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Groundwater and Sustainable Development Goals: Analysis of Interlinkages

Lisa Guppy, Paula Uyttendaele, Karen G. Villholth and Vladimir Smakhtin

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GRIPP
GROUNDWATER SOLUTIONS INITIATIVE FOR POLICY AND PRACTICE

CGIAR
RESEARCH PROGRAM ON Water, Land and Ecosystems

LED BY: IWMI International Water Management Institute

CONTENTS

EXECUTIVE SUMMARY

Groundwater represents 97% of the world's available freshwater resources and is extensively abstracted throughout the world. While abundant in a global context, it can only de developed to a certain extent without causing environmental impacts. Also, it is highly variable across the globe, and where it is heavily relied on, it is less renewable. Hence, it is critically important that this resource is managed sustainably. However, the Sustainable Development Goals (SDGs) of the 2030 Development Agenda do not, as a rule, account explicitly for the significant role that groundwater plays and will continue to play in sustainable development. This report aims to unpack and highlight this role through consistent analysis of the interlinkages between groundwater and the targets of the SDGs.

The key features of groundwater relevant to the SDGs are its use, management and sustainability. The methodology used to analyse groundwater interlinkages with SDG targets includes, first, identification of 'evidence-based' and 'logical' interlinkages. The first type of interlinkages is supported by existing data, while the second is by information and logic that needs to be drawn from existing bodies of relevant research. While only a few interlinkages may be seen at present as "evidence-based", more data are continuously emerging to make more interlinkages supported by hard-core evidence.

Subsequently, the interlinkages are classified into either 'reinforcing', 'conflicting' or 'mixed' - depending on whether achievement of a target will have predominantly positive, negative, or mixed impact on groundwater. The interlinkages are also classified into 'primary' and 'secondary', depending on how strong and direct the impacts on groundwater from achieving the targets may be. The report presents a summary of key interlinkages, and subsequently provides the narrative of all 'primary' ones.

The analysis suggests that more than half of interlinkages are 'reinforcing', while only a few are 'conflicting'. From a policy perspective i) *conflicting* interlinkages are the most critical and difficult ones to manage, and ii) it is important to draw synergies between SDG initiatives and groundwater to allow *reinforcing* interlinkages to materialise. Nearly a third of all identified interlinkages were classified as '*mixed*'. This means that when target activities are planned, careful consideration must be given to possible impacts on groundwater to avoid unintended negative outcomes that may not be evident at first. *Primary* interlinkages that constitute 43% of all may be the easiest to understand and the most important to plan for. However, there are even more *secondary* interlinkages. This means that groundwater experts need to be able to share knowledge to a range of actors involved in addressing the targets with secondary interlinkages to groundwater, and vice versa.

It is also shown that i) the importance of groundwater to sustainable development is poorly recognised and captured at the SDG target level; ii) there is a lack of globally useful, up-to-date and SDG-relevant groundwater data available, which makes it difficult to make globally, and even locally, relevant recommendations for groundwater use, management and sustainability in the SDG era, and iii) there are often poor links between targets and their indicators. This may signal that all groundwater-related and groundwater-relevant aspirations may not be translated into real, let alone, measurable action.

This report is not a comprehensive analysis and involves an element of subjectivity, associated primarily with the data and information paucity on one hand, and with the imperfection of the SDG target and indicator system itself – on another. However, even with these limitations, the report shows how significant groundwater is in sustainable development, even if the current SDG framework is implicit about this. Furthermore, it suggests a structured way to improve the visibility of groundwater in the SDG framework as it continues to develop.

Keywords: *groundwater, groundwater use, groundwater quality, groundwater management, Sustainable Development Goals (SDGs), SDG targets, SDG indicators, interlinkages*

INTRODUCTION

In 2015, the world leaders adopted the 2030 Agenda for Sustainable Development. The results' framework of the 2030 Agenda comprises 17 Sustainable Development Goals (SDGs). The SDGs are described in the 2030 Agenda as indivisible and integrated, balancing the economic, social and environmental dimensions of sustainable development (United Nations, 2015).

