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Technical Report 3.1 | Green and Blue Infrastructure

Green and Blue Infrastructure in Addis Ababa

A review of challenges and response strategies

A Technical Report commissioned by the Addis Ababa Urban Age Task Force

URBAN AGE

Addis Ababa Urban Age Task Force

The purpose of the Addis Ababa Urban Age Task Force (AAUATF) is to support the City of Addis Ababa in advancing its strategic development agenda. The Task Force's work builds upon the Addis Ababa City Structure Plan (2017–2027), exploring opportunities for compact and well-connected urban growth that can be delivered through integrated city governance.

In addition to advisory activities and capacity building, it identifies strategic pilot projects to address complex urban challenges around housing, urban accessibility, green and blue infrastructure, and urban governance.

The AAUATF is a partnership between the Addis Ababa City Plan and Development Commission (AACPDC), LSE Cities at the London School of Economics and Political Science, the Alfred Herrhausen Gesellschaft, and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

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1. Brief profile of Addis Ababa

1.1 Location

Addis Ababa is located at the geographical centre and in the central highlands of Ethiopia between 8,048’ and 906’ North latitudes and 38,038’ and 38,054’ East longitudes. The current land area is 540 square kilometers (km^2). The city is surrounded by Oromia Special Zone Surrounding Finfine (OSZSF) and bordered by five intermediate urban centres within OSZSF: Sululta, Lega Tafo-Lega Dadi, Gelan, Sebeta, and Burayu (Figure 1). Administratively, the city is divided into 10 sub-cities.

1.2 Topography and drainage

The altitude of the city ranges from the highest peak at Mount Entoto, which is 3,100 metres above sea level (m.a.s.l) to 2,200 m.a.s.l at the lower part of Akaki plain (Figure 2). Elevation and slope generally decrease from north to south (Figure 3). Addis Ababa lies along the upper part of Awash Basin, and its northern boundary lies along the water divide between Awash and Abay rivers.

Addis Ababa is endowed with three major rivers, Kebena, Little Akaki and Big Akaki, rivers as well as numerous streams, which originate in the north, northwest and northeastern parts of Addis Ababa, flow towards the south, and drain to the Awash River (Figure 4).

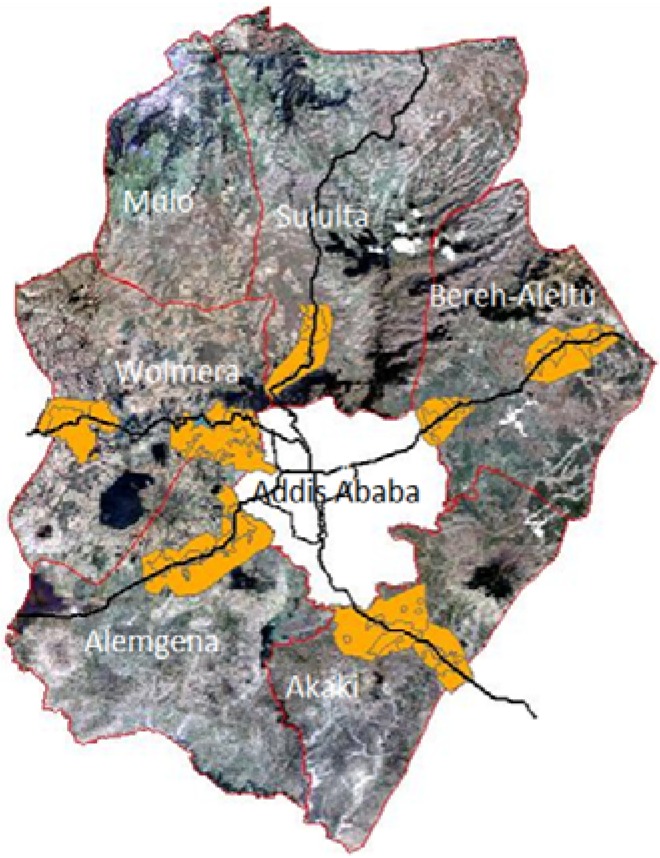


Figure 1: Location map of Addis Ababa within OSZSF

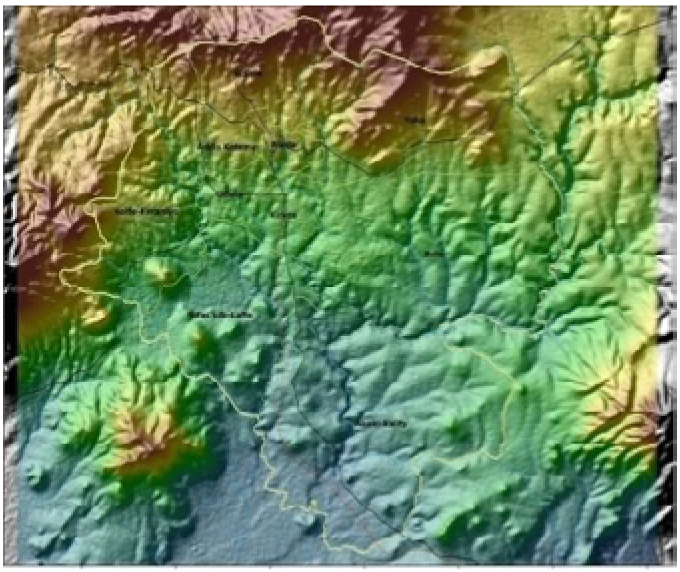


Figure 2: Digital elevation model

Topographic features of Addis Ababa city area

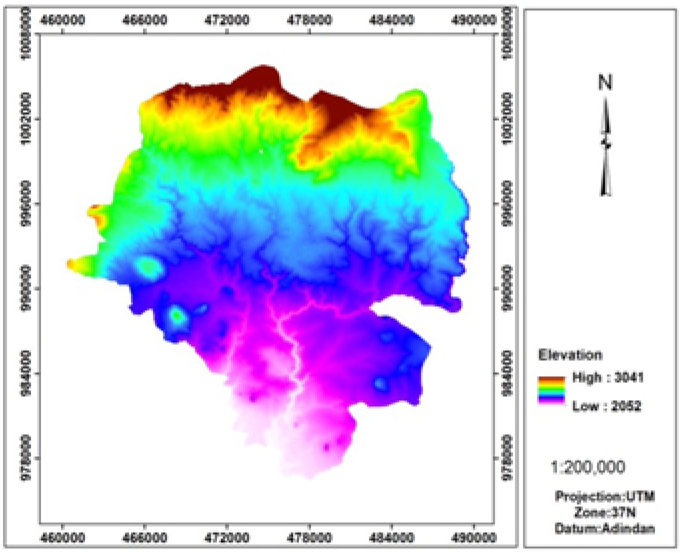


Figure 3: Elevation map of Addis Ababa

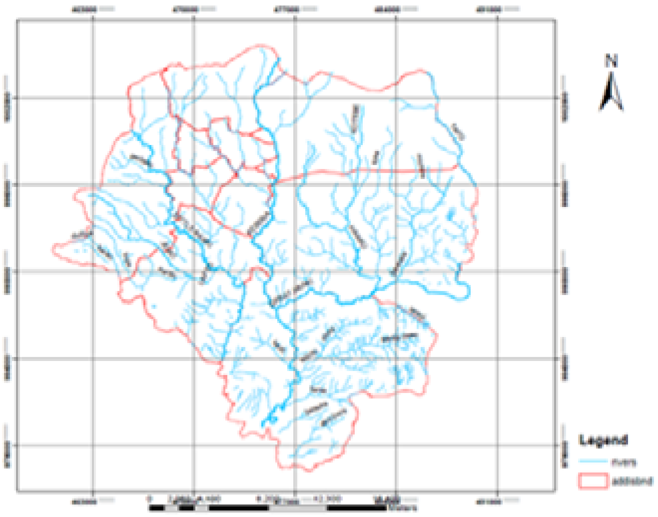


Figure 4: Drainage map of Addis Ababa

Map showing the three major rivers and their tributaries.

1.3 Population

The 2007 Census shows that the population of Addis Ababa was 2,739,551, which was approximately 3.7% of the total Ethiopian population of about 73.8 million and 22.77% of the 11.86 million people who live in urban areas (Central Statistical Authority [CSA], 2012). In 2019 the population was approximately 4.1 million, and it is expected to reach about 6 million in 2030 (Figure 5).

Between the 1994 and 2007 Census years, the average annual growth rate for Addis Ababa was 3.4% (Central Statistical Authority [CSA], 2008). Because of the fast population growth, the demand on natural resources has increased significantly, leading to natural resource degradation, including green and blue infrastructure (GBI).

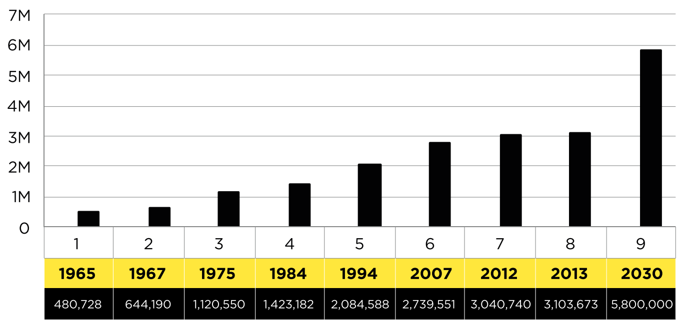


Figure 5: Addis Ababa Population

Population of Addis Ababa from 1965 to 2014 and projection to 2030

(Central Statistical Authority [CSA], 2012)

1.4 Economy

Recently, the city has been characterised by fast economic growth, particularly in regard to growth in the industrial sector (about 20% per annum on average, Addis Ababa City Administration 2017). This is a sector that requires a huge amount of natural resources including water and is prone to climate change impacts.

1.5 Urban green

Urban green spaces in Addis Ababa include public and private green areas or belts which include urban forest, urban agriculture, gardens, squares, roadside and road median tree plantation, trees and gardens within individual households, shade trees, windbreaks and shelterbelts, churchyards and buffer zones (to provide separation between conflicting land uses or to protect vulnerable areas), natural reserves (protected areas), etc.

Addis Ababa gets most of its water supply from reservoirs that are located some 20 km northwest and 10 km northeast of the city and from groundwater around the southern part of the city boundary. Addis Ababa needs to manage the problems of green area and water resource depletion, water pollution, and flooding associated with increased population growth and increased urbanisation, industrialisation, and development.

1.6 Objective of the study

The objective of this work is to review the status of GBI in Addis Ababa in relation to urbanisation and climate change impacts.

Addis Ababa has a number of documents in place that support or affect the delivery of GBI in some way. These include:

- Structural Plan of Addis Ababa 2003-2013
- Structural Plan of Addis Ababa 2017-2027
- CRGE strategy of Addis Ababa
- Clean and Green Addis Ababa society documents
- City strength, Addis Ababa, Ethiopia
- City strength, Resilient Cities Programme
- Evaluation of support to C-40 Cities leadership group
- Addis Ababa Rivers and Riversides Development Plan Project documents, including:
  - Catchments and Vegetation Management Study for Addis Ababa Rivers and Riversides Development Plan Project
  - Pollution and Sanitation Study for Addis Ababa Rivers and Riversides Development Plan Project
  - Socio-economic Baseline Assessment Study for Addis Ababa Rivers
  - Urban Landscape Designing and Planning Study for Addis Ababa Rivers and Riversides Development Plan Project
- Research Outputs and Technical Reports on AA GBI (see Reference List)

2. GBI: Definition, components and importance

2.1 Defining GBI

Green and blue infrastructure (GBI) is strategically planned, well designed and maintained, interconnected networks of natural, semi-natural and artificial green space and water environment, and sustainable drainage systems (SuDS) which support a wide range of ecosystem services and quality of life benefits that maintain natural ecological processes, sustain air and water resources, and contribute to the health and quality of life for communities and people. It is referred to as "infrastructure" because it is as important as other types of infrastructure such as roads, schools and hospitals.

Green Infrastructure (GI) refers to projects that include vegetated design elements such as natural, semi-natural and artificial spaces, urban forests, parks, greenbelts, alleys, woodlands, private gardens, street trees, allotments, playing fields, cemeteries and newer innovations such as vertical and horizontal gardens and planters, green roofs, etc.

Blue Infrastructure (BI) refers to infrastructure related to the hydrological functions or urban water cycle, including rainwater and urban storm water systems as well as surface water and groundwater aquifers, wetlands, rivers, etc.

GBI is an important means of dealing with flooding and extreme weather events because it can consist of a network of interconnected water reservoirs, wetlands and their associated (natural) open spaces developed along rivers, which serve several interrelated purposes including: (i) water storage, especially for agriculture's irrigation and industry use; (ii) regulators of the river system, particularly the prevention of floods during extreme rainfall events; (iii) habitat for plants and animal wildlife (nature conservation); (iv) a cleaning system of polluted water, particularly absorbing fertilisers that are often washed away from farmland and which tend to cause algae blooms in rivers and lakes; (v) areas for the growth of wetland crops, such as reed, for second generation biofuel production; and (vi) zones for the pursuit of suitable recreational activities.

2.2 GBI components

A wide variety of GBI components have been classified for designing resilient areas in the past several years. GBI components can be broadly categorised according to function, position, and scale.

Table 1 shows the classification used for green and blue infrastructure in Addis Ababa in this document.

GBI can be delivered at a range of scales, from building scale initiatives to precinct scale or regional features. Regardless of scale, these systems all typically will have the following characteristics in common.

- Vegetation, providing amenity and habitat;
- Soil, of adequate volume, nutrient content, and drainage characteristics;
- A link to rainwater, storm water or recycled water supply, with a frequency and quantity sufficient to support vegetation and soil health.

In addition, some systems may provide additional water management functions:

- Water treatment capacity, utilising natural process to filter local water supplies and reduce pollutants entering local waterways;
- Water storage capacity, using volumes within soils or above ground space to provide detention of storm water.

Table 1: GBI elements and descriptions

GBI element	Description
Urban forests	Urban forests are large areas of dense plantings of trees, shrubs, and ground covers found primarily in the northern part of Addis Ababa. They include remnants of indigenous forests, regrowth, and newly created urban forests. They play an important part in the water cycle, creating pervious area to absorb storm water.
Urban agriculture	Urban agriculture can be defined as (i) the growing of plants and the raising of animals within and around cities for sale and personal consumption, (ii) related activities such as the production and delivery of inputs, and the processing, distribution and marketing of food and other products within urban and suburban areas, (iii) its related physical and organisational infrastructure and associated policies and programs. Urban agriculture is the local production of food products. This includes community-held, small-scale urban farms located along riverbanks. Suitable alternative water sources can be harnessed for irrigation.
Green corridors	Green corridors are linear green spaces that can provide a range of connectivity services including natural habitat river corridors, river and canal banks, cycle ways/ bridleways, rights of way and recreational pathways.
Parks and gardens (including urban parks, country parks and formal gardens)	Parks and gardens are public open space areas which provide the local community with a range of recreational activities such as football. These could be irrigated using an alternative water supply or designed to provide storm water detention and infiltration. Storm water can be directed into parks and gardens to provide passive irrigation, or an active irrigation system can be provided, fed by alternative water sources.
Sports grounds (outdoor sport spaces)	Sports grounds are large open space areas with natural or artificial surfaces which support active recreational activities including pitches for football, tennis courts, bowling greens, golf courses, school and other institutional playing fields. These could be irrigated using an alternative water supply or designed to provide storm water detention and infiltration.
Amenity green space (most commonly but not exclusively in housing areas)	These include informal recreation spaces, green spaces in and around housing, domestic gardens and village greens.
Street trees	Street trees are planted in growing medium underneath sidewalks which can be designed to be passively irrigated from storm water runoff from pavements and roads. These can also be designed to enhance storm water pollutant removal with the inclusion of special filter media. Permeable paving also can be used to channel storm water into underground soil areas to support trees.
Cemeteries and churchyards	These often contain noticeably rich biodiversity which are the main habitats of urban plants and animals.
Green walls	Green walls are a vertical garden on the side of a building which comprises vegetation planted within a growing medium which is attached to the wall. Rainwater or grey water from the building can be used to support plant health.
Green roofs	Green roofs are building roofs which have been partially or completely covered in vegetation which is planted into a growing medium sitting above a waterproof membrane. Harvested rainwater can be used for irrigation.
Water ways	Water ways are channels that capture and convey flows from catchments. They include streams, creeks, and rivers and can be natural or modified systems (eg, rock-edged or even concrete-lined).
Wetlands	Most of the wetlands in Addis Ababa are found in Akaki-Kality and Nifas Silk-Lafto sub-cities in the southern part of Addis Ababa.
Ponds and lakes	There are no significant ponds and lakes within the city boundary but they are found at a short distance around the city.
Swales	Swales are shallow, vegetated open channels that convey and treat storm water. The vegetation can vary from mown turf to sedges.
Rain gardens	Rain gardens are garden beds which are designed to capture, detain and treat storm water runoff as it filters through the underlying filter media before it is discharged at the base of the system, either into the surrounding soils or into the local storm water network.

2.3 Importance of GBI

Addis Ababa's GBI is supposed to provide a number of services and goods for the local population and the economies of Addis Ababa and to perform a range of socio-economic and environmental and climatic functions that improve the quality of life and can help to alleviate the consequences of climate change in Addis Ababa.

Benefits of GBI include decreased water demand through using rainwater harvesting, enhanced water quality, removal of air pollution, removal of odour and noise, provision of habitat for species, improved aesthetics and perception of neighbourhood quality, potential food production, reduced temperatures, climate change mitigation (carbon sequestration), traffic calming, energy savings in buildings, recreational opportunities and associated public health benefits, increased social cohesion, reduced traffic, reduced storm water management costs, provision of educational opportunities, reduced stress and increased resilience.

2.3.1 Socio-economic benefits of GBI

- GBI creates upgraded space for recreation, exercise and social activities and therefore helps to improve human physical and mental health improving wellbeing while also attracting residents, businesses and tourism. These amenities reduce individual and public health costs;
- GBI creates attractive workplaces and desirable tourist destinations;
- GBI supports social interaction and social integration as it increases the tendency to use open spaces for activities in groups and the commitment to spend time with families, neighbours and communities;
- GBI improves the aesthetic and social attractiveness of the environment. It will increase property (land and building) values;
- By improving social and aesthetic attractiveness of surrounding land and buildings, GBI increases tourism, property values and real estate values;
- The creation of GBI signals a city's overall attractiveness and livability and increases the reputation of a city's governmental institutions to take care of their residents' living conditions;
- GBI protects natural and semi-natural sites of national/international importance and hence supports biophilia – people's affinity with nature – as it reconnects people with natural forms, elements and processes that have major benefits for human happiness and willingness to protect nature;
- Food, fibre and fuel production: GI such as urban agriculture in home gardens and green spaces can play a role in food and fuel production. In some cities of the world, up to 30% of food consumption is estimated to be locally produced. Enhancing urban agriculture can contribute to providing various functions of the urban GI and food for its residents. Hence, commercial land uses, such as forestry and agriculture, provide multifunctional and cost-effective delivery of GI goals and objectives should be considered a priority in strategy development;
- Creating jobs for urban/regional areas in the production of goods (farm produce);
- GBI decreases storm-water financial costs in a holistic and long-term way.

2.3.2 Environmental and climatic benefits of GBI

- Water-related benefits (quality and quantity control);
- Water regulation;
- Green sustainable urban drainage solutions (SuDS); such as swales, water gardens and green roofs increase the infiltration and slow the removal of rainfall into the drainage system, reducing the risk of surface water flooding;
- SuDS contribute to reducing storm water runoff: that is, detention and retention components. Detention components can store water during and after extreme precipitation and gradually discharge it to the sewer system. On the other hand, retention components can store water and gradually infiltrate it to the ground without any connection to the sewer system. Storage retention components are natural storage basins with low infiltration capacity that are always filled with water. Infiltration retention components infiltrate water directly without containing it;
- GBI provides high-quality water resources, managing flood risk and increasing water retention: Well-maintained greenspaces can help to increase natural storage capacity, reduce the run-off rate of storm water, and increase onsite water purification and infiltration. They also can promote river corridor management to provide multifunctional benefits for flood defence, recreation, landscape, and biodiversity. GBI provides groundwater storage, stability for water systems, improvement in water quality, and water purification. It is a very vital water-related network service;
- Improves water quality by absorbing nutrients through plant roots and soil;
- Instils effective storm water controls through onsite flood storage, retention, and infiltration reducing peak discharge of storm water and balancing stream base flow rates;
- Secures water for regional and agricultural development;
- Drought amelioration;
- GBI decreases the global warming effects, moderates the temperature, and supplies air ventilation. It plays an important role as a moderator for climate;
- Modulates the urban climate by reducing urban heat island effects, balancing diurnal temperature fluctuations and supporting natural air ventilation;
- Carbon storage;

- Improves air quality: absorbing pollutants to clean the air;
- Provides wind-breaks to protect buildings from damage;
- Supports soil formation, nutrient recycling, etc;
- Controls soil erosion and associated windborne air pollution and dust hazards;
- Noise reduction;
- Increases urban biodiversity rich zone.

Evaluating the costs and benefits of GI is complicated by its multi-functional nature. The costs of green infrastructure need to be considered on a project-by-project basis. It is difficult to assign costs to specific services or benefits provided by a GI component. In addition to economic costs for installation and maintenance, there may be other disadvantages that need to be accounted for and managed. Trees and plants may have negative impacts due to pollen dispersal and emission of volatile organic compounds and ozone which can contribute to air pollution. Tree roots and branches may also damage roads and pavements, and leaves require sweeping. Insects, birds and other species can contribute to increasing the cost of pest control and cleaning. Not all GI components are suitable in all conditions. More detailed monitoring of air pollution, biodiversity and surface water is needed to support better prediction of environmental quality and the impact of GI. There is a risk that GI components may be implemented inappropriately, undermining benefits and increasing costs and likelihood of failure. There is also the risk that, unless GI is well-integrated into the urban environment, it can become a space that is visited for a specific activity, rather than being used and experienced on a daily basis. There are concerns that infrequent use of green space may reduce its capacity to provide health and well-being benefits and limit social cohesion.

GI provides considerable benefits to cities, and better integration and connection within the city could further enhance a city's ability to respond to these problems. Accounting for the costs and risks associated with green infrastructure, and addressing the need to strengthen the evidence base about its function and impacts alongside its benefits, will allow for more robust decision-making and adaptive approaches to planning and management.

2.4 GI-related problems in Addis Ababa

The major problems of Addis Ababa that can at least partially be solved by proper planning and implementation of GBI are:

- Air quality degradation;
- Water management problems;
- Biodiversity loss;
- Health and well-being.

2.4.1 Air quality issues

The problem

Burning fuels, disturbing dust from construction sites and some biological processes such as pollen shedding release fine particles (particulate matter) into the air. Fine particles can be breathed in by people and are related to various respiratory illnesses. Combustion, including in car engines, and industrial processes also release gaseous pollutants. These include sulphur dioxide (SO_2), ozone (O^3), carbon monoxide (CO), nitrogen dioxide (NO_2) and nitric oxide (NO). (NO and NO_2 together are referred to as NOx). Ozone release also has been associated with some tree species.

How can GI help?

GI can improve air quality by providing barriers to sources of pollution such as busy roads and by increasing dilution and dispersion of pollution, directly removing pollutants from the air by deposition and absorption on plant surfaces and counteracting the urban heat island effect.

Trees and shrubs can act as pollution sinks to reduce the concentration of particles in the atmosphere. The vegetation filters out the particles which are deposited on leaves and branches. Trees also remove gaseous air pollution primarily via leaf-stomata uptake, so these pollutants are absorbed into the tree. Vegetation and water bodies can reduce air temperatures through shading, evaporative cooling and evapotranspiration.

2.4.2 Water management

The problem

Unlike the ground surfaces in natural environments, urban surfaces tend to be impervious and have less vegetation cover. In conventional urban surface water management, the runoff is drained away from urban surfaces as quickly as possible using engineered drains, sewers and channels. This infrastructure is typically buried below ground, so that maintenance is difficult, problems can go unseen and people have limited knowledge of where water flows in the city. These drainage networks result in high volumes of polluted runoff that is discharged to water bodies or transferred to sewage treatment works. Urban runoff may carry high phosphorus and nitrogen loads that can contribute to pollution of water bodies and lead to algal blooms and ecological imbalances. Toxic metals as well as bacteria and pathogens also may be present in high concentration in urban runoff, which can impair the aquatic habitat as well as impact human health. Population growth will increase stress on local water resources and the volume of wastewater flowing through the sewers.

