FLOODS IN SEMI-ARID ZONE: EXAMPLE OF THE OURIKA (HIGH ATLAS OF MARRAKECH, MOROCCO)

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In the High Atlas of Marrakech, the watershed areas are submitted to important and frequent floods, associated with landslide and rockslide. Morphological and lithological characteristics of the basins watershed have a clear influence on the rising waters strength and the hydrogram's shape. The products of erosion accumulated in the upstream part as gravity accumulation and fans are remobilised during high floods when the discharges increase. This situation make flows muddy and torrential. The consequences of these natural risks can be grave in term of damage and cost. In the Ourika valleys, we are confronted to the amplification and repetition of this process owing to its deepness and narrowness. Furthermore, the degradation of environment speeds up because of the development of tourist activities. All these conclusions suggest the management of these suddenly beating of flows.

Keywords: floods, high atlas, landslide, erosion.

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Introduction

In arid environments rising waters accompanied by landslides, the consequences of which can be very serious in terms of damage and cost, are quite frequent. In the Ourika basin (High Atlas of Marrakech, Morocco), the rising waters rapidly turn the roads dangerous and consequently out of use, especially as the valley is linked to the outside world by a unique fragile and vulnerable road.

On August 17th, 1995, the High Atlas of Marrakech, and most particularly the Ourika valley witnessed floods of enormous strength which occurred in an unexpected brutal way [1, 2]. In an unprecedented short time, the

floods caused human casualties (more than 200 death and unaccounted for) and huge material damage. The torrential rain and the mudslides whish followed swept away road infrastructures, agricultural lands, houses, hospitals and schools as well as a great part of the irrigation infrastructures [3]. On the whole, the material damage (vegetable and animal production, hydro-agricultural network and properties) are estimated at 155 million dirhams (about 15 millions US dollars) [4]. This catastrophe caused a great imbalance as far as the production system and the ecological environments is concerned.
This paper is a study of the hydrological, lithological and geomorphological aspects of the Ourika basin. The primordial purpose of this study is: 1 – to understand the dynamics of this natural fragile environments, 2 – to provide indications allowing for a characterization of its hydrological behaviour.

Characterisation of the Ourika basin watershed

The hydrological behaviour of a basin watershed depends mainly on its climatic and geomorphological characteristics. In fact, just like the weather, the physical environment can provide appropriate grounds for brutal pulsations of rising waters. A heavy rain, whish falls on a sloppy basin with deep watershed and with little permeable substratum, can cause flows on the surface with a very short time response of water concentration.

Geographic and climatic situation

The Ourika basin at Aghbalou, about forty kilometers south of Marrakech (Fig. 1), is situated between 31° and 31°20′ North and between 7°30′ and 8° West. Several aridity indexes place the sector in a semi-arid zone with a sub humid tendency where oceanic (west perturbations), continental and mountainous influences interfere. The average annual temperature is 17.6 °C at Aghbalou, but the difference in temperatures between the hottest mounts (July) and the coldest (January) can reach 15 °C. The region is characterized by precipitations of a spatio-temporal variability and by relative irregularity in superficial flows. The average annual rainfall is 584 mm per year at the Aghbalou station with a 34 % variation rate. The monthly and seasonal variability is even more marked respectively by 50 and 55 % variation rate. According to the Marrakech hydraulic regional office, the average annual discharge at the basin vary from 0.59 m^3/s to 29.6 m^3/s. However, the marked trace of the Ourika flows corresponds to the highly occasional flow discharge which can reach several hundred of cubic meters per second.

