“BABEŞ-BOLYAI” UNIVERSITY CLUJ-NAPOCA

F A C U L T Y O F G E O G R A P H Y

PhD THESIS

- Summary –

A GIS AND REMOTE SENSING – BASED RESEARCH ON THE CLUJ-NAPOCA MUNICIPALITY URBAN HYDROLOGY

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Keywords: impervious surfaces, HEC-HMS, flowpathways, ponds, road surface water quality, Cluj-Napoca.

1. INTRODUCTION

Urban hydrology is a branch of hydrology that studies the hydrological cycle, the water regime and water quality within urban areas. Surface runoff and accumulated rainwater in urban areas is directly influenced by the nature of surface areas. Impervious surfaces have been expanding remarkably in recent years, which is primarily due to urbanization processes. Amid urban population growth and impervious surface expansion we are currently witnessing an increase in urban runoff and surface water quality degradation.

1.1 Motivation and research objectives

The reason for choosing this research theme is reflected in the desire to offer a retrospective and current outlook on rainwater runoff and accumulation in urban areas in the context of urbanization and industrialization and on surface rainwater quality. This paper focuses specifically on the study of surface runoff and accumulated rainwater on the surface of urban areas using GIS and remote sensing techniques.

The main *objectives* of the study were:

- pervious and impervious surface extraction from remotely sensed data based on satellite imagery for the period 1986-2014, to provide an overview of the expansion of the urban area;
- evaluating the hydrologic response to impervious surface variation for the period 1986-2014 in order to highlight the impact of urbanization on surface runoff;
- delimiting basin areas on the floodplain, slopes and urbanized drainage divide of Cluj-Napoca and identifying watercourses based on a Digital Elevation Model (DEM) and a Digital Surface Model (DSM) in order to highlight urban flood risk areas;
- the quality assessment of surface runoff and accumulated rainwater to gain real information about the degradation degree of urban rainwater;
- estimating rooftop runoff volumes for their subsequent catchment and storage.

According to these objectives, the paper was divided into nine main sections outlined as follows: establishing research objectives – learning about the research topics – creating a database – presentation of the urban drainage system – impervious surface extraction from remotely sensed data based on satellite imagery for the period 1986 – 2014

– defining the hydrologic response to impervious surface variation – identifying watercourses and delimiting basins within the urban area – quality assessment of surface runoff and accumulated rainwater in the urban area – presenting and implementing techniques to reduce runoff volume and to improve rainwater quality.

1.2 The geographical location of the study area

The municipality of Cluj-Napoca is located in Southeast Europe, in the northwestern part of Romania (46 ° 46 'N and 23 ° 36' E), in the heart of Transylvania at an average elevation of 360 m.

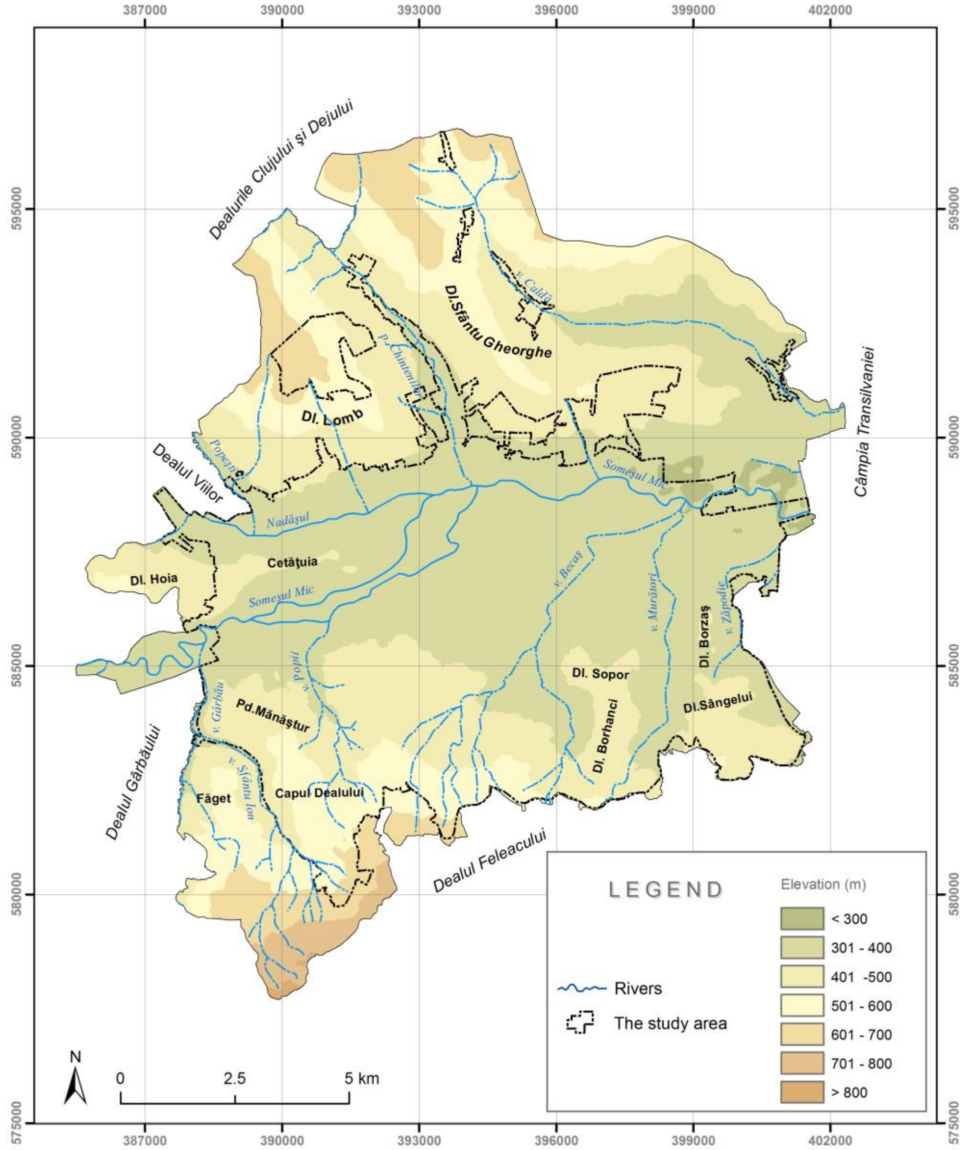

Fig. 1.1 Hypsometric map of Cluj-Napoca.

The town has developed along the river Someșul Mic especially in the direction west-east, but also sideways on the terraces of the river Someș in the contact zone among the Apuseni Mountains, the Someșan Plateau and the Transylvanian Plain. It also sprawls over the valley of the Nadăș River and to some extent over the secondary valleys of the Popești, Chintău and Popii rivers (Fig. 1.1). The geographical position of the city influences its climate, which can be characterized as moderate continental with warm summers and winters generally devoid of blizzards.

According to statistics provided by the National Institute of Statistics (NIS, 2015) the population of Cluj-Napoca was of 320 547 inhabitants in 2014 and the population of Cluj county was of 718,633 people. The population growth of the city was of about 3% in the period 1986-2000 and of 2% between the years 2005 and 2014 with a negative growth rate of about -1.7% during the period between 2000 and 2005.

Urban dynamics and development entail permanent changes in the original physical appearance of the city structure. Land cover types within the urban area directly affect surface runoff, thus being important variables in the study of urban hydrology.

2. LEARNING ABOUT THE RESEARCH TOPICS

Urban areas frequently experience flooding due to heavy rains or the failure of the drainage system to collect rainwater. As a result, more papers began to focus on studying the water regime and water quality in urban areas.

2.1 The study of drainage networks in urban areas

Delineation of water flow networks in urban areas is determined by slopes, and after a pronounced rainfall the process of infiltration begins, but when rainfall intensity exceeds the infiltration capacity of the soil, excess water begins to pond on the land surface. The ponded water fills depressions and potholes in the ground surface and water starts to flow downstream concentrating in a stream flow over the steepest slopes.

The Digital Elevation Model (Biali, 2012; Biali et al., 2013) plays a significant role in outlining the overland networks (Haidu and Ivan, 2016 a). A DEM based overland flow modeling method is GIS screening, which was described and implemented by DEFRA (Department for Environment, Food and Rural Affairs) in 2008 within the project “Integrated Urban Drainage Pilot Study - Hogsmill River Catchment”. In this project the methodology used for determining overland flow paths was based on the “rolling ball” technique and in basins on the "Contour Polygon Screening" technique. The "rolling ball" technique was introduced by O'Callaghan and Mark (1984) and has been used in numerous studies by Daroussin and Dobos (2005); Evans (2008); Jenson and Domingue (1988); Liu and Zhang (2010); Pourali et al. (2014); Tarboton and Ames (2001) for the automatic delineation of drainage networks based on DEM . The "Contour Polygon Screening" method (DEFRA, 2008) was also used by Podobnikar (2012) for detecting mountain peaks and for the automatic delineation of their shapes using DEM and Gis, by De Carvalho et al. (2013) for detecting karst depressions with three different DEMs, ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) SRTM (Shuttle Radar Topography Mission) and ALOS / PRISM (Advanced Land Observing Satellite).

2.2 The study of impervious surfaces

The processes of urbanization and industrialization over the years have led to the expansion of urban land cover and the spread of built environments. These resulted in increasing impervious surface coverage in urban areas.

For the assessment of the variation of impervious surfaces for a longer period of time numerous studies have used remotely-sensed satellite data. Remote sensing allows quickly obtaining information concerning the structure and expansion of the city over time. (Haidu and Ivan, 2016 b).

Among the most popular methods for the extraction of impervious surfaces from remotely sensed data we can mention the method of Linear Spectral Mixture Analysis (LSMA) (Deng et al., 2012; Lu and Weng, 2009; Lu et al., 2012; Lu et al., 2008; Lu and Weng, 2006; Yuan and Bauer, 2007), the supervised classification method of Maximum Likelihood (Hodgson et al., 2003; Parece and Campbell, 2013; Xu, 2007; Weng, 2001) and MESMA -Multiple Endmember Spectral Mixture Analysis (Shahtahmassebi et al., 2012).

Based on these methods and remotely sensed satellite data, we can determine the Total Impervious Area (TIA) and the Effective Impervious Area (EIA). EIA is the portion of the total impervious area within a basin which is directly connected to the drainage collection system (street surfaces, paved driveways connecting to the streets, parking lots, rooftops) and can be estimated based on the equations developed by Sutherland (2000). In his paper "Methods for Estimating the Effective Impervious Area of Urban Watersheds" (Sutherland, 2000) he describes the methodology for estimating EIA by developing six equations widely used in numerous studies.

The impact induced by the spread of impervious surfaces on surface runoff can be analyzed based on the Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS). This model permits the assessment of the hydrologic response to changes in land cover over a longer period of time.

2.3 The study of urban stormwater quality

There is nowadays an increasing concern on the quality of urban surface water (rivers, lakes, channels and creeks) (Ivan et al., 2016). Dry summer months or dry periods between rainfall events allow for pollutant build-up to occur on road networks or on other impervious surfaces.

Mahbub et al. (2001) focused on assessing pollutant build-up on urban roads with different traffic parameters located in areas with different types of land use and others like Hilliges et al. (2013); Helmreich et al. (2010); Westerlund et al. (2003) were concerned with pollutant build-up during different seasons. The study conducted by Bannerman et al. (1993) aimed to assess water quality by identifying the critical source areas such as roads (primary and secondary), parking lots, roofs, driveways and lawns that generate contaminants washed off three different land uses: residential, commercial and industrial. While simulating the amount, intensity and duration of rainfall using a rainfall simulator, Eckley and Branfireun (2009); Egodawatta et al. (2007); Egodawatta and Goonetilleke (2008); Herngren et al. (2005) assessed the quality of street runoff.

2.4 The study of alternative urban stormwater management practices

Impervious surfaces such as road networks, pavements, rooftops or parking lots are the main source of stormwater pollution especially during the first flush phase. In order to reduce the volume of urban runoff and to improve water quality certain solutions have to be implemented, such as the expansion of pervious surfaces or the introduction of techniques for rainwater capture and storage (Haidu and Ivan, 2015).

An alternative method for improving the quality of runoff and accumulated rainwater on the surface of the urban area and for reducing the volume of urban runoff is to introduce techniques for rooftop runoff capture and storage.