The sewerage network in Addis Ababa is mostly a combined sewer system, where household and industrial wastewater is combined together with surface water runoff in a single pipe system to be conveyed to sewage treatment plants. While a separate piped system for each type of flow has become the norm for newer development in outer Addis Ababa, the combined system dominates the network in central areas. While the combined sewage system functions well under normal conditions, problems arise when the volume of water in the sewers exceeds their capacity. This usually occurs during a heavy storm event, when surface water runoff fills the sewers. The result is that the sewers overflow into local rivers, discharging untreated storm water and wastewater into the environment.

This "grey infrastructure" solution will improve the safety, ecology and aesthetics of the receiving rivers, but it needs to be complemented by green infrastructure to achieve multiple benefits for surface water management and to improve sewer capacity across Addis Ababa. Parts of Addis Ababa are at high risk of surface water flooding, which occurs when rain falls faster than it can drain away or soak into the ground. Surface water flooding can occur very quickly in heavy storm events without adequate drainage or space for water to flow into, leading to flash flooding. In combined sewer areas, surface water flooding is more likely where sewers are operating close to capacity, with little room to convey additional water from runoff. Climate change is predicted to increase the intensity of rain events in Addis Ababa, leading to increased surface water runoff. Furthermore, flooding can cause health and safety hazards, economic losses and inconvenience to local residents and businesses.

How can GI help?

Surface water management that aims to reduce local flood risk and water pollution can benefit from GI, which slows down runoff, captures pollutants and increases the amount of water soaking into the ground instead of running into drains.

Properly functioning SuDS will have the ability to:

– Mimic natural infiltration to delay and reduce discharges and reduce concentration/volume of pollutants;
– Attenuate peak surface water flows to reduce flood risks;
– Capture and store storm water for future uses.

By incorporating GI in the drainage system, rainwater can be retained and re-harvested while surface water runoff can be reduced. This alleviates the stress on the piped sewage system and reduces the frequency and volume of sewer flooding and Combined Sewer Overflows (CSOs). At the catchment scale the health and function of rivers and streams can be restored and maintained. SuDS may include natural greenspaces, as well as semi-natural spaces such as rain gardens, bioswales, planter boxes and bioretention ponds. In addition, "grey" measures such as permeable pavements and downspout disconnection also are used in sustainable drainage systems. GI installed as part of sustainable drainage systems and natural flood risk management approaches can control the quantity and speed of storm water runoff and thereby manage the impact of flooding on people and the environment. Contrary to conventional drainage systems that are designed exclusively for conveyance of storm water runoff to the downstream, GI techniques can be used to help capture, use, retain and delay discharge of rainwater. Retaining rainwater may be used in sustainable drainage systems to slow down surface water runoff and can have additional benefits to water supply. Rainwater harvesting provides temporary, local storage of water that can be reused instead of running off into the sewer. Infiltration of rainwater into the ground, instead of running off, can replenish groundwater supplies and soil moisture. GI has the ability to physically remove and chemically or biologically treat pollutants from storm water runoff using soils and vegetation. Vegetated surfaces not only can reduce runoff volume, they also can provide some treatment to the storm water by removing sediments and pollutants from the still or slow-moving water. While certain measures, such as green roofs and urban canopies, can perform sediment trapping alone or in combination with other techniques, bio-retention systems (such as bio-swale, rain garden, planter box, anaerobic bio-retention), ponds and wetlands are generally implemented when a reduction in pollutant load is needed in storm water management.

2.4.3 Biodiversity Conservation

GI creates opportunities to preserve biodiversity in urban environments, and counteracts some of the negative ecological impacts of urbanisation. Effective planning for biodiversity in cities relies on protective planning policies and the development of GI initiatives to maintain existing habitat and create new opportunities for biodiversity in urban areas.

The problem

Shifts towards urbanisation in Ethiopia will see at least 30% of the country's human population living in urban areas by 2030. In general, the development of urban environments is characterised by the transformation of natural green spaces into grey infrastructure comprised of substantial expanses of impervious surfaces. As a result, urban biodiversity typically is restricted to highly fragmented, disturbed and degraded habitat patches. This leads to an overall reduction in native biodiversity (species richness and evenness), as the remaining habitat is unable to support complex ecological communities, due to disruption of ecological processes from lack of resources and barrier effects of grey infrastructure. The ecological footprint of urbanisation often extends beyond municipal boundaries and impacts can be felt at regional and global scales. Species may be impacted differentially by urbanisation, where species that are more sensitive to habitat loss and fragmentation will be most affected. In contrast, more urban-tolerant species often increase in richness and abundance. This means that ecological communities within urban areas often show overall patterns of low species richness but high abundance, reflecting increases in populations of urban-tolerant species and a loss of sensitive species. Conserving urban biodiversity and maintaining the ecological integrity of urban ecosystems is important to the provision of many vital ecosystem services. Loss of urban biodiversity also is leading to the "extinction of experience" for people living in urban areas due to a lack of interaction with the natural world. Disconnection from nature can result in apathy towards wider environmental issues. As human populations become more urbanised, it will be increasingly difficult for people to interact with nearby nature, and there will be considerable conflict between developers and conservationists over use of increasingly valuable land in cities.

How can GI help?

Increasing habitat and connectivity of green spaces in cities can encourage greater abundance and diversity of species. A diversity of planting encourages invertebrate diversity.

2.4.4 Health and well-being improvement

The World Health Organisation defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 2017). Accordingly, health can be divided into three concepts: physical, mental and social. The natural environment is considered to be beneficial for all aspects of human health and often is used as a quality of life indicator.

The problem

Physical health: Urban residents face several unique health challenges, including high levels of air pollution. Urban residents face additional threats due to the urban heat island effect, as prolonged periods of high temperature can result in excess deaths, particularly in the elderly and infirm. Physical inactivity is a major contributor to many health conditions, including coronary heart disease (CHD), obesity, type-2 diabetes and mental health disorders.

Mental health: Urban environments are associated with higher incidences of anxiety and depression; however, mental ill-health is complex and poorly understood, and stigmatisation has often led to poor reporting rates.

The inherent variability of mental health therefore makes quantifying its effects difficult.

Social well-being: Urban areas are associated with less opportunity for social interaction and are characterised by high risk of crime.

How can GI help?

Access to green spaces has been demonstrated to improve human physical and mental health. Physical activity may be higher in areas with access to good quality green space. Exposure to nature and a green environment reduces anxiety and improves mental ill-health.

Green spaces and infrastructure also may be associated with improved well-being, lower crime rates and a stronger sense of place.

Urban GI provides space for city dwellers to spend time outdoors in semi-natural environments. Access to GI has a number of human health and well-being benefits, such as increased levels of physical activity, reduced symptoms of poor mental health and stress, increased levels of communal activity and greater opportunities for active transport.

Social cohesion: Social cohesion is important to the health and well-being of people in a community. Improved and increased interactions between residents can help reduce crime and create a sense of safety.

Built environment aesthetics: GI plays a role in shaping the aesthetics of the urban environment, and the presence of green infrastructure typically is viewed as having a positive effect on the character of urban spaces.

Local food production: Urban GI can support the local production of food, typically in allotments and domestic and community gardens. This reduces reliance on food production systems outside of the city, increases access to locally produced food and supports the creation of new businesses.

Skills and employment: Urban GI and the biodiversity it supports offer a wide range of opportunities to develop skills and employment opportunities. GI provides the spaces for people to interact with biodiversity and learn skills to utilise nature in the urban environment. Horticulture and beekeeping training courses which can be used to further careers in these areas can be offered. The forest provides space to learn about medicinal herbs, where local herbalists lead walking tours of the area, teaching about the medicinal properties of plants on the site.

Nature tourism and leisure activities: Offering space for biodiversity can also attract economic activity from a range of nature tourism and leisure activities. Botanic Garden in Addis Ababa could be a tourist attraction if properly developed.

3. GI and urbanisation in Addis Ababa

3.1 Addis Ababa GI

Spatially until 1975 Addis Ababa was limited to an area designated today as a Central Business District and to some patchy areas along the five main roads leading to different provinces. Leap-frog type of development was the main characteristic. The total land area of Addis Ababa has grown from about 6,000 hectares in 1975 to about 54,000 hectares in 2017.

The urban population has increased from 1.1 million in 1975 to about 4 million in 2017. The urban population density was about 183 persons per hectare in 1975. The density in 2017 was about 74 persons per hectare. This shows that since 1975, the urban population density of Addis Ababa has declined almost two and a half times, indicating that land conversion occurs at a higher rate than population growth. This observation also was substantiated by Zewdie et al. (2017) which reflects the population density of about 178 persons/hectare in 1984 and a density of 93 persons/hectare in 2014. This rapid land conversion has significantly expanded built-up areas at the expense of natural areas, particularly natural forests and agricultural areas (Table 2 and Figure 6).

3.1.1 Natural Vegetation of Addis Ababa

Addis Ababa was covered with natural indigenous vegetation in the past. Historically, the natural vegetation belongs to Afro-montane forest and woodland. The natural forest has been dominated by tid (juniperus procera), weira (Olea europaea subsp. cuspidata), kosso (Hygenia abyssinica), amija (Hypericum revolutum and H. quartinamum) and zigba (Podocarpus falcatus) and highland acacias or girar (Acacia abyssinica and A. negril) in some of the more disturbed valleys. Asta (Erica arborea) appears where the altitude goes over 3,000 m.a.s.l. Shrubs include species with fleshy fruits like qega (Rosa abyssinica) and agam (Carissa edulis), which attract fruit-eating birds. The number of herbs both in the undergrowth of the forest and in the meadows is very large and includes a number of endemics, particularly clover or maget.
In addition to the aforementioned species, Vernonia amygdalin, Croton macrostachyus, and Euphorbia abyssinica are common inside churches, palaces and old institutions.

At the turn of the last century, with the growth of the city, the population had removed nearly all trees in and around the city through urban and agricultural expansion to meet the fuel and construction wood consumption by the town dwellers and the surrounding farmers.

As the result of deforestation, the mountainous areas are heavily eroded and degraded. The deforestation of watersheds has resulted in loss of genetic resources, severe soil erosion, flooding of the city, damages to houses and infrastructures, wood scarcity and deterioration of living conditions.

Table 2: Summary of Landsat classification results in terms of area and percentage

Land cover class	1984		1995		2003		2014		Relative change
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	1984-2015 (%)
Forest	11,200	21.5	6,100	11.7	4,000	7.8	2,900	5.4	-74.6
Urban	8,000	15.4	13,800	26.6	19,200	36.9	34,100	65.4	324.9
Agriculture	32,900	63.1	32,200	61.7	28,900	55.3	15,200	29.2	-53.8

Source: Zewdie et al. (2017)

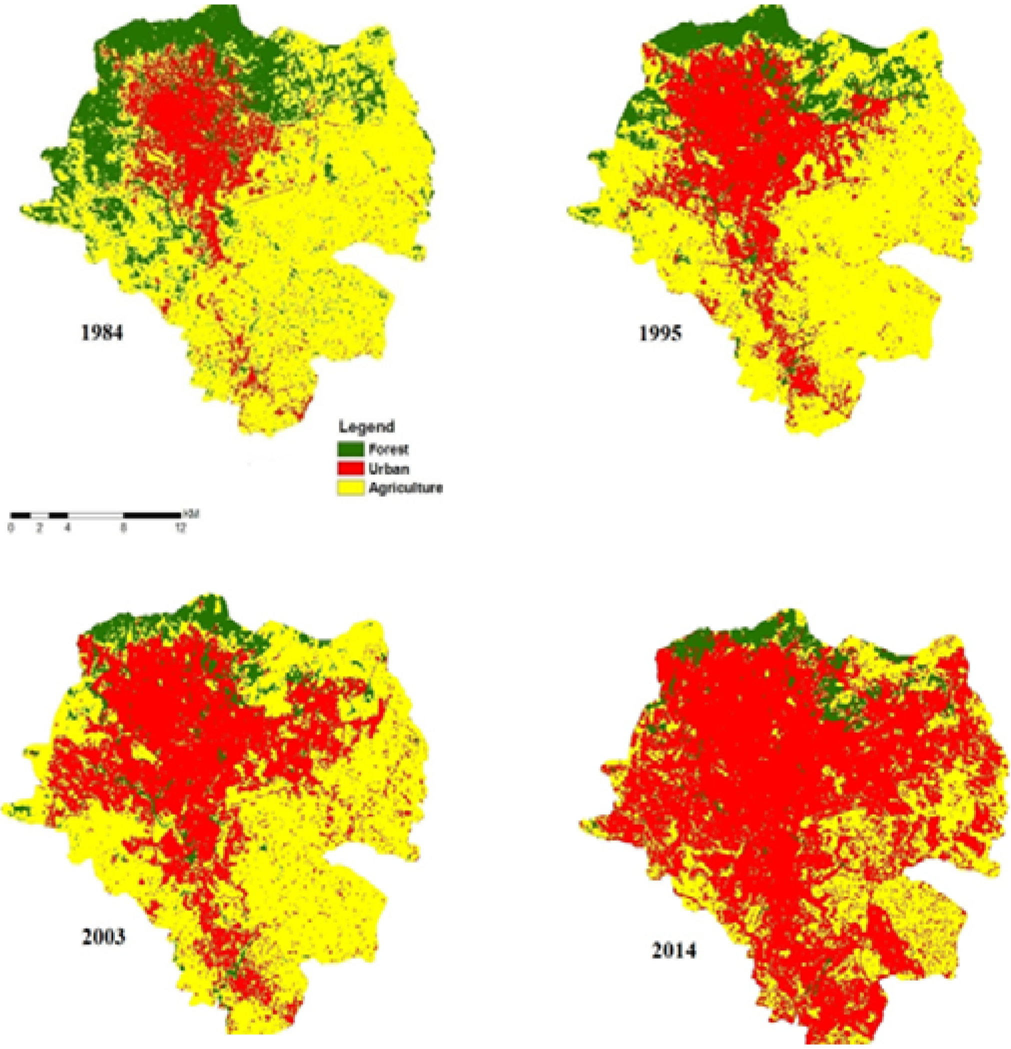


Figure 6: Landsat land use land cover classification showing urban growth pattern of Addis Ababa from 1984 to 2014 (Zewdie, et al., 2017)

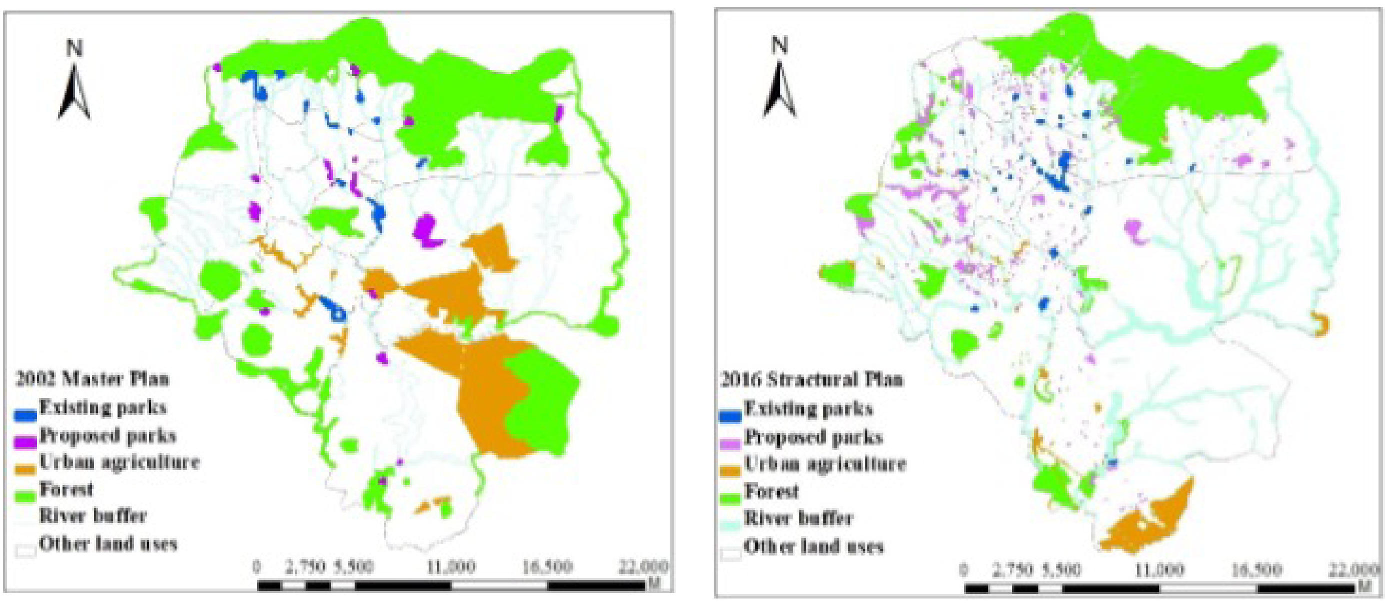


Figure 7: Environmental map of Addis Ababa showing the extent of green areas and other environment-related land uses in 2003 (left) and 2017 (right)

Loss of biodiversity ranks among the fundamental environmental problems facing our age. A plant or animal species that dies out today is lost forever, along with its ecological function and economic potential. Despite growing recognition of the utilisation potential and economic significance of genetic resources and biological raw materials, the earth's biodiversity is continuing to erode. Biodiversity conservation by government organisations has a shorter history in Ethiopia than in other countries. This resource provides tremendous services like crop pest control, soil formation and protection, pollination, clean water, pure air and the provision of foods. The loss of this resource reduces nature's basket of goods and services, from which we constantly draw. Ethiopia has some of the world's rarest animals and plants but these are now in danger of disappearing forever due to overuse and loss of natural habitat.

The 2003 Master Plan of Addis Ababa has given new stimulus for intensified and concerted efforts in protecting and developing Addis Ababa's natural assets and endowments for the benefit of present and future generations. The Master Plan sets ambitious policy goals for the green sector: about 22,000 ha or 41% of the total land area of Addis Ababa is reserved for the green frame (Table 3). However, the master plan suffered improper implementation. Of the 22,000 ha (41%) of the city's total area reserved for the green sector, 470 ha of land is for parks development, including 700 ha for Botanic Garden, 1,140 ha for river buffer, 7,170 ha for urban agriculture, 28 ha for roadside and median tree plantation, and the rest (12,160 ha) for urban forests (Table 3).

3.1.2 Forests

Although there is no inventory result over the precise figure of the forest cover in Addis Ababa, the coverage is estimated at nearly 12,160 ha, covering about 22.5% of the total area. About 99% of this are plantation forests. Natural forests remain only in small pockets, inaccessible hillsides, around churches, graveyards, and embassy compounds. Natural forest covers an estimated area of around 550 ha. There are various reasons for deforestation in Addis Ababa. Some of the main reasons of deforestation are clearing of forests for settlement and cutting of trees and shrubs for various purposes, particularly for fuel wood, charcoal, construction materials, etc. The underlying causes of deforestation in Addis Ababa are, however, related to a vicious circle of mutually reinforcing factors, i.e. poverty, population growth, and poor economic growth.

3.1.3 River and river banks

Three major rivers (Kebena, Little Akaki and Big Akaki) are fed by 75 tributaries. These rivers are mostly seasonal, run generally from north to south, and converge at Akaki Beseka to create Aba Samuel Lake. The total area designated for river buffer is only about 1,140 ha. This is because the wider flood plain areas are allocated for urban agriculture and some of the wider river buffers at the outskirt of Addis Ababa are sited for urban forests in the 2003 Master Plan. In the inner city, the minimum standard of a buffer zone along the riverbanks was set to 15 metres on each side of the river; in the peri-urban areas (expansion areas), buffers ranging from 50-100 m on each side of the river have been suggested. The buffer zones along rivers have a good potential for income generation. Riverbanks near settlement areas are frequently used as waste disposal sites and other informal activities. Many riverbanks are denuded since riverside vegetation was cleared by humans and/or browsed by animals. To make the situation worse, nowadays there is a tendency to give riversides for the development of micro and small enterprises. A multiple-use approach is suggested, as these sites can be used for urban forestry, fruit tree cultivation, crop production, horticulture, small dairy farming, beekeeping and recreation. From a conservation viewpoint, they can serve as a network of protected areas and wildlife corridors.

Urban GI and the built-up area during the two Master Plans	2003		2017	
	Area/hr.	%	Area/hr.	%
Urban forest	12,168	23.4	10,301.5	19.7
River and river buffer	1,144	2.2	4,026.5	7.7
Urban agricultural	7,176	13.8	996.1	1.9
Urban parks	468	0.9	938.7	1.8
Total GI	**20,956**	**40.3**	**16,262.8**	**31.1**
Built-up Area	31,044	59.7	36,029.2	68.9
Total Area	52,000	100	52,292	100

Table 3: Table showing the proportion of GI in the 2003 and 2017 Master Plans

3.1.4 Urban agriculture and food security

The area allocated for urban agriculture in the 2003 Master Plan of Addis Ababa is about 7,170 ha. Current activities in urban agricultural areas are mixed farming such as horticulture, cereal crops, beekeeping and animal husbandry. Urban agriculture plays an important role in Addis Ababa's daily economic activities. It generates employment for the urban poor and contributes to the fuel and food supply of the city. For instance, it has been estimated that 30% of the demand for vegetables in Addis Ababa is supplied by farmers producing within city limits. The horticultural activities along the rivers depend on the use of unpolluted river water.

The role of urban agricultural in urban economies was not well recognised in Addis Ababa in the past. However, the value of urban agriculture as an important input for sustainable urban development now has been recognised by the policymakers. The sector is integrated into the local urban economic and ecological system. Urban agriculture is recognised to have numerous benefits, specifically nutrition, income generation and poverty reduction, community well-being, waste management and conversion of food items.

Urban agriculture is one source of food supply for Addis Ababa residents and could be made a useful tool for making productive use of urban spaces, for treating urban solid and liquid wastes, and generating income and employment as a growing industry.

Urban and peri-urban farms of the city supply considerable amount of foodstuffs to the city from primary sources. About 60-70% of milk, 40-50% of eggs, 30% of vegetables and about 3% of food grains and meat are supplied from urban and peri-urban farms.

There are some socio-economic and environmental issues to be addressed in relation to urban agriculture (UA).

Socio-economic issues include:

- Integration of UA in city development plans;
- Contribution to local economic development through provision of food supply and food security, employment creation and income generation, livelihood support and poverty alleviation/ reduction ;
- Role in social inclusion of the urban poor and women in particular;
- Provision of physical and/or psychological relaxation, recreational opportunities for citizens or educational functions (bringing youth in contact with animals, teaching about ecology, etc.);
- Healthy nutrition: access to fruits and vegetables, especially in low-income areas that have limited access to affordable, healthful foods ;
- Health risks associated with UA include (i) occupational hazards from exposure to pathogenic organisms and toxic elements while farming, handling and distributing food and non-food items; (ii) short- and long-term effects of consuming foods contaminated by organic compounds and heavy metals, which cause gastrointestinal, skin, nerve, lung, liver, brain, and kidney damage and cancer.

Environmental issues include:

- Contribution to the greening of the city;
- Improvement in urban waste management (to minimise waste in cities through productive reuse and recycling wastes and improve nutrient recycling and to improve water management through wastewater use;
- Contribution to decreased storm water runoff;
- Contribution to decreased air pollution, creating an improved microclimate and increasing the O_2 - CO_2 balance;
- Contribution to soil conservation;
- Increasing urban biodiversity and species preservation;
- Environmental challenges related with spatial location and additional inputs applied to improve productivity of agricultural products, which causes soil erosion and river siltation as well as water pollution, respectively.

Urban managers and planners in Addis Ababa think of the city more in terms of housing, transport, commercial services and industry, rather than in terms of agriculture, which generates relatively low yields. Presently UA in Addis Ababa suffers from a combination of planning and political restraints.

The absence of policy supports for UA results in unplanned, unprotected, and unsupported practices of UA in terms of its socio-economic and environmental service provision.