Water is key to sustainable development. It supports industry, agriculture and ecosystems, and is essential for human life and livelihoods. Therefore, water will serve as a foundation for the achievement of many of the SDGs, including SDG 6, the dedicated water goal: 'To ensure availability and sustainable management of water and sanitation for all'.

Groundwater represents 97% of the world's available freshwater resources. It is extensively abstracted throughout the world. During the 20th century, there was an enormous boom in well construction for urban water-supply, irrigation and industry, facilitated by advances in drilling and pump technology, geological knowledge, and support from state subsidies, especially for irrigation. Groundwater has therefore de facto become a key resource supporting human well-being and economic development. It presents a critical resource in terms of risks as well as opportunities for development in a changing world. Hence, it is obvious that any concern related to water resources in general are equally pertinent to groundwater. Importantly, due to groundwater being indirectly recognizable in the landscape while acting as the underpinning and often fall-back resource, groundwater requires dedicated and explicit attention.

However, groundwater use is often unsustainable. Groundwater supplies are diminishing in some regions, with an estimated 20% of the world's aquifers being over-exploited (Gleeson et al., 2012). Groundwater quality deterioration is also increasingly becoming evident. It is essential that these trends are reversed in order to sustain the critical role of groundwater.

Still, groundwater is inadequately referenced in the current SDG framework. Because of this, there is a risk that interlinkages of groundwater, synergistic or antagonistic, with SDGs will be missed by managers and decision makers, limiting SDG progress, or making it long-term 'unsustainable'. If such links are made more visible, there may be more cross-sector priority on improving groundwater sustainability, which could accelerate progress against many SDG targets and help minimise trade-offs and unintended, negative outcomes, while building on possible synergies.

This report aims to do exactly that – to make such links more explicit and describe their strength and direction to assist decision-makers' understanding of where and to what extent groundwater must be taken into consideration when planning and implementing SDGs.

This report also aims to contribute to improved incorporation and accounting for groundwater in the SDG framework. While it is unlikely that significant changes will be made in the near future to an already complex global SDG target and indicator framework, the review process and opportunities of such refinements are ongoing[1]. It is important to inform this process and also think beyond 2030, when an updated target and indicator system may be adopted by UN Member States.

The primary target audiences of this report are governments, ministries and other national partners responsible for implementing the 2030 Agenda and reporting on progress towards achieving the SDG targets. The report focuses on the most significant links between SDG targets and groundwater – those that are likely to have an impact on planning, implementation and decision-making at different administrative levels. It is, however, not a comprehensive analysis of all possible links, and some that are not covered may be of importance in specific circumstances. Also, national priorities and acceptable trade-offs vary between countries. Countries therefore will need to make similar analyses for their specific national settings and priorities.

METHODOLOGY

The methodology used to analyse groundwater interlinkages with SDG targets[2] builds, to some extent, on i) the UN-Water (2016) analysis of links between SDG 6 and other SDGs, ii) the International Association of Hydrogeologists' (IAH) Strategic Overview Series (IAH, 2015, 2016, 2017), which describes the role of groundwater in several sectors and the interlinkages between groundwater and SDG 6, and iii) the International Groundwater Resources Assessment Centre (IGRAC) position papers and brief on groundwater and SDGs[3]. However, the methodology differs in scope and approach.

First, each SDG target was considered, and the targets that were interlinked to 'groundwater use', 'groundwater management' and/or 'groundwater sustainability' were counted. Targets were counted as having a groundwater

[1] https://unstats.un.org/sdgs/iaeg-sdgs/
[2] https://unstats.un.org/sdgs/metadata/
[3] https://www.un-igrac.org/news/igrac-brief-groundwater-sustainable-development-goals-available-online

interlinkage if: i) the target or its indicators' formulation used the words 'groundwater' or 'aquifer', or similar terms, explicitly, or ii) at a global level, an interlinkage between the target theme and groundwater was either "evidence-based" or "logically based".

