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A review of the sustainable drainage technics suitable for paved roads in the tropical area: the case of Douala city

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Abstract. Douala is one of the very attractive cities in central Africa. It is the supply point for many countries of the sub-region such as the Central Africa Republic and Chad Republic that have no access to the sea. Drivers from these countries often have to travel very long distances before reaching Douala. For this reason, paved roads are very important to enable safe and pleasant traffic. Knowing that Douala is one of the rainiest cities in the country particularly in July and August, with a relatively flat topography, it is important to sustainably drain excess stormwater water from paved roads. This piece makes a review of the drainage technics that enable a sustainable removal of water such as drainage kerbs, swales, bioswales, and wet swales. This article goes further than listing the drainage technics but also proposes design criteria and the types of maintenance activities to be done in order to ensure the proper functioning of the infrastructures. ISO mentions the relevant persons involved in the realization and maintenance of these drainage facilities. This is typically the case of politics through municipalities and technicians.

Keywords. Paved roads, stormwater, kerbs, vegetation swales, bioswales, wet swales.

1. Introduction

Paved roads are very important for humans as they enable a suitable movement of people and goods. Some factors such as overload, poor quality of road pavement, and natural disasters reduce the lifetime of paved roads [13]. weighing of vehicles crossing the roads through a weighbridge, elaboration of construction standards, controlling works during construction and maintenance phases as well as management of stormwater appear as actions to prevent road degradation. Precipitations such as rainfall increase the presence of cracks on the road and reduce the frictional resistance between vehicule tires and paved surfaces [32]. As precipitation is an act of nature, although the important contribution of anthropogenic activities increase its frequency and intensity [5], man can only find adaptative ways to deal with it. This is typically the case of draining water from paved roods.

Nowadays, the protection of the environment has increased in importance. Hence, the most important is no longer to drain water, but to drain water in an environmentally friendly way. This article makes review of common sustainable technics used to drain water. The case study is Douala which is the most developed city of the country.

2. Material and Method

The methodology will mainly consist of a general review of the current publications made on the topic. When doing it, I will highlight the design criteria as well as best maintenance practices applicable to the tropical zone in general and Douala in particular.

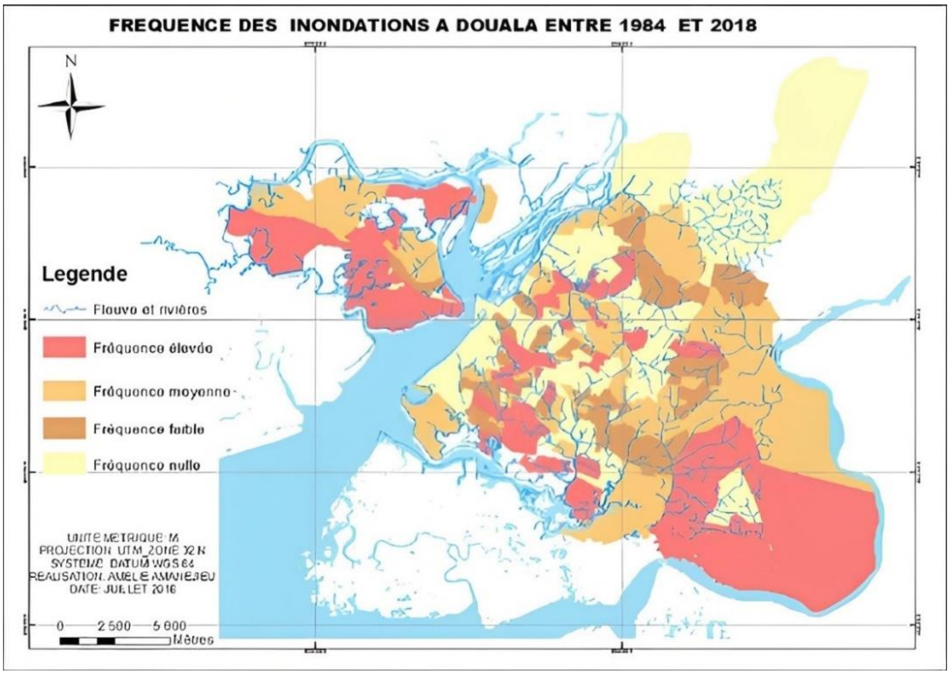

Figure 1. Frequency of flooding events in Douala from 1984 to 2018. Red color, dark yellow color, brown color and light yellow represents high frequency, moderate frequency, low frequency, and negligible frequency. Source: [2]

3. Physical Environment of Douala

Douala is the economic capital of Cameroon, it is characterized by the great-intensity of rain falls the months of July and August where precipitation reaches up to 700 mm [28, 31].

