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Relationships among man, environment and sediment transport : A spatial approach

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Résumé de l'article

En Méditerranée l'environnement est soumis aux pressions du développement agricole et urbain, aux changements dans les pratiques agricoles et les marchés internationaux, et au changement climatique. Par ailleurs, de nombreux travaux témoignent d'une augmentation croissante de la pression agro-pastorale et de la dégradation des sols et de leurs conséquences sur les ressources en eau et en sol, et in fine sur les conditions de vie des populations locales. Mais peu de travaux abordent ces questions à l'échelle intégratrice des grands bassins versants. La conférence de Tipaza en Algérie, dont sont tirés plusieurs articles parus dans la Revue des Sciences de l'Eau en 2013, avait pour objectif de mener une réflexion sur les problématiques, méthodes et outils disponibles pour étudier les relations homme, environnement et transports solides à cette échelle, avec comme issue attendue d'améliorer le potentiel de dialogue entre les chercheurs et les développeurs qui ont à prendre des décisions pour des surfaces macro régionales. Les thèmes traités lors de cette conférence et qui apparaissent dans les articles publiés ici concernent les facteurs à l'origine de la variabilité des transports solides : changement climatique, changements anthropiques – tels que les activités agricoles et aménagements hydrauliques; les liens entre l'occupation du sol, les processus pluie-débit et le transport sédimentaire; la modélisation des transports sédimentaires; et l'utilité d'une approche multi-échelle, principalement spatiale, pour appréhender les réalités géographiques de grands bassins et la question du transfert d'échelle, en particulier dans les régions méditerranéennes et semi-arides.

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RELATIONSHIPS AMONG MAN, ENVIRONMENT AND SEDIMENT TRANSPORT: A SPATIAL APPROACH

Relations homme, environnement et transport solide : une approche spatialisée

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ABSTRACT

In the Mediterranean the environment is under pressure from agricultural and urban development, changes in agricultural practices and international markets, and climate change. Moreover, many studies show a steady increase in the agro-pastoral pressure and land degradation and their impacts on water resources and soil, and ultimately the lives of local people. But few studies address these issues across the inclusive scale of large river basins. The conference held at Tipaza in Algeria, from which come several papers published in the Journal of Water Science in 2013, was intended to reflect on the topics, methods and tools available to study the relationships among humans, the environment and sediment transport at this large scale, with the result expected to improve the potential for dialogue between researchers and developers who make decisions for regional macro surfaces. The topics discussed at the conference that appear in the articles published here concern the factors responsible for the variability of sediment transport: climate change and anthropogenic changes, such as agricultural activity and water projects; relationships between land-cover/land-use, rainfall-runoff processes and sediment transport; modeling of sediment transport; and the interest of a multi-scale approach, predominantly a spatial one, for addressing the geographical realities of large basins and scale transfer issues, particularly in Mediterranean and semi-arid areas.

Key words: Mediterranean, humans, soil, erosion, solid transport, climate change, spatialization, GIS

RÉSUMÉ

En Méditerranée l'environnement est soumis aux pressions du développement agricole et urbain, aux changements dans les pratiques agricoles et les marchés internationaux, et au changement climatique. Par ailleurs, de nombreux travaux témoignent d'une augmentation croissante de la pression agro-pastorale et de la dégradation des sols et de leurs conséquences

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sur les ressources en eau et en sol, et *in fine* sur les conditions de vie des populations locales. Mais peu de travaux abordent ces questions à l'échelle intégratrice des grands bassins versants. La conférence de Tipaza en Algérie, dont sont tirés plusieurs articles parus dans la Revue des Sciences de l'Eau en 2013, avait pour objectif de mener une réflexion sur les problématiques, méthodes et outils disponibles pour étudier les relations homme, environnement et transports solides à cette échelle, avec comme issue attendue d'améliorer le potentiel de dialogue entre les chercheurs et les développeurs qui ont à prendre des décisions pour des surfaces macro régionales. Les thèmes traités lors de cette conférence et qui apparaissent dans les articles publiés ici concernent les facteurs à l'origine de la variabilité des transports solides : changement climatique, changements anthropiques – tels que les activités agricoles et aménagements hydrauliques; les liens entre l'occupation du sol, les processus pluie-débit et le transport sédimentaire; la modélisation des transports sédimentaires; et l'utilité d'une approche multi-échelle, principalement spatiale, pour appréhender les réalités géographiques de grands bassins et la question du transfert d'échelle, en particulier dans les régions méditerranéennes et semi-arides.