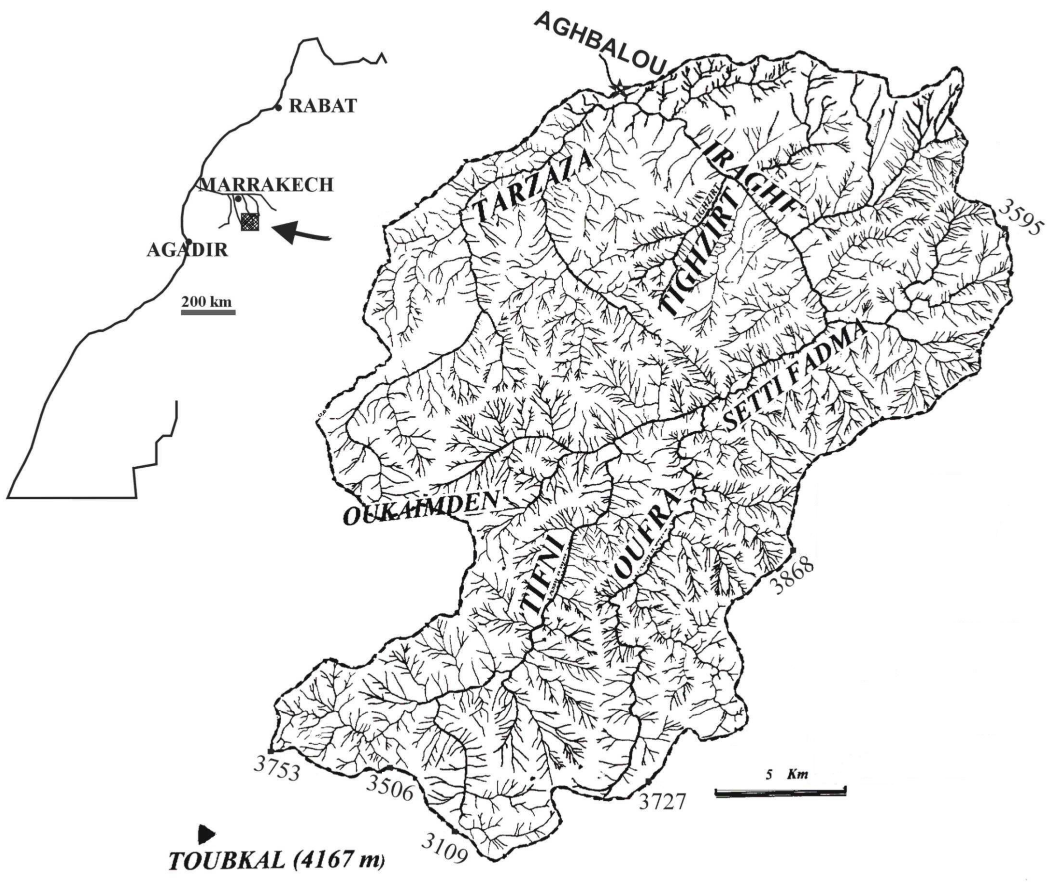

Fig. 1. *Ourika basin watershed: location map and hydrographic network*

Morphological characteristics

The basin watershed shape can have important hydrological consequences, mainly the rain-discharge relationship and the evolution of the flows in periods of rising waters. In other words, and besides the nature of the rainfall, it is basin's morphological characteristics that condition the shape of hydrograms observed downstream the basin. Several formulae and indexes illustrate these characteristics (Table 1).

The Gravelius compactness index ($Kc = 0.28\ P/\sqrt{S}$); where P is the perimeter and S the surface) offers and idea of the basin's geometrical shape; it is the range of 1.3. This relatively mediocre compactness grants the basin with an elongated shape. The main flow forms a linear valley, fed on the two banks, by a succession of tributary ravines (Fig. 1). This situation allows for the waves of rising waters to swell downstream while being fed by the tributaries.

The analysis of the distribution of the altitude parts is made of the basis of a topographical map at 1/100 000 m Oukaimeden-Toubkal. The altimetric distribution at the Ourika basins shows the predominance of sites situated between 1600 and 3200 m (75 %); the average altitude reaching 2500 m, Fig. 2.

Table 1

Morphological characteristics of the Ourika basin watershed

Perimeter (km)	104
Surface (km²)	503
Compactness index	1.3
Length of the main (km)	45.5
Length of the equivalent rectangle (km)	39.2
Width of the equivalent rectangle (km)	12.8
Maximum altitude (m)	4001
Minimum altitude (m)	1070
Average altitude (m)	2500
Average slope of the main flow (%)	2.15
Average slope of the main tributaries (%)	9.35
Average slope of the basin watershed (%)	35

