case studies have the potential to support the cooperation of European, including Russia, as well as Middle East countries, analyzing the different urban planning and management perspectives.

FIG. 1 THE GEOURBAN STUDY AREAS (TYUMEN, TEL AVIV AND BASEL) (SOURCE: GOOGLE EARTH)

The city of Tyumen is situated on the Tura River 1,700 km east of Moscow, covering an area of 23,500 ha with a population of 580,000. The climate is humid continental with fairly warm humid summers and long cold winters (Köppen Dfb climate). Town Planning Code of the Russian Federation (RF TP Code) regulates the urban planning in Tyumen.

Tel Aviv covers an area of 5,200 ha with a population of 404,000, becoming the second most populous city in Israel after Jerusalem. The climate is Mediterranean with warm to hot dry summers and mild rainy winters (Köppen Csa climate). The Master Plan of Tel-Aviv is based on the Strategic Planning approach, which combines modern planning concepts. The planning process involved is participatory, with residents and other stakeholders having the ability to express their opinions regarding the city's problems.

The city of Basel has 188,000 inhabitants with an area of 3,695 ha, while its agglomeration has 730,000 inhabitants covering an area of 48,200 ha. The climate is oceanic with mild winters and warm and sunny summers (Köppen Cfb climate). Three city agencies are responsible for urban planning in Basel: the Agency of Cantonal and Urban Development in the presidential department (responsible for all significant developments in the city and the agglomeration), the Planning Office in the department of construction and traffic (responsible for town construction and the projection in the public space and sphere) and the Agency for Environment and Energy in the department of economic, social and environmental affairs (responsible for any harmful or disagreeable influences). Moreover, the Trinational Eurodistrict Basel (TEB) was founded in 2007 to coordinate regional planning across national borders. The EO data used in GEOURBAN to cover the above cities are given in Table 1.

TABLE 1. EO-DATA IN THREE STUDY AREAS

Study Area	EO-data	Spatial resolution
Tyumen	Landsat-5 TM Landsat-7ETM+ TerraSAR-X ASTER MODIS RapidEye	30m 30m 1m, 3m, 16m 30m 10Km 5m
Tel Aviv	Landsat-5 TM Landsat-7ETM+ TerraSAR-X ASTER WorldView2 MODIS RapidEye	30m 30m 1m, 3m, 16m 30m 0.46m, 1.84m 10Km 5m
Basel	Landsat-4 TM Landsat-5 TM Landsat-7ETM+ TerraSAR-X ASTER MODIS RapidEye Quickbird	30m 30m 30m 1m, 3m, 16m 30m 10Km 5m 2.51m

Preprocessing is mostly essential as most satellite data providers do not provide geometrically corrected data in standard level data. Geometric correction is performed based on a two-step procedure. In the first step, mathematical transformation is applied to the raw image coordinates to obtain actual locations of the pixels. In the second step, the brightness values of the image are resampled to be assigned to geometrically corrected pixels. As an example the preprocessing of Landsat TM and ETM+ images is described below.

Preprocessing of Landsat TM and ETM+ data was done using the current equations and rescaling factors for converting calibrated digital numbers (DNs) to absolute units of at-sensor spectral radiance, Top-Of-Atmosphere (TOA) reflectance, and at-sensor brightness temperature. Scaling factors for TM and ETM+ are available from the meta-information of Landsat scenes (MTL.txt files) or Chander et al. (2009).

Indicators Development and Evaluation

State of the art techniques (Chrysoulakis, 2003; Frey and Parlow, 2009; Keramitsoglou et al., 2012; Lu and Weng, 2007; Lu et al., 2004; Mitraka et al., 2012; North et al., 2009; Toutin, 2001; Wurm et al., 2011) were applied to the above datasets to evaluate the selected urban environmental indicators. A set of EO products were initially derived from the raw EO datasets and in the following, the selected indicators were estimated using these products. For example, as described by Chrysoulakis et al. (2014), a satellite radiometer recorded the incoming radiance at several parts of the electromagnetic spectrum. This multispectral data is the EO data recording at the satellite. By analyzing this EO data by means of a maximum likelihood classification method, a land cover map can be derived. This is the respective EO product derived from the initial EO data, by implementing this particulate analysis method. Furthermore, by selecting the pixels corresponding to built-up areas in this land cover map and by estimating their density within specific administrative boundaries, the built-up density can be derived. The latter is an EO-based indicator which has been evaluated from the land cover map (EO product). The indicators that were developed in the framework of GEOURBAN are presented in Table 2.

TABLE 2. GEOURBAN INDICATORS

Categories of Indicators		**Indicators**
Urban Surface Structure	Density indicators	Built-up density
		Building density
		Open Space Density
		Green Space Density
	Area/Edge indicators	Edge Density
	Ratio indicators	Imperviousness-Open space ratio
		Imperviousness-Green space ratio
	Diversity indicators	Class Richness Density
		Ecological Effectiveness Ratio
Urban Surface Type		Imperviousness
		Fractional Land Cover
		Surface Albedo
		Surface Emissivity
Urban Sprawl		Urban Fringe
		Change Detection
Urban Environmental Quality		Surface Urban Heat Island
		Aerosol Optical Thickness
Vulnerability to hazards		Distance to critical services
Socioeconomics		Exposure to PM

