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Abstract
The issue of stormwater is one frequently raised by local decision-makers in developing countries. This issue becomes particularly problematic when there is heavy rainfall that floods the settlements situated in the lowest parts of towns. The effects of such rainfall are manifold: sanitation, material, economic and environmental impacts, etc.
Stormwater management is a highly complex process that involves a number of factors, each significant in determining the effectiveness of its results. These factors fall into 4 groups: natural factors, human activity related factors, factors related to the management of urban space and factors associated with insufficient or lack of stormwater management capacities.
Several innovative approaches have been implemented to address these factors. However, these are not yet sufficiently well-known or disseminated. The key principles to be borne in mind include: clearly distinguishing between the geographic scale of the stormwater management issue and the scale of intervention; taking all interactions with other urban services into account in stormwater management planning; and, lastly, organising the sector using an upgradeable and complementary approach to utilising both traditional solutions and those that draw on alternative or compensatory techniques.

Keywords
Impacts, Challenges, Urbanisation, Urban stormwater management, Developing countries

INTRODUCTION

This document contains an analysis of issues, existing practices and areas for research related to urban stormwater management in developing countries. As frequently highlighted by their elected officials, this is a topic that is becoming increasingly important for towns in developing countries. Whilst the extent of the issue becomes particularly apparent when there is heavy rainfall that floods the settlements situated in the lowest parts of towns, it at the same time encompasses a large number of urban development issues. The present document is based on both a synthesis of a literature analysis and interviews with subject matter experts. This work was monitored by a scientific committee of experts in development and urban issues.

Urban stormwater management, as understood in this document, refers to all the measures undertaken to improve the way in which the flow and volumes of water generated by rainfall and surface runoff in urban areas are controlled and managed.

STORMWATER MANAGEMENT HISTORY IN DEVELOPED COUNTRIES

Step one: channel and store for evacuation or flow management

In the middle of the 19th century, when the first urban sewer systems were being constructed, stormwater was essentially seen as a nuisance to be evacuated from the city as quickly as possible. The hygienist movement thus put sanitation equipment in place with a view to ensuring **public health**.

In the middle of the 20th century, as a result of urban growth coupled with developments in agricultural practices, the perception of urban stormwater changed and instead began to be seen as a threat liable to cause flash flooding. Technicians therefore developed a **hydraulic approach** that involved optimising the use of evacuation systems and further equipping these with large retention ponds to control peak discharge.

Step two: treat the discharge and regulate flow

During the 1980s, driven by growing environmental concerns, focus turned to the pollutants contained not only in runoff but also in combined sewer overflows. In addition, it was becoming

increasingly clear that traditional sewer systems were often no longer able to regulate all the stormwater. New, so-called alternative or compensatory techniques were thus introduced to supplement the hydraulic approach with a **regulatory and environmental approach.**

Step three: reuse the stormwater
At the end of the 20th century, work undertaken to optimise these techniques, coupled with fears over the impact of climate change on the future availability of water resources, soon led to further expansion of this environmental approach; first, through urban planning to **reintegrate stormwater into urban water cycles**; then by recognising urban stormwater as a **resource**, as is increasingly the case today.

ISSUES DRIVING STORMWATER MANAGEMENT IN DEVELOPING COUNTRIES

The increasing urbanisation of the world's population is constantly creating new challenges for stormwater management. Although rain is vital for both human beings and their environment (to replenish rivers, water points and groundwater, grow vegetation, etc.), rainfall events generate flows and volumes of water that can be difficult to control and that accumulate in the lowest parts of towns, flooding residential areas and creating pools of stagnant water. The impacts of such rainfall can be broken down into four types: sanitary, material, economic and environmental.

Safeguarding public health

Flooding and the pools of stagnant water created by heavy rainfall events pose major public health risks for the population: epidemics caused by stagnant and contaminated drinking water (bacteria, parasites), injury and death (drowning), discomfort (mud).

