Ecosystem Services 20 (2016) 30–36

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Geosystem services: A concept in support of sustainable development of the subsurface

C.C.D.F. Van Ree [a,b,*], P.J.H. van Beukering [a]

[a] VU University, Institute for Environmental Studies, De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands
[b] Deltares, Unit Geo-engineering, P.O. Box 177, 2600 MH Delft, The Netherlands

ARTICLE INFO

Article history:
Received 11 March 2016
Received in revised form
8 June 2016
Accepted 14 June 2016

Keywords:
Geosystem services
Ecosystem services
Subsurface
Environmental economics
Sustainability
Urbanization

ABSTRACT

Because functions of the subsurface are hidden from view, its important role in society is often taken for granted. Underground use in cities and subsurface resource extraction rapidly increase. Ensuring sustainability of the subsurface role requires balancing between exploitation and conservation, recognizing the non-renewability of abiotic resources and the long time cycles in the subsurface.

This paper introduces the **concept of geosystem services** as a framework to analyze the issue of sustainable use of the subsurface in a systemic and holistic manner. Four main elements make up the framework: geosystems, services, values, and governance. Complementarity between the concepts of geosystem and ecosystems services is highlighted by classifying geosystem services in provisioning, regulating, cultural and supporting services. Geosystem services are distinguished from ecosystem services by systematically reflecting on three cross-cutting themes (i.e. space, scale and time). Applying the concept of 'geosystem services' results in improved integration in areas where trade-offs occur between 'geosystem services' stemming from the subsurface and 'ecosystem services' at surface. The geosystem services concept helps framing a more sustainable process of urbanization, and contributes to a spatially explicit linkage of (mineral) resource production to consumption, environmental impacts on the ecosystem and (global) governance of resources and resource efficiencies.

1. Introduction

When thinking about their surroundings humans are particularly aware of the visible environment, such as landscape, air and water. The subsurface is mostly seen as a dark, useless and even threatening place. However, the subsurface is much more important than most people are aware of in providing key functions and services to fulfill the needs of societies. With the world population growing to 9.7 billion people, the urbanization rate rising to 66%, and global economy to triple in size in 2050 (United Nations Population Division, 2014, 2015; OECD, 2014), the impact and dependency on the subsurface is likely to increase significantly in the coming decades (Crutzen and Stoermer, 2000; Andrews-Speed et al., 2012).

The subsurface[1] is defined as the zone below the earth's surface, both in subterranean as well as submarine areas. On the one hand, we distinguish ecological systems, e.g. biomes at surface in the terrestrial environment and marine ecosystems, which are related to biotic communities and activity influenced by for example the availability of light, water and oxygen. The lithosphere and its geosystems, on the other hand, are associated with low biological activity due to the lack of light and often anaerobic conditions. The geosystem can be characterised by specific geological sequences, structures, landscapes and the rocks, minerals and fossils that are present. Additional distinctive features used in characterising geosystems relate to geophysical and geochemical drivers of change such as the risk of specific natural hazards (e.g. earth quakes, landslides, liquefaction, and subsidence) as well as specific anthropogenic pressures (e.g. subsurface construction, mineral extraction, contamination).

Sustainable development of the subsurface requires the framing of (mainly) abiotic resources (including 3D-space) and their importance for human well-being (e.g. Kennedy et al., 2015; Zhang et al., 2013). To date, authoritative assessments on the role of the subsurface and the related environmental trade-offs are missing. The main reason for this lacuna is the lack of a comprehensive and integrative framework to address the subsurface and its contributions to human welfare (De Mulder et al., 2012). We express

* Corresponding author at: Deltares, Unit Geo-engineering, P.O. Box 177, 2600 MH Delft, The Netherlands.
E-mail address: Derk.vanRee@deltares.nl (C.C.D.F. Van Ree).

[1] In theory the 'subsurface' includes everything between the Earths' surface and the very center of the planet, 6370 km below our feet. However, humans have never penetrated much deeper than 12 km and it is not likely that a significant number of activities will go beyond that depth over the next few decades. Oil and gas recovery are generally amongst the deeper extractions and are withdrawn from depths between 2 and 3 km on average (EIA, 2015). The deeper open cast mines reached 900 m of depth. The depth to which urban infrastructure (networks, buildings, tunnels) is constructed is generally much less and ranges from meters to tens of meters on average (De Mulder et al., 2012).

http://dx.doi.org/10.1016/j.ecoser.2016.06.004
2212-0416/

our support for operationalising the new concept of geosystem services, in conjunction with the concept of ecosystem services. By introducing this new concept, we do not only provide a better basis for understanding the complexity of biophysical and anthropocentric processes of the subsurface, we also reach out to a group of geo-based scientists and stakeholders that felt only weakly connected to the strong ecosystem services movement.

From a visibility point of view this gap between ecological processes at surface and the structure and processes in the subsurface are similar for terrestrial biomes and marine ecosystems looking at the transition between the (deep) sea and the diverse life it contains and the sub-sea bed with its importance for minerals, oil & gas and infrastructure (e.g. submarine cables, foundations of oil rigs and wind turbines) (see e.g. Armstrong et al., 2012). The lithosphere is even less accessible than the deep sea, which also contributes to data scarcity.

