EDITORIAL

Experimenting criteria for risk mitigation in fluvial-coastal environment

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Vanishing beaches and hungry water[1] originated by different human pressure are a worldwide issue, with significant and sometimes unpredictable socio-economic and environmental impacts (Kondolf, 1997). The United States Environmental Protection Agency estimates that between 80% and 90% of America's sandy beaches have been eroding (EPA, 1994). In most cases, single beaches may be losing only a few centimeters per year, but in some cases the problem is much worse: the coast of Louisiana is losing about 15 m of shoreline per year (NOAA, 2003).

In Europe about 40% of the shoreline is eroding, in some countries an erosion range between 50% and 70% was registered (Beachmed, 2008).

These problems should be tackled on a large scale and with a different approach. Rivers and coasts, *i.e.* the border between land and water, represent transition environments which are extremely sensitive to perturbations, both natural or anthropogenic. Each environmental component, whether a physical, biotical or anthropic element, mutually influences the adjacent one and thus triggers interactions. These complex processes do not follow the linear physics of cause-effect, but are dominated by a non-linear or chaotic physics. Therefore, small modifications in the catchment due to a forcing could cause significant variations of shoreline, out of phase and also far from the river mouth, often with amplified feedback.

Historically, in planning and managing, rivers and coasts are considered as separated domains with very different dynamics. The river mouth represents the common point where waters and sediments coming both from land and sea interchange.

A modern approach should be based on the criterium of *flumen unicum*, whereby the river basin and the facing littoral are considered as a single indissoluble and continuous space-time system. Actually, both these environments are strictly linked to each other, from the farthest end of the watershed to the seabed down to 15 m depth, where the main geomorphic and sedimentary processes take place.

For the same reason, the facing littoral does not end at the river mouth, but extends to the entire coastal physiographic unit, that is the bay delimited at the margins by promontories in which the river discharges the sediments drifted by waves and marine currents. This approach does not consider the river and the shoreline as bi-dimensional elements, but tridimensional ones, that include the whole waterscape with its drainage network, littoral prism and sea bottom.

Global warming, for which human activities partly contribute, and the accelerated subsidence of urban areas promote sea-level rise and consequent coastal erosion. The alternation of hot-arid and cold-humid climatic crises, ranging from a 150-200 to a 10-40 year duration, at medium latitude where megalopolises and large industrial plants are present activate floods and landslides in catchments, following severe rainfall.

Moreover, starting from 1900, and especially since the 1950's due to socio-economic policies linked to the postwar period, the demand for land rapidly increased and its availability gradually decreased. Urbanization developed particularly in Mediterranean climate areas *sensu* Koppen (1936) and James (1966), including non-European regions such as California, China, South Africa and Australia. Consequently, certain river valleys and coastal zones became the most anthropized areas thanks to their less complex morphology, abundance of freshwater and geomaterials such as sand and clay which fostered the rapid development of settlements and infrastructures.

At the same time, the demand for energy increased over the last century, and its production required the construction of hydroelectric power plants, with reservoirs barred by a series of large dams along major rivers. Dams regulate watercourse flows, but change their environmental and hydrogeomorphological features, by trapping sediments and starving the river mouth and beach and thus triggering coastal erosion processes.

Mitigation consisted in the construction of various coastal defenses over time, to protect settlements and reduce risks. However, some defenses often proved to be ineffective, or activated other focuses of erosion in the coastal physiographic unit. From this point of view, the dam-river-coast system is characterized by a higher complexity compared to the anthropized fluvial-coastal environment.

The crucial questions nowadays are firstly how to properly intervene in the river basin without irreparably affecting the

1. According to Kondolf (1997), if the continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels for fish (as smaller gravels are transported without replacement from upstream).

coast and secondly how to intervene along the coast without substantially altering the river mouth or the low valley.

