Monitoring the healthy status of urban streams

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Abstract. The objective of this study is to demonstrate the effective use of remote sensing and ground-based techniques in conjunction with geographic information systems (GIS) to achieve two important goals: (a) to conduct a rapid and comprehensive assessment of soil and water quality in urban streams and (b) to emphasise the critical importance of continuous monitoring of environmental indicators. This approach ensures the ecological integrity of the fragile ecosystems in urban streams and emphasises their important role in human mental and physical health. It also emphasises the interdependence of the environment and human well-being.

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1 Introduction

As the human population grows, so does its impact on the surrounding ecosystem. The more cities grow, the greater urbanization's impact on the environment. An example of this is the urbanization of rivers and streams around the world, which eventually leads to their degradation. This phenomenon can be referred to as the "urban stream syndrome" [1,2]. Walsh et al. (2005) point out that in such streams, sensitive taxa are absent, channel complexity is reduced, channel width has increased, and high levels of pollutants can be detected in the water bodies. In addition, these impacts are related to other symptoms, such as reduced base flow and an increase in suspended solids. Another impact of urbanization on rivers is that it occupies their margins and removes or greatly reduces all riparian vegetation and floodplains [3]. Furthermore, river ecosystems are among the most vulnerable ecosystems on earth [4], as they are directly affected by industrial activities such as canalization, impoundment and water discharge, leading to their further degradation [5,6,7].

This work therefore aims to contribute to filling the gap and focus on the development of monitoring strategies that can serve as a basis for assessing the status of urban streams due to the above-mentioned challenges. The work specifically addresses the application of remote sensing in conjunction with ground surveying using GIS to detect polluted urban streams. These tools have proven useful in identifying environmental indicators of stream health. This emphasizes their application in management decisions that are essential for environmental conservation, socio-economic stability and human health [8]. The approach taken in this paper can be summarized as follows: The different monitoring methods such as earth observation, riparian zone monitoring, soil survey and water quality survey were conducted to provide a solid basis for measuring the impact of cities on river ecosystems.

2 Monitoring urban stream health: Integrating remote sensing, ground techniques, and geoinformatics

To track urban streams' health, researchers and environmental managers can use a range of methods, including earth observation (EO), ground monitoring of soil and riparian vegetation, water chemistry and biological modeling, including fish health assessment, all under the umbrella of geoinformatics and statistics (Fig. 1).

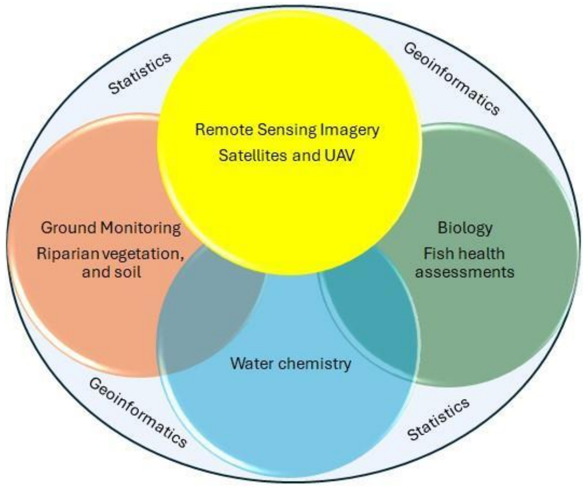


Fig. 1. Schematic diagram showing the interaction of different disciplines related to water and soil stream monitoring

2.1. Remote sensing Imagery

Remote sensing imagery is based on satellites, aircrafts and unmanned aerial vehicles (UAVs). They enable temporal and spatial monitoring and further quantification of environmental quality in urban rivers and lakes and their surrounding areas [9]. Recently, remote sensing imagery produced synoptic maps of suspended solids (SS), colored dissolved organic matter (CDOM), chlorophyll content and even thermal pollution in lakes, rivers and coastal waters has gained prominence in the scientific world. Although remote sensing using satellites has been successfully used in the marine environment, it is not suitable for monitoring smaller bodies of water such as rivers due to its limited resolution. This means that satellite images with higher spatial resolution are needed for monitoring inland waters. This type of imagery can be obtained from remote sensing platforms developed for land applications, such as Sentinel-2 or the Landsat series [10].