The allocation of land on the structure plan is not made on the basis of land suitability for UA, and in most cases marginal or wastelands are allocated for it. Because UA could not compete with other land uses, the 2003 Master Plan proposed most of the riverbanks for horticultural production. At a regional level there is no plan which indicates a suitable area for peri-urban agriculture on which the city is based to drive its food requirements. Legislative support for UA does not exist, making it difficult to protect the land allocated for UA in development plans as well as people involved in and deriving livelihoods from it. Also, UA cannot contribute to the provision of environmental services to the urban community at large. Lack of adequate land is a key problem facing urban and peri-urban farmers, who resort to informal use of government lands, from which they are frequently ejected. Even areas allocated for UA in structure plans are lost easily to competitive land use, especially for residential purposes within the city. Jemo site is a good example, where UA land use is converted into condominium housing. Limited land tenure, access to water and inadequate capacity development and funding also can present significant challenges and risks to the success of UA.

China is famous for its highly intensive urban cropping systems and, to this day, many of its large cities are largely self-sufficient in food produced on adjacent land areas administered by them. Beijing, now a city of more than 10 million people, still administers its own adjacent farmland. In Shanghai, only 20% of the land administered by the city authorities is actually built on; 80% of the land, mainly in the urban perimeter, is used for crop growing, making the city region self-sufficient in vegetables and producing much of the rice, pork, chicken, ducks and fish. With their unique system of governance, Chinese cities administer vast adjacent areas of farmland and aim to be self-sufficient in food from this. Is this model of urban-rural linkages relevant to Addis Ababa city?

The existing urban agricultural activities in Addis Ababa have concentrated in unwanted lands along riverbanks. Because of such land use allocation, UA in Addis Ababa presents potential environmental and health risks. Important factors to consider include proximities to industry, and pollutants such as heavily polluted river water. Water and soil pollution due to fertiliser and pesticide application is common. Soil and water also are contaminated with industrial wastes and pollutants such as heavy metals (lead, cadmium, chromium, zinc, copper, nickel, mercury, manganese, selenium and arsenic); acids or bases; asbestos; solvents or combinations of contaminants; or pathogenic organisms. Inadequate assessment, cleanup or containment of a site can pose serious health problems to both producers and consumers through contact with contaminated water and soil or consumption of contaminated foods. Because of the undervaluation of UA and stiff competition for land, UA was pushed back to marginal areas within the city such as steep riverbanks where its operation negatively affected the fragile ecosystem. Inappropriate farming practices along the river banks and steep slopes lead to reduction of vegetation, cover soil erosion, and land degradation and siltation of water bodies, reduction in channel capacity and subsequent flooding. This is in conflict with environmental objectives of managing the riparian buffers, which are meant to protect the riverbanks from such environmental problems. UA uses also have caused land-use conflicts. Some urban dwellers currently perceive UA within the city as a nuisance and a health hazard. This perception arises from the use of poor quality, untreated wastewater to cultivate crops, such as vegetables that are often eaten uncooked, inappropriately managed compost facilities, use of chemical fertilisers and pesticides, and poor cultivation, harvesting, and poultry- and animal-keeping practices.

3.1.5 Parks

Twelve governmental recreational parks cover an area of about 130 ha. In addition, 16 proposed parks totalling 340 ha also are allocated by the 2003 Master Plan. There are also many private parks, which are informally established. Squatters have invaded many of the parks. The use of parks and recreational areas in Addis Ababa is basically limited to providing social services like marriage and engagement ceremonies. They are not well managed for several reasons, mainly attributed to insufficient planning, development and management, human capacity limitation as well as budgetary constraints. City parks do not play their role significantly in creating a comfortable environment by easing urban pollution and creating a green urban environment, serving as places for physical exercise, rest and relaxation for the community as well as in providing education. For the large and growing population of Addis Ababa, the existing parks are insufficient. The public park area per inhabitant in Addis Ababa in 2002 was only about 0.4 m and one functioning public park serves about 263,636 people. There is some improvement in the provision of land for parks in the 2016 Master Plan, but the development is still at the infant stage (Table 4).

3.1.6 Roadside green areas

Roadside green areas, parkways (roadside, median, roundabout/squares) cover approximately 28 ha in the 2003 Master Plan. Tree care and maintenance is frequently neglected. Fencing is mandatory for tree survival, yet fences do not always have a nice design. Besides, there is frequent damage due to reckless driving. For all major roads (including ring roads) and newly constructed roads, roadside plantings should become mandatory. Moreover, all available open public spaces should be beautified with ornamental and shade trees. At the moment, only Bole Road got this opportunity.

3.2 Governance of GI in Addis Ababa

The 2003 Master Plan recommends establishment of an independent institution responsible for the stakeholder coordination in the green sector. As a result, the Addis Ababa City Administration Environmental Protection Authority (AAEPA) was established to hold the mandate of administrating areas classified under greenery. Such institutional measures would ensure that attempts pertaining to urban green development are carried out in a manner that will accord with (besides production) the environmental management objectives of the city. Towards this end, the AAEPA has acquired ownership certificate of the green areas from the Land Administration and Development Offices of the respective sub-cities. The Authority, through the responsibility granted to it, has protected and developed the areas to the best of its capacity, and / or coordinates, monitors and supports other relevant GO institutions, NGOs, community and individual efforts towards the common environmental management goal.

There are different forms of green area development activities underway in the city by GO, NGOs and communities. These have been implemented mainly by planting trees and other plants in forest areas, riversides, parks, roadsides, median, squares and in private holdings. Catchment development projects were conducted in Akaki - Kebena - Bulbula watersheds/catchments by the Authority. Woodlots and agroforestry development activities were supported by the Authority in urban and peri-urban areas of the city as an extension package component. The AAEPA centrally managed two nurseries, having a capacity of 1.2 million seedlings per annum. Seedlings of both exotic and indigenous tree species used to be raised in these nurseries to support the tree-planting initiative of the different actors. However, this mandate was recently divided among different institutions, causing institutional fragmentation which made managing the city's greenery difficult. In addition, the mandate calls for the delimitation and demarcation of river and stream sides for vegetation buffer development.

Table 4: Proposed and supplied urban parks (UPs) during the structural plans of 2003 and 201a

Sub-city	Available UPs in 2002	Proposed UPs in 2003	Implemented UPs in 2012	Proposed UPs in 2017	Available and implemented UPs in 2020
Akaki Kality	-	3(22.9)	1(5.5)	35(45)	2(5.93)
Nefas Silk Lafto	1(46.4)	1(8.4)	-	163(79)	3(26.4)
Kolfe Keraniyo	1(31.1)	3(50.7)	1(0.7)	66(361)	2(7.4)
Gulelle	4(45.1)	1(10.6)	-	105(65)	4(18.2)
Lideta	-	2(10.8)	-	17(19)	6(6.5)
Kirkos	1(6)	2(14.5)	-	31(68)	4(27.8)
Arada	2(5.3)	1(0.8)	-	31(24)	3(30.6)
Addis Ketema	-	-	-	15(24)	-
Yeka	2(10.2)	2(26.9)	-	30(98)	4(9.4)
Bole	1(44.7)	1(133.6)	-	4(43)	1(36.4)
City Total	**12(188.8)**	**16(279.2)**	**2(6.2)**	**504(825)**	**29(168.7)**

Note: Figure in parenthesis

4. BI and urbanisation

4.1 Addis Ababa and its urban water cycle

Three components of the urban water cycle were identified in the Addis Ababa system (Worku 2017): water resources, water supply, and wastewater management systems.

4.1.1 Water resources

Water resources in and around Addis Ababa are classified into four major groups: rain water, surface water, groundwater, and wastewater.

4.1.1.1 Rain water

The city has two minor rainy months (March and April) and three heavy rain months (June, July, and August - Figure 18). More than 70% of the rain occurs between June and September. According to the rainfall data obtained from NMSA (2014) the average annual rainfall recorded at the Black Lion Hospital meteorological station is 1,164 mm. This implies that water resource potential from rainfall is substantial. However, most of the rain water will end up in rivers and streams, which carry water away from Addis Ababa as storm water to Awash river. Therefore, it can be concluded that although there is substantial water available from rain water, it is not usable because of a lack of storage facilities and because of pollution from urban storm water runoff.

4.1.1.2 Surface water

With three main rivers and about 75 tributaries (Figure 8), Addis Ababa has an extensive network of BI providing a distinctive landscape and benefits for people, but it also has the risk of flooding. The main watercourse is Big Akaki River, with major tributaries the Little Akaki and Kebena rivers joining the Big Akaki River at Aba Samuel Lake south of Akaki Kality sub-city.

All rivers and their tributaries give rise to flooding following heavy rainfall.

Surface water resources in and around Addis Ababa are Lagadadi Dam, Dire Dam, Geffersa Dam, and Little and Big Akaki rivers and their tributaries (Figure 9). Little and Big Akaki rivers are urban streams which literally serve as open sewers.

Future potential water sources include Sibilu River, the source for the future Sibilu Dam, Gerbi River, the source for the future Gerbi Dam, Aleltu River, the source for the future Aleltu Dam, Jida-Robi River, the source for the future Jida-Robi Dam, and other small water bodies scattered around Addis Ababa region (Figures 8 and 9).

Most of the storm drainage systems in Addis Ababa city literally convey heavily contaminated domestic and commercial wastes. This is because:

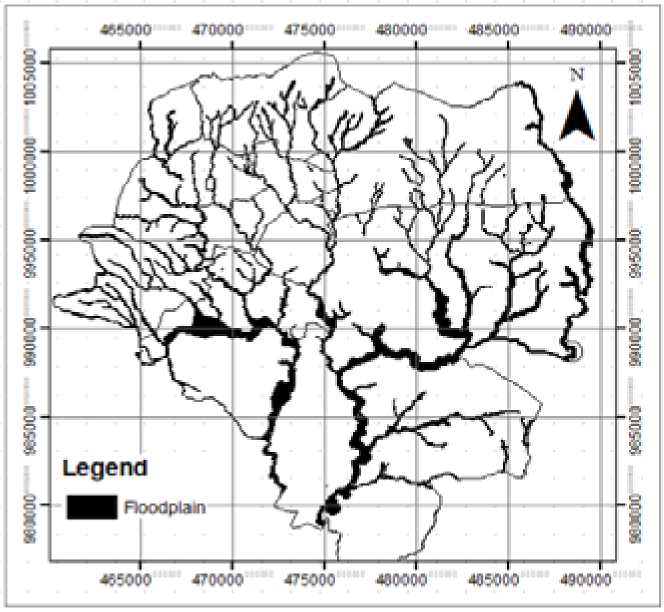


Figure 8: Surface water in Addis Ababa

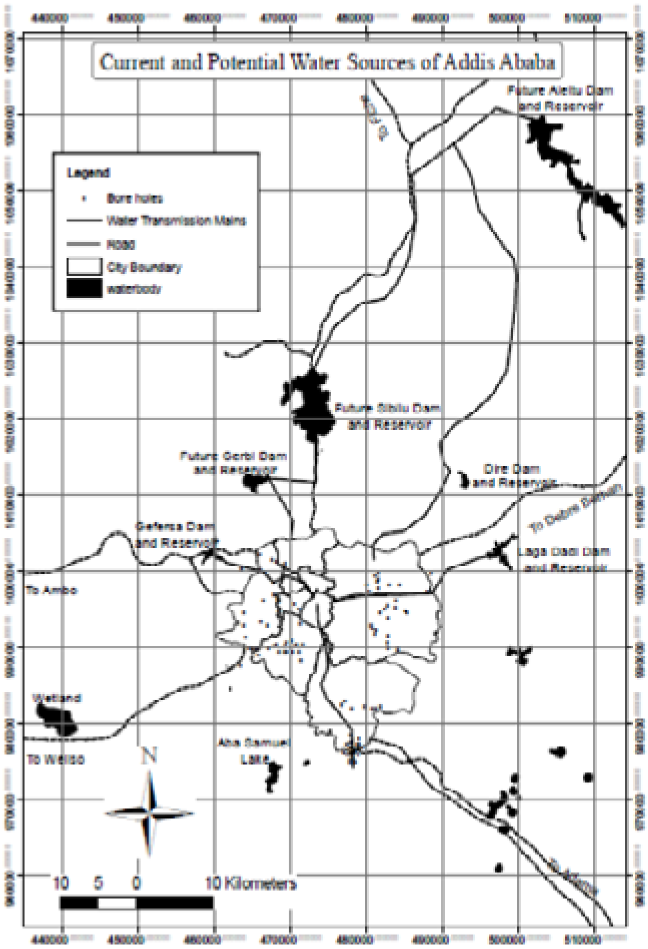


Figure 9: Surface and groundwater sources currently in use and future potential water sources for Addis Ababa

- Solid and liquid wastes are simply dumped into storm drainage systems;
- Many septic tanks and pit-latrines are illegally connected to storm drainage systems;
- Some pour-flush type toilets are also directly connected to storm drainage systems;
- A number of institutions, which include hotels, garages, offices and industries, are directly connected to storm drainage systems.

It can be concluded here that, apart from the dams in upper stream locations, surface water in Addis Ababa is extremely polluted and cannot be used for any purpose without treatment.

4.1.1.3 Groundwater

The groundwater resources in and around Addis Ababa are gravity springs, shallow wells distributed within Addis Ababa city and deep wells in the Akaki well fields (Figure 9). Gravity springs are located in the northern part of the city along the foot of the Entoto mountain chain. They were the first identified sources for Addis Ababa's water supply dating back more than 100 years ago. From well inventory records, approximately 300 water wells are used for water supply sources within Addis Ababa area. The yields of these wells decrease towards the north. To supplement shortages in its water supply, Addis Ababa Water and Sewerage Authority (AAWSA) has drilled deep boreholes in the Akaki well field in the southern part of the city. The well field was put into operation in 2001. The Akaki well field and some springs and boreholes supply about 100,000 cubic metres per day (AAWSA, 2011, 2012). Currently, the boreholes around the southern periphery of the city are being used intensively to address the acute shortage of water supply, but there is evidence of over exploitation (AAWSA, 2011, 2012), which may lead to serious environmental consequences. The largest private users of groundwater in the city include industries such as breweries, soft drink bottlers, tanneries, and tyre and metal factories.

4.1.1.4 Wastewater

Wastewater adds a substantial amount of water to the water resources of Addis Ababa. Approximately 300,000 cubic metres (m^3) of water is supplied to Addis Ababa per day from surface water and groundwater sources (AAWSA, 2011, 2012). Of this amount, about 80% joins Addis Ababa Rivers as wastewater, which is an enormous amount in volume. However, there are only few treatment facilities to date to treat this potential resource so that it can be put to appropriate uses.

4.1.1.5 Quality of water sources

A number of pollution-related studies conducted so far (including Alemayehu, 2001) have indicated that most governmental and private establishments, such as most government hospitals and other health facilities, industrial

Figure 10: Water pollution sources from industries

Figure 11: Water pollution sources from garages and workshops (left) and domestic wastewater

Figure 12: Solid water directly dumped into surface water bodies (left) and combined impacts of solid waste and informal settlements

facilities, government institutions, schools, and large numbers of hotels, restaurants, bars, garages, fuel and service stations, and car washing facilities, in addition to many residences, are discharging their effluents into nearby watercourses, streams, rivers, storm sewers and open fields without any form of treatment. Both in terms of quantity and quality, industry is identified as the largest source of water pollution in Addis Ababa (Figures 10-12).

Furthermore, overflowing and seeping pit-latrines, septic tanks, public and shared toilets, and open field defecation are major pollution sources. It is estimated that about 25% of the housing units in Addis Ababa do not have any form of sanitation facilities; therefore open field defecation is a common practice (CSA, 2008). Commercial, domestic, and industrial solid wastes, which are often piled on available open ground, in waste collection bins, on stream banks, under bridges, and the like is causing severe pollution problems for water resources in Addis Ababa. Solid waste that is not collected on time, in addition to littering many parts of the city, is often transported by storm water runoff into streams.

Several studies, including one by Alemayehu (2001), have indicated that some of the common pollution indicators in river waters in Addis Ababa include:

- Significant changes in physical, chemical, and bacteriological water quality characteristics;
- Presence of environmentally hazardous substances;
- Significant changes in color and odour;
- Depletion of dissolved oxygen and creation of septic or anaerobic water environments that favor algal bloom and the presence of anaerobic organisms;
- Disappearance or death of aerobic/fresh water organisms;
- Prevalence of waterborne diseases.

It can be concluded that no stream originating or crossing the city is a reliable source of fresh water. Aba Samuel Lake is the recipient of all of the domestic, commercial and industrial wastes generated in the city. As a result, it is heavily polluted. Unless efforts are made to improve the prevailing conditions, the pollution in the lake represents a serious threat downstream to human health and the environment. Furthermore, the pollution of Aba Samuel Lake means that pollution enters Awash River, one of the most highly exploited rivers in the country. Moreover, pollution of surface waters can also means the pollution of groundwater sources. There are indications that water from the boreholes in the Akaki well field is polluted, and some boreholes have been abandoned because of excess nitrate pollution (Teferi, 2014).

4.1.2 Water supply

History of water supply and sanitation

Addis Ababa has grown to its current size of about 540 km^2 and 3.3 million residents (as projected for the year 2014) over the past 128 years. During its early years, its principal sources of water were springs located at the foot of the Entoto Mountains. The larger springs were tapped and distributed to different parts of the city. Continued population growth necessitated the construction of the Shiromeda water treatment plant in 1938, and Gefersa Dam with a treatment plant in 1944. The Gefersa system contributes 30,000 m^3 of water of the current total of about 300,000 m^3 supplied to the city per day. The major expansion of the water supply schemes commenced in 1970, with the commissioning of the Lagadadi dam and the first phase of the treatment plant with output capacity of 50,000 m^3 per day (AAWSA, 2011, 2012 and Teferi, 2014). Expansion of the water supply systems was conducted during the 1980s under the Stage II Water Supply Project (AAWSA, 2003). The capacity of the water treatment plant increased to 150,000 m^3 per day, and the total supply grew to about 180,000 m^3 per day, which was projected to be sufficient to serve the need of Addis Ababa until 1992 (AAWSA, 2011, 2012 and Teferi, 2014).

Although the combined design capacity of these two systems is about 180,000 m^3/d, the current production is limited to approximately 150,000 m^3/d, which is far less than the current demand. This has led to chronic shortages of water supply. To meet the present and future water demand of the city, development of Gerbi and Sibilu rivers further north of the city has been under discussion since the 1990s, but no tangible progress has been made so far.

The delay in the implementation of the Stage III Water Supply Project, which commenced in the early 1980s, called for an emergency programme to develop two water supply projects (part of Akaki well field and the Dire Dam). A programme of borehole drilling and spring rehabilitation has also provided improved water supplies to out-of-the-way areas of the city.

4.1.2.1 Water supply infrastructures

Dams and water treatment plants

The main components of the Addis Ababa water supply system are the Gefersa and Lagadadi dams and their water treatment plants. Gefersa Dam is located 18 kilometres northwest of the city. Its catchment area is 56 km^2, and its mean water inflow is about 55 million cubic metres per year (MCM/y). Lagadadi and Dire dams are located 35 and 42 km to the northeast of the city with catchment areas of 205 km^2 and 78 km^2 and mean annual water inflows of 86±16.5 and 50±9 MCM/y, respectively. Lagadadi Dam was established in 1970 and Dire Dam in 1998 (AAWSA, 2003, 2005 and 2011, 2012; Teferi, 2014).

The treatment processes in both the Gefersa and Lagadadi dam treatment plants follow similar steps, such as pre-chlorination, coagulation, flocculation, sedimentation/clarification, rapid sand filtration, and finally, pH adjustment (Teferi, 2014).

Service reservoirs

There are 92 clean water reservoirs in the city, ranging in size from 50 m^3 to 20,000 m^3 in capacity. Water is supplied from the reservoirs both by gravity feed and by pumps (AAWSA, 2003, 2011, 2012).

Delivery/ transmission/ distribution system

Water transmission mains and distribution lines are as old as 50 years, especially the ones that transport water from the water treatment plants to the city centre. The transmission lines consist of two types: pipes ranging from 40 mm to 125 mm in diameter, and those greater than 125 mm and less than 1400 mm. The distribution network in Addis Ababa is at present supplied from four major sources: Gefersa treatment plant, Lagadadi treatment plant, Akaki well field, and wells and springs scattered within the city (AAWSA, 2011, 2012). The city generally slopes from north to south, with an elevation difference of more than 800 m over a distance of about 29.4 km. The distribution systems work mostly through gravity.

4.1.2.2 Water production and consumption

As mentioned earlier, the present water supply is obtained from four sources. The river-fed reservoirs of Lagadadi and Dire dams (165,000 m^3/d), Gefersa Dam (30,000 m^3/d), and groundwater pumped from Akaki well field and wells and springs scattered within the city (100,000 m^3/d).

Figure 13 shows the yearly water production capacities of the different water sources, water distributed, and Non-Revenue Water (NRW) or water loss from the fiscal years 1994-95 to 2013-14, and the difference between the amount of water distributed and that which is actually consumed. The gross NRW obtained from the difference between water production and billed volume is about 37% on average. The total loss could be due to old and deteriorated piping, broken lines due to high pressure in parts of the system and by construction, illegal connections, errors in water meter reading, faulty/malfunctioning water meters, unmetered connections, low quality workmanship during implementation, and the like (AAWSA, 2011, 2012). This large amount of water lost as NRW per year not only costs the city a huge amount of money, but it has also created water scarcity and unsustainable water use. These losses indicate that the current water supply infrastructure and management practices are ineffective and inefficient.

4.1.2.3 Water demand, supply, and coverage of Addis Ababa

Planning for future water supply (design, sizing, and phasing) requires forecasts of important indicators, such as population projections, changes in the mix of household types, or changes in land use and economic development. This study used CSA's forecast of population of Addis Ababa based on the 1994 census with assumptions that the growth rate should be constant throughout the projection period (AAWSA, 2005).

The CSA 1994 population census, which provided a population figure of 2.11 million and an annual growth rate of 2.9% (CSA, 1994) are the official figures that AAWSA used for future water demand projections. The projections were made by the Water Supply Stage III Project, which was intended to satisfy the demand of the city to the year 2025 (AAWSA, 2005). In this water demand projection exercise, water for domestic, industrial, and commercial uses were taken into consideration. Future demand projections to 2025 are shown in Figure 14.

According to the Addis Ababa Water and Sewerage Authority 2011 annual report, the total amount of yearly water production from different sources in 2010/11 was 112,215,567 m^3; 70,152,807 m^3 of this water was from surface water sources and 42,062,760 m^3 from underground sources. The distributed amount was

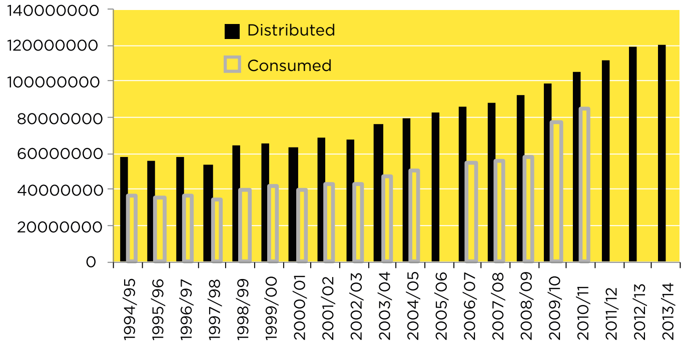


Figure 13: Water Production and Consumption

The total amount of water produced and distributed versus the amount of water actually consumed.

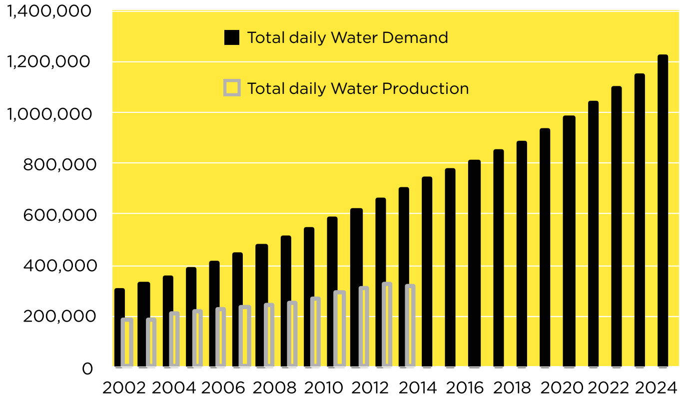


Figure 14: Water Demand and Supply

The total daily water demand versus supply in m3 from 2002 to 2025 (data from Teferi, 2014).