In order to estimate the volume of water that runs off impermeable catchment areas (rooftops), one can resort to using the Simplified Michel SCS-CN model that can be applied to completely impervious surfaces and that has been developed based on the SCS-CN model.

3. CREATING THE DATABASE

Establishing a database was the first and most important step in the study. The acquisition, processing and analysis of a complex set of data from different fields have enabled us to create a specific database for our research.

3.1 Cartographic database

In our study we relied on using maps for extracting information regarding elevation for the target area as well as for collecting information on existing ground surface characteristics (buildings, roads, pavements, drains).

- *Topographic plans of 1:5000 scale*

I used high resolution topographic plans (IGFCOT, 1974) in order to achieve a high accuracy DEM. The map sheets that were used:

  - L-34-048-C-a-2-III; L-34-048-C-a-2-IV;
  - L-34-048-C-a-3-II; L-34-048-C-a-3-IV;
  - L-34-048-C-a-4-I; L-34-048-C-a-4-II; L-34-048-C-a-4-III; L-34-048-C-a-4-IV;
  - L-34-048-C-b-3-II; L-34-048-C-b-3-III;
  - L-34-048-C-c-2-I; L-34-048-C-c-2-II;

The extraction of elevation data from these map sheets implied georeferencing this dataset in Stereo 70 projection system and digitizing contour lines.

- *Topographic plans of 1:500 scale*

Based on the 1:500 scale topographic plans (GEONET, 2004) we extracted the following characteristics for the study area: buildings, street and pavement networks, stormwater drains. These thematic layers were used to create a Digital Surface Model (buildings) with the purpose of observing the flow path of surface runoff (street and pavement networks) and locations where water tends to accumulate and pond (proximity of drains).

- *Topographic maps of 1:25000 scale*

Based on the 1:25000 scale topographic maps the contour lines and sample points were manually digitized in order to obtain an elevation dataset with lower spatial resolution.

3.2 Digital database

Digital data use is the basis for spatial analysis and GIS modeling in order to achieve expected results.

- *Digital Elevation Model*

In the present study the Digital Elevation Model (DEM) was created using the interpolation method of Topo to Raster and was based on the altitude values of contour lines and sample points manually digitized from topographic plans of 1: 5000 scale and topographic maps of 1: 25000 scale.

To highlight the influence of horizontal grid resolution of DEM on water flow path delineation in urban areas four altitude datasets with different spatial resolutions were used: DEM (5 x 5 m), DEM (20 x 20 m) GDEM ASTER (30 m) and SRTM (90 m). By adding some thematic layers (buildings) to the DEM (5 x 5 m) the Digital Surface Model (DSM) was created.

- *Digital Surface Model*

The Digital Surface Model (DSM) was based on the Digital Elevation Model (5 x 5 m) and vectorized building footprints from topographic plans of 1:500 scale.

Thus the obtained Digital Surface Model shows not only the elevation values representing the actual ground surface but also the height of buildings in the study area (Fig. 3.1). In addition to these altitude values we can also add the height values of other objects (fences or road curbs) that can significantly impact surface runoff.

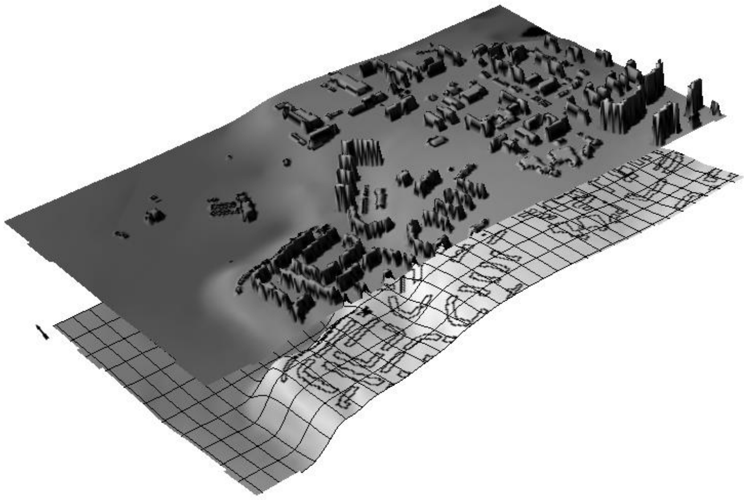

Fig. 3. 1 Digital Surface Model Representation (DSM).

- *Satellite imagery*

Land cover changes that occurred over the years in the urban area of Cluj-Napoca were investigated using remote sensing.

The satellite images used in the study were procured from the free USGS database (USGS, 2014) for four different years (August 8, 1986, April 21, 1993, August 28, 2002 and March 14, 2014). These scenes were selected from Landsat 5, Landsat 7 and Landsat 8 images (Path 185 / Row 27), all with 30 m spatial resolution. To validate results we used images from the archives of Google Earth (Google Earth, 2014) from the years 2002 and 2014.

- *GMES Urban Atlas dataset*

GMES Urban Atlas 2009 (GMES, 2009) database with a reference scale of 1: 10000 was used to analyze land use in the city of Cluj-Napoca. GMES Urban Atlas dataset was used to determine the parameter Curve Number (CN) which is necessary to estimate the volume of surface runoff in the urban area.

- *SIGSTAR-200 dataset*

The GIS of Soil Resources of Romania SIGSTAR-200 (SIGSTAR, 2011) dataset provides help to generate thematic layers related to soil type, soil texture and hydrologic soil group for Cluj-Napoca.

- *GPS measurements and water samples*

GPS measurements were implemented to locate sampling sites to assess the quality of runoff and accumulated rainwater on the surface of the urban area and depressions, which are filled with rainwater after heavy rainfall, were located on the ground surface.

3.3 Numerical database

Numerical data on demographic information and weather conditions were used in this study.

- *Weather data*

To estimate surface runoff and rooftop runoff volumes daily rainfall data was used from the ECA & D database (European Climate Assessment & Dataset).

- *Demographic data*

Demographic data was used for the numerical analysis of the population growth in Cluj-Napoca, respectively for the analysis of the urbanization process in Cluj county. This data was provided by the National Institute of Statistics (NIS, 2015).

4. URBAN DRAINAGE SYSTEM

The processes of urbanization and industrialization have led to the spread of impervious surfaces (pavements, parking lots, built surfaces) within the urban area. This expansion of urban land cover has resulted in higher runoff volume and rate, increased flood risk and water quality degradation. Due to increasing runoff volumes the capacity of the urban drainage system (street gutters, drainage or sewer system) is often exceeded.

4.1 Causes of surface runoff in urban areas

Urban settlements are affected not only by surface runoff but also by the amounts of water flowing in from their surrounding areas and by the increasing water levels in the river that flows through them. Drainage systems in urban areas must collect and convey surface runoff, must ensure the transfer of water coming from upstream areas and in the case of downstream flooding (Stănescu, 1995).

The analysis of the drainage systems in Cluj-Napoca revealed the possibility of the first two situations and the chance for their occurrence depending on the spatiotemporal relations existing between the urban area and its surrounding areas. Besides these natural causes of surface runoff anthropogenic factors have to be considered as well: domestic and industrial wastewater, water discharges that enter the drainage system by accident and which do not have controlled drainage (Conţiu, 2007).

4.2 Factors affecting surface runoff

In urban areas surface runoff is affected by both natural and anthropogenic factors.

Natural factors generating surface runoff in urban areas are precipitation, land surface morphology, vegetation and soil cover. The morphology of the land surface, especially the slope of the land plays an important role in the appearance of water flow paths and sites of water accumulation on the surface. Vegetation and soil cover are essential for drainage.

Among the anthropogenic factors roads and pavements are of importance because they serve as pathways for water streams in urbanized areas. During heavy rainfalls certain objects on the land surface can become real obstacles in the watercourse, increasing flood risks. Such event can happen when certain materials accumulate in the drain and stop the water from entering the underground drainage system.

4.3 Drainage system components

The drainage system in Cluj-Napoca presents two forms: an organized one that allows water control and management and an unorganized one that is more difficult to control.

The organized drainage system consists of bypass channels, the proper sewage system of the city, flood protection lines, gravity drainage systems (Stănescu, 1995).

- *The sewage system*

As part of the organized drainage system, the sewage system in Cluj-Napoca has a length of 385 km and it follows the path of the water distribution network in most areas. It is a gravity sewer system which collects wastewater and storm water and conveys them by gravity through combined sewer systems in 80% of the drainage system and in 20 % in separate sewers. The tendency witnessed by the sewage system is that of continuous expansion in order to ensure the most efficient drainage for the entire urban area.

Within the organized drainage systems we can mention water streams, which constitute natural flow paths for water. The river Somesul Mic, the main water stream which underwent numerous management changes, flows through the city over a distance of 16 km in west-east direction.

Unorganized drainage systems are the areas which show high infiltration rates: gardens, yards with permeable surfaces, undeveloped road surfaces, urban areas lacking sewer systems (Conțiu, 2007). These areas are actually the pervious surfaces in an urban area and are characterized by high rates of infiltration and drainage is difficult to control.

4.4 Modern drainage systems

The possibility for surface runoff control in urban areas can be achieved by modern techniques of capture, transport and drainage in addition to the traditional ones. Alternative techniques can be applied at building-level, at yard-level, and at district-level (Zaharia, 2006).

- ***Building-level applications***

Best management practices that can be implemented for buildings: roof catchment systems or storage tanks adjacent to buildings.

- *green roof*

They play an important role in reducing rooftop runoff volumes and help improve water quality in the urban area.

- *rainwater capture in rain barrels or storage tanks*

These systems play an important role in reducing runoff volumes and supply water for residential or commercial use (irrigation, washing yards).

- ***Yard-level applications***

Water storage or water infiltration techniques can be implemented at yard-level.

- *infiltration basin*

An infiltration basin is an impoundment designed to capture storm water runoff which allows it to infiltrate into the ground and depending on the soil media it facilitates the percolation of water (UA CDC, 2010).

- ***District-level applications***

Within city districts techniques can be applied at street-level or at the level of natural environments (parks, yards, spaces between buildings, parking lots etc.).

- *pervious pavements*

Pervious pavements allow precipitation to infiltrate into the soil, help reduce runoff volumes, improve surface water quality in the urban area and contribute to groundwater recharge (Fig. 4.1).

Fig. 4.1 Pervious pavement in a parking lot in Cluj-Napoca (foto, 15th May 2013, Ivan K.).

- *subsurface storage system*

These systems collect, store and remove water into the drainage system or to the soil.

- *vegetation acting as a filter system*

They play an important role in reducing runoff volumes and help improve water quality in the urban area.

- *tree filter systems*

  These systems, in addition to the aesthetic value they hold, are effective in filtering out contaminants from water reaching the sewage system.

- *infiltration trenches*

  They are effective in controlling runoff volumes and recharging groundwater through infiltration.

- *urban wetlands*

  They allow rainwater collection and mitigate peak rates.

From these alternative drainage systems several were applied in Cluj-Napoca: lateral infiltration trenches (shallow depth and paved with permeable materials), vegetation and tree filter systems having important roles in the collection and slow disposal of surface runoff. Within parking areas, commercial and public areas and yards pervious pavements were used which allow the natural infiltration of rainwater. Moreover, the installation of green roofs is planned in some residential areas.

The drainage system is of major importance within a community. In case of heavy rains it removes surface runoff, controls runoff rate and conveys water to major a collection line.

5. DELINEATING IMPERVIOUS SURFACES WITHIN AN URBAN AREA

In urban areas pervious surfaces (parks, recreational lands, gardens) alternate with impervious surfaces (buildings, streets, pavements, parking lots).

Areas with impervious surface cover in an urban basin are important when generating water flow. These are divided into two categories: directly connected impervious areas (DCIA) from which runoff flows to the urban drainage system directly via concentrated flow and indirectly connected impervious areas (ICIA) from which runoff spreads over pervious areas before entering the urban drainage system. The directly connected impervious area is the effective impervious area (EIA) and it is an important parameter because it directly affects the volume of runoff. Directly and indirectly connected impervious areas to the urban drainage network constitute the total impervious area (TIA).

Within this chapter we aim to offer a retrospective outlook on urban land cover growth, particularly the extent of impervious surfaces in Cluj-Napoca for the period 1986-

2014. The spatiotemporal variation of impervious surfaces for the reference period was analyzed using Landsat satellite imagery.

