Soil–Sediment–River Connections: Catchment Processes Delivering Pressures to River Catchments

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Abstract This chapter presents and discusses the soil–sediment–river connections and summarises the pressures at the basin scale from their causes (natural and anthropogenic drivers) to their consequences (impacts on biophysical status). Nine important pressures on river basins are evidenced with respect to their temporal and spatial scale of occurrence and their impact on the river basin at the basin scale and concerns: erosion, sealing, compaction, hydromorphological changes, salinisation, contamination, changes in water quantity, acidification and reduction of soil organic matter. Each pressure can affect the biophysical status, and the simultaneous presence of pressures can have cumulative or compensatory impacts on biophysical status through propagation. Eight biophysical statuses were identified (concentration of chemicals, trophic status, biota status, buffering capacity, salinity, suspended matter and sediment, water level, morphology and pedology), and the pressures are described in this chapter in the sense of impacts on these biophysical status.

Keywords Anthropocene system • Biophysical status • Ecosystem • Natural system • Pressures • Sediments • Soils

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1 Introduction

Water covers three quarters of the earth surface and is omnipresent, in rivers, groundwater, lakes, seas and oceans. The amount of water on the planet does not change but continues to transform, through the various stages of steam, liquid water and ice, to perpetuate the ongoing cycle of water (Fig. 1).

Water is a ubiquitous reactant, occurring in all internal and external geodynamical cycles. Most of the geological phenomena involve water, whatever period or scale. The Earth's surface can be considered as a physical interface between the lithosphere, on the one hand, made of solid rock and soils encompassing all elements of the relief of the continents and the hydrosphere and atmosphere, on the other hand, that consist of gases and particles. Fluid-rock interaction mechanisms in the upper crust are important in earth sciences to understand the phenomena existing and decipher past events [1, 2]. Indeed, the fluids are present at all levels of the crust and play a fundamental role in physical and chemical processes that affect the Earth's crust, being an essential component of chemical reactions. Through their composition, they influence the nature of rock or sediment in which they are present and/or circulating. They are the main carrier of chemical elements mobility, of the mobility enabling chemical reactions and the transfer of materials at different scales.

On one hand, the water cycle governs the exchange between the major terrestrial reservoirs, the atmosphere, the hydrosphere and the geosphere (Fig. 1). This is the main process governing the formation of soils and sediment mobility. Two entities of the environment are jointly organising the flow of water, the hydrograhic network and aquifers [3]. The first one is more or less dense and branched and can disperse or confine the waters with a variable carrying capacity according to the fluvial system (alluvial fan, braided channels, meandering, braided, delta plain, etc.). The second one is formed by the porous formations, open fractures and karst systems, and geological heterogeneities constrain the volumes and the flow of groundwater.
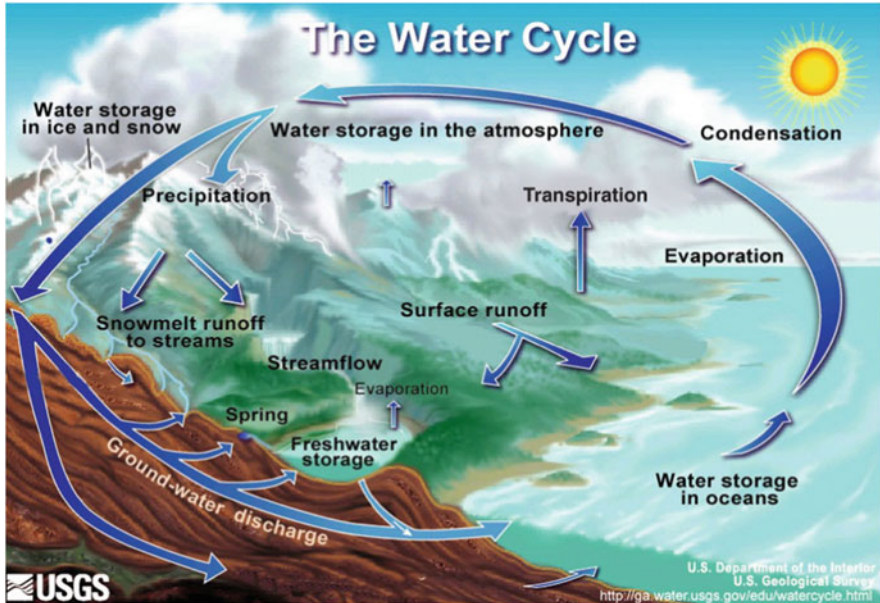
Fig. 1 Representation of the water cycle (Figure used by permission of USGS) (See: at http://ga.water.usgs.gov/edu/watercycle.html)

On the other hand, economic activities over the world induce pressure at the river catchment scale. These pressures may affect the chemical and ecological status along the water cycle (from rivers to groundwaters) and may impact the soil–sediment–water resources [4].

This chapter aims at providing a synthesis of soil–sediment–water connections at the catchment scale with regard to pressures that are delivered either by the natural (eco)system or the anthropogenic one. More particularly, this chapter is dedicated to assess and characterise causes of degradation of the river basin at large scale, processes involved and consequences on biophysical status. The selected focus in this chapter originates from a large panel experts consultation through workshops (Orléans, Leipzig, Berlin) managed during the course of the RISKBASE project.

2 The Natural System (Ecosystem)

2.1 Continental Weathering and Erosion: The Soil Formation

Chemical and mechanical destruction of rocks is the primary source of soil materials and solid load transported by rivers. This affects all rock types, igneous,[1]

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[1] Granite or basalt rock type formed through the cooling and solidification of magma or lava

metamorphic[2] and sedimentary.[3] Rock fragments are produced by the mechanical action of the erosion processes, e.g. through natural physical agents like rocks cracking due to temperature changes, particularly important in rocks composed of different minerals with different expansion coefficients, or other processes like abrasion, wetting and drying, freezing and action of living organisms and plant roots. Primary minerals and rocks are split into fragments due to physical weathering, and the new environmental conditions, like the increase in surface area, favour chemical weathering (Fig. 2).

Water is the basis of chemical weathering of rocks thanks to the dipole behaviour of the water molecule due to its electrical charge. This property is due to the asymmetric covalent bond that links the hydrogen and oxygen atoms. The polar nature of the water molecule allows the establishment of hydrogen bonds between molecules in tetrahedral groups then inducing properties of the water structure such as the character of the solvent [6].

Chemical weathering involves the alteration of the chemical and mineralogical composition of the material being weathered. Different processes induce chemical weathering like hydrolysis, hydration, oxidation, reduction and carbonation.

Hydrolysis involves the destruction of the molecular structure (e.g. the primary minerals) and transformation into other molecular structures (e.g. the secondary minerals such as clays). Water molecules at the mineral surface dissociate into H^+ and OH^- and the mobile H^+ ions (H_3O^+) penetrate the crystal lattice, creating a charge imbalance, which causes cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) to diffuse out. When hydration occurs, i.e. the incorporation of water molecules to low-hydrated minerals (attachment of H^+ and OH^- ions to a reacted compound) increasing the volume of the mineral thus promotes the destruction of the rock. This is due to the property of ions to hydrate when H_2O is present and dissociate. Carbonation occurs when rain combines with carbon dioxide or an organic acid to form a weak carbonic acid which produces the solubilisation of limestone, dolomite and evaporite rocks under the action of CO_2 dissolved in water. Oxidation–reduction concerns minerals that contain Fe^{2+} (and Mn^{2+}). If there are oxidising environmental conditions, the Fe^{2+} is oxidised to Fe^{3+} that precipitates as an insoluble oxyhydroxide, usually either ferrihydrite or the stable mineral goethite. Mn^{2+} is oxidised to Mn^{3+} or Mn^{4+} partly inside the minerals, resulting in a positive charge balanced either by a loss of some oxidised iron and manganese ions or some cations dissociated from the mineral.