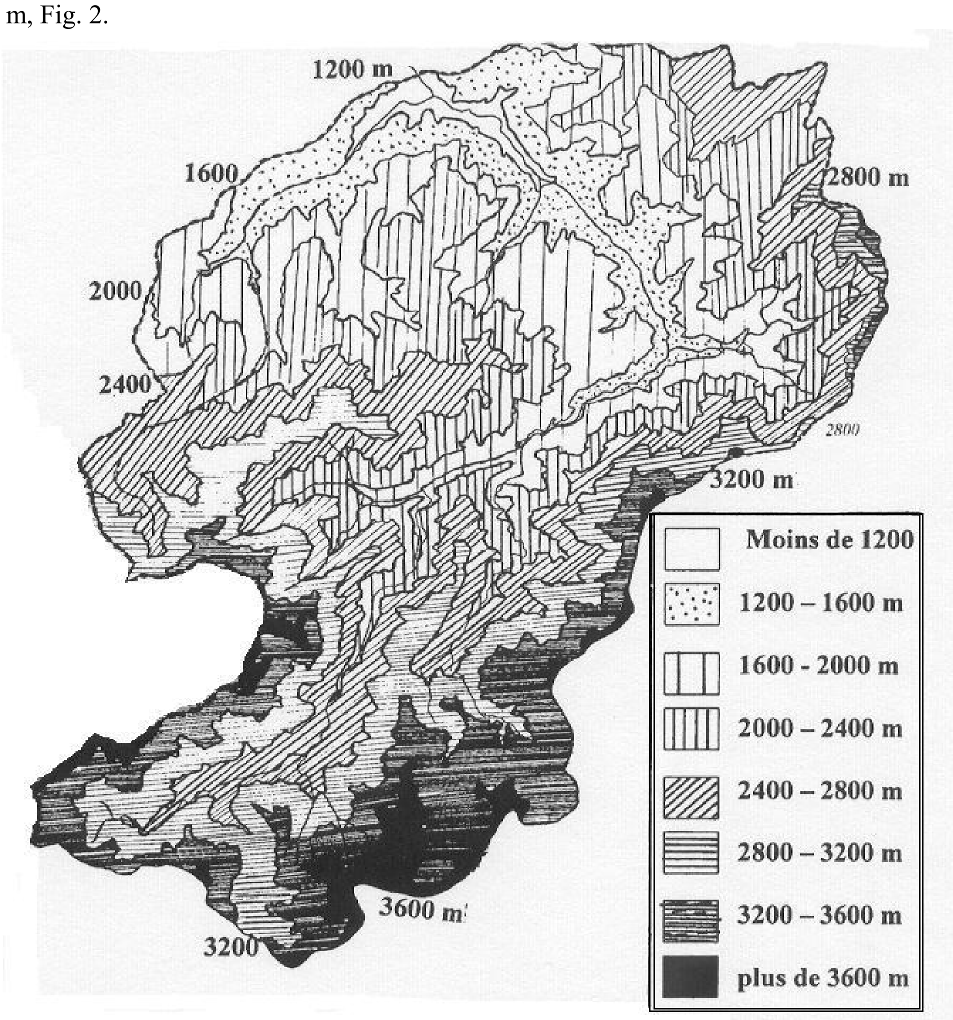

Fig. 2. *Hypsometry of Ourika basin*

The calculation of the Ourika slopes shows that the main flow slopes are not particularly high (0 to 5 %). However, the speed and the violence of the flows are mainly governed by the most important slopes of the tributaries. All the tributaries feed the main flow with very important slopes. The Tarzaza that drains the Oukaimeden massif follows an average slope of 11 %, but the most sloppy little valleys are situated upstream the basin with slopes reaching, in some places 30 to 40 %, Fig. 1 and 2.

Geological context of the basin

On the geological side, the basin slope offers two types of facies (Fig. 3):

– The upstream part, situated at heights superior to 2000 m, is composed of igneous and metamorphic rocks wish form the Atlas chain platform. We found especially plutonic, mainly granite and granodiorite rocks, volcanic (andesites, rhyolites, …) rocks and metamorphic rocks (such as gneiss and migmatites).

This crystalline mosaic is appropriate for a rapid flow of the rain waters.

– The septentrional part, situated at heights inferior to 2000 m, is composed of permo-triasic and softer quaternary deposits. These facies are formed by conglomerates, sandstones, siltites and clays [5].

