Study of subterranean waters through a sump sunk in a site in high-land of Madagascar

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A sump sunk in a site located in the high lands of Madagascar was initially conceived to block and deviate an underground water flow making its way to the foundations of a dwelling house. it is possible to explain the infiltration or the surface flow in a porous surrounding and confirm some characteristics proper to the flows of a real fluid by studying the height of the water in the sump and the flow coming out through an exhaust pipe during three rainy seasons and that since 2004. the pluviometrics of the site and the Reynolds number can complete the studies.

1. INTRODUCTION

After a few days of intermittent rains, a sump built to protect against water flowing up into a dwelling house is the object of a particular phenomenon. Consequently, the water has a tendency to jet out over the brinks of the sump instead of following totally the cylindric exhaust pipe. At the height of the rainy season when the rain is important we also notice that some flows do not follow the chronological order of variation.

To find a solution to that, and to understand those phenomena, we seal the sump hermetically with a thick glass. The purpose of that operation is to move any disorder coming from the subterranean sheet of water to the lower part of the exhaust pipe. Indeed, after torrential intermittent rains, the water jets out intermittently with slight production of sound. That phenomenon can last a few days.

The sump doesn't have the shape of usual wells [1, 2]. It has a rectangular section and is rather shallow. Many works are also carried out on the hydrology and the subterranean waters in the high-land of Madagascar. Some of them are quoted in [5, 6, 7, 8, and 9].

In this study, we show that through the sump it is possible to explain and rediscover phenomena linked to the subterranean flow of a real fluid coming from a subterranean sheet of water of the site.

Therefore, first of all we are going to develop general considerations giving details of the methodology that we adopt. Second, we are exposing results, analysis and discussions.

2. GENERAL CONSIDERATIONS

2.1. Geographical location of the sump

The sump is sunk in an estate located in the site of Antsahameva situated in the flat part of basin shaped area. The upper edge is bordered by the University Campus of Antananarivo at an altitude of 1323m and the Professors' blocks of tenements at Fort Duchesne at 1304m. The latitude and longitude of the estate are 18°54'30'' South and 47°33'17'' East, respectively. Its altitude 1290m indicates that we present a study carried out in the high lands of Madagascar. Its red soil is lateritic and of ferralitic nature, geological characteristics confirmed by the works of [5]. The climate is characterized by two seasons: a dry season from the month of June to September, and a rainy season from October to May of the following year.

2.2. Description of the sump

The sump is sunk to block and deviate the trajectory of a subterranean flow making its way to the foundations of a house (Figure 1). It has the shape of a rectangular parallelepiped: 0.91m long, 0.71m wide and 0.75m deep. Its lateral walls are made of reinforced concrete and one of the walls is provided with weeping –holes to allow the subterranean water to flow in. A cylindrical exhaust pipe fitted to a swallow-hole located at the upper part of the sump will allow the out flow of the water when the sump is overfull. The exhaust pipe is placed at ground level with a 10° slope. During the rainy season, the water jets out more or less strongly depending on the duration and the importance of the rain falling on the site.