"*Evidence-based*" interlinkage would mean that there are global data or evidence available that support the interlinkage. As an example, in some regions of the world, a high proportion of irrigated agriculture is groundwater-dependent, and that proportion is estimated in more than one global - or regional-level database. Hence, the link between groundwater and *sustainable food production systems and …resilient agricultural practices that increase productivity…* [SDG target 2.4] can be said to be evidence-based. Three key databases may be used to support this analysis: *Aquastat*[4] from the Food and Agriculture Organization (FAO); *GEMStat*[5] from the GEMS/Water Programme under UN Environment; and *GGIS*[6] from IGRAC. Other useful global databases for groundwater-related information, even though not focusing only on groundwater, include JMP[7], IB-NET[8] and EAWAG (German acronym for Swiss Federal Institute of Aquatic Science and Technology)[9].

"*Logically based*" interlinkage would mean that there are no robust, global level data available to inform the interlinkage, but the relation is widely recognised in practice and in published literature from more than one region of the world. The report then provides qualitative reasoning drawn from research. For example, it is logical to assume that *the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services* [SDG target 15.1] is interlinked to groundwater resources when ecosystems are groundwater-dependent. Even though there is a current lack of global systematic data on the extent, status and importance of groundwater-dependent ecosystems, relevant literature exists and is growing.

It should be noted, however, that all global datasets on groundwater resources and hydrogeological conditions that are currently available, though central to understanding groundwater conditions globally, may not be considered adequate in the context of assessing progress against SDG targets; nor can they be considered to present a reliable interpretation of groundwater status and trends. The data available in the mentioned databases often have gaps (even if the intention is for global coverage); may be poorly classified (with respect to groundwater), or heterogeneous, particularly in terms of type of information and temporal coverage. At the same time, there are multiple and continuous efforts to complement and compensate for the lack of groundwater-related data, including global remote sensing techniques like GRACE (e.g. Tapley *et al.*, 2004) and hydro-economic and global scale models (e.g. Wada *et al.*, 2016). Therefore, the distinction between these two types of interlinkages is dynamic and diminishing.

Subsequently, each SDG target that had an identified interlinkage to groundwater was evaluated to identify whether the indicators under the target had interlinkages to groundwater as well. Although this report focused on the target level, this 'indicator scan' was carried out to give an additional, semi-quantitative representation of how strongly groundwater was interlinked with a target. Further analysis identified what type of interlinkage was present: either i) reinforcing, ii) conflicting or iii) mixed.

- *Reinforcing* - the achievement of a target will improve groundwater parameters (use, management, sustainability). For example, decoupling economic growth from environmental degradation [SDG target 8.4] should lead to positive groundwater outcomes. This category also includes interlinkages that the UN-Water (2016) described as 'interdependent' – where positive groundwater parameters must be achieved in order to achieve the target. For example, good groundwater management is needed to achieve the protection and restoration of water-related ecosystems [SDG targets 6.6 and 15.1]. These two categories ('reinforcing' and 'interdependent') were merged in this report as the differences between them were either difficult to unpack at the global scale, or too subtle.
- *Conflicting* - if linkages are not understood and managed, conflicts may arise. For example, ensuring water for all [SDG target 6.1] could have a negative impact on groundwater resources depending on how policies are designed and implemented. This also included the category that the UN-Water (2016) report described as 'constraining' – when groundwater concerns may restrict the ways in which a target can be achieved. For example, ensuring

[4] http://www.fao.org/nr/water/aquastat/main/index.stm: Provides data, at country level, on groundwater availability, exploitable total groundwater, withdrawal by economic sectors, area equipped for irrigation by groundwater, and by mixed surface and groundwater, etc.
[5] http://statistics.gemstat.org/gems.php; Provides data on water quality parameters (fluoride, arsenic, etc.) at station, country and river basin level.
[6] https://www.un-igrac.org/global-groundwater-information-system-ggis. Provides delineation of transboundary aquifers, and details on some 200 aquifers with information on recharge, depletion, natural quality, water use by sectors, governance, etc.
[7] https://washdata.org/data. Joint Monitoring Programme for Water Supply and Sanitation and Hygiene (JMP) – a collaboration between UNICEF and the WHO - the primary source of statistical data (by country) on SDG targets 6.1 and 6.2. This is key for groundwater information, as the JMP categorises water sources.
[8] https://www.ib-net.org/. Provides water and sanitation utilities performance data, by country.
[9] https://www.eawag.ch/en/research/human-welfare/drinkingwater/gap/

universal access to affordable, reliable and modern energy [SDG target 7.1] needs to be achieved in such a way as to not jeopardise groundwater quality or the sustainable management of groundwater. These two categories ('conflicting' and 'constraining') were merged in this report as the differences between them were either difficult to unpack at the global scale, or too subtle.