Climate is the most important factor affecting chemical weathering processes by controlling the rate of weathering that takes place through regulation of moisture and temperature.

Soil formation involves processes that develop layers or horizons in the soil profile. Five major factors influence soil formation, namely, the parent material, the climate, living organisms (especially native vegetation), the topography and the time. Parent material is the material from which a soil forms and generally consists of

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[2] Arise from the transformation of existing rock types through metamorphism (initial rock subjected to high temperature and pressure causing profound physical and/or chemical change)

[3] Formed by the processes of compaction and cementation of sediment over a long period of time
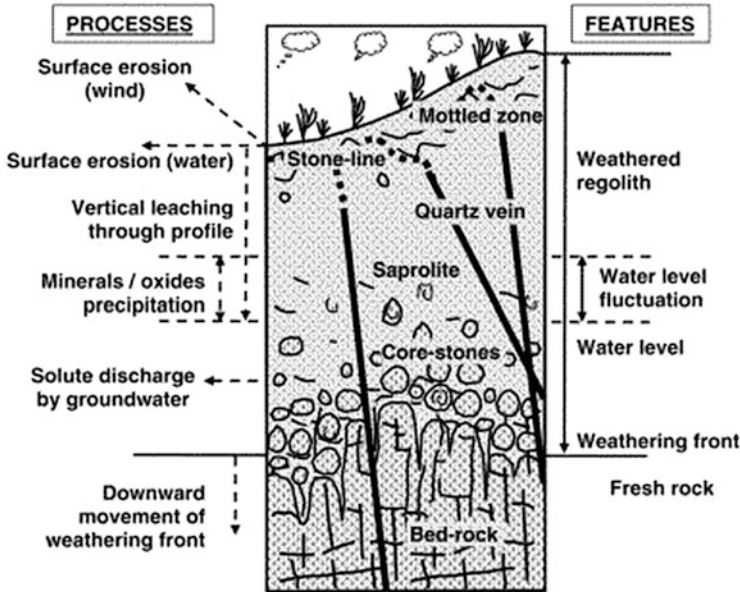
Fig. 2 Schematic sketch of the representative weathered profiles over Precambrian basement of South-West Nigeria, modified after Tijani et al. [5]

unconsolidated and more or less chemically weathered mineral or organic material. Resulting parent material is alluvium, lacustrine or marine if water is the mode of deposition. Water and ice result in glacio-fluvial, glacio-lacustrine or glacio-marine; ice results in till; wind results in eolian; and gravity results in colluvium.

Soils are named and classified on the basis of physical and chemical properties in their horizons (layers). Texture class is one of the first things to be determined for a soil examination. It is related to weathering and parent material as illustrated in the Fig. 3. The differences in horizons may be due to the differences in texture of their respective parent materials. Soil taxonomy identifies more than ten soil orders; more than 60 suborders are recognised at the next level of classification, about 300 great groups and more than 2,400 subgroups. They are labelled using a short-hand notation of letters and numbers [7]. They are described and classified by their colour, size, texture, structure, consistency, root quantity, pH, voids and boundary characteristics and if they have nodules or concretions [8].

The Critical Zone concept, defined as the Earth's outer layer from vegetation canopy to the soil and groundwater that sustains human life, is a recent way of networking scientists investigating processes within the Critical Zone in the same large field site case studies (Critical Zone Exploration Network (CZEN) is a community of people and a network of field sites[4]). The Critical Zone encompasses the sequence of individual

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[4] See http://www.czen.org/
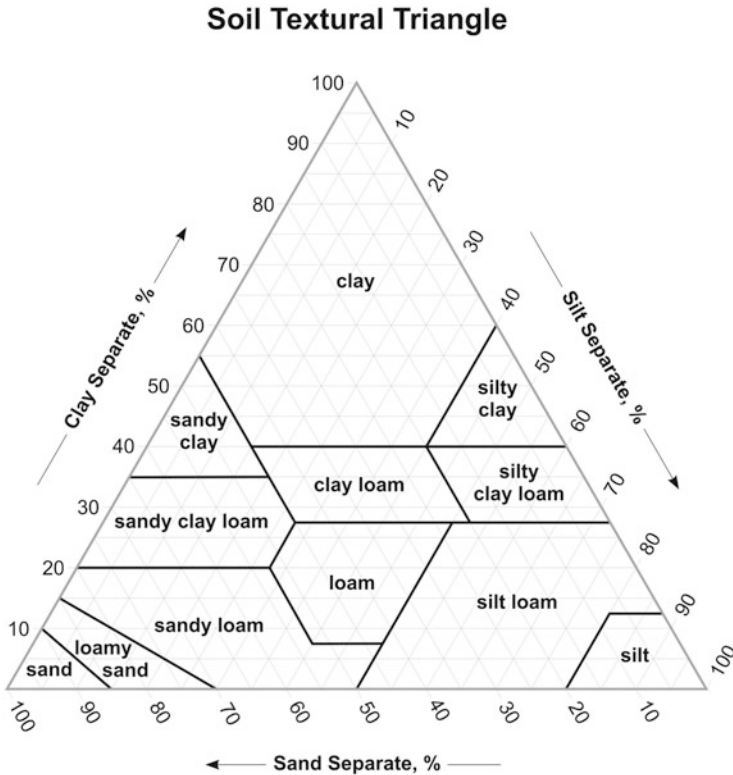
Soil Textural Triangle

Fig. 3 Soil texture triangle classification, from USDA (free of permission) (See Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Series Classification Database. Available online at http://soils.usda.gov/technical/classification/scfile/index.html. Accessed [15/09/2012].)

natural systems like plant communities, soil, weathering mantle, regolith, vadose zone and groundwater layer and represents, therefore, an extremely complex super system. The SoilCritZone[5] project (FP6) aimed to bring together the fragmented European soil research community so that we can better understand what policy needs to be developed for the sustainability of European soils in the twenty-first century, in line with the aims of the European Soil Strategy. SoilCritZone aimed to mobilise the scientific and engineering community to develop a European research and innovation strategy on soil science. The SoilCritZone project concludes that the key research priorities identified (soil degradation, weathering, biodiversity, life cycle of soils) would benefit from well-instrumented field soil observatories enabling long-term studies in Europe. These long-term soil observatories need to be based on the main soil types of Europe;

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[5] See http://sustainability.gly.bris.ac.uk/soilcritzone/

soil types are influenced by the underlying geology, geography, climatology and tectonics of the area [9].

2.2   The Solid Transportation Over Continent

Rivers and aquifers play a central role in the natural system (ecosystem), from upstream to downstream; the river is the place of erosion, transit and deposition; and in this system, soil erosion is a natural process (Fig. 4). In the upstream part of the rivers, the natural load of a river appears as the product of the interaction, either chemical or mechanical, between runoff and rocks. For chemical erosion, this product is in dissolved form [6], while for mechanical erosion, it is in particulate form [10]. In a fluvial system and its watershed, the water flow is a continuum from precipitation to the ocean through runoff, evapotranspiration, infiltration, runoff into rivers, unsaturated zone and aquifer systems (Fig. 4).