Figure 2 describes the development approach adopted by the GEOURBAN project in order to achieve its objectives. GEOURBAN explored the potential of EO to support urban planning and management by providing guidelines towards sustainability objectives at micro, local and regional scales, as well as towards climate change adaptation. These guidelines were the result of the combination of several EO-based indicators using the web-based information system that was developed. The web-based character of this tool made it easily transferable from city to city and the indicators can be evaluated if EO data were available. The EO data was the main input for GEOURBAN indicators. Well-known EO analysis methods were used to calculate products from raw data. It should be noted that the development of new EO data processing tools was not among the objectives of GEOURBAN, but rather state of the art methods were implemented. These methods were implemented off-line, therefore they were part of the information system; only the products were used as inputs. The end-users at GEOURBAN case studies (local authorities, urban planners and decision makers) were involved in the project from the beginning via a Community of Practice (CoP) approach. They provided the consortium with requirements related to urban planning and management, as well as to adaptation to climate change. A sub-set of these requirements that can be supported by EO methods and data were extracted after a round of CoP meetings in all case studies. A second round of CoP meetings, or an umbrella CoP, was organized during the demonstration of the GEOURBAN information system. In the framework of the demonstration procedure, hands-on applications were organized to give the end-users the opportunity to be familiarized with the final version of the information system. User requirements led to EO-based indicators, as well as to specifications for the information system design. The consortium released several versions of the information system during its development exercise. Since it was a web-based tool, the end-users were able to evaluate it online and provide their feedback to the consortium. The consortium took into account the end-user suggestions to develop the next version of the information system. The final version was available during the demonstration event which was organized at the end of the project.

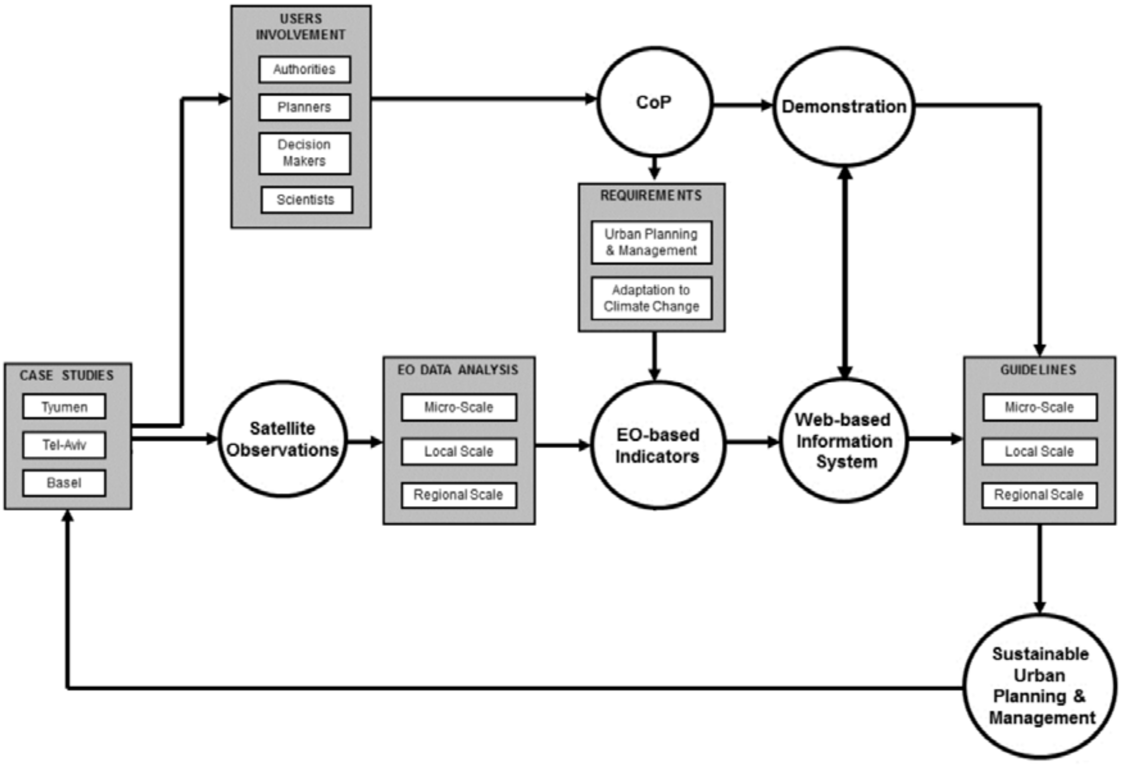


FIG. 2 THE GEOURBAN METHODOLOGY FLOWCHART

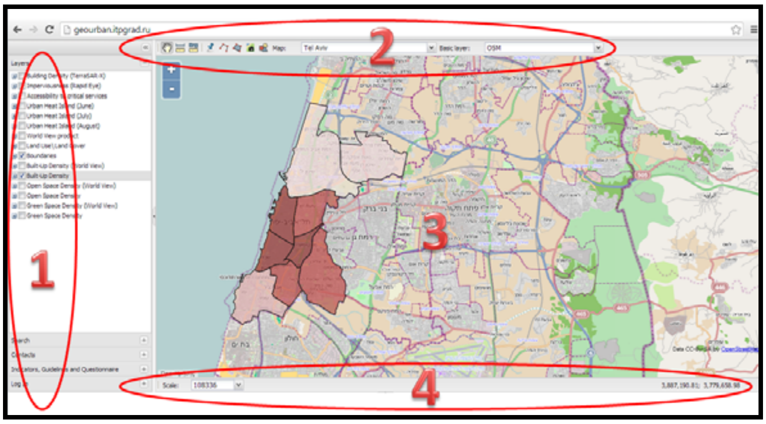
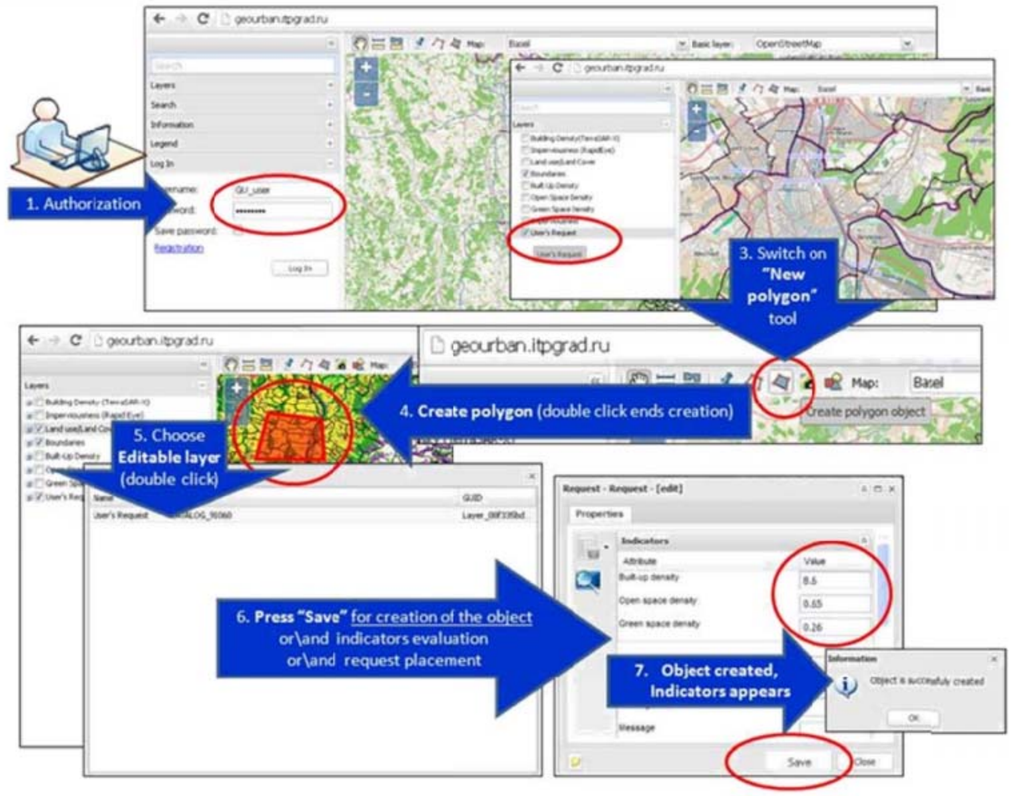