The lithological observations deduced from the geological map at 1/500 000 m and from land prospections show that soft to averagely soft rock represent an outstretch inferior to 40 % while the hard substract represents about 65 % of the basin outstretch. Thus, the source of the blocks and the drifting pebbles carried by Ourika came essentially from the platform which constitutes the axial part of the Atlas chain. As for lateral softer materials coming from the watersheds, their entrances into the main drains are very varied: alluvial materials (contact with the cones of dejection and the tributary confluences) and non alluvial materials (debris cones and landslides). Nevertheless, the geomorphological environments is marked by two major groups of forms of deposits: the dejection cones and fluvio-torrential terraces. These two units are intimately linked in time and space.

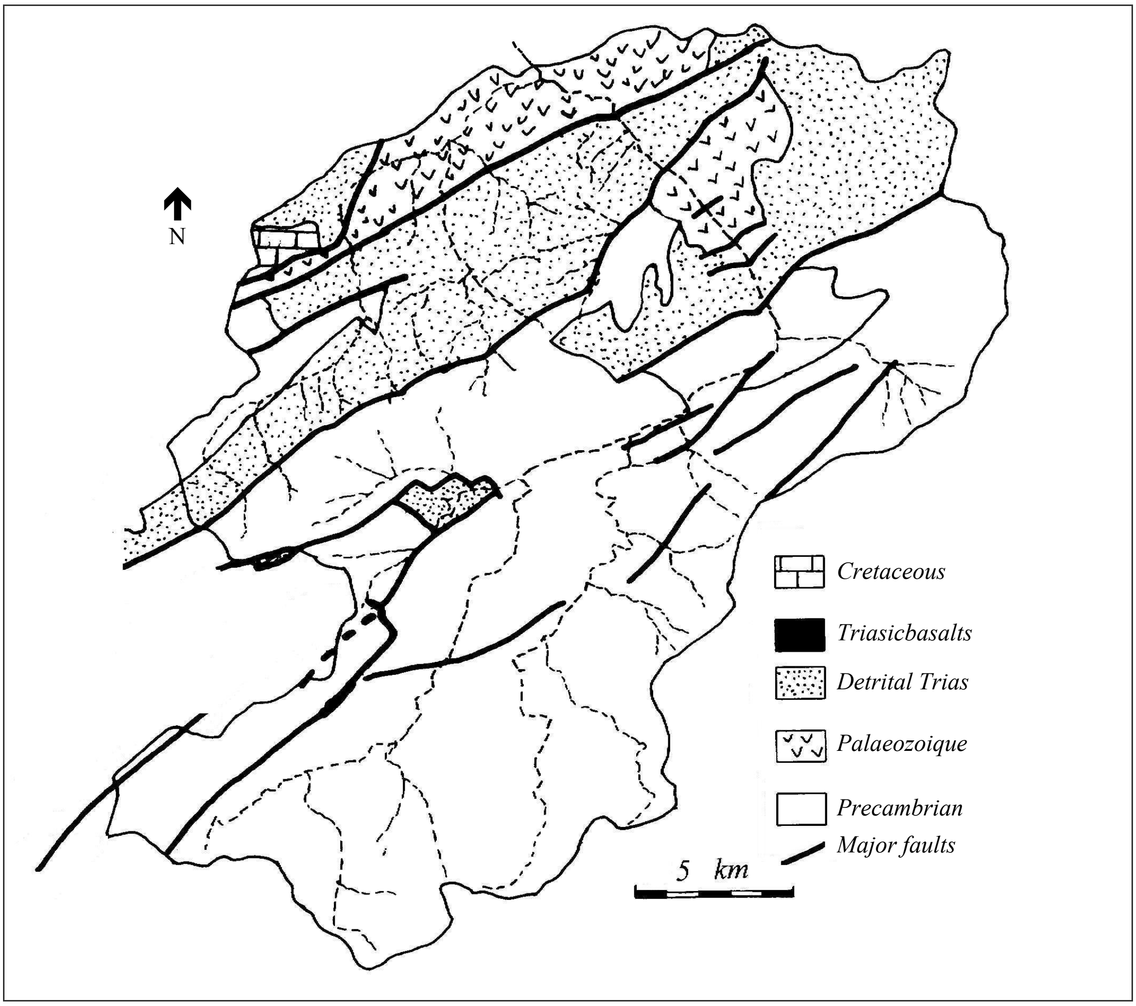

Fig. 3. *Geology of Ourika basin*

Consequence over the flowings and the solid discharge

Flowings

All the analysed morphological and lithological characteristics have a clear influence on the rising waters strength and the hydrogram's shape. The rising waters of Ourika are generally violent and of short duration [1, 2, 6]. The observed hydrograms downstream (Fig. 4) are often marked by quite brief mounting waters (generally about 10 minutes) and by subsiding waters that lasts several hours. The concentration time, relatively short, is estimated at 5 hours, calling, thus, for the necessity of installing warning system stations upstream. As a response of this worry a network of measurement stations have actually been put in place in four spots upstream the Ourika basin. These instantaneous informations will be of paramount interest in the prevention of floods downstream where it is highly frequented by tourists. One of the most deadliest and devastating floods was that of August 17th, 1995 [1, 2]. It was a consequence of a meteorological situation favouring the development of thunders according to the national meteorology. In fact, in altitude, a south flux carried humid, cold and convectively instable air over the High Atlas region from the Canary islands. On the surface, the hot air of continental origin followed a cyclonic curvature and produced upon the High Atlas chain from the North getting humidified in its way in contact with maritime air coming from the Atlantic. This air arrived in the afternoon with a temperature exceeding 40 °C producing a sudden outbreak of instability caused partly by the thermic convection and partly by