Mots-clés : Méditerranée, homme, sol, érosion, transport solide, changement climatique, spatialisation, SIG

1. INTRODUCTION

The relationships between human activities, water resources, erosion and sediment transport are very complex issues, in both space and time. They combine the effects of local agro-pastoral practices on the environment (change in vegetation and soil surface conditions), the runoff processes and infiltration, and global effects that are associated with increased population and the impacts of climate change. The increase of the agropastoralism pressure and of the hydraulic infrastructures, combined with the climate variability and change, have an impact in the long term and at large-scale on soil and vegetation, which requires a multidisciplinary approach that must gather demographers, climatologists, geographers, hydrologists, soil scientists, and other disciplines.

This dialogue between disciplines is critical, as it should allow, from a mutual information about variables and quantities involved, and their interactions and impacts at various scales, identifying indicators for environmental monitoring that reflect all interacting factors on the watershed and which, ultimately, have a significant impact on flow production, erosion and sediment transport. Sediment transport is a major problem in the Mediterranean countries, because it has been increasing for several decades, and causes accelerated siltation of reservoirs, leading to a loss of storage volume of reservoirs, and a reduction of their useful life. The other large impact is the loss of soil with high agricultural potential.

This synthesis is an introduction to a number of papers on this topic, which were presented during a conference in Tipaza, Algeria in June 2011.This conference was funded and supported by two international programs: the SIGMED program (Spatial Approach of the impact of agricultural activities in Maghreb on solid transports and water resources of large river basins) funded by the AUF (Agence Universitaire de la Francophonie), and the MEDFRIEND group, UNESCO FRIEND program (Flow regimes from international and experimental network data) for the Mediterranean countries (MAHÉ *et al.*, 2010).

The studies are grouped in four sub-topics:

- climate change and sediment transport;
- links between human activities and sediment transport along with the soil types and farming practices;
- modeling of sediment transport;
- multiscale approaches and ways of understanding the geographical realities, spatial extrapolation techniques of information (scale transfer).

The main questions about the spatial approach of the relationships among humans, environment and solid transport refer to the main goals of the Plan Bleu (BENOIT and COMEAU, 2005) to meet the challenge of sustainable development in the Mediterranean: to keep soils and landscapes, to better valorize water resources, to re-boost the links between society and the environment, and to develop multidisciplinary research open to dialogue with all actors, and particularly among developing countries.

The last decades of the history of the Mediterranean countries are marked by large scale human migrations, within and between countries, due to several causes including political and development reasons, the increase of populations and the decrease of available arable soils. In Algeria and Morocco, for instance, people moved toward alluvial valleys and littoral plains, looking for areas with a high agricultural potential, but other factors are triggering these migrations such as insecurity, the land dispatching during colonial eras, etc. Studying the relationships between socio-demographic dynamics and land-cover, with geostatistical methods, leads to a good assessment of the level of pressure on land and the related risk of land degradation of soils by erosion. The scale of the risks is linked, among other factors, to the location of the rural cities, to the density of the rural population and to the size of the water management structures, which lead to transformations of landscapes, affecting in turn the stability of the soils, more or less sustainably.

2. CLIMATE CHANGE AND SEDIMENT TRANSPORT

In the Mediterranean basin, soils are fragile and vulnerable to aggressive climate, low vegetation cover and human activities. Climate change has induced changes in rainfall patterns in terms of the number of rainy days, the intensity and spatial distribution of precipitation, and increased temperatures. This has a direct impact on erosion.