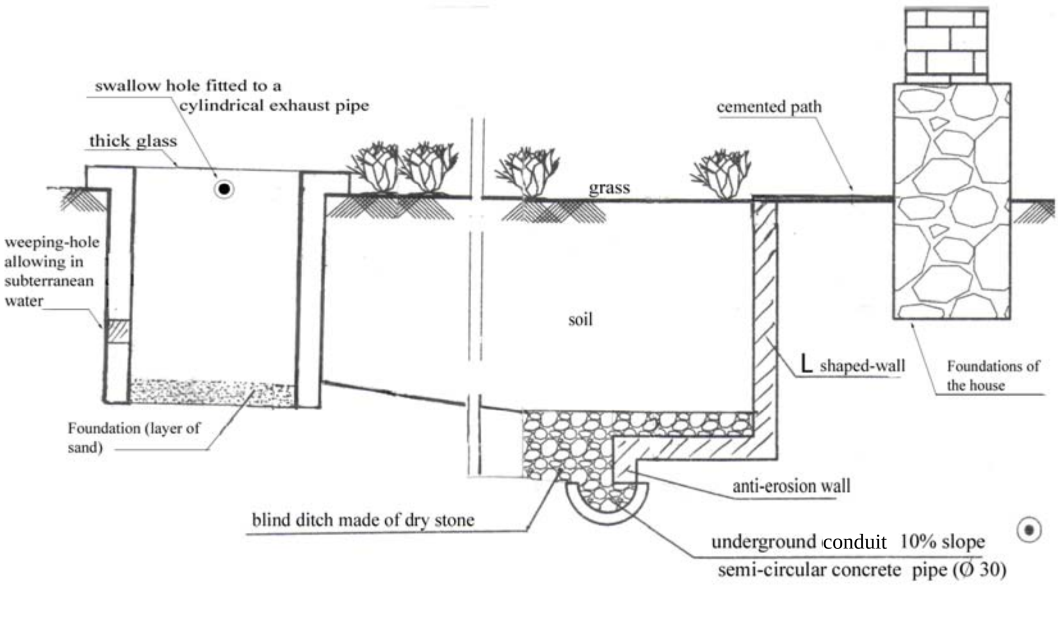

Figure 1: Section of the sump and the protection system [10]

2.3. Hypothesis

We suppose that:

- The site subterranean sheet of water is fed by the infiltration of rain waters
- The inner surface of the sheet is watertight and has cracks connected to the sump by underground channels which join together afterwards to become one at the entrance of the sump.
- The sheet can have several cracks providing water to other springs. We don't take that into consideration.
- The inner surface of the sheet is watertight.
- The infiltration from the site's sewages do not influence the water flow in the pipes: conservative flow.
- The water flow takes place irrespectively of the geological components of the sheet.

3. EXPERIMENTS AND RESULTS

The experiments are carried out during three successive rainy seasons since 2004. They are done in two stages

3.1. First stage

It is around the study of the evolution of the water height in the sump. It is carried out only in September 2004 which is the end of the dry season and the arrival of the first drops of rain. The measures are taken eight times every four days. A measuring apparatus is made to read the variations of the water height outside the sump. A metallic road equipped with a stylet is fastened on a parallelepiped shaped polystyrene float. The rod slide freely up and down between two rings fixed on a wooden board. The stylet moves along a graduated ruler with a reading incertitude of 1mm (Figure 2).

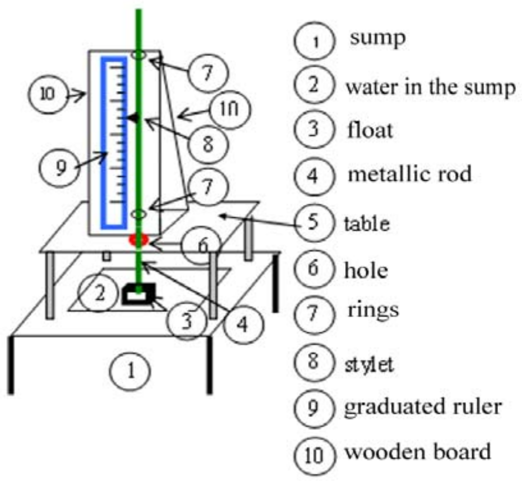

Figure 2: Principle scheme of the measuring apparatus

The operations start with emptying the 0.485 m^3 of water. The measuring apparatus is then put on the edges of the sump. All the measures always start at 9a.m. They are taken every 30mn and stopped when all the values remain constant for at least 60mn. They are the values of the maximum height noted hmax. The height of the rain is given by a pluviometer with incertitude of 0.1mm (Table1). To ensure best experimental conditions, the sump and the measuring apparatus are placed under a small shelter.