At the earth surface, there are numerous streams flowing off the mountains and large rivers meandering in plains [11]. Each river basin is a functional group in which different reservoirs (e.g. rocks, water, vegetation, etc.) and interfaces are intimately connected. The geomorphological characteristics change gradually from the river source to its mouth, depending on the slope, the relative topography and the base level. In the most upstream part of the river system, erosion processes dominate, producing the majority of sediment load of the river system. The streams converge toward the transition zone between relief and flood plain. At this level the flow diverges and the transport capacity decreases and the coarser sediments accumulate to build up an alluvial fan. Beyond the alluvial fan, the coarser load (gravels, sand) has been deposited, and currents flow in the direction of the steepest slope. Toward downstream, the slope is decreasing, the currents lose their energy and then the finer particles (silts) are deposited. As the base of the channels will be less erosive, braided channels will gradually evolve to sinuous and meandering channels. In the river flood plains, silt and sand are deposited with some mud, creating fertile plains.

During high floods period, the currents coming out of channels, being more erosive, disperse the particles previously deposited in the flood plain. The solid products of chemical weathering and mechanical erosion transported by rivers join the ocean through the transition zone between continental and marine environments [12], i.e. estuaries and deltas. Although intermediates exist between the two types of mouth, usually when the river has a dominant influence, a delta is formed; if the marine influence is dominant, the river mouth has the morphology of an estuary. In estuaries, under the influence of tides and waves, fine particles are washed out and sand flats are left behind. When the sea level drops, these become workable soils (i.e. exploitable for agriculture) but poor in nutrients.

Considering the Europe's sediment budget, Owens and Batalla [13] gave a preliminary view to enhance the extent and budgets of European sediment, from erosion to delivery to oceans and seas, including partial deposition and remobilisation in catchments. The budget they gave was based on general estimates of soil erosion, sediment yield and sediment storage on river channel and floodplain environments
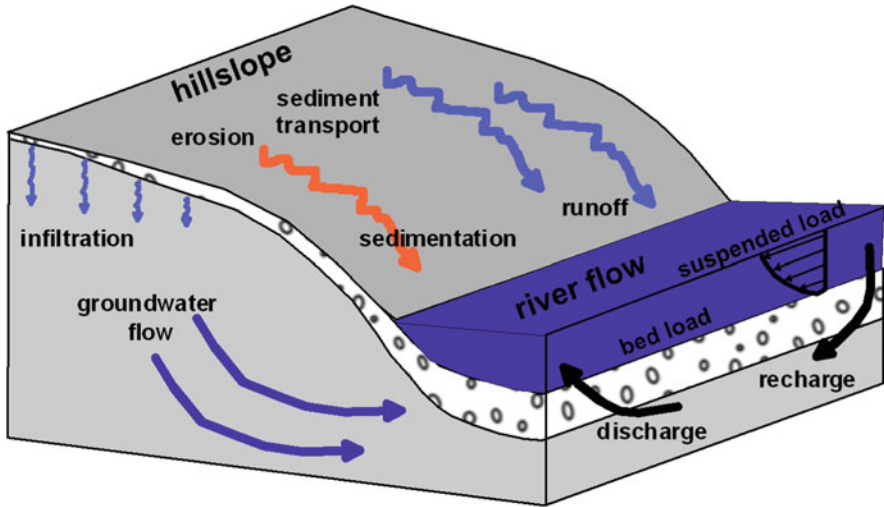
Fig. 4 Conceptual model of surface-subsurface water, sediment and flow bed transport

and in reservoirs, on one hand, and estimates of the sediment discharge to oceans and seas, on the other hand. The authors considered only the suspended sediment load (e.g. the particulate matter carried out in the water column) and did not take in consideration the bed load (e.g. coarse-grained sediment transported by saltation onto the river channel bottom).

The most recent erosion rates representing the sediment production of the European catchments were estimated by Owens and Batalla [13]. From humid environments in the northern and mid-southern Europe to semiarid regions in the southern Europe, they gave an estimate of around ca. $1{,}800 \times 10^6$ tonnes year^{-1}. Additionally, they estimated the total amount of sediment transported by rivers toward the lowermost land areas (deltas and estuaries, harbours, etc.) of around ca. 714×10^6 tonnes year^{-1}. Among the amount being eroded from rocks and soils and delivered to rivers, around 30 % would be deposited on floodplains, 20 % would be deposited in reservoirs and 10 % would be extracted for aggregate, leading to 40 % reaching the lowermost deposition zones and the coastal zone.

2.3 The Anthropocene System

It is well recognised that the human imprint on the environment, starting since the 1800s, has now become so large and active that it impacts the functioning of the Earth system. The term anthropocene, introduced about a decade ago [14], has only recently become widely, but informally, used in the global change research community [15, 16]. The anthropocene corresponds to the current epoch in which humans and our societies have become a global geophysical force. The development

of the anthropocene began around 1800 with the onset of industrialisation as analyses of air trapped in polar ice have shown an increase in the concentrations of carbon dioxide and methane. Since introduced, anthropocene was used in many studies of the environment, in the sediment investigations [17, 18], carbon and climate [19], land cover change [20] or rather more political reflections [21].

In the anthropocene, economic activities (drivers) lead to inputs, which are called pressures, to the ecosystem (see Fig. 1 in [22], this volume). The ecosystem adapts, resists, modifies and transforms these inputs into outputs, which correspond to stressors and lead to modification in the level of ecological service from the river basin [23] which is the ecosystem response. Thus, this leads to a segmentation of the ecosystem in a physical system on one hand and the aquatic life sensu stricto on the other hand, both being linked through stressors. Stressors are the results of socioeconomic activities as they are experienced by aquatic and terrestrial life and they reflect the unnatural inputs to the system that disturb the controlling factors, structure and processes in the ecosystem (see also Fig. 2 in [22], this volume). An example given by Negus et al. [24] demonstrates that a change in land use (indirect pressure/human activity) results in an increase in sediment load entering a stream (direct pressure), which affects stream turbidity (stressor) which in turn may lead to a changed ecological condition (ecosystem response).

A reasonable working hypothesis would be that good chemical status and good ecological status of water is a necessary condition for good performance of ecological services in a river basin. This implies that the assessment of status and impacts in aquatic systems in the river basin is relevant not only for the protection of aquatic life but also for wider issues concerning ecological services in the river basin. The health of the aquatic system is an important indicator of the health of the whole river basin system. The inventory of the drivers causing pressures and of the consequences of pressures on biophysical status showed that most drivers were correlated to most pressures and pressures had multiple impacts on biophysical status, reflecting the complexity of the system and its interconnections.

2.4 Relevant Pressures at the Basin Scale

Pressures or causes of degradation are defined as factors/phenomena which can reduce the resilience of the system, e.g. its resilience to cope with climate change, and whose occurrence or propagation has significant consequences on the biophysical status at large scale in the river basin. Two main types of drivers causing pressures on the biophysical status can be distinguished: the anthropogenic drivers, which are mainly associated to human land use and activities (agriculture, industrialisation, river basin network activities and other activities such as tourism), and the natural drivers, which include geological and climatic changes, inducing extreme events such as droughts, floods and natural hazards (Fig. 5). Pressures caused by natural drivers may be increased by human activities, but with regard to the ecosystem, it does not matter whether a pressure is man made, natural but intensified by human activities or just natural.
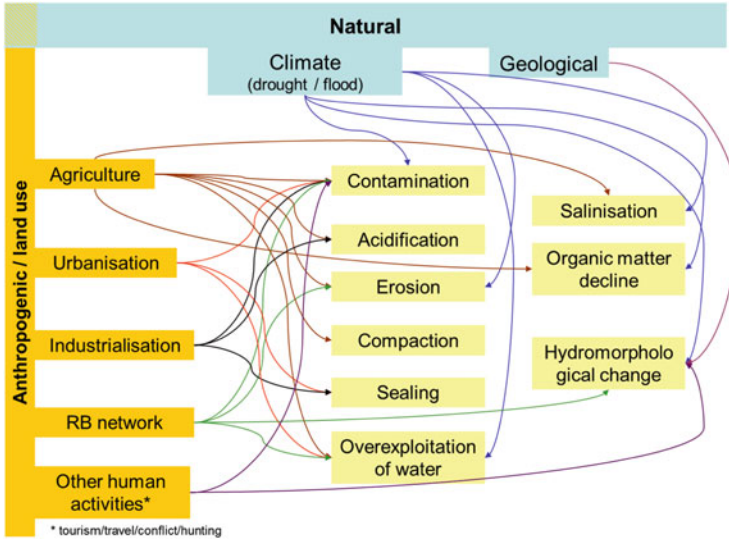
Fig. 5 Relevant pressures controlled by natural and anthropogenic drivers at the river basin (RB) scale and illustration of the complexity of the relations between drivers (natural and anthropogenic) and pressures