Stormwater-related diseases
Diseases are transmitted through:

- direct contact with the water used for drinking, cooking, cleaning and personal hygiene which has been contaminated by parasites (flooding can disperse the ascaris, trichuris trichiura, hookworm eggs and facilitate their development) and chemical or organic pollutants;
- vectors of disease, such as mosquitoes (yellow fever, dengue fever, filariasis, malaria), rats (transmit leptospirosis through their urine) and snails (schistosomiasis) that thrive in these conditions.

Accidents and injury
Heavy rainfall events can lead to numerous accidents and injuries, caused by people being swept away by the current, landslides and subsidence and by traffic accidents.

Protecting the land, housing and urban infrastructure

Flash flooding and the stagnant water that can follow periods of heavy rainfall cause considerable deterioration and even the destruction of urban areas. In this context, key issues are:

- Maintaining the stability of developed and developable land to minimise the risk of landslides caused by a combination of erosion and flooding.
- Preventing the degradation or destruction of housing, public buildings and equipment and those providing basic services (water supply, sanitation, energy, etc.) and roads (to enable the mobility of people and goods).

Safeguarding economic development

Public commercial facilities (markets, bus stations, etc.), industrial, economic and commercial equipment, as well as the roads and tracks that enable the movement of people and goods, all support the economic activity of urban centres. By protecting these different types of infrastructure, stormwater management aims to safeguard economic development.

Protecting the environment

Stormwater collects pollutants (as it comes into contact with wastewater and solid waste and flows down roads) and is most often discharged into the environment without treatment, contaminating the waterways.

FACTORS INFLUENCING STORMWATER MANAGEMENT IN DEVELOPING COUNTRIES

In developing countries, urban stormwater management is generally inadequate or non-existent. Where they exist, stormwater collection systems serve only the most central or wealthiest areas. Due to a chronic lack of care and maintenance, they are in extremely poor condition. In outlying neighbourhoods, water runs along natural ravines, but these are not able to evacuate all surface runoff during heavy rain. This water collects pollutants (wastewater, trash, sediment) and constitutes a significant public health, economic and environmental risk. Stormwater management is a highly complex process, the effectiveness of which is influenced by a number of different factors. The principal factors are listed below.

'Natural' factors

Rainfall patterns (frequency and intensity): In countries in the Sahel, tropical or equatorial zones, precipitation is 3 to 4 times more intense than rainfall in temperate areas, thus rendering urban stormwater evacuation all the more difficult and costly. Enormous drainage systems are required and these can reduce the effectiveness of storage or alternative infiltration solutions, which have more limited capacities.

Characteristics of the catchment area: Prior to developing any form of response to stormwater issues, it is vital that a study is carried out to identify the exact characteristics of the catchment or mini-catchment area (relief, size, land use plan, etc.).

Soil type: The type of soil will directly affect the infiltration capacity. Lateritic soils, in particular, are highly impermeable.

Presence of a river Water level fluctuations in watercourses have a direct impact on the flood risk.

Climate change[1]*:* Specialists estimate that the current climate change process will lead to an increase in extreme weather events, such as drought or severe storms, in certain zones: the increased intensity of rainfall in these areas will therefore increase the flood risk.

Human activity-related factors

Extension and densification of urban areas: Although, overall, urban growth rates have fallen over the last 20 years, in most developing countries they remain very high, both in capital and secondary cities. Thus, the urban landscape is constantly expanding and becoming denser, extending into areas with no stormwater drainage system and leaving the authorities struggling to cope.

Impermeability: Increasing urbanisation leads to increased soil impermeability; thus, water is no longer absorbed by the soil but runs off along the surface, increasing the quantities of water to be treated and preventing groundwater recharge. It is estimated that a city with relatively low housing density is able to absorb up to 35% of its surface runoff, whereas a city with high housing density can absorb only 10%.

Degradation of plant cover: The degradation of plant cover both upstream of and within cities increases the surface runoff within the entire urban catchment. Within the city itself, during heavy rains, this degradation of plant cover increases both the speed and volume of runoff in urban areas, causing soil erosion, landslides and mudslides, as well as clogging the networks with solid particles.