There are a few suitable solutions for each case, which are effective for a given time interval in relation to the variability of the environmental versus the anthropogenic system, and to the available technique selected to mitigate the risk. Multidisciplinary research, based on surveys of the long-term period and the monitoring of the short-term one, could help to improve the planning and management of interventions in anthropized transition environments.

Hydrogeological imbalance

Landslides and floods cause substantial economic losses and thousands of casualties in the world each year, especially in tropical and Mediterranean climate areas. Several factor combinations trigger these phenomena: persistent rainfall or strong rainstorms, non-vegetated permeable soils, slope gradient, deforestation, fires, incorrect plowing of agricultural fields and earthquakes.

Manmade interventions along the basin slopes and river over time, such as the engineering of river banks and riverbeds, dam construction, change in the river flow (Kondolf and Matthews, 1993) could cause flash floods with high sediment load. These are dangerous and harmful especially along urban streams, reaches of a watercourse crossing a town, usually engineered or tunneled, and with a reduced section compared to the natural one (Magdaleno and Fernández, 2011).

When a watercourse is transformed in a culvert and hidden from sight, the population loses memory of the existence of the urban river. Tragically, the memory suddenly resurfaces turbulent during a flash flood.

In Europe and the United States, in the last 20 years floods have increased, especially in urban areas (Jongman et al., 2012; Kundzewicz et al., 2013). Since the 1990's, the basin authorities and local government agencies have laid down the rules for hydrogeological and coastal defense. These are based on research and mathematical models that have not always taken in due consideration the close relationship between river basin and coastal-marine environment, and their degree of anthropization.

Dams

The dams, as well as the vegetation, behead the river floods and regulate river flow. However, dams represent a sediment trapping, causing a lack of deposits downstream and a starvation of sediments to the coast (Willis and Griggs, 2003; Slagel and Griggs, 2008), especially if the reservoir is sufficiently close to the river mouth (less than 50 km). The sand and gravel supply is dramatically reduced, but the silt and clay in suspension can partly bypass the barrier, gradually turn the beach sediment grain size and composition into finer and more easily erodible deposits. Moreover, these barriers reduce hydrological connectivity, which is essential to the ecological integrity of the landscape. Reduction or enhancement of this property by humans may have major negative environmental effects, contributing to dramatic losses in global aquatic biodiversity and associated ecosystem integrity (Pringle, 2003). Dams and other manmade structures in rivers have also altered thermal and sedimentary regimes as well as energy and material flows, and consequently, the extent and distribution of available habitat for many river species (Ward and Stanford, 1995).

Floods have relevant effects on the ecogeomorphic integrity of rivers altered by flow regulation (Magdaleno, 2017), especially along those rivers barred by several dams.

Particularly, the riparian ecosystems downstream of the dam suffer significant alterations and the river banks may be affected by landslides, due to the lack of sediments and the reduction of river flow and floods.

Dam reservoirs emit greenhouse gases such as methane and therefore represent a significant source of climate pollution. Large dams reduce water quality and quantity, dry up forests and wetlands, flood productive land, and deplete fisheries.

In California 70 out of more than 500 dams, over 50 years old, are responsible for 90% of the sediment reductions to the coast and make any sediment management efforts far more localized in southern areas, where threatened beaches reach 70% (Willis and Griggs, 2003). About 18% of the main dams in Italy have an average age of 50 years, 1.5% are full of sediment, 4.5% show a reduced capacity of 50%, 17.5% of 20% and 76.5% of 4% (Molino et al., 2007a,b), which makes them partially ineffective and hazardous. More extreme rainfall will increase the siltation of dams, reducing their life cycle, and also increase the risk of failures and catastrophic flood releases.

Coastal hazard

Coastal hazard is due to several interrelated factors, by descending order of influence: man-made structures, shoreline erosion, landslides, storm waves, river flooding and local seismicity and volcanism (De Pippo et al., 2008, 2009; Valente et al., 2014). In Mediterranean climate areas, global warming and the consequent increase of sea storm frequency as well as sea-level rise have accelerated beach erosion in the last 50 years. In particular, wind direction change and the absence of wind calm have triggered new erosion focuses since the mid-1970's, especially along densely urbanized river mouths.