FIG. 3 THE APPEARANCE OF THE WIS GEOURBAN: 1) CONTROL BAR WITH LAYERS, SEARCH FUNCTION, CONTACTS, INDICATORS, GUIDELINES AND QUESTIONNAIRE AND LOG IN FOR AUTHORIZATION, 2) TOOL BAR WITH BUTTONS 'NAVIGATION', 'DISTANCE', 'SQUARE', 'CREATE POINT OBJECT', 'CREATE LINE OBJECT', 'CREATE POLYGON OBJECT', 'SAVE MAP TO PNG', 'SAVE LAYER TO FILE', 'MAP' PANEL FOR CHOOSING CASE STUDY AND 'BASIC LAYER' PANEL FOR CHOOSING A BACKGROUND, 3) MAP DISPLAY AREA AND 4) STATUS BAR.

To on-line evaluate the GEOURBAN indicators a Web-based Information System (WIS) was developed. The WIS prototype is at http://geourban.itpgrad.ru/. It is a fully dynamic system exploiting all internet capabilities and the “open layers” availability. The user solely needs a web-browser and internet connection to access it.

The WIS includes a standard set of tools which allow users to manage maps - switching layers on and switching them off, changing scale and displaying object’s attributes such as value of indicator evaluation, measuring distance and evaluating square. The appearance of the WIS is illustrated in Figure 3. All buttons and items of Tool Bar highlight and a message with the information about the function appears. The prototype of the GEOURBAN WIS also includes a Configuration panel which is available for the administrator session. It allows configuring all visualization parameters for managing a set of maps and layers especially for each user and searching options.

The on-line evaluation process includes the steps as indicated in Figure 4 (1. Authorization, 2. Switch on editable layer “user’s request”, 3. Create new polygon, 4. Choose editable layer, 5. Save an object, 6. Wait for object creation and evaluation of indicators and 7. See the result).


1. Authorization

3. Switch on "New polygon" tool

4. Create polygon (double click ends creation)

5. Choose Editable layer (double click)

6. Press "Save" for creation of the object or\and indicators evaluation or\and request placement

7. Object created, Indicators appears

FIG. 4 ON-LINE EVALUATION PROCESS

In the following section the development of each category of indicators listed in Table 1 is described and the resulting indicators are presented.

Urban Surface Structure

The urban surface structure indicators are extracted from land cover map products, using administrative political community boundaries, or user-defined boundaries (polygons). The value of each indicator was estimated using a dedicated formula within each polygon. The urban surface structure indicators are further divided to: density indicators, area/edge indicators, ratio indicators and diversity indicators, as shown in Table 1.

Built-up density refers to the density of built-up areas (impervious areas). As a sum of impermeable landscape features, including buildings, roads, parking lots etc., built-up density is a key indicator for addressing many environmental issues such as water quality and urban biodiversity (Yang and Liu, 2005). The built-up density indicator was calculated using the percentage of urban land cover (high-medium-low density residential and industrial/commercial), which is included within administrative political boundaries, as shown in Figure 5. The aim of this indicator is based on the need of urban planning in having a measurement of built-up areas within specific geographic entities. Low values of built-up density indicate large areas where water can be infiltrated, while large values belong to areas with large built-up cover.