89,772,454 m^3, the balance being the losses discussed earlier in this paper. The amount of water distributed suffices only to meet about 50% of the demand, contrary to AAWSA 92% demand coverage reports in 2011.

In 2014, a total production of 317,792 m^3/d was obtained from existing sources, which is far less than the 699,000 m^3/d demand, indicating a deficit of 55% (see Figure 14). The present, severe water supply shortage in the city is additional evidence supporting these data. Although there are reports stating that the water coverage in Addis Ababa was 48%, 53%, 64%, 73%, and 73%, respectively, for the years 1999 to 2003 (Teferi, 2014), the true water demand coverage is far less than this as evidenced by the current observed water shortages, intermittent supplies, and inconsistency of data in different reports.

The projection of total water demand was based on daytime population estimations and per capita daily water demand taking into consideration all water demand categories. Figure 14 shows the current and projected water demand in Addis Ababa from 2002 to 2025 and the supply and coverage from 2002 to 2014 (Teferi, 2014). These data show that the water supply is already below 50% of the water demand in 2014, and demand by the year 2025 is expected to rise approximately fourfold from the present level of production (Tefari, 2014). Climate change

Table 5: Existing and planned decentralised wastewater treatment plants in Addis Ababa

Decentralised treatment plants	Capacity
Existing	
Kality WW treatment plant	10,000 m^3/d
Gelan WW treatment plant	7,000 m^3/d
Kotebe WW treatment plant	4,000 m^3/d
McClelland WW treatment plant	3,000 m^3/d
Sub-total	24,000 m^3/d
Planned	
Kality WW treatment plant expansion	100,000 m^3/d
Chefe WW treatment plant	20,000 m^3/d
South Akaki WW treatment plant	60,000 m^3/d
Western Sewerage System	80,000 m^3/d
Sub-total	260,000 m^3/d

Source: Teferi, 2014

is also expected to aggravate the demand and reduce the supply even further in the future.

4.1.3 Wastewater management

Addis Ababa has a modern sewerage system, but its coverage is very small, and the wastewater treatment plant currently serves only some parts of the city. The construction of Kality wastewater treatment plant, the first wastewater treatment plant in the city, with a capacity of 7,600 m^3/day, was designed to serve an equivalent population of 200,000. The treatment plant was completed in 1981. The trunk sewer lines have a total length of approximately 70 km with approximately 400 km of secondary sewer lines and laterals. The number of people connected to the existing system is about 13,000, with institutional and commercial connections contributing a further 27,000 population equivalent. There also are other, small, decentralised treatment plants designed to serve newly developed condominium houses. Their treatment capacities, along with the public treatment plant and plants that are planned for the future, are shown in Table 5.

Other onsite sanitation systems in the city are generally pit latrines and septic tanks. Sludge is collected by AAWSA and privately operated suction trucks. The collected sludge is dried on drying beds at Kality and Kotebe treatment plants. Kality sludge drying beds and sludge lagoons were constructed in 1999 to alleviate the immediate problems of dumping raw sludge in Akaki River. The sludge drying beds and lagoons have been sized to treat 110,000 m^3/year of sludge. Apart from the provisions of the very small coverage provided by the sewerage system, the liquid waste management problem in the city is immense and has seriously affected the overall environment in general and the public's health in particular. Illegal connection of septic tanks to the roadside storm drainage system and poor wastewater disposal practices in the city have created bad odours and breeding sites for flies and other pests.

Illegal connections of the storm drainage system to the nearby rivers and a system of indiscriminate disposal of wastes presently practiced in and around the city could be one of the major causes of environmental pollution that leads to the emergence of health problems, particularly during the rainy season.

The impacts of the rudimentary wastewater treatment infrastructure in Addis Ababa are twofold: on one hand, the untreated wastewater poses considerable health and environmental problems, and on the other hand, the contribution to the water supply that could be obtained from treated wastewater is missing.

It is well known that all of Addis Ababa's city wastewater drains towards Akaki River, and, finally, to Awash River and Koka Lake. Consequently, downstream water users are critically suffering from pollution-induced impacts. Livestock drinking polluted river water and people using the polluted water either for domestic use or for irrigation purposes are exposed to serious health hazards.

4.2 Urban water management problems and constraints to growth

The rapid urbanisation of Addis Ababa and its surroundings is creating major challenges as the city seeks to provide an increasing population with adequate and sustainable water supply and sanitation services. Urban population growth is almost 3% per year (CSA, 2012). According to CSA's statistics in July 2012, the population of Addis Ababa was 3.14 million. Given the current economic growth and urbanisation trends, Addis Ababa was expected to have a population of 4.37 million by 2020 and 5.27 million by 2030 (CSA, 2012). Industry is also growing at the rate of 20% per annum (AACA, 2017).

As a result of the rapid population and industrial growth, the demand for water by the domestic, commercial, agricultural and industrial sectors continues to rise while water availability continues to decline because of competing uses, environmental degradation and climate change. The city already has outgrown its local water resources and will require, in the near future, conveying fresh water from long distances or deep aquifers.

Service infrastructures in Addis Ababa, ranging from water supply to wastewater management, are unable to provide the residents of Addis Ababa with the means to lead healthy and productive lives. In addition, the city is not able to sufficiently protect or enhance the environment. The result of urban growth, combined with the inability of the city administration to respond satisfactorily to water supply and sanitation service demand, is already worsening the degradation of the aquatic environment and increasing the constant danger of water-related diseases.

By gathering data and involving stakeholders, this study identifies two main factors that compromise the growth of Addis Ababa city. These are:

- Current inadequacies of the water management system;
- Future water scarcity as a result of population and economic growth and climate change.

These two key factors are further subdivided into the following strategic issues that require intervention in both the short/medium-term and long-term:

- Insufficient water resources in and around Addis Ababa for present and future uses;
- Lack of protection for available water resources and lack of water conservation: susceptibility of the upper source catchment to extensive erosion and increased risk to downstream properties;
- Inadequate urban water supply infrastructure;
- Inadequate coverage of the water distribution system;
- Intolerable leakage as a result of the advanced age of the existing pipe network, leading to water losses of up to 40%;
- Lack of storm water and wastewater management and deterioration in water quality from effluent loading into highly sensitive receiving waters;
- Lack of appropriate spaces for water storage (detention, infiltration, and evaporation) and water recreation;
- Organisational inadequacy: extensive and slow-moving bureaucracy and unresponsiveness in the water supply office;
- Lack of trained and qualified manpower: lack of equipment and spares;
- Data management problems: inconsistency of data in different reports;
- Frequent power interruptions exacerbating the shortage in the water supply.

To provide solutions to these urban water management problems, it is important to introduce an Integrated Urban Water Management (IUWM) strategy. IUWM in Addis Ababa is at a rudimentary stage. In this regard, water supply management, wastewater management, and flood management, all integral parts of IUWM, have been handled separately. Furthermore, integration of these urban water management components with land use planning thus far has not taken place. The city never has had a drainage master plan to address storm water management. Policy and legislative provisions are not complete. Water is priced at far less than the actual cost of providing water to users (AAWSA, 2011, 2012). Human resources and financial capacities are very limited.

5. Climate change impacts on urban systems of Addis Ababa

5.1 The climate of Addis Ababa

The climate of Addis Ababa is analysed only on the basis of temperature and rainfall data. Taking 60 years of temperature data from Addis Ababa Observatory (NAMSA, 2014), segmenting the data into three periods' averages and computing the rate and magnitude of change in temperature within the last 60 years shows that both maximum and minimum temperatures are increasing (Figures 16 and 17). The average maximum temperature from 1953 to 1973 is 22.5°C, while from 1974 to 1993, the maximum was 22.6°C. Finally, from 1994 to 2013 the average maximum temperature increased to 23.6°C. This shows that the rate of change in recent years is greater, and the temperature has increased faster, during the last two decades than during the previous two-decade periods. All ten of the warmest years were recorded after 1997. Furthermore, the average minimum temperature increased from 9.1°C in the period from 1953 to 1973, to 10.67°C for the period from 1974 to 1993, to 10.85°C for the period from 1994 to 2013.

Mean annual rainfall distribution over the city for the last 60 years is characterised by three months of heavy rainfall each year with a long and mostly dry period in between (Figure 17).

The average annual rainfall at the Addis Ababa observatory station from 1953 to 1982 was 1156 mm, while the average mean value from 1984 to 2013 was 1213 mm. Although the average rainfall did not show a significant change, it did show significant variability within each decade (Figure 18).

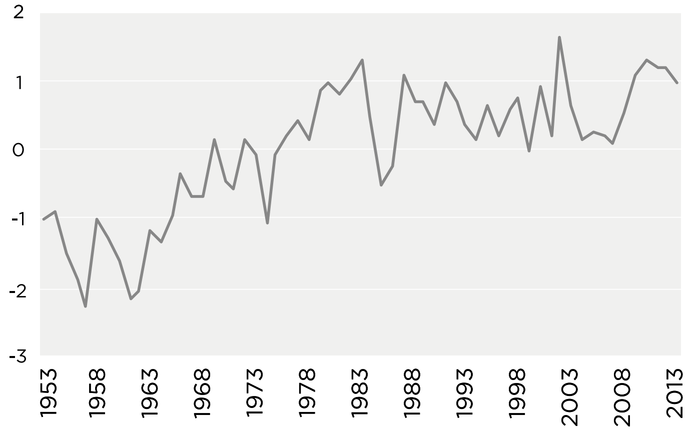
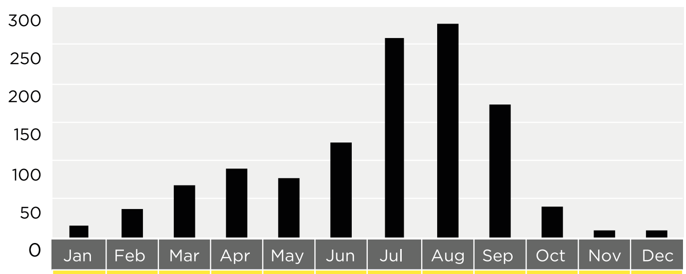


Figure 16: Climate data of Addis Ababa: minimum temperature anomalies (°C)



Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16.8	36	68.2	88.8	76	123.5	259.4	278	174.1	41.1	8.3	10.2

Figure 17: Mean monthly rainfall (mm) from the Addis Ababa observatory station in Addis Ababa

Sources: National Meteorological Agency [NMSA], 2014

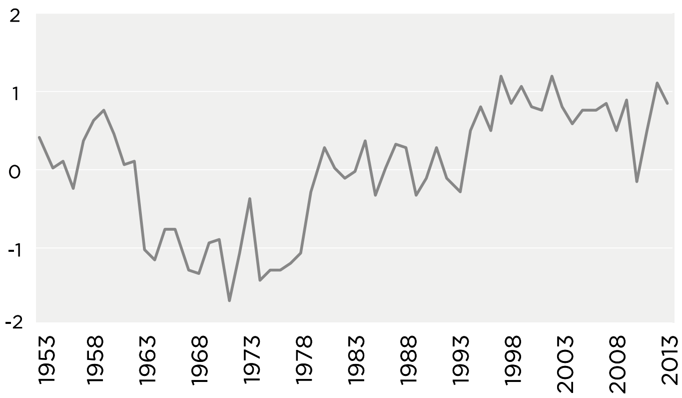


Figure 15: Climate data of Addis Ababa: maximum temperature anomalies (°C)

Source: National Meteorological Agency [NMSA], 2014

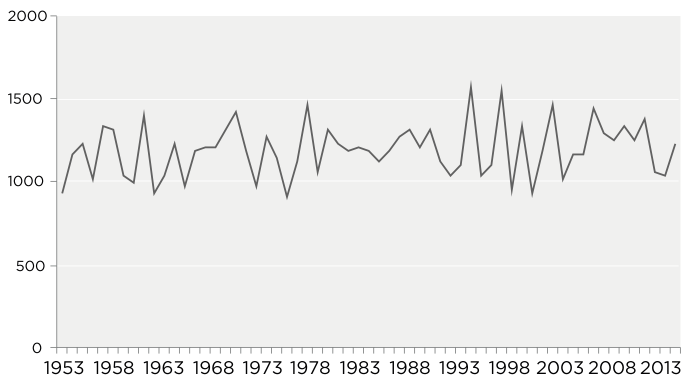


Figure 18: Graphical representation of rainfall data from 1953-2013 from the Addis Ababa observatory station in Addis Ababa

Source: National Meteorological Agency [NMSA], 2014

5.2 Impacts of CC on urban system components of Addis Ababa, including GBI

Climate change (CC) is now recognised as posing a serious threat to the sustainable development of Addis Ababa city. As a consequence, city authorities are showing increasing interest in combating CC by streamlining adaptation measures into city development planning through a comprehensive and integrated approach. Nevertheless, in the past, the integration of CC adaptation into urban planning (UP) and landscape design (LD) was not given adequate consideration by planners and designers due to lack of knowledge regarding CC and the efforts that can be taken to mitigate its effects.

Climate change poses a serious threat to sustainable urban development, placing many cities at risk. Despite many uncertainties concerning the magnitude and frequency of hazards and their specific impacts, CC will inevitably increase the susceptibility of urban environments if no effective adaptations take place (see IPCC, 2007; UNHABITAT, 2011; Leichenko, 2011, and Global Report on Human Settlement, 2011). As a consequence, city authorities increasingly face the challenge of finding ways to include adaptation strategies in their work (Wamsler et al., 2013). As CC adaptation is still a relatively new field of activity, related knowledge and competence in designing and implementing adaptive measures is still scarce and fragmented (UNISDR, 2010).

Various researchers (eg, McSweeney et al., 2008; Ward and Lasage, 2009; Conway et al., 2010; Capuano et al., 2013; Jalayer et al., 2013; De Risi et al., 2013; Jalayer et al., 2014; Cavan et al., 2014) have conducted studies related to CC country profiles, CC scenarios, CC impacts, and the vulnerabilities to CC of the urban systems in Addis Ababa. A foundation for the assessment of CC scenarios and their impacts on urban areas in Africa, with a specific focus on the city of Addis Ababa, is provided by Ward and Lasage (2009) and Di Roucco et al. (2013). Jalayer et al. (2013) conducted a CC-induced risk analysis of Addis Ababa city. The delineation of flood-prone areas and the identification of residential hotspots in Addis Ababa and Dar es Salaam, Tanzania, were conducted by De Risi et al. (2013), and a probabilistic study using a GIS-based method for the delineation of urban flooding hotspots was conducted by Jalayer et al. (2014). CC-induced heatwave hazards in Dar es Salaam and Addis Ababa were evaluated by Capuano et al. (2013) and urban morphological determinants of temperature-regulating ecosystem services in these two cities was performed by Cavan et al. (2014). Woldegerima et al. (2016) characterised the urban environment of Addis Ababa through urban morphology types (UMTs) mapping and land surface cover analysis. Fetene and Worku (2013) have thoroughly analysed and developed a management plan for the conservation and sustainable use of urban forestry in the upper catchment of Addis Ababa whereas Woldegerima et al. (2017) conducted an ecosystem services assessment of the urban forests of Addis Ababa. All of these studies have deliberated on the analyses of CC impacts to and vulnerabilities of the urban systems in Addis Ababa, but thus far, there has been no attempt made to integrate CC impacts and vulnerability mapping into the UP and LD of Addis Ababa city. As a result, information on the integration of CC adaptation strategies in UP and LD activities currently being considered, planned or implemented in the city is not available.

The way cities grow is both a key driver of CC and CC impacts, and at the same time, leaves urban populations very vulnerable to CC impacts. The predominant planning practices in use at this time seem not to offer sufficient answers to address this double challenge. There is growing consensus that appropriate UP and LD approaches are key to mitigating and adapting to CC. The growing number of extreme weather events of the last few years and their dramatic impact on fragile urban infrastructures and on settlements in risk-prone areas illustrate the urgency of reducing risk through better planning and design practices (De Risi et al., 2013; Jalayer et al., 2013; Worku, 2015). UP and LD have the potential to reduce vulnerability to the various CC-related hazards, such as floods, drought and the urban heat island (UHI) effect.

Climate awareness in spatial planning has increased over recent decades due to the increasing frequency of extreme-weather disturbances. Concepts such as mitigation, adaptation, and resilience have gained prominence, as much to prevent as to deal with climate-related disturbances. Because investments in defensive projects are costly and the project goals themselves difficult to achieve, strategies involving adaptation increasingly need to be considered for land use management in and around cities. To this end, new planning practices can help mainstream CC considerations into urban development processes (Wamsler et al., 2013). For new UP and design practices to be efficient, they will need to incorporate CC responses into current urban realities and future planning approaches.

The studies mentioned previously show that Addis Ababa has become more vulnerable to CC impacts such as flooding and UHI effects over recent years than it was in the past. These impacts are further exacerbated by rapid population growth, improper urbanisation, and lack of climate sensitive UP and LD, even in a finalised (in 2017) master plan, despite various recommendation provided by experts and academicians (e.g. Worku, 2012). This latest opportunity for integrating CC impacts into the city's master plan and LD was missed. This is primarily due to the knowledge gap affecting many urban planners as to how CC can be streamlined into urban development endeavors. To integrate CC impacts into city development planning, it is important to identify key components of CC impacts and vulnerable urban systems that contribute to the deterioration of the environmental, social and economic conditions of the city (Worku, 2015).

CC affects urban areas through two main mechanisms: long-term and gradual climate risks, and extreme weather events. Long-term and gradual climate risks involve global temperature rise, changes in precipitation, changes in other variables and weather patterns and changes in large-scale circulations. These changes to the global earth system will be experienced locally as changes in water availability, drought, storm surge damage, land loss and changes in seasonal climate patterns. Extreme weather events, the frequency and intensity of some disasters, such as droughts and floods, could increase, with adverse impacts on urban social, economic and environmental assets (World Food Programme [WFP], no date).

CC in Addis Ababa is expressed by an increase in the intensity and frequency of heavy rainfall and consequent flooding, reduced rainfall and consequent drought, and extreme temperature with more heatwaves and hotter, drier events. Extreme events such as floods, drought and heatwaves (Figure 19) have been identified as the built environment's main, potential CC vulnerabilities.

5.2.1 Impacts of increased intense and variable rainfall

Increased intense and variable rainfall is the cause of flooding in Addis Ababa. The city is vulnerable to flooding from a variety of sources, key of which are flooding from the city's three main rivers and their tributaries (fluvial flooding) and from heavy rainfall (surface water flooding) as a result of an improper drainage network associated with roads (Figures 20-22). Because Addis Ababa is located on a highlands ranging in elevation between 3100 m.a.s.l. and 2200 m.a.s.l., location and topography make some parts of Addis Ababa vulnerable to flooding. The existing state of the drainage system, road network, and sewerage system exposes most parts of the city to street and riverine flooding. Landslides are also becoming a major threat, especially in the Gulele and Yeka sub-cities in the northern part of Addis Ababa. Because of construction in the city (frequent excavations), the ground is becoming increasingly unstable, causing major landslides. Most of the population in flood-prone areas lives in houses constructed from mud and wood, which greatly increases their vulnerability. Current urbanisation trends would significantly reduce the city's vegetated areas and riverine corridors. When the loss of vegetation is combined with the changing rainfall patterns, this will dramatically exacerbate the city's flooding problems.

The impact of a major flood in Addis Ababa would be significant. The city is heavily urbanised, and 10% of its surface area lies in floodplains and on the banks of Addis Ababa's rivers. Currently, significant numbers of people, properties and a substantial proportion of the city's infrastructure are at risk of surface and fluvial flood. The consequences of flooding will increase as Addis Ababa's population grows and more property and infrastructure is located in areas of flood risk. There also will be a large number of flood-vulnerable communities at risk. The degree of sensitivity to anticipated flooding varies from community to community due to variations in topography, poverty levels, access to basic social services, quality of housing and settlement patterns. Flood risk in Addis Ababa is principally unmanaged, and there is no significant system of flood defenses and drainage networks. Therefore, Addis Ababa has a lower and much more variable standard of protection against fluvial and surface water flooding. Moreover, the probability of all forms of flooding is projected to increase as a result of surface sealing as intense and heavy rainfall events become more frequent. The cumulative impact of paving front and back gardens has increased the pressure on drainage system and increases the likelihood of flooding. The drainage system has been designed on an ad hoc basis without taking into consideration the amount of storm water it is expected to transport. Advance warning times for fluvial and surface water flooding do not exist, and public awareness of flood risk and the public's capacity to act are very low.

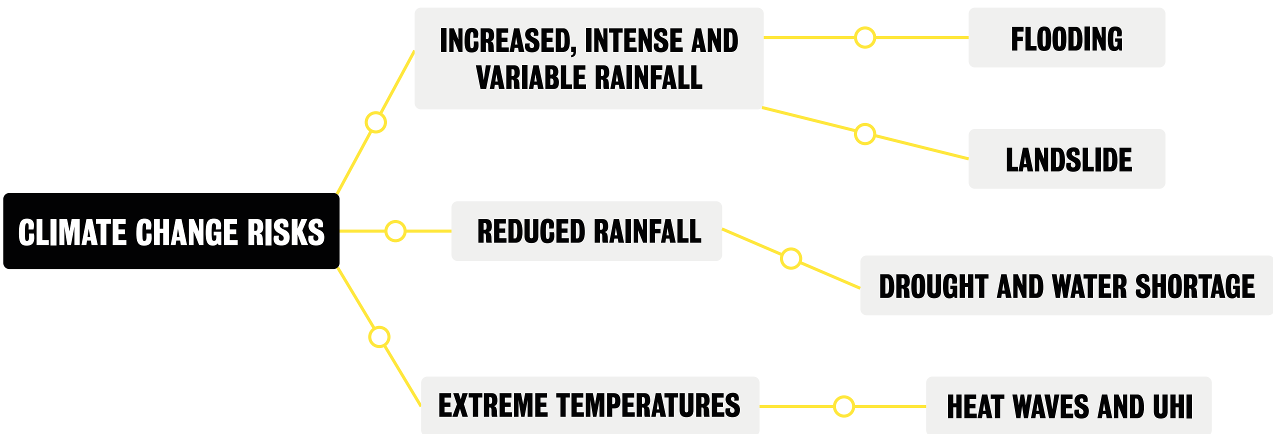


Figure 19: Climate change impacts and risks of Addis Ababa

Source: Worku, 2017b

Flood impacts in Addis Ababa include:

- Loss of life and injuries (humans and animals);
- Health impacts due to increased pollution, contamination and disease from flood and sewer water and contact with contaminated flood water;
- Direct damage to property and public utility objects and networks (destruction of infrastructure, such as residential, commercial and public buildings, roads, bridges and other transport infrastructure, space, and assets, parking lots, pipe systems, electricity, communication and water systems and other vulnerable objects);
- Soil erosion and land degradation, widening of river channels and loss of land space; and disruption of traffic, the electricity network, the communication system, breakup of communities and social networks; loss of business and income and delayed economic development; dislocation of people, etc. (Figure 23).

5.2.2 Impacts of reduced rainfall

The variability in rainfall, reduced rainfall and drought are ongoing states in Addis Ababa and the surrounding areas, and they are likely to occur occasionally in the future with CC. The most significant and inherent risk from drought—a risk that is considered critical and requires immediate and ongoing management—is an insufficient water supply for Addis Ababa. Currently, the occasionally extreme dry conditions in Addis Ababa are projected to persist, with an increase in the durations between rainfalls. Frequent and prolonged droughts would affect the city's water supply, water-dependent businesses, Addis Ababa's green spaces and biodiversity and water courses.

The likelihood of drought having a significant impact on Addis Ababa is currently high. As in most years, there is insufficient water to meet demand. The present supply is met only by withdrawing more water from the environment than can be sustained. In the future, less seasonal rainfall, greater demand for water and the limited amount/volume of water that can be removed from the environment will threaten the security of the city's water supply.

Without action, Addis Ababa will experience an increasing frequency of drought. Management measures, such as water storage, water recycling, and restrictions on water use—for example, non-essential uses bans—are inevitable. Increasing water storage and reducing water use could improve the city's drought resilience, safeguard the environment and save residents money through reduced utility bills.