Climate models predict a decrease in rainfall (DRIOUECH *et al.*, 2009, 2010) and an increase in extreme events, which, combined with an increase in evapotranspiration due to higher temperatures, will have a negative impact on the vegetation cover. This degradation of natural vegetation, combined with the degradation induced by the expansion of cultivated land and pasture, weaken the soil and make it more vulnerable to erosion. Heavy rainfall in recent years, after a long period of reduced rainfall (SINGLA *et al.*, 2010) and temperature rise, has significant impacts on erosion.

Several researchers have studied erosion as a result of climate change. FAVIS-MORTLOCK and BOARDMAN (1995) found that increased precipitation by 7% could lead to an increase of 26% of erosion in the United Kingdom. According to PANAGOULIA and DIMOU (1997), in Greece an increase in both length and frequency of flood events will lead to a possible increase in bank erosion. SCHULZE (2000) suggested that a 10% increase in precipitation would lead to an increase of 20 to 40% of runoff and increased erosion in South Africa. In Brazil, FAVIS-MORTLOCK and GUERRA (1999) predicted an increase from 22 to 33% of average annual sediment with a 2% increase in annual precipitation.

To adopt appropriate measures and prevent land degradation and its negative consequences on agriculture and engineering structures, assessing the impact of climate change on erosion in the Mediterranean region is essential. We must address the issues assessing the impact of climate change on land use and erosion, on field observations or climate model outputs.

Usually hydrologists study the variability of rainfall (MEDDI and HUBERT, 2003), flow rates and runoff coefficients, at yearly, monthly and daily time steps (HAIDA *et al.*, 1999; SNOUSSI *et al.*, 2003). Runoff coefficient time series provide information on the evolution of the relationships between rainfall and runoff, and thus allow one to identify changes in these relations; the causes can then be searched for among other environmental variables (soil, groundwater), which may undergo significant changes due to human activities (MAHÉ, 2009). We focus on the climate signals recorded by the series, in the context of the global climate change.

The average concentrations of sediment transported by the wadis in Algeria vary from 50 to 150 $g \bullet L^{-1}$ with maximal values that can sometimes achieve 600 $g \bullet L^{-1}$ (MEDJBER, 2011), whereas the specific erosion of 30 basin hillsides varies from 30 to 3350 $t \bullet km^{-2} \bullet yr^{-1}$. Graphic comparison of the interannual average of the precipitation and of the average rate of erosion showed an increase of the solid load according to the increase of the pluviometry (MEDJBER, 2011).

The study of climate change in the Ouergha basin (Rif region in Morocco), site of the biggest hydraulic dam of Morocco (El Ouahda dam), is based on series of rainfall and temperature. The study shows an increase of 0.15°C per year in temperature, and separates two different periods: a rainier period from 1956/57 to 1982/83, and a drier one from 1982/83 to 2007/08 (BOUKRIM, 2011). We note a decrease of 3.7 $mm \bullet yr^{-1}$ in rainfall, rigorous winters and dry summers, which was characterized by a negative effect on water resources in the basin of Ouergha. HALLOUZ *et al.* (2013) also reported a decrease in precipitation since the mid 1970s in northwestern Algeria.

3. LINKS BETWEEN HUMAN ACTIVITIES AND SEDIMENT TRANSPORT ALONG WITH THE SOIL TYPES AND FARMING PRACTICES

Human activities such as agriculture and pastoralism modify the soil land cover and vegetation. The construction of hydraulic infrastructures also modifies sediment transport, trapping sediment in dam reservoirs, thus depriving downstream reaches of sediment that should maintain the fertility of the banks. Soil and vegetation change have an impact on vulnerability to soil erosion. These relationships are also dependent on soil type and the local morphology (ROOSE *et al.*, 1993).

