ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 6 , June 2016

Solid Discharge Modeling in an Urbanized Drainage Basin within a Developing Country: the Abiergué Drainage Basin Case Study

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ABSTRACT: Floods are natural phenomenon which effects are aggravated by anthropogenic activities such as uncontrolled urbanization, poor land use, quarrying, improper waste management... In developing countries where the urban drainage system is very poor or absent in some cases, the development of floods is more recurrent. The Abiergué drainage basin was targeted to study the hydrological transformation of rainfall into runoff that conveys waste in the drainage system. This was to enable the development of a model which could explain the link between the various components that come in play in the drainage system: solid domestic wastes and soil sediments. This was to bring forth a method that will enable to take into consideration the major factors that are at the origin or amplification of floods in developing countries in the design of new drainage systems.The model developed at the end of this study described the relation between the various components under study. It was found out that solid domestic wastes and soil sediments evolved following a linear and quadratic pattern respectively with regard to runoffs.

KEYWORDS: Floods, Model, Runoff, Solid Domestic Waste, Soil Sediment,

I. INTRODUCTION

In countries with developing economies, people live in dire conditions most often concentrated in slums and one major problem associated with these countries is that of poor drainage system. These slums have arisen as a result of rapid population growth and little or no proper planning. The increase in the population density by inference logically brings about a significant increase in the quantity of waste produced. According to [1], this is because as long as humans have lived in settled communities, solid domestic waste generation has been an unavoidable and decisive issue both in developed and developing nations.

Unfortunately, improper solid domestic waste management further affects the drainage systems as they are often used as routine routes for discarding the waste especially at rainy seasons. Once the drains are blocked by these wastes, they cannot efficiently evacuate rain water (runoffs) and this induces the genesis and amplification of floods within such areas (drains) at the slightest rainfall event. These channels are equally blocked by soil sediments that arise from erosion and from anthropogenic activities such as agriculture, construction activities, etc.

These ***wastes*** (solid domestic wastes and soil sediments) which are conveyed by runoff most often ends up in larger downstream water bodies. Their continuous accumulation over time in these water bodies ends up diminishing their carrying and conveying capacities, consequently increasing in return the rate of floods events.

It will be as such important to develop appropriate drainage systems, which will take into consideration solid domestic wastes, sediments and runoffs, regarding the fact that, notwithstanding the waste collection, a greater part of it remains in the nature and is later on conveyed into the drainage system as well as the poor management of soil which enhances soil erosion.

This study was carried out in an urbanized drainage basin called *Abiergué* which is significantly representative of Cameroon in particular and developing countries in general[2]. It aims to develop a formulation of conveyed volume of waste and sediments in the drainage system. Such an approach will enable an appropriate appreciation of the drainage system functional capacity and it will provide a novel way to manage the floods risk.

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II. METHODOLOGY

A. Area of study

Situated utterly within Yaounde, the drainage basin of Abiergué is located between latitudes 3°53'30'', 3°54'0''North and longitudes 11°26'30'', 11°30'00''East. According to the latest administrative zoning (carried out in 2008), this drainage basin is found within the district of Yaounde II and VII, department of Mfoundi, Center region, Cameroon, Africa [2].

B. Settlement characterization

This drainage basin is known to contain the two main types of district configurations identified in Cameroon in particular and developing nations in general: structured and spontaneous settlement as illustrated on TABLE 1. These settlement patterns possess different behavior with regard to solid waste management.

Table 1: Settlement pattern in the drainage basin

District	Districttype	Household per ha	House density	Road accessibility
Cité-Verte	Structured	15	(Low)	Good
Nkolbisson	Structured	19	(Average)	Good
Oyomabang	Structured	24	(Average)	Average
Average	*Structured*	*19*	*Low to average*	*Average to good*
Etetack	Spontaneous	30	(High)	Poor
Melen	Spontaneous	35	(High)	Average
Messa	Spontaneous	32	(High)	Poor
Nkolso	Spontaneous	13	(Low)	Poor
Nkolbikok	Spontaneous	14	(Low)	Average
Mokolo	Spontaneous	33	(High)	Average
Carrière	Spontaneous	32	(High)	Average
Madagascar	Spontaneous	37	(High)	Average
Average	*Spontaneous*	*28*	*Low to high*	*Poor to average*
Average	*Both district type*	*26*		

