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# DISCOURSE ON METROPOLITAN EVOLUTION: NAVIGATING URBAN POLLUTION FLUXES, CLIMATE CHANGE, AND THE DATA PREDICTIVE MODEL FOR GREEN INFRASTRUCTURE

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**Abstract**:

*Urban environments are significant contributors to environmental pollution through surface discharge and atmospheric deposition. These emissions originate from diverse sources, including transportation, industrial brownfields, wastewater treatment facilities, and contaminated air masses. This pollution encompasses a wide range of anthropogenic contaminants such as organic chemicals, petroleum hydrocarbons, solvents, toxic metals, and metalloids, making it a complex global issue. We address this challenge by focusing on the quantification and analysis of urban pollution fluxes in both spatial and temporal contexts. Specifically, the project targets urban, near-coastal, and industrial sites, aiming to develop advanced solutions for data-driven environmental modeling, which are crucial for effective green infrastructure planning. A critical aspect of study is the concept of the "urban halo" effect, wherein pollutants originating within cities extend beyond their boundaries, impacting surrounding ecosystems. This phenomenon is influenced by the nature of the contaminants and their mode of entry into the environment. The project employs two primary approaches to urban hydrological modeling: one examines the influence of urbanization within a defined catchment area, while the other constructs hydrological models with specific boundary settings. Both approaches facilitate a deeper understanding of pollution dynamics and their interactions with climate variables.*

*The overarching objective is to achieve a comprehensive assessment of the interactions between urban pollutants and climate dynamics, thereby advancing our understanding of geochemical fluxes under changing climate conditions. By leveraging this knowledge, the project aims to develop data-driven predictive environmental models, supporting the design and implementation of resilient green infrastructure strategies. These outcomes will not only enhance pollution management but also promote sustainable urban development in vulnerable regions.*

**Keywords**: *urban pollution, geochemical fluxes, hydrological modeling, green infrastructure, climate dynamics.*

Significant amount of environmental contamination and water pollution is related to the surface discharge and atmospheric deposition being exhausted by transport emissions, industrial brownfields, wastewater treatment facilities, polluted air masses. Contamination from anthropogenic sources may release various pollutants including organic chemicals, petroleum hydrocarbons, solvents, toxic metals and metalloids **[1]**. However, the modern society produce a lot of emerging pollutants that are not understood well yet. Sustainable remediation as well as prevention of emerging pollutants coming into the environment provide benefits to human health and the environment. The best solution would be to prevent the sources of pollutants to cease out; however, this might seem utopic idea for next few decades when environmentally neutral materials and perfect recycling would be achieved. On the other hand, the diffuse pollution of various substances is almost not possible to prevent coming into biological chains however the green infrastructure solutions which would prevent those coming to, e.g., rivers and seas, would be important step towards achieving sustainability. By urban runoff and especially stormwater flushes this pollution have greatest fluxes towards watersheds and from diffuse pollution transform to the point source as water urban runoff (**fig. 1**) is mostly collected in several single points and we cannot estimate changes of these fluxes during stochastic events. The Intergovernmental Panel on Climate Change (IPCC) has stated that the frequency of extreme precipitation is expected to grow over midlatitude regions by the end of the century. This is consistent with the Clausius-Clapeyron (CC) equation, which states that atmospheric water vapor pressure increases at a rate of 7% $°C^{-1}$ of warming. However, the relationship between warming and precipitation, and particularly with extreme precipitation, is complex and depends on many factors such as type, return period, and duration of rainfall. Currently, a significantly large body of literature is available on the impacts of climate change on water resources.