- *Mixed* - some targets may have more than one of the above characteristics depending on contextual circumstances, so a target that is reinforcing in one situation may be constraining or conflicting in another. For example, while improving groundwater quality can support the reduction of poverty [SDG targets 1.1, 1.2, 1.4], water supply infrastructure development aimed at reducing poverty (implicit in SDG target 1.4) could have a negative impact on groundwater quality if proper policies are not in place.

Generally, the aspirations associated with economic development may indicate some degree of conflicting interlinkage; aspirations focused on environmental protection are likely to have reinforcing interlinkage, while a mixed relationship could be associated with other aspirations. Yet, this picture is normally more complex as it depends on how groundwater is influenced by the measures implemented to achieve particular targets.
The final step in the analysis was to identify what degree of interlinkage existed – i.e. whether it was a 'primary' or 'secondary' interlinkage.

- *Primary* - groundwater and the theme of the target connect directly. For example, SDG target 2.3 – "*double the agricultural productivity and the incomes of small-scale food producers…*" - will directly impact the use of groundwater in many parts of the globe where agriculture depends on irrigation from groundwater resources. For most practical purposes, primary interlinkages are those that should be considered first.
- *Secondary* - groundwater and the theme of the target do not link directly, but groundwater contributes in some way to the target theme. For example, SDG target 3.1 aims to *reduce the global maternal mortality ratio to less than 70 per 100,000 live births*. It is impossible to say that without groundwater resources this target cannot be achieved. Yet, in areas that draw municipal water from groundwater resources, improvements in groundwater management could ensure that hospitals and health centres have sufficient and clean water to improve hygiene standards, offer better sanitation services and ensure safe drinking water for mothers and infants.

Interlinkages were also classified as *secondary* if the target appeared to be linked to groundwater, but all of the indicators of that target were not. The relationship between many targets and indicators is not simple, and most of identified targets had indicators that did not have an interlinkage to groundwater, even though the target did interlink. For example, SDG target 9.1 is: "*Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.*" This wording could indicate a primary interlinkage if the infrastructure referred to was groundwater pumping, for example. However, both the indicators under SDG target 9.1 refer to transport infrastructure, so the interlinkage was deemed to be secondary.

There is a total of 169 SDG targets, including 43 means of implementation (MoI) targets, which are indicated by a letter after a goal number (for example, 6.a and 6.b). An MoI is defined as 'the interdependent mix of financial resources, technology development and transfer, capacity-building, inclusive and equitable globalisation and trade, regional integration, as well as the creation of a national enabling environment required to implement the new sustainable development agenda' (United Nations Technical Support Team, 2014). The aim of MoI targets is to implement the core, or 'operational' targets, and it was concluded that linking core targets to groundwater and then also attempting to link MoI targets to groundwater does not make logical sense. Consequently, only 126 core targets were included in the analysis.

OVERVIEW OF GROUNDWATER INTERLINKAGES WITH SDG TARGETS

Only one SDG target (6.6) was found to have an explicit reference to groundwater in target wording: "*By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes*". None of the indicators include groundwater-related terms in their wording. The terms 'groundwater' or 'aquifer' do appear explicitly in detailed methodologies of some indicators under SDG 6 targets: e.g. indicator 6.4.2 (water stress), and 6.5.2 (transboundary cooperation). However, searching all indicator methodologies for groundwater-related terms was beyond the scope of this report.

Only two SDG targets (2.1 and 6.5) may be seen, strictly speaking, as being "evidence -based", while all other interlinkages are "logically based". However, as mentioned above, there is more data and evidence continuously emerging to make more interlinkages supported by hard-core data / evidence.