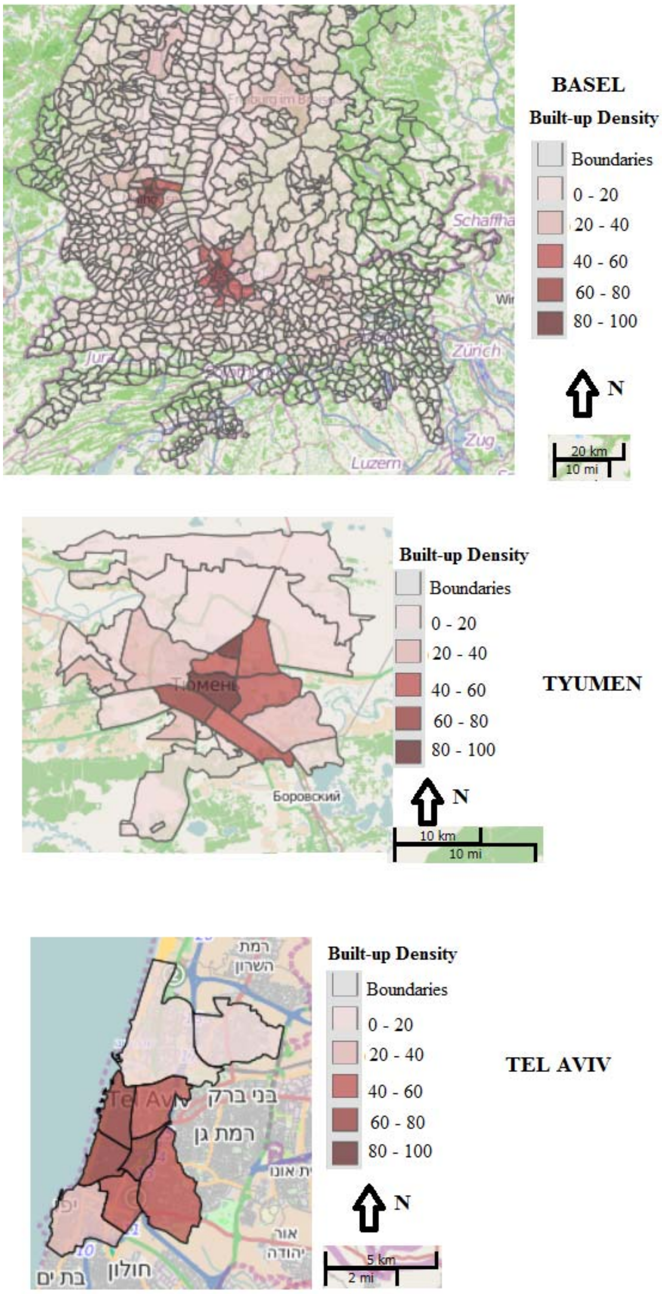


FIG. 5 BUILT UP DENSITY INDICATOR FOR BASEL, TYUMEN AND TEL AVIV

TerraSAR-X observations (Werninghaus, 2004) were used in GEOURBAN to allow the extraction of building density, since the radar is sensitive to vertical structures and can therefore separate buildings from other built-up structures. The detection and delineation of urban areas are based on pre-processing of the SAR data by analyzing the local speckle characteristics in order to provide a texture layer, which highlights the built-up areas. This pre-processing is followed by a pixel-based image analysis in order to identify settlements. The characterization of urban structures within the delineated areas is made by estimating the building density, which occurs by computing the first order statistics and Haralick texture measures (Esch et al., 2011). Open spaces in urban environment provide many valuable services to residents, including recreational activities, aesthetic enjoyment and environmental functions (micro-climate stabilization and water purification). Open spaces refer to a number of land uses, such as green spaces (e.g. sports field), agricultural land and undeveloped land (Brander and Koetse, 2011). Open space becomes an important factor in improving urban life and its value increases with population density.

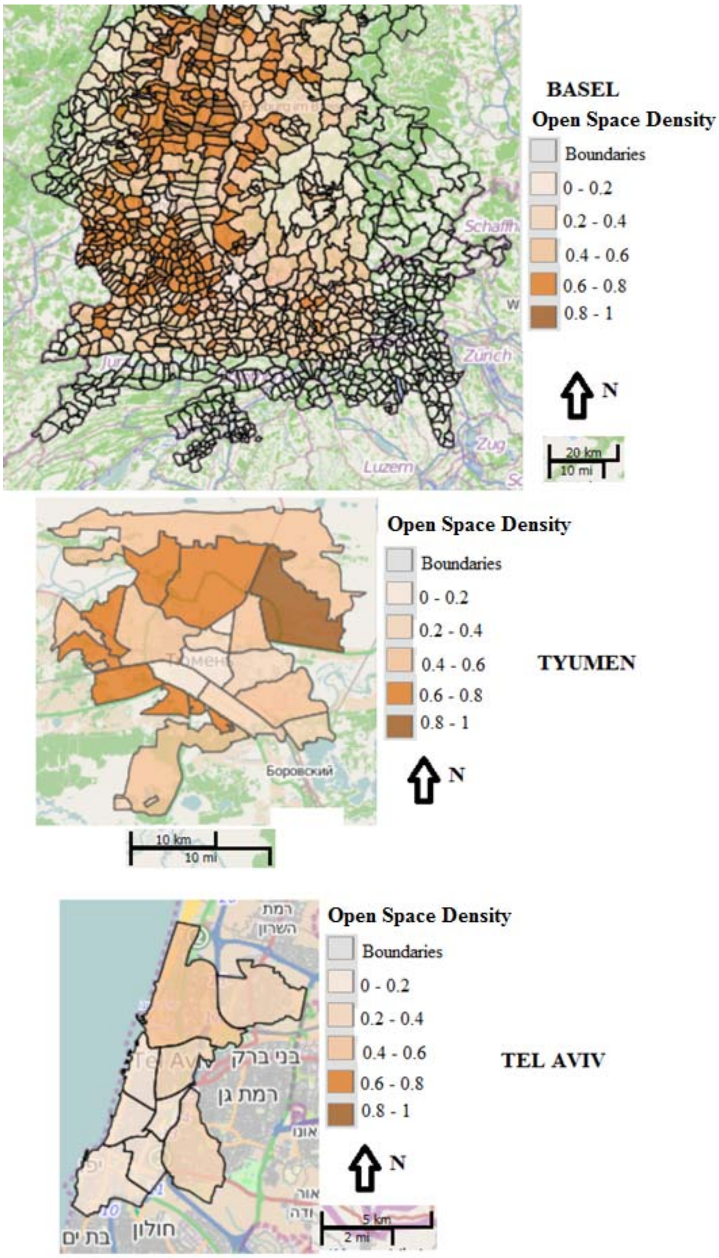


FIG. 6 OPEN SPACE DENSITY FOR THE THREE CASE STUDIES

More specifically, in dense residential places the indicator of open space density plays a powerful role in estimating the urban well-being. In this study, the indicator Open Space Density (OSD) was calculated as the ratio between the pixels of open spaces (grassland and agriculture) and the total number of pixels within the political community boundaries. OSD is a measure of fragmentation of open spaces. Low values indicate fewer patches, while higher values indicate more patches of open spaces and therefore a higher spatial heterogeneity (Figure 6).