the orographic effect. A local formation of thick thundery clouds was the result. The cloudy cell over the Haouz takes a remarkable dimension at about 19.00 h and begins to dissipate while moving towards the east at about 21.37 h. The thunderstorm hit the mountains in a restricted zone between 2000 and 3000 m of altitude. The intensity of precipitations is estimated at 100 mm/h, over a 228 km^2 surface [4].

The floods only lasted for three hours, but the rising duration was particularly short (hardly a quarter of an hour). The highest delivery rate at Aghbalou reached 1030 m^3/s with a volume of 3.3 million m^3. The hydrogram (Fig. 4) illustrates the characteristics of a simple monogenic flood with very strong rising level.

According to the instantaneous annual maxima rate of the delivery established by the Marrakech regional hydraulic office, and with the help of a statistical computerised data we have managed to adjust a certain number of statistical laws with a sample of the Ourika flood. The result obtained shows that the most adequate laws of these floods are the log Gamma, log Pearson and normal log laws; they allowed us to estimate the heights of certain rising waters as follows.

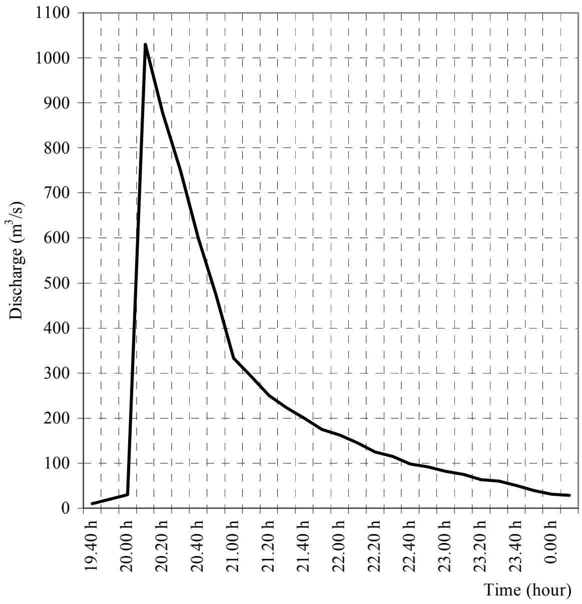

Fig. 4. *Hydrogram of the 17th August 95 floods of Ourika*

Rising median	Period rising, year			
	5	10	50	100
103 m^3/s	280 m^3/s	485 m^3/s	1320 m^3/s	1700 m^3/s

Erosion and solid load

Up to now, the studies devoted to the erosion and to the fluvial transport estmation in Morocco have all focused on the quantitative importance of the exported loads through the basin watersheds in semi-arid climate [7, 8]. Nevertheless, the global approach often used for the result estimation of the transported materials in semi-arid zones is confronted to the big hydrological irregularities of Moroccan rivers [8, 9].

In normal flow period, the solid load constitution of the water flows, carried in suspension, is mainly the result of contributing surfaces rather than the entire basin watershed [10]. This load comes generally from sectors submitted to intense erosion. At the level of watersheds formed by furniture, the erosion is particularly accelerated by the reduction of the vegetal layout, for reasons of natural fragility and anthropic over exploitation. The fine sediments can have three origines:

– Permo-triasic argillaceous-siltic dominated lands favourable for erosions and landslides despite their weak argillaceous swollen proportions [11];
– Argillaceous-muddy lands corresponding to soils;
– Terrace alluvia and dejection cones.