5.1 Methodology for determining the total impervious area

The most common methods for determining the total impervious area (TIA) are analyzing classes of land use and aerial photos or satellite images. In the study, in order to extract impervious surfaces, we resorted to using remotely-sensed satellite data for the reference years (1986, 1993, 2002 and 2014) and a supervised classification method.

Before applying a method to extract urban impervious surfaces, the satellite images from DN values were calibrated in TOA reflectance (Top of Atmosphere) and, subsequently, in surface reflectance using the Dark Object Subtraction algorithm (DOS), using the software ENVI 5.1, thus eliminating the atmospheric effects (Haidu and Ivan, 2016 b). After image calibration of converting DNs (Digital Numbers) to reflectance values, an atmospheric correction was performed in order to obtain surface reflectance.

After atmospheric correction and reflectance calibration, images were subjected to a supervised classification method which allowed the extraction of impervious and pervious surfaces for each reference year (1986, 1993, 2002 and 2014).

In the context of supervised classification it is necessary to know the land cover types in order to classify them. Once land cover types were identified, the next step was to select the target land cover classes (representative samples) for extracting thematic information.

Four land cover classes of interest were chosen for extracting thematic information: forest, herbaceous vegetation, soil and impermeable surfaces. Water bodies were masked out during the classification process and were not included in the sample classes because their spectral features are similar to those of dark and shadowed impervious surfaces (Deng et al., 2002; Lu and Weng, 2009; Xu, 2007; Lu et al., 2008). Afterwards, based on the polygons corresponding to each sample class, reflectance data was extracted for each one (forest, vegetation, soil and impermeable surfaces) (Fig.5.1).

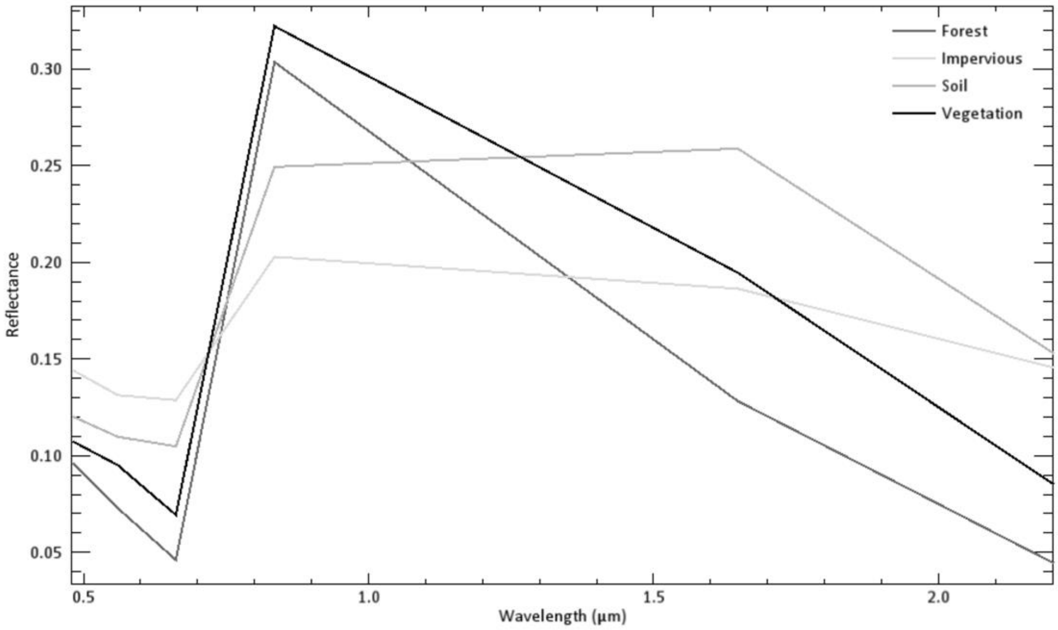

Fig. 5. 1 Spectral signatures obtained for the used training regions. Reference image 2002 (Haidu and Ivan, 2016 b).

After selecting the most representative samples of land cover classes, the next step was to choose the most suitable method of classification that allows the most accurate extraction of impervious urban surfaces (Ivan, 2015).

In order to find the most suitable method of supervised classification, that will allow us to obtain a high accuracy for the entire study area, first we applied four methods, widely used in extracting impervious urban surfaces namely the supervised classification Maximum-Likelihood, Mahalanobis Distance, Neural Networks and Support Vector Machine (Haidu and Ivan, 2016 b).

To assess the accuracy of the classification result we computed the overall classification accuracy for sample pixels and the kappa coefficient, and the results were subsequently validated based on reference points in the field.

Comparing the results obtained for the four mentioned methods showed that the best classification accuracy of the result classification is given by the method Maximum-Likelihood (96 %), which allowed us to obtain a validation in the field also high (90%) Haidu and Ivan, 2016 b).

Based on these results we resorted to using the Maximum Likelihood classification method to extract impervious urban surfaces for the four reference years (1986, 1993, 2002 and 2014). After running the classification algorithm we obtained a thematic map corresponding to the four training regions chosen (forest, vegetation, soil and impervious surfaces). Later forest, vegetation and soil classes were grouped into pervious surfaces which enabled us to obtain a thematic map consisting of two classes: pervious and impervious (Haidu and Ivan, 2016 b; Ivan, 2015).

These thematic maps were the basis for the spatiotemporal analysis of the growth in impervious surface coverage in Cluj-Napoca for the period 1986-2014. Based on the obtained thematic maps (Ivan, 2015), the percent variance of impervious surfaces in the city was determined as follows (Ahn, 2007; Ray, 2010):

$$I = \frac{(i_1 - i_o)}{i_o} \text{ x } 100 \tag{5.1}$$

Where,

i_1 - represents impervious surfaces from the following year;

i_0 - represents impervious surfaces from the previous year;

5.2 Methodology for determining the effective impervious area

Effective impervious area (EIA) is the portion of the total impervious area (TIA) within a basin that is directly connected to the drainage collection system (street surfaces, paved driveways connecting to the street, parking lots, rooftops).

According to Jones et al., (2003) the most common methods for determining EIA are:

- *direct measurement in the field;*
- *empirical equations;*

Empirical equations were developed by Sutherland (2000) to compute realistic values of EIA using total impervious area (TIA) data obtained from satellite images.

5.3 Spatio-temporal analysis of impervious surfaces in Cluj Napoca municipality

Spatio-temporal analysis of impervious and permeable surfaces, obtained from the processing of satellite images, has facilitated the identification of changes that occured in land cover in Cluj-Napoca for the period 1986-2014 (Fig. 5.2).

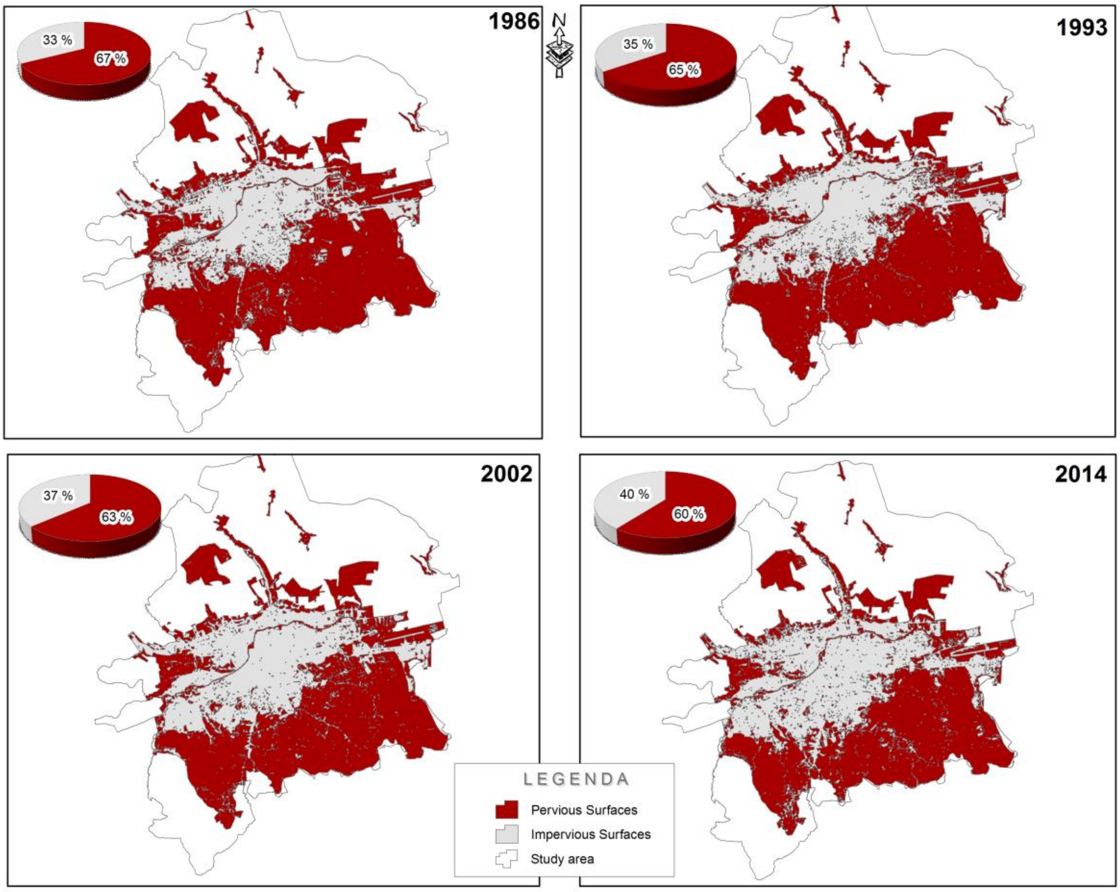

Fig. 5. 2 The increase of impervious surfaces in the period 1986-2014, Cluj-Napoca. (Ivan, 2015).

Impervious surface areas showed an expansion from 33% in 1986 to 40% in 2014. That impervious surfaces have expanded significantly in the southern and eastern parts of the city and more moderately in the northern parts of the city (Ivan, 2015).

When calculating the percent variance of impervious surfaces in Cluj-Napoca, the results showed increases of 6% (1986-1993), 5% (1993-2002) and 8% (2002-2014) (Ivan, 2015).

The spatio-temporal increase of impervious surfaces within an urban basin is due to population variability. According to the statistical data provided by the NIS (NIS, 2015), the population of Cluj-Napoca showed a 3,4% growth rate between the years 1986 and 2014, a 1.8% growth rate in the period 1986-1993, a 0.5% growth rate in the period 1993-2002 and a 1.1% growth rate in the period 2002-2014. In the county of Cluj urbanization trends are noticeable after 1970, the rural population witnessed a decline from 340554 in

1970 to 239250 in 2014, while the urban population showed an increasing trend growing from 147 986 in 1930 to 479383 in 2014 according to NIS data (Fig. 5.3) (Ivan, 2015).

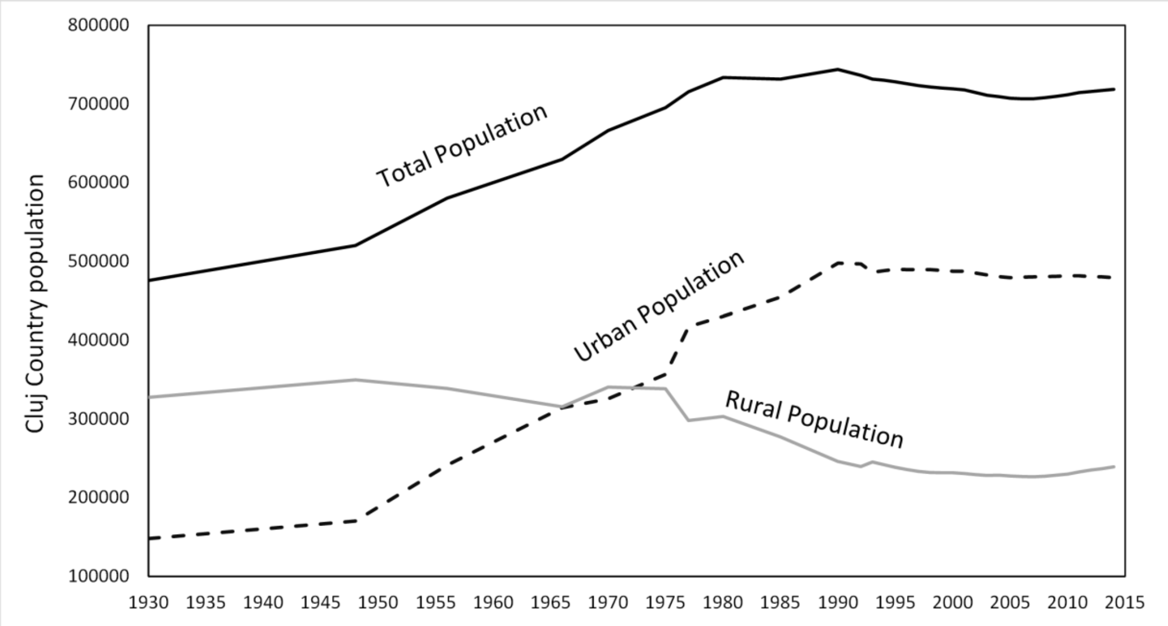

Fig. 5. 3 Population change for the period 1930–2014 in the Cluj County (Ivan, 2015).