Erosion processes change morphology, reduce width, increase the gradient and grain size of beaches, and end up dismantling the coastal dune with changes in vegetation assemblage, like in the Mediterranean maquis. This results in a huge loss of sand, as well as environmental and cultural heritage. The sand eroded by sea is mobilized along the seabed by littoral drift and secondary cell circulation and confined in the coastal physiographic unit . The inshore depth is thus reduced and the siltation of harbor down-drift is initiated.

Mitigations

The high degree of complexity and variability inherent to dam-river-coast systems hinders the selection of universally-valid mechanisms to protect both the natural and the anthropized environment. Mitigation measures are numerous and diverse, but in certain regions a few types are recurrent. Different national management approaches to coastal protection exist. They depend on the large variability of physical, political and economic attributes as well as the cultural heritage of the regions affected by floods and coastal erosion.

Frequently, the measures address only the emergency situation and/or are implemented in limited areas. Sometimes obsolete techniques are adopted and the problem is simply shifted elsewhere allowing maladaptive strategies to prevail over adaptive ones.

Both in Europe and extra-Mediterranean areas floods are rarely mitigated through interventions at basin scale but more commonly along the channel bed and banks. Frequently, only specific reaches of the mainstem or some tributaries are regulated and engineered, especially in the case of urban rivers (Kondolf et al., 2003).

Future attempts to release artificial floods should also focus on solid flow transport from the dam, and on the most adequate procedures to couple flow and sediment releases (Magdaleno, 2017). Sediment routing, flushing and hydrosuction are some of the adopted solutions, and sand bypass systems seem to aim in the same direction (Wang and Kondolf, 2013): they are designed for new dams, but the problem for old dams filled with river sediments remains.

In this case it might be possible to turn a liability into an asset by dredging deposits from the reservoir, separating the gravel and sand from the silt and clay. The mixed sand-gravel can be reused for the artificial replenishment of rivers and the sand for the nourishment of beaches, while the silt and clay for soil amendment in agriculture and light aggregates production for building construction, depending on their mineralogical composition (Ock et al., 2013). These solutions have an additional economic cost, but a greater final benefit compared to common defense systems or the coastal retreat itself with irremediable loss of valuable transition environment, structures and infrastructures.

When a reservoir is almost ineffective and potentially really dangerous, dam removal followed by river restoration and beach nourishment could be the appropriate solution, as attested to by the intervention on the 1921 San Clemente dam (Capelli, 2007) on Carmel River in California, which was initiated in 2014. Dam removal has become an increasingly widespread management choice in the United States (Maclin and Sicchio, 1999), where more than 450 barrages have been removed.

Several techniques are used to mitigate coastal erosion: groins, jetties, sea walls, breakwaters both emerged and submerged, artificial sand nourishment, dewatering system (Donadio and Valente, 2007). All of them show different impacts, even on shorelines that are far from the intervention sites. The main effects are indentation of the shoreline due to a focused retreat (cove) or progradation (salient, tombolo); eutrophication of sea water segregated in small basins at the back of breakwaters; proliferation of allochtonous species of marine organisms (algae, polychaetes, molluscs) on the secondary rock substratum represented by breakwaters emplaced on the sandy seabed; change of color, composition and grain size of beach deposit by allochtonous bioclasts and gravel coming from the artificial barriers. These effects of environmental alteration cause unpleasant use of littorals, therefore produce a negative impact on tourism.

Beach nourishment is a common solution to replace the lost sand, by pumping on the littoral the marine sediments dredged offshore, but this intervention is time consuming and expensive and needs to be repeated every few years to preserve the beach. Beach dewatering systems show a lower impact compared to many others, but their efficiency depends on local environmental conditions, *e.g*. river sediment supply even when it is not abundant.