Sentinel-2 belongs to the European Union's Copernicus Earth observation program [11]. Its main objectives are to produce high-resolution, globally systematic, high repetition rate multispectral imagery; and to provide operational products such as geophysical variables, maps of land cover, and land change detection. Another objective of it is to improve the continuity of the multispectral imagery provided by the Satellite Pour l' Observation de la Terre (SPOT). Sentinel-2 is equipped with a wide-swath, multispectral imager of high-resolution that allows it to record up to 13 spectral bands, offering a new viewpoint of the land and vegetation it monitors. The satellites primarily deliver agricultural and forestry management data. The imagery procured from them can be used to determine various plant indices, such as chlorophyll, leaf area and water content indexes. Aside from these purposes, the Sentinel-2 can be employed to monitor land cover changes and to assess the condition of global forests. Furthermore, it provides pollution statistics for lakes and coastal waters.

Technological advances have led to improvements in rechargeable batteries, cameras, sensors, image processing tools and techniques. These technological improvements have made UAVs a cost-effective tool that is fast and accurate enough to study water resources. UAVs can help researchers to record and assess the structure and shape of features in river catchments as well as hydrological processes at high spatio-temporal resolution in a non-invasive manner. For example, Koparan et al. (2018) [12] have developed an unmanned airborne water quality measurement system (UAMS) for real-time measurement of electrical conductivity (EC), pH, dissolved oxygen (DO), and temperature. Their results were compared to data from a commercial multiparameter probe and showed differences of 2.1% for DO, 3.43% for EC, 3.76% for pH and less than 1.0% for temperature.

2.2. Ground techniques

The riparian zone corresponds to the area bounded by a) the lowest and highest water levels of a stream and b) the terrestrial part extending spatially from the highest water level of the stream towards the uplands, where vegetation can be influenced by water tables height and soil's ability to hold water [13]. In terms of their composition and the number of species, riparian areas show striking differences to the terrestrial neighboring regions [14], with the vegetation generally being hydrophilic. The riparian zone acts as a natural biofilter of the river or stream environment against surface runoff of pollutants because of anthropogenic activities (agriculture, urbanization, tourism, industrialization) and natural processes (erosion and excessive sedimentation), partly accelerated by climate change (extreme temperatures, change of the precipitation patterns) [15,16].

Riparian-ground monitoring can be divided into a) quality assessment of the riparian zone and b) soil characterization. Well-known visual protocols, used worldwide to assess riparian zones quality [17], are: 1. the Stream Visual Assessment Protocol (SVAP) [18], 2. The Rapid Appraisal of Riparian Condition (RARC) [19], 3. the Ecological Status of Riparian Vegetation Index (QBR) [20], 4. Riparian Macrophyte Protocol (RMP) [21], 5. The Riparian Quality Index (RQI) [22], and 6. The Riparian Condition Index (RCI) [23].

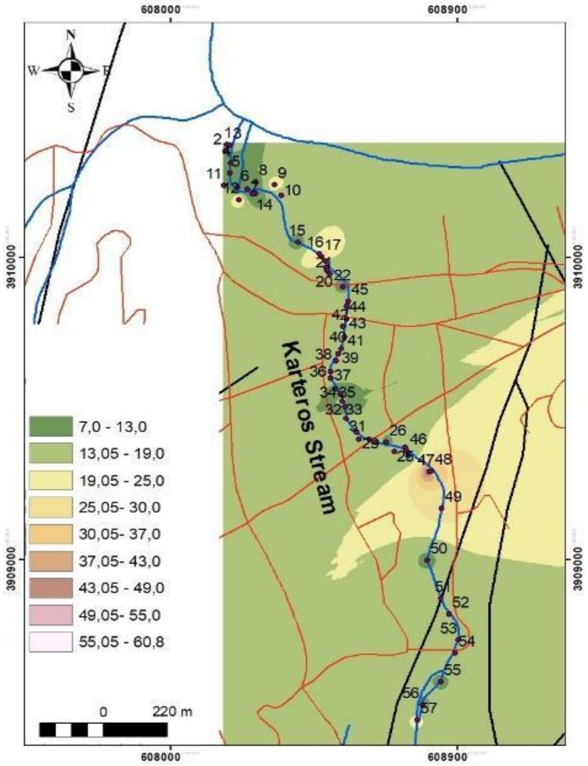
Urban Soil quality can be assessed by physical indicators (such as texture, bulk density, water holding capacity, pore space volume, penetration resistance and stable aggregates), chemical indicators (pH, electrical conductivity, Phosphorus, Potassium, Magnesium, Manganese, Copper and Boron), biological indicators (such as Microbial biomass C, and N, Basal respiration, Total organic C, and N, Dissolved organic C, and N, and others) and soil metals (Arsenic, Barium, Cobalt, Lead, Antimony, Nickel, Zinc and others) [24]. Environmental geophysics [25] offers a variety of techniques that contribute to the assessment of urban soil quality. Some geophysical techniques are particularly focused on the detection of contamination in topsoil and vegetation, urban soils and soil pollution from industrial emissions [26, 27, 28, 6, 7].