Water erosion of soils is a major problem in semi-arid environments. It is particularly due to the combined action of deforestation in areas with steep relief (mountains, hills, plateaus), overgrazing, poor agricultural practices (MORSLI *et al.*, 2004), chaotic urbanization, and the torrential nature of rainfall.

Erosion assessment is an integral part of the process of integrated management of water and soil resources. Dam silting is also a major problem, as it accelerates along the increase in erosion, reducing the freshwater storage capacity of these works (REMINI and HALLOUCHE, 2004; SNOUSSI *et al.*, 2002). Several examples are discussed by MORSLI *et al.* (2013) about erosion processes, and by ONSOY *et al.* (2011) and MEGNOUNIF and GHENIM (2013) about the impact of dams on sediment transport.

Even on steep slopes (20 to 40%), sheet erosion does not exceed 1-20 $t \bullet ha^{-1} \bullet yr^{-1}$ according to the land cover. On the other hand, runoff during intense thunderstorms, saturating the ground, provokes very active linear erosion (erosion in channels and gullies in the range 90-300 $t \bullet ha^{-1} \bullet yr^{-1}$) in Mediterranean mountains. Solid transport on hillsides is often stopped by the vegetation before it reaches rivers (colluvions), but the river digs itself deeply into the valley and the banks during the exceptional floods and very high flows.

Several different strategies have been tried to mitigate or reverse the loss of fertile soil due to erosion. Huge amounts of money have been committed against these risks: more than a million hectares of protected terraces and benches of all types, thousands of hectares reforested in the mountains and along the desert, hundreds of hill dams to catch runoff and store their sediment load, not to mention the efforts of foresters to preserve the remaining ancient forests and overgrazed range land. Nevertheless, surveys have shown little impact of these efforts to contain the physical manifestations of natural processes of young landscapes developed on soft rock raised recently on the edge of the Mediterranean. Local farmers are the mountains managers; their participation in the process to develop effective techniques against erosion is thus necessary to ensure its success.

4. MODELLING OF SEDIMENT TRANSPORT

The measurement of soil erosion is important to characterize the sediment supply from different types of surfaces, and the contributions of different environments. We measure the quantities of suspended fluxes in streams to estimate the tonnages of materials exported by water, which then settle either naturally in estuaries and coasts, or artificially in reservoirs. However, direct measurement of erosion and sediment transport is long and tedious. It is rarely possible to multiply the measures as it would be desirable to obtain a good quantification of sediment transport, especially for large basin areas. The model is then a method that can allow one to extrapolate point measurements over large environments. Whatever the kind of modeling, from statistical correlations or coupled with hydrological models, this method should allow the optimal use of the knowledge acquired by occasional research teams for several decades in the Mediterranean region ROOSE *et al.* (2011).

Due to the fact that hydrological watersheds have their own characteristics and also that each point within each watershed has time-varying characteristics, sediment transport is a space- and time-variable problem that cannot be modelled by a single universal equation. For that reason, different attempts have been made available in the literature to model sediment transport either at the hillslope- or watershed-scale, using data observed in the field or measured in laboratories.

The use and development of sediment transport models is still expanding dramatically (AKSOY and KAVVAS, 2005). Models so far developed can be categorized according to different criteria that may encompass process description, scale, and technique of solution (SINGH, 1995). A model may be based on an empirical or a conceptual framework. Such models are called empirical and conceptual models, respectively. Empirical models are limited to conditions for which they have been developed. In conceptual models, a watershed is represented by storage systems. If a model is constructed by using a mass conservation equation of sediment, it is called a physically-based erosion and sediment transport model. For instance, USLE (WISCHMEIER and SMITH, 1978) is an empirical model based on a large amount of data from the United States. AGNPS (YOUNG *et al.*, 1989) uses a modified form of USLE. The hydrological part of ANSWERS (BEASLEY *et al.*, 1980) is a conceptual process. KINEROS (SMITH, 1981), WESP (LOPES, 1987), SEM (STORM *et al.*, 1987), SHESED (WICKS, 1988) and EUROSEM (MORGAN *et al.*, 1998) are some examples of physically-based erosion and sediment transport models. Recent use of soft computational methods such as artificial neural networks, fuzzy logic, principal component analysis, genetic programming, etc. can alternate with the above models, provided that their input data are sufficiently diverse that none of the affecting factors needed to accommodate the physics of sediment transport in the model are missing (AYTEK and KISI, 2008; GURMESSA and BARDOSSY, 2009; HARKAT *et al.*, 2011; NAGY *et al.*, 2002; SALHI and TOUAIBIA, 2011; TAYFUR *et al.*, 2003).