4. Topography

The relief of Douala varies from 3m to 84 m above sea level. The Nord-East side of the city has high altitudes, this is the case of Logbessou and Lendi. On the contrary, quarters of the West side (Bonaberi) are characterized by low altitudes this is the case of Mabanda, Bonjongo and Ndobo.

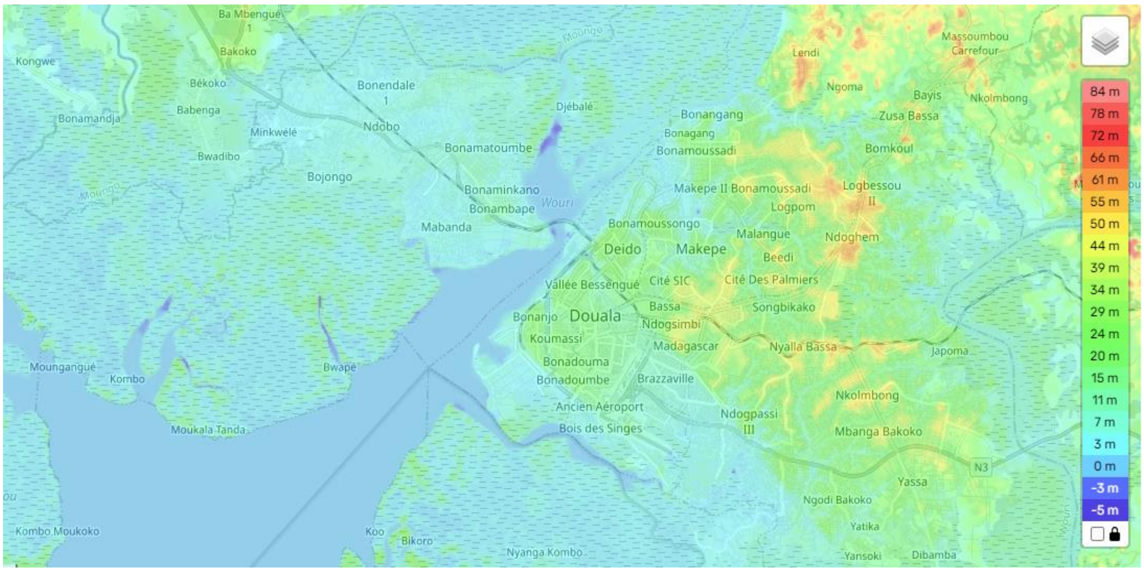

Figure 1. The topography of Douala from openstreet map

5. Sustainable solutions for road drainage in Douala

5.1. paved roads

There are two types of paved roads: the impervious and pervious ones. Factors to be taken into consideration when choosing one of the two alternatives should include design criteria, the materials used, the surface drainage, and the maintenance cost [30].

According to [25] Impervious paved roads are generally made up of fundation soils, structural layers and surface course. The foundation soils support all the other layers of the road. Structural layer is generally made up of binder, concrete slab and sub-base and the surface course is constituted of asphalt or slab concrete. More detail is provided in the figure 3 below. In order to manage the runoff water adequately, impervious pavement is usually associated with drainage facilities. Most of the primary roads of Douala such as RN3 have this kind of Pavement.

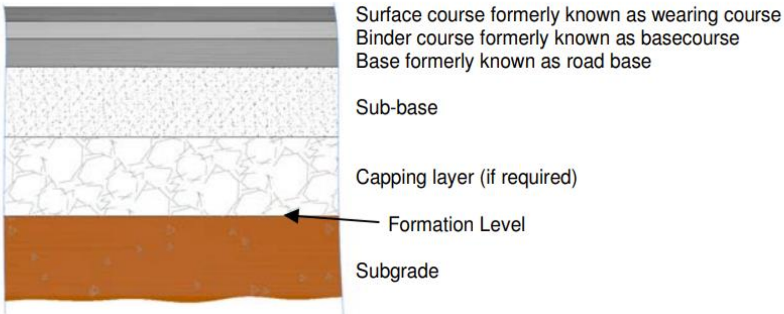

Figure 2. Impervious pavement components; source [25]

According to [9], implementation of permeable pavement is a management technic for which the main goal is to facilitate water infiltration into soil. Three main types of permeable layers are generally recorded: porous asphalt, pervious concrete and permeable interlocking concrete pavement.

