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Impacts of Impervious Surfaces on the Environment

Chithra S.V. [1,*], Dr. M.V. Harindranathan Nair[2], Amarnath A[3], Anjana N.S.[4]
[1,2,3,4]School of Environmental Studies, Cochin University of Science and Technology, Kochi, Kerala, India.

Abstract: *Anthropogenic surfaces that prevent the infiltration of water into the underlying soil such as buildings and paved surfaces (asphalt, concrete), roads, parking lots are called impervious surfaces. Increasing urbanization and pressure of population stimulates the growth of impervious surfaces in the cities. Tremendous increase in impervious surfaces has far reaching effects on the landscape and environment of the region. Impacts of impervious surfaces on climate and hydrology are reviewed here. This review suggests that increasing impervious surfaces strongly alters the hydrology by reducing infiltration and increasing surface run-off. It increases the Land Surface Temperature (LST) by creating Urban Heat Islands (UHI).*
Keywords: *Impervious surfaces, pollution, water quality, Land Surface Temperature, Urban Heat Islands.*

I. INTRODUCTION

Impervious surfaces are defined as the surfaces that prohibit the infiltration of water from the land surface into the underlying soil. Imperviousness is the most critical indicator for analyzing impacts of urbanization on the water environment.[1,2] With the advent of urban sprawl, impervious surfaces have also become a key issue in growth management and watershed planning due to their impact on habitat health.[2] Impervious surface increases the frequency and intensity of downstream runoff and decreases water quality. Increasing urbanization has resulted in increased amounts of impervious surfaces - roads, parking lots, roof tops, and so on - and a decrease in the amount of forested lands, wetlands, and other forms of open space that absorb and clean storm water in the natural system.[3,4] This change in the impervious-pervious surface balance has caused significant changes to both the quality and quantity of the storm water runoff, leading to degraded stream and watershed systems.[5,6,7,8] Stream quality starts to degrade, if more than 10 percent of the watershed is impervious.[1]

A good number of researchers attempted to find the watersheds' response to land use/ land cover changes over time.[9,10] Many authors[11,12,13] have noted that an increase in impervious surface reduces base flow. This is because impervious surfaces prevent infiltration, thereby reducing groundwater recharge and base flow.[14] Impervious surfaces can be used as an alternate measure for the cumulative impact of urbanization on water resources without having to consider specific factors. The other benefit is that it can be measured by a variety of procedures.[2] Watersheds with large amounts of impervious cover may experience an overall decrease of groundwater recharge and base flow and an increase of storm flow and flood frequency.[8,15] Furthermore, imperviousness is related to the water quality of a drainage basin and it's receiving streams, lakes, and ponds. Increase in impervious cover and runoff directly impact the transport of non-point source pollutants including pathogens, nutrients, toxic contaminants, and sediment.[16] Increases in runoff volume and discharge rates together with non-point source pollution, will predictably alter in-stream and riparian habitats, and the loss of some critical aquatic habits.[17] In addition, the areal extent and spatial occurrence of impervious surfaces may significantly influence urban climate by altering sensible and latent heat fluxes within the urban areas.[18] As impervious cover increases within a watershed/administrative unit, vegetation cover would decrease.

Four basic qualities of imperviousness that make it an important indicator of environmental quality are:

(1) Although the impervious surface does not directly generate pollution, a clear link has been made between impervious surfaces and the hydrologic changes that degrade water quality;
(2) An impervious surface is a characteristic of urbanization;
(3) An impervious surface prevents natural pollutant processing in the soil by preventing percolation; and
(4) Impervious surfaces convey pollutants into the waterways, typically through the direct piping of stormwater[2].

The development of the scientific basis to establish the relationship between land use changes and the amount of impervious surfaces took place in the field of urban hydrology primarily during the 1970s. The majority of current impervious surface analyses rely on the methods of these original studies and subsequent studies that correlated percentage of impervious surfaces to land use largely by using estimates of the proportion of imperviousness within each class. A good number of studies estimate the percentage of Total Impervious Area (TIA) as well as Effective Impervious Area (EIA) by coupling remote sensing and GIS[10, 19].

