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Study the discharge capacity of the main collectors of sewerage for the city of fez, Morocco

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Abstract

The city of Fes has expanded significantly during the past few years. As a matter of fact, ground and surface of the land has been artificialized. Therefore, a remarkable increase in runoff coefficient took place, and as a result, the discharge capacity of the main sewerage collectors has been affected. This urban expansion is somehow special, since it is carried out upstream of the existing sewerage system. In this context, a procedure was conducted based on the delineation of major watersheds' sewerage system, which involves specific design parameters namely the average slope, the runoff coefficient and the coefficient of elongation in order to estimate the peak flow that can be caused by a decennial downpour (return period of 10 years). These calculated flows will then be compared with the full sections' flow (Qps), which represent the flows that can convey each collector while keeping a real flow speed (Vr) lower than 4.5m / s. The results prove that the studied sewerage collectors can't cope with an eventual overload with a percentage of insufficiency ranging between 18.21% and 94.48%.

Keywords: *Sewerage, Drainage capacity, Overload, Saturation*

1. Introduction

Under the circumstances of the city's expansion, the ground's artificialization which causes a considerable loss of natural surfaces, along with climate change that increases the frequency of extreme phenomena, the evacuation capacity of sewerage networks become weaker, and unable to evacuate the flows' peaks. The city's expansion is particularly special compared to most Moroccan cities since it is performed upstream of the existing sewerage networks, and thus induces an overload of these, which in return increases the risk of overflow and / or flooding. The current work aims to determine the peak flows per watershed, the calculation of existing collectors' full section flow rates, the determination of actual flow's speed and how the latter relates to the standards. The main purpose is to study the discharge capacity of the main collectors of sewerage for the city of Fez.

2. Presentation of the study area

2.1. Geographic location

The city of Fès is located at an altitude of 387 m, representing the point of convergence of four large natural regions and the intersection of three large parts of Morocco: the Middle Atlas from South and East, the Fès-Meknes plain from West, and the Rif from North. Its site is located between the foot of the Tghat mountain (837 m) and Zalagh's one (900 m), where the Oued Fez river, after crossing the marshy plain of Saïss, accelerates to join the Oued Sebou [1].