3 An example from Heraklion Crete (Greece)

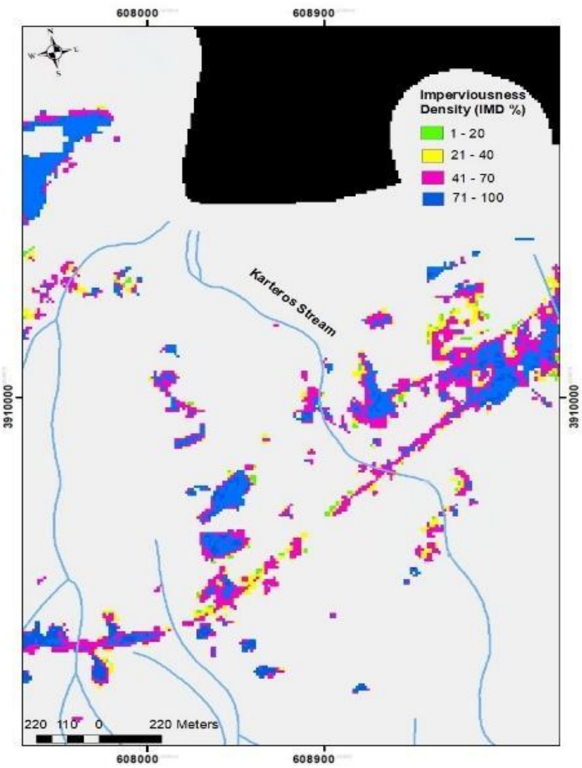
Karteros stream (Fig. 2a, b) is in the eastern part of Heraklion, Crete, surrounded by olive groves and vast vineyards. Karteros area is also important from the archaeological point of view because of its contribution to our understanding of the Minoan civilization and Crete's history. This case study was chosen because the area perfectly highlights how the pressure from urbanization, tourism and agricultural activities affect the ecological status of a stream and how the proposed methods were of use in order to monitor them.

The change and percentage of soil sealing can be assessed by the imperviousness density (IMD). In the present case we used data from Copernicus (https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/status-maps/), harmonized to the national coordinate system (GGRS87). In Figure 2a, high IMD values corresponding to higher degree of urbanization, are present in the lower part of the Karteros Stream. Next, we compared IMD (Fig. 2a) with the low-field magnetic susceptibility (LFS) along the stream (Fig. 2b). High IMD values along Karteros stream correspond to relatively higher LFS values.

The frequency domain electromagnetic method (FDEM) is a powerful tool for detecting and mapping sub-surface conductivity variations, identifying pollution leakageto the sub-soil. FDEM works by measuring subsurface' response to an electromagnetic field generated by a transmitter coil. Conductive materials in the subsurface, such as saline fluids, will alter the subsurface electromagnetic properties and result in a measurable response detected by the receiver coil. FDEM is a non-invasive and non-destructive technique that can provide high-resolution images of the subsurface without the need for drilling or excavation. It is therefore a useful tool for environmental monitoring and remediation efforts. However, FDEM is not a standalone technique. As an example in this work, we present the response of the stratigraphy near to Karteros stream (Fig. 3) up to a depth of 5 meters using 4 frequencies (510 Hz, 45270 Hz, 67650 Hz and 90030 Hz).