The European Union (EU) supported several research projects on coastal erosion and flooding hazard, protection strategies, technical expertise, legal-institutional instruments, Integrated Coastal Zone Management (ICZM), taking also into account extra-Mediterranean experiences: Eurosion (2004), Conscience (2007), Beachmed (2008), OurCoast (2008), Pegaso (2008), Coastance (2009), Theseus (2009), Maremed (2010), Shape (2011), FaceCoast (2012), Ritmare (2012), CoastGap (2013), Mare Nostrum (2013), Medsandcoast (2014), and many others.

Recently, an EU Directive (2014), based upon a previous Directive (MSP 2008), introduced a common framework for European Maritime Spatial Planning (MSP), urging public authorities and stakeholders to produce a coordinated, integrated and trans-boundary approach to coastal issues for when and where anthropic activities take place at sea (Pranzini et al., 2015).

Considerations

Within the dam-river-coast system, conflicting priorities exists between the populations living far from the coastland, who need protection from river flooding and landslides, and those living along the flood prone coasts, for whom the river sediment, supplied to the coastline by floods, is indispensable to counteract erosion processes. This conflict could be resolved only within a wider approach, even wider than a single Integrated Coastal Management (ICM) and MSP. A possible solution could be found by merging together ICM and River Basin Management (RBM).

With reference to the size and the current state of this wide-ranging problem, international research policy should be pursued or established. This could be implemented by developing multidisciplinary research aimed at river restoration, preservation of fluvial connectivity, rehabilitation of dam efficiency and desilting or at its removal, beach sand nourishment and coastal dune renaturation.

Human interaction in coastal and fluvial environments needs modern approaches to management, such as engineering solutions and soft techniques which take in due consideration habitat protection as well (Charlton and Oxford, 2002).

Morphodynamics and morpho-evolutionary trends of river basins and coasts are usually carried out by analysis of historical cartography, aerial photos and satellite image interpretation, littoral drift detection, monitoring of morphosedimentary and vegetation aspects of sand dunes as sensitive environments. Along the coastland, accelerated erosion rates represent the main issue and are, sometime incorrectly, considered as a consequence of anthropogenic impact (Pranzini et al., 2017). In this perspective, sea-level rise is a result of global warming while decrease of river sediment input is due to river damming, overmining of sediments by the river bed, land use changes in catchment, construction of ports and coastal defenses.

To date coastal defenses have been constructed along relatively short segments of littorals, with limits coinciding to administrative boundaries. This approach definitely failed, considering the impact along adjacent shorelines, frequently resulting in downdrift erosion processes and floods.

These changes make it difficult for people and ecosystems to adapt to a changing climate.

Therefore, new tools are required for the study of the dam-river-coast systems. They should aim at defining in the medium-short term: (i) river longitudinal zoning, (ii) concentration time evaluation and return time, (iii) catchment erosion rate, (iv) quantification of silting of reservoir, (v) littoral drift and morho-evolutionary trend of littoral prism.

Each of these items is related to others, and is quite complex in term of stages and implications. In particular, longitudinal zoning allows to highlight the relationships between natural and engineered reaches of a mainstem and its tributaries and to measure their lengths, to describe the interventions and morphography of an urban river compared to the buildings over time. Concentration time permits to assess if a flash flood could occur: the probability is high especially when the value is lower than one hour. The catchment erosion rate, through surveys and modelization, may point out the main criticalities of slopes and relationships with sediment load and silting of reservoir. Sand trapped by dam, together with other meteomarine and anthropic factors, may drive the morho-evolutionary trend of littoral prism.

According to the methodological approach change, these tools can work in two ways: on one hand they are a *reflection* of the approach, on the other hand they are an *instrument* of the approach. Actually, this systemic approach aims to select adaptive rather than maladaptive strategies, following a policy of forecast, prevention and protection.

Ecological engineering techniques and environmental design are fundamental to recover and remediate endangered transition environments, considering integrated interventions in dam-river-coast system based on resilience rather than resistance.

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