The availability of attractive green spaces is a critical part of urban living. It is generally accepted that urban green spaces are essential for the health of citizens, making better standards of living. Urban planning pays much attention to preserving green areas and therefore, the indicator of green space density becomes an important tool in planners' requirements for "green livability" (Herzele and Wiedemann, 2003). Although green spaces can be considered as open spaces, in GEOURBAN, green spaces were examined as a separate indicator in order to give strength to areas with high green coverage. Therefore, green spaces were considered as the forest and the grassland areas. The Green Space Density (GSD) indicator was estimated as the ratio between the number of pixels of green spaces and the total number of pixels within the political community boundary. GSD is a measure of fragmentation of green spaces. Low values indicate fewer patches, while higher values indicate more patches of green spaces and therefore a higher spatial heterogeneity (Figure 7).

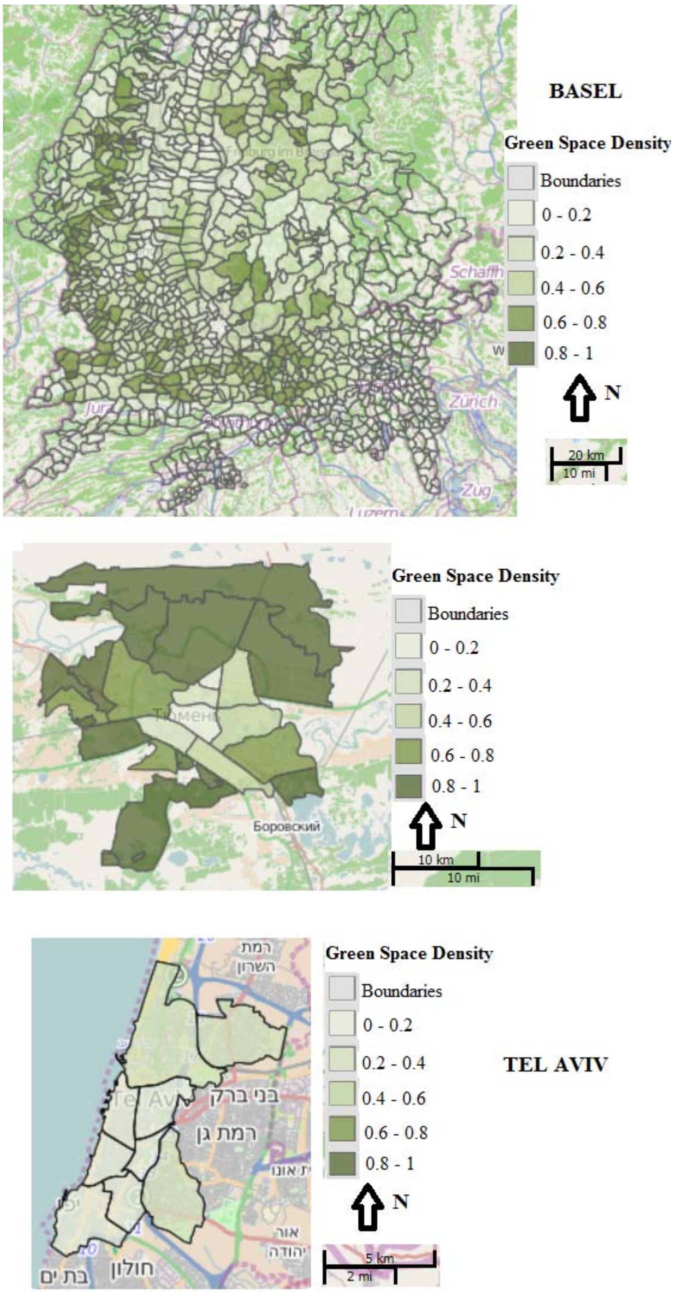


FIG. 7 GREEN SPACE DENSITY FOR THE THREE CASE STUDIES

Area / Edge indicators consider both the complexity of the shape of the patches and their spatial distribution. For Edge Density, low values imply that there are relatively fewer and simpler patches of the specific land use, whereas large values imply that there are many complicated patches. The Edge Density indicator of a class within administrative boundaries was calculated as the total length of the edge of patches divided by total area of administrative boundaries.

Imperviousness-Open space Ratio (IOR) and Imperviousness–Green space Ratio (IGR) are two ratio indicators, characterizing the analogy between different classes of landscape. IOR is an urban indicator which combines the built up density indicator with open space density indicator. High values of IOR indicate large impervious areas or small open space areas within an administrative boundary. IGR is a comparison of impervious and green areas which exists within an administrative boundary. High values of IGR indicate urbanized areas with low green spaces.

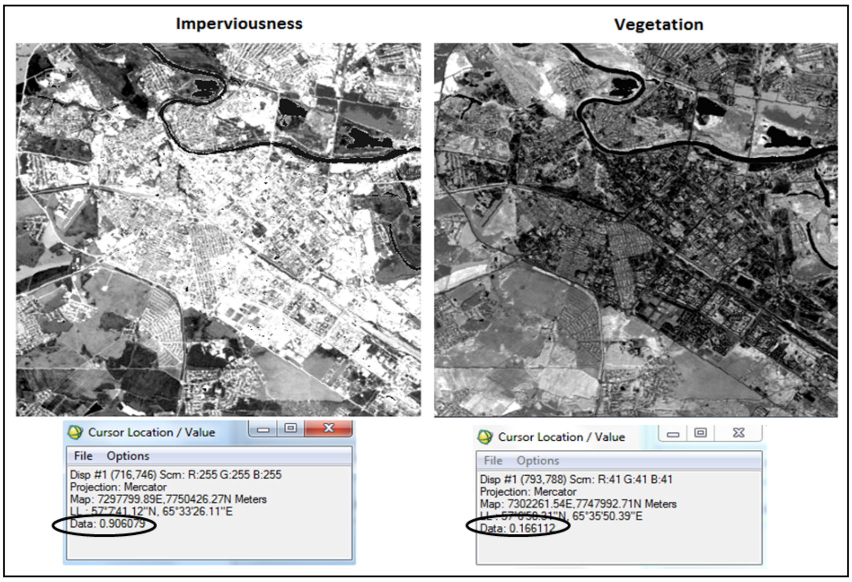
Diversity indicators are mathematical measures of different patches (which belong to different land uses) in a landscape. They provide information about landscape composition, as well as rarity and commonness of patches.