In total, 53 SDG core targets (42% of all core targets) were found to have a link to the theme of groundwater. Figure 1 summarises the proportion of identified groundwater-related targets for each SDG. It shows that all targets under SDG 6 (clean water and sanitation), SDG 12 (responsible production and consumption), and SDG 13 (climate action) were identified as having interlinkages to groundwater. Three goals – SDG 14 (sustainable use of oceans, seas and marine resources), SDG 16 (just, peaceful and inclusive societies), and SDG 17 (global partnership for sustainable development) were considered as having no linkages to groundwater at target (or indicator) level. However, looking beyond the current discrete and rigid SDG framework, there are possible links to groundwater in these SDGs. Groundwater discharge to coastal areas may have implications for marine water quality and quantity and submarine transboundary aquifers (SDG 14); equitable access to groundwater may be a promotor of piece (SDG 16); and there is a definite need for global partnerships on groundwater management (SDG 17).

A subsequent review of indicators for all of the 53 identified core targets suggests that in almost all cases, there is no or poor connection between a target and its indicators in the context of groundwater. Even if the target, as an aspiration, has a link to groundwater, the indicators chosen to measure that target, as a rule, do not have such links.

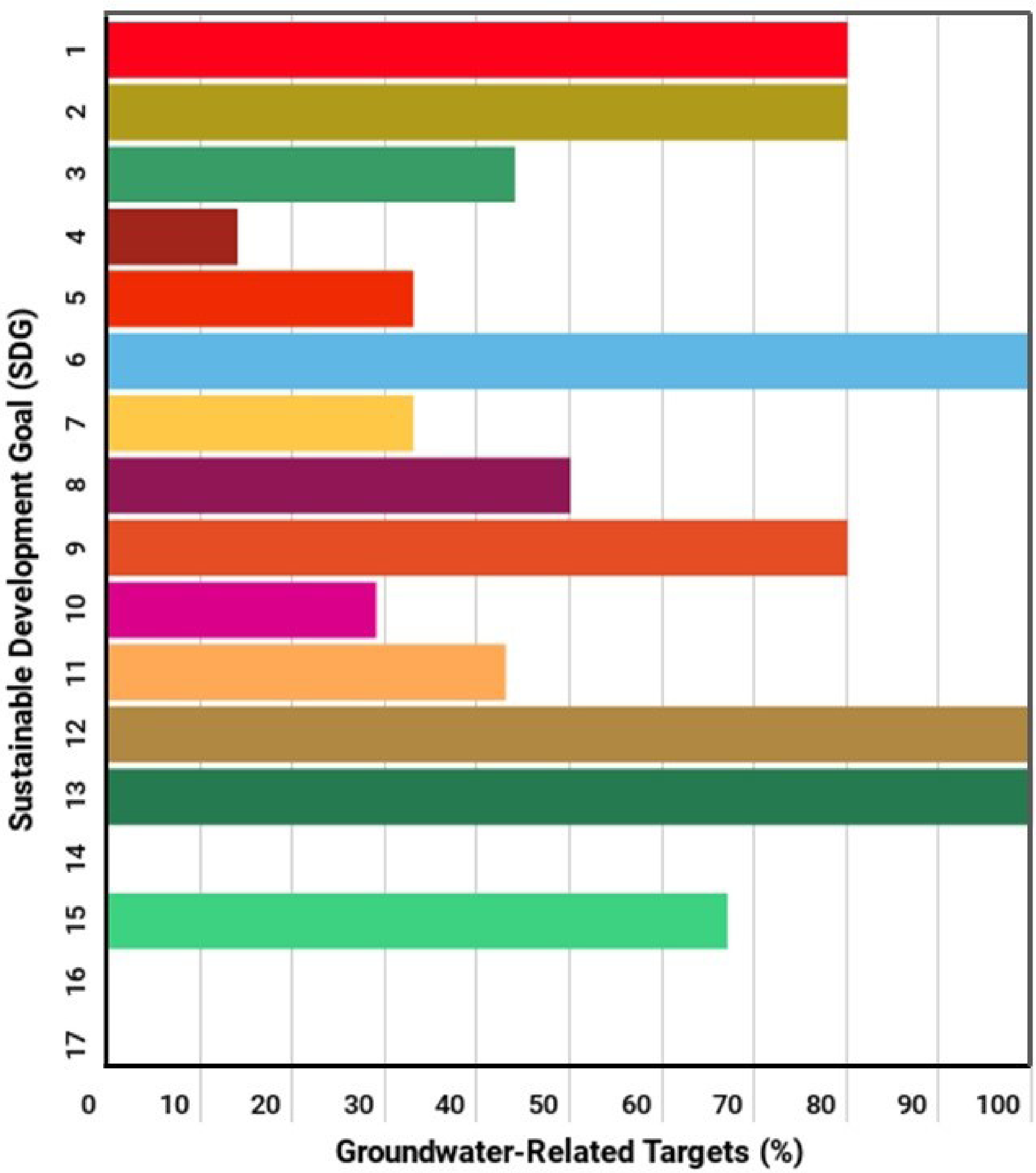

Figure 1. Percentage of groundwater-related targets per SDG

The characterisation of the 53 targets that were seen as having explicit or thematic interlinkage to groundwater is summarised in Table 1. The 'Target theme' column gives an abbreviated version of the target wording. Data in Table 1 shows that only a few (3) interlinkages are '*conflicting*', while more than 50% of interlinkages (34) are '*reinforcing*'. Close to a third of all identified interlinkages (16) were classified as '*mixed*'. In terms of SDG implementation, the types of interlinkages imply the following:

- it is important to draw synergies between SDG initiatives and groundwater in order to allow *reinforcing interlinkages* to materialise
- *conflicting* interlinkages are the most critical and difficult to manage and should take priority in order to avoid negative development outcomes in the race for positive singular goals