(a)



(b)

Fig. 2. a) IMD (%) and b) LFS in Karteros stream (Crete, Heraklion). The stream network corresponds to light blue line, the traffic network to orange line and the geological faults to black line

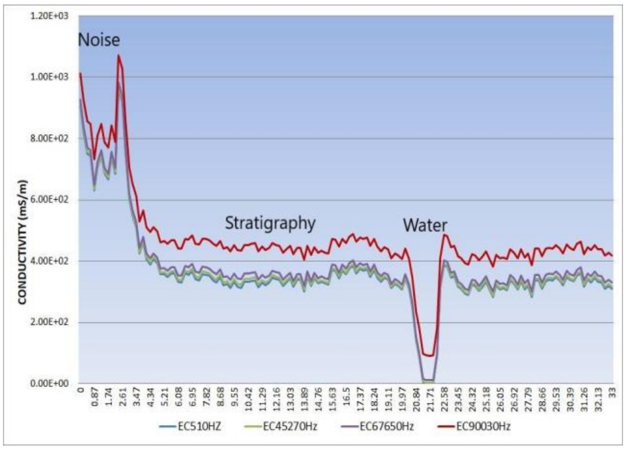


Fig. 3. GEM-2 response in Karteros Stream in four frequencies

The connection between human and ecosystem health cannot be overlooked, since the first is firmly linked to ecosystem services with the most important benefit being that it enables people to have healthy lives. Sandifier et al. (2015) [29] note that the ultimate service the ecosystem could provide is enhancing human health and well-being. This is because "One Health" is gradually gaining ground. If such a holistic view is adopted more sustainable cities will emerge, supporting and solving the needs and concerns of their citizens, especially the most vulnerable, while also providing quality ecological services.

4 Environmental impacts and hydrological challenges of urban stream systems

Urban streams are the main recipients of runoff generated in their respective urban catchments. The specific attributes of urban runoff can influence the methodology used in environmental monitoring, particularly with regard to the selection of sampling techniques and parameters (Fig. 4). The following discussion highlights some of the potentially significant differences between urban and rural rivers. These differences are primarily related to source characteristics and hydrological responses. While the various pollutant sources influence the parameters that should be monitored, recent research on urban stream health [30] suggests that pollutants generally have a much smaller impact on stream health than the reduction in habitat quantity and quality caused by hydrologic conditions and exacerbated by bank and channel construction. The input of pollutants can only become a significant factor in the health of watercourses if the habitat of the watercourses is not restricted.

Concerning the parameters illustrated in Figure 4, the flow regime is of particular significance. Given the greater proportion of impermeable land in urban catchments relative to rural catchments, runoff water is transported at a faster rate and with greater efficiency into the river channel. In comparison to natural systems, peak flows are observed to be higher, while base flows are found to be lower, due to the rapid concentration of runoff. The increasing frequency and intensity of storm surges result in the scouring and erosion of riverbanks, even in urban areas that are not directly affected by the storm surge itself. This has the effect of reducing or eliminating the habitat of benthic organisms in urban streams. In light of the considerable risk of flood damage in high-value urban areas, local authorities are undertaking measures such as straightening or relocating the channel with the aim of accelerating the discharge of flood waters. As a consequence, the area is no longer perceived as a stream but rather as a channel or floodplain, which further restricts or destroys the aquatic habitat. It is also important to note that the groundwater recharge rate is reduced as a result of increasing impermeability. In smaller streams, groundwater discharge in dry weather is therefore generally lower and unsustainable. This has significant implications for the quality and availability of aquatic habitats, up to and including the complete drying of the stream, through the deposition of eroded particles and higher stream temperatures.

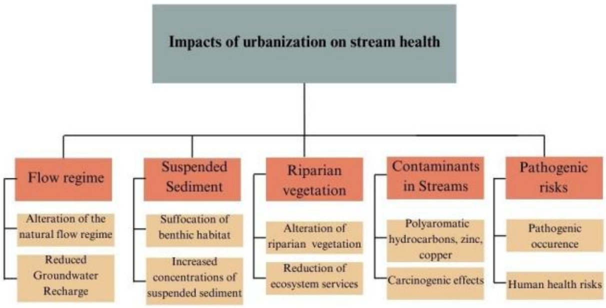


Fig. 4. Impacts of urbanization on stream health

Another parameter that is the subject of current research is that of suspended solids (SS). The concentration of suspended solids is observed to increase as a consequence of the pollution of urban soils. As Williamson (1993) [31] notes, the concentration increase is between 100- and 1000-fold. It is only when the mobilized sediments have re-adapted to the new flow regime that the suspended solids in the drainage networks return to a more normal level, particularly in areas where residential buildings have been constructed. The concentration of suspended solids gradually decreases to a level below that of pre-development pastureland as urban areas reach their full size. The complete smothering of benthic habitats by suspended solids (SS) is a common consequence of urban expansion, with streams with rocky bottoms being particularly susceptible.