It is also important to consider the complexity of the links between human activities, natural changes and the pressures listed above as illustrated in Fig. 5. The pressures discussed in this chapter were selected with respect to their temporal and spatial scale of occurrence and their impact on the river basin at the basin scale. The pressures definition originates from a large panel experts consultation through two workshops organised in RISKBASE according to two main themes, i.e. "understanding processes and measurements of both soil/sediment and water compartments" and "monitoring and remediation soil/sediment and water compartments". The pressures in the river basins thus identified may reflect the main concerns for the management of river basins, and these pressures are as follows: erosion, sealing, compaction, hydromorphological changes, salinisation, contamination, changes in water quantity, acidification and reduction of soil organic matter.

It is thus important to estimate that the links between human activities, natural changes and the pressures are complex and never can be all embracing. Figure 5 gives an illustration of such complexity. One pressure can have a direct effect on biophysical status, but several pressures can also interact to result in cumulative or compensatory effects on the biophysical status. The simultaneous presence of several pressures can originate from two different phenomena: (1) they appear individually in the basin due to specific human activities or (2) the presence of one pressure entailed to the presence of another or several other pressures.
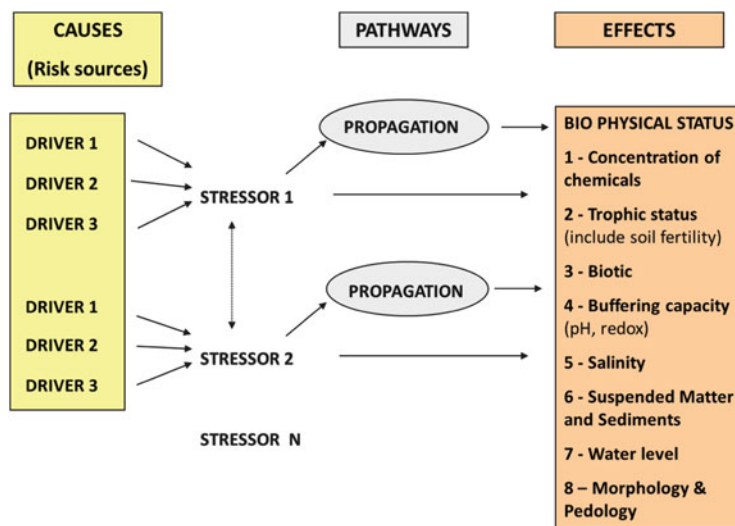
Fig. 6 Drivers and stressors (causes) via propagation (pathways) linked to their effect (notable as postulated changes) on the biophysical status

2.5 Pressures and Biophysical Status

Pressures, as causes of degradation, are directly related to specific drivers, pathways and biophysical status as summarised in Fig. 6. The pressures (e.g. erosion, sealing, compaction, hydromorphological changes, salinisation, contamination, changes in water quantity, acidification and reduction of soil organic matter) may have significant consequences on the biophysical status at large scale in the river basin (see Fig. 6). The propagation is defined as the potential for pressures to propagate at large scale through vector media, such as water, through dissolved and solid loads of surface water, groundwater and air. Each pressure affects the biophysical status and the simultaneous occurrence of different pressures, and their propagation can have cumulative or compensatory impacts on biophysical status.

Biophysical status has to be described, in terms of measurable characteristics, i.e. indicators. The description must follow two ways: it should be linked to the pressures and it should be relevant for the assessment of impacts on aquatic life. As stated earlier, the optimal description of biophysical status may vary as a function of the geological and ecological conditions in river basins (see Fig. 5). Thus, eight indicators may be used for the characterisation of the biophysical status:

- The chemicals contents: contents of inorganic and organic compounds in water, soil and sediment compartments.
- The trophic status: overall level of biological productivity in water and fertility in the soil. It refers to the concentrations of key nutrients (phosphorus, nitrogen, etc.) and planktonic algae (or phytoplankton).

- The biota status: all the interacting organisms living together in a specific habitat (biodiversity).
- The buffering capacity: ability of water or soil to resist and adapt to chemical property changes.
- The salinity: quantity of salt content in a soil (sediment), quantity of dissolved salts in water. Mainly refers to sodium chloride, but other salts occur.
- The suspended particulate matter and sediment: load that is carried for a considerable period of time in suspension. This particulate matter that can be transported by fluid flow and may be deposited as a layer of particles in form of bottom sediment.
- The water level: variation of level (or hydraulic potential) of water in groundwater (e.g. aquifers) or surface water.
- The morphology (a) and pedology (b): (a) the nature and history of the landforms on the surface and of the processes that create them and (b) the nature, properties, formation, distribution and function of soils.

Modification of the biophysical status is either a direct consequence of the pressure on a water body or an indirect consequence of the pressure due to its propagation at large scale in the system. Therefore, for each pressure, its occurrence at large scale and its potential propagation in the system are assessed. Consequences are also assessed with respect to biophysical status (and indicators) but do not give information on whether the consequence has a positive or a negative effect on the biophysical status, which was considered to be too dependent on the environmental settings. For example, erosion may lead to remobilisation of contamination in polluted areas with increasing contamination level downstream or may lead to buffering/reducing pollution acting as a trap for contamination present in water and/or dilution of contaminated sediments with clean eroded soil and sediments.

2.5.1 Erosion

Erosion is a process that can potentially affect all the river basin area through various erosion processes (e.g. hillslope erosion, channel bank erosion, landslide, gullying and sediment dynamics at landscape scale). Chemical erosion is also a main feature especially on catchments which are heavily transformed by human activities such as reservoirs and dams (e.g. of the Ebro River basin accommodating more than 170 dams). The geological settings as well as river management control the chemistry of erosion (see above). Different causes of erosion processes can be incriminated, either natural (storm magnitude and frequency, topography, wildfires, etc.) or anthropogenic (sensitive land-use types, specific soil management regime and depopulation of mountain areas, etc.). The causes vary significantly with catchment type, relief, land use, soil type, etc. [25]. It is noteworthy that historical land management has changed the vulnerability and the intensity of the phenomenon [26]. Human settlements and the implementation of intensive agriculture have led to a shift from natural geological erosion to anthropogenic, accelerated erosion [27, 28].

An example can be given regarding the Ebro River basin. The use of a large set of chemical data covering the last 2 decades (1981–2004) allowed Négrel et al. [29] to estimate the export fluxes for dissolved and solid matter loads on the catchment scale of the Ebro River basin over a long time period of more than 20 years. They defined mean annual dissolved fluxes between $1,600 \times 10^3$ tonnes year^{-1} upstream and $5,900 \times 10^3$ tonnes year^{-1} close to the river outlet, leading to specific export rates around 70–90 tonnes km^{-2} year^{-1}.

