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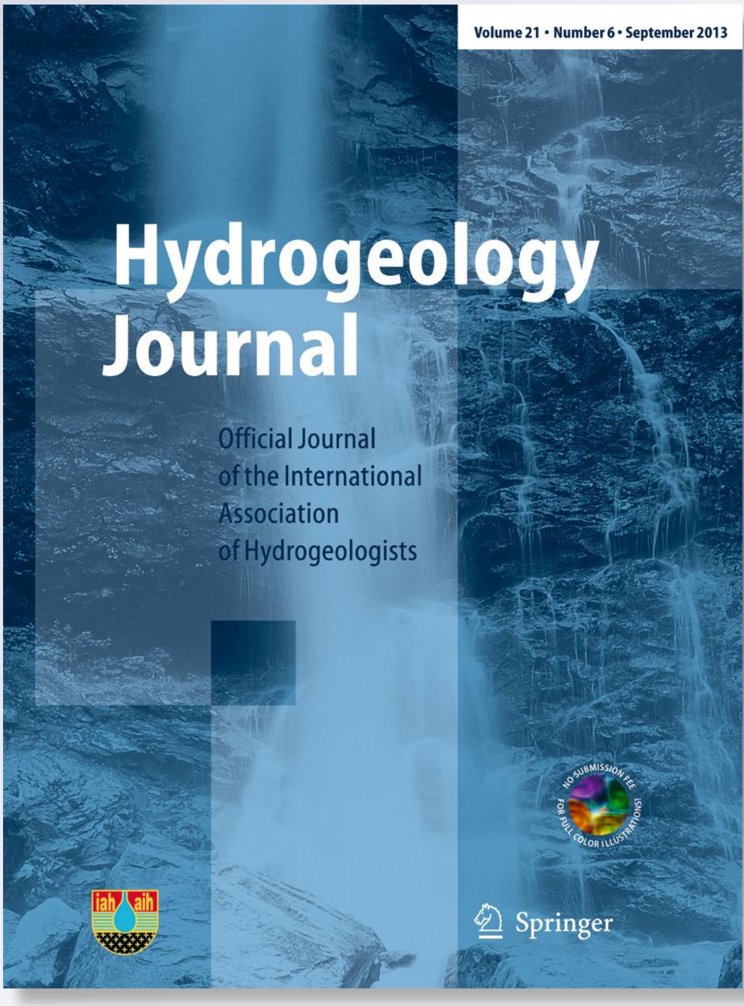

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ESSAY

Is UN Sustainable Development Goal 15 relevant to governing the intimate land-use/groundwater linkage?

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Abstract

The close link between land use and groundwater has long been recognised, but not widely translated into integrated policy and management practices. Common understanding is needed to facilitate cross-sector dialogue on governance. The process of land-use planning advocated by the United Nations Sustainable Development Goal (UN-SDG) 15 for 2030, coupled with the launch of an independent global land-use monitoring initiative known as Land Matrix, appear to provide windows of opportunity for hydrogeologists to make specific proposals for the inclusion of groundwater protection needs in national land-use plans and the consideration of groundwater sustainability threats from major land deals and contracts. Ignoring the groundwater dimension in land-use management can result in high long-run costs for drinking-water supply and aquatic ecosystems. Thus, coordinated governance based on a coherent set of land-use sustainability criteria, aimed at enhancing both the food and groundwater harvest, is crucial for the future.

Keywords Groundwater governance · Groundwater protection · Land-use management · UN-SDGs for 2030

Why do land–groundwater interactions matter?