Existing physically-based sediment transport models are deterministic where the sediment transport process is formulated by deterministic differential equations without consideration of the stochastic behaviour. Only recently, KAVVAS *et al.* (2004) developed a two-dimensional physically-based rainfall-runoff model coupled later on to an environmental module accommodating the erosion and sediment transport processes considering the random behaviour of the watershed as well as rill formation on the soil surface (KAVVAS *et al.*, 2006). Clearly this type of analysis is not an easy task. To simplify Nature, different approximations can be used in formulating the erosion and sediment transport processes. For example, the three dimensional topographical terrain is reduced to a two- or one-dimensional form. A two-dimensional model without consideration of rilling was provided by BESSENASSE and PAQUIER (2011). Another model further simplified to the one-dimensional form was developed by BOUHENICHE and TOUABIA (2013) for quantification of sediment eroded from the watershed and that will later be deposited in reservoirs. Quantification of sediment before it reaches the reservoir is extremely important, in order to be able to act against its movement towards the reservoir and hence to save the reservoir's active storage.

Some physically-based models do not consider the time derivative term. WEPP is such a model (NEARING *et al.*, 1989). Also FOSTER and MEYER (1972) used the steady state continuity equation of mass transport, which is the basis for the ANSWERS model (BEASLEY *et al.*, 1980). The case for most of the existing physically-based erosion and sediment transport models is the unsteady state where the time derivative of sediment concentration is taken into consideration. Initial and boundary conditions are important in cases where the model simulates erosion and sediment transport continuously. Continuous simulation models generate large numbers of small events that may not cause significant runoff or soil loss. Data required for the aforementioned models are a matter of temporal scale used in the model. Data requirements increase with a decrease in the time interval used in the model.

Some physically based models were, therefore, designed as event-based models that can be run for each specific event. This modeling indicates that erosion is dominated by only a few events per year. EUROSEM is such a model. However SEM, SHESED and WEPP among others can simulate erosion and sediment transport continuously. Then sampling during floods becomes an important issue in practice.

Increase in the number of dimensions requires higher number of parameters and results in more intensive computations by the model. While developing sediment transport models, parameterization of the model becomes an obstacle for creating detailed models as a higher number of parameters is then required. Data are needed either from the field or in the laboratory (AKSOY *et al.*, 2013). These recall the simple practice of the rating curve established between the flow and sediment discharges (BENKHALED and REMINI, 2011; BOUANANI *et al.*, 2013; KHANCHOUL and BOUKHRISSA, 2011).

Sediment discharge due to rainfall and runoff erosion from a hillslope in a watershed is under the influence of a number of variables including the geometry of the hillslope, characteristics of water and of soil listed by JULIEN (2010), such as flow discharge, rainfall intensity, length of the hillslope, mass density and kinematic viscosity of the fluid, the critical and applied boundary shear stresses, and the bed surface slope. Among these characteristics flow discharge and slope have been found to be the most dominating variables (PROSSER and RUSTOMJI, 2000) ending with an equation such as

$$q_s = \alpha q^{\beta} S^{\gamma} \quad (1)$$

Equation (1) can further be simplified as a function of slope only

$$q_s = \alpha S^{\gamma} \quad (2)$$

In equations (1 and 2), q_s is sediment discharge, q is flow discharge, S is topographical slope, and α, β, γ are parameters.