The population growth led to the expansion of constructed surface areas, which also implied the expansion of impervious surfaces, water quality degradation, increased runoff water volume and increased urban flood risk (Ivan, 2015). In order to reduce the extent of impervious surface areas, durable solutions must be implemented by local authorities, such as the expansion of recreational lands, parks and green areas near roads and pavements (Ivan, 2015).

5.4 Validation of the thematic results

The validation process involved comparing the relation between the information provided by the thematic map for each point and the corresponding field data. Thus field data with their corresponding points on the thematic map was validated using Google Earth images for 2014 and 2002 respectively (Ivan, 2015).

Validation results showed high classification accuracy, classification images significantly corresponded to the reality on the fields, a fact also confirmed by an overall accuracy of 90.34% for 2014 and of 93.22% for 2002 (Haidu and Ivan, 2016 b; Ivan, 2015). These values indicate that the results obtained are correct and can be used within a more detailed study.

6. EVALUATION OF THE HYDROLOGIC RESPONSE TO THE SPATIO-TEMPORAL EVOLUTION OF IMPERVIOUS SURFACES

Within this chapter we aimed to evaluate the effect induced by spatio-temporal evolution of impervious surfaces on surface runoff. The fieldwork has been conducted on two drainage sub-basins in Cluj-Napoca municipality.

6.1 Description of the drainage sub-basins

In case of the present study the drainage sub-basins have been delimited using the Hec-GeoHMS extension of ArcGIS program, based on a 5 x 5 m DEM. The resulted and analysed sub-basins are described in the following:

- *B1 sub-basin* is located in the southern part of Cluj-Napoca municipality. In the period 1986-2014 impervious surfaces have increased in this area from 41.7% in 1986 to 76.1% in 2014.
- *B2 sub-basin* is located in the northern part of the municipality. Within this sub-basin major changes have not been observed in the type of land cover in the period 1986-2014.

6.2 Input data necessary for modelling

- *Meteorological data*

The rainfall-runoff process in the analysed subwatershed, based on a series of daily recorded rainfall value (Haidu and Ivan, 2016 b), obtained from ECA&D (European Climate Assessment & Dataset).

- *Data about the land cover*

In order to evaluate the impact induced by the increase of the impervious surfaces on the surface runoff, for drainage sub-basins B1 and B2, we used TIA data for the period 1986-2014, data obtained from the supervised classification of satellite images.

- *Data on the soil type*

Data on the soil type and the land cover type, formed the basis for determining the CN (*Curve Number*) index for each sub-basin and for all the reference years.

6.3 Evaluation methodology of the hydrologic response to the increase of the impervious surfaces

In order to assess the impact induced by the increase of the impervious surfaces on runoff, we used the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model. This model allowed us to simulate the hydrologic response to the variability of the surface nature during 1986-2014 (Haidu and Ivan, 2016 b).

Hydrological modelling includes several processes, among which we can mention evapotranspiration, seepage-loss, surface runoff, and the final result of the modelling is represented by the drain hydrograph. Hydrological simulation models can be classified into physical, analogical and mathematical models.

The HEC-HMS hidrologic model has been chosen to simulate rainfall-runoff processes based on land cover type data in the period 1986-2014. This model has allowed us to analyse the effects of urbanisation on surface runoff in the past 28 years.

The HEC-HMS hidrologic model uses separate models to represent the components of the drainage process, each with a different number of modelling methods (USACE, 2000):

- model to calculate the volume of the runoff;
- direct runoff model;
- ”baseflow” model
- ”channel flow” model

Within the HEC-HMS models we have chosen the model to compute runoff volume and the model of direct runoff (Haidu and Ivan, 2016 b).

- ***Model to calculate the volume of the runoff***

In case of the sub-basins the simulation of the drainage water volume was made based on the SCS-CN (SCS Curve Number Loss Model) method.

The SCS-CN method is described mathematically (USACE, 2000):

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (6.1)$$

Where : P_e - excess rainfall accumulated in *t* time

P - rainfall accumulated in *t* time

S - water-retention parameters

I_a - initial loss

This model allowed us to calculate the volume of the runoff for both sub-basins, based on the series of precipitation and the characteristics of the sub-basins.

- ***Direct runoff model***

This model simulates the drainage process form the excess rainfall. The transformation of the excess rainfall into direct runoff has been determined based on the empirical model of the SCS Unit Hydrograph. The input parameters of the model, delay time (t lag) and the surface of the sub-basins, were determined using the HEC-GeoHMS. Thus for each sub-basin several basic characteristics have been determined based on the DEM, and a series of parameters based on data about soil types and land cover type.

Tabel 6. 1 Characteristics and basic parameters of the analysed sub-basins.

Characteristics of the sub-basins		**Sub-basins**	**Parameters of the sub-basins**			
Area (km²)	*Slope*	**B 1**	**1986**	**1993**	**2002**	**2014**
1.54	6.8	CN composite	88.9	91.3	92.7	94.7
		Impervious %	41.7	54.7	63.9	76.1
Area	*Slope*	**B2**				
0.85	10.1	CN composite	87.7	87.8	88.5	89.0
		Impervious %	25.8	26.23	30.6	32.0

Thus, on the basis of the characteristics and input parameters, we modelled the runoff volume using the SCS CN loss method and, on the basis of the SCS Unit Hydrograph method, the direct runoff (Haidu and Ivan, 2016 b).

6.4 The impact of the increase of impervious surfaces on surface runoff

The simulation results corresponding to the two analysed sub-basins have shown a growing tendency of the peak flow, along with the increase of the percentage occupied by impervious surfaces.

For the drainage sub-basins B1 and B2, simulations were performed based on the series of precipitation, taking into account the percentage occupied by impervious surfaces for each reference year, 1986, 1993, 2002 and 2014. The results show an increase of the total volume of the runoff and of the peak flows in the two analysed sub-basins, along with the increase of impervious surfaces between 1986 and 2014. Regarding the total losses, they show a declining trend, along with the increase of impervious surfaces.

These results are embodied in the form of hydrographs corresponding to each reference year separately (Haidu and Ivan, 2016 b) (Fig. 6.1).

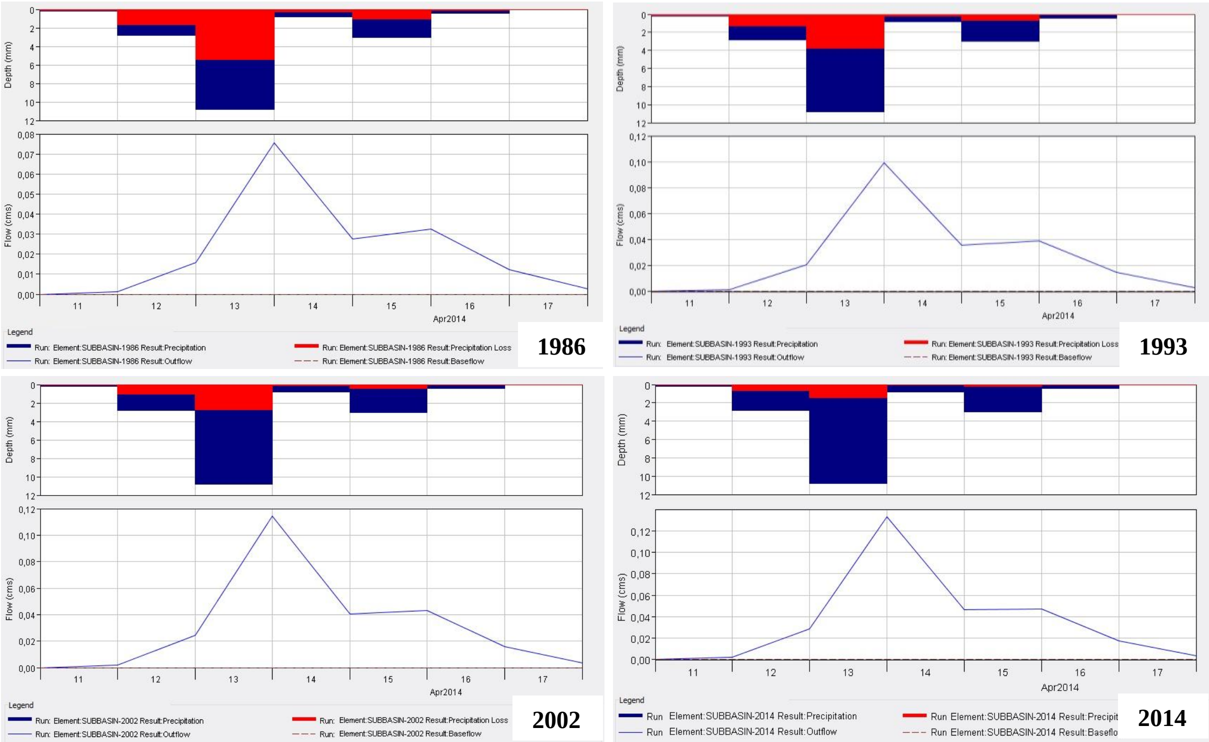

Fig. 6. 1 Runoff histograms and hydrograms corresponding to the B1 sub-basin (1986-2014).

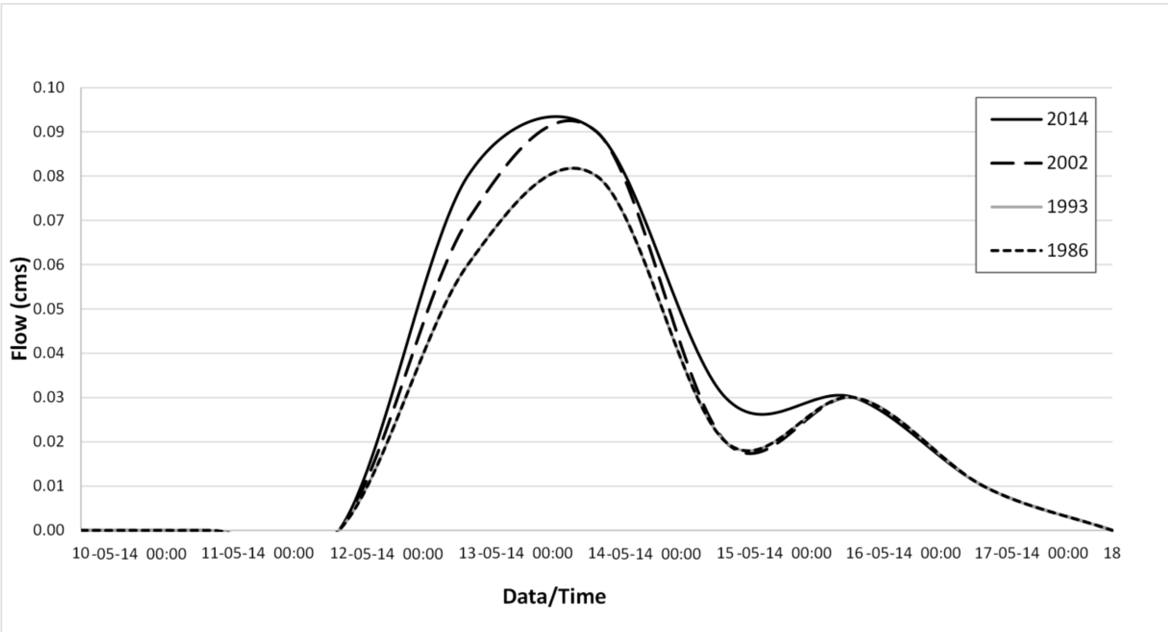

Fig. 6. 2 The series of hydrographs results for the B2 subwatershed (1986-2014).