Table 1: Maximum height hmax and rain height

September 2004

Date	**Maximum height hmax (cm)**	**Duration (mn)**	**Variation Δhmax (cm)**	**Rain height (mm)**
2	57.3	360	0.0	-
6	55.9	450	-1.4	-
9	-	-	-	2.0
10	53.7	300	-2.2	-
14	55.9	390	+2.2	-
18	57.0	480	+1.1	-
22	57.5	510	+0.5	-
26	58.0	510	+0.5	-
29	-	-	-	2.1
30	58.0	510	0.0	-

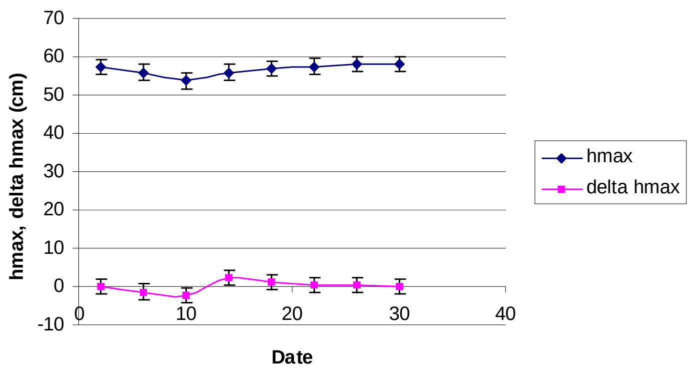

Figure 3: hmax , Δhmax depending on the date

3.2. Second stage

Rain becomes important in October. The value hmax increases and the water begin to flow out of the exhaust pipe on December 7, 2004 at 3 p.m. All the measures of the flow are then taken at that same time during three rainy seasons until May 2007. In order to avoid water splashing, the upper part of the sump is hermetically closed with a thick glass.

The water flow Q coming out of the cylindric pipe is calculated from the volume of water collected in a 250 mL graduated test tube with a precision of ± 2mL for 5seconds, using a stop-watch. Each time, three volumes are collected and the average figure of those three volumes is kept.

Two groups of values received particular attention: the flows of December 18 to 22 2004 (Table 2), the water flow Q is represented by the Figure 4, and those of January 9 to 20, 2005. (Tables 3), Q is represented by the Figure 5

Table 2: Water flow Q (December 18-22, 2004)

Date	**Q ($L.h^{-1}$)**	**Hrain (mm)**	**Duration**	**Re**
18	66.0	24.0	8h -9h	915
19	69.0	38.7	12h-21h	957
20	153	0.0	-	2121
21	129.6	0.0	-	1797
22	144.0	3.3	16h-17h	1996

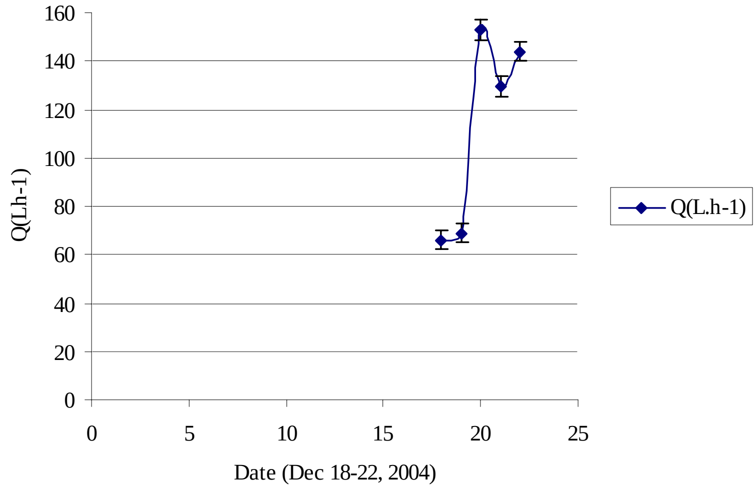

Figure 4: Water flow Q according to the date

Table 3: Water flow Q (January 09-20, 2005)

Date	**Q ($L.h^{-1}$)**	**Hrain (mm)**	**Duration**	**Re**
09	144	51.5	18h30-20h	1996
10	180	19.0	17h-18h	2495
11	225	-	-	3119
12	252	-	-	3493
13	180	-	-	2495
14	180	-	-	2495
15	198	-	-	2745
16	198	-	-	2745
17	180	-	-	2495
18	180	-	-	2495
19	216	-	-	2995
20	216	13.1	16h-19h	2995