As more than 97 % of the Ebro drainage basin is affected by the presence of dams, the retention of sediment in dams and the decrease in water discharge have produced a drastic decline in the supply of river suspended matter: from $20–25 \times 10^6$ tonnes year^{-1} in 1880 to 2.2×10^6 tonnes year^{-1} in 1960 and 0.12×10^6 tonnes year^{-1} in 1991 [30]. The long-term flux calculated by Négrel et al. [29] is around 0.1×10^6 tonnes year^{-1}, and the specific export rate is 1.2 tonnes km^{-2} year^{-1} near the outlet, close to that given by Guillén and Palanques [30] and Palanques et al. [31]. The specific export rate for suspended matter in the Ebro can be compared to other rivers in Western Europe. Manickam et al. [32] and Négrel and Grosbois [33] reported 8 tonnes km^{-2} year^{-1} for the Loire Basin. Meybeck and Ragu [12] reported 9 tonnes km^{-2} year^{-1} for the Seine River Basin and Roy et al. [34] reported 6 tonnes km^{-2} year^{-1} for the Seine at Paris. Higher values are given for the Rhine River Basin (15 tonnes km^{-2} year^{-1}, [12]) and the Garonne River Basin (20 tonnes km^{-2} year^{-1}, [35]). Geographically close to the Ebro Basin, Rovira et al. [36] reported a specific export rate for suspended matter of around 8.5 tonnes km^{-2} year^{-1} in the Tordera Basin (NE of the Ebro). Further north in France, Serrat et al. [37] reported between 40 and 103 and 40 tonnes km^{-2} year^{-1}, respectively, for the Agly and Têt rivers. This places the Ebro River artificially with very low suspended matter fluxes and the associated weathering and erosion processes. The lack of relationship between suspended matter and discharge also supports the fact that dams play an important role in controlling suspended matter fluxes and regulating water flow. This is particularly of primary importance for the mouth of the river and its evolution. The evolution of the mouth of this river during the last 2,000 years, from an estuary to a delta, was interpreted as a process accelerated by the land management and the human impacts [13, 38].

In the European context, propagation of erosion is often significant at the basin scale. A recent assessment of the rate and spatial variation of soil erosion in Europe concluded that total sheet and rill erosion in Europe as covered by the CORINE database[6] is estimated to be ca. 5.5×10^8 tonnes over a total surface area of ca. 4.46×10^8 ha. Thus, the average sheet and rill erosion rate for Europe is estimated to be slightly over 1 tonnes/ha/year, but this average rate may vary between 0.2 and 3.2 tonnes/ha/year on a per country basis. Mean rates per land-use class show very important variations, the value for arable land being around 3.6 tonnes/ha/year. The study also highlighted high spatial variability in soil erosion

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[6] See http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-4

rates, 70 % of the erosion being produced by 15 % of the area. It is certain that within these 15 % of the area, soil erosion and its associated consequences represent a major environmental issue [39]. Apart from the local degradation of the soil functions, erosion processes result in an increase in sediment transport as particulate matter and associated chemicals as dissolved load, which are transferred throughout the river basin. The consequences are hence very diverse from the loss of fertile topsoil, organic matter and soil biodiversity [40] to the occurrence of muddy floods [41], the siltation of reservoirs [42, 43], the pollution of continental and estuarial sediments and water bodies [44, 45] and eventually the modification of the landscape topography. Erosion is therefore a degradation that can potentially affect all the river basin area. In Europe, the main vector for particles (soil, sediment and associated chemicals) is surface water, including overland flow; notwithstanding in localised sandy areas, wind erosion can be significant.

However, erosion is not only a negative process as sediments are an important vital constituent of river basin development and functioning, moreover considering earth cycles. This occurred over the geologic times when large erosive periods and lithospheric dynamic shaped the landscape. The removal by erosion of large amounts of rock from a particular region, and its deposition elsewhere, impacts the load on the lower crust, generally causing tectonic or isostatic uplift. Therefore, the sediment behaviour concerns the erosion processes, transit and sediment deposition that punctuated the land-ocean continuum. Once going through the barrier between continent and ocean (e.g. estuaries or deltas), suspended solids and bed loads transported by rivers combine with particles only of marine origin and, through sedimentary and diagenetic processes, form sedimentary rocks. The sediment cycle continues through the passage into the oceanic trenches and subduction zones giving a large and continuous cycle.

2.5.2   Sealing

Sealing is generally described as the covering of soil by impermeable structures like buildings and infrastructure. Soil sealing is a complex phenomenon with various causes including the loss of structure due to the impact of rain or soil labouring, the dispersion of colloids and the compaction [46, 47]. Natural [48–50] and anthropogenic [51] sealing can be distinguished. The ever-increasing urbanisation in Europe will have effects at the river basin [52], especially on the water regime.

Like compaction (see Sect. 2.5.3), soil sealing increases surface runoff and prevents infiltration but does not propagate as such, although secondary effects may propagate to larger scales. Secondary effects may be the enhanced spreading of urban and agricultural pollution, and thus, sealing is now to be considered as an important emerging problem [53]. In situ consequences of sealing are dramatic and affect largely ecosystems. In a European context, propagation of the interactions of sealing on the other pressures (e.g. erosion) is often significant at the basin scale. Soil sealing reduces infiltration and increases runoff and its transport capacity. The water regime of the underlying soil is severely altered by sealing [54, 55]. In addition to the general decrease in soil moisture content, there is a

lowering of water tables in urban areas. Erosion is also significantly modified by soil sealing [56, 57]. The increase of impervious surfaces can have consequences also on the quality of water, due to the reduced filtering capacity of the soil [58, 59]. It also has been reported that pH and salinity may be affected by sealing [60]. The negative effects of sealing can also induce loss of plant production and natural habitats [51] and generally results in biodiversity loss [61].

2.5.3 Compaction

Compaction is mainly due to anthropogenic process and affects the first soil horizons. It is defined as: "the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the bulk density" [62]. Soil compaction is a particularly important issue in the broad field of soil management as one of the causal agents of soil erosion, nutrient depletion and pollution [63] even if it does not propagate at catchment scale. Compaction also affects the mineralisation of soil organic carbon and nitrogen [64] as well as the concentration of carbon dioxide in the soil [65]. Soil compaction therefore adversely affects soil physical fertility [66], particularly storage and supply of water and nutrients, through increasing soil bulk density, decreasing porosity, increasing soil strength and decreasing soil water infiltration and water-holding capacity [67]. The main incriminated reason that exacerbates the compaction process is the increased size and use of machinery, particularly in remodelled landscape [68]. Secondary reasons include working the soil at the wrong soil water content [67], timber harvesting [69, 70], industrial activities such as the extraction of minerals [71] and the installation of underground pipelines [72]. Increasing soil porosity or decreasing bulk density reduces or eliminates soil compaction. Compaction does not propagate as there is no vector through the river system, and the amount of compacted soil must be very large before effects, such as reduced replenishment of aquifers, become significant at large scale. However, it should be noted that tramline wheel tracks are the principal culprits, often leading to overland flow both within field and off field; furthermore, the flow may redistribute sediment, nutrients and pesticides within the field and beyond [63], increasing connectivity at the field scale.