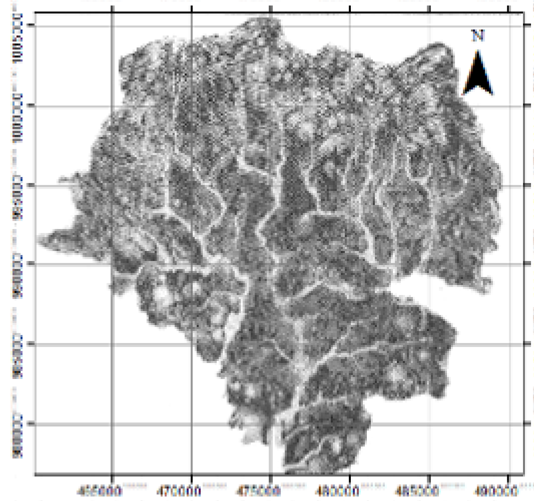


Figure 20: Areas of fluvial flood risk based on wetness index

Source, De Risi et al., 2013

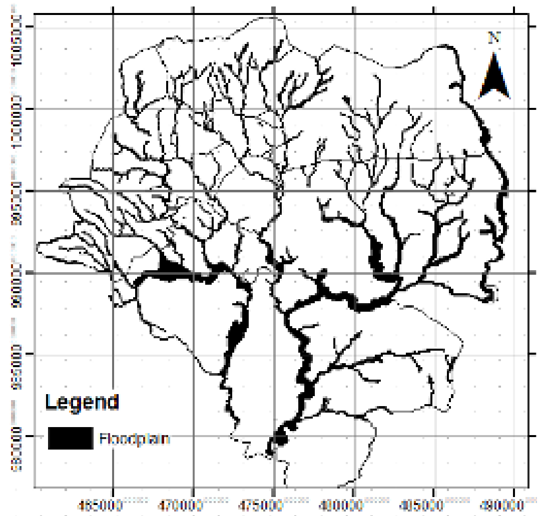


Figure 21: Delineation of flood risk areas based on aerial photographs and field mapping

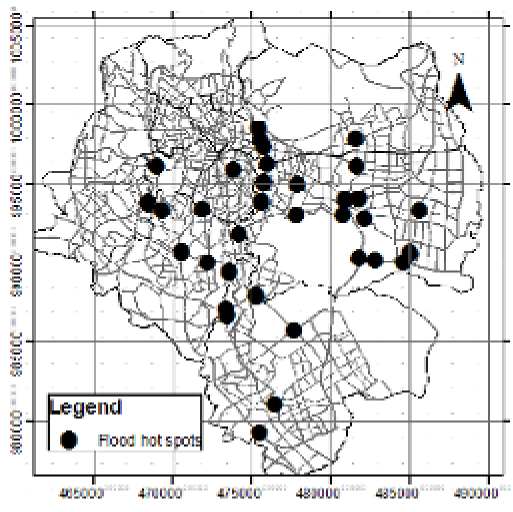


Figure 22: Hot spots of street flooding areas as a result of improper drainage network design

(Modified from AACRA, 2013).

CC is expected to affect water availability and related ecosystem through:

- Reducing river/surface waters flows;
- Reducing groundwater replenishment (recharge);
- Increasing evaporation;
- Increasing demand for water from people and wildlife;
- Impacting biodiversity due to insufficient environmental flows resulting from the reduction in water availability;
- Increasing health problems related to declining water quality—for example, an increase in waterborne infectious diseases;
- Increasing issues of social inequity and public conflict resulting from prolonged water restrictions, leading to incidents of water theft and restrictions infringement;
- Creating side effects on tourism;
- Creating a huge impact on the energy sector;
- Creating social impacts by the possible increase of water prices due to the implementation of compensating measures;
- Income losses and fall in gross domestic product (GDP) growth.

5.2.3 Impacts of extreme temperature/ overheating

Overheating is a term used to describe situations in which temperatures are hot enough to affect residents' health and comfort or affect the infrastructure. Heatwaves are typically defined as extended periods of hotter than average temperatures. As a result of CC, extreme heat events and heatwaves are predicted to become more frequent, intense, and longer lasting over most areas of Addis Ababa. Without action, the risk of overheating and the increase in intensity and frequency of heatwaves is expected to grow as average temperatures get hotter—and as Addis Ababa grows.

While the physical manifestations of CC can have an impact on both rural and urban areas, urban settlements generate unique local conditions that interact with heat events. Compared with rural areas and city peripheries, central Addis Ababa tends to have higher air and surface temperatures due to the UHI effect—the tendency of the city to retain heat more than is the case in its peripheries and in surrounding rural areas. For Addis Ababa, this phenomenon has caused air temperatures in the central city that are up to 5°C higher than in the surrounding areas. Mean maximum and minimum annual temperatures have increased by about 1.1 and 1.14° C respectively in the last 60 years. Climate models suggest that Addis Ababa is expected to be warmer on average by 1.3°C in 2030, 2.7° C in 2060, and 4.2°C in 2090 when compared to year 1900. The physical layout of the city's areas, the city's population size and density and the structural features

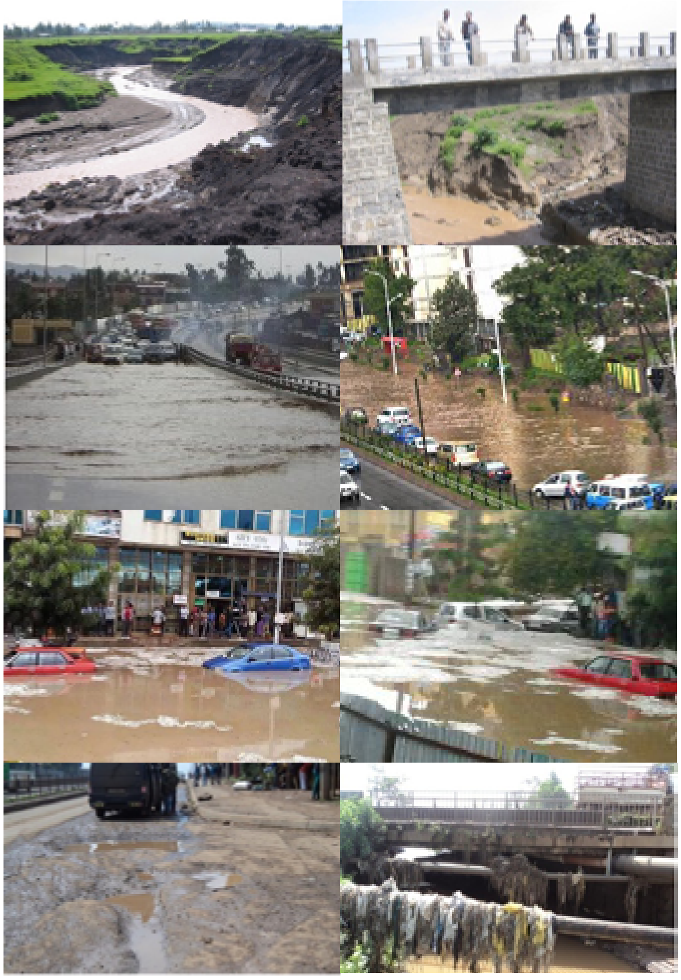


Figure 23: Flood impacts in Addis Ababa

(a) Collapsed stream banks and land loss; (b) damage to transport infrastructure (bridge); (c-f) flooded streets in the middle of the city causing disruption of the transport system; (g) damaged roads as a result of flooding leading to increased maintenance and replacement requirements; (h) flood markers showing bridge overtopped by flood (Worku, 2017a)

of the built environment all influence the strength of the UHI effect. Stronger heat island effects have been linked to compactness and limited areas of green space. The heat generated in the city by traffic and other energy uses also acts to raise temperatures, which has a significant local impact in high-density areas.

Wind plays a special role in the interaction between the urban fabric and weather, not only because reduced wind speed generally increases UHI strength, but also because wind paths may offer opportunities to ventilate the city. Streets, oriented in the same direction as wind flow, tend to channel the air into the city. However, the planning of the city did not take climate elements into consideration to make use of this opportunity.

The factors responsible for increasing the risk of overheating in Addis Ababa include:

- Weather conditions – UHI effects have a strong relationship with weather parameters, such as wind and cloud cover.

- The city's size, geometric configuration of buildings and streets, and the materials used in the construction of urban spaces define UHI effects' characteristics. Orientation and spacing of buildings play crucial roles in the formation of UHIs. Dense high rise buildings and narrow streets can restrict air movement and trap heat, thus building up hot spots.
- The functioning of the city and increased man-made heat contributions—anthropogenic heat generated by human activity (eg, heat released by the combustion of fuels from mobile or stationary sources, energy use and air pollution) have a bilateral relationship with the UHI effect.
- The increase in development density from Addis Ababa's growth;
- The physical, human and environmental geography of the city parts, including topography, rural surroundings and climate;
- Reduced evaporative cooling.

CC impacts of overheating are:

- An increase in heat-related discomfort, illness and mortality;
- An increase in demand for energy-intensive cooling, such as air conditioning;
- A rise in the demand for water, increasing the pressure on limited water resources and causing water shortages;
- Impacts on quality of water resources, including water pollution caused by a combination of low water flow and heat;
- Damage to temperature-sensitive infrastructure, such as electrical systems and transport networks, and increased maintenance costs of assets and infrastructure;
- An increase in fire risk in green spaces;
- Changes in patterns of vector-borne diseases;
- Increased prevalence of food-borne disease;
- Disruptions to outdoor events due to hot weather;
- Impacts on the economy.

5.2.4 Climate change impact on GI and UA

Climate change impacts on GI and UA in Addis Ababa are complex but potentially arise from temperature increases, droughts, floods, shifts in climatic zones and extreme weather events. As far as UA is concerned, most studies indicate that a range of potential effects could occur from climate change including production changes for staple food crops.

Agricultural activities are more sensitive to climate change /environment fluctuation. Flooding and landslide, drought, water stress, and higher temperatures partially or totally damage agricultural production and productivity.

The impacts of intense precipitation on agriculture can be defined as crop and animal damage by flooding and landslide. Increased soil moisture beyond the crop requirement, waterlogging, creates favourable conditions for soil-borne pest incidence and retards or limits crop growth.

Erratic rain fall and insufficient rain fall distribution during crop production, lack of water for animal production, and water shortage for pasture development are the main factors affecting agriculture production and productivity during the drought /water stress period.

Higher temperature affects agricultural activities through increased evaporation and transpiration of water from the soil and crop; increased crop pest and animal disease incidence creates favourable conditions for the occurrence of unusual crop pest and animal disease. In general higher temperature affects physiological activity of crops and animals as well as reduces agriculture production and productivity.

The impacts of CC on GI and UA in Addis Ababa are summarised as follows:

- CC changes population size and causes shifts in plant and animal communities with possible local extinctions;
- CC causes range expansion of many invasive species and of insect pests affecting plants, reduced biodiversity, and ecosystem services;
- Changes in population size; shifts in plant and animal communities, with possible local extinctions;
- Effects from direct loss of habitat due to altered weather patterns. This can be compounded by other indirect effects such as changes in the distribution or spread of wildlife diseases; parasites; changes in invasive or non-native species, including plants, animals, and pathogens;
- Higher water temperatures and decreased river flow degrades habitat of aquatic species and causes loss of habitat;
- Decreased precipitation leads to:
  - Drying up of vegetation–drying of wetland ecosystems reduces biodiversity and affects ecosystem services;
  - Forest mortality and potential decrease in resilience, accompanied by damage from pests and pathogens;
  - Forest fires occurrence and changes in plant community structures;
- Direct crop damage from flooding;
- Soil erosion and soil fertility reduction;
- Unusual pest incidence;
- Yield decline due to waterlogging;
- Creation of conditions favouring fungal infestations in certain crops;

- Reduced availability of irrigation water and yield decrease;
- Negative impact on rain-fed agricultural production;
- More favourable climate for weed and insect pests, reducing yields;
- More rapid drying of soil after rainfall or irrigation;
- Negative impact on freshwater fisheries, including local extinctions;
- Direct negative health impacts for livestock and changes in ranges of diseases affecting it.

5.2.5 Climate change impact on the urban water cycle of Addis Ababa

The impacts of climate change on the water system are manifested by reduced precipitation, increased precipitation and increased temperature. The hydrological cycle of Addis Ababa has been strongly affected by these manifestations of climate change.

5.2.5.1 Impacts of climate change on water sources

Both the quantity and quality of the water available to Addis Ababa have been affected significantly by climate change. Increasing temperatures lead to changes in the hydrological cycle causing longer and more extreme periods of dry weather/droughts and intense precipitation/floods. By changing the amounts of precipitation and runoff, water resources are seasonally rising or diminishing.

With its dependence on a stressed, centralised water supply system, Addis Ababa's water supply is vulnerable to a shifting climate. In recent years, the city already has been feeling the pressure of unprecedented drought because of reductions in seasonal rainfall, reductions in river flows, reductions in inflow into reservoirs, falling groundwater tables and increased temperatures, which increase evapotranspiration from the reservoirs. With reduced precipitation, rising temperatures and population growth, demand for water for all consumptive uses, including irrigation, domestic and industrial uses in the city, increases and is expected to continue to increase in the future, leading to stronger competition for water resources or requiring the sourcing of alternative water supplies.

In addition, the increased occurrence and intensity of rainfall events cause erosion within river catchment areas, increasing the turbidity levels of the water. Turbidity affects water quality and drinking water production by interfering with treatment processes, by requiring greater expenditure for coagulants and the handling of solids and by overloading process functionality.

Addis Ababa is supported by a number of urban systems that are reliant upon water, including food production and green spaces. These systems, which are dependent upon the timely availability of sufficient quantities of water, will be altered by projected changes in the quantity and seasonality of precipitation. Addis Ababa's responses to diminishing water sources and increased water demand have included implementing water restrictions and considering alternative water sources from distant areas, such as the Jidda and Aleltu rivers further to the north to diversify the water supply sources (Figure 8).

5.2.5.2 Impacts of climate change on water quality

Water quality has been affected by flooding not only through erosion and consequent turbidity increases but also through increases in non-point pollution and through damage to wastewater treatment plants and consequent bacterial contamination of water. Water quality also has been affected by decreased precipitation, which concentrates pollution. Precipitation decrease and its impact on surface water will result in increased extraction of groundwater and the use of sources with lower water quality, which also affects treatment processes.

5.2.5.3 Impacts of climate change on water infrastructure

Climatic events damage the infrastructure related to urban water systems. Flooding negatively affects the physical infrastructure of the water system through direct damage to pipelines and facilities, sedimentation of reservoirs and overloading of capacity. Climate change reduces the functionality of drinking water treatment by—for example—lessening the effectiveness of treatment processes such as chlorination or by causing overly high disinfection byproduct levels in the distribution systems.

The functionality of water infrastructure also is affected by increased temperatures, which favor the proliferation of equipment-clogging algae and which lead to greater expense for treatment to remove the taste and smell linked to bacterial and fungal growth. Colder temperatures during the months of October to December also affect functionality by freezing the water in pipes, which leads to cracks and leaks. Pipes also can crack because of the drying of soils during drought conditions.

Addis Ababa is characterised by a predominance of impermeable surfaces. Such surfaces are less capable of absorbing increased rainfall and therefore increase the intensity of rainfall runoff and overwhelm the current drainage systems. As rainfall becomes more intense, surface runoff levels exceed the capacity of the storm water system and cause sewer overflows, leading to street flooding and to a significant amount of a combination of untreated sewage and rain water entering the city's rivers, causing frequent health dangers due to contamination.

Climate change also is expected to result in increased and more frequent flooding because of the disappearance of natural systems that act as temporary sponges or slow releasers (such as surrounding green spaces).

The costs and consequences of flooding are magnified by growing population density and economic activity in at-risk areas, as well as by the existence and spread of informal settlements in Addis Ababa.

Drying and shrinking soils caused by droughts generate cracks in pipes, storm water drains and sewers. Not only does this lead to contamination problems, it also increases maintenance costs. Changes in vegetation and soil characteristics due to increased temperatures and higher rates of evapotranspiration also change attenuation and infiltration rates, affecting soil retention capacity.

5.2.5.4 Impacts of climate change on wastewater

Much like the water supply, the integrity and functionality of the wastewater treatment infrastructure also is affected by climate change. The infrastructure of collection lines and wastewater treatment, including outfalls, pipelines and tanks, are physically damaged by flooding caused by increased precipitation. Functionality is also impaired by increased temperatures. Higher temperatures coupled with reduced rainfall lead to increased pipe breakage due to the drying and shrinking of the soils as well as increased deterioration of pipes due to corrosion from a buildup of hydrogen sulphide. Wastewater management is also indirectly influenced, as increased temperatures affect the oxygen levels of receiving water bodies and therefore lead to more stringent wastewater treatment requirements in order to stabilise these levels so as not to endanger ecosystems.

To summarise, the impacts of increased precipitation on the water system of Addis Ababa are manifested by:

- Increased erosion, which causes an increase in suspended solids/turbidity, leading to sedimentation of reservoirs and decreased water storage capacity, reduction of channel capacity within the drainage infrastructure and impacts on the water supply due to influence with treatment processes;
- Decreases in groundwater recharge as heavy precipitation exceeds soil infiltration capacity and increases surface runoff;
- Flooding of water and wastewater facilities causing damage and contamination of water and erosion of pipelines;
- Contamination of water bodies as a result of point and non-point source pollution from increased runoff of nutrients, pathogens, and toxins;
- Capacity overload of water and wastewater treatment plants.

The impacts of reduced precipitation are:

- Surface water and groundwater shortages due to decreased river flow and decreased groundwater recharge;
- Increased groundwater use as surface water availability declines;
- Increased water withdrawals from low-quality sources due to shortages, leading to increased requirements for water treatment than is the case for water from high-quality sources;
- Water quality deterioration through reduced water oxygen concentrations and other chemical and biological changes to river features, which can lead to algal blooms and increased water treatment requirements.

Increased temperature causes:

- Increased water demand, and hence, increased water extraction for domestic, agricultural and industrial uses;
- Increased evaporation and evapotranspiration of surface waters and salinisation of groundwater;
- Reduced water quality due to reduced oxygen concentrations and increased occurrence of eutrophication and toxic algal blooms;
- Increased groundwater extraction to compensate for reduced river flows;
- Increases in microbiological activity and bacterial and fungal content in the water, requiring additional treatment to remove odour and taste;
- Reduced oxygen content in wastewater effluent receiving waters, leading to more stringent wastewater treatment requirements;
- Corrosion of sewers and physical destruction of transmission and distribution infrastructures.

6. GBI in the management of urban development and the impacts of climate change

In urban areas there is a logical interdependency between GBI, urban development and climate change mitigation and adaptation.

6.1 GI in mitigation of, and adaption to, climate change

Addis Ababa needs to promote GI and sound watershed management to create a network of interlinked, multi-purpose open spaces to support its regeneration and development. This should be delivered through a programme of projects that are designed to enhance the potential of existing and new green spaces to contribute to carbon sink, conserve water resources, absorb and store water and prevent flooding, reduce storm water runoff, control erosion, reduce siltation of rivers, mitigate the urban heat island effect, cool the vicinity, improve public health, protect fisheries and investments in hydro-electric power facilities, preserve biodiversity, connect people and places and provide a diverse mosaic of habitats for wildlife. The following five categories of actions are needed to enhance the ecosystem services performed by Addis Ababa's GI:

- *Quality:* Improve the resilience of Addis Ababa's green spaces through proper management and by reducing harmful impacts, such as pollution and invasive species;
- *Quantity:* Protect existing green spaces and increase the area of green space in Addis Ababa by looking for new opportunities, even where there is no apparent "space" for greening the city, considering options such as street trees, green roofs and green walls;
- *Function:* Design new green spaces into new or refurbished development to maximise their use (such as cooling or flood storage). Identify and pursue opportunities to enhance the function of existing green spaces (for example flood storage in riverside parks);
- *Connectivity:* Many of the ecosystem services provided by green spaces would be enhanced by increased connectivity. New green spaces should be designed to improve links between new and existing spaces for people and wildlife;
- *Communication:* Ensure good communication and coherency across all organisations working on delivering new green spaces and managing existing ones.

Given the multiple services that GI provides to society and the role they play as habitats of a diverse fauna and flora, their maintenance/enhancement is critical for building resilience to future risks, including climate-related ones. These ecosystem services are essential to the well-being of residents of Addis Ababa and Addis Ababa's resilience to climate change. Improving the quality, quantity, connectivity and diversity of Addis Ababa's green spaces will create a "GI". This will increase their resilience and therefore increase the capacity of Addis Ababa and Addis Ababa's biodiversity to adapt to a changing climate. Some of the adaptation measures required to ensure Addis Ababa continues to offer its residents a high quality of life will also increase, or add to the city's biodiversity.

The preservation and expansion of trees and green spaces in Addis Ababa contributes to both climate change adaptation and mitigation. Vegetation absorbs carbon, helps keep the city cooler in the summer and increases the amount of groundwater recharge, thereby lowering flood risk. Urban structures such as asphalt and buildings absorb more solar energy than grass and trees, increasing the local temperature – a phenomenon known as the urban heat island effect. Vegetation in the congested urban parts helps decrease this effect, providing a safer environment health-wise and lowering the need for air conditioning.

6.1.1 Adaptation

In the context of Addis Ababa, for green space to fulfill its full potential in relation to urban environment, a number of potential adaptation (planned) measures have been suggested (see Worku, 2017).

6.1.1.1 Urban forest management and biodiversity conservation

An estimated 14% of Addis Ababa's land area is under forest cover. Indigenous trees are relatively robust, and in the medium term, climate change is not likely to have a serious adverse impact on existing trees, although increased drought stress may shorten their lifespan. However, over time, the species composition of Addis Ababa's forests may change as the changing climate benefits some species and limits others. To scale up GI development, particularly afforestation, reforestation and river rehabilitation programmes to adapt to the changing climate, the following response options were proposed:

- Encourage afforestation or reforestation programmes and delineate areas for conservation, production, reforestation, agroforestry, and recreational functions;
- Replace vegetation with drought-tolerant, low-maintenance native species that can also provide shade and reduce heat island effects;
- Produce the "Right Trees for Addis Ababa's" Changing Climate database of tree species and their climate sensitivity. Attention should be paid to tree species that can tolerate the microclimate of the area, that are fast-growing and that can supply economic benefits. Agro forestry projects consisting of highland fruit plantations would provide a win-win situation;
- Improving urban forest management practices to protect/preserve existing forests from losses by various practices;
- Promote urban forest development and management to contribute to carbon sink, conserve water resources, reduce storm water runoff and prevent flooding, control erosion, reduce siltation of rivers, mitigate the

urban heat island effect, improve public health, protect fisheries, reduce maintenance investments in hydro-electric power facilities and preserve biodiversity;

- Develop an Urban Forestry programme to consolidate policies and ordinances regarding tree-planting, maintenance and removal, including:
  - Comprehensive inventory and analysis of the urban forest and trees; trees in the city must be counted and tagged;
  - Tree-planting target;
  - Establishing guidelines for tree-planting (deciduous vs. evergreen, low-VOC producing trees, drought-tolerant native trees and vegetation; and monitor survival and impact);
  - Imposing a ban on tree felling;
  - Provide land in the city plan for agriculture/food producing areas: Agricultural practices that respond to land degradation issues and enhance soil quality while reducing agro-based GHG emissions should be implemented.
- Maintain and increase ecosystem resilience: enhancing the ability of ecosystems to absorb and recover from change while maintaining and increasing biodiversity;
- Develop habitat plans to protect and enhance the pattern of natural and semi-natural habitats including biodiversity conservation;
- Increasing habitat heterogeneity within reserves and between reserves;
- Reducing and managing existing stresses, such as fragmentation, pollution, over-harvesting, population encroachment, habitat conversion and invasive species;
- Maintaining ecosystem structure and function as a means to ensure healthy and genetically diverse populations are able to adapt to climate change;
- Increasing the size and/or number of reserves;
- Conducting restoration and rehabilitation of habitats and ecosystems with high adaptation value;
- Intensive conservation management to secure populations, including for threatened and endangered species;
- Translocation or reintroduction of species at risk of extinction to new areas that are climatically suitable for their existence;
- Ex situ conservation eg, seed banks, zoos, botanic gardens, captive breeding for release into wild;
- Continue pest and invasive species monitoring programs which occur as a result of climate change as an added stressor;
- Emphasise connectivity for all GIs within the city and across the city periphery to rural areas.