Factors linked to the management of urban space

Lack of planning and poor land management

Poor planning results in urban development that fails to follow norms and recommendations**:** numerous neighbourhoods spring up haphazardly in flood zones without any respect for urban development plans. There is, therefore, no proper land management of those areas where construction is not allowed. These areas (marshes, low-lying land, erodible areas), particularly when they are near town, attract low-income

[1] Likely caused by human activities, this factor could also be included in 4.2

populations due to the convenience of their location (close to work, shops and services). However, these areas in turn become over-populated and problematic, exposing the population to the risk of flooding and landslides.

Overlap between stormwater, wastewater, solid waste and drinking water

Lack of management and the poor state of infrastructure mean the different public services encroach on each other.

Wastewater discharged into the stormwater drainage system: In the dry season, the intrusion of stagnant wastewater into the stormwater drainage system creates major smell and hygiene issues. During the wet season, stormwater is mixed with this same wastewater, and with solid waste, seriously contaminating flooded areas and the environment.

Brazzaville (Congo), erosion with disastrous effects (EGIS BCEOM International, 2009).

Due to their sandy and easily eroded banks, the Urban Development Plan of 1980 forbids any building on the hills overlooking the north-west of Brazzaville. However, subsequent land pressure led to this constraint being partially lifted. This prompted work on numerous uncontrolled activities, notably the careless clearing of sloped areas and earthworks, leading to often catastrophic erosion during the rainy season. As a result of this erosion, huge ravines appear, engulfing tens and hundreds of houses and cutting off access roads. This erosion also produces thousands of tons of sandy sediment, which is deposited in the central reaches of the collectors where the gradient is lower, filling sections of the road crossings; this leaves roads underwater whenever there is heavy rain and causes insufferable flooding for residents. This phenomenon is further compounded by the lack of any collection and storage system for solid waste, which is systematically dumped into the beds of waterways and, carried by floodwater, accumulates causing obstructions. In addition to obstructing the flow of water, this waste spreads pollution so also poses a risk to public health.

Solid waste dumped in the stormwater drainage system: The lack of an effective solid waste collection system causes the stormwater drainage system to become blocked.

Stormwater contamination of drinking water: Stormwater, loaded with pollutants, contaminates underground water resources (wells and boreholes).

Factors directly linked to stormwater management

Lack of knowledge and information

Although clearly identified as a major issue in times of flooding, the responsible agencies often lack the knowledge and tools required to deal with stormwater management. In many African countries, rainfall data is frequently lacking, obsolete or inaccessible.

Developing countries often make use of the approaches implemented in developed countries during the 20th century: their aim is to evacuate the water from the city as quickly as possible, rather than endeavour to store and reuse it. Alternative and additional measures (storage /infiltration/delayed surface runoff) remain relatively unknown and rarely used in developing countries.

Lack of coordination between sector stakeholders

The large number of actors involved in stormwater management (ministries of urban planning, the environment, municipalities, operators in charge of sanitation, etc.) renders management and coordination of the sector difficult. There is currently no specific stormwater management sector within the public authorities: stormwater management is rarely dealt with by a dedicated department, but responsibility for its design, planning and financing is instead usually dispersed among the different development, road or sanitation departments. As there is no clear legal and institutional segmentation, stormwater management does not strictly constitute a sector.

Stormwater management decentralisation policies still in their infancy

As part of a decentralisation process, the management responsibility for different services is progressively transferred to local authorities. However, responsibilities for stormwater management lack clarity and the allocation of financial responsibilities between the state and local authorities is not properly defined.

The myth of the master plan or poor alignment of planning to local capacities
Stormwater management master plans have been developed for a number of cities. However, the majority of these have been poorly (or never) implemented. The main reason for this being that the investment capacities of local and national governments rendered the cost of technical recommendations prohibitive.

Failure to take the populations' expectations into account
Although stormwater management is considered a priority by the populations of the majority of African towns and cities, this issue is not always prioritised by the public authorities.