On what concerns the massive rocks of the platform and of the rigid layout temporarily covered by snow, the erosion can be equally important in places. In this region, where the peri-glacier and the arid (two extreme climatic models) coexist side by side, the alternation of the cold and the hot favours the thermoclastic and cryoclastic process whish facilitates the desegregation of the granitic and schistic rocks. Therefore, the abundance of inverse faults in the platform and their Triassic bites favours the swelling of plastic rocks, whish fragilises even further the rigid rocks and which paves the way for the development of massive movements. The size of the materials produced in these sectors varies from sands to pebbles and blocks reaching several meters in diameter. These materials of varied crystalline nature (Palaeozoic and Precambrian rocks) are generally stocked upstream scattered in form of debris and dejection cones, in the slopes ruptures at the bottom of watersheds or confluences.

In flood period, the accelerated erosion consumes progressively a mass of furniture sediments corresponding to big dejection cones. Thus, we observe an hyperconcentrated flow which 10 to 35 % of alluvionary particles concentration [12]. A few kilometres downstream Setti Fatma, the Ourika valley has opened a deep button whole in the complex structures of the north side of the High Atlas of Marrakech. These button wholes, present a slope reaching 10 % in some places. The strong slope, the narrowing as well as the increase of the depth of the flow that follows create a drilling effect for blocks reaching 50 cm of diameter, which need a transport speed of 4 to 5 m/s and a system of supercritical turbulent flow with a shooting effect as commonly known in mountain torrents [3]. Examining the profiles length (Fig. 1), the Ourika valley presents the junction of several tributaries, mainly the Tifri, the Oufra, the Tighzirt and the Tarzaza. These different junctions are distinguished downstream by a relative loading, the slope declining more than 12 to 5 %, so the great part of the gross load coming from the watersheds is stocked on torrential cones consumed in rising periods.

Socio-economic consequences and preventive measures

Since August 17th, 1995 catastrophe, the interventions concerned all the sinistered sectors. The various researches undertaken on the sites during these last years, and in comparison with the existing data and situations before this date, show a significant improvement on the socio-economic side of the sinistered zone [4]. These interventions concerned mainly the hydrographic and road networks. However, in the protective function of the works realized in effective concerning the average and even strong rising waters, it is, on the contrary, not so concerning very strong rising waters of rare occurrence. At the level of certain tributaries of the Ourika river, certain works have been recently realized to intercept the solid discharge carried by the river. The observations made following the recent strong rising flows show that these work are insufficient and are along way from guaranteeing a full interceptive function of the discharge correctly during strong intense rising flows.

Therefore, despite the protective actions, the valley suffers from a lack of reforestation, a lack of means fighting against erosion, and a lack of adequate hydro-meteorological equipment. The erosion is always continuing, which imposes the choice of great works such as:

− the construction and the reinforcement of works of discharge breakers, of protective walls, to limit the damage and to enhance the downstream soil;
− the installation of warning systems upstream;
− the fixation of dykes set up to stop erosion;
− the reforestation of watershed slopes and the addition of fruit-bearing trees likely to preserve the soil and to prevent it from sliding;
− the installation of well-equipped meteorological stations at key sites allowing for the constitution of a data bank that is liable both for studying the rising flows and for being used for agricultural purposes.

Conclusion

The morpho-climatic environment and the litho-structural context of the Ourika watershed basin, mainly the deep slopes and the impermeable lands of varied lithological nature, grant the flowings a torrential muddy character, and offers an environment favourable for sudden pulsations for water flows.

The damaging impacts, either on the environment in general, or on the road network, the agricultural lands and on the housing sites are visible in the valley wherein we are confronted to the amplification and repetition of the phenomenon because of the collecting nature of the valley and its ability to concentration the flowing. Therefore, the degradation of the site is accelerated by the housing and tourist activities.

All these conclusions call, then, for a better management of the sudden pulsations of the rivers by improving the hydro-meteorological equipment, by taking preventive hydraulic measures in form of dykes and appropriate works and by sensitising the population about the dangers of this natural risk in order to avoid human losses.

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