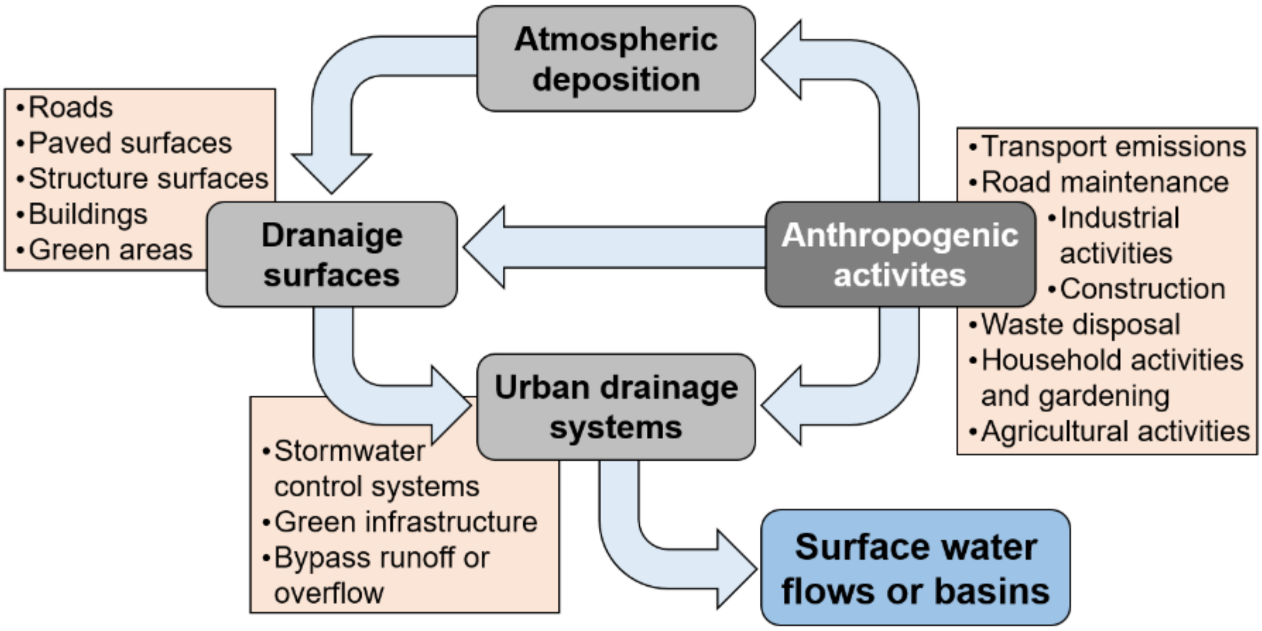


***Fig. 1.*** *Stormwater pollution sources*

The list of problems for finding solutions is: toxicity of contaminants; pH levels promoting mobility of contaminants; excess sodium, sulfates and chlorides, significant amounts of heavy metals, microplastics and emerging pollutants coming in relatively tiny concentrations, but in high amounts during stormwater flushes **[2, 3]**. Managing the risks posed by contaminants at stormwater treatment and outflow sites involves understanding the possible pathways and applying appropriate measures to measure, monitor in time and space, discover best options for treatment, or remove sources, adding amendment substances and green infrastructure buffers in appropriate places where the problem is solved before it enters back in diffuse pollution state. We need improve soil geochemistry and promote environment in a combined way to reduce toxicity, emission risks and stabilize physical properties, at the same time minimizing or eliminating energy consumption or the consumption of other natural resources by using natural resources and mimicking nature processes when designing green infrastructure.

The discharge of hazardous substances from urban areas into water basins continues to be high. Three factors contribute to this increase:

1. Many areas have sources of potentially hazardous substances as parts of cities are built on and/or around areas with artificial landfills, or brownfields. Floods affect many sources of potentially harmful elements: old waste dumps, manmade fillings, roads and railroads, contaminated soils, harbor areas, fuel and chemical storages **[4]**.
2. Cities expand and density into these areas **[5]**. The increase in sealed surfaces and artificial surfaces (e.g., roofs) leads to increased surface runoff, which also affects urban flood patterns.
3. Climate change causes increases in precipitation and cloudbursts. These three factors lead to an increase surface and subsurface discharge and subsequent increase of hazardous substances discharge **[6]**.