6.1.1.2 River restoration or rehabilitation or remediation

- Set river restoration or rehabilitation or remediation vision, goals and objectives;
- Delineate appropriate river buffer plans, restore, rehabilitate or remediate Addis Ababa's rivers per the set vision, goals and objectives; clean up contaminated land and water;
- Weather for industrial or residential function or other functions, orient facing direction of the plots towards the river and separate from the buffer by road or foot path in local plans. This will ensure that the rivers are public property and will not be used as a backyard solid and liquid waste dumping site.

6.1.1.3 Parks

Parks and green space also can play an important role in decreasing the impacts or occurrence of flooding from heavy rainfall. Parks can be used for detention and infiltration of storm water. Climate change is predicted to exacerbate undesirable agents of rapid change such as invasive pests or indigenous pests which are opportunistic to new environmental stress. Monitoring is essential to ward off major problems before they exceed our ability to control them. Climate change will exacerbate the implications of habitat isolation necessitating a renewed effort to increase habitat connectivity. The Park Management Plan must include considerations for climate change such as "wind-proofing", appropriate site selection/ planting practices, species selection and pest monitoring. These considerations will need to be applied to other urban green spaces and trees, including development landscape plans, street trees and trees on private property.

- Standardise park planning and attach major functions and proper management; provide adequate, attractive and accessible parks at the city, sub-city, woreda and neighborhood levels, having different functions;
- Link parks and people by introducing park connectors such as green corridors for people to stroll, jog, and cycle between parks; to date, Addis Ababa has no park connectors.

6.1.1.4 Green roofs and walls

- Build "gardens in the sky" by encouraging developers to incorporate green roofing;
- Develop vertical gardening by encouraging developers to incorporate green walls.

6.1.1.5 Clean and green cemetery

- Plan, develop and manage clean and green cemeteries in the city.

6.1.1.6 Street planting

The planting and management of street trees and other trees in parks and gardens may require new approaches to ensure that new trees are suitable for the changing climate. The "Right Place, Right Tree" approach should be promoted to ensure that these factors are considered. It is suggested to produce the "Right Trees for Addis Ababa's Changing Climate" database of tree species and their climate sensitivity (Worku, 2018). The database offers users the ability to identify suitable tree species to replace and supplement Addis Ababa's existing tree stock according to the conditions of the proposed planting site and a range of climate variables. Further research will identify and provide planting and maintenance best practices to manage urban trees under a changing climate and to minimise vandalism.

There should be suitable shade trees along pavements and appropriate shrubs along road median so as not to hinder traffic visibility; tree-planting on vacant land and new development sites needs to be undertaken.

6.1.1.7 Urban Agriculture and food security

The prospects for UA are good in Addis Ababa and the surrounding areas. However, it is crucial that planners start recognising the importance of UA in the rich mix of activities that characterise modern cities. As the city population increases, greater local food self-reliance, using nutrients accumulating in the city, must be regarded as an important aspect of sustainable urban development. UA can reduce the "ecological footprint" of the city if the environmental goals are combined into an overall urban development policy.

Addis Ababa produces very little of its own food, leaving urban residents overwhelmingly reliant on food supplies imported from distant rural areas and often even transcontinental shipping. Local food security is often subject to a range of demographic and economic trends at global, national and local scales, including population growth, changes in consumption patterns as income levels rise, competition for agricultural land, and energy and transportation costs. These combined factors can strain food supplies, raise real food prices and make cities vulnerable to food shortages.

The foremost challenge before the sector is to adequately provide for the food and fibre needs of a growing population without irreversibly damaging the fragile ecosystem. Being open to the vagaries of nature, the urban agriculture sector is highly vulnerable to climate change phenomena. Climate change will impact the food security of the country mainly through reduced crop productivity and adverse impacts on livestock health, productivity and reproducibility as well as through increased production losses caused by extreme events (floods, droughts and high temperatures).

Urban Agriculture has been identified as one of the key sectors for adaptation in Addis Ababa. To enhance UA the future action/strategy should focus first on promoting Agricultural Urbanism (AU). Agricultural Urbanism is a newly developing planning framework, promoted in different forms and under different labels by practicing architects, landscape architects, and planners, that sees municipal food networks as analogous to other vital infrastructure such as roads or sewers. It aims to improve food access, security, and knowledge by integrating context-sensitive UA and other food-related activities into a wide range of development settings both at the regional and city levels. Planners have to recognise UA as an important component of sustainable and resilient environments and are required today to link UA with planning practices. Local food production can be an important complement to planning strategies that address community building, environmental health, food security, storm water management and jobs generation. Regional plans have to identify working agricultural land in the city and on the city fringe as a necessary resource to address food-systems planning and maintain the flow of locally grown produce to urban and suburban consumers. Lands should be zoned in the city and on the fringes of cities for UA and these actions be supported by legislation to protect it from encroachment and development.

Presently, most of the land available for UA in Addis Ababa is along the riverbanks, which are either highly contaminated or prone to contamination. There has been concern about the suitability of such contaminated urban land for food growing. Generally, land polluted by heavy metals, such as cadmium and lead, requires special precautions. Research has shown that these problems can be tackled in a number of ways if Addis Ababa wants to continue using these areas for UA. Firstly, maintaining a high pH with additions of plenty of lime, and high organic matter levels through additions of compost or manure helps to immobilise heavy metals in the soil. The second and most feasible option in the case of Addis Ababa is to use these contaminated areas for growing ornamental and perennial fruit trees instead of vegetables.

The objective is creating socio-economically viable and environmentally friendly UA and food systems that reduce climate change impacts in Addis Ababa.

6.1.1.8 Development of climate resilient cropping systems appropriate to the agro-climatic conditions' not 'to agro-climatic condition

Major adaptation strategy includes:

- Promoting Agricultural Urbanism (AU) – provide land in the city and along the city periphery for food producing areas;
- Introducing closed loop environmental technologies

Specific actions include:

- Formulate appropriate guidelines and tools for participatory and sustainable city planning that integrates a citywide UA plan to accommodate urban agricultural production and marketing;
- Identify the predicted demand for urban farmed food and recommend location and distribution of UA and urban agricultural institutions;
- Develop a plan that will promote healthy, local, and, where possible, organic food production, and include multiple stakeholders currently involved in food production and job training;
- Increase the number of city farms and gardens in parks, on vacant lots, school grounds, and other appropriate and available areas;
- Enhance non-traditional agriculture such as mushroom cultivation in order to expand these farming systems that require relatively smaller land areas;
- Promote value addition methods such as storage, processing, packaging and utilisation;
- Promote UA as a business so that it can effectively contribute to income generation, achievement of sustainable livelihoods and poverty reduction;
- Recycle organic waste from UA and promote greening of the environment: encourage composting programs to separate food, yard and garden waste from recyclable and non-recyclable solid waste. These programmes reduce the amount of organic waste being sent to landfills and provide nutrient-rich soil for gardeners;
- Introduce interventions such as safe irrigation techniques, improved shallow wells and boreholes that will minimise health risks in the use of marginal quality water;
- Effectively coordinate interventions in education and training in the safe use of pesticides especially for fresh vegetable production;
- Develop incentives and support for urban farmers and farm enterprises;
- Provide technical support and capacity strengthening in sustainable urban production to farmers through agricultural extension agents;
- Build the capacity of local growers and city residents in how to grow food: encourage public and private health professionals, food-security organisations and other community-based nonprofit organisations to play important roles in developing and implementing a variety of nutrition, health, food literacy and environmental-stewardship programmes;
- Strengthen the infrastructure necessary for widespread, sustainable urban food production;
- Local and federal governments and other stakeholders should make budgetary provision to institutionalise UA;
- Establish credit schemes for urban farmers;
- Provide grants for UA activities;
- Explore synergies between key stakeholders through appropriate information exchange and learning platforms.

6.1.1.9 Connectivity among different GI components

- Use existing and planned GIs such as rivers, street medians and sidewalks to create connectivity among various GI components

6.1.2 Mitigation

Mitigation involves GHG emission reduction through GI (interventions to enhance carbon sink).

Urban green spaces can mitigate the impacts of climate change through:

- Absorption of pollutants, including greenhouse gases;
- Influencing people’s behaviour in order to reduce emissions of greenhouse gases.

6.1.2.1 Absorption of Pollutants

Although the main climatic benefits of urban green space is cooling and shading, vegetation and soils, particularly trees, can counter poor air quality by absorbing greenhouse gases such as carbon dioxide and other air pollutants. Green space can act as "carbon sinks". Trees take in carbon dioxide during photosynthesis and store carbon until they are burnt or die. This can be especially effective if trees are located close to a pollution source. Soils generally also will store carbon, especially rich, organic soils.

6.1.2.2 Influencing behaviour

Stopping or slowing deforestation and forest degradation (loss of carbon density) and sustainable management of forests may significantly contribute to avoided emissions, may conserve water resources and prevent flooding, reduce runoff, control erosion, reduce siltation of rivers, and protect fisheries and investments in hydro-electric power facilities; and at the same time preserve biodiversity.

Preserving forests conserves water resources and prevents flooding. By reducing runoff, forests control erosion and salinity. Consequently, maintaining forest cover can reduce siltation of rivers, protecting fisheries and investment in hydro-electric power facilities.

In addition to reducing the amount of GHG emissions that are produced in the city, one means through which urban actors in Addis Ababa could address the challenge of mitigation is through carbon sequestration. Carbon sequestration involves removing GHG emissions from the atmosphere, either through enhancing natural ‘carbon sinks’ (eg, conserving forested areas and enhancing river environments), the development of new carbon sinks (eg, reforestation or afforestation) or through the capture and storage of GHG being produced within the city. The capture of methane from landfill sites for energy generation is also a form of mitigation.

Traditionally, such activities have been peripheral to the main focus of urban mitigation activity. However, new developments in carbon capture and storage technologies, growing interest among national governments in carbon capture and storage, especially in developed countries and the more industrialised developing countries, and the increasing availability of carbon finance through international policy instruments – such as the CDM – are making carbon sequestration schemes more popular at the urban level. Regionally, carbon sequestration schemes are more common in developing country cities, often associated with gaining CDM credits or development programmes. Actions promoting urban tree-planting and restoration, preservation or conservation of carbon sinks should be taken in Addis Ababa for reasons of environmental protection or the preservation of urban green spaces at the same time associating them specifically with climate change mitigation objectives.

Most carbon sequestration initiatives at the urban level relate to tree-planting schemes and the restoration and preservation of carbon sinks. Urban tree-planting programmes frequently rely on cooperation between the city government and citizens. The city government has to develop technology transfer and promotion campaigns for urban tree-planting. However, the results depend largely on the voluntary intervention of citizens – for example, the One Person, Two Trees Tree Planting Incentives programme in 2007 was a very good approach but was not very successful because of lack of after-planting care for the trees.

The programme started in 2007 with the objective of planting two million trees in Addis Ababa. Preservation and restoration of carbon sinks is also dependent on government intervention, a ban on tree felling has to be imposed, and trees in the city must be counted and tagged to prevent felling. Carbon sequestration can be combined with city beautification, particularly when a range of measures to create and protect green spaces and facilitate public access are combined.

CDM mechanisms may help to initiate afforestation and nature conservation programmes with carbon sequestration benefits. The EPA of Addis Ababa, in cooperation with CDM Ethiopia, needs to develop a five year project (2015 to 2020) for the afforestation of 30 km of road (0.5 million trees) around the ring road of Addis Ababa. The project is expected to contribute to the reduction of GHG emissions (100,000 tonnes of CO_2eq per year) and to local sustainable development objectives.

A wide range of actors in both public and private partnerships have to develop Addis Ababa into a "Garden City". The effort should attempt to increase the aesthetic appeal of the city, providing public open spaces and improving air quality, protecting carbon sinks and reducing the urban heat-island effect. The key strategies for carbon sequestration in Addis Ababa are:

- Increasing canopy cover citywide as a measure to help mitigate climate change. Map canopy coverage with land use, identify tree deficient areas and work to add tree space. Hot spot and vulnerable population mapping can be overlaid with canopy coverage to target certain areas for shade provision;
- Urban carbon capture and storage; the development of schemes to capture CO_2 emissions from GHG emitting sectors within the city and place in long-term storage using trees;
- Restoration of carbon sinks which seek to restore areas of natural carbon sinks in the city;
- Preservation and conservation of carbon sinks which seek to preserve and enhance areas of natural carbon sinks in the city;
- Carbon offset schemes to implement the purchase of carbon sequestration offsets by actors within the city from schemes located either in the city or elsewhere;
- CDM mechanisms should be introduced to initiate afforestation and nature conservation programmes with carbon sequestration benefits.

CRGE strategy of Addis Ababa has suggested that implementation of GI activities listed above has an abatement potential of approximately 13.41Mt CO_2e which leads to zero net emissions in 2030.

6.2 BI in the management of urban development and the impacts of climate change in Addis Ababa

6.2.1 Adaptation to climate change

The water management objectives for Addis Ababa's adaptation to climate change are to:

- Ensure adequate water supplies while encouraging water use efficiency;
- Improve flood prevention strategies while encouraging people to be prepared for this risk.

These objectives are achievable through IUWM strategies, which involve managing the entire urban water cycle, including:

- Water resources protection and conservation;
- Reliable water supply (response to reduced rainfall, drought, and water scarcity);
- Storm water management and flood control;
- Efficient wastewater management;
- Development of water spaces to provide space for water storage (detention, infiltration, and evaporation) and water recreation.

6.2.1.1 Water resources, protection and conservation at different spatial levels

Water resources, protection and conservation should be undertaken at the catchment, neighbourhood, street and household levels. At the watershed/catchment level, various water resources conservation strategies should be undertaken to enhance infiltration and water quality so that upstream land use will not create problems or shift them downstream. The interventions should involve terracing and/or infiltration ditches or swales, which can reduce soil erosion and improve permeability and groundwater recharge. In areas with limited infiltration, the focus should be on surface water retention. Water from retention ponds can be used for various purposes. Retention ponds could be part of the city's forest and park system or located in recreation areas in various parts of the city. Retention ponds also can create attractive views for city neighbourhoods.

At the neighbourhood level, bioretention systems should be provided to slow down, collect and filter storm water runoff. Bioretention basins should be designed to collect water and give it time to infiltrate into the ground or evapotranspirate into the air. Alternatively, a bioretention system could be constructed directly into drainage channels or swales as conveyance treatment devices rather than storage devices. Because of their relatively small footprint and flexible design features, bioretention systems can easily fit into urban landscapes or other areas where space is limited. Bioretention systems can remove a wide range of pollutants from storm water runoff, including suspended solids, nutrients, metals, hydrocarbons and bacteria. They also can be used to slow water flow to reduce peak runoff rates.

At the street level, highly porous/permeable cobblestone pavement should be used for walking and parking areas and to accommodate motor vehicles on low- to moderately travelled streets. Permeable pavement should be specially designed to allow storm water to infiltrate through the pavement and into the ground to recharge the water table. Permeable pavement is ideal for planting trees in a paved environment because it allows adjacent trees to receive more air and water, while still permitting full use of the pavement.

At the household or building level, several water conservation strategies can be implemented as described in the sections below.

6.2.1.2 Reliable water supply (response to reduced rainfall, drought and water scarcity)

The primary response to reduced rainfall, drought and water scarcity involves updating drought management plans to recognise changing conditions as well as providing information and increasing public awareness about how climate change impacts water supplies and how residents can reduce water use. To have a secure supply of water that is affordable and safeguards the environment and hence achieves the sustainability objective, it is important to improve the balance between Addis Ababa's water supply and demand. This will allow Addis Ababa to mount a robust response to drought by improving water supply and demand management to counter climate change impacts.

To adapt against the impacts of drought, it is important to avoid climate-dependent water management and to prepare water resource management plans detailing how to provide sufficient water to meet demand and manage environmental impacts. This plan should balance supply and demand by decreasing water use or increasing supply, (ie, through demand and supply management) over a long period of time.

Water supply management

The most urgent strategy for intervention in water supply management should focus on expanding and diversifying water supply sources. This includes construction of new surface water reservoirs/dams, augmenting surface water supplies, inter-river basin transfers, developing new groundwater sources/boreholes, maximising rainwater harvesting/storage by capturing urban runoff through distributed water harvesting structures, and developing advanced wastewater treatment capacity/grey water recycling systems for effluent reuse in new and retrofitted buildings. Effective leak detection and repair and enhancing GI also contribute to the supply side.

An intervention strategy is urgently needed in the management of Addis Ababa's water supply. This strategy should focus on expanding and diversifying water supply sources. This includes:

- Constructing new surface water reservoirs/dams;
- Augmenting surface water supplies;
- Facilitating inter-basin transfers from such resources as the Gerbi, Sibilu, Aleltu and Jida river basins;
- Developing new groundwater sources/boreholes;
- Maximising rainwater harvesting/storage by capturing urban runoff through distributed water harvesting structures;
- Developing advanced wastewater treatment capacity/grey water recycling systems for effluent reuse in new and retrofitted buildings.

Increasing reservoir capacity, either by increasing existing water storage facilities and/or by constructing new surface water reservoirs, will increase sustainable storage capacity to sustain the urban water supply under conditions of more frequent river-flow variations and greater competition for water.

Sourcing of alternative water supplies, such as rainwater harvesting or reuse of treated wastewater effluent for non-potable demand—for example—for watering parks and, potentially, for irrigation, needs to be implemented. Effective leak detection and repair and enhancing a GI also contributes to the supply side.

Increasing reservoir capacity, either by increasing existing water storage facilities and/or by constructing new surface water reservoirs, increases sustainable storage capacity to sustain the urban water supply under conditions of more frequent river-flow variations and greater competition for water.

Water demand management

A water demand management strategy that is considered appropriate for Addis Ababa is demand reduction through water conservation and efficiency increases. These measures should involve reduction/restriction of high nondomestic water consumption through replacement by recycled water, water recycling for other appropriate uses, using water-efficient technologies and equipment that cut water use in buildings, active leakage management, behaviour change/awareness raising about water conservation, and economic incentives, including increasing supportive tariffs/pricing to encourage water conservation, such as setting progressive tariffs with a pricing structure that charges more for high consumption.

In the past, conventional water resource management strategies, such as the construction of storage reservoirs and digging deep wells, have been adopted to meet growing water demands (AAWSA, 2003, 2005, 2001, 2012). It is now recognised that unlimited water resource utilisation through conventional surface water and groundwater development (supply management) is not the only option available. The implementation of water conservation strategies can successfully achieve the same objective of bridging the gap between demand and supply (Addis Ababa City Administration [AACA], 2015).

A water demand management strategy appropriate for Addis Ababa should involve:

- Reducing high non-domestic water consumption through replacement by recycled water and water recycling for other appropriate uses;
- Using water-efficient technologies and equipment that cuts water use in buildings;
- Engaging in active leakage management;
- Encouraging changes in behaviour and building awareness of the importance of water conservation and economic incentives, including pricing to encourage water conservation such as setting progressive tariffs with a pricing structure that charges more for high consumption.

Water of potable quality that must be used for drinking, food preparation, cooking, and cleaning represents less than 30% of the water used in Addis Ababa. We must, therefore, explore ways of reusing water or using lower quality water for uses that do not require potable quality water. Demand for potable quality water could be reduced by onsite recycling of grey water for toilet flushing or garden watering. Local area management and treatment of wastewater flows could be used to water parks and gardens and in industrial cooling. The high nondomestic water consumption and demand in Addis Ababa as a result of the booming construction and other industries is costly in terms of treatment infrastructure both for water supply treatment and wastewater treatment, and conveyance of water streams. High-quality, potable water use needs to be reduced or replaced by recycled water.

The combined application of low-flow plumbing fixtures, including water saving taps, showerheads, and toilets, and the reuse of grey water from bathing and washing for toilet flushing, will result in a 50% reduction of water use. Rainwater and recycled water can be used for watering gardens and car washing and can save up to 10% of potable water. Application of appropriate demand management that suits local conditions can save more than 50% of potable water (AACA, 2015).

6.2.1.3 Response to increased rainfall and flooding

To respond to increased rainfall and flooding and to make flood-prone areas more resilient, four strategies could be implemented.

The first strategy is planning and preparedness, which involves:

- Identifying areas at greatest current and future flood risks;
- Increasing understanding of how climate change will alter the risks;
- Implementing forecasting and early warning systems using climate and weather information;
- Preparing an emergency plan or coping mechanisms.

The second strategy is implementing appropriate spatial planning to avoid locating flood-vulnerable land uses in high flood-risk areas through zoning changes to discourage or prohibit development in flood-hazard areas.

The third strategy is implementing flood defence structures, including retaining walls, gabion walls or sheeting piling, which should be used to protect/ prevent/ defend vulnerable land uses.

The fourth strategy is flood accommodation, which can be achieved by implementing source control techniques, such as sustainable flood/storm water management. This involves modifying urban landscaping requirements to reduce and attenuate storm water through:

- Implementing various water storage and conservation techniques, including green roofs, porous paving, swales, rainwater harvesting, and detention and retention ponds and basins;
- Improving and extending infrastructures conveying storm water away from the city, such as drainage and sewerage systems;

- Innovative design of buildings and infrastructure, integrating climate change into building codes and spatial planning to adapt building and planning codes to require greater flood-resistance in structures located within floodplains;
- Raising awareness and knowledge of flood risks among the public and engaging in capacity-building efforts groups as a mechanism to cope with floods and flood risks;
- Implementing insurance for damages.

6.2.1.4 Response strategies to flood impacts and urban development

To respond to the impacts of flooding, to make flood-prone areas more resilient, and to avoid/reduce loss of life and damage to property, feasible strategies to be implemented in Addis Ababa include:

- Identifying and mapping flood-prone areas and division of the areas into various flood management zones;
- Re-naturalising rivers and channels/river restoration;
- Managing surface water/storm water at city, sub-city, neighborhood, site/project and building levels;
- Flood defence and accommodation;
- Flood risk management.

Identifying and mapping flood plain/flood-prone areas and division of these areas into various flood management zones

To limit development in flood plain/flood-prone areas, vulnerable zones should be indicated on an environmental map/spatial plan. Mapping of flood risk areas—who and what is at flood risk from all sources of flooding today and in the future, taking CC scenarios into account—should be conducted at the city, sub-city, neighbourhood and project/site levels.

To ensure safety, flood-prone zones should be established according to flood risk and site elevation, and areas where construction is allowed and areas where construction is forbidden should be defined. Natural floodplains should be preserved to provide space for streams and rivers to expand during periods of high rainfall. Floodplains should be separated from flood-safe zones by setback lines, and the floodplains should be classified into two different zones: an inviolable zone/restricted zone, which is strongly vulnerable to floods and should be free of any construction, and a buffer zone, where seasonal and occasional floods are experienced.

Inviolable zones are areas which are extremely vulnerable to floods and are used to retain the regular floods. Any housing structures or land uses that impact the natural setting of the river or channel in these zones should be banned. In addition, development and infrastructure in these hazardous areas should be moved or abandoned. Land use planning should avoid locating structures in these risky areas. Environmental Impact Assessment (EIA) should be utilised for any intervention sought in such areas.

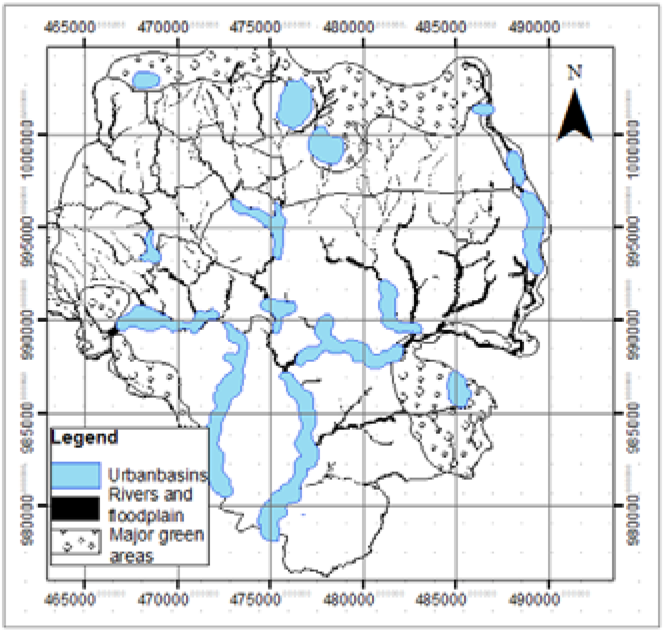


Figure 24: Map of Addis Ababa

Map showing the location of flood plains, decentralised urban basins, and major green areas

Source: Worku, 2017b

To utilise land within a floodplain and to ensure that flood waters are not constrained, a buffer zone should be developed in the floodplain. Within this buffer zone, flood-friendly land uses/open land uses or development, such as agriculture, parks, playgrounds or flood-proofed buildings that would ensure that the hydrological function of the natural floodplain might be allowed to continue, but an EIA for the development site must be conducted before a decision is made.