[3]

C.Soil traps

Many hydraulic engineers and geomorphologists, have for long tried to establish relationships that could permit to determine the amount of solid particles transported by runoff water within drainage systems. Many methods have been discovered ranging from empirical formulae to those involving the use of models. Some of these methods estimate the quantity of sediments in a direct way and others in an indirect way utilizing hydraulic data of the channel in which water flows as well as its characteristics [4]. It is in this regard that Soil traps (precisely the check dams and trenches) have been used to assess the experimental parameters. Check dams, trenches are all used (individually) for quantifying solid particles in runoff but can equally be used combined depending on the objective of their use or of the study. Soil traps are temporary devices installed on a construction site to capture eroded or disturbed soil that is washed off during rain storms, and protect the water quality of a nearby stream, river, lake, or bay [5].
In this method, the volume of sediments transported by water is determined via the relationship between the amounts of sediments held in the trap during a given amount of time or an event.
This permitted to carry out direct measurements (in situ) about the flow of solid particles within the drainage basin. In order to obtain the quantity of particles transported, the material accumulated in the trap was removed after every rain day and next weigh. This enabled to calculate the average solid flow per unit time (day). Many variables exist as far as the sizes and shapes of the traps are concerned but all exploit the same principles. This method is recommended for channels that are not very deep and sloppy.

1) Construction

In artificial drains (concrete) the check dams were made up of a wooden frame on which was attached wire gauze. Small spacing was chosen for the wire gauze. Indeed, the objective was not to prevent water from flowing but to retain gross particles and slow the flow of water. The wire gauze had net spacing of 2 cm.

In natural drains, trenches were used together with check dams. Within the trench an additional wire gauze material was placed at its base. This material was to be the structure on which the transported solid material in the runoff which crossed the check dam was to be dropped on. It had to give the possibility for water to drain throughout easily leaving behind it the material of interest (soil particles). The wire gauze used here had a net spacing of 0.5 cm.

2) Measurement and monitoring

It is important to note that not all solid particles are responsible for drain blockages, suspended particles flow easily to main water bodies in the drainage basin meanwhile those of more significant size sometime settle in these channels and their accumulations ends up by blocking the drains. The suspended material in general can contribute in blockage of channel only after the more significant ones or other solid materials such as solid domestic waste have already settled in and/or paralyzed the channel. That is why the study focalized on those particles susceptible to initiate the blockage of the channel. It is from such judgment that the spacing of the wire mesh was established. The solid domestic waste was collected after every rainy day. With the help of a container of known volume (A bucket of 10 l), the solid domestic waste was collected in situ.

D. Modeling

The collected data were processed with different computer software programs. The main purpose of working with these various software packages was to rapidly and efficiently determine the existence of any relationships between the different variables under study and if yes, how significant the relation was and of what nature. This was to enable the elaboration of mathematical models that will best describe this hydrological behavior within the drainage basin.
In order to ascertain the causal effect of one of the variable upon the other, the freeware called ® *(version 3.1.0)* was used. ® is a software package for scientific development that uses a program language specialized in calculations and statistical analysis [6]. In order to understand the hydrological process of the transformation of precipitation into runoff which later on conveys ***waste***within a drainage basin, the software program STELLA (version 10.0) was used. STELLA (an acronym for Structural Thinking Experimental Learning Laboratory with Animation) is a software package that permits to simulate the dynamic function of a liquid system, to follow their evolution [7]. This software package enabled to simulate within its environment this hydrological behavior. The simulation was to describe the behavioral pattern of one variable with respect to another (in case a relation existed) from which the nature of the relationship could be identified.
The various variables processed in ® to determine the existence of the relationship were used as entries for the model. The variables were: *Precipitation; Solid domestic waste and Soil sediment*. A number of hypotheses were formulated for the exercise. The results (transformation process) generated from these interactions using STELLAwhich were to be closest to the data obtained from the field was that to be consider as the model.
The rainfall was used in the models as the component responsible for conveying the ***waste*** particles but in reality, the volume of ***waste*** is found to evolve with respect to the effective rainfall which is, the part flowing directly when in contact with the soil (runoff). Within a drainage basin, rain is transformed into runoff with respect to a coefficient that depends on three main factors: slope, soil cover and type of soil. This runoff coefficient takes into consideration: Evaporation; Infiltration and storages in depressions. With respect to a surface area A, the volume of runoff is linked to rainfall R as shown on equation 1.