Smoothing irregularities (rills and interrill areas) over a hillslope is another simplification, although it has been shown experimentally by GOVINDARAJU *et al.* (1992) that erosion in rills is, at least, one order of magnitude greater than erosion on interrill areas. Therefore, sediment transport models should take into account the rill-interrill interaction on a hillslope (AKSOY *et al.*, 2013).

Geographical Information Systems (GIS) have been very useful tools for hydrologists, in particular for physically-based modellers in providing the spatially distributed data. GIS can also supply the time distribution of the hydrological data. GIS use digital elevation models (DEM) that can provide information on elevation, slope and aspect of the catchment (ABDELBAKI *et al.*, 2011; TOUMI *et al.*, 2013). It is possible to incorporate the physical heterogeneity in a catchment by using GIS.

AKSOY and KAVVAS (2005) projected the future of sediment transport models from deterministic models to the probability-based stochastic modelling technique to include the probability distribution of rainfall at space and time. The spatial and temporal distribution of rainfall as a random input into the model will result in randomly simulated runoff. Heterogeneity in the physical structure of the watershed, rill occurrence for example, can be given by probability distribution functions. Also model parameters have probability distributions due to heterogeneity in the watershed.

5. MULTISCALE APPROACHES AND MODES OF APPREHENSION GEOGRAPHICAL REALITIES

One difficulty in studies of relationships among past climate, humans and land cover is the diversity of spatial and temporal scales to consider. The scales that characterize climate variability are often incompatible with the scales of agro-pastoral and demographic dynamics. Indeed, the regional and / or domestic scale is often preferred to understand the behavior of rainfall regimes and their effect on the distribution of major vegetation types. However, to understand the effect of climate variability on land cover and societies, the local scale is no longer appropriate if we want to reflect the heterogeneity of environments.

Climatic variability is most often characterized at small geographical scales, whereas the dynamics of agrarian environments, including production systems and farming practices, are visible at the level of the village. In addition, tools and representation techniques are varied and are often not suited for the treatment of all the diversity of geographical objects. For example, in statistics, spatial information is often missing and the problems of scales are often mismanaged, which is why we use remote sensing and GIS methods including geostatistics and spatial analysis.

In this context, the preferred methodology for studying land use and socio-economic activities will include multi-scale remote sensing (high resolution and low resolution), which will track and quantify changes in surface conditions in relation with human activities and also with the influence of climate (seasonal changes) (BROU *et al*., 2005). The study of land use dynamics involves the coupling of remote sensing data with field data, socio-economic and demographic statistical data, within a GIS. This will help to understand the interactions among population dynamics, the types of development and surface changes, as in BROU (2005).

For this issue, the main question to answer was: "What are multiscalar approaches allowing to identify the relevant spatial scales in the studies concerning the interactions among humans, climate and the environment"?

BROU *et al.* (2013) demonstrated the vulnerability of the soils of the Bouregreg basin in Morocco, due to the agricultural practices and the variability of the annual and seasonal vegetation productivity in a context of climatic instability. The vulnerability increases especially in the case of autumn intense rains. The follow-up on the seasonal scale of the 10-days NDVI of the Spot vegetation sensor over the period 2001-2009 reveals a gap of the start and the end of vegetative seasons, i.e., an extension of the period during which soils are quasi-bare during the exceptional years of drought. MAHÉ *et al.*, (2012) completed a study on the Bouregreg by studying the effects of climate variability on water and edaphic condition of the Bouregreg watershed related to human activities, mainly agriculture and grazing. In order to achieve this goal, statistics based on satellite images of the Moderate Resolution Imaging Spectroradiometer (MODIS), AQUA sensor, were used. Statistical and remote sensing analysis based on the pair combinations of biological and climatic parameters that are vegetation index, surface temperature and albedo lead to the conclusion that this watershed is deteriorating significantly.