Cities that have not yet started to deal with increasing surface and subsurface discharge like to learn from experiences made so far and how to improve them, also respecting hazardous substances. Urban geochemical processes profoundly impact harmful substances in cities, altering their distribution and causing distinctive environmental effects. A study **[7]** highlighted gaps in ecosystem models, not considering human-induced changes like altered water flow, structures, and urban development. These shifts affect substance movement and retention, leading to unique urban flooding. Urban areas experience water quality changes due to altered flow, temperature, sedimentation, and habitats. Chemicals quickly enter aquatic systems, modifying their behavior and movement from soil to water bodies. Urban waste and emissions spread beyond cities, depending on their properties and introduction into the environment – a phenomenon termed the "urban halo effect" **[8]**, involving atmospheric and waterborne transportation. Traffic-driven air pollution poses a significant global health risk due to daily exposure to vehicle-generated dust particles. Metals from tires, brakes, and exhaust contribute to diverse car-related pollutants. Road dust directly threatens human health through ingestion, inhalation, and skin contact. Generally, urban soils serve as a storage for most solid and chemical pollutants from atmospheric deposition. The issue of lead contamination from historic gasoline usage is exacerbated today by catalytic converters, which introduce platinum group elements (PGEs), mainly Pt and Pd, into the environment. A study **[9]** revealed that high PGE concentrations align significantly with Pb anomalies in Naples, Italy's soil along the city's road network. Urban brownfield sites, remnants of past industrial activity, release inorganic and organic pollutants, posing a health risk to residents **[10]**. The USA has an estimated 400,000 to 500,000 brownfields, Europe has 300,000 to 1.5 million, and Canada has over 30,000 **[11, 12]**. As cities expand, brownfield sites are attractive for redevelopment, emphasizing the need for proper remediation before reuse to prevent harm to human health. For example, the Bagnoli brownfield area in Naples, is still releasing metals and organic compounds years after industrial activity **[13]**. Urban stormwater management (fig. 2) is a critical concern, particularly in cities with outdated or combined sewage treatment plants. These plants struggle to handle the large volumes of water during heavy rains, resulting in untreated water overflows that significantly pollute downstream bodies of water. Outdated treatment plants often inadequately remove contaminants like salts, soluble phosphorus, bacteria, endocrine-disrupting chemicals (EDCs), and pharmaceutical and personal-care products

(PPCPs) from the final effluent, posing a human health threat **[14]**. EDCs and PPCPs, considered emerging contaminants, are found in urban watercourses worldwide, presenting potential health risks if ingested **[15]**. These emerging contaminants encompass everyday use compounds, such as pharmaceuticals, detergents, plasticizers, and industrial additives, suspected to be harmful if introduced into the human body. The role of some inorganic contaminants such as toxic metals, including Hg and REEs, has been studied to a small extent with greater attention only to Hg. Studies indicate the estimated median total Hg concentration in, e.g., beach wrack 7.6 ng/g dry weight; then 1 km long beach segment may receive 6 g of Hg per season, adversely affecting flora and fauna. Nevertheless, a broad and consistent investigation of inorganic contaminants over several seasons has not been performed in the selected area. Therefore, biogeochemical cycling analysis of elements of concern can give valuable information to understand the integrated environmental processes. The growing contribution of recycled Hg, including the legacy of previous anthropogenic emissions, is driven by climate change and increasing anthropogenic pressures affecting all ecosystems **[16, 17]**. The consequences of the perturbed global Hg cycle are expected to be more severe for the marine environment, compared to terrestrial and freshwater ecosystems **[18]**. The marine ecosystem is particularly vulnerable to Hg contamination, as it originates from different sources, including not only atmospheric deposition but also waterborne input and direct point sources located on land and sea **[19, 20]**.