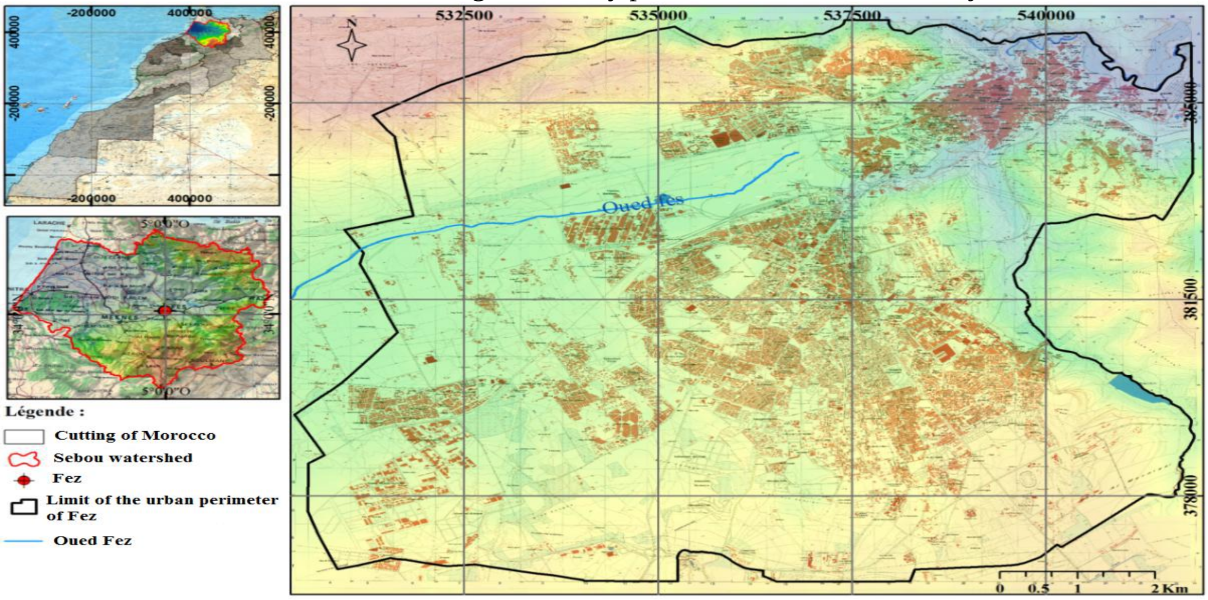

Figure 1: Map of location of Fez

The city of Fez is one the largest cities of Morocco and has a decisive role in the development of the country. Its region is known for its economic, touristic and agricultural activity which constitutes its greatest wealth mainly with arboriculture, cereal cultivation and legumes… etc. According to the 2014 survey, the population of this city is around 1.112.072 inhabitants [2].

2.2. Climate context

The region of the city of Fez has a variety of weather stations that are widespread and distant from each other. The data from the Fès-DRH station allows to have an overview about rainfall due to its proximity to the study's area and the detail it offers about the region's climate history. The overview of the monthly average precipitation (Figure 2), which was established over a period of 34 years, from 1980 to 2014, shows that a year can be separated into two periods: A dry season that starts from June to September which corresponds to the summer season and a wet season that begins from October to May. The rainiest months are from November to January [3].

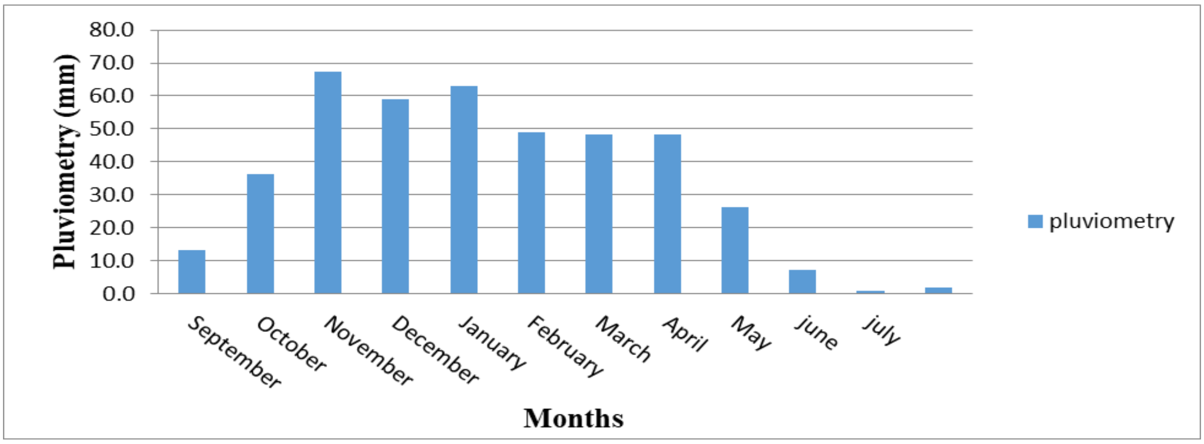

Figure 2: Monthly average precipitation

2.3. Sewerage system

The construction of the city of Fez on an area where water resources are abundant has favored the development of water distribution and sewerage systems in the city from the 11th century. Consequently, the water transport networks consisted of the following [4]:

- Clean water networks ensuring the supply of religious buildings, houses and public baths, as well as the irrigation of gardens or the mills' functioning; this network came from the Bab Boujloud's dispatcher;
- Sewerage network consisting of underground pipes called Sloquias passing under the houses and pour directly into the Oueds Boukhrareb and Zhoun, joining the river of Sebou downstream the city. It also carried out household wastes which was easily degradable in water [5].