$$\mathbf{R} = \frac{V_{out}}{(C_r \times A)} \quad (1)$$

where:
V_{out}= Volume of runoff at the outlet (m^3)
A = Surface Area (m^2)
C_r = Runoff coefficient
C_r can be looked upon as the ratio between the volumes of water that flows at the outlet V_{out} of a point to the total volume of water (V_{tot}) that fell in that drainage basin [8]

$$C_r = \frac{V_{out}}{V_{tot}} \quad (2)$$

but

$$V_{tot} = \mathbf{R} \times \mathbf{A} \quad (3)$$

replacing (3) in (2)
implies

$$C_r = V_{out} \times \left(\frac{1}{R \times A}\right) \quad (4)$$

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 6 , June 2016

and
$\boldsymbol{V_{out}} = \boldsymbol{C_r} \times \boldsymbol{R} \times \boldsymbol{A}$……………………….………………………………...……………………….……...(5)
The 'C_r' used in this case was obtained from previous studies[8]. It was chosen based on the nature of the drainage basin. 'A' was determined in with the use of GIS tools and 'R' was obtained from local meteorological stations. With equation (5), V_{out} was assessed for the various settlement types identified in the drainage basin and later on used to determine the constants of the model so as to have the volume of ***waste***as a function of volume of runoff; $V_{\mathbf{waste}}$= fn (V_{out}). This was computed with the help of *Microsoft Excel 2007*.

III. RESULTS AND DISCUSSION

A.Relationship between runoff and quantity of solid domestic wasteswith sediments

The generation of box and whisker plot graphs with ® showed that the variations between the variables were very high enough to admit the existence of a relation between the variables despite the fact that it was not very explicit to permit to identify what type of relationship it was. The analysis was pushed further using STELLA which could readily tell on what bases and how far these variables were related.
Using STELLA, a modeled scenario of the hydrological transformation was carried out, so as to bring forth the nature of the relationship between the various variables under study. Going from the idea that they was no clear direct link between the variables, a good number of assumptions were made by proposing various types of equations (Linear, exponential…) as well as nature of variables (cumulative values or not…) and running the simulations, comparing at each time the results with that collected on the field. Final results were obtained when their average significance values were greater than 0.95.
STELLA revealed that the solid domestic waste and soil varied following two distinct patterns: a Cumulative Linear pattern for solid domestic waste ($V_{sdw} = a \times \mathrm{R} + b$) and a Cumulative Quadratic pattern for soil ($V_{soil} = a \times \mathrm{R}^2 + b \times \mathrm{R} + c$) with respect to precipitation itself a Cumulative function,
where:
V_{sdw}= Volume of Solid domestic waste
V_{soil}= Volume of soil sediment
a, b and c = constants
R = Rainfall (Precipitation)
The different equations (models) for the quarters are as presented in TABLE 2.