Anthropogenic activities can result in the relocation of contaminants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), microplastics and even pharmaceuticals from shipping channels, harbours, and ports into the marine environment where these components may exert a negative effect on the marine ecosystem. Defined primary contaminants are all persistent in the marine environment and have a significant anthropogenic input. PAHs can be naturally released during forest fires and by volcanic activity, but are mainly linked to anthropogenic sources such as fossil fuel burning, waste incineration, oil refining, oil spills, and industrial and agricultural outfalls. PCBs were used as coolants, plasticisers and lubricants, and were banned in the mid-'80s, however, remaining sources such as old equipment, disposal of waste and transport of contaminated sediments, still contribute to contamination in the marine environment. Both PAHs and PCBs have a slow degradation rate in anaerobic sediment, allowing for their bioaccumulation and biomagnification in the marine environment **[21]**. Metals can be naturally released into the environment due to volcanic eruption, sea-salt sprays, forest fires, biogenic sources and rock weathering, a process where metals are released from their endemic spheres into the environment **[22]**.

Pharmaceutical residues have become a serious global concern due to their release from various sources, including hospitals, industries, and domestic activities **[23, 24]**. Improper management of these wastes leads to environmental contamination, particularly in developing countries **[25]**. Studies show that certain pharmaceuticals like IBU, GEM, and SMX can achieve >99% biodegradation during soil composting **[26]**. Understanding pharmaceutical biodegradation in urban settings is critical.

Urban hydrological models are classified by time and space scales, with two main approaches: catchment-scale models covering broad time-space dimensions and city-scale models with finer resolution. Over 50% of small-area models (<10 km$^2$) use time steps of 6 minutes or less, while larger areas (>10 km$^2$) often adopt 1-hour intervals. GIS tools (ArcView, ArcGIS, ArcInfo) are widely used for data processing and model parameterization, leveraging digital models for catchment boundary determination. Remote sensing, including LIDAR and rainfall radar, supports model precision **[27,28]**. Hydrodynamic routing and hydraulic modeling are fundamental for simulating urban water systems, with methods ranging from conceptual equations to the de Saint Venant equations.