   In the European context, the propagation of the interactions of compaction on the other pressures (e.g. erosion) is often significant at the basin scale. Soil compaction is estimated to be responsible for the degradation of an area of 33 million ha in Europe [73]. The extent of compacted soils may decrease if the shift from conventional agriculture toward simplified cultural techniques is pursued. It should however be noted that compaction, either due to natural (rainfall, plant roots, foot traffic of man, or animal) or artificial (mechanical operations) causes, is not reversible at a human time scale, and a very recent review by Nawaz et al. [74]) summarises the advances in understanding, quantification and prediction of the effects of soil compaction. They highlighted the results of the experimental studies that confirm some parameters increase (soil strength, bulk density, volumetric water contents, field capacity) and

the decrease of others (total porosity, soil aeration, water infiltration rate, saturated hydraulic conductivity) in relation with soil compaction.

2.5.4 Hydromorphological Changes

Issues of water quality have generally dominated river research. However, also a better understanding of the ecological effects of a wide range of changes in physical habitat is needed and thus management and conservation being more crucial [75]. Rivers are increasingly exploited, regulated or otherwise modified through flood-defence engineering, impoundment, river restoration, climate change and the spread of alien species [76]. The EU Water Framework Directive [77] risk assessments, carried out in 2005, showed that hydromorphological pressures and impacts are one of the most important risk factors of failing to achieve WFD objectives. Hydromorphological integrity is central to conservation since it provides the template upon which all other ecological structures and functions are built [78]. Hydromorphological elements are hydrological regime, quantity and dynamics of water flows, connection to groundwater bodies, river continuity, morphological conditions, river depth and width variations, structure and substrate of the riverbed and structure of the riparian zone [79].

There exists a feedback between hydromorphology and ecology as they influence each other; the hydromorphology of the river will define the type of habitats that can settle which in turn may affect the sediment stability and release [80, 81]. The river hydromorphology has also a direct impact on the physical connectivity, which has not always been identified as a major issue in river basin management, though it plays an important role. Physical connectivity embraces horizontal and vertical connectivity and is scale dependent [82]. It depends on environmental and weather conditions (e.g. intensity of storm events).

Hydromorphological change is not a threat that propagates. The extent of the issue depends on infiltration capacity/land uses in the catchment. In a European context, propagation of the interactions of hydromorphological change on most of the other pressures is often significant at the basin scale and is a major issue. This is the main focus of the EC FP7 REFORM project (see further Sect. 2.7 in [83], this volume, also for more information on hydromorphological degradation).

2.5.5 Salinisation

Salinisation is the process that leads to an excessive increase of soluble salts in the soil solution compared to the natural levels generally observed. Salt-affected soils are defined as soils having salts in the solution phase and/or sodium ions on the cation exchange sites exceeding the specified limits. Major cations in these soils are sodium, calcium, magnesium and to a lesser extent potassium. The major anions are chloride, sulphate, bicarbonate, carbonate and nitrate. These soils are generally divided into three broad categories: saline, sodic and saline-sodic according to their electrical conductivity and sodium adsorption ratio [84].

Salinisation concern excess salts hinder the growth of crops by limiting their ability to take up water. Salinisation may occur naturally or because of conditions resulting from management practices. Soil salinity is mainly controlled by geological factors (presence of evaporates, e.g. soluble salts—such as sulphates of sodium, calcium and magnesium in the soil) and climatic factors (drought, low annual rainfall, high rate of evaporation). However, any change in the hydrologic cycle, such as results from draining or flooding areas (irrigation in intensive agriculture) changing the shape of the land's surface or increasing or reducing vegetative growth, can affect soil salinity [85, 86]. In the European Union, about 1 million hectares of soils are salt affected, mainly in the Mediterranean countries. Salinisation is also a major cause of desertification [87]. In Spain 3 % of the 3.5 million hectares of irrigated land are severely affected, reducing markedly its agricultural potential, while another 15 % are under serious risk [88, 89].

The water compartment is also affected by salinisation, and the main cause is the salt intrusion in coastal groundwater often occurring when coastal aquifers are over-exploited because of the demands of growing urbanisation, industry and agriculture. Over-exploitation of aquifers can also lead to leakage from deep salty aquifers. The phenomenon also occurs when the aquifer is near the surface, as the water table limits the depth to which salts are leached and moreover evaporation carries the salts back to the upper soil level. Climate change induces rise of the sea level that will accelerate the salinisation of coastal aquifers. Mine industries and urbanisation are also responsible of salinisation. While salinisation originating from mining decreases, salinisation in coastal areas drastically increases due to tourism extension and climate change. Artificial estuary deepening for navigation purposes greatly affects the estuary hydrodynamics especially with regard to salt–water intrusion [90, 91].

Salinisation thus affects soil, surface- and groundwater quality. This threat can be of significance at the river basin scale, depending on the affected surface area and on the main lithologies of the catchment and the land use. Salinisation is not a threat that propagates through the whole river system with respect to the soil compartment. However, mineral dissolution with the release of chemical elements in solution (e.g. salts) and the propagation of elevated level of salts from the soil to the groundwater and the surface water can occur by the means of vectors such as infiltration water or drainage water network like on the Ebro River basin [29, 89]. Salts are also deposited by dust and precipitation. In dry regions, salts may accumulate leading to naturally saline soils. Salty waters can then affect large part of the river basin, both surface- and groundwater compartments. The groundwater compartment thus affected by salinisation can propagate through the natural water cycle up to the surface waters.

Salinisation, as a pressure, may thus affect several biophysical statuses. First, the concentration of chemicals and the trophic status will be impacted because of the change in the basic natural chemistry of the water (surface water and groundwater). Salinity increases till an improper water quality for users (drinking-water supply, irrigation, etc.) is reached. Salinisation affects the biological status with damages on plant growth leading to growing salt-tolerant crops. Ultimately, when crops are too strongly affected by the amount of salts, soil erosion will increase, affecting the suspended matter and sediments status.

In a European context, propagation of salinisation per se can be significant at the basin scale for specific areas: coastal zone, mining areas, specific lithologies like evaporates and dry areas. In Europe, Romanian, Hungarian and Greek soils are mainly affected; Spain and Italy also present areas under this specific pressure (European Commission—Joint Research Centre Institute for Environment and Sustainability[7]).

2.5.6 Contamination

Contamination is the introduction of hazardous substances into the soil and water system due to emissions and discharges originating from various sources often linked to human activities (see [83], this volume). Generally a distinction is made between point sources (direct inputs into the system at specific points) and diffuse sources (indirect inputs, for instance, atmospheric deposition of pollutants emitted to air or fertilisers inputs in agricultural areas).

The impact of anthropogenic contamination on the ecosystem can stem from multiple diffuse and point sources including mining wastes [92], spills, pesticide use and wastewater emissions with associated chemicals (e.g. pharmaceuticals, [93]). However, also high natural background concentrations may affect the system as shown for arsenic in groundwaters [94, 95] or selenium (Se) in different environments [96]. Investigations of environmental problems due to contamination generally aim at deciphering between natural and man-made origin of contaminants [97], but the way land is used may often influence the fate of contamination and its impacts. An interesting example is selenium (Se) contamination in the Lower Arkansas River, where the Se concentrations are linked with the NO_3 ones, revealing that the influence of the later, sourced and transported by fertilisation and irrigation, promotes the dissolution of Se from geologic and soil material [98].

Contaminated sites, the historical legacies like mine tailings dam failures [99], metal-contaminated sediments [100, 101], former industrial and military sites, are often addressed as a separate area of policy in most industrialised countries. Other contamination of special interest is diffuse pollution with persistent organic pollutants (POPs, [102]), from rural or industrial sites [103] but also in urban areas, that may form large impacted zones. Finally, as recently evidenced, emerging compounds like veterinary medicines and endocrine-disrupting chemicals (natural estrogens, pharmaceutical estrogens or industrial chemicals) are contaminants of increasing concern [104].