The ability to quantify diversity is an important tool for urban planners trying to understand urban structure. Two diversity indicators are considered Class Richness Density (CRD) and Ecologically Effectiveness Ratio (EER). CRD was considered as a measure of richness of different classes within administrative boundaries. The more classes exist in a administrative boundary, the higher the CRD becomes. Therefore, CRD is the ratio between the number of different classes within an administrative boundary and the total area of this boundary. EER was calculated as the ratio of the ecologically effective surface area to the total land area.

The ecologically effective surface area is the result of combining the areas of different ecological parts of the study area, where for each part a weight is suitably assigned. The different ecological parts take a weight according to their ecological value, as per Lakes and Kim (2012): Forest 1, Water 1, Agriculture 0.5, Grassland 0.7, Residential and Industrial 0. Therefore, the EER is calculated by summing the area of different land types multiplied by their corresponding weight and dividing the sum by the total area of each administrative boundary.

Urban Surface Type

The Land Cover Map is an important urban indicator because it provides useful information about earth surface coverage. Land cover information derived from satellite images can be used for urban analysis in order to extract useful characteristics of urban areas such as land cover pattern and land cover change. The Land cover map is also important because it can be used to produce other indicators such as built-up density, open-space density, etc. Therefore this indicator, which can be easily produced by land cover classification from remotely sensed imagery, can be a useful tool in urban planning and management.



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Disp #1 (716,746) Scrn: R:255 G:255 B:255
Projection: Mercator
Map: 7297799.89E,7750426.27N Meters
LL : 57°7'41.12"N, 65°33'26.11"E
Data: 0.906079
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Disp #1 (793,788) Scrn: R:41 G:41 B:41
Projection: Mercator
Map: 7302261.54E,7747992.71N Meters
LL : 57°6'50.31"N, 65°35'50.39"E
Data: 0.166112
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FIG. 8 FRACTIONAL LAND COVER FOR TYUMEN (IMPERVIOUSNESS – VEGETATION CLASSES)

Fractional land cover refers to the proportion of a pixel by predefined land cover types. The estimation of fractional cover is called “spectral unmixing” and the proportions of each land cover in a pixel should sum to one. A Linear Spectral Mixing Analysis technique (Adams et al., 1995) was used in GEOURBAN. According to this method, the spectrum which returns to the sensor is a linear combination of all the components spectra (end-members) within a pixel (Lu and Weng, 2006; Roberts et al., 2012). The selection of endmembers is usually an image-based process, where endmembers can be easily obtained from the extreme purest pixels of the image. The band scatterplots and the Pixel Purity Index (PPI) were used for end-members selection (Phinn et al, 2002). The resulting fractional land cover map for the case of Tyumen is shown in Figure 8.

Surface Albedo

The surface albedo is the diffuse reflectivity (reflecting power) of a surface and it expresses the ratio of reflected radiation from the surface to incident radiation upon it. The values of the surface albedo ranges from zero (no reflection – black body) to 1 (perfect reflection – white surface). The urban surface broadband albedo is important for urban energy balance. Among several types of broadband albedos the total shortwave albedo covering the wavelength range from about 0.4…2.5 μm is of main interest for urban planning purposes. Spectral albedo is derived by directional integration of land surface reflectance recorded at the sensor and is therefore dependent on the Bidirectional Reflectance Distribution Function (BRDF), which describes the dependency of reflectance on view and solar angles. At local scale, the GEOURBAN surface broadband albedo indicator was calculated by Landsat Lambertian narrowband albedos by employing the conversion formulas suggested by Liang (2000). At city scale, the surface albedo was estimated from the MODIS derived white-sky (completely diffuse) and black-sky (direct beam) albedo products (Schaaf et al. 2002). The wavelength, the optical depth, the aerosol type and the terrain can be used for diffuse component calculation. Therefore, for partially diffuse illumination actually occurring, the spectral albedo may be approximated as a linear combination of the limiting cases. For this approximation, the fraction of diffuse radiation should be calculated; its calculation can be performed as per Benas and Chrysoulakis (2014), as a function of solar zenith angle and Aerosol Optical Thickness (AOT).

The surface emissivity is the relative ability of a surface to emit energy by radiation and equals to the ratio of energy radiated to the energy radiated by a black body at the same temperature. The emissivity of land surface varies with vegetation, surface moisture, and roughness. Emissivity not only depends on the surface type but also on its physical condition imposing additional large temporal changes. There are several methods for the estimation of surface emissivity from satellite data. In GEOURBAN, the surface emissivity was calculated as a function of the Normalized Difference Vegetation Index (NDVI) as per Sobrino et al. (2004). The limitations of this method for urban areas are well-known and alternative approaches have been recently proposed to overcome the mixed pixels problem (Mitraka et al., 2012). However, the NDVI method was used in GEOURBAN because of its simplicity and it's capability for on-line implementation.