The scale of land-use change is huge

Globally over the past 250 years more than half the ice-free land has been directly modified by human activity, mainly by conversion of native forest to arable land (70%) and pasture land (30%; Meiyappan and Jain 2012). There are now about 1,500 Mha under arable cultivation, of which about 20% are irrigated. These changes can be attributed to growth in population and food demand, but it is not a simple relationship. Up to about 1950, the rate of conversion was higher than that of population growth, and occurred mainly in Europe, North America and Asia. However, latterly, the conversion rate slowed, with most deforestation now occurring in tropical latitudes of America and Asia. Since 1960, global population has increased by 230% and food demand by 300%, yet the total agricultural land area has only expanded by 10%, with increased food production coming mainly from crop intensification and improved yields (FAO-UN 2011).

Thus, the pathways of land-use change are complex, and shaped by the interaction of various economic, political, technological, and sociological factors at different scales. Today, the globalisation of commodity markets has become the main driver of change, with certain national and local factors attenuating or amplifying their effects (Meyfroidt et al. 2013). Global forces influence both the land-use choices of millions of small producers, and international investors (driven by opportunities in commodity markets) are developing large-scale agricultural projects in less-developed countries. According to estimates by Land Matrix (an independent global land-use monitoring initiative), they have targeted at least 36 Mha since 2000, and a large proportion of major land acquisitions also entail preferential and/or unregulated access to freshwater, and thus may be termed 'water grabs' (Woodhouse 2012).

Land use and groundwater are intimately related

Most groundwater originates as excess rainfall infiltrating the land surface; thus, land use has a major influence on both groundwater quality and recharge. Every land-use practice has a 'water resource footprint', and may result in diffuse

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groundwater pollution. Similarly, land-use practices can influence groundwater recharge rates considerably, especially under more arid conditions. However, given the large storage capacity of most aquifer systems, groundwater response to land-use change will usually be gradual, but also long-lived and costly to remediate (IAH 2016).

Some of the more significant changes for underlying groundwater include clearing natural vegetation, converting pasture to arable land, extending irrigated agriculture, intensifying dryland and irrigated agriculture, introducing biofuel cropping, and reforestation and afforestation with commercial woodland (Foster and Cherlet 2014). However, extending irrigated agriculture using surface water has the greatest impact—significantly increasing groundwater recharge but degrading its quality.

Globally there is a need to increase production of staple grains (such as maize, rice, and wheat), whose yields are generally only 30–50% of those in 'more advanced' agriculture, but concerns are growing about its impact on groundwater recharge due to increasing consumptive water use, and excessive nutrient and/or pesticide leaching. For the intensification of vegetable and fruit cultivation, farmers tend to use precision irrigation (such as pressurised drip and micro-sprinkler systems), which markedly decreases recharge rates (Garduño and Foster 2010). In some senses, the large-scale introduction of solar panels is a welcome development, since it reduces pressure on groundwater providing that the energy generated is incorporated into the national or local grid and not used directly for powering water-well pumps.

Areas with a shallow water table are essential to sustain aquatic ecosystems which depend on groundwater discharge. Over more extensive areas, some natural terrestrial ecosystems depend on deep-rooted vegetation being able to reach the water table at depths from 2 to 15 m or more.

Water-table rise is a different phenomenon which often has very negative impacts, and can result from:

- Land-use change: for example, introducing irrigated agriculture using surface water, which increases groundwater recharge rates and leads to waterlogging and salinisation
- Climate change: for example, increase in rainfall events of exceptional intensity can result in higher water-table levels than previous maxima causing groundwater flooding

Both are very costly because they cause sharp reductions in agricultural land values and marked increases in property insurance costs.

Land and groundwater degradation can be irreversible

When natural land is taken into arable cultivation, it results in the permanent removal of soil organic matter, reducing its capacity to provide ecosystem services including the retention of nutrients and adsorption of herbicides. Land degradation is use-specific and sometimes (although not necessarily) permanent. A loss of soil ecosystem health is often associated with exhaustive agricultural production. Whilst concise definitions and reliable surveys are still lacking, globally more than 1,000 Mha of land have already been seriously degraded (Vlek et al. 2017).