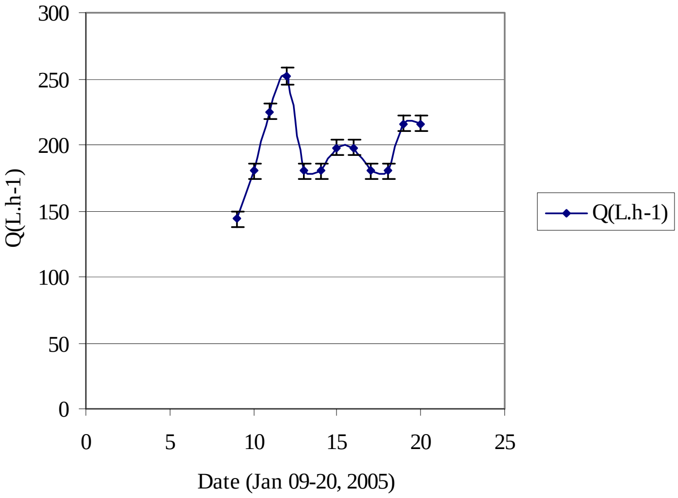

Figure 5: Water flow Q according to the date

4. ANALYSIS AND DISCUSSIONS

4.1. About the first stage

The purpose of the present study is to show that the subterranean sheet of water and the sump are two communicating vessels.

When the subterranean sheet of water is fed by rainwater, it gains potential energy of pressure which is one of the causes of the flow in the subterranean channels feeding the sump. Table 1 shows that when the quantity of water stored by the subterranean sheet is important, only 390mn are necessary to cause the variation Δhmax = +2.2 cm in the sump on September 14. Four days later, on September 18, the subterranean sheet evacuates a part of its energy. Much more time is necessary, 480mn to produce Δhmax = +1.1 cm. Four days later, on September 22, 510mn are necessary to obtain Δhmax = +0.5 cm. The filling speed of the sump is then very weak. The potential energy of pressure of the subterranean sheet of water becomes null, that is why on September 26 and 30, the maximum height hmax are identical: Δhmax =0 (Figure 3), two reservoirs are in hydrostatic balance. No flow can then come out of the subterranean sheet. We can conclude that the subterranean sheet of water and the sump are a pair of communicating vessels and the flow is conservative because the infiltrations from household sewages in the site do not influence the height of the water in the sump, otherwise Δhmax =0 can never be reached. .

4.2. The second stage

It consists in explaining the physical phenomena which has been noticed, and in rediscovering characteristics of the flow of a real fluid.

The subterranean water sheet and the sump being two communicating vessels, the results obtained from one of them could be interpreted to explain what happened in the other. The Tables 2 and 3 make it possible to affirm that the rains which fell on the site on December 18 and 19, 2004 are steady downpours. Therefore the infiltration of water in the subterranean sheet of water is important. But the rain on January 9 and 10, 2005, is torrential and of short duration. The surface flow is preponderant over infiltration [9, 10] which is confirmed by the variation ΔQ of the flow at the level of the sump on December 20, 2004 and January 11, 2005, 24 hours after the end of the steady downpours and the torrential rains (Table 4).

Table 4: Variation of ΔQ after 24h

Date	**Duration of rain (h)**	**Hrain (mm)**	**ΔQ (Lh^{-1})**	**Rain**
18-19 Dec -04	10.0	62.7	84	Steady downpours
9-10 Jan-05	2.5	70.5	45	torrential

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The Table 2 also shows that from the maximum value of 153 $L.h^{-1}$ of the water flow, the other value did not follow chronological order of the decrease. To explain that phenomenon, we use the Reynolds number as follows:

$$Re = \frac{UD}{\nu} \qquad (1)$$

In which:

- U: Average speed of the flow ($m.s^{-1}$)
- D: Internal diameter of the pipe (m)
- ν: Kinematics viscosity of the water ($m^2. s^{-1}$)