Main components in surficial Earth system, like N, P and S, have similarities with the contaminants issue but are often considered separately under the headings acidification for nitrogen (N) and sulphur (S) and eutrophication for N and phosphate (P). Phosphate and nitrogen levels in many soils are a legacy of historical fertilisation. Levels are "saturated" in many agricultural areas. The different causes of degradation

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[7] http://eusoils.jrc.ec.europa.eu/library/themes/salinization/

for contamination by such elements are the current and past fertiliser application [105], both mineral and organic; the natural organic matter mineralisation that can be affected by tillage management; the acidification by NO_x that has increased atmospheric N inputs; and finally the natural background because some areas have high phosphate levels (anoxic zones in sediments of marine origin, volcanic soils). In groundwater the reduction of nitrates due to the oxidation of pyrite can enhance the amounts of nickel and arsenic as trace elements in pyrites and subsequently in the surface water. Specifically for nutrients N and P, as they are very strong regulators of ecological quality, impacts are important in freshwaters (for P) and in marine systems (for N).

Contamination affects both the soil and the water (groundwater and surface water) compartment, and contaminants propagate differently at the basin scale according to their physico-chemical properties. They are transported adsorbed and absorbed by sediments, suspended matter and organic matter and/or transported in the dissolved phase [106]. Selected contaminants can be temporary stored in soils and released according to local changes, e.g. modification of redox conditions. Contaminants (e.g. pesticides and their metabolites) and nutrients load stored in groundwater can cause problems for drinking-water supply in wells/springs and for recreation in mainly groundwater fed lakes and rivers even decades after the application of the contaminants or fertilisers [107–109].

The biophysical status can be affected by the concentration of chemicals through change in the basic natural chemistry of the water and increase the concentration of specific chemical elements (e.g. metals). The trophic status may also fluctuate as nutrient loads change, and this may lead to an increase in risk to human health (degradation of drinking-water quality, cumulative effects in the food chain) and risk to farm animals.

Numerous studies on the sources and pathways and consequences of the selected types of contaminants were conducted, especially through European Commission funded research projects like AquaTerra [110]. The large inputs from mining activities and from industrial megasites have been considered [111] for characterising the water flowpaths or to help environmental megasite managers in establishing an appropriate management approach for their megasites like in the WELCOME project [112] or AquaTerra [110]. Other examples are the contamination of the Danube and several of its tributaries by organic contaminants (phthalates like DEHP, PAH, tributyltin, nonylphenol) and heavy metals, including copper and nickel [113] or recent research on the links between natural background concentrations of contaminants and their concentrations in groundwater [114].

In a catchment context, contamination is significant at a large scale especially for diffuse pollution caused by urbanisation (increasing of sealing, wastewater), tourism and agriculture. Point source pollution shall currently be under local regulations (source control), and such contamination of soil, sediment, surface and groundwater is significant at the basin scale in specific context (megasites, region with industrial and mining histories). Historic contamination in sediments can be mobilised under extreme events due to extreme weather conditions, oceanographic conditions and water regime of rivers in relation with global climate changes. These changes may impact and modify drastically riverine processes like currents and erosion, thus

inducing important physical, geochemical and biological reactions. Floods and storm flows will likely lead to remobilisation of sediment and soil associated, historic contamination as well as to high-energy mass flows (eroded soil and remobilised sediment), and both will induce impact on river ecosystems [115].

Through comprehensive sampling and monitoring campaigns in diverse European river basins, using newly developed leading-edge approaches and methods, AquaTerra could show that many man-made chemical compounds can be found today ubiquitously, in all compartments, in air, in soil and sediments, in surface waters as well in groundwater.

2.5.7 Changes in Water Quantity

There are natural and anthropogenic drivers for changes in water quantity. The major natural driver is climate change causing region-specific reduction or increase of water quantity [116]. The spatial changes of water availability under climatic scenarios are generally evaluated on the basis of projections of general circulation models,[8] giving the variation worldwide of the precipitation [117].

Anthropogenic drivers for changes in water quantity include the decrease of infiltration at recharge areas or intensive use of the water resource mainly in coastal, industrial and urban areas. Concerning anthropogenic drivers, the nationwide and local anthropogenic impact on the water quantity is much more considered by states or local authorities and may have high economical and societal costs evaluated by various UN programmes (e.g. World Water Assessment Program[9]). The water crisis is reflected well, at both local and national consideration, in Australia as south and north parts of the continent are affected by wet/dry seasonal climatic conditions. In particular, increasing climate variability in the south together with declining rainfall resulted in reduced surface- and groundwater supplies and increasing competition for water from irrigators, urban/domestic, industrial and mining users [118].

In Europe, the propagation of changes in water quantity can be significant at the basin scale. As water is itself a vector through surface- and groundwater, the water quantity change is implying variations of groundwater level and surface-water runoff. Notwithstanding, floods remain one of the major natural disasters at the earth surface. At the opposite, drought or water deficits have also major impact at the basin scale. Water-level changes are the more important impact of water quantity changes at the basin scale. Furthermore, various authors showed that large rainfall/runoff events are responsible for high proportions of erosion [119–122]. Concerning floods, rising of groundwater levels leads to large and persistent floods while surface-water runoff may be responsible for fast, intense and destructive flood ([123] and see several websites[10]). One dramatic example of a groundwater-induced flood is the

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[8] See http://www.ipcc.ch/ (IPCC (Intergovernmental Panel of Climate Change), available at http://www.ipcc.ch/; IPCC (2009) Climate change and Water. IPCC reports, 7 Dec 2009, p 200)

[9] See http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/ (World Water Assessment Program. Available at http://www.unesco.org/water/wwap/)

[10] See http://www.acqwa.ch/; http://www.crue-eranet.net/; http://www.floodsite.net/

repetitive and uncommonly severe floods which France was subject to in 2001. Early in the year, catchments in the north and west of the country were flooded for several weeks, and areas in eastern France were affected as early as December 2000. After the lowest discharge in August 1999, strong and continuous river-discharge increase was observed up to the damaging flood event that took place in the basin in April 2001, due to immense groundwater storage in the chalk aquifer [124, 125].

Mobilisation of contaminants and change in the basic natural chemistry of the water are also important effects of water quantity changes. Salinity and concentration of chemicals are diluted or concentrated with water-level changes [126]. Possible changes in flows between surface water and groundwater and within the hydrogeological systems may also induce changes in water contamination due to leakages and leaching of previously unsaturated zones. In coastal areas, over-pumping of groundwater resources or decrease of the recharge may lead to salinisation by raise of the seawater intrusion.

The water quantity and most particularly surface-water increase may change the morphology of the basin. The impact of floods on channel morphology is highly variable in intensity and response type as it depends on various factors, and there is therefore no correlation between the flood magnitude and its morphological impact [127, 128]. The role of the extreme events has been recognised as significant in conditioning channel river form [129]; episodic behaviour of extreme events has lasting effects on the river system. Increase of surface-water level also impacts the valley morphology and channel incision [130]. Water quantity changes may induce local variations in hydraulic connectivity. Surface-water and groundwater interrelationships may then change due to severe drought of flood episodes [124, 131, 132]. Longer lasting severe droughts have a strong impact on the drinking, irrigation and cooling water supply as reported from the river Po basin during the hot summer 2003 [133]. Under unfavourable geological circumstances, long-lasting severe droughts can cause even regional land subsidence [134].