Porous asphalt is mostly used for packing lot. It is same as conventional asphalt but with less sand and other fine materials. This is to facilitate water infiltration. It has an average lifespan of 20 years and is effective in water purification owing to infiltration process. As it enables water table replenishment, rather than conveying all the received water into the sewerage network, porous asphalt reduces the quantity of rain water to be treated [26]. More details on advantages offered by porous asphalt are provided in the table below.

Table 1. Some advantages associated with porous asphalt

Benefit	Sources
Reduction of runoff water and removal of pollutants owing to a gradual filtration of water in the underground layers.	[33]
High efficiency in removal of total suspended solids, metals, oil, and grease and moderate efficiency in removal of phosphorus from water.	[4], [23]
Reduction in contamination in water runoff and sediment loading	[18], [15]
Low-impact development and cost-effective technology for stormwater management by reducing need for drainage structures and rights of way.	[15]
Improved wet-weather visibility, tire spray, and hydroplaning	[18]
Absorption of noise from tires and engines	[18]
Reduction in stormwater runoff volume	[18]

Source: (WAPA, 2015)

Pervious concrete (figure 4) is a mixture of coarse aggregate, cement and fine aggregates (less than 10% of the total aggregates). [3] highlighted four main advantages liaising with pervious concrete:

(1) Water treatment by pollutant removal, (2) Less need for curbing and storm sewers, (3) recharge of local aquifers, (4) Less mass grading is required to create drainage gradients. Furthermore, pervious pavement goes very well with smooth slope surfaces such as Bonaberi. Meanwhile, ground re-profiling is necessary in case of high altitudes.

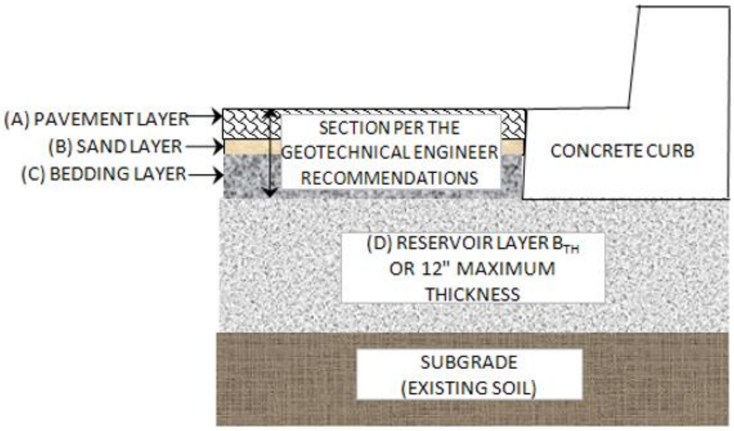

Figure 3. Concrete pavement cross section; source: [22]

As maintenance helps to sustain the serviceability of the equipment, it should be properly handled. The table 2 below provides useful elements for both pervious concrete.

Table 2. Maintenance schedule associated with pervious concrete

Schedule	Activity
Ongoing	Keep adjacent landscape areas maintained; Remove clippings from landscape maintenance activities; Remove trash and debris
Utility Trenching other pavement repairs	Replace structural section and reservoir layer in kind. Re-pave using pervious concrete/asphalt. Do not pave repaired areas with impermeable surfaces.
After storm events	. Inspect areas for ponding
2-3 times per year	. Vacuum the permeable pavement to reduce the chance of clogging
As needed	Remove and replace damaged or destroyed permeable pavement

Source:[22]

Permeable interlocking concrete pavement (figure 5), also referred to as PICP, consists solid concrete paving units with joints that create openings in the pavement surface when assembled into a pattern [10].

Many secondary roads of Douala such as PB cite CIC are constructed with permeable interlocked blocks. Some primary road such as the one linking Bepanda to Bonamoussadi through “sable” also have this material. A clear detail of the components of interlocking concrete pavement is provided in Table 3, below.