Table 2: *Waste*-rainfall for some neighborhoods in the drainage basin

Neighborhood	Channel (nature)	Domestic Waste Function	Soil Lost Function
Etetack	Line	V_{sdw} = 3.3 x R+0.2621	V_{soil} = 1.4 x R^2+6.1 x R+0.5175
Oyomabang	Line	V_{sdw}= 3.2 x R+0.7488	V_{soil}= 2.7 x R^2+3.1 x R+0.7433
Nkolso	Line	V_{sdw}= 2.4 x R +0.4140	V_{soil}= 3.5 x R^2+2.7 x R +0.2057
Cite Verte	Line	V_{sdw}= 2.4 x R +0.3247	V_{soil}= 2.5 x R^2+3.8 x R +0.5988
Etetack	Natural	V_{sdw}= 2.0 x R +0.2797	V_{soil}= 1.5 x R^2+3.4 x R+0.5413
Oyomabang	Natural	V_{sdw}= 2.9 x R +0.5402	V_{soil}= 5.3 x R^2+3.2 x R +0.7449
Nkolso	Natural	V_{sdw}= 2.8 x R +0.3756	V_{soil}= 3.4 x R^2+ 4.8 x R +0.2832
Cite Verte	Natural	V_{sdw}= 2.6 x R +0.354	V_{soil} = 2.3 x R^2+ 4.8 x R+0.6891

*B.*Simulation

The equations presented on TABLE 2 express mathematically the relationship that exists between ***waste*** and runoff via the amount of rainfall. Most of the ***wastes*** found in natured are conveyed by runoff to the different outlet, but most often because of poor town planning, lack of adequate drainage system, most of these domestic wastes find their end point in channels causing floods. As such in order to take into consideration the risk linked to the generation of flood because of***waste***, the latter has to be taken into consideration during the design of the drainage system and this can only be achieve by redesigning the peak factor. This peak factor will take into consideration the volume of solid domestic waste, soil sediments and runoff compared to the case where only the liquid component runoff is used.

TABLE 3 presents the result of the simulation exercise for bringing forth the volume of ***waste***that was generated with respect to a characteristics rain (in the case of the study, it correspond to the highest precipitation value = 63.8 mm) and the consequent revised peak factors with respect to the nature of channel and neighborhood.

Table 3: Revised peak values simulated for four quarters in the watershed

In Natural channels

	Simulated amount produced					
Neighborhood	Surface area (km^2)	Runoff (m^{3}m^{-2})	SDW (m^3 day^{-1} km^{-2})	Soil lost (m^3 day^{-1} km^{-2})	C_r	peak factor simulated
Cite Verte	0.00493	0.4785	1.5981	3.51251	0.75	11.68048
Etetack	0.01298	0.3828	1.19842	2.06262	0.60	9.51892
Nkolso	0.00766	0.3828	1.44744	1.75214	0.60	9.35834
Oyomabang	0.01183	0.3828	1.95462	2.32563	0.60	12.18141

In Line channels

	Simulated amount produced					
Neighborhood	Surface area (km^2)	Runoff (m^{3}m^{-2})	SDW (m^3 day^{-1} km^{-2})	Soil lost (m^3 day^{-1} km^{-2})	C_r	peak factor simulated
Cite Verte	0.00429	0.5423	1.62622	3.39476	0.85	10.25860
Etetack	0.02220	0.4785	1.84115	3.75689	0.75	12.69915
Nkolso	0.03347	0.4785	1.5624	2.29901	0.75	9.06983
Oyomabang	0.01251	0.4785	2.256075	2.84484	0.75	11.66023

The value of the peak factor presented on table 3 illustrates how much its value is compare to the case where only runoff is the only parameter used in the design of the drainage system. For instance the peak factor for line drainage systems in structured neighborhood like Cité Verte is 10.2586 which implies this value is 10.2586 times greater than the normal value of runoff

IV. CONCLUSION

For so long, developing countries have been faced with the difficulties of managing the ***waste*** they produce. Factors such high birth rate in these countries, inadequate number of skips, poor collection system worsens the more the situation. Improper solid domestic waste management significantly affects the drainage system as they are often used as routine routes for discarding these wastes especially at rainy seasons and hence aggravating the development of floods. Regrettably the designs of drainage system in these countries don't usually take into consideration solid domestic waste and soil sediments in the flow. This paper as such provides a novel approach in the mitigation of the impact of floods in developing countries as it seeks to develop a model that quantifies the relationship between runoffs, solid domestic wastes and soil sediment as such giving the possibility to develop a peak factor which takes into account these elements. If this peak factor is as such used during the design of the drainage system, it is likely that the problems link to floods occurrence in developing countries will be significantly reduced.

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ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

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