II. HYDROLOGIC EFFECTS OF IMPERVIOUS SURFACES

The water cycle is the most critical processes in supporting life on this planet, and fresh water is central to all aspects of our lives. Hydrology is the study of the movement, distribution and quality of water on earth and urban hydrology is the interdisciplinary science of water and its interrelationships with man in an urban watershed. In urban areas, due to the intense alteration of natural environmental processes by human activity, the watershed response to precipitation are also significantly altered (e.g. reduced infiltration, decreased travel time, higher runoff, urban flooding etc.). Although urban areas are quiet small relative to un-urbanized land, they significantly alter hydrology, biodiversity, biogeochemistry and climate at local, regional and global scales. Land development causes pervious soft surfaces such as grass lands, water bodies and green vegetation being replaced by hard impervious surfaces. While forests capture much precipitation through interception and infiltration, even more is evapotranspired by the trees.[20] Open land, such as a pasture or cultivated land, allows less infiltration than forest, and is often more prone to runoff. Water enters into the soil through infiltration and the velocity with which water enters the soil is infiltration rate. Land use can have significant impacts on the amount and speed of infiltration in a basin. Impermeable surfaces, such as roofs, parking lots, and roads allow zero infiltration, forcing all water that falls onto them to runoff. The changing proportions of these land use types within a basin can have serious effects on discharge and response to storms, either increasing total yield of water, or decreasing and smoothing the hydrograph.[21] Increased impervious cover generally results in more storm water runoff and less ground water recharge. More runoff, in turn, increases stream flows during storm periods. Stream banks erode, more sediment is carried into the streams from surrounding lands, and aquatic habitats are disrupted and degraded. Less recharge means less ground water discharges to streams during dry periods. High levels of impervious cover are associated with dense development, which sends greater pollutant loads to runoff flow channels.

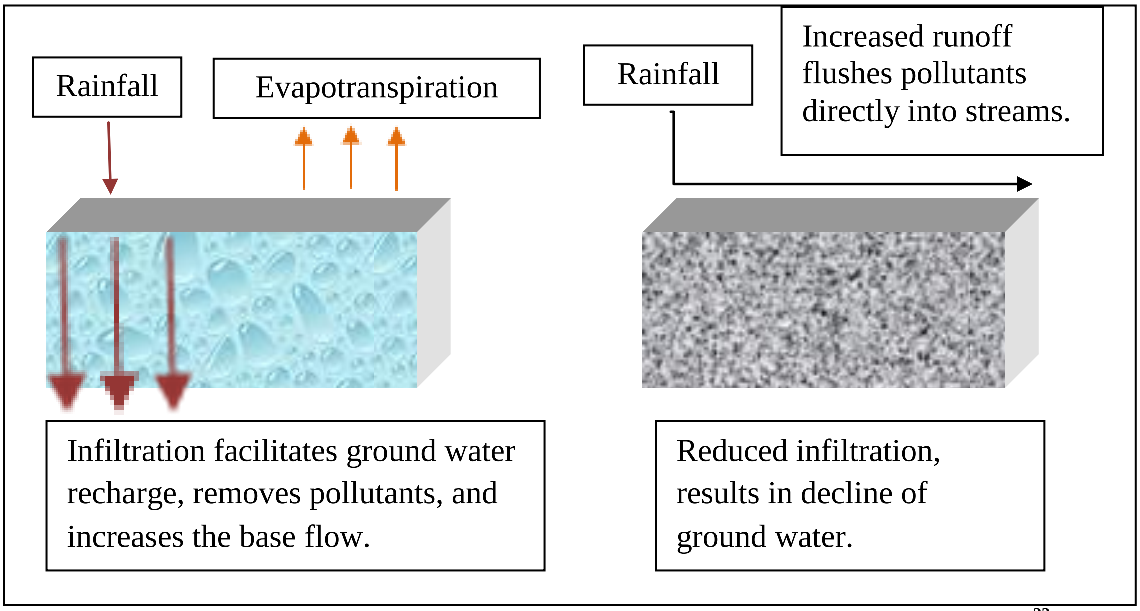

Figure 1. The Effects of Pervious surfaces and impervious surfaces on rainfall[22].