Furthermore, the development of urban areas can have an impact on the vegetation that grows along riverbanks. As is the case with all streams, these changes affect the climate and shading along the riverbank, which in turn affects water temperature and dissolved oxygen levels. However, riparian vegetation can also influence the dissolution of organic matter in streams, which in turn affects the concentration of suspended solids. This can be particularly beneficial in urban streams, as it can reduce the bioavailability of potentially harmful metals [32]. In urban areas, the revegetation of riparian zones is a common practice. However, this technique has been demonstrated to result in the reduction of ecological value.

It is a near-universal phenomenon that the sediments of urban streams contain considerable quantities of polyaromatic hydrocarbons (PAHs) and zinc (Zn). This is because urban precipitation from tires and galvanized iron roofs (Zn), in addition to combustion byproducts and oil, contains considerable quantities of these substances [32]. Furthermore, river sediments contain considerable quantities of copper (Cu), which is derived from brake linings and vehicle abrasion. The removal of lead from gasoline has resulted in a notable reduction in the concentration of lead in urban runoff. A multitude of additional hazardous substances are also present in urban runoff, and thus in urban streams. However, these are typically the result of industrial contamination or the improper disposal of pesticides, rather than a general input from the urban catchment area. The concentration of Zn, Cu, and PAHs in urban rainwater frequently exceeds the limits set for water quality. However, these concentrations are typically associated with particulate matter, rendering the chemicals unavailable. Even though low-flow urban streams frequently exhibit traces of Cu and Zn that exceed chronic water quality limits, the results of laboratory toxicity tests have been observed to vary inconsistently, with occasional instances of damage to laboratory animals (31). Polycyclic aromatic hydrocarbons (PAHs) are particularly hazardous to animals, with some of them known to cause cancer in humans. However, the majority of these compounds are associated with the particulate component of runoff and are insoluble in water. There is evidence that the high prevalence of carcinoma in bottom-dwelling fish is caused by PAHs, and, probably, the issues associated with PAHs in urban runoff will also be observed in sediment-feeding organisms. Nevertheless, it remains uncertain to what extent urban runoff and industrial discharges contribute to the accumulation of PAHs in sediments.

Notably, pathogens are frequently detected in urban streams. A comparison of urban streams and sewage water indicates a low occurrence of enteric pathogenic bacteria and viruses [31]. Additionally, moderate levels of pathogenic organisms that can lead to skin, ear, and eye infections have been detected. However, there is less epidemiological evidence that these diseases occur in contact with urban streams. This is most likely because stormwater runoff usually occurs at times that are less convenient for water activities. Nevertheless, it is not advisable to consume mussels that originate from the mouth of an urban stream, as this poses a risk to human health.

5 Conclusions

Streams in urban centers are characterized by various factors such as changes in hydrology, pollutant inputs and habitat fragmentation, making it difficult to identify universal forms of stressors affecting streams. This work means that there needs to be a holistic approach to assessing and managing the ecological status of streams in urban areas. This can be achieved by integrating the remote sensing data with a ground-based approach and the accompanying chemical and biological data with appropriate statistical and geoinformatics tools.

The use of remote sensing makes it possible to hence monitor several indicators that are important in evaluating the condition of the streams in urban areas including suspended solids (SS), chlorophyll, and thermal pollution. Coupled with conventional approaches such as riparian zone quality assessments, and soil characterization, these techniques form a strong basis for the evaluation of pollution hotspots, as well as the interactions of the stream environment. For example, the application of water quality UAVs for detecting real-time parameters in water bodies provides a potential path for enhancing the density and frequency of monitoring activity.

The positive outcome of an integrated approach can be illustrated by the results of the case study on the Karteros Stream in Heraklion, Crete. In particular, the low-field magnetic susceptibility (LFS) and imperviousness density (IMD) seem to be an ideal combination to detect possible pollution. Similarly, frequency-domain electromagnetic (FDEM) methods showed limitless capabilities in visualizing subsurface stratigraphic changes that would help explain the processes underlying the stream's hydraulic cycle.

Thus, it is crucial to enhance the development of new technologies and approaches in the domain of water and soil assessment for the preservation of urban stream freshwater ecosystems. These efforts will not only improve the approaches to protect and restore the urban streams but also help the sustainability of the urban environment endowed with greater resilience.

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