Urban Sprawl

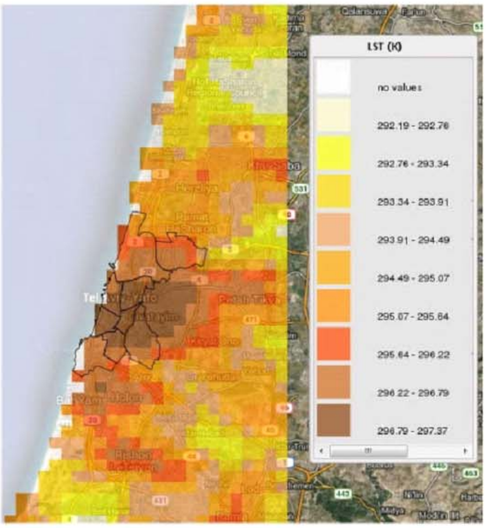
Urban sprawl has one or more of the following characteristics: non-compact growth, low density suburban development, scattered or random linear development and strip or ribbon structure (Wassmer, 2000; Ewing, 2008). Urban sprawl has negative impact in cities because of high and unsustainable energy consumption and increased use of cars and heating, the reduced level of means of transportation in the suburbs and the fragmentation of urban development and ecological impacts (CEC 2006, 2011). The reduction of urban sprawl not necessarily implies reduction of urban expansion, but poses some rules in that it becomes more functional. The urban fringe is a measurement of sprawl and is defined as the built up areas which have neighborhoods that are 30-50% built up. Scatter Development is another measurement of sprawl which describes the built up areas which have neighborhoods that are less than 30% built up. The size of a neighborhood was set at 500 m. The size of neighborhood is an optimal size as equivalent of a ten-minute walk at an easy pace. This limited area is more accessible to the stores, post-offices, schools, transit stops, etc. Change detection is the process where identification of the differences of a phenomenon takes place within a time interval (Chrysoulakis et al., 2013). Therefore, change detection of urban land uses is of great importance in urban planning and management, because it provides to urban planners a clear representation of urban growth, identifying the areas of rapid change which need special treatment. In GEOURBAN, change detection was applied using land cover maps 1984, 1993 and 2011. The change detection indicator was related to urban land cover changes and therefore, it focused on the detection of non-urban areas which became urban.

Urban Environmental Quality

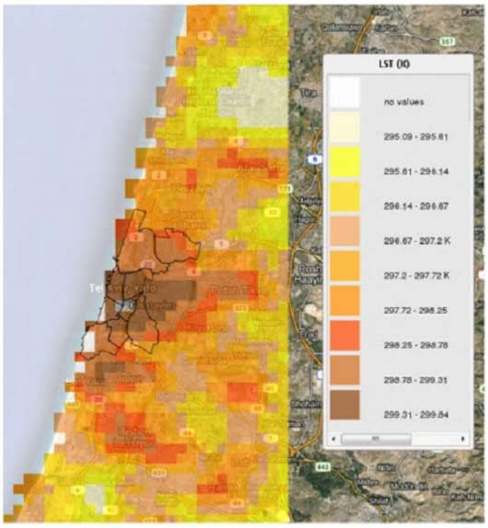
The Surface Urban Heat Island (SUHI) intensity describes the difference in surface temperature between a conurbation and the surrounding rural area. Urban geometry, compactness, population, land use and vegetation cover influence the urban heat island. SUHI can be estimated from the spatial distribution of the Land Surface Temperature (LST), which can be derived by satellites with thermal infrared acquisition capabilities, such as MODIS. MODIS daily observations are automatically processed by inversion algorithms accounting for emissivity and atmospheric effects (Wan et al., 2004, Tran et al., 2006) and producing daily LST products, on-line available at 1 km x 1 km spatial resolution. Despite its low spatial resolution, the MODIS LST product is acceptable in SUHI studies, because of its high temporal resolution (Benas et al., 2014). In Figure 9 an example of MODIS derived nigh-time LST distribution for Tel Aviv is presented (average monthly LST for 13 years).

Furthermore, MODIS Level 2 is a category of higher level products, available on-line on a daily basis, including the Aerosol Product, which monitors aerosol properties. AOT is an important aerosol parameter included in this product. Therefore, the MODIS derived daily AOT at 10 km × 10 km was used in GEOURBAN as a proxy to the air quality in the three case studies.

June 2000 - 2012



July 2000 - 2012



August 2000 - 2012

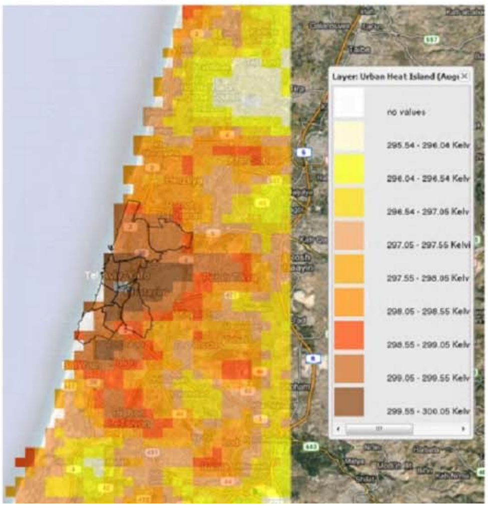


FIG. 9 AVERAGE MONTHLY LST (KELVIN) FOR 13 YEARS IN TEL AVIV

Vulnerability to Hazards

The vulnerability to natural hazards should be carefully assessed in urban areas because people need should be safe in the environment in which they live. Droughts, floods, earthquakes and other natural hazards have become frequent and therefore, disaster response plays an important role in case of emergency. Accessibility to critical services is an indicator of the environmental vulnerability. In GEOURBAN, the distance of specific points of critical infrastructure is considered to assess the vulnerability of each area. Therefore, distance maps of specific points of interests such as hospitals were prepared. In Figure 10 the accessibility to critical services (hospitals) for Tel Aviv is presented.