III. IMPERVIOUSNESS AND WATER QUALITY

Impervious surfaces serve as a key indicator for health of aquatic ecosystems.[2] Increased impervious cover is strongly related to increased degradation of aquatic ecosystems. Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other line and point sources. During storms, accumulated pollutants are quickly washed off and rapidly delivered to aquatic systems. As the area under impervious cover increases, more water reaches the ocean as surface water run-off. Storm water runoff is the rain or snowmelt that runs off streets, rooftops, parking lots, lawns and other land surfaces and eventually runs into our streams. Storm water also picks up pollutants as it flows across land surfaces. Pollutants include sediment, pesticides, asphalt, fertilizers, bacteria and disease-causing organisms from failing septic systems; petroleum products such as oil and grease. Sometimes pollutants (e.g., used oil, paint thinners, etc.) are illegally dumped directly into storm drains and waterways. Urban pollutant loads are linked to watershed imperviousness and it serves as a key predictive variable in most simulations and empirical models used to estimate pollutant loads. The simple method assumes that pollutant loads are a direct function of watershed imperviousness.[23]

Impervious surface affects the hydrology of a watershed, the geomorphology of stream beds, temperature, fish populations, macro invertebrates, microbes, algae, and macrophytes. Nutrients, toxins and sediment disrupt aquatic ecosystems and contribute to degraded water quality. The reduced stream flow and more extreme stream temperatures will stress aquatic ecosystems. The abundance and diversity of fish and macro invertebrate populations is harmed as the concentration of impervious surfaces increase.[24] A few works studied the impacts of urbanization on stream insect communities by taking Impervious Surface Area as an indicator.[25] They noticed a steep decrease in stream insect community structure as impervious surfaces increase above 6% of the total catchment area. Water temperature increased as total percentage of impervious surface increases.[26]

The expansion of urban areas is creating more impervious surfaces, such as roofs, roads, and parking lots, which collect pathogens, heavy metals, sediment, and chemical pollutants and quickly transmit them to streams, rivers, estuaries or sea downstream during rain. This non-point source pollution is one of the major threats to water quality and is linked to chronic and acute illnesses from exposure through drinking water, seafood, and contact recreation. Impervious surfaces also lead to pooling of storm water, thus increasing the potential breeding areas for mosquitoes, the disease vectors for dengue hemorrhagic fever, Chikungunya and other infectious diseases. Traditional strategies to manage storm water and treat drinking water require large infrastructure investments and face difficult technical challenges. Reducing storm water runoff and associated non-point source pollution is a potentially valuable component of an integrated strategy to protect public health at the least cost. Runoff from roofs, roads, and parking lots can contain significant concentrations of copper, zinc, and lead, which can have toxic effects in humans. Bioaccumulation of insecticides at levels considered harmful to organisms, raises concern about carcinogenic effects and disruption of hormonal systems in humans.

When storm water moves more quickly into streams, it also has a greater capacity to carry non-point source pollutants into the streams. Community drinking water supplies are commonly disinfected with chlorine and, if the source is surface water, it is filtered to remove sediment and associated pollutants. Several common disease carrying microorganisms are resistant to treatment with chlorine and filtration, although the effectiveness of the filters varies with their pore size. Suspended sediment in source waters further reduces the effectiveness of chlorine. Nitrogen also poses direct health threats. Exposure to nitrate in drinking water increases the risk of methemoglobinemia, causing shortness of breath and blueness of the skin, especially for infants. Consumption of water with elevated nitrate is also suspected to increase miscarriage risk. Major sources of nitrogen from urban and suburban areas may include fertilizers carried by storm water, vehicle exhaust, and septic systems. Fecal coliform bacteria in surface waters commonly exceed standards for recreation, and exposure to bacteria and parasites from swimming and other forms of recreation in water contaminated with urban runoff has caused numerous cases of illness, including ear and eye discharges, skin rashes, and gastrointestinal problems. Increasing impervious surface without storm water controls leads to increased runoff. Elevated fecal coliform levels also have been detected in suburban streams.