Limited local capacities for financing investment
Most technical solutions developed to address stormwater management issues require costly civil engineering infrastructure. The investment costs involved commonly exceed local authorities' investment capacities.

Limited capacities for financing operation and maintenance
Operating even the simplest form of stormwater drainage system (cleaning out the drainage channels before the rainy season) is extremely labour-intensive. As such, it is also a costly activity and one that local authorities struggle to finance.

Failure to comply with best construction practice
Failure to comply with equipment design and construction standards increases both the risk of flooding downstream (poor evacuation) and flood damage.

INNOVATIVE ACTIVITIES IMPLEMENTED IN DEVELOPING COUNTRIES

The most common response for dealing with the problems caused by stormwater in developing countries is to construct drainage channels; however, this does not enable the full extent of stormwater management needs to be addressed. Nevertheless, some activities have been identified that are having an influence on a number of factors, although these remain highly disparate and localised.

Activities influencing the natural factors

Controlling runoff upstream from the city
Controlling runoff upstream of cities can not only considerably reduce the volumes of water to be evacuated, but also invigorate the local economy by encouraging agriculture, aquaculture and reforestation.

Reducing erosion
Certain techniques, such as introducing shallower gradients (e.g. Bogota, Colombia) can help reduce erosion.

Stormwater management by controlling runoff, *Dogondoutchi in Niger (RAIL-Niger 2009)*
In the city of Dogondoutchi, problems of stagnant water have been considerably alleviated by the retention and infiltration systems that have been installed upstream from the city, namely filter dykes and half-moon terraces. In addition to the significant reduction in runoff within the city, these techniques have enabled land to be reclaimed for farming and the reforestation of desert areas and have also led to a reduction in silt build-up in a pond used for aquaculture and irrigation.

Activities for improving the management of urban space

Promoting collaboration between different local authority departments
Some African local authorities have a 'Runoff Control' unit (e.g. Dogondoutchi in Niger), mainly composed of staff from the environmental and the land use and rural engineering departments. This type of collaboration helps develop the required linkages between these different specialists to harmonise stormwater management related activities.

Developing multi-service approaches
Certain stormwater management initiatives are not restricted solely to the development and maintenance of drainage systems. Such initiatives combine stormwater activities with activities linked to other basic services, notably household waste and water supply.

Integrated management of urban water
One commonly recommended approach is that of Integrated Urban Water Resources Management. This essentially involves applying Integrated Water Resources Management (IWRM) principles to the urban context**:** sustainable development, economic efficiency and social equity. This method enables all urban water related issues to be addressed, in all their forms, in an integrated manner at catchment level. Although recognized as an effective way of managing urban water without harming either the environment or human health, this approach involves a long and complex methodology. It is a general recommendation framework and thus is often difficult to implement in developing countries.

Activities for improving stormwater management

Improving operation and maintenance services
Drainage service improvement programs tend to focus on design and construction yet afford little importance to improving operation and maintenance.

Using alternative techniques
There are a number of advantages to using alternative techniques for stormwater management. Depending on the technique used, it is notably possible to utilise the water as a resource or to retain then infiltrate stormwater to compensate for the inefficiencies of the evacuation system. Ultimately, these techniques help to reduce not only flood events and the creation of stagnant ponds but also the volume of contaminated water discharged into the environment. Although there is a relatively wide choice of techniques available, very few of these solutions are actually used in developing countries.
e.g.: porous pavement, streets and roads used as a drainage system, retention ponds, reforestation and hillside retention

Computer modelling
Commonly used in developed countries, computer modelling is an effective tool for designing, sizing and improving stormwater drainage systems.

Involving different stakeholders
A stormwater management strategy that involved the different stakeholder groups and ensured their expectations and needs were taken into account has been piloted in Nepal.