Inadequate irrigation management can result in salinisation of shallow groundwater, which can have serious implications for all groundwater users, and lead to soil degradation and land infertility (Leduc et al. 2017). Globally about 5 Mha of land are lost to salinity every year, offsetting much of the gain being made in agricultural productivity elsewhere (FAO-UN 2011). Many of the causes (indiscriminate aquifer pumping, seepage from canals and fields, and inadequate drainage) are groundwater related.

Anthropogenic impacts on groundwater systems, some of which are irreversible, have increased markedly over the past 50 years as a result of radical global changes of land use in aquifer recharge zones (IAH 2016). All too commonly, groundwater resources have, in effect, been 'abandoned to chance' and 'business-as-usual' will further degrade the resource base. Sustainable land management is required to avoid such degradation and conserve soil ecosystem services, including adequate groundwater recharge. The International Association of Hydrogeologists (IAH) Strategic Overview Series (IAH-SOS) has systematically reviewed how groundwater targets can be incorporated into UN-SDG 6 (water) for 2030 (IAH 2017), but this sustainable development goal did not consider explicitly the critical role of land-use change.

How in practice can land-use management incorporate groundwater?

Instruments for coordinated governance

Integration of land-use and groundwater governance can be facilitated by a range of instruments falling under three broad headings (Table 1). Their usefulness will depend on the strengths and weaknesses of the prevailing political and legal framework, the level of stakeholder and public awareness, and of the threat to groundwater sustainability. However, it would appear unwise to put too much faith in the ability of 'agri-tech developments' to contribute consistently to groundwater conservation (Foster and Perry 2010). Indeed groundwater-fed agricultural economies are quite widely under threat from aquifer depletion (Petit et al. 2017).

Over 60 years, the European Union (EU) has accumulated valuable experience of agricultural intensification and groundwater. Today the environmental cost of excessive and/or ill-timed fertiliser and pesticide application is well recognised

Table 1 Instruments for the coordinated governance of land use and groundwater

Instrument	Applications	Limitations
National guidelines		
Best agricultural practices (BAPs)	BAPs should always incorporate groundwater conservation needs, and be effectively propagated to reduce agrochemical leaching from permeable soils whilst maximising crop production and protection	BAPs do not guarantee groundwater quality conforming with drinking-water guidelines or environmental standards where soil profiles are most vulnerable to leaching
Point-source pollution abatement	Measures for point-source pollution control (from urban conurbations, industrial complexes, transportation hubs, and military installations) are essential and should be propagated from national level to underpin action at local level	Not applicable for the control of diffuse agricultural pollution, but relevant to point-source pollution control from farm buildings and intensive livestock units
Regulatory procedures		
Statutory agency consultation	Municipal/local government departments legally required to consult (ground)water resource agency on all significant land-use changes, with the power of veto in some instances	Not generally applicable for the control of diffuse agricultural pollution
Pesticide registration requirements	Banning sale of compounds which are exceptionally mobile to, and toxic in, groundwater	Generally requires the availability of suitable substitute compounds
Local planning procedures	Groundwater protection can be incorporated into local government land-use planning zones with restrictions imposed to reduce risk of pollution	Effective and adaptable to local conditions, but requires administrative consistency and trained personnel
Participatory incentives		
Land-leasing arrangements	Water-utility compulsory purchase of their source capture zones to permit farming or recreational use under licence with specific controls (low-intensity pasture, deciduous woodland, or eco-farming)	Large initial capital outlay for full control and generally only attempted on inner parts of source capture zones
Agri-environmental stewardship	Land owners/tenant farmers encouraged to carry out agri-environmental management measures to enhance groundwater recharge, which can simultaneously counteract soil degradation and effect carbon capture	Maybe in conflict with crop productivity and monetary compensations can be difficult to negotiate and maintain

(Foster and Candela 2008). A more balanced policy of agricultural and environmental co-management for farmland has evolved. Specific legislation now exists aimed at reducing agricultural impacts on the aquatic environment from both intensive arable cropping and intensive livestock rearing, and at promoting the retention of natural forestland in view of the positive outcome for groundwater. Where recharge areas form distinct terrestrial or aquatic ecosystems, and remain sparsely populated and free from intensive agriculture, it is feasible to incorporate them into national parks, where special ecological protection will preserve groundwater.