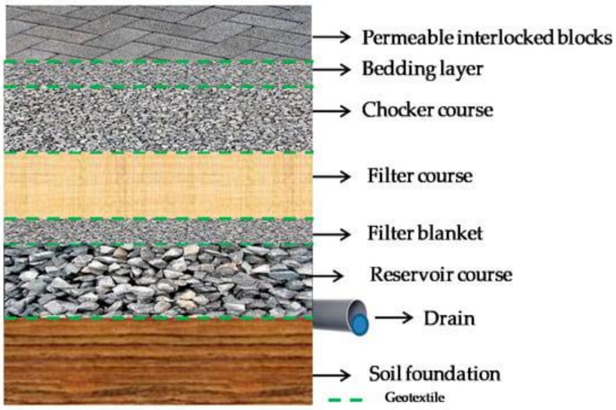

Figure 4. Cross section of a permeable interlocking concrete pavement

Table 3. design criteria of permeable interlocking concrete pavement

Layer	Function	Aggregates	Thickness
Bedding layer	As a permeable surface, for interlocked blocks accommodation and load distribution to the underlying layers	Coarse aggregate with uniform particle size and a maximum particle size of 9.5 mm [11] or between 3.0 mm and 6.3mm [16, 17]	5.0 mm [10]
Choker course	Mechanical support, surface levelling, reservoir layer, and filtration	Washed gravel aggregates containing few fine particles, continuous particle size with a minimum voids volume of 32%. When sized as a reservoir layer, the voids volume must be greater than 40% [1]. The particle diameter should be between 4.75 mm and 25.0 mm.	The thickness depends on the structural and hydraulic pavement design. In general, the thickness is 25.4 mm when used as a damping layer and 100 mm when it is also used as a temporary reservoir [10].
Filter course	This is an optional layer used for improving the quality of filtered water for non-potable purposes.	This layer consists of sand with a uniform grain size with a maximum diameter of 4.75 mm. The coefficient of permeability is between $3.5 * 10^{-5}$ and $2.1*10^{-4}$ m/s	The minimum thickness is 300mm.
Filter blanket	With the presence of the filter course, there is a need for an intermediate layer between this and the reservoir course, called a filter blanket. The presence of this layer avoids the likelihood of migration of thin material to the voids of the lower layer.	Granular material (maximum diameter 9.5 mm) with continuous gradation or particle size intermediate to the materials used in the filter course and reservoir course.	Minimum thickness is 80 mm [29]
Reservoir course	This is the layer to temporarily store the stormwater that is infiltrated in the structure.	Composed of coarse aggregate with continuous gradation and the void volume must be greater than 40.0% [1], [11] The particle nominal sizes range from 50.0 mm to 75.0 mm [11]	The thickness depends on the structural and hydraulic design.

source: [12]

Detail regarding the different layers associated to permeable interlocking concrete is provided in the table below.

5.2. Methods used for a sustainable drainage of paved roads

5.2.1. Swales

Swales is one of the oldest technics used for stormwater management [19]. Grass swale was first introduced to reduce pollution severity from storm water before discharge. As environmental issues increase with time, grass swale was optimized into infiltration swale, wet swale and bio swale [7, 8, 20, 34]. The figure below figures show the different types of swales. These type of facilities are mainly located at Koto and Bonamoussadi in Douala V subdivision.

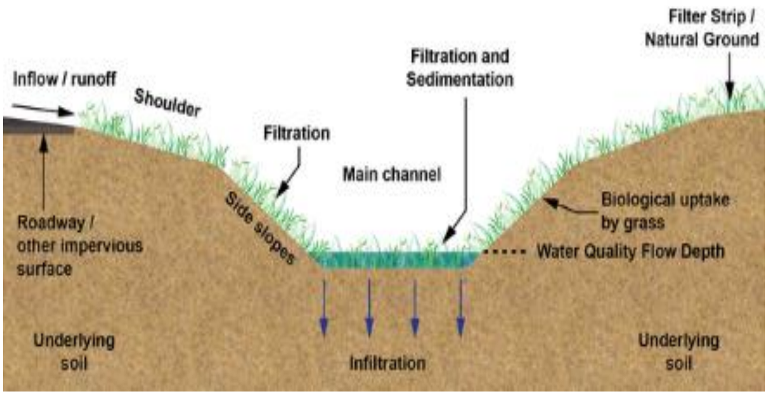

Figure 5. Grass swale; source [7]