2.5.8 Acidification

Acidification can be caused by industrial activities through emissions of sulphur oxide and nitrogen oxide in the atmosphere. This may impact the river catchment [135], for instance, via acid mine drainage [136, 137]. It can be the consequence of land-use change or practices such as afforestation with conifers [138], ammonia deposition resulting in nitrification [139] and H^+ release and absence of tillage resulting in pH depletion in the top few cm of the soils. In addition, it can also be due to wind erosion through desertification (i.e. there is no more buffer effect of the vegetation and thus weathering increases), CO_2 concentrations and landfill leachate. Acidification has occurred in many regions of Europe and North America where slowly weathering bedrock(s) and base-poor soils are unable to neutralise acidifying deposition of sulphur (S) and nitrogen (N) and is a great challenge to be solved since the 1980s [140]. Nowadays, sulphur oxide and nitrogen deposition generally tends to decrease

enabling the catchment to recover from acidification even though this can lead to dissolved organic carbon dissolution [141].

Acidification causes local and regional degradation. The media affected by acidification are the water, sediment and soil profile. Effects can be propagated by air or surface-water transport: however, in a European context, propagation of acidity is not significant at the basin scale except in specific areas (e.g. Poland and east part of Germany[11]).

The biophysical status can be affected by acidification through increasing availability of heavy metals, aluminium and nutrients. Acidification also influences the hardness of the water and therefore the degradation of specific plant communities (see [83], this volume). The trophic status may fluctuate as soil fertility decreases. Finally, the buffering capacity is a function of the soil fertility decrease and the variation (generally the decrease) of carbonate in rivers. Therefore, the buffer capacity as well as the increase of acidity in the river may have an impact on the ecosystem [142].

2.5.9   Soil Organic Matter Reduction

Organic matter is defined as any material that is part of or originated from living organisms. It includes soil organic matter, plant residue, mulch, compost and other materials. More specifically, soil organic matter (SOM) is the total amount of organic matter present in the soil. It can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues (the active fraction) and the well-decomposed and highly stable organic material. Surface litter is generally not included as part of SOM [143, 144].

SOM is an important part of soil physical, chemical and biological fertility. With respect to biological fertility, dissolved organic carbon (DOC), which is a fraction of organic matter, is known as being an important food reservoir for the ecosystem [145–147]. Moreover, the importance of SOM as a sink for carbon storage has been recognised in climate change and CO_2 debate [148].

Loss of SOM is usually related to the loss of topsoil through erosion. Organic matter is also lost by microbial oxidation, in which soil microorganisms use organic matter as a food source during their normal metabolism. Intensive agriculture or the shift from forest plantation to cash crops can lead to a decrease in SOM levels that will affect the ability of the soils to fulfil their different economic, cultural and ecological functions. Cultivation practices affecting SOM levels include crop management and residue management (removal of straw vs. incorporation), tillage management (aeration increases mineralisation, no till can increase SOM [149]), deforestation, water abstraction/drainage of peat soils (compaction plus mineralisation) and increased intentional burning and wild fires [150].

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[11] See http://www.eurolimpacs.ucl.ac.uk/

Decline of SOM is more frequently observed in southern Europe than in northern Europe where the amount of organic matter in soils may even increase. The amount of soil where organic matter has declined below certain critical limits is poorly understood. However, at the river basin scale, organic matter decline in soil is only relevant if the decline takes place in large parts of the basin. Decline of organic matter does not have a mean to propagate in the river basin.

Reduction in SOM levels, as a pressure, may thus affect several biophysical statuses. It may interfere with the concentration of chemicals as the reduction of SOM may reduce the contaminant retention and thus increase the transfer and release. DOC is also an efficient vector of metals (like nickel), of organic pollutant transport and an oxygen carrier. In the same way, the soil buffering capacity is modified because of a decreasing filtering capacity, reduction of Cation Exchange Capacity (CEC) and reduction of carbon stocks. The reduction in SOM impacts the trophic status because of reduction of the soil fertility (need to increase the fertilisers input). The biotic status is also affected by the reduction and change in the biodiversity that is enhanced by the reduction of the soil capacity to hold water and nutrient when SOM decline. A further consequence is change in water level in the soil because the water-holding capacity decreases. Finally, morphology and pedology can be modified due to the decreasing buffering capacity and reduction of water-holding capacity when SOM decrease.

3   Summary and Recommendations

Water is a ubiquitous reactant, occurring in all internal and external geodynamical cycles in the earth. Chemical and mechanical destruction of rocks remains the primary source of soil materials and solid load transported by rivers. Climate is the most important factor affecting chemical weathering processes by controlling the rate of weathering. In the natural system (e.g. without any anthropogenic influence), rivers and aquifers play a central role, being the place of erosion, transit and deposition. The human imprint on the environment has now become so large and active that it impacts the functioning of the Earth system, allowing to create the "anthropocene" that corresponds to the current epoch in which humans and our societies have become a global geophysical force. In the anthropocene, our economic activities lead to pressures to the ecosystem which, as response, adapts, resists, modifies and transforms these pressures into stressors (i.e. the sources of risk).

Based on discussions in the RISKBASE workshops (see Sect. 1 in [151], this volume), we provided in this chapter a synthesis of soil–sediment–water connections at the catchment scale with regard to pressures that are delivered either by the natural system or the anthropogenic one. Thus, nine important pressures on river basins are evidenced: erosion, sealing, compaction, hydromorphological changes, salinisation, contamination, changes in water quantity, acidification and reduction of soil organic matter. Each pressure can affect the biophysical status, and the simultaneous presence of pressures can have cumulative or compensatory impacts on biophysical status through propagation. Eight of such biophysical statuses were identified: concentration

of chemicals, trophic status, biota status, buffering capacity, salinity, suspended matter and sediment, water level and morphology and pedology.

Furthermore, the discussions in the RISKBASE workshops resulted in some recommendations. The first recommendation is that the water and soil compartments should be investigated together, especially for contamination. Management of contamination of biophysical system must include interactive surface- and groundwater and soil management as they are interconnected. Thus, there is a need to provide consistent concepts and applicable tools to identify relevant stressors in multiply stressed environments and to better understand the interaction of different stressors (see also [83, 152], this volume). This will help water managers who are frequently confronted with a multiple stressor situation of toxic pressure, organic pollution, eutrophication, adverse hydromorphological conditions, pathogens and invasive species to develop effective programmes of measures for improving the status of aquatic systems. On the other hand, there is an urgent need to provide tools for the identification of emerging pollutants that pose a risk to aquatic ecosystems (see also [83], this volume). The very large and increasing amount of chemicals and environmental transformation products, the general tendency toward higher polarity and complexity of emerging compounds and the increasing relevance of compounds with highly specific modes of action (e.g. pharmaceuticals) demand more innovative approaches and techniques for isolation, structure elucidation and effects assessment. For this, the recent development of CSIA (compound-specific stable isotope analysis; see [153] and references therein) for organic contaminants provides valuable and sometimes unique information for deciphering their origin and studying their degradation processes in the environment.

Finally, as most management is based on knowledge acquired at a certain time, there is a need of prospective studies to meet the potential requirement of the system to adapt to futures changes (see also Section B). Protecting and managing surface and groundwater resources is a critical action for safeguarding drinking-water supplies. However, organic contaminants, which derive from industry, oil spills, improper disposal and/or leaking storage tanks, landfill leachates, household use, motor-vehicle emissions, agricultural fertilisers and pesticides, pose a threat to soil and freshwater resources. For this, the application of high-grade analytical tools (see also [83], this volume) offers a new potential way to distinguish the different sources within contamination plumes and even to estimate the different source inputs at the catchment scale. In addition, the possibility of such high-grade analytical tools for evaluating in situ transformation reactions is of fundamental importance for studying the fate of organic pollutants. This is particularly crucial for designing remediation strategies that rely on monitoring natural and/or engineered attenuation of organic contaminants in ecosystems.

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