ABDELBAKI *et al.* (2011) used a GIS approach to propose management solutions to mitigate erosion in the Wadi Bouguedfine micro watershed in Algeria. They produced a global map of vulnerability to erosive phenomena considering the physical climate factors that are responsible for water erosion, such as slope, rainfall, lithology, slope exposure, land use and its nature. The result was used to develop a development map of the sub-basin.

6. DISCUSSION

Remote sensing and GIS greatly contribute to monitoring and management of erosion dynamics. Remote sensing indeed offers numerous possibilities due to the variety of the sensors supplying images of varied spatial and temporal scales, from low to very high-resolution.

These spatial data answer various types of scientific objectives and are adapted to the studies of land cover at the seasonal and multiannual scales. For the vegetation, for example, remote sensing is very useful for following changes in land use and the seasonal dynamics of the vegetation phenology. In addition, the remote sensing data allow regular observations of often inaccessible areas.

Nevertheless, field data are still indispensable and have to serve to validate the theoretical results obtained by image processing. Besides, the field data determine the results of the spatial modeling. For example, in studies on the soil erosion, the slope can be misleading because in certain cases, a steeper slope can provoke less erosion. A ground check is thus necessary before integrating data into a GIS. Note also that the universal equation of WISCHMEIER and SMITH (1978) measures only the erosion upstream in the basin, but it can be adapted to every zone of the basin.

The question of the temporal scales also presents a big interest. The follow-up of land use changes at several dates is indeed useful to know the speed of the erosion. This multidates analysis of land use has to be made by coupling with the topography of the environment. It thus seems important to update the topographic maps in this case. For example, in Algeria, the topographic maps date from the 1950s; new field measurements suggest recent morphological evolution with the creation of new thalwegs and the filling of ancient ones.

The question of the availability of the data is a very crucial one. Indeed the conference participants noted the existence of a multitude of national and international digital databases, available in free access on the Web, which must be widely advertised. Open source software to process the data are also of great interest in developing countries.

An integrated approach appears as the best way to work, as it takes into account the variety of the data, scales, disciplines and actors. The basin has to be, in fact, considered as an integrative space, on the physical, economic, social and cultural levels. It is thus advisable to work together in a spirit of sharing the results and the data among the various actors upstream and downstream of the projects. The questions which remain to discuss are:

- What is the information we have that can be used to model the reality?
- What is the good size to represent an object and for which objective?
- Finally, how to foresee an integrated approach?

7. GENERAL SYNTHESIS

Assessing the impact of climate change on erosion and sediment transport of rivers is essential in the Mediterranean region. Contributions to the conference have shown interest in using concentration and flow data and measures of dam silting to assess the sediment load of the wadis. To analyze the effect of rainfall fluctuations on the generation of the hydrograph and transport of suspended sediments, statistical models are applied, revealing the role of rainfall. However, the time series used must be long enough, spatially dense and reliable. The application of hydrological models is recommended to generate a runoff series based on changes in rainfall and of potential evapotransporation. Studies on climate change showed evidence in many parts of the Mediterranean region of global heating and lower rainfall. But to better understand climate change, it makes sense to refine the analysis at the scale of events (time-frequency-intensity rainfall). It is necessary to highlight the various databases of information to make valid comparisons between the measured sediment transport in the wadis and the measured siltation in dams. Regarding erosion, all the papers discuss the processes and factors of sediment transport, integrating the impact of human actions, but few lead to proposals for erosion participatory control. Erosion and deposition processes are simultaneous. Where and how is eroded sediment deposited? In North Africa, the data are often unavailable or unreliable. Conventional and innovative methods have been used but their accuracy has not been sufficiently analyzed. The dominance of gully erosion over sheet erosion in the Mediterranean environment has been challenged. Human influence is reflected by either a negative impact on vegetation cover and soil infiltrability or by a positive impact on the temporary storage of water and sediments, but during rare storm rainfall events there is a risk of mass movement. Looking ahead, we must encourage young researchers towards applied research for sustainable development.

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