- *mixed* interlinkages may prove to be the most complex to deal with. These interlinkages often present contexts where a comprehensive understanding of groundwater characteristics, trends, management options and potential social, economic and environmental impacts is required in order to build on synergies and avoid negative outcomes.

Data in Table 1 further suggest that 43% of all targets (23) listed have been categorised as having a *primary* interlinkage to groundwater. It is logical to consider primary interlinkages as of higher policy priority, and hence the subsequent analysis is focusing only on these. However, there are even more secondary interlinkages (30 or 57%), meaning that groundwater experts need to be able to share knowledge to a range of actors involved in addressing the targets with secondary interlinkages to groundwater as well.

PRIMARY INTERLINKAGES EVALUATION

The targets in Table 1 that have been classified as having a primary interlinkage to groundwater are presented in three sections: first are primary, reinforcing interlinkages; next are primary conflicting interlinkages; and last are primary mixed interlinkages (Figure 2). Where it made sense, the interlinkages between a group of similar SDG targets and groundwater were analysed in a lumped form, as opposed to a standalone SDG target.

Reinforcing interlinkages

When planning and implementing work to address targets that have primary and reinforcing interlinkages with groundwater, synergies could mean that SDG success could be accelerated by leveraging positive opportunities. Sixteen targets have been identified in this category as shown in Table 1 and Figure 2.

1.5 *By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters*

2.4 *By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality*

13.1 *Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries*

These three targets are similar in their linkages with groundwater through the common denominator of 'resilience'. Potential interlinkages between the impacts of climate change, extreme events and disasters on one hand, and groundwater on another, are numerous.

Firstly, while few global studies exist on the impacts of climate change on groundwater storage (Döll and Flörke, 2005), it is generally accepted that the estimates related to such impacts, and critically - on renewability of groundwater, are still associated with large uncertainty (Taylor *et al.*, 2012). Both physical and chemical properties of groundwater may be affected (Kløve *et al.*, 2014). In shallow aquifers, groundwater temperatures may increase due to increasing air temperatures. In arid and semi-arid areas, increased evapotranspiration may lead to groundwater salinization.