Table 1. Stakeholder groups and their interests and priorities in urban drainage planning

Stakeholder group	**Interests and priorities**
Public and community leaders	Largest community of residents and service users/beneficiaries
Slum dwellers	Low-income communities who often inhabit areas which are at risk from flood
Land developers	Construction of new developments for new housing or industry
Farmers	Peri-urban community with agricultural interests
Environmentalists	Protection of quality of water resources and conservation of natural habitat
Local politicians	Priority issues responding to local constituents' demands
Councillors and civil servants	Trade-off between cost-benefits in relation to municipal expenditure
Architects and land planners	Planning and design of urban space
Private sector, business community	Protection of industrial and commercial interests

Adapetd by Parkinson (2005) from Bhattarai and Neupane (2001).

User-targeted activities

Flood risk prevention and reduction strategies

As an urban drainage system often reaches the limit of its hydraulic capacities during a particularly heavy rain event, in addition to improving the drainage system's hydraulic capacities, some cities also adopt non-structural measures, requiring no physical intervention:

- Activities aimed at preventing flooding;
- Risk reduction measures aimed at reducing the extent and duration of floods;
- Flood damage reduction measures: in the event of flooding, this involves helping those affected recover from and repair the damage caused by the flood.

Risk prevention plans

Dynamic flood warning system: an integrated approach to disaster mitigation in Bangladesh(Aziz, 2002)

An integrated flood management plan has been adopted in the district of Sundarganj (Thana) in the north-east of Bangladesh that includes the following elements:

- Identification of flood risk areas;

- A real-time flood warning system (using a hydrodynamic model and GIS);

- Identification of accessible routes to evacuate people during a flood emergency.

Re-housing families living in high risk zones: In particularly high risk areas some municipalities decide to re-house the most vulnerable families.

*In **Bogota, Colombia**, the municipality undertook an initiative to protect 6,000 highly vulnerable families living in high risk zones. The initial stage consisted of identifying and mapping these zones to develop a risk reduction strategy that focused on redeveloping the land. Where structural work was not viable (reducing slopes, reinforcing houses), families were re-housed. In order to ensure the sustainability of this relocation and prevent new families from moving into these high risk zones, the legal land development market needed to be more competitive than the illegal market. To this end, the housing system was restructured to provide access to housing for the most socially vulnerable families earning below the minimum wage. Key to the success of this operation was the role played by the municipality in developing a suitable policy, an official plan and procedures.*

Source: The Together Foundation and UNCHS 2004

Setting up warning systems: Due to the recurrent nature of floods, the populations of some flood risk areas have developed response strategies, creating a warning system to alert residents to evacuate their homes and thus avoid danger.

Voluntary individual protection: Users act on their own initiative to develop their own means of protecting themselves from heavy rainfall and thus dealing with the deficiencies of the stormwater evacuation services. These initiatives can include:

- Improving the land or house:
  - Constructing houses on stilts, raising the building's foundations;
  - Sealing doors, raising electrical equipment;
  - Using more resistant materials;
- Neighbourhood protection:
  - Constructing protective walls (around the house or the neighbourhood);
  - Deliberately blocking the drainage channels to protect against flooding.

These initiatives, when not coordinated between the different neighbourhoods, considerably increase the flood risk further downstream.

Involving the most vulnerable users in the management and development of the service

Dialogue between users and the local public authorities is an essential part of the service improvement process. It is particularly important to include the poorest communities in such discussions, as these are the people most affected by poor stormwater management and who are too

often insufficiently consulted or completely ignored.

Involving residents in infrastructure construction and management
It is vital that residents and all those with a vested interest in improved stormwater drainage are involved in stormwater management decision-making and planning.

CONCLUSION

Substantial work is still required in developing countries to develop knowledge and practices and to test different approaches to stormwater management. Although complete answers remain to be found, we have identified a number of potential options for addressing this issue . The majority of solutions presented seek to expand on the practices seen in the field. In order to deal with stormwater management issues, it is appropriate to use complementary types of approaches: clearly distinguishing between the geographic scale of the stormwater management issue and the scale of intervention, and taking into account interactions with other urban services, and organising the sector using an upgradeable and complementary approach utilising both traditional solutions and those that draw on alternative or compensatory techniques.

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