Socioeconomics

Exposure to Particulate Matter (PM) of both fine (PM2.5) and coarse (PM10) particles is used as a socioeconomic indicator in urban areas. PM has serious effects on human health, increasing morbidity and mortality. Respiratory problems, cardiovascular diseases and decreased birth weights and lengths are some of the negative PM impact on human life. PM monitoring is based primarily on ground measurements, for which their spatial and temporal coverage is highly variable. Therefore, PM estimation using satellite remote sensing techniques is more than appropriate. AOT is the most common satellite derived parameter used for PM estimation. One of the several methods for PM estimation is the multiple regression analysis technique, which is based on satellite derived AOT and other related parameters, such as surface temperature and relative humidity (Benas et al., 2013; Al-Hamdan et al., 2014). All the above environmental parameters were MODIS derived in GEOURBAN. A large fraction of urban population is exposed to levels of PM10 in excess of threshold values set for the protection of human health. Exceedance days are defined as days with PM10 24-hours average above 50 mg/m^3 according to European Commission regulation (EU Air Quality Standards). Exposure to PM10 is the annual population average exposure to air pollution by PM10 and was estimated using the calculated PM10 values and the spatial distribution of population in the GEOURBAN case studies.

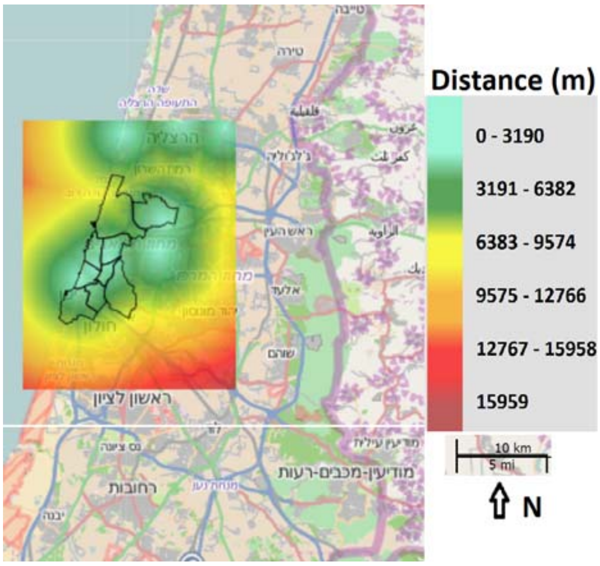


FIG. 10 ACCESSIBILITY TO CRITICAL SERVICES (HOSPITALS) FOR TEL AVIV

Discussion and Conclusions

This study focused on the exploitation of EO data to develop and to on-line evaluate environmental indicators capable of supporting urban planning and management. The on-line evaluation was performed using a WIS that was developed in the framework of the GEOURBAN project. The considerable potential of using such indicators in urban planning and management offers an unprecedented opportunity for making the appropriate decisions for both daily urban planning and climate change mitigation and adaptation.

Satellite technology can substantially provide alternative tools for urban planning by supporting the development of urban environmental indicators within a low cost, efficient, precise and non-time-consuming framework. Urban remote sensing is a relatively new research and application field developing especially since the launch of high spatial resolution radiometers. At present, a large range of sensors is operational and the different characteristics of the available data allow very different methodological and thematic developments - from classification algorithms to applications in thematic fields, such as urban planning, population assessments and risk analysis. The specific characteristics of urban areas imply certain requirements for EO data, depending on the geo-information product relevant for the user.

An important outcome of GEOURBAN project was the WIS prototype for the on-line evaluation of the EO-based indicators that were presented in this study. One of the main capabilities of this WIS prototype is the indicator evaluation module, which allows the end-user to evaluate each EO derived indicator within user-defined specific areas (polygons). In this way, the set of urban indicators evaluated using EO data through the WIS may become an important tool in the process of assisting cities to improve their current environmental, social and economic conditions. Notwithstanding the limitations arising in applying the proposed indicators in other urban areas, the adoption of the current research remains unaltered.

In GEOURBAN, the significant challenge arising from EO data capabilities, to urban planning was considered. Because of coexistence of economic, social, and environmental dimensions in sustainable urban development, future endeavors must integrate the qualities associated with the above dimensions and their interactions. Therefore, these concepts should integrate several tools and technologies (EO, GIS) and data types (satellite imagery, census data). The achieved result from by such an approach was the WIS prototype that was developed in the framework of the GEOURBAN project. However, more efforts are needed to this direction, for global monitoring applications in terms of availability of satellite data and image processing analysis within a cost and time effective framework.

In this study, a number of applications were introduced, which have been developed in order to provide innovative approaches in supporting decision making in urban planning and management. The usage of EO data in developing urban environmental indicators makes the GEOURBAN approach useful in day-to-day planning, as well as in climate change mitigation and adaptation, providing assistance to local, or regional governmental needs. The usability of urban environmental indicators makes them powerful tools in sustainable urban planning and management, generating a more effective decision process, transparency and communication. Whilst various indicators were applied in different ways in GEOURBAN project, the aim pursued is the same; the support of urban planning and management initiatives. Developers of urban indicators should specify the objectives and intended users of the indicators. All indicators are used to sustain urban development, but there are more specifics objectives within this general aim. Indicators cannot meet all the objectives and an indicator which was used to cover one objective may be different to another indicator which was designed to cover another objective. Similarly, indicators cannot be the same for the interested end-users; local decision makers, scientists or community parties. For example built-up density can be successfully used for local authorities to design planning tools but it wouldn’t be as much appropriate for a scientist looking for urban ecology as AOT is.

Indicators are powerful tools in promoting sustainability if designed properly. But, it is a truth that many indicators are hard to apply. It is for research use only or for a specific target group. It is a demand of usable urban indicators for everyday needs of urban planners and decision maker. Our approach, GEOURBAN, actually tried to bridge the gap which exists between theory and practice and to provide useful urban indicator from EO datasets.

ACKNOWLEDGMENT

This work was partially performed in the framework of the GEOURBAN project (ERA.Net-RUS-033) and partially in the framework of the PEFYKA project within the KRIPIS Action of the GSRT. The project is funded by Greece and the European Regional Development Fund of the European Union under the NSRF and the O.P. Competitiveness and Entrepreneurship. The authors thank the RESA/ RapidEye and the TerraSAR-X science teams for providing EO data based on the research proposals 504 (RapidEye) and LAN0896 (TerraSAR-X).

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