The technical basis for delineation of different types of groundwater conservation and protection zones is now well established, with definition of the following specific land-surface zones at varying geographical scales being possible:

- Groundwater resource conservation: delineated by groundwater flow analysis and modelling to counteract aquifer depletion through imposing constraints on new water-well construction and/or reducing abstraction from existing water wells
- Groundwater salinisation control: where saline-water upconing is constrained by reducing aquifer abstraction and/or augmenting recharge, and mobilisation from depth and return by soil leaching avoided by restricting water-well depth
- Groundwater quality protection: setting priorities for land-use management, environmental audit of industrial premises, pollution control in the agricultural advisory system, groundwater quality monitoring, and public education.

Since hydrogeologic settings exhibit wide variation in their susceptibility to resource depletion and salinisation, and in vulnerability to pollution from the land surface, applying special protection in specific zones provides better socio-economic and environmental returns than treating all land equally.

Impediments to introducing land-use controls

When attempting to integrate groundwater-based zones into land-use planning and decision-making, certain impediments frequently have to be overcome:

- *Legal and institutional constraints*. Whilst land and groundwater are generally governed by separate use rights (which is sound practice as regards water-resource management), the principal institutions involved (agriculture, water resources, environmental planning, municipal government, land-use administration and water-service utilities) sometimes operate in separate 'silos' with ill-defined and poorly articulated interactions on groundwater. Institutional barriers will always exist and cannot be completely eliminated (since structural change often only rearranges them); thus, it is essential to design institutional arrangements which nurture communication and collaboration at institutional and stakeholder level.

- *Economic impacts*. A common consequence of declaring a 'groundwater resource conservation zone' is that the value of land with water-well use rights rises sharply compared to neighbouring land, often by a factor of 200–700% (Garrido et al. 2006; Garduño and Foster 2010), and the water resource administration will need to resist considerable pressure for illegal water-well drilling and corrupt use-right transactions. However, groundwater quality protection zones can have the reverse effect (lowering land values because potential crop productivity is reduced) and will require management by encouraging higher-value lower-intensity agricultural cropping.
- *Social considerations*. The dynamics of groundwater flow are such that those best placed to take action to augment, conserve or protect groundwater may not be the principal beneficiaries of their actions. Well-designed agri-environmental stewardship schemes with appropriate incentives can overcome this impediment. Nevertheless, landowners are still likely to raise objections about reduced land values, and local authorities may tend to be more interested in allowing activities that increase rateable land value and thus augment disposable municipal income.

The opportunity provided by UN-SDG Target 15.3

UN-SDG Target 15.3 expresses serious concern about the 'creeping phenomenon' of land degradation, which is reducing the capability of soil systems to provide environmental benefits, and thus the UN Commission on Sustainable Development (CSD) has proposed the need to reverse land degradation by 2030 through introducing the 'land degradation neutrality' (LDN) concept. This recognises planetary limits on the drive for increased land productivity, and government ministries are encouraged to promote natural capital resource accounting, to assess the status of their national land holdings and to develop LDN development plans.

It is believed that this mechanism provides a unique opportunity for groundwater protection considerations to be formally incorporated into national land-use planning. Hydrogeological professionals thus need to advocate that the mapping of groundwater conservation and protection zones forms a standard element in the elaboration of LDN development plans, and to consider carefully the related scale issues and land-water linkages. Moreover, the related launch of Land Matrix appears to provide an opportunity for hydrogeologists working at the provincial and national level to identify specific major land deals and agricultural production contracts that pose a significant threat to groundwater resource sustainability and/or quality.

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