When the water flow Q was introduced, the expression (1) is written

$$Re = \frac{4Q}{\pi \nu D} \qquad (2)$$

- Re: Reynolds number
- Q: Water flow out ($L.h^{-1}$)
- ν: Kinematics viscosity of the water ($m^2. s^{-1}$)

Table 2 also makes it possible to explain the splashing of the water in the sump accompanied by production of sound. Indeed, the flow is initially turbulent (Re=2121), the fluid particles begin to take disordered trajectories. Important friction forces appear and cause the decrease of the water flow from 153 $L.h^{-1}$ to 129.6 $L.h^{-1}$ after 24 h. One day later, on December 22, the disordered caused by the transition of the flow from a quiet one to a turbulent one tends to dissipate because the subterranean sheet is no longer fed again and no other perturbation takes place. The consequence is that it increases and reaches 144 $L.h^{-1}$ while remaining inferior to 153 $L.h^{-1}$. That value is taken at 3 p.m., one hour before the December 22 rainfall.

Table 3 also makes it possible to explain the splashing of the water in the sump accompanied by production of sound. Indeed, the flow is initially turbulent in the exhaust pipe. It is different from the December 2004 flow. The torrential and intermittent rain feeding the subterranean sheet causes a pressure increase. It is also a perturbation which creates elastic waves. As the flow is turbulent, the perturbation is amplified to the level of the sump.

In order to show the importance of energy which causing the variation of height water in the sump, the volume of out flow water by the exhaust pipe during three rainy seasons is consigned in the Table 5 and represented by the Figure 6.

Table 5: Volume of out flow water for three rainy seasons

	December	**January**	**February**	**March**	**April**	**Total**
Volume (m3) 2004-2005	62,38	149,52	121,43	125,61	61,85	520,68
Volume (m3) 2005-2006	64,71	67,30	86,42	71,28	46,22	335,92
Volume (m3) 2006-2007	53,27	227,52	314,93	294,19	164,43	1054,25

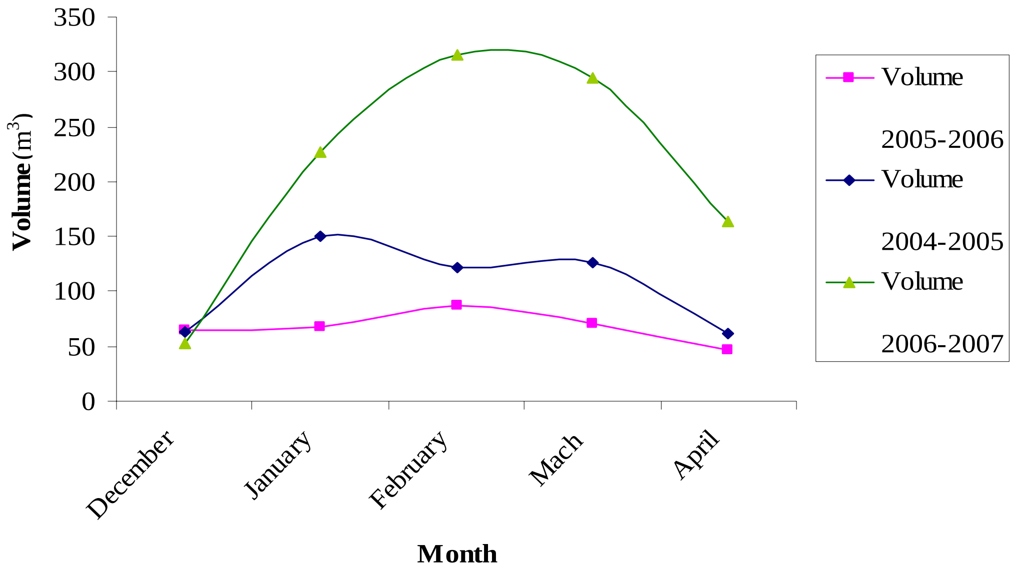

Figure 6: Volume of out flow water during three rainy seasons

At the entrance of the weeping holes, the kinetic energy of the fluid turns into a potential energy which causes the variation of the height of the water in the sump. The subterranean sheet and the sump being two communicating vessels, the perturbation which starts in the subterranean sheet carried on to the exhaust pipe hole. If the variation is irregular and important, the splashing phenomenon happens. Such phenomenon is noticed several times during the three years of experiments each time the rains are intermittent and torrential. The example of January 17 to 25, 2007 is rather clear because of the passage of a tropical depression over Madagascar (Table 6), Q is represented by the Figure 7.