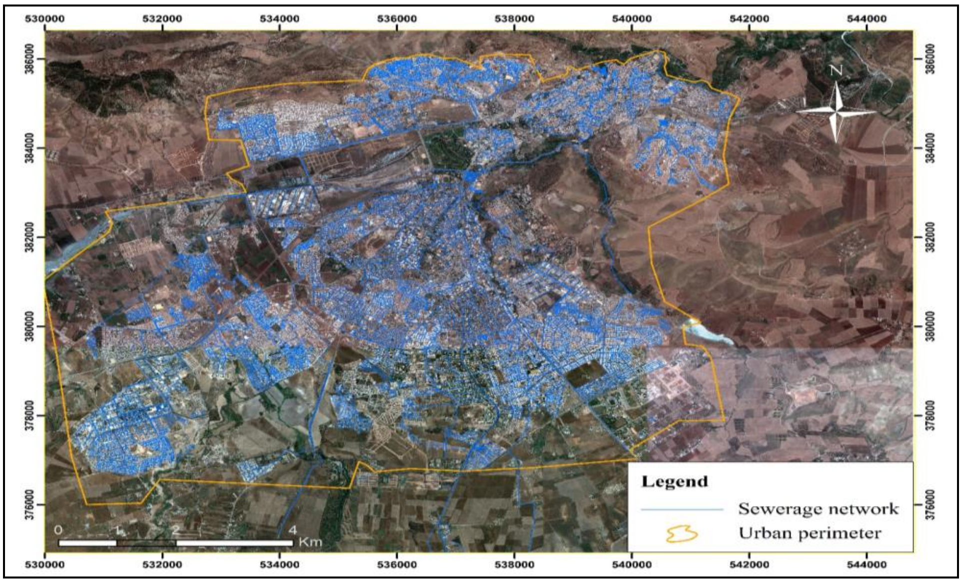

Figure 3: Sewerage network of Fez

3. Materials and methods

In order to achieve our goal mentioned earlier, an approach was conducted based on the topographic study of the area, the delineation of watersheds, the determination of parameters to find out the flows, the calculation of flows' peak and finally the study of discharge capacity of major collectors in the city.

3.1. Topographic study

The topographic study allowed us to draw the digital model of the area, which in turn allowed us to draw up the contour line map and the slope map.

3.2. Delineation of watersheds

In general, the watershed is a fundamental geographic entity in the studies of surface water; it corresponds to the natural drainage area of surface water towards a stream. In our case, we are going to study the watersheds connected to the sewerage collectors. This step aims to determine the catchment's surface of each collector.

3.3. Definition of calculation parameters by watershed

After defining watersheds, we are going to define the basic parameters of calculation including the slope of the pavement, the average slope watershed, the runoff coefficient and the parameters related to the shape of the watershed.

3.4. Calculation of peak flows

Based on the calculation of different parameters as well as the area of each watershed, we determine the peak flows by basin then we proceed to the assembly of the watersheds in order to determine the equivalent corrected peak flow after assembly. The formulas used are:

- **Caquot's surface method**

Among the different formulas well known around the world, the Caquot's surface method has been used for many decades. By involving all the mechanisms of flow, it allows to calculate the peak flow which will be used to determine the hydraulic dimensions of the collectors. This improved model is inspired by the formulas of P. Koch (1930) relating to rainwater sewerage. The method of Caquot is used for urban basins with an area less than 200ha [6].The explicit formula of peak flow for a given return period takes the following expression:

$$Q_m = K^{\frac{1}{u}} * I^{\frac{V}{u}} * C^{\frac{1}{u}} * A^{\frac{w}{u}}$$

With: Q_m : Average flow (m^3/s) ; I :Average slope of watershed(m/m) ; C: Runoff coefficient;

- A : Watershed's surface (ha); K : $\left[\frac{a\times 0.5^b}{6.6}\right]^{\frac{1}{(1-0.28\times b)}}$; u : $\frac{1}{(1+0.287\times b)}$; y : $\frac{-0.41\times b}{(1+0.287\times b)}$:w : $\frac{(0.95-0.507\times b)}{(1+0.287\times b)}$ a(T) and b(T) : coefficients of Montana.

The average flow (Qm) has been adjusted by a peak coefficient (m) which depends on the extension coefficient of the watershed (M):

$$\boldsymbol{M} = \frac{L}{\sqrt{A}} \text{ and } \boldsymbol{m} = \left(\frac{M}{2}\right)^{\left(\frac{0.84*b}{1+0.287*b}\right)}$$

With: M :Coefficient of elongation; L :Hydraulic length of the watershed (m);A :Surface of watershed(m^2) ; m :Influence coefficient, adjusting flow and Qp: adjusted peak flow.