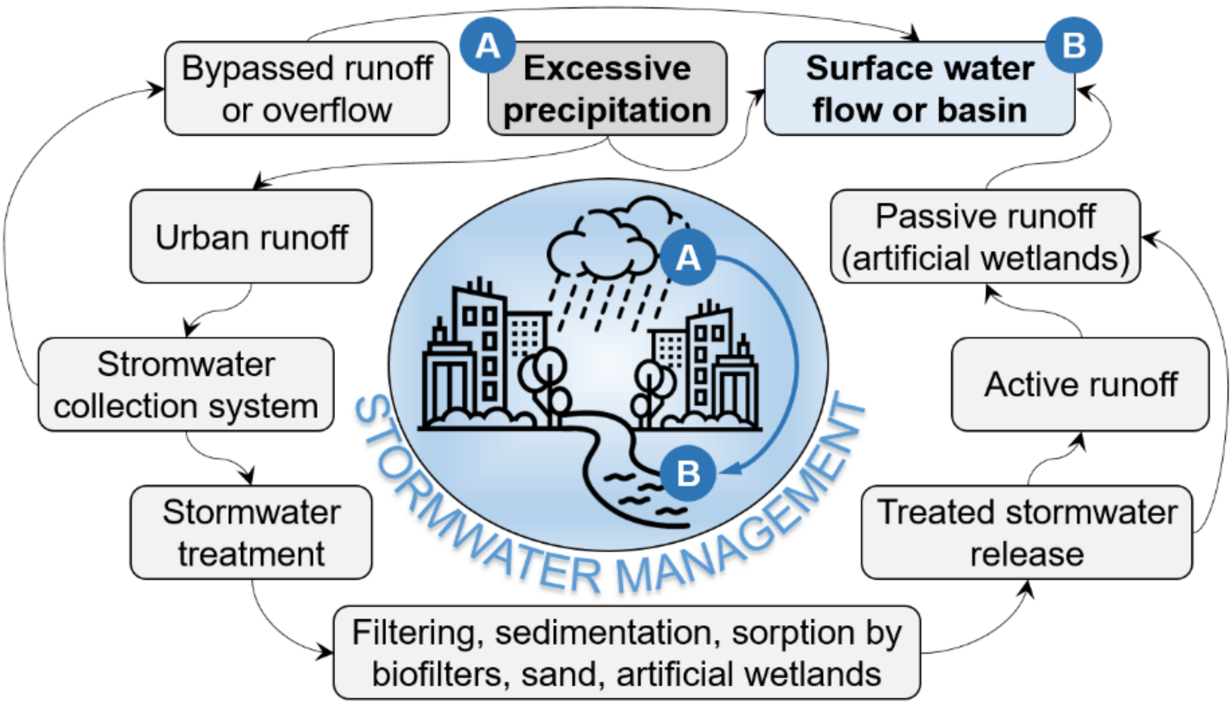


***Fig. 2.*** *Stormwater management in urban areas*

Urban hydrology differs from classical hydraulics primarily in scale, emphasizing surface runoff, rainwater collection, and sewer systems. Model developers must balance complexity with purpose, choosing processes and detail levels to suit their objectives. Such models are essential for understanding urbanization's impact on infiltration, runoff, and drainage formation **[29,30]**.

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# ДИСКУРС ЩОДО ЕВОЛЮЦІЇ МЕГАПОЛІСІВ: УПРАВЛІННЯ МІСЬКИМИ ПОТОКАМИ ЗАБРУДНЕННЯ, ЗМІНАМИ КЛІМАТУ ТА ПРОГНОЗНОЮ МОДЕЛЛЮ ДАНИХ ДЛЯ ЗЕЛЕНОЇ ІНФРАСТРУКТУРИ

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**Анотація**

Міські середовища значною мірою сприяють забрудненню довкілля через поверхневі стоки й атмосферні осади. Такі викиди походять із різноманітних джерел, включаючи транспорт, промислові території (браунфілди), станції очищення стічних вод та забруднені повітряні маси. Це забруднення охоплює широкий спектр антропогенних забруднювачів, таких як органічні речовини, нафтові вуглеводні, розчинники, токсичні метали й металоїди, що робить його складною глобальною проблемою. Ми підходимо до вирішення цього питання шляхом кількісної оцінки та аналізу міських забруднювальних потоків у просторовому й часовому контекстах.

Конкретно цей проєкт орієнтується на міські, прибережні та промислові території, маючи на меті розробку передових рішень у сфері екологічного моделювання на основі даних, що є критично важливим для ефективного планування зеленої інфраструктури. Важливим аспектом дослідження є концепція ефекту «міського гало», за якої забруднювачі, що виникають у містах, поширюються за межі їхніх територій, негативно впливаючи на навколишні екосистеми. Це явище залежить від характеру забруднювачів та способу їх проникнення в довкілля. Проєкт використовує два основні підходи до міського гідрологічного моделювання:

перший досліджує вплив урбанізації в межах визначеного водозбірного басейну, другий створює гідрологічні моделі із заданими граничними умовами. Обидва підходи сприяють глибшому розумінню динаміки забруднень та їх взаємодії з кліматичними факторами.

Загальна мета полягає в комплексній оцінці взаємодії між міськими забруднювачами та динамікою клімату, що дозволить поглибити розуміння геохімічних потоків в умовах зміни клімату. Використовуючи отримані знання, проєкт прагне розробити прогностичні екологічні моделі на основі даних, які допоможуть у розробці та реалізації стійких стратегій зеленої інфраструктури. Ці результати дозволять не лише покращити управління забрудненням, але й сприятимуть сталому розвитку міських територій у регіонах, що є найбільш вразливими до змін клімату.

**Ключові слова:** міське забруднення, геохімічні потоки, гідрологічне моделювання, зелена інфраструктура, кліматична динаміка.