Impervious surfaces both absorb and reflect heat. During the summer months, impervious areas can have local air and ground temperatures that are 10 to 12 degrees warmer than the fields and forests that they replace. In urban areas, trees that could provide shade to offset the effects of solar radiation are usually absent. Other factors such as lack of riparian cover and ponds, were also demonstrated to amplify stream warming, but the primary contributing factor was impervious cover.[26]

IV. IMPERVIOUSNESS AND WEATHER CHANGE

Urban heat islands (UHI) refer to the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in the surrounding rural areas due to urbanization.[27] The prime driving force behind UHI is impervious surfaces. The UHI occurs due to differences in thermal, and radiative properties of urban surface materials from the ones of natural surfaces, multiple reflection and absorption of sunlight by urban surfaces (due to specific geometry), anthropogenic heat sources and lack of evapotranspiration in urban areas.[28] The Thermal properties of various urban surface types are given in Table 1. The UHI may greatly change the local climate and thus should be captured by climate models on local and regional scales.

Sl.No.	Surface Type	Emissivity	Absorptivity
1	Highly reflective roof	0.85-0.9	0.3-0.4
2	Galvanized roof sheets	0.25-0.28	0.85-0.9
3	Grass	0.97-0.98	0.7-0.75
4	White tile	0.9-0.95	0.1-0.5
5	Tar and Gravel	0.28	0.82-0.97
6	Brick or Stone	0.87	0.6-0.8
7	Asphalt	0.92	0.8-0.95
8	Concrete	0.9	0.65-0.9
9	Dense Canopy trees	0.95-0.99	0.82-0.85
10	Water	0.99	0.95-0.98
11	Black loamy soil	0.66	0.82-0.87

Table 1. The Thermal properties of various urban surface types[29]

Fei Yuan and Marvin E Bauer compared the Normalised Difference Vegetation Index (NDVI) and percent impervious surface as indicators of surface urban heat island effects by investigating the relationships between the Land Surface Temperature (LST), percent impervious surface area and the NDVI.[30] Landsat TM and ETM data were used for the study. They reported a strong linear relationship between LST and percent impervious surface for all seasons, whereas the relationship between LST and NDVI is less strong. Hua Li and Qinhuo Liu (2008) compared the normalized difference built-up index (NDBI) and Normalised Difference Vegetation Index (NDVI) as indicator of Surface Urban Heat Island (SUHI) effects in MODIS imagery by investigating the relationships between the Land Surface Temperature (LST), NDBI, NDVI from four different seasons for Changsha-Zhu zhou- Ziangtan (China) metropolitan area.[31] Scatterplots of NDBI, NDVI and LST for all the images were compared to find the relationships of LST to NDBI and NDVI. Results suggest that NDBI is an accurate indicator of SUHI effects and can be used as a complimentary method to the traditional NDVI. A good number of works reported the prevalence of heat island effect in various cities throughout the world.[29, 32]

Some authors have questioned the accuracy of impervious surface measures with regard to their impact on water quality and quantity.[33] For example, Total Impervious Area (TIA) includes all of the impervious surfaces in a watershed, regardless of what kind of connection exists between the impervious surfaces and the basin's water bodies. Most of the satellite based estimates calculates the TIA only. Effective Impervious Area (EIA) includes only the portion of a watershed that allows water to cross only an impervious pathway to reach the water. Years of scientific inquiry has firmly established impervious surface coverage as a "reliable and integrative indicator of the impact of development on water resources".[2] This combined with the fact that impervious surface is a measurable parameter, makes it an ideal substitute for measuring water quality in an urban environment.

Conclusion:

A good number of studies have commented on the impacts of impervious surfaces on urban hydrology. Impervious surfaces significantly reduce the water quantity and quality in a watershed. It is reported that the impervious surface degrades the watershed quality by greatly reducing the stream flow and increasing the stream temperature. They carry huge pollutant loads downstream, causing due harm to aquatic life. Surface urban heat islands are another phenomenon caused by impervious surfaces. Attempts have been reported from all over the world to quantify the area under impervious surfaces as well as its impacts.

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