- **Rational formula**

The rational formula implemented by the American Kuichling (1889) and the English Lloyd-Davies (1906) gives the peak flow Qp (T), corresponding to a return period T, to the watershed's outlet of a surface A and runoff coefficient C, during a rainfall of duration equal to the concentration's time tc of the basin and of average intensity I (tc, T) [7]. The

rational formula was publically known from Australia to the USSR and across most European countries [8]. The rational formula is written in its most simplified expression, supposing a rainfall on an elementary surface:

$$Qp = C * I * A$$

With: C :Runoff coefficient ; I :rainfall intensity(mm/h) and A: Surface of watershed (m²).

Up until today, Caquot's surface method and rational formula are the basis of the calculation of storm water flows [9].

3.5. Study of the evacuation capacity of the main collectors

During this stage, we compare flow rates and real flow speed with flow rates and full section speed (Qps and Vps) of existing collectors. The objective is to determine the sections of insufficient collectors and the percentages of insufficiency per section. In sewerage networks, the prevailing type of flow is gravity flow; hence the mathematical expression used to size the collectors is Manning Strickler formula [10]:

$$Q_{pc} = K_s * S * R_h{}^{\alpha} * \sqrt{I}$$

With: Q_{pc} :Peak's flow(m^3/s) ; S :Pipeline section (m^2) ; Rh :Hydraulic radius of the pipeline; I :Pipeline's slope (m/m) ; K_s : Coefficient of roughness ; α : Coefficient depending on the type of water to be treated, for wastewater α=2/3 and for rainwater and α=3/4.

- **Rational formula**

After calculating the flow, the next step is to determine the flow's speed at full section of the pipelines:

$$V_{PS} = K_S * R_h^{\frac{2}{3}} * \sqrt{I}$$

With: Vps :flow's speed at full section (m/s) ; Rh :Hydraulic radius of the pipeline (m) ; and I: Pipeline's slope (m/m).

- **Determination of the flow ratio**

$$R_q = \frac{Q_{pc}}{Q_{ps}}$$

With: Rq: ratio of the flow ; Qpc: Peak's flow (m^3/s) ; and Qps: full section flow (m3/s).

- **Calculation of the real flow's speed**

Based on the value of the flow ratio Rq, we determine the speed ratio Rv which is determined using a chart of the circular pipelines which we will use to determine the value of the real speed.

$$V_r = V_{ps} * R_v$$

With: Vps :flow's speed at full section (m/s) ; Rv :ratio of speed and Vr: real flow's speed (m/s). The flow's speed of water inside gravity pipes must be between 0.6 m/s and 4.5 m/s when the pipe flows at its full capacity [11].

4. Results and discussions

4.1 Topographical study

The map of the slopes shows a variation in altitude over the entire urban perimeter of the city with relatively steep slopes in the North, North East and East, others are low in the West. The land's slope in the city of Fez is generally low with a percentage of more than 57% for the class of slopes that are low to zero.

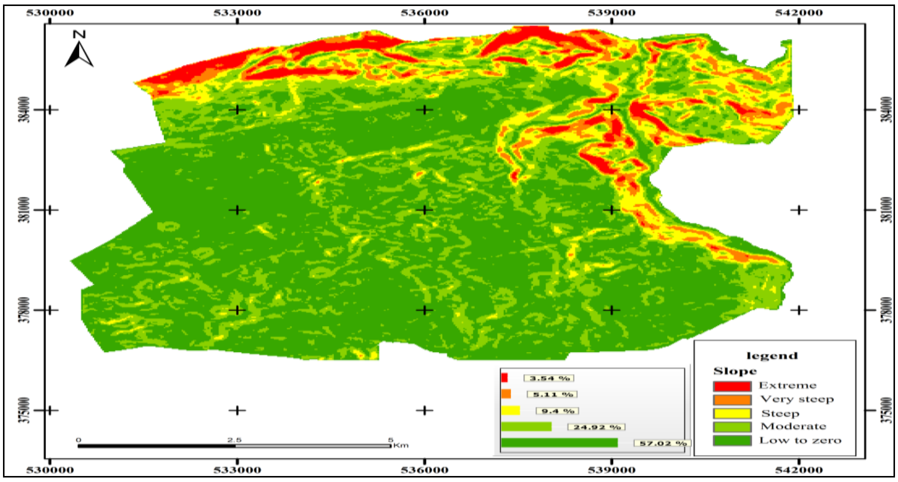

Figure 4: Map of the slopes of Fez

4.2 Delineation of watersheds

In our case, the watersheds are delineated to determine the exact contributing surface of each main collector; they are in the order of 14 having a surface area varying from 1.06 km² in the case of the Bab Siffer watershed, to 18.83 km² for the Massira-Dokkarat watershed. Figure 5 shows the different watersheds of Fez.