Table 6: Water flow Q (January 17-25, 2007)

Date	**Q ($L.h^{-1}$)**	**Hrain (mm)**	**Re**
17	486	20.3	6737
18	468	10.5	6488
19	504	70.4	6987
20	468	0.0	6488
21	432	3.0	5989
22	432	0.0	5989
23	450	3.5	6228
24	432	15.0	5989
25	414	5.6	5739

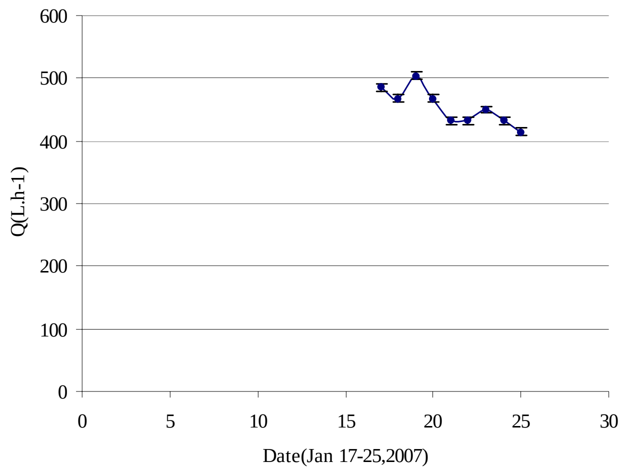

Figure 7: Water flow Q according to the date

The studies do not take into account the geological characteristics of the subterranean sheet and the sewage waters which can influence the flow of the sump. They suppose that the subterranean sheet acts like a wide reservoir full of porous materials through which water can seep its way and escape through cracks. The result Δhmax =0 at the end of the dry season means that there is no fluid arrival neither in the subterranean sheet nor in the subterranean channels. It means that there is a balance of water contained in the subterranean sheet and the sump.

The purpose of the glass sealing hermetically the sump is to avoid water splashing and to have a forced flow into the exhaust pipe. In that case the sump was no more than a passage through which the water goes to flow out of the exhaust pipe. The system made of the sump, the subterranean channels and the subterranean sheet is then equivalent to a wide subterranean reservoir flowing out through a cylindrical exhaust pipe fixed at ground level.

5- CONCLUSION

At the end of this article, it is proper to note that the results obtained are about the flows of real fluids through experimental approaches. The work site is part of the high-land of Madagascar. The studies are made from a sump which was one element of a protecting system against water flowing up into a dwelling house.

The regular observation of the maximum height hmax of the water in the sump at the end of the 2004 dry season made it possible to show that the site's subterranean sheet of water and the sump are two communicating vessels. It is possible to verify the hypothesis of a conservative flow when Δhmax is null in the absence of rain for several days.

The study of the water flow jetted out by the sump during three rainy seasons since December 2004 makes it possible to rediscover and to explain phenomena linked to the flow of a real fluid in a porous surround and in channels with watertight surfaces. The pluviometrics of the site and the Reynolds number provided precious help.

When the rain is torrential and of short duration, the surface flow is preponderant over infiltration. The inverse phenomenon happens when the rain is steady downpour.

The water flow diminishes first, and then increases when the flow changes from a quiet flow into a turbulent one.

A perturbation introduced at the upper part of a turbulent flow develops and has repercussions downstream at the level of the sump. That explains the water splashing on the edges of the sump.

The consideration of the geological constituents of the site and a theoretical study will allow completing the results of those experimental approaches.

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