Secondly, whilst groundwater storage is potentially vulnerable to climate-related hazards (like floods and droughts) that are intensifying globally, surface waters are much more susceptible to negative impacts. Hence, groundwater is a key resource for vulnerable populations experiencing surface water shortages and/or quality degradation during and in the aftermath of disasters (Villholth, 2009). The increasing variability and unreliability of surface water resources entail larger demand for groundwater, which will impact groundwater availability indirectly (Treidel *et al.*, 2012). Quality-wise, groundwater could also be impacted indirectly by climate change, e.g. through shifts in use of sanitation (McGill et al., 2018). Solutions where various water sources are used and managed conjunctively hold promise in terms of enhancing resilience towards droughts and water scarcity (Evans *et al.*, 2012). Aquifer-based solutions to water scarcity can also increase resilience to water-related disasters – floods and droughts - and progressive climate change and improve overall water security and agricultural productivity on a local or river basin scale (GRIPP, 2018; WWAP, 2018; Pavelic *et al.*, 2012). It is

Table 1. A summary of interlinkages between groundwater and SDG targets

SDG target	Target theme	Type of interlinkage	Degree of interlinkage
1.1	Eradicate extreme poverty	Mixed	Secondary
1.2	Reduce poverty	Mixed	Secondary
1.4	Access to basic services	Mixed	Primary
1.5	Resilience to extremes and disasters	Reinforcing	Primary
2.1	End hunger	Conflicting	Primary
2.2	End malnutrition	Reinforcing	Secondary
2.3	Double agricultural productivity	Conflicting	Primary
2.4	Sustainable agriculture	Reinforcing	Primary
3.1	Reduced maternal mortality	Reinforcing	Secondary
3.2	Reduced child mortality	Reinforcing	Secondary
3.3	Reduced water borne diseases	Reinforcing	Secondary
3.9	Reduced mortality from pollution	Reinforcing	Secondary
4.1	Equitable education	Reinforcing	Secondary
5.4	Domestic work	Mixed	Secondary
5.5	Women in decision making	Mixed	Secondary
6.1	Drinking water	Mixed	Primary
6.2	Sanitation and hygiene	Reinforcing	Primary
6.3	Improved water quality	Reinforcing	Primary
6.4	Water use efficiency	Reinforcing	Primary
6.5	Transboundary cooperation	Reinforcing	Primary
6.6	Ecosystems and water	Reinforcing	Primary
7.1	Access to energy	Conflicting	Primary
8.1	GDP growth	Mixed	Secondary
8.2	Productivity through innovation	Mixed	Secondary
8.3	Job creation	Mixed	Secondary
8.4	Resource efficiency in production	Reinforcing	Primary
8.5	Full employment	Mixed	Secondary
9.1	Resilient infrastructure	Conflicting	Secondary
9.2	Sustainable industrialization	Conflicting	Secondary
9.4	Clean technologies	Reinforcing	Secondary
9.5	Enhanced scientific research	Reinforcing	Secondary
10.1	Income growth	Mixed	Secondary
10.7	Migration and mobility	Mixed	Secondary
11.1	Safe and affordable housing	Mixed	Primary
11.3	Urbanization planning	Reinforcing	Primary
11.6	Environmental impact of cities	Reinforcing	Primary
12.1	Sustainable consumption	Reinforcing	Secondary
12.2	Sustainable natural resources	Reinforcing	Primary
12.3	Reduced food loss	Reinforcing	Secondary
12.4	Management of chemicals and wastes	Reinforcing	Primary
12.5	Reduced waste generation	Reinforcing	Secondary
12.6	Sustainable large companies	Reinforcing	Secondary
12.7	Sustainable procurement plans	Reinforcing	Secondary
12.8	Awareness for sustainable development	Reinforcing	Secondary
13.1	Resilience and adaptive capacity	Reinforcing	Primary
13.2	Climate change policy	Reinforcing	Secondary
13.3	Climate change awareness	Reinforcing	Secondary
15.1	Terrestrial ecosystems	Reinforcing	Primary
15.2	Afforestation and reforestation	Mixed	Primary
15.3	Combat desertification	Reinforcing	Secondary
15.4	Mountain ecosystems	Reinforcing	Primary
15.8	Invasive species	Reinforcing	Primary
15.9	Ecosystems in policies	Reinforcing	Secondary