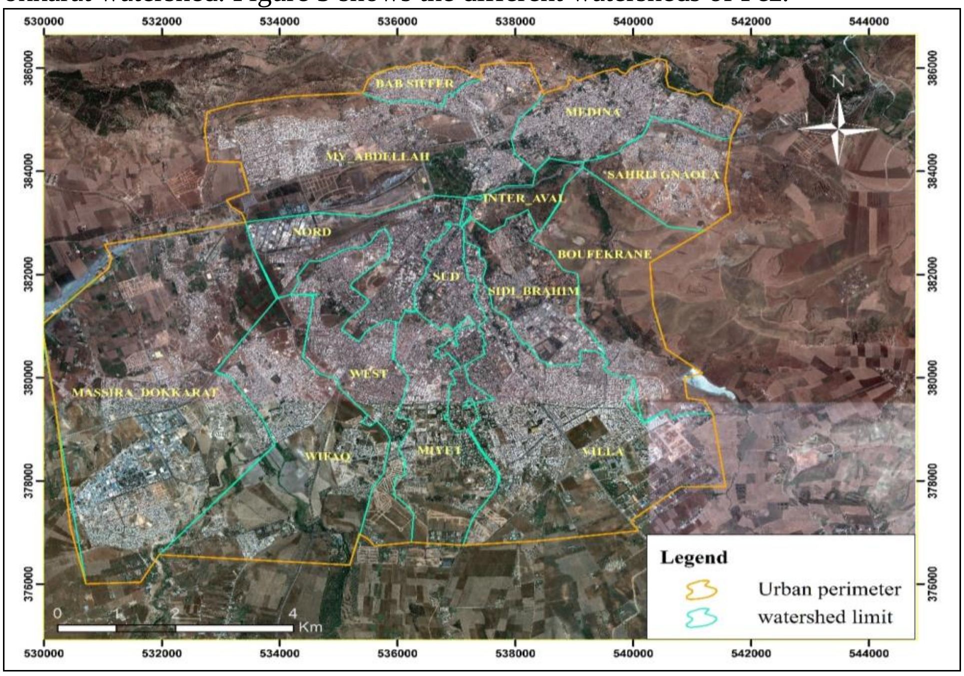

Figure 5: Elementary watersheds of the city of Fez

4.3 Definition of calculation parameters by watershed

Table 2 presents the main parameters for calculating flow rates per watershed, namely the coefficient of expression (K) which depends on the Montana parameters (a and b), the surface of the watershed (A) and the coefficient of elongation (M) which informs us about the shape of the watershed.

4.4 Calculation of peak flows

Based on the parameters determined in the previous step, the corrected peak's flows (Qpc) were calculated for the most vulnerable collectors to eventual overload during heavy rainfalls (period T10). The table below shows the peak flows corrected by watershed and by collector

Table 1: Characteristics of watersheds

Watershed	Hydraulic length (m)	I Average %	K	Surface A (ha)	M
BAB SIFFER	1700.52	4.31	1.909	106.201	1.65
BOUFEKRANE	5218.47	2.85	1.909	654.633	2.04
MASSIRA DOKKARAT	8872.93	0.38	1.909	1883.34	2.04
MEDINA	1589.73	0.58	1.909	431.813	0.77
MIYET	4957.24	0.6	1.909	471.687	2.28
MY ABDELLAH	4666.1	1.09	1.909	1149.37	1.38
NORD	3430.2	0.91	1.909	444.585	1.63
SAHRIJ GNAOUA	3233.46	5.47	1.909	342.126	1.75
SIDI BRAHIM	4018.02	1.58	1.909	349.443	2.15
SUD	5495.98	1.22	1.909	246.216	3.50
VILLA	6659.5	1.12	1.909	1213.72	1.91
WEST	6414.5	0.8	1.909	487.66	2.90
WIFAK	6140.73	1.08	1.909	1002.89	1.94
Intercepteur Aval	2468.86	2.96	1.909	131.13	2.16