To provide sufficient distance from water bodies, a construction setback from riverbanks, floodplains, flood ways and generally flood-prone areas should be maintained. The setback line should be defined by an EIA and should separate flood-prone areas from flood-safe areas.

In floodplain/flood-prone areas, flood damage can, therefore, be avoided by appropriate spatial planning, which involves avoiding locating flood-vulnerable land uses in high flood-risk areas and identifying where current developments should be removed or exchanged for less flood-sensitive land uses in the future. Decisions regarding banning or avoiding the construction of buildings and other important structures, such as houses, health facilities, industrial buildings, etc., in current and future flood-prone areas should be based on spatial planning to avoid flood damage.

Spatial planning plays an important role in flood prevention by restricting building in flood plains, conserving flood retention areas, and minimising impermeable surfaces. A green scoring factor for new urban developments, which ensures that a certain proportion of the development will consist of green space, should be used. Different development covers should receive different scores, depending on their efficiency (eg, sealed surface = 0; green roof = 0.7; vegetation on the ground = 1), allowing the developer some flexibility while ensuring that the requirements for the provisions of green space are met.

Re-naturalising rivers and channels /river restoration

To ensure successful flood protection, rivers and channels should be re-naturalised to their original state. This will encourage infiltration, help reduce bank erosion and enhance the natural habitat along rivers and channels. Four main strategies to re-naturalise rivers are:

- River channel improvement by removing obstructions, such as solid waste, weirs, and impounding constructions, to increase flood retention capacity and retain the original flow velocity. Modifying rivers and channels by removing sediments and increasing the depth and/or width of channels is not recommended unless the assessment of such modifications recommend such actions;
- Re-meandering riverbeds to their natural curves to enhance the storage capacity of river plains, delay flood peaks, reduce flow rates and erosion, increase bank infiltration and allow for a wider distribution of silt deposition;
- Reconnecting rivers with floodplains to allow better water storage capacity by lowering riverbanks to their natural levels, lowering embankments, and setting back levees and dykes;
- Re-naturalising embankments/increasing natural river bank stabilisation measures or preserving ecological buffers. Embankments should only be considered for highly vulnerable stretches of the riverbank; less vulnerable banks should be returned to close to natural conditions. Where necessary, embankment design should reflect natural conditions using techniques such as planted gabion or cellular concrete blocks instead of solid concrete lining. These measures help to protect embankments from erosion, enhance infiltration of floodwater, and slow down flow velocity. Additionally, the wider distribution of sediment deposition will provide better conditions for vegetation growth, creating wildlife habitat and improving the aesthetics of the rivers and channels.

Managing surface water/storm water at city, sub-city, neighbourhood, site/project and building levels

Surface water/storm water should be managed at catchment, site, source and inlet levels, a practice commonly considered to be a sustainable storm water management technique. This technique reduces the amount of storm water that needs to be taken up by the sewerage system, thus reducing the necessity to extend and upgrade the existing sewerage system. Managing surface water and storm water includes a variety of techniques that aim at reducing the quantity and improving the quality of storm water at or near its source by using infrastructure or natural physical resources, such as soil and water conservation techniques. Sustainable storm water management strategies in the context of Addis Ababa at the catchment, neighbourhood, site/project and building levels should involve infiltration and permeability, retention and detention/storage and drainage and conveyance.

Infiltration and permeability

Facilities for infiltration and permeability include:

Reduction of impervious areas: To reduce the overall runoff and provide more space for water infiltration, the impervious coverage of a site should be limited to a minimum. To reduce the building footprint, building density has to be increased on built-up surfaces by relaxing the building height limitations. Reduction of road widths and the amount of surface parking should be considered, especially in compact, high-density areas where public transport and services are within walking distance. Impervious surface materials for open spaces should be avoided.

Absorbent landscape (soil and vegetation): To optimise storm water runoff, the landscape should be designed to increase the water-absorbing capacity of the urban landscape to allow infiltration and evapotranspiration. Typically landscape soils store up to about 18% of their volume as water before becoming saturated and generating flow-through or runoff (Brandenburg University of Technology Cottbus, 2013). The absorbent soil surface layer should have a high organic content, and the surface vegetation should be composed of herbaceous plants with thickly matted rooting zones (such as shrubs or grass), deciduous trees with high leaf density, or mixed growth forests. Runoff from landscaped areas can be reduced by up to 50% by providing a 300 millimeter layer of landscaped, absorbent soil (Brandenburg University of Technology Cottbus, 2013).

Permeable pavements and surfaces: To prevent runoff from paved surfaces, permeable paving materials, such as cobblestone, should be used for roads and parking lots. Permeable paving allows infiltration, either because it is porous or because specific openings, such as spaces between paving blocks, have been provided. In areas with limited vehicular traffic, permeable paving can be applied on driveways, shoulders of roadways, sidewalks and parking areas. A prerequisite for the use of permeable paving designed for infiltration is that the groundwater table's seasonal height must be more than 1 m below the base of the paved area. Therefore, the use of permeable surfaces is only effective in elevated areas. In some areas of Addis Ababa, however, permeable pavements and surfaces have been installed in areas with shallow groundwater levels. As a result, the pavement has experienced considerable sinking.

Infiltration basins: To temporarily store surface water runoff, infiltration basins should be considered. These allow water to gradually infiltrate through the soil of the basin floors. This practice helps to recharge groundwater to balance the water resources. Infiltration basins may take any shape and should also receive storm water from drainage systems. The basins and drainage systems should be part of the landscape design, as they can contribute both to the site's aesthetic value and facilitate biodiversity protection through habitat provision.

Water retention and detention/storage

Water retention and detention/storage facilities should be designed in the city using the public realm and involving urban forests, urban agriculture, parkland, sports fields, public squares, road spaces, university campuses, school compounds or below-ground spaces so that flooding of more vulnerable land uses can be avoided or reduced. At present, this option is underutilised in Addis Ababa, and many areas of open space could be designed to reduce the risk to built-up areas and roads. It can also increase the attractiveness of public spaces. The specific facilities for water retention and detention include:

Decentralised urban storage basins/dams: To hold water temporarily, regulate the flow of water through drainage systems, and decrease flood levels in rivers and channels during flood events, a network of urban storage basins/dams should be planned in the city. Excess floodwater can be held back and kept from entering the river or be diverted from rivers and channels to the basins, and then released back into the water network when the flood event is over or when river capacity is available. These urban basins should be located in the city plan, making use of urban forests, urban agricultural areas, big parks, and river floodplains after conducting an EIA (Figure 25).

Temporary water storage: To attenuate flood flow, the storage of a significant volume and controlled overflow of water should occur naturally in a catchment—for example, within a floodplain or in ponds. Artificially created storage facilities include flood storage reservoirs and retention and detention ponds, such as bioretention basins. In the context of Addis Ababa where space is limited, it is possible to make use of areas with other primary functions, such as parks, playing fields, school compounds, university campuses or car parks, to provide temporary storm water storage.

Constructed wetlands: Constructed wetland systems are shallow, extensively vegetated water bodies that use enhanced sedimentation, fine filtration, and pollutant uptake processes to remove pollutants from storm water. To improve urban storm water quality, constructed (artificial) wetlands should be designed as part of the accessible open space areas.

Rainwater harvesting and reuse: To increase the supply of water in areas where water is scarce and to reduce peak runoff, rainwater should be harvested within the Addis Ababa watershed by collecting and then storing the water in numerous tanks and storage structures. The water thus stored can be used for non-drinking purposes, resulting in the conservation of potable water resources. Harvested rainwater can also be used for drinking purposes if proper purification equipment is installed. The expansion of storm water harvesting and reuse is the highest value, highest priority, adaptive action that can be undertaken by Addis Ababa city. Harvesting and reusing storm water effectively works to reduce the likelihood and consequence of many risks. The benefits of reusing storm water include:

- Diversifying the water supply to the city, while reducing the impacts of drought and low rainfall, most notably in the maintenance of parks, gardens and sports fields;
- Helping to cool the urban environment by the proliferation of urban water bodies, which contribute to the control of extreme heat-related risks;
- Potentially reducing the likelihood of urban flash flooding in major rainfall events;
- Providing new, high-quality amenity values through the creation of urban water features

Green roofs and façades: To limit the impact of unavoidable impervious surfaces, green roofs should be designed for buildings. Green roofs collect rainwater, which is used for building cooling and insulation, and provide water for reuse. Green façades also collect rainwater and comprise climbing plants, either growing directly on a wall or specially designed supporting structures.

Drainage and Conveyance

Drainage and conveyance facilities are recommended in areas of excessive storm water flows and include:

Infiltration drainage: It is recommended that infiltration drainage solutions be developed to transfer excess water from the site to urban basins or drainage systems where infiltration and a reduction in drained runoff volume can take place. Infiltration drainage techniques include swales, grass-covered filter strips and filter drains. If these solutions cannot be applied, relief channels/subsidiary channels, drainage or sewers might be an option in densely developed areas.

Drainage and the sewerage system: To carry storm water/flood water away from the city, the following drainage/sewerage improvement activities should be conducted:

- Channel improvement (dredging and straightening of channels) to facilitate outfall/increase river water flow and the volume that can be accommodated at any particular time;
- Improvements to drainage and the sewerage system design by incorporating rainfall projections and catchment analysis;

- Continued upgrading, maintenance and cleaning of the drainage system;
- Increasing the capacity of storm water collection systems and better drainage and storm water capture;
- Designing subsidiary channels or relief channels to reduce discharge to the main river channels during very high floods.

Flood defence and accommodation

In cases in which it is necessary to build in floodplains and where important land uses cannot be relocated, flood defence actions, such as backfill, dykes, flood protection walls, retaining walls, gabion walls or pilings, river dams, retention ponds and barricades should be used to protect vulnerable land uses and to accommodate flood.

Backfill and elevation of construction sites for high-priority development areas: In cases in which an existing urban area or a planned, high-priority development area identified in the city plan is located in a flood risk zone, filling of the overall construction site to achieve a minimum height can be considered to facilitate development. Such measures should not be planned within the defined inviolable zone, but they can be considered for the flood-prone buffer zone. Backfill is costly, and it can cause new flood risk for the surrounding areas, increase downstream floods, and result in land subsidence. Thus, it is generally not recommended. To limit backfill in flood-prone areas, only urban areas with a high priority should be permitted to use backfill measures to facilitate future development after evaluation of environmental impacts.

Structural flood protection for high priority development areas: In cases of existing urban areas or a planned, high-priority development area that is identified in the city plan, a permanent flood defence/structural protection for the development site could be considered. These measures also should not be planned within the defined inviolable zone, but they can be considered for flood-prone buffer zones. These defenses can be dykes, dams, levees, sand bags or floodgates. Although these dry flood-protection measures are generally not recommended because they are costly, require professional engineering technologies, good operation and maintenance, and can increase downstream floods, they could be designed after critical evaluation of environmental impacts.

Building protection in buffer zones: To make new buildings and infrastructure flood proof by appropriate design and material use, innovative design of buildings and infrastructure, such as elevation of buildings in areas at risk, backfilling, elevated entrances and building structures on stilts, are some options to be considered.

The integration of CC consideration should be addressed in spatial planning laws and building codes to require more flood-resistant structures in floodplains. Inclusion of flood resistance into spatial planning laws and building codes can decrease losses from floods. However, CC has not yet been included in the planning law and building code of Ethiopia for the design of buildings and other civil engineering works and construction projects.

The following solutions specifically apply to areas or buildings that are located within buffer zones that experience seasonal or occasional flooding.

Backfill and elevation of buildings: To enable development close to water bodies with flood risk, the filling of a building block to a minimum height can be considered according to the flood risk and elevation of the site. This measure is intended to raise the foundation above the level of the groundwater table. This measure should be designed after conducting an EIA and in close coordination with environmental specialists. While this measure helps to protect the building from floods, it does not help to mitigate flood risk in general, and it is a costly solution. Therefore, it is generally not recommended.

Permanent waterproof building floors and walls: To increase the resilience of built structures to flooding, permanent waterproof floors and walls should be installed. To prevent seepage, ground floors and basements should be sealed by flood resistant walls, reaching a height of at least 50 cm above the maximum projected flood level. In addition, doorsteps should be raised as high as possible.

Flood-resilient ground floor: To allow development without impacting the site elevation, buildings should be designed on stilts or, alternatively, the floor levels intended for residential or commercial use should be raised, so that the ground floors are dedicated to temporary uses, such as parking or storage, which can be allowed to flood temporarily without causing extensive damage.

Flood risk management

Flood risk can be managed through:

- Forecasting and early warning systems;
- Awareness raising and capacity building;
- Regulations and fiscal incentives;
- Insurance of damages.

Forecasting and early warning systems: Mapping of flood risks, forecasting and early warning systems enhance flood preparedness. Warning the authorities and the public by forecasting severe weather events several days or hours ahead of their approach is crucial for emergency actions. These actions can include evacuating vulnerable areas and buildings and transporting people to shelters. This can be done by:

- Increasing the use of climate and weather information in managing risk and events – including the systems that ensure that at-risk populations get warnings and are able and willing to move temporarily to safe locations when needed;
- Updating flood maps to reflect changes in risk associated with CC.

Awareness raising and capacity building for all groups to help them cope with floods and flood risks: Awareness raising, knowledge building, capacity building and training are important tools to enable cities and residents to cope with flooding. The goal is to reduce the risk of wealth destruction and adverse human health impacts by increasing the resilience of buildings and infrastructures and by preparing evacuation and recovery plans to prevent loss of life and preserve the value of property, businesses and livelihoods.

Regulations and fiscal incentives: These measures consist of:

- Taxes or incentives, concerning—for example—the amount of sealed, impervious area per property, the amount of wastewater reused (including rain water);
- Obliging all new development projects to allow for storm water channelling;
- Collecting taxes based on the imperviousness level of properties;
- Disconnecting rain water drainage from the sewerage network of all urban areas in order to separate rain and wastewater.

Insurance of damages: Insurance serves to finance the repair or replacement of structures that suffer irregular and unforeseeable losses. Ethiopian insurance companies have not yet included CC-driven flood events in their insurance portfolios. Well-designed insurance contracts can provide incentives for risk reduction. However, insurance can also provide disincentives for people to prevent losses if, for example, those insured become less diligent about reducing losses due to the safety net that insurance provides.

Wastewater management

Large volumes of water are extracted from water sources in and around Addis Ababa, while investments in wastewater management are lagging behind (Van Rooijen, Biggs, Smout and Drechsel, 2010). The resulting environmental degradation within and downstream of the city has multiple consequences for public health, in particular through the use of untreated wastewater in agricultural irrigation, cattle watering and even for domestic use.

Wastewater management protects rivers from harmful discharges and pollution, however, despite significant efforts to increase wastewater treatment, options for safeguarding public health via conventional wastewater treatment alone remain limited. Therefore, it is necessary to implement demand management to reduce wastewater generation and by controlling pollution at its source. Pollution entering the surface water system can be reduced by applying industrial and domestic wastewater monitoring and control, fixing sewer misconnections and reducing contamination from urban runoff, enhancing sewer coverage, use and appropriate siting of decentralised natural treatment techniques, improving treatment technology, construction of protective barriers, or lifting of equipment of wastewater treatment facilities around rivers to high grounds.

Water space planning and integrating GBI

For combined water conservation and flood management purposes, the strategy should focus on developing water spaces in the city to provide space for water storage, detention, infiltration and evaporation, as well as for water recreation and, where applicable, for water transportation. Furthermore, designing city parks in a way that allows their integration into the built environment, water bodies and green spaces enhances the sustainability of the city and sustainable use of water resources. These areas can be enhanced by rehabilitation and restoration of the river and lake system in and around Addis Ababa.

6.3 Response strategies to rising temperature and UHI impacts through GBI

Response strategies to rising temperature and UHI impacts include:

- Developing an urban climate map to identify hot spots of UHI impact;
- Establishing fresh air corridors at the city level;
- Providing a high ratio of vegetated green surfaces at the city level;
- Reduction of ground level temperatures at the neighborhood/site level;
- Integration of LD and architectural measures;
- Reducing anthropogenic heat.

6.3.1 Developing urban climate map

To know where the UHI effects are severe and to prioritise heat-vulnerable populations in order to take the necessary measures during heat emergencies, UHI hot spots in the city are mapped for integration into Addis Ababa city planning. The parts of Addis Ababa that are affected by the UHI effect are shown in Figure 25.

6.3.2 Providing fresh air corridors at the city level

To cool down urban areas and provide fresh air for heat-stressed zones, the importance of providing fresh air corridors at the city level should be emphasised. Through appropriate spatial planning, it is important to ensure that fresh air from green areas outside the city can flow into urbanised areas. The main fresh air corridors of Addis Ababa should cut through the city in the northeast and southwest direction. Unfortunately, there is no space to provide this orientation. It is, however, possible for major roads, rail tracks, the network of river buffers, and streets with the correct orientation to serve this purpose (Figure 25). Smaller, neighborhood level corridors should also be clearly defined and kept free from development. For smaller corridors, it is important that they are as long and as wide as possible within the existing planning constraints, as this will have an effect on the wind exposure.

6.3.3 High ratio of vegetated green surfaces (urban forestry, urban parks and street trees)

Installing trees and vegetation is the simplest way to reduce the UHI effect and to cool the city by encouraging evapotranspirative cooling and shading built surfaces. Hence, increasing the proportion of green space to urban land cover could be of great value. Urban temperatures can be reduced substantially by planting trees, which help in increasing the albedo—the fraction of solar energy reflected back into space—of the surfaces. Trees directly reduce CO_2 from the atmosphere as they use carbon from the atmosphere in photosynthesis. The green ratio of 30% of the total land area for cities in Ethiopia, according to the city planning strategy, should therefore be implemented to provide the sought ratio of vegetated green surfaces. It is recommended that native or climate-adapted trees and plants be selected to minimise artificial irrigation requirements and to lower the demand on the general water supply of the city.

6.3.4 Reduction of ground level temperature at the neighborhood/ site level

At the development/site level, intelligent urban design has to be conducted to ensure sufficient cooling and ventilation of urban spaces to create a pleasant climate at the pedestrian level. Interventions to provide this pedestrian-level climate include:

- Orientation to prevailing wind;
- Facilitating ventilation by including buildings of different heights;
- Increasing vegetation;
- Including open water surfaces/water sensitive urban and landscape planning/design.

Orientation to prevailing wind: To ensure fresh air supply within city quarters, both street patterns and buildings should be oriented to the prevailing winds to create breeze pathways that enhance natural ventilation. As wind directions in the tropics are seasonally variable, the most reasonable orientation is the direction of the monsoonal wind. Streets should either be parallel to the wind flow or angled by 30 to 60 degrees. Road cross-sections must be wide and should not be blocked by smaller buildings or trees. Furthermore, it is important to orientate streets and buildings to provide shade in hot seasons and passive solar gain in the cold season.

Facilitating ventilation by including buildings of different heights: To improve ventilation, buildings with different heights should be designed to allow variations in wind speeds. Taller buildings are able to catch wind on higher levels, redirecting fresh air to the ground level. Therefore, these taller buildings should be located downwind of lower buildings.

Increasing vegetation: To provide fresh and cool air for city blocks, optimising street widths to allow for the planting of appropriately scaled deciduous street trees and planning for green areas orientated to the prevailing winds to enhance fresh air distribution capacity should be implemented. In addition, wide park areas are able to provide fresh air distribution for a whole neighbourhood, while small green surfaces in neighborhoods can help to enhance micro air ventilation.

Including open water surfaces/water sensitive urban and landscape planning/design: Water bodies store heat, which is consumed through evaporation, thereby reducing local temperatures. Open water bodies built as part of storm water management efforts will also reduce the temperature through evaporation and increase water availability for various uses in the city (Figure 26).

6.3.5 Integration of landscape design and architectural measures

To reduce the heat load and manage solar radiation at the development/site level, appropriate landscape and architecture design concepts should be applied. The aim is to create a pleasant climate, particularly at the pedestrian level and within buildings. The interventions in this regard include:

- Green roofs and facades;
- White reflective roofs and facades;
- Use of reflective and bright-coloured materials for public spaces/increased albedo;
- Shading.

Green roofs and facades: To reduce indoor temperatures and help save on the energy required for cooling, green roofs, green walls and climbing plants should be installed. Green roofs have positive effects on air quality, however, the contribution of green roofs to cooler temperatures at the pedestrian level is low. Green roofs can be used on a variety of roof types and on any property size, although large area roofs are generally more cost-effective than smaller areas. Green facades have similar benefits to green roofs. They can reach up to 2 m into the street, and therefore help to provide cooling at the pedestrian level. Green facades are suitable for use where space is limited. Green facades are created using climbing plants, either growing directly on a wall or on specially designed supporting structures.

White reflective roofs and façades: To lower the indoor temperature and reduce energy consumption spent on cooling, white reflective roofing and façade materials are recommended.

The use of steel and some types of glass as facade construction materials should be limited, as these materials warm up to a large extent when exposed to direct solar radiation. High-glare facades and finishings should be avoided, and natural materials such as wood or bamboo warm up significantly less than metal or glass.

Reflective and bright colored materials for public spaces/ increased albedo: To reduce UHIs, reflective and bright-colored surface materials should be used for public open spaces to increase solar reflection and reduce heat storage by allowing the heat to dissipate more rapidly than is the case with dark surfaces. Even with the use of reflective materials, the amount of paved areas should be minimised. Recommended are porous and permeable pavements, which can be cooled by evaporation and allow for rainwater infiltration. Light colours reflect more solar radiation than dark ones; hence, surface temperature at the pedestrian level can be decreased. There are several possibilities to enhance the reflective properties of paving materials, such as the use of light-coloured aggregates in asphalt and white cement in concrete.

Shading: To limit the rise of air temperature during daytime and to provide an attractive and pleasant ambience for people, shade should be provided for pedestrian areas. Shading solutions include:

- Preservation, or cultivation, of a large tree canopy;
- Shade provided by buildings;
- Overhanging roofs, balconies, and arcades;
- Installation of shading elements in public spaces.

6.3.6 Reducing anthropogenic heat

Heat generated by human activity, such as that which is released by the combustion of fuels by mobile or stationary sources, should be reduced. The use of mass/public transport reduces private vehicle use. This results in less waste heat from exhaust and reduces the formation and effects of ground-level ozone.