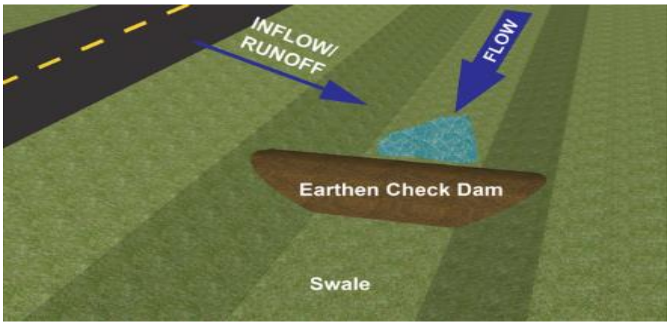

Figure 6. Infiltration swale; source [7]

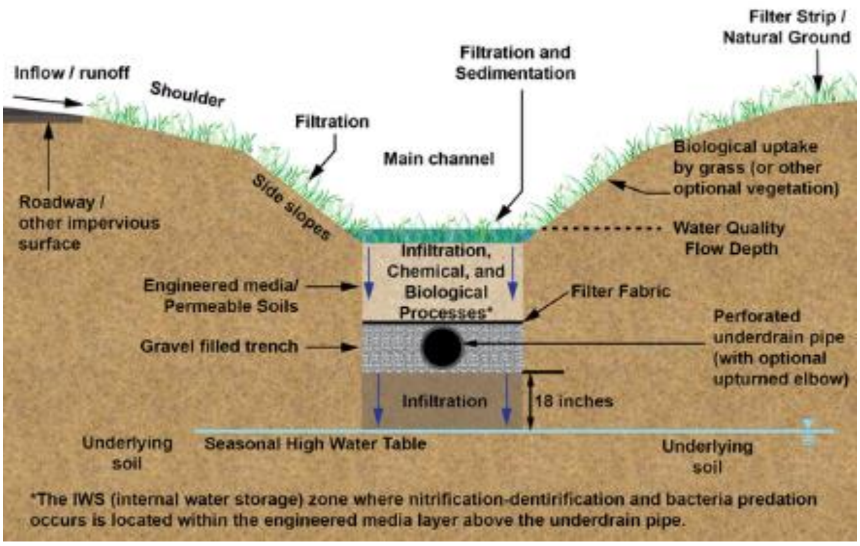

Figure 7. bio swale; source [7]

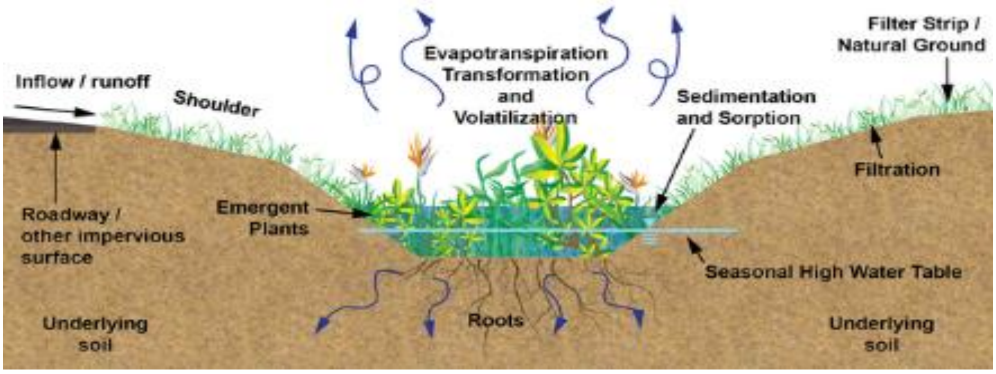

Figure 8. Wet swale; source [7]

The table 4 below present the design criteria applicable to each type of swale.