Table 2: Peak’s flow by collecting and watershed

Watershed	Collector	Qpc(m^3/s)	Watershed	Collector	Qpc(m^3/s)
BAB SIFFER	BAB SIFFER	1.18	BOUFEKRANE	BOUFEKRANE	1.96
	BAB SIFFER	4.59	VILLA	BEN ABD ALLAH	0.63
	BAB SIFFER	8.51		BEN ABD ALLAH	1.65
MAS-DOK	MAS-DOK	0.37		VILLAS	6.01
	MAS-DOK	2.68	SUD	SUD	1.27
	MAS-DOK	3.28		SUD	1.34
	MAS-DOK	4.15	WEST	WEST	2.47
	MAS-DOK	4.71		WEST	4.74
MIYET	Miyet G	1.65		WEST	4.55
	Miyet D	1.93		WEST	6.70
	Miyet	5.26		WEST	9.97
	Miyet	0.82		HIMER I	0.63
My Abdellah	My Abdellah	2.79		HIMER I	3.09
	My Abdellah	4.43		HIMER II	1.01
	My Abdellah	15.57		HIMER II	6.59
	My Abdellah	18.20	WIFAQ	WIFAQ	1.68
NORD	Hypodrome	2.46		WIFAQ	3.58
	NORD	22.22		WIFAQ	3.49
SIDI BRAHIM	S-BRAHIM	1.09		WIFAQ	3.61
	S-BRAHIM	5.11		WIFAQ	2.16
	S-BRAHIM	8.46			
	S-BRAHIM	8.98			

4.5 Study of the evacuation capacity of the main collectors

In gravity flow the actual flow speed (Vr) must not exceed 4.5m/s. An excessive speed is considered as an alarm signal indicating the saturation or overload of the sewerage collector studied. The result of the calculation of the actual flow speed shows that the majorities of collectors have excessive flow speeds and therefore greater vulnerability to possible blockages and / or overflow. The hydraulic insufficiency has been quantified in order to determine what percentage of the collectors can be saturated; the table below summarizes the result of the calculation of the hydraulic insufficiency of the collectors studied.

Table 3: Evacuation capacity of the main manifolds sewerage

watershed	Collector	Qpc m3/s	I (m/m)	diameter (mm)	Vr (m/s)	Verification
BAB SIFFER	BAB SIFFER	1.18	0.0202	600	4.19	insured
	BAB SIFFER	4.59	0.018	1000	5.85	uninsured
	BAB SIFFER	8.51	0.019	1000	10.84	uninsured
MASSIRA-DOKARAT	MAS-DOK	0.37	0.0038	400	2.96	insured
	MAS-DOK	2.68	0.0035	1000	3.41	insured
	MAS-DOK	3.28	0.0039	1000	4.17	insured
	MAS-DOK	4.15	0.0034	1000	5.29	uninsured
	MAS-DOK	4.71	0.0034	1200	4.16	insured
MIYET	Miyet Gauche	1.65	0.0062	500	8.39	uninsured
	Miyet Droit	1.93	0.006	500	9.83	uninsured
	Miyet	5.26	0.0066	600	18.60	uninsured
	Miyet	0.82	0.0069	500	4.20	insured
My Abdellah	My Abdellah	2.79	0.0109	600	9.86	uninsured
	My Abdellah	4.43	0.012	800	8.80	uninsured
	My Abdellah	15.57	0.0108	1400	10.12	uninsured
	My Abdellah	18.20	0.0105	1400	11.82	uninsured
NORD	Hypodrome	2.46	0.0102	600	8.71	uninsured
	NORD	22.22	0.0108	1600	11.05	uninsured
SIDI BRAHIM	S-BRAHIM	1.09	0.0109	600	3.87	insured
	S-BRAHIM	5.11	0.015	1027	6.17	uninsured
	S-BRAHIM	8.46	0.01	1392	5.56	uninsured
	S-BRAHIM	8.98	0.011	1392	5.90	uninsured
BOUFEKRANE	BOUFEKRANE	1.96	0.0285	600	6.92	uninsured
VILLA	BEN ABD ALLAH	0.63	0.0352	400	5.00	uninsured
	BEN ABD ALLAH	1.65	0.0298	600	5.83	uninsured
	VILLA	6.01	0.0198	1027	7.25	uninsured
SUD	SUD	1.27	0.0155	600	4.50	insured
	SUD	1.34	0.0157	600	4.75	uninsured
WEST	WEST	2.47	0.143	500	12.59	uninsured
	WEST	4.74	0.0122	1000	6.04	uninsured
	WEST	4.55	0.0126	1027	5.50	uninsured
	WEST	6.70	0.0133	1027	8.09	uninsured
	WEST	9.97	0.0139	1392	6.55	uninsured
	HIMER I	0.63	0.0125	500	3.23	insured
	HIMER I	3.09	0.0175	800	6.15	uninsured
	HIMER II	1.01	0.0179	500	5.12	uninsured
	HIMER II	6.59	0.0177	1027	7.95	uninsured
WIFAQ	WIFAQ	1.68	0.0087	800	3.35	insured
	WIFAQ	3.58	0.0088	1000	4.56	uninsured
	WIFAQ	3.49	0.0085	1027	4.21	insured
	WIFAQ	3.61	0.0079	1027	4.35	insured
	WIFAQ	2.16	0.0081	800	4.31	insured