6.4 Land use implication of CC adaptation strategies

The response strategies elaborated above involve appropriate UP and LD for climate change adaptation. Although UP and LD can minimise adverse impacts of CC at the city level and establish a climate-resilient city, a key point of CC adaptation in Addis Ababa is that many of these actions require that more land be preserved as open space, and/or a less dense built environment. Current approaches to flood water management suggest the provision of features that will allow for more natural infiltration, and these features require space. More water to manage often means that more space is needed to manage it. Similarly, adding (or not removing) space-using greenery is an important step in preventing or treating UHI effects. Low-rise buildings or buildings that are moderate in height and are placed to facilitate ventilation between individual dwellings provide adaptation to higher temperatures, but they also tend to reduce density. Although there is little adaptation benefit from low-density, sprawling development, it appears that moderate density with significant fingers of GI running through

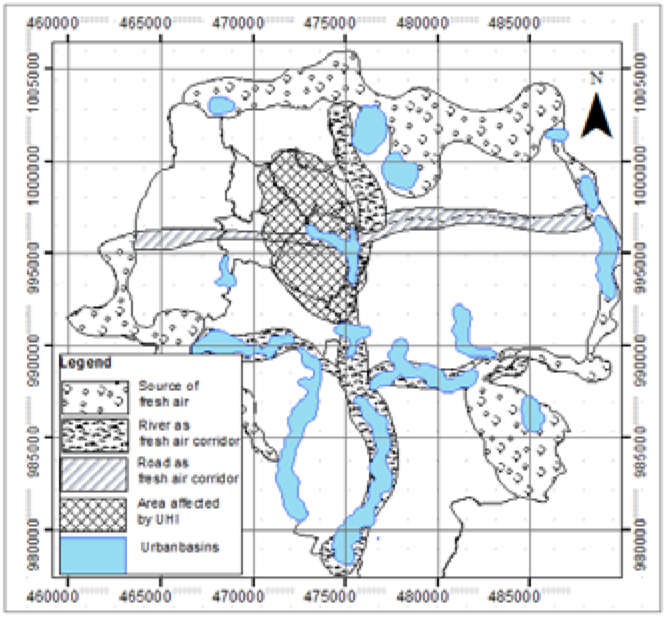


Figure 25: Schematic diagram showing major adaptation strategies to UHI effects that could be incorporated in UP and LD of Addis Ababa

Source: Worku, 2017b

the city may be the most effective form for minimising UHI effects. Therefore, it is essential to balance the space requirements of adaptation options and the impacts of CC during UP and LD in the city.

7. Main challenges for successful implementation of GBI in Addis Ababa

Despite its importance to people and the environment, GBI in Addis Ababa are characterised by the following major challenges.

7.1 Major challenges

7.1.1 Declining in area

The proportion of urban areas that are made up of green space in Addis Ababa has declined over time. The provision of GBI in the 2003 and 2017 structural plans show that the total area has declined from 41% of urban area in 2003 to 30% in 2017. One possible contribution to this reduction is converting green areas to other land uses such as housing, manufacturing industries etc. As a result of land management and control shortcomings, most spaces for GI are occupied by informal settlements. Absence of land development control that protects the use of fragile land and steep slope for settlement and other uses has aggravated the problem.

Furthermore, the boundaries of the green frame on the ground are not permanently demarcated and compensation claims of current legal users of the green frame were not assessed. City-wide inventory and assessment of the green frame also were not carried out.

7.1.2 Uneven distribution

There are problems related to siting/distribution. The distribution of green areas is uneven across Addis Ababa sub-cities, with Bole and Nefas-silk Lafto sub-cities facing more challenges in accessing green spaces compared to the other sub-cities. The 2017 Structural Plan provided no or very little green spaces for these sub-cities despite their location in peripheral areas. Furthermore, the areas reserved for urban GI is leftover land located on steep slopes, rugged and degraded terrain, river valleys, etc. that cannot be used for other purposes. As a result, there is a lack of availability and accessibility of green and other open spaces within a specified distance of every residence for use, ie, GI is limited and difficult to access. Much of the GI in Addis Ababa is spatially concentrated around the city margins, making public access problematic.

7.1.3 No monitoring mechanism to determine the quality of urban blue and green space

Quality of GBI is an important determinant of the benefits it provides. However, there is no monitoring mechanism in place to determine whether quality is increasing or decreasing, which is a notable gap in knowledge. GBI solutions can be seen as optional extras that get in the way of meeting the need for other land uses like housing, and are therefore not treated as an important dimension of plans resulting in quantity at the expense of quality for new housing, for example. Condominium housing development areas where GBI are erratically designed can be seen as a good example. This led to lack of appreciation of the full benefits of GBI. GBI can be seen purely as a cost by local authorities, with the benefits not being quantified or recorded.

7.1.4 Climate change impacts on GBI and lack of water and soil moisture loss is immense

This makes management/maintenance of GBI more difficult.

7.1.5 Lack of integration among GBI, city development and climate change

7.1.6 GBI and food security issues

GBI in Addis Ababa were not fully utilised to address food security issues.

7.2 Root causes of these challenges

7.2.1 Regulatory institutional challenge

Regulatory/institutional challenge/barriers refer to the lack of political support, rapid staff turnover which prevented continuity of GBI projects, need for collaboration, lack of cooperation and coordination between government agencies and non-government organisations, and the interdisciplinary nature of GBI that requires interdisciplinary policies. Mainstreaming of urban GBI faces the challenge of finding a suitable regulatory environment. There is no clear processes for regulating GBI and its assumed benefits. Relatively poor integration of regulatory bodies into a system that fully appreciates the multidimensional benefits of urban GI remains a key challenge.

In terms of the regulatory challenge, cities need regulatory pathways in place that capture GBI's multidimensional benefits. Integrating different levels of government is problematic; therefore, creating a new spatially defined regulatory body that overrides other branches of the complex regulatory apparatus is needed. Stakeholder engagement can help to implement GI in cases where regulatory pathways are not viable.

Laws, directives and instructions concerning the green frame were not developed and enforced. Another important regulatory challenge is lack of stable institutional set-up for the sector. The frequent restructuring of institutions has led to discontinuity of planned activities and community participation. It is also responsible for the inadequate budget.

The questions that need to be answered include: Which legal mechanisms exist to guide GI intervention projects and how do these mechanisms translate into practice? Which regulatory mechanisms can function as drivers for implementation? Which regulatory mechanisms act as barriers for implementation?

Several efforts have been made in the past: clean and green Addis Ababa Society, CRGE Strategy, TACC, Addis Ababa Rivers and Riversides development studies, park planning and development endeavours, etc. but none of them were implemented because of lack of political support. Successive mayors in the last 20 years could not develop a single park although they are planned.

To illustrate the importance of political commitment/support, it is important to mention the efforts made by the prime minister of Singapore, who was a strong and loud supporter of the GBI-focused ABC Waters Program, while the secret of the completion of Unity Park in Addis Ababa in such a short period of time and 45% of the river and riverside rehabilitation project in just three months is the political commitment and full support provided by the prime minister of Ethiopia.

7.2.2 Socio-economic challenge

In Addis Ababa, it is common to find that low-income neighbourhoods have less vegetation and access to green space than wealthy neighbourhoods, which at least have green in their large plots/compounds. Because of the important ecosystem services that nature provides, this disproportional access to green space results in an environmental justice issue. In different locations around the world, marginality can arise as a function of income, age, religion, density, caste or education, and in all cases, marginality usually means lack of access to the benefits of GI.

Public participation/stakeholder engagement (academics, NGOs, private sector, community) has been identified as a critical aspect for implementing decisions that could affect urban residents such as GI projects. Regarding the socio-economic challenge, we see equity issues involved around GI, where low-income communities are disproportionately affected.

Lack of awareness of the environmental role of GI by the communities led to inappropriate management and utilisation of green resources.

The questions to be answered here are how can underrepresented communities be included in the greening of the city? What challenges do poor neighbourhoods face that can be alleviated through GI projects? How does one promote the active participation of vulnerable communities in GI intervention projects?

7.2.3 Standard challenges and technological barriers

There is a lack of enforceable/compulsory standards for a minimum amount of GBI in new or existing developments. The design standards challenge reflects the significant uncertainty around how best to plan, design, implement and maintain GI. Technological barriers include maintenance (lack of maintenance can reduce effectiveness), deficiency of data (it is difficult to quantify GI benefits), insufficient technical knowledge and experience, reluctance to change engineering practices, and difficulties with irrigation systems. Technological barriers include capacity limitation, deficiency of data about performance characteristics and insufficient technical knowledge and experience. Design guidelines which are tailored to local conditions of cities and respond to their specific threats and availability of resources are essential for the successful planning, design, implementation, operation, maintenance and evaluation of urban GI.

GI design must consider the multi-functionality aspect that includes social uses (recreation) and ecological uses (habitat and landscape connectivity). For a successful design, the input of users and specialists must be considered.

The following challenges need to be addressed here: how to design more efficient GI projects; which plant species are most efficient and what combination of plant species are recommended for small-medium-large projects; what spatial configuration of GI projects works better (clusters vs. isolated projects) at the parcel, neighbourhood and city scale; which types of GI designs require less maintenance and are cheaper to implement.

7.2.4 Financeability challenge

The financeability challenge lies in the difficulty of quantifying the multi-functionality of GI. Flood reduction benefit of GI, for example, may be an economic incentive for cities. However, it remains unclear how to reliably estimate the costs and benefits of GI technology, and how to translate these cost/benefit calculations into financing models to fund capital and operational expenditure. Who finances GI is another challenge.

The questions here are: how can funds be channelled for transdisciplinary research projects that involve stakeholders in the planning and designing of GI? What economic instruments exist for GI implementation and how do these translate into action? What funding mechanisms can be used for long-term maintenance and for the monitoring of GI benefits and downsides? GBI projects can be financed by joint budgeting of different agencies and private investors. Unity Park and Riverside projects in Addis Ababa provide excellent examples.

7.2.5 Innovation challenge

GBI provides an opportunity for innovation, where grey, blue and GBI can be combined to provide multiple ecosystem services with dual purposes, depending on the need. Stakeholder engagement and close collaboration between different groups can result in the wide implementation of GBI with public support and agreed maintenance commitment. Because GBI is a relatively new concept in terms of its relationship to urban resilience, it is necessary to find innovative mechanisms that combine grey, blue and GBI to provide a wide array of ecosystem services to urban residents.

The questions to be addressed here are: what types of innovations exist? What can be developed around existing GBI and grey infrastructure that can guide the future planning of cities?

8. Recommendations: Promoting GBI for making Addis Ababa healthy, prosperous and resilient

GBI features can be planned, designed, and implemented at different scales: building scale, neighbourhood scale, city scale, catchment scale and across landscapes. Depending on the topography, soil and ground conditions, hydrology and microclimate at the site, the design can be modified to maximise the benefits while reducing risks. Furthermore, while GBI measures can be implemented to treat and control storm water runoff, improve air quality and biodiversity locally, the effectiveness can increase as a cumulative effect when the GBI measures are used to fully integrate the water cycle, ecosystems and the built environment.

One of the most powerful advantages of GBI is its potential for multi-functionality. Multi-functional benefits vary between different types of GBI and their primary function. In terms of hydrological benefits, a single GBI measure – if designed and managed effectively - can address both quantity and quality control of surface water runoff. Additional measures can be combined to target a site-specific issue and to deliver wider benefits such as enhanced biodiversity, air quality, urban cooling and recreation. With this flexibility and adaptability GBI can be integrated into urban development, where its function can go beyond surface water management, air quality improvement and biodiversity, to improve well-being, urban design and social cohesion.

Rainwater that usually flows directly to the sewage system or a water body can be collected for non-potable uses, or even potable uses if properly treated. By using rainwater harvesting systems as well as other measures such as bio-retention systems, rain gardens and pervious surfaces, surface water runoff can be stored to satisfy future needs. GBI can also make use of under-utilised land, buildings and neglected urban spaces to provide habitat and connections across the city.

GBI increases carbon storage in cities, helping to mitigate carbon emissions that contribute to climate change. GBI increases evapotranspiration and shading, cooling urban buildings and spaces and counteracting the urban heat island effect. This in turn can reduce the energy costs associated with cooling. Rainfall may become more extreme and unpredictable due to changes to the climate; therefore, controlling and treating surface water runoff near or at the source using GBI allows the drainage system to be more easily adapted to future hydrologic changes. Providing habitat and landscape connectivity may improve the capacity for species to adapt their range and habitat in response to changing climate and habitat fragmentation. In addition, if widely adopted and properly used, the benefits can be long-term and cumulative, city-wide or even nationwide.

Using GBI appropriately can protect the natural ecology, morphology and hydrological characteristics of the sites, and restore or mimic natural evapotranspiration and surface water runoff and ecosystems.

A green urban landscape and a sustainable water cycle is central to the success of cities and towns. GBI planning, therefore, seeks to ensure cities are healthy, prosperous and resilient, with the following core objectives.

8.1 Healthy – making the best of our local environment

Core planning and design principles to create healthy cities and towns:

8.1.1 To support year-round passive and active recreation

- Select appropriate species that will support recreation needs year-round and in future climates;
- Secure local water supplies to provide irrigation for key sporting grounds;
- Utilise passive irrigation techniques for urban landscapes;
- Integrate GBI with key walking and cycling routes to provide shaded connections.

8.1.2 To protect and enhance local waterways and aquatic environments

- Integrate Water Sensitive Urban Design measures to provide treatment of storm water runoff using vegetation and soils;
- Slow and reduce urban storm water runoff by managing storm water on the surface, and using vegetated surfaces to increase infiltration and evapotranspiration;
- Enhance waterway corridors through naturalisation of modified waterways and riparian planting; revitalise not just beautify; value the living landscape;
- Re-connect floodplains to the waterway and encourage subsurface flows through riparian zones; link river landscapes across Addis Ababa; conserve the Akaki wetlands and floodplain for aquifer recharge for Addis Ababa's future water security.

8.1.3 To support urban biodiversity

- Select locally appropriate species that provide diversity and complement local ecosystems;
- Use a diverse range of species to build biodiversity and resilience;
- Look to enhance remnant fragments and build connectivity between them for habitat linkages.

8.2 Prosperous – making changes to better our city

Core planning and design principles to create prosperous cities and towns:

8.2.1 To improve the amenity of the urban environment

- Support integration of healthy trees and vegetation, ensuring provision of sufficient growing space, and ongoing access to good soil, nutrients and water;
- Locate GBI in key gateway areas to the city and core business areas and pedestrian routes;
- Design with maintenance needs in mind to provide easy access and to ensure that long-term amenity benefits can be delivered within budget.

8.2.2 To create stronger connections between communities and nature

- Provide opportunities for nature play and passive and active learning about natural processes;
- Provide a variety of natural systems, such as gardens, trees and building integrated vegetation, within all residential and employment areas;
- Involve local communities in the design and management of features.

8.2.3 To improve the functionality of urban places

- Avoid clashes with other urban utilities and infrastructure through good design and proactive management;
- Enhance the performance of the urban infrastructure such as pedestrian pathways, roads, parking areas, buildings and drainage systems by using natural areas to provide for shade, cooling, storm water management and air filtration.

8.2.4 To drive increased tourism and visitation

- Showcase initiatives and plan in tandem with key attractions and city gateways;
- Integrate views of green areas and water from public spaces.

8.3 Resilient – making sure we are ready for challenges

Core planning and design principles to create resilient cities and towns:

8.3.1 To make use of alternative water supplies locally to prepare for drought

- Utilise alternative water resources generated by urban areas, such as rainwater, storm water or wastewater for irrigation purposes to support green areas and trees;
- Identify areas with demands for alternative water which can be co-located with potential storages which can also provide landscape benefits (eg, wetlands, ponds);
- Use vegetated systems (such as wetlands or biofilters) to provide treatment of alternative water supplies for local use. Use alternative water from buildings to support green walls and green roofs.

8.3.2 To reduce the impacts of flooding

- Increase permeability of urban areas by increasing proportions of green space and unpaved areas to reduce storm water runoff volumes;
- Direct storm water runoff to vegetated areas and maximise soil volumes to create storage and to maximise infiltration and evapotranspiration, therefore minimising runoff and reducing pressure on drainage systems;
- Integrate "sunken" areas and overland pathways within green spaces that can occasionally accommodate flood waters but can be used for alternative purposes otherwise.

8.3.3 To provide pleasant and cooling environments during hot weather

- Maximise tree canopy and vegetated cover in highly pedestrianised areas to provide shade;
- Increase presence of vegetated ground cover, moist soil and open water to provide natural cooling in an urban environment;
- Look for areas where prevailing winds can blow over urban water features or saturated soils and provide passive cooling.

8.4 For a successful implementation of the planned GBI:

8.4.1 A strong vision is the engine for change

- Make efforts in public relations and convince the urban community about the benefits of GBI;
- Use visions of livability and prosperity to show the advantages of GBI (e.g. for Climate Resilience, Green City Vision, Biophilia, Sustainable Urban Design, Water Sensitive and Water Wise City).

8.4.2 Employ pilot projects as learning tools

- Pilot projects can become paradigm examples and have a high relevance for other cases;
- Pilot projects offer opportunities to test and execute experiments to deepen the understanding of needs and open up opportunities for GBI under diverse local conditions;
- Pilot projects serve as long-term references and are effective for fostering a GBI planning culture;
- Pilot projects demonstrate the long-term financial, social and ecological benefits and win-win effects;

- With pilot projects, key officials and the wider public can be convinced of the feasibility of GBI.

8.4.3 Focus on know-how transfer by standards and guidelines

- Set standards and build up necessary knowledge and experience in a handful of projects;
- Document the acquired knowledge in handbooks and guidelines to allow transferring single-project experience to future projects at different scales;
- Implement effective, enforceable, and sanctionable GBI guidelines and regulations in urban planning processes (drainage regulations, exact requirements for rainwater inflows, etc.);
- Be aware and promote that institutionalisation helps to reduce transaction costs and create new paths of development.

8.4.4 Look for windows of opportunity to initiate GBI

- Cities are in need of long-term adaptation processes to cope with current and future challenges. These challenges are the "gateways" for implementing GBI. Water-related health issues, climate change mitigation and adaptation, biodiversity loss and other disasters have proven to be promising gateways. But action is needed to move beyond old habits and business-as-usual;
- Often the need for renovation or upgrading of old, grey infrastructure offers good opportunities, as the comparative cost advantage of newly built GBI over grey infrastructure renovation can be very significant;
- Instead of a complete restructuring of the urban system, a step-by-step approach can take place, as the decentralised, adaptive character of GBI is very flexible.

8.4.5 Mobilise people, citizens and social capital for GBI projects

- Drivers of GBI often rely on the direct support of networks of professionals, NGO activists and civil society;
- Involvement of people from the affected neighbourhoods and catchment of GBI projects fosters public awareness and civic support;
- Identify persons and groups with a particular level in society to elicit volunteerism and enable these partners to support and strengthen GBI advocacy.

8.4.6 Create partnerships and networks for GBI

- Build effective collaborative working relationships with external actors to enhance strategic capacity;
- Establish GBI networks and regard them as resources irrespective of single projects;
- Push GBI networking on an institutional level eg, by platforms and clearinghouses.

8.4.7 Build up capacity for further GBI projects

- A critical mass of GBI practitioners in a city can help to create momentum for further GBI projects. Use external expertise at an early stage to develop guidelines (eg, best practice examples, handbooks with recommendations, toolboxes) and to build up GBI capacities in your city;
- Recognition of good practice examples through public competitions and publications can be very helpful and support the movement towards GBI cultural capacity and development in a city.

8.4.8 Overcome silo mentality

- Establish leaders and offices with high competence for integration, situated directly under the mayor's office;
- Involve external consultancy and promote knowledge exchange across departments;
- Promote policy integration and inter-agency coordination to ensure knowledge exchange;
- Support professionals who can transcend institutional boundaries;
- Support GBI-related interdisciplinary training programmes and workshops, staff rotation, and career programmes;
- Support GBI-related professional networks and associations across departments.

8.4.9 Take care of operation and maintenance

- Case studies show that long-term costs for operation and maintenance of GBI are often not foreseen or budgeted. It is crucial to have a clear picture of the lifecycle costs and long-term funding for maintenance and to clarify the responsibilities for maintenance in advance;
- Operations, maintenance and programming are the most creative processes in GBI.

8.4.10 Implement joint budgeting and mixed financing, as GBI has multiple purposes and provides benefits for different stakeholders

- Real estate owners and insurance companies can "earn" by investing in budgets for flood prevention and climate resilience;
- Merged and joint budgets can secure funding for increased inter-agency involvement and coordination, especially cross-agency budgets for GBI (earmarked money);
- Develop programme budgets and funding incentives across departmental lines.

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Addis Ababa Urban Age Task Force Reports

Theme 1 | Urban Housing and Retrofitting

Policy Brief 1 | *The Addis Ababa City Block: a high-density, mixed-use and inclusive housing solution for the urban core*

Technical Report 1.1 | *The Addis Ababa City Block: inclusion and livelihood though the horizontal-above-vertical concept*, by Elias Yitbarek Alemayehu

Technical Report 1.2 | *Finding Housing Affordability: cost estimates and affordability paths for the Addis Ababa City Block,* by Jacus Pienaar

Technical Report 1.3 | *Sustainable Building Materials: exploring green construction options for new housing in Addis Ababa*, by Hannah Langmaack, Peter Scheibstock and Thomas Kraubitz (Buro Happold)

Theme 2 | Transport and Mobility Services

Policy Brief 2 | *Beyond Car Growth: digital van service as alternative to private car use in Addis Ababa*

Technical Report 2.1 | *Digital Van Service Demand: gauging interest in mobility alternatives among current and aspiring car owners in Addis Ababa*, by Philipp Rode, Bethany Mickleburgh, Jennifer Chan and Rebecca Flynn

Technical Report 2.2 | *Digital Van Service for Addis Ababa: understanding the transport landscape and the potential for digital bus aggregation in Ethiopia's capital* by Chris Kost and Gashaw Aberra (Institute for Transportation and Development Policy (ITDP))

Theme 3 | Green and Blue Infrastructure

Policy Brief 3 | *Working with Nature: next generation green and blue infrastructure for Addis Ababa*

Technical Report 3.1 | *Green and Blue Infrastructure in Addis Ababa: a review of challenges and response strategies*, by Hailu Worku

Technical Report 3.2 | *The Social Functions of Green and Blue Infrastructure: international case studies and insights for Addis Ababa*, by Santiago del Hierro, David Jácome and Tigist Kassahun Temesgen

Theme 4 | Urban Governance and Planning

Policy Brief 4 | *Urban Governance and Strategic Planning: how Addis Ababa could benefit from human-centred, inclusive design, participatory pilot projects and improved data management*

Technical Report 4.1 | *Participatory City Making: polycentric governance and human-centred, inclusive urban design,* by Meinolf Spiekermann and Marc Steinlin

Technical Report 4.2 | *Urban Knowledge Management: solutions for the Addis Ababa City Administration*, by Bersisa Berri

Technical Report 4.3 | *International Building Exhibitions (IBA): an approach to innovative city making in Addis Ababa* by Efrem A. Tesfaunegn, Anka Derichs and Michael von der Mühlen

Technical Report 4.4 | *Addis Ababa Spatial Compendium: mapping and urban analytics for Ethiopia's capital*, by Alexandra Gomes and Philipp Rode (LSE Cities)

Addis Ababa Urban Age Task Force

Founding Partners

The Task Force is a partnership between the Addis Ababa City Administration Plan & Development Commission (AAPDCo), LSE Cities at the London School of Economics and Political Science, the Alfred Herrhausen Gesellschaft, and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

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The Urban Age Programme, jointly organised with and supported by the Alfred Herrhausen Gesellschaft, is an international investigation of the spatial and social dynamics of cities. The programme consists of conferences, research initiatives, task forces and publications. Since 2005, 17 conferences have been held in rapidly urbanising regions in Africa and Asia, as well as in mature urban regions in the Americas and Europe.

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Addis Ababa Plan Commission

Addis Ababa City Plan and Development Commission is committed and fully dedicated to preparing research-based city-wide short, medium and long term strategic development plans (both socio-economic and spatial) in order to transform the city to one among the middle-income cities in the world; create a liveable city for the citizen; and make Addis Ababa the best destination for investment in Africa. The commission is accountable to promote urban economy and jobs; deliver urban renewal and housing for citizens; improve urban environment and quality of life; and support policy decisions that will register accelerated, sustainable and equitable economic growth and a climate resilient green economy.

The Alfred Herrhausen Gesellschaft

The Alfred Herrhausen Gesellschaft promotes a free and open society and its cohesion. Democracy, the social market economy and sustainability are the foundations of such a society. Our work is based on the values of Alfred Herrhausen: on freedom and responsibility, on competition and compassion. Alfred Herrhausen thought and acted with the aim of crossing and overcoming boundaries. In his memory, the Alfred Herrhausen Gesellschaft creates platforms for discussions to enrich relevant discourses during selected events, and in publications and other media.

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LSE Cities

LSE Cities is an international centre at the London School of Economics and Political Science that carries out research, conferences, graduate and executive education and outreach activities in London and abroad. It studies how people and cities interact in a rapidly urbanising world, focusing on how the physical form and design of cities impacts on society, culture and the environment. Extending LSE's century-old commitment to the understanding of urban society, LSE Cities investigates how complex urban systems are responding to the pressures of growth, change and globalisation with new infrastructures of design and governance that both complement and threaten social and environmental equity.

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