In this paper we identify gaps and lack of attention to the subsurface in the current treatment of ecosystem services leading to an underestimation of the value of geosystems services. Next, we explain the specific challenges in sustainable development of the subsurface. We conclude this paper by broadly describing the geosystem services concept, and providing recommendations for further development of this new approach.

2. Do current approaches sufficiently address the complexity of services from the subsurface?

The ecosystem services concept evolved from the recognition of the need to protect biodiversity and world ecosystems for human well-being (TEEB, 2010; De Groot et al., 2010). The concerns for the conservation of ecosystems e.g. led to the Natural Capital project (Daily et al., 1997, 2009) and the Millennium Ecosystem Assessment (MEA, 2005). The concept has gained wide interest and is also being embedded in global and national environmental policies (Cornell, 2011).

The ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill the needs and wants for human life. Nature includes both living nature and abiotic elements. However, abiotic products and services are excluded from the definition of ecosystem services (EEA, 2011). For example, despite being a globally leading study, the UK NEA assessment on ecosystem services excluded purely abiotic provisioning and knowledge services (UK NEA, 2011; Gray, 2013). Subsurface aspects such as geodiversity and soil erosion were omitted despite the alleged high values of soil functioning (Robinson et al., 2014). In theory, geodiversity can be included in ecosystem assessments but up to date has been largely underrepresented and undervalued (Gray, 2004, 2005, 2012; Gray et al., 2013). In fact, ample scientific knowledge on the subsurface and its function in earth's ecosystem as well as the benefits provided to human have been largely ignored in ecosystem services studies so far (Dominati et al., 2010).

Ambiguity amongst environmental economists regarding the role of abiotic services prevails. On the one hand, according to the Mapping and Assessing Ecosystem Services (MAES) framework (EU, 2013) and the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013), natural capital encompasses both abiotic and biotic components. On the other hand, for CICES however, it is specifically recommended not to take abiotic outputs from nature as an ecosystem service (Haines-Young and Potschin, 2013). Although Van der Meulen et al. (2016) address this specific recommendation, the examples they provide are all related to surficial functions and services without a systematic treatment of all services provided by the subsurface. Brouwer et al. (2013) conclude that "the exclusion of abiotic resources from assessments of the natural environment has the disadvantage of omitting potentially important economic impacts and ignores the trade-offs that may exist between biotic ecosystem services and abiotic resources such as valuable minerals." Furthermore, Brouwer et al. (2013) conclude that the lack of understanding of ecosystem functioning and biotic and abiotic service provision is one of the most challenging aspects for ecosystem services concept to be incorporated in economic accounting systems.

While the abiotic environment as a source of non-renewable resources and material flows was generally ignored in the ecosystem services concept, this dimension receives much more attention in the field of sustainable materials management of natural resources. This abiotic focus, however, is strongly related to material flow analysis such as resource productivity and trade related stocks and flows (OECD, 2012, 2015; UNEP, 2010). For example, the focus in sustainable materials management is mostly on the small tradable fraction of mining materials and not on the mining wastes which often is relatively large, e.g. 1 t of copper relates to 400 t of mining wastes (Highley et al., 2004). Also, the subsurface as a vertically separated spatial compartment of the ecosystem is excluded from the natural resources analysis. Furthermore, authoritative multidisciplinary assessments on sustainable use of mineral, fossil and other abiotic resources such as fluids and gases are lacking, making sustainable materials management of natural resources unfit for capturing the total value of geosystem services (UNEP, 2010, 2011b).

3. What is special about sustainable development of the subsurface?

Illustrating the specific role of the subsurface in supporting natural capital of the global ecosystem, Fig. 1 distinguishes two distinct components: ecosystem capital and geosystem capital. The combination of subsoil asset and abiotic flows is considered to be geosystem capital. The ecosystem capital is related to the capital present in biomes and marine ecosystems. The arrows represent how human interventions utilize natural capital, in different ways. Arrow 1 symbolizes activities that depend on ecosystem capital such as agriculture and fisheries. Arrow 2 represents activities that rely on geosystem capital in 2D such as surface mining. Arrow 3 shows links to use of the subsurface and geosystem capital in a 3D manner such as underground infrastructure and oil drilling. Arrow 4 illustrates the mutual dependency of geosystem and ecosystem capital such as the created through variation in groundwater levels.

Looking at the System of Environmental Economic Accounting 2012 Central Framework (SEEA) land is separated from natural resources in recognition of its distinct role in the provision of space (UN, 2014a,b). When assessing sustainable landscapes, de Groot (2006) identified the carrier function as a fifth services category which included amongst other habitation and mining. This, however, has not been included in CICES. Therefore, the main question arises whether the subsurface can or should be fully integrated in the ecosystem services concept or that the challenges to be addressed are too distinct and therefore require a separate approach.

This question of selecting the most suitable approach is a challenge that can be addressed by describing the typical settings were trade-offs in the subsurface emerge. For example, the urban environment is such an important setting. Whereas the urbanization rate has risen significantly the urban land use is estimated to cover 'only' 0.35% of the earth's land surface, in relatively urbanised Europe this is 5.5% (Klein Goldewijk and Verburg, 2013; JRC, 2015). For the EU it is estimated that between 2000 and 2010