Table 4: Percentage of insufficiency of the main sewerage collectors

Watershed	Collector	Existing diameter (mm)	I (%)	Qps (m^3/s)	Qpc (m^3/s)	Insufficiency (%)
BAB SIFFER	**BAB SIFFER**	600	2.02	0.97	1.18	18.21
	BAB SIFFER	1000	1.80	3.73	4.59	18.91
	BAB SIFFER	1000	1.90	3.83	8.51	55.05
MASSIRA-DOKARAT	**MAS-DOK**	400	0.38	0.14	0.37	62.92
	MAS-DOK	1000	0.35	1.64	2.68	38.70
	MAS-DOK	1000	0.39	1.73	3.28	47.08
	MAS-DOK	1000	0.34	1.62	4.15	61.01
	MAS-DOK	1200	0.34	2.67	4.71	43.24
MIYET	**Miyet G**	500	0.62	0.33	1.65	80.28
	Miyet D	500	0.60	0.32	1.93	83.43
	Miyet	600	0.66	0.55	5.26	89.47
	Miyet	500	0.69	0.34	0.82	58.40
My Abdellah	**My Abdellah**	600	1.09	0.71	2.79	74.49
	My Abdellah	800	1.20	1.65	4.43	62.79
	My Abdellah	1400	1.08	7.28	15.57	53.26
	My Abdellah	1400	1.05	7.18	18.20	60.56
NORD	**Hypodrome**	600	1.02	0.69	2.46	72.06
	NORD	T220	1.08	10.51	22.22	52.69
SIDI BRAHIM	**S-BRAHIM**	600	1.09	0.71	1.09	53.85
	S-BRAHIM	T130	1.50	3.66	5.11	39.59
	S-BRAHIM	T180	1.00	6.90	8.46	22.67
	S-BRAHIM	T180	1.10	7.23	8.98	19.47
BOUFEKRANE	**BOUFEKRANE**	600	2.85	1.15	1.96	70.00
VILLA	**BEN ABD ALLAH**	400	3.52	0.42	0.63	50.00
	BEN ABD ALLAH	600	2.98	1.18	1.65	40.00
	VILLA	T130	1.98	4.20	6.01	42.94
SUD	**SUD**	600	1.55	0.85	1.27	50.00
	SUD	600	1.57	0.85	1.34	57.14
WEST	**WEST**	500	14.3	1.56	2.47	58.33
	WEST	1000	1.22	3.07	4.74	54.55
	WEST	T130	1.26	3.35	4.55	35.81
	WEST	T130	1.33	3.45	6.70	94.48
	WEST	T180	1.39	8.13	9.97	22.67
	HIMER I	500	1.25	0.46	0.63	37.50
	HIMER I	800	1.75	1.99	3.09	55.56
	HIMER II	500	1.79	0.55	1.01	82.14
	HIMER II	T130	1.77	3.98	6.59	65.77
WIFAQ	**WIFAQ**	800	0.87	1.40	1.68	20.00
	WIFAQ	1000	0.88	2.60	3.58	37.50
	WIFAQ	T130	0.85	2.75	3.49	26.64
	WIFAQ	T130	0.79	2.66	3.61	35.81
	WIFAQ	800	0.81	1.35	2.16	60.00