Table 4. Design guidance regarding swales

Design Component	Design Guidance	Reason (s)
All swales		
Hydraulic retention time	Between 5 and 6 min	Extended HRT allows particle settling
Flow depth	Below grass height (10–15cm)	Treats all runoff passing below grass height for water quality swale
Grass type	Blend of non-clumping species with stiff blades Adapted to ambient climate conditions	Prevents concentrated flows and resulting erosion or sediment contribution
Grass density	Dense turf. Aim for grass cover of good-excellent for the selected species (3000–9000 stems/m2)	Greater surface area provides opportunity for adsorption of small particles and ions. Good or better cover and uniform stands of grass facilitate filtration and sedimentation, while limiting internal erosion
Swale length (as function of drainage area)	75 m/drainage ha (100 ft/drainage ac)	Needed for sedimentation
Longitudinal slope	Less than 3%	Prevents “short-circuiting”
Side slopes	3:1 (H: V) or shallower for trapezoidal channel. 6:1 (H: V) or shallower for triangular swales	Provides pre-treatment increasing swale efficiency
Cross-sectional geometry	Trapezoidal (Flat-bottomed)	Allows greater contact area and more likely to meet flow depth below grass height requirements
Grass height (Post-construction maintenance requirement)	Between 10 and 15 cm (4–6 inches). Can extend grass height in areas with high flows due to very intense rainfalls	Proper grass height allows sedimentation and filtration
Check dams (Optional for grass swale)	Provide earth (stabilized and vegetated) check dams at locations that will not hinder maintenance activities, preferably at the downstream end of swale. Maximum height for check dam is 60 cm.	Water retention increases infiltration and sediment settlement
Bioswale		
Pre-Treatment	Provide forebay and minimum one check dam	Forebay diffuses concentrated flow and captures trash/debris. Check dams increase water storage, hydraulic retention time, and ultimately infiltration.
Geometry	Base width: 0.9–1.5 m (3–5 ft); Length: 8–30 m (25–100 ft); Slope: 1% or less. Maintain minimum 0.45 m (1.5 ft) between media bottom and the seasonal high-water table.	Bottom width and flat slopes allow greater contact time and infiltration to the media
Engineered media specifications	0.45–0.90 m (1.5–3.0 ft) depth; Low to moderate organic matter (5% of total weight or 10% of total volume); fines between 8 and 12%; phosphorus-sorptive material.	Engineered media needed for enhanced nutrient reduction and bacteria removal.
Drainage	Provide perforated underdrains wrapped in geotextile fabric, if native soils are permeable (infiltration rate >1 cm/h), include IWS	Infiltration will provide runoff reduction. The process of infiltration will encourage filtration and thereby enhance pollutant reduction.
Wet Swale		
Pre-Treatment, Swale Area, and Vegetation	Provide high surface area to drainage area ratio (approximately 5%). Add diverse mix of wetland vegetation to reducesediment and associated pollutants if wetland soils and hydrology are present. Provide a forebay and check dams if not already flat slopes.	Vegetation maintains infiltration and provides nutrient uptake and removal functions, especially N. Forebay diffuses concentrated flow and captures trash/debris. Check dams promote and sustain wet conditions.

Source: [7]

Swales options are chosen on the basis of pollutant to be removed as clearly shown in table 5 below.

5.2.2. Drainage Kerb

The environmental benefit of kerb drainage is to remove coarse debris such as sediment, water bottle and grasses from stormwater. Meanwhile, care should be taken to avoid the clogging of the water entrance by these debris. For this reason, a regular maintenance should be done [27]. This job is generally handled by the municipality. Drainage kerb are located at “Nouvelle route of Bonaberie” and at pavement of Port Area (PAD). It is among the most use drainage facility.

Table 5. Swale removal options

Target Pollutant	Swale Options
Sediment	Grass Swale, Infiltration Swale, Bioswale, Wet Swale
Heavy metals	Grass swale, Infiltration Swale, Bioswale, Wet Swale
Phosphorus	Bioswale
Nitrogen	Wet Swale, Bioswale with internal water storage (IWS)
Bacteria	Bioswale

Source: [7]

Figure 9. Drainage kerbs; source: [21]

One of the inconveniences of drainage herbs is the inability to revome very fine particles from water. This lead [35] to optimize the kerbs' system through inclusion of a filtrering systems before the kerbs. This can be seen in the below figure.