Between 1986-2014 the variation of the peak flows and the volume of the runoff has registered larger differences in the B1 sub-basin, while in the B2 sub-basin these differences were smaller (Fig. 6.2).

In the B1 sub-basin greater differences are due to the high variability of impervious surfaces from 41.7% in 1986 to 76.1% in 2014, while in the B2 sub-basin the small differences are due to the smaller areas occupied by impervious surfaces and also due to their low variability in the analysed period, from 25.8% in 1986 to 32.0 % in 2014.

6.5 Statistical analysis of the results

In order to establish a relationship of dependency between variables: the percentage of the impervious surfaces and the total volume of the runoff, respectively total losses, these were distributed in an XOY system of axes, thus forming a correlation field.

In both analysed sub-basins, the hydrological model results have shown an increasing tendency of the total volume of runoff along with the increase of impervious surfaces in the 1986-2014 period. This tendency is shown in the regression model, Fig. 6.3. The intensity of the linear dependence between variables, impervious surfaces and total runoff, for analysed subwatershed was determined using Pearson's correlation coefficient, it being 0.99 respectively 0.97 (Haidu and Ivan, 2016 b).

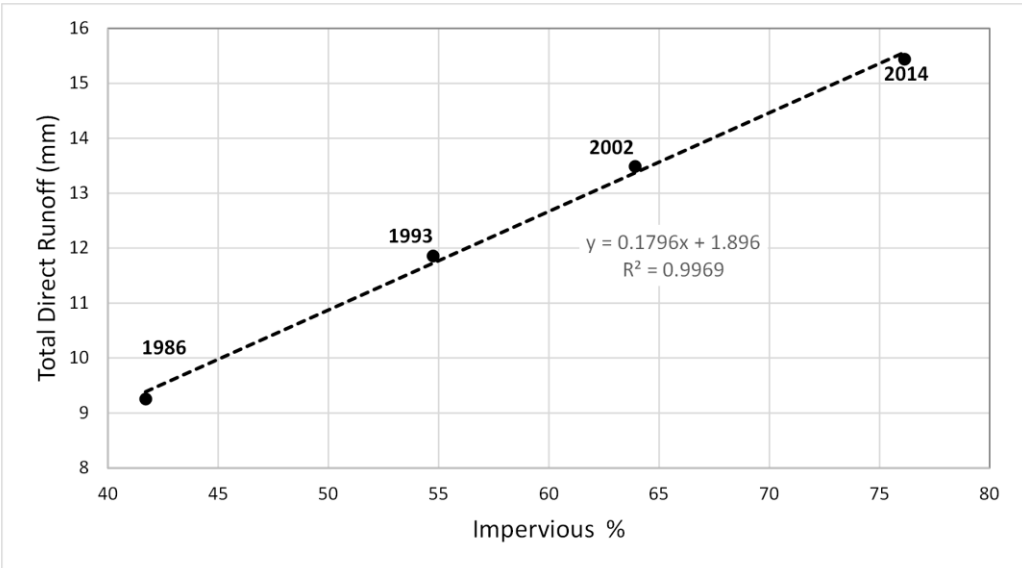

Fig. 6. 3 The relationship between impervious surfaces and the total runoff, subwatershed B1 (Haidu and Ivan, 2016 b).

The research of statistical relationship between variables, impervious surfaces and total losses, have shown that concomitant with the increase of the impervious surfaces, the total losses decrease in the two analysed sub-basins. There is an indirect linear connection between these two variables. The coefficients of determination of 0.99 respectively 0.94, indicate that the variable (X) of impervious surfaces explain the variations of variable (Y) total losses, at 99% respectively 94%.

All these increasing tendencies of the runoff volume, respectively of peak flows, must constitute a warning to local authorities in order to implement certain measures to mitigate these tendencies in the future (Haidu and Ivan, 2016 c).

7. THE IDENTIFICATION OF DRAINAGE NETWORKS FROM URBAN AREA SURFACES

Urbanisation and industrialisation have led to the increase of impervious surfaces, the reduction of water infiltration into the soil and the increase of runoff volume.

Some part of the rainfall water volume on the pervious surfaces seeps through, while water on impervious surfaces tends to accumulate into small ponds. Following the enhancement of precipitation, rainfall water tends to run off along the road network, between the buildings or other open spaces, following certain preferential pathways for water transport, depending on the land slope (Haidu and Ivan, 2016 a).

7.1 The modelling of surface water flows

Surface water flow modelling involved the identification of preferential flow pathways and ponding areas, in case the spouts are clogged or the sewerage system can no longer handle the flow of water, without taking into account the possibility of their interaction with the flow in the sewerage system. Knowing these ponding areas and the water flow pathways is important in the identification of areas exposed to flooding (Haidu and Ivan, 2016 c).

- *identification of the preferential flowpathways*

The identification of the overland preferential flowpathways was conducted in this research by the use of the *rolling ball technique* (DEFRA, 2008) or the D8 method (Evans, 2008). This technique implies the identification of the preferential flowpathways based on the flow and accumulation directions by using the GIS tools and the elevation data (Haidu and Ivan, 2016 a). To achieve a correct representation of the flow direction, the sinks occurring within the DEM should be filled (Haidu and Ivan, 2016 a). The filling of these sinks within the study was conducted by means of the *Fill* function (Haidu and Ivan, 2016 a), while the flow direction and the flow accumulation were determined based on the DEM with filled sinks, using Arc Hydro tool (Fig. 7.1).

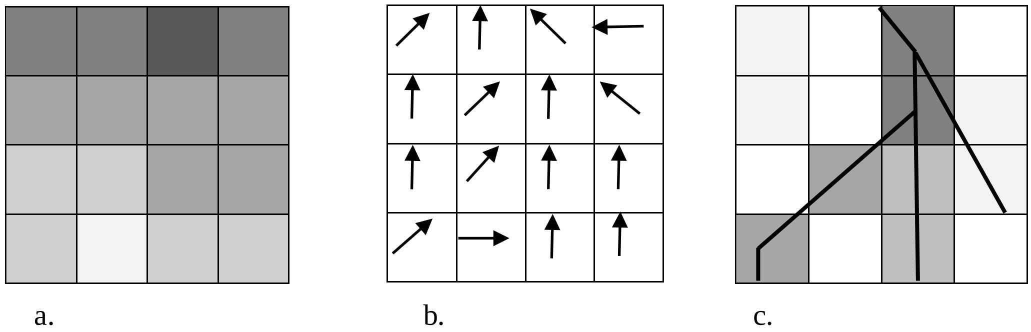

Fig. 7. 1 Illustration of the delimitation of flow pathways a) Altitudinal dataset b) Thematic layer about flow direction c) Thematic layer about the accumulation of drainage and flow definition.

To render a more accurate representation of the flowpathways in the urban area, these were delineated also based on the developed DSM (Haidu and Ivan, 2016 a).

- *identification of the ponds*

The ponds are natural or man-made areas intended for storing water during or after rainfalls (Haidu and Ivan, 2016 a). In this study we followed the delimitation of the ponding areas, depending on the topography of the land, namely surface areas where the rainwater might accumulate during precipitation. The ponds in the study area have been identified by adapting and developing the Contour Polygon Screening method (DEFRA, 2008) based on the DEM (Haidu and Ivan, 2016 a). The GIS tool used in delineating the ponds was the Spatial Analyst extension within the Arc GIS 10.1 program.

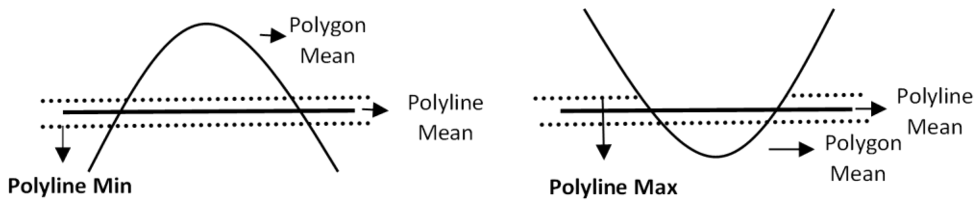

Fig. 7. 2 . Representation of the ponds delineation (left) for the polygons mean value higher than the polylines mean value; (right) in case of the polygons mean value smaller than the polylines mean value (Haidu and Ivan, 2016 a).

The procedure consisted in identifying the lowest areas of the land based on the contours derived from DEM (Haidu and Ivan, 2016 a). A delimitation of all the cells contoured by the polyline (the knoll or pond border) was achieved. Where the mean value of the cells within the polygons was higher than the mean value of the polyline, the minimum or, on the contrary, the maximum value of the polyline was considered when delineating the ponds and knolls (Haidu and Ivan, 2016 a) (Fig. 7.2).

The depth of each pond was calculated for the study area based on the volume and area resulting from applying the Cut/Fill function (Haidu and Ivan, 2016 a).

7.2 Case study Cluj-Napoca

This research includes applications on a 5.4 km² area within the city, which includes the Mănăștur, Zorilor, and Grădinile Mănăștur neighborhoods, as well as the Plopilor area, located in the South of the city (Haidu and Ivan, 2016 a).

- *Identified preferential flow pathways*

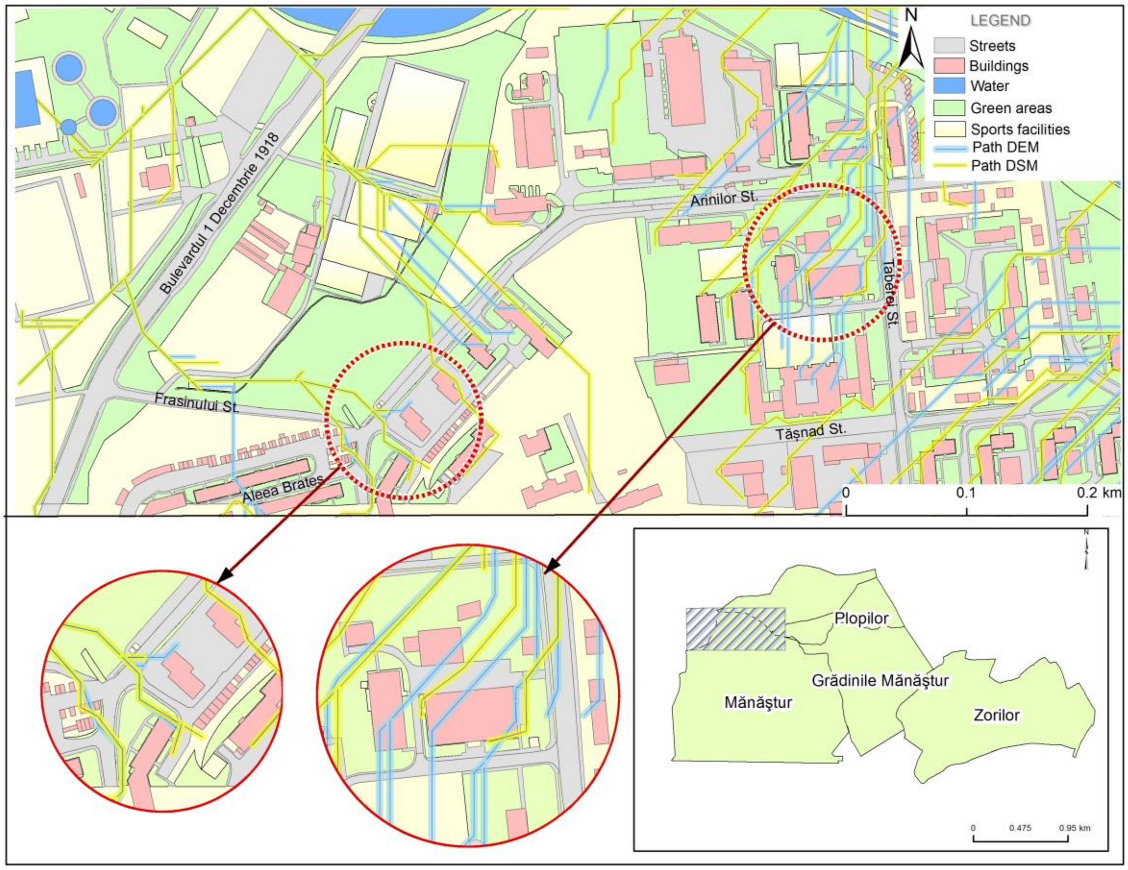

Fig. 7. 3 The preferential flowpathways identified within the study area (Haidu and Ivan, 2016 a).