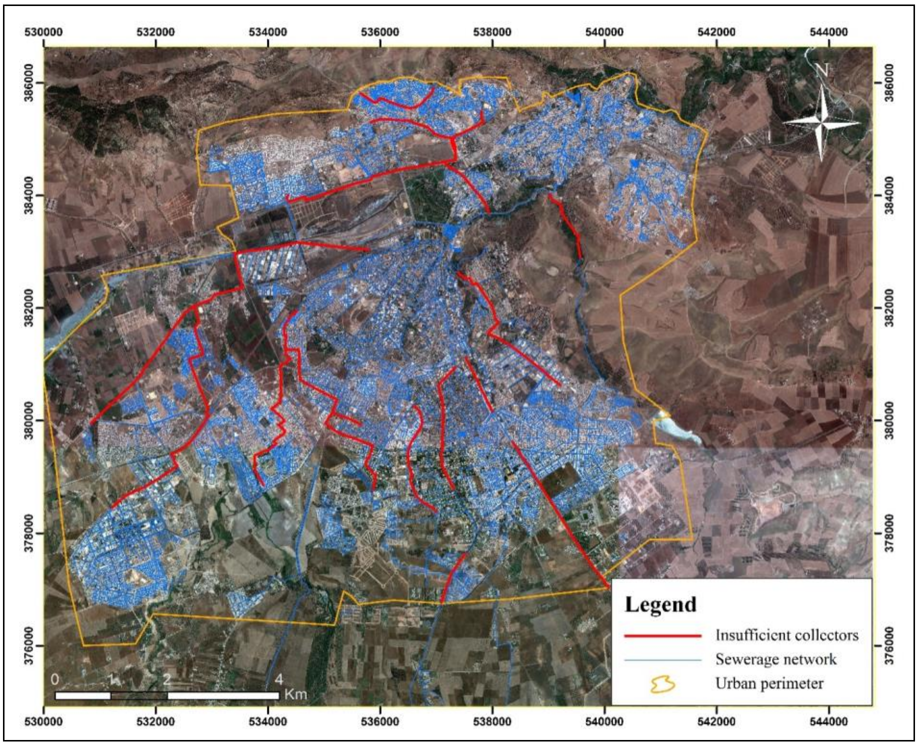

Figure 6: Sections vulnerable to overload

The figure 6 represents the most vulnerable sections to saturation. Let's point out that this overload is managed through storm overflows which are distributed in different points of the city, something which is difficult to manage with the rapid extension of the city upstream of the existing networks and which forces the managers of the sewerage network to throw part of the pollution directly into the rivers crossing the city in order to relieve downstream pipes, which is inconceivable in a city that is equipped with one of the most modern wastewater treatment plants in Morocco.

5. Conclusion

The study of liquid sewerage collectors is carried out to check their evacuation capacity in the face of a ten-year downpour (T10) and it has demonstrated the vulnerability of some of them to a possible saturation. It appears clearly that with an urban extension from the upstream of the existing sewerage network, downstream collectors are more exposed to frequent overloads during the rainy period (T10). The percentage of hydraulic insufficiency of the collectors studied varies from 18.21% to 94.48%. These percentages can be reduced by improving the flow conditions, namely the adoption of collectors with larger sections or having an internal covering to minimize their roughness. The solution which seems to be more reliable and more interesting will therefore be the adoption of alternative rainwater drainage techniques which consist in multiplying the brakes on rapid convergence so as to reduce the intensity of the flows to pass through. This solution can only be done by adopting a participatory approach bringing together all stakeholders in the water sector and the city's environment.

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