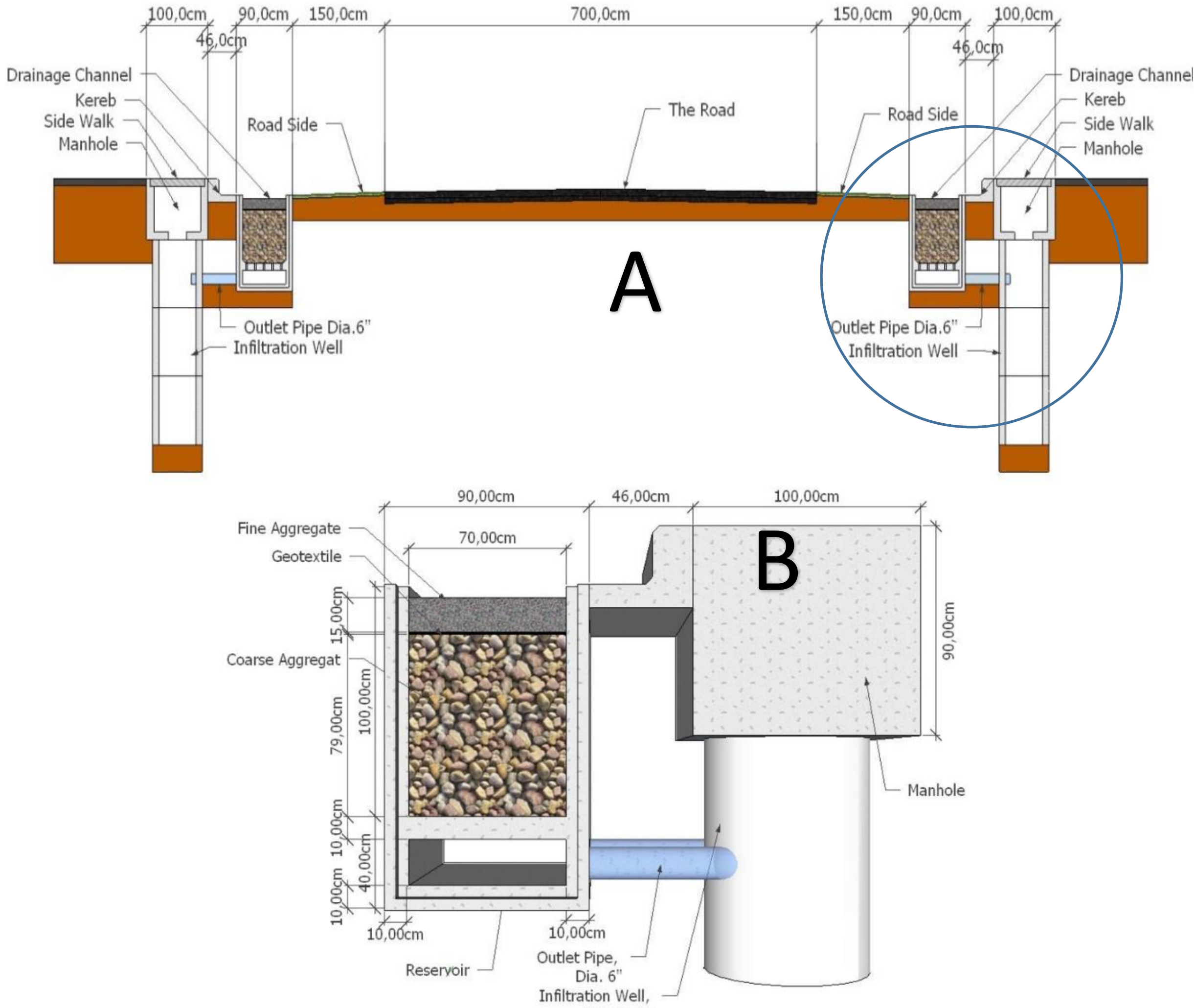

Figure 10. Presentation of the drainage system with filtring side located before kirb. B is the zoom of read circled image of A; source: [35]

6. Conclusion

We have seen that sustainable drainage systems are very crucial to mitigate the impact of flood event on the road itself but also on the surrounding environment. Local authorities such as municipalities should play an important role to ensure an appropriate maintenance of these facilities. No doubt that if the city of Douala experimented these technics with appropriate maintenance, this will increase its attractivity.

Conflict of interest

There is no conflict of interest liaising with this publication.

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