The identification of water flow pathways of the urban area surfaces has revealed that these are usually formed on street surfaces, sidewalks, near drainage openings and they follow the directions of the lines on the greatest slope of the land.

For the delimitation of the water flow pathways in addition to the Digital Elevation Model (DEM), which represents the uncovered surface of the field, we have also used a Digital Surface Model (DSM), which contains the buildings from the surface. The results obtained from the two altitudinal datasets have revealed that, the flowpathways achieved based on the DSM (yellow) bypass the buildings and follow generally the street line, while those achieved only based on the DEM (blue) overlap the buildings in some locations. (Haidu and Ivan, 2016 a) (Fig. 7.3). Thus, it can be noted that the results obtained from the Digital Surface Model (DSM), which, besides the numerical representation of the surface also gives the height of buildings in the study area, has allowed us to obtain results much closer to reality than based on DEM.

- *identified ponding areas*

Ponding areas accumulate water on field surfaces, usually after a torrential rainfall and can exist a shorter or longer time on the surface, depending on the amount of precipitation, their volume and the capacity of the sewerage system.

Fig. 7. 4 Pond in the urbanized floodplain, June 22nd, 2013, Plopilor Street, Cluj-Napoca (Haidu and Ivan, 2016 a).

The delineation of these ponds in the urbanized floodplain in Cluj-Napoca (the Plopilor area) based on the DEM (5m x 5m), the results highlighted a number of 32 ponds, with depths between 0.2 m and 1.57 m (Haidu and Ivan, 2016 a).

A ponding area of this kind with great depths was formed on the 1st August 2012 at around 16.30, due to the great pressure on the sewerage system caused by a torrential rainfall. This pond has affected the traffic at Plopilor street for about 20 minutes. Another pond with great depths has formed in Cluj Napoca, on the 22nd June 2013 at around 20.30 on Plopilor street and directly affected the drivers and pedestrians. (Fig. 7.4).

In the urbanized terrace and slope areas by means of the GIS technique 5 ponds were delineated in this area, with with depths between 0.08 m and 1.55 m (Fig. 7.5) representing 0.029 % of the total area of 5.35 km² and these can store a volume of 787 m³ of water (Haidu and Ivan, 2016 a). In this zone ponding areas are temporary due to greater slopes and they are formed on street surfaces or near the drainage openings.

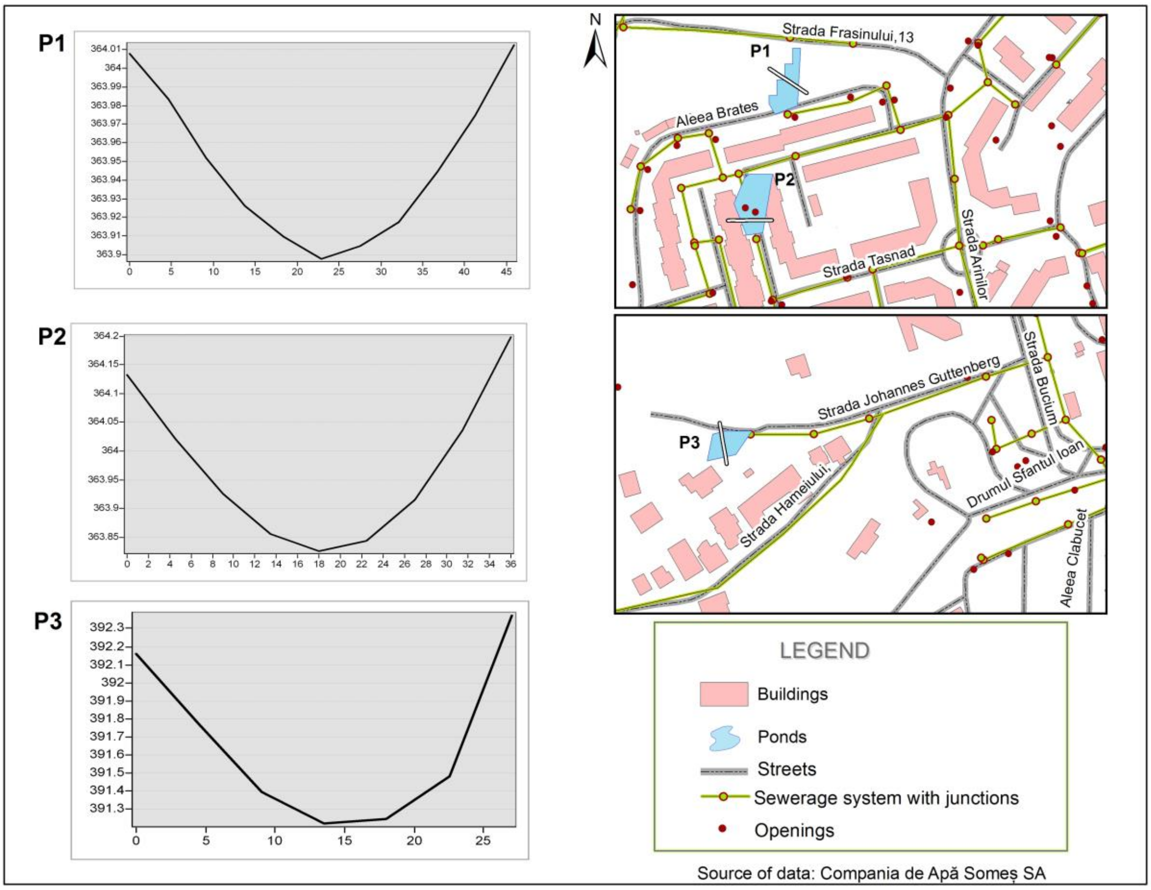

Fig. 7. 5 Temporary ponds in urbanized terrace and slope (Haidu and Ivan, 2016 a).

The ponds in the urbanized interfluves (Zorilor neighborhood) do not have distinctive features due to the abrupt landforms and streets perpendicular to the city longitudinal axis oriented in a west-easterly direction. Following the delineation of these ponds based on the DEM and GIS, a single pond was revealed in the urbanized interfluves, with 1.99 m depth and the ability to store a volume of 67 m^3 of water (Haidu and Ivan, 2016 a).

As a result of torrential rainfall, a ponding area was formed in the Zorilor neighbourhood in Cluj Napoca, on the 5th of August 2010 at around 20.00, and another one was formed on the Observatorului street in the Zorilor neighborhood on the 25th of September 2015, both affecting drivers and pedestrians.

- *The effect of spatial resolution in the delimitation of water flows in urban areas*

The identification of the flowpathways and ponds based on the four elevation datasets SRTM DEM, ASTER DEM, DEM (5 x 5 m and 25 x 25 m), the results have thus highlighted a linear relation between the decrease of the ponds' number and the flowpathways' number, together with the decrease of spatial resolution of the used datasets (Haidu and Ivan, 2016 a). These differences regarding the number of the preferential flowpathways and of the ponds obtained based on the four elevation datasets reflect the significance of the DEM spatial resolution in delineating the overland flows (Haidu and Ivan, 2016 a).

The identification of the locations of water accumulation on various relief types from the urban area can help local authorities verify whether the sewerage system can deal with increasing water flows due to urbanisation (imperviousness). Based on the observations and forecasts, depending on the evolution of the impervious surfaces, sustainable solutions can be found and implemented, for instance resizing the sewerage system or rehabilitation of the street network.

8. QUALITY ASSESSMENT OF STORMWATER ACCUMULATED ON URBAN AREA SURFACES

In this chapter, we assessed the quality of stormwater accumulated on the road surface following rainfalls in three different areas in the municipality of Cluj-Napoca (industrial, commercial and residential) (Ivan et al., 2016). Locations with various land use types were selected to avoid the influence of a certain type of area on the pollutant concentrations as the land cover type may influence the quality of surface runoff (Ivan et al., 2016).

The water quality assessment has been made for two different periods (cold and warm) in order to highlight the variation of the pollutants and their possible source in the stormwater accumulated on road surfaces in the two different periods.

8.1 Urban pollution

The stormwater runoff can carry a number of pollutants from the surface before accumulating in the sewerage system. Urban stormwater pollution is generated through two processes:

- **accumulation of the pollutants (”*build-up”*)** involves the deposition of pollutants on the ground surface during the dry period, namely before the rainy period (Herngren, 2005).
- **wash of the pollutants (”*wash-up”*)** is achieved along with the falling stormwater.

8.2 Stormwater quality assessment methodology from urban area surfaces

In the quality assessment of stormwater accumulated on urban area surfaces three main roads were selected in zones with various land use (industrial, commercial and residential) from Cluj-Napoca municipality (Table 8.1).

Stormwater in these three areas was collected from the accumulations near the roadside stones in case of industrial and residential areas, and in case of the commercial area it was collected from a water accumulation point located in the middle of a parking area, during two different seasons, a warm and a cold one.

Tabel 8. 1 Characteristics of the study area (Ivan et al., 2016).

Land Use	Industrial	Commercial	Residential
Site name	Oașului St.	Iulius Mall parking	Nicolae Titulescu St.
Geo-Coordinates	46° 47′ 42.8″ 23° 36′ 07.19″	46° 46′ 21.2″ 23° 37′ 35.1″	46° 46′ 10.5″ 23° 36′ 34.1″
Average daily traffic	977	559	1155

Out of each sampling point 1.5 l of water was collected which later was transported to the accredited laboratory of the Wastewater Treatment Plant in Budapest, Hungary for laboratory analysis.

- ***Cold period***

Water samples corresponding to the cold period were collected in the period 23-25 February 2015, following a total of 12 dry days.

- ***Warm period***

Water samples corresponding to the warm period were collected in the period 22-24 May 2015, following a total of 4 dry days.

Water samples were collected on each day, at approximately the same time, in the morning, pH, electrical conductivity and water temperature were also measured onsite with a WTW handheld pH/Cond 340i instrument (Fig. 8.1) and the asphalt temperature was measured with an infrared thermometer.

Fig. 8. 1 Onsite measurements with a WTW handheld pH/Cond 340i multi-parameter instrument (Ivan et al., 2016).

The drained and accumulated stormwater on the urban area surfaces may be contaminated with heavy metals or other toxic compounds. In the present study the following water quality indicators were analysed associated with the urban environment:

- Chemical Oxygen Demand (COD);
- Biological Oxygen Demand (BOD_5);
- Total Organic Carbon (TOC);
- Total Suspended Solids (TSS);
- Total Settleable Solids (SS);
- Chloride (Cl^-);

- Sodium (Na^+);
- Total Phosphorus (TP);
- Total Orthophosphate (PO_4);
- Total Nitrogen (TN);
- Total Kjeldahl Nitrogen (TKN);
- Total Organic Nitrogen (Norg);
- Ammonium (NH_4 - N);
- Nitrite (NO_2-N);
- Nitrate (NO_3-N);
- Coliform bacteria;
- Heavy metal:
    - Total Iron (Fe);
    - Total Copper (Cu);
    - Total Nickel (Ni);
    - Total Zinc (Zn);
    - Total Lead (Pb);
    - Total Mercury (Hg).

All these water quality indicators were analysed in the laboratory of the Wastewater Treatment Plant in Budapest, while the pH, electrical conductivity and water temperature were measured onsite.

8.3 Principal Components Analysis

Due to the large number of analysed parameters within the study (a total of 24 parameters) a bivariate analysis would not have been relevant enough, for this reason we decided to use a multivariate method. Out of the multivariate methods, the Principal Component Analysis (PCA) method was applied. The analysis and data processing was performed using the Microsoft Excel XLSTAT extension and the SPSS program

8.4 Identification of the sources of pollutants over time periods

- *Cold period*

The results of the PCA (Fig. 8.2) analyses revealed a strong relation between most of the heavy metals (except mercury) in the stormwater accumulated on the road surface, which denotes their common source (Ivan et al., 2016).

The source of heavy metals in the surface stormwater runoff includes road transportation, industrial activities (US EPA, 1999), building corrosion, atmospheric depositions, various intentional or accidental discharges (Herngren et al., 2005). The main source of Zn and Cu in stormwaters in urban areas are the roofs (Bannerman et al., 1993; Brown and Peake, 2006; Chow et al., 2013; Gnecco et al., 2005). The lack of correlation

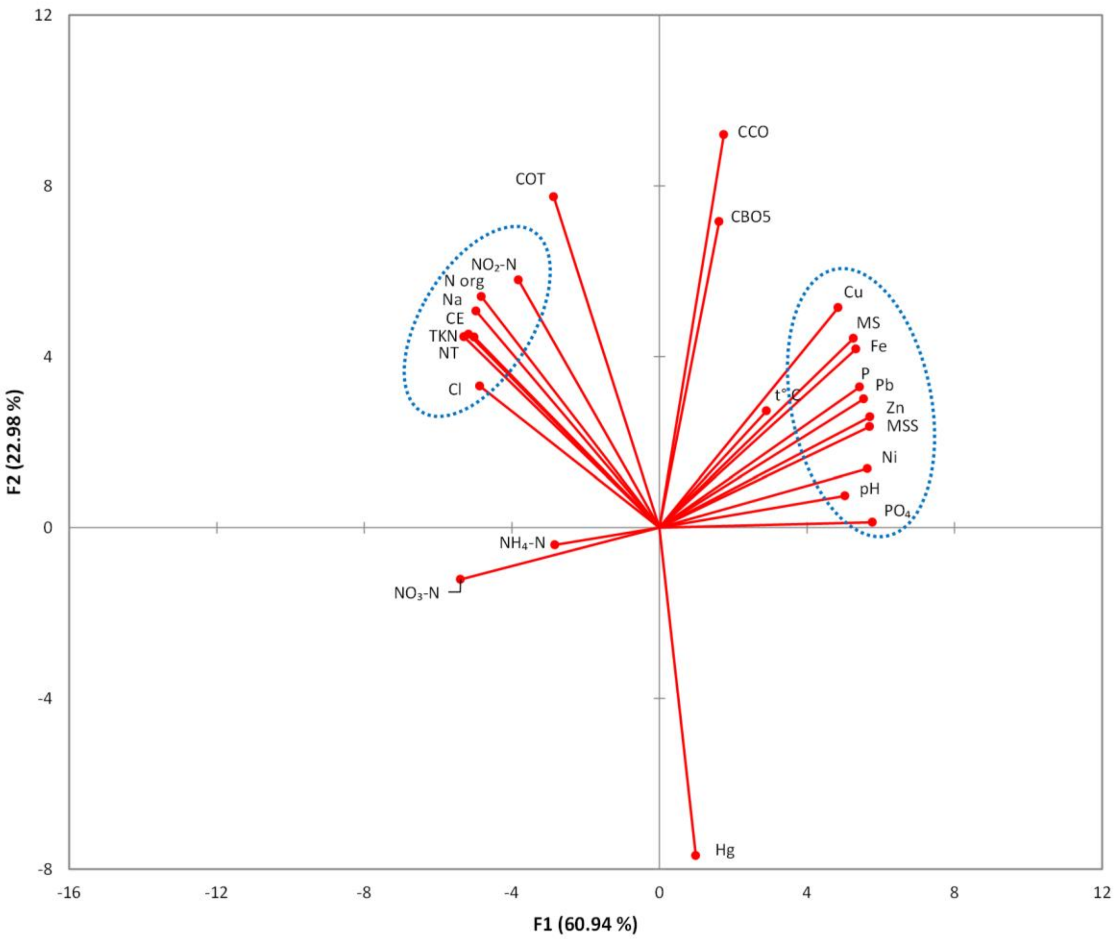

Fig. 8. 2 PCA of all physico-chemical parameters for cold season (Ivan et al., 2016).

between mercury and the parameters analyzed above highlight the fact that the mercury source in urban surface runoff is different from that of other metals. According to studies conducted by Eckley and Branfireun (2009), Herngren (2005), the mercury source in urban surface stormwater is represented by the atmospheric depositions.

The strong relationship between the heavy metals (Fe, Cu, Ni, Zn and Pb) and the TSS out the fact that these heavy metals in the road surface stormwater are insoluble and accumulate in the suspended solids (Ivan et al., 2016). The TSS source in urban stormwater may be represented by human activities, erosion of pervious surfaces or atmospheric depositions (US EPA, 1999).

The direct correlation between the heavy metals, respectively TP and PO4 highlights that most of the analyzed heavy metals are present as phosphates and are insoluble (Ivan et al., 2016). The detergents, the atmospheric depositions or the animal wastes are the phosphorus and nitrogen source in urban surface water (US EPA, 1999).

The relation between nitrogen compounds indicates the fact that these variables have a common source of origin (vegetable scraps or animal wastes) (Ivan et al., 2016).

- *Warm period*

The results of the PCA analysis revealed a relationship between the analysed heavy metals (except Hg) respectively TSS and TP, which indicates that these heavy metals present in stormwater from road surfaces during the warm period are insoluble and are accumulated in suspended solids in the form of phosphates, similarly to the cold period.

This relationship between the heavy metals, namely TSS and TP can be observed in the regression analysis in Fig. 8.3, where it can be observed that between the Zn and TSS and P concentration there is a direct relationship.

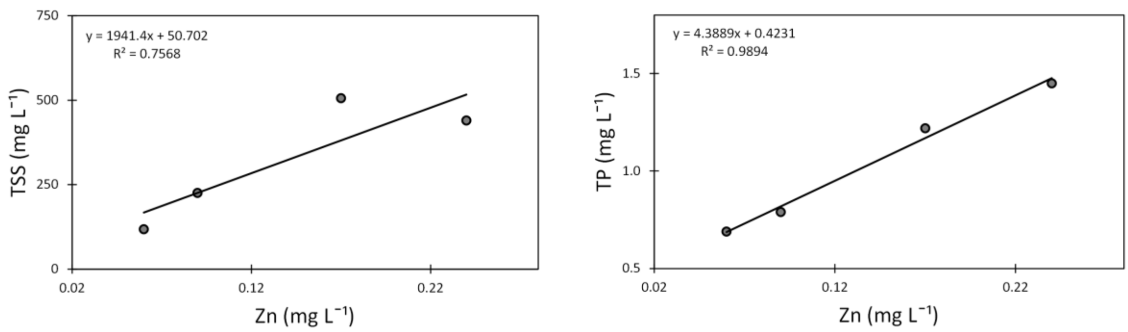

Fig. 8. 3 Illustration of the relationship between Zn respectively MS and P during the warm period.

Another important water quality indicator are the Coliform bacteria. Coliform bacteria were analysed for each water sample from the three areas (industrial, residential and commercial) adequate for the warm period. The source of Coliform bacteria in the accumulated water on road surfaces can be represented by birds, bacteria coming from animal guts (especially homeothermic species).

During the warm period suspended solids have a chemical impact on the urban surface stormwater quality due to the heavy metals and some nutrients accumulated in there. The results of the principal component analysis have revealed a strong relationship between Fe, Cu, Pb and Zn in this period, which also indicates their common source (road traffic). An exception is the mercury, whose source could be atmospheric deposition in the warm period.

8.5 The assessment of stormwater pollution from road surfaces

The pollution level of urban surface stormwater is given by the water quality indicator values.

In order to evaluate the pollution level of the stormwater under the conditions of its discharge into the sewerage system, we have compared the measured water quality indicators with the maximum permitted levels determined in NTPA - 002 Normative (GD 352/2005). Within the NTPA - 002 Normative maximum values only 11 water quality indicators were set out of the 24 analysed.

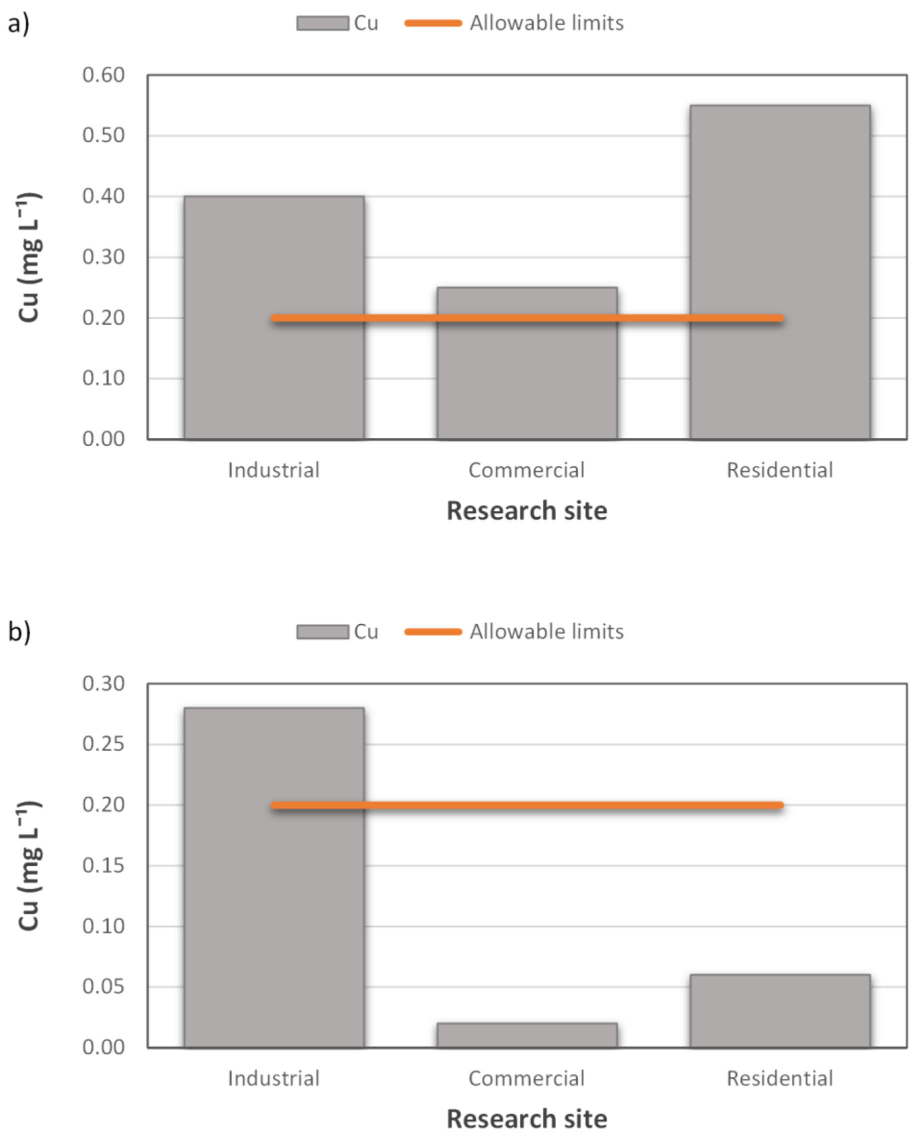

Fig. 8. 4 Variations in copper concentration in the three urban areas and the maximum allowable limits a) in winter b) in summer (Haidu and Ivan, 2015).

Given the *water evacuation into the sewerage system*, its organic material pollution level was high in the residential area during the cold period and during the warm period in the industrial area. The low values of NH_4^+-N and TP during the two periods indicate a very low level of pollution with the mentioned parameters of the water accumulated on road surfaces.

The pollution level of the water with Cu was high during the cold season in all three sample areas, and during the warm period it was high only in the industrial area (Fig. 8.4). In the two periods the influence of zinc and lead on the degradation of water quality was minimal.

Water pollution with TSS was high in the industrial area in both periods and low in the commercial area. The TSS influence on the degradation of water quality in the residential area was higher in the cold period than in the warm one.

In order to evaluate the stormwater pollution level drained on road surfaces directly to the natural receivers, we have compared the measured water quality indicators to the maximum permitted values for 17 water quality indicators, according to the national legislation in force (G.D. 352/2005).

In the conditions of *water discharge into natural receivers* the water pollution level was high with Chlorides during the cold season for all sample areas. The level of water pollution with Chlorides during the cold period is due to the frequent use of salt and sand mixture in the removal of snow or ice from road surfaces, while another source is represented by the windshield cleaning solutions.

Within the heavy metals, water pollution level with Zn was high during the cold period in the industrial and residential areas, while in the warm period only in the industrial area. The Fe content was high during the cold period in all sample areas, while in the warm period it was high only in the industrial area and in small proportions in the residential area. Also in the conditions of stormwater discharge into natural receivers the Hg pollution level of water exceeded the maximum permitted level only in summer in all sample areas, during winter the influence of mercury on the degradation of water quality was minimal (Fig. 8.5). Water pollution with TSS was high during the cold period in all sample areas, while in the warm period was high in the industrial area and in small proportions in the residential area.

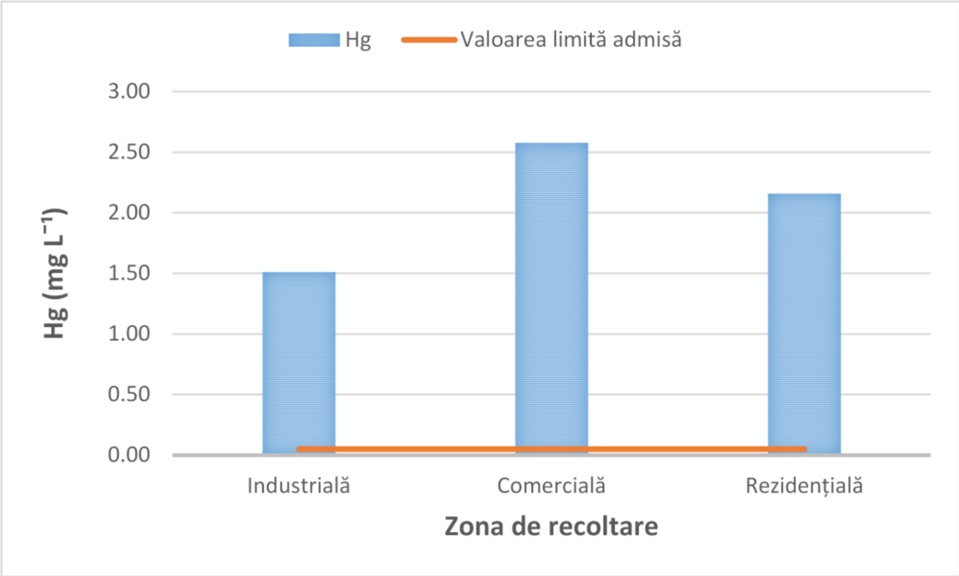

Fig. 8. 5 Hg variation in the three urban areas and the maximum permissible limit in case of water evacuation into natural receptors. a) cold period; b) warm period.

Analysis has revealed that stormwater drained on road surfaces often contains pollutants which exceed the maximum permissible limit, when they are discharged directly into the natural receivers. Thus even in the case of using separator water discharge systems, a stormwater treatment would be indicated before its discharge into the natural receivers.

9. STORMWATER MANAGEMENT IN ORDER TO REDUCE THE VOLUME OF RUNOFF AND SURFACE WATER QUALITY IMPROVEMENT IN URBAN AREAS

Nowadays many urban areas are facing quality degradation of drained and accumulated water on the surface, and the high runoff volume from the urban surface areas is mainly due to the large areas occupied with impervious surfaces.

In order to reduce the runoff volume and to improve surface water quality, a number of solutions can be implemented, out of which we could mention the implementation of techniques to capture and store the storm water from the roofs of buildings.

9.1 The methodology for estimating rooftop runoff volume from an impervious capture area (roofs)

In this chapter we have followed the estimation of drainage water volume from roofs for an area of 0,68 km² in Cluj-Napoca municipality, which could help local authorities in the implementation of sustainable stormwater capture and storage techniques.

- *Michel Simplified SCS-CN Model (MSCN)*

Based on the model SCS-CN, was developed the Michel Simplified SCS-CN model (MSCN). This model was developed for three soil moisture store levels (Haidu and Ivan, 2015) as follows (Michel et al. (2005) citat de Singh et al., 2013):

$$\text{For AMC I}: Q = P\frac{P}{S+P} \tag{9.1}$$

$$\text{For AMC II}: Q = P\frac{(0.48S+0.72P)}{(S+0.72P)} \tag{9.2}$$

$$\text{For AMC III}: Q = P\frac{(0.79S+0.46P)}{(S+0.46P)} \tag{9.3}$$

Where,

Q – direct runoff

P – total rainfall

S – potential maximum retention

AMCI - dry condition

AMC II – normal condition

AMC III - wet condition of watershed.

The estimate of the volume of water that could later be captured by a roof catchment was achieved based on the daily precipitation data, collected and analysed for the period 1969-2013 (ECA&D), applying the model (9.3) which is adapted to wet or completely impervious surfaces (Sahu et al, 2007; Singh et al, 2013).

In the period under review, the average monthly rainfall values were the highest in June (95.3 mm), July (93 mm), May (75 mm) and August (66.8 mm), it can be stated that the summer season is the most suitable period for capturing the largest volume of rooftop runoff rainwater and its future harvesting (Haidu and Ivan, 2015).

When estimating the volume of water draining from rooftops, in addition to using the daily rainfall data, a CN parameter with the value of 98 was assigned to completely impervious surfaces (buildings). (Haidu and Ivan, 2015).

9.2 The potential of rooftop runoff, estimated for days and months

The results concerning the estimation of rooftop runoff volumes for each day for 2013 revealed large amounts of runoff during the summer season (Haidu and Ivan, 2015). The greatest amount of rooftop runoff rainwater corresponds to the rainfall event (P = 25 mm) recorded in July with a runoff depth of 23,3 mm (Figure 3c).

In June, the highest value of runoff depth (21,6 mm) corresponds to the rainfall event (P = 23,2 mm) (Fig. 9.3b), and in May and August the greatest amounts of rooftop runoff were 12.6 mm and 19, 4 mm respectively (Haidu and Ivan, 2015).

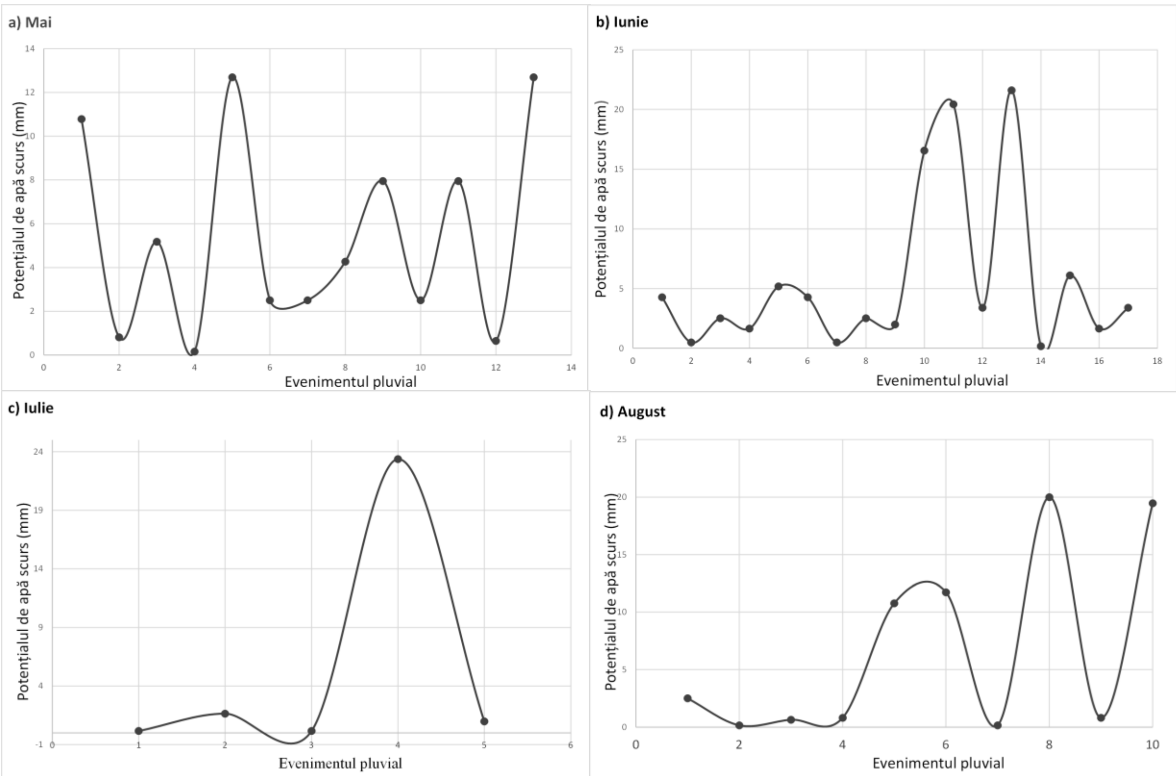

Fig. 9. 1 Daily potential of rooftop runoff for the months of May, June, July, August (Haidu and Ivan, 2015).

Rooftops make up a significant percentage of the impervious surfaces within an urban area and roof-catchment systems are the most suitable for rainwater harvesting in these areas. Collecting rainwater in urban areas can offer a number of benefits: washing roads, watering gardens and also for reducing overland flow in the urban area (Haidu and Ivan, 2015), namely to reduce the costs of wastewater treatment. The reuse of the captured water for washing road surfaces during warm period would be useful because, dry summer months or dry periods between rainfall events allow for pollutant build-up to occur on road networks or on building rooftops (Haidu and Ivan, 2015).

CONCLUSIONS

Data processing and analysis obtained by remote sensing for the period 1986-2014 have revealed an increase of the impervious surfaces of 6% (1986-1993), 5% (1993-2002) and 8% (2002-2014).

By the evaluation of the hydrologic response to the evolution of the impervious surfaces in the period 1986-2014 for the two analysed sub-basins, results have shown an increase of the peak flows and of the runoff volume, alongside with the increase of impervious surfaces.

Following the delimitation of water fluxes based on DSM and DEM, results have revealed a tendency of flow pathways, based on DSM, which usually follow the street lines, sidewalks, bypassing the buildings, while results based on DEM in certain areas overlay with buildings. The identification of the ponding areas in the urbanised riverside, slope and interfluve of Cluj-Napoca has revealed a high number of depressions in the urbanised riverside, urbanised terraces and slopes, ponding areas having a temporary character. The identification of the flow pathways and of the ponding areas based on four altitudinal datasets with different spatial resolutions (SRTM DEM, ASTER DEM, DEM 5x5 and 20x20 m) have highlighted a direct linear relationship between the decreased number of ponding areas and flow pathways along with the decrease of spatial resolution of datasets.

The evaluation of the stormwataer accumulated on road surfaces have revealed a number of possible pollutant sources present in stormwater: (1) road traffic for the heavy metals Fe, Cu, Zn, Ni and Pb, (2) atmospheric deposition for Hg, (3) vegetable and animal residues for compounds of azote, (4) roofs for Zn and Cu, (5) detergents used for car wash for phosphorus, (6) windshield cleaning solutions and mixture used in snow removal for chlorides. By analysing the level of water pollution under the conditions of its discharge into the sewerage system, results have revealed a high level of pollution with Cu in the cold period in all three sampling areas, and in the warm period in the industrial area. The level of water pollution with Zn and Pb was minimal. Water pollution with TSS was high in the industrial area in both periods and low in the commercial area. The assessment of urban stormwater pollution level under the conditions of its direct discharge into natural receivers has shown a high level of pollution by chlorides in the cold period. The level of water pollution with Zn was high in the cold period in industrial and residential areas, pollution with Fe in the cold period was high in all sampling areas, with Hg exceeds the maximum permitted level only during the summer, in all sampling areas, while water pollution with TSS was high in the cold period in all sampling areas.

The estimation of rooftop runoff volume for its further capture and storage has revealed a high potential of runoff water during the summer months. The highest quantity of runoff in one day (23 mm) was registered in July 2013, while the highest runoff in a month was registered in June (96.5 mm). The captured water can be used for washing road surfaces, garden irrigation.

In order to reduce the runoff water volume and to improve water quality on the ground surface, sustainable solutions should be found in the future and these ought to be implemented by local authorities, such as resizing the sewerage system or the rehabilitation of the street network, the paving of sidewalks and parkings with permeable pavements, in order to allow water infiltration into the soil, the implementation of water collection techniques, and the expansion of urban green spaces (recreational areas, parks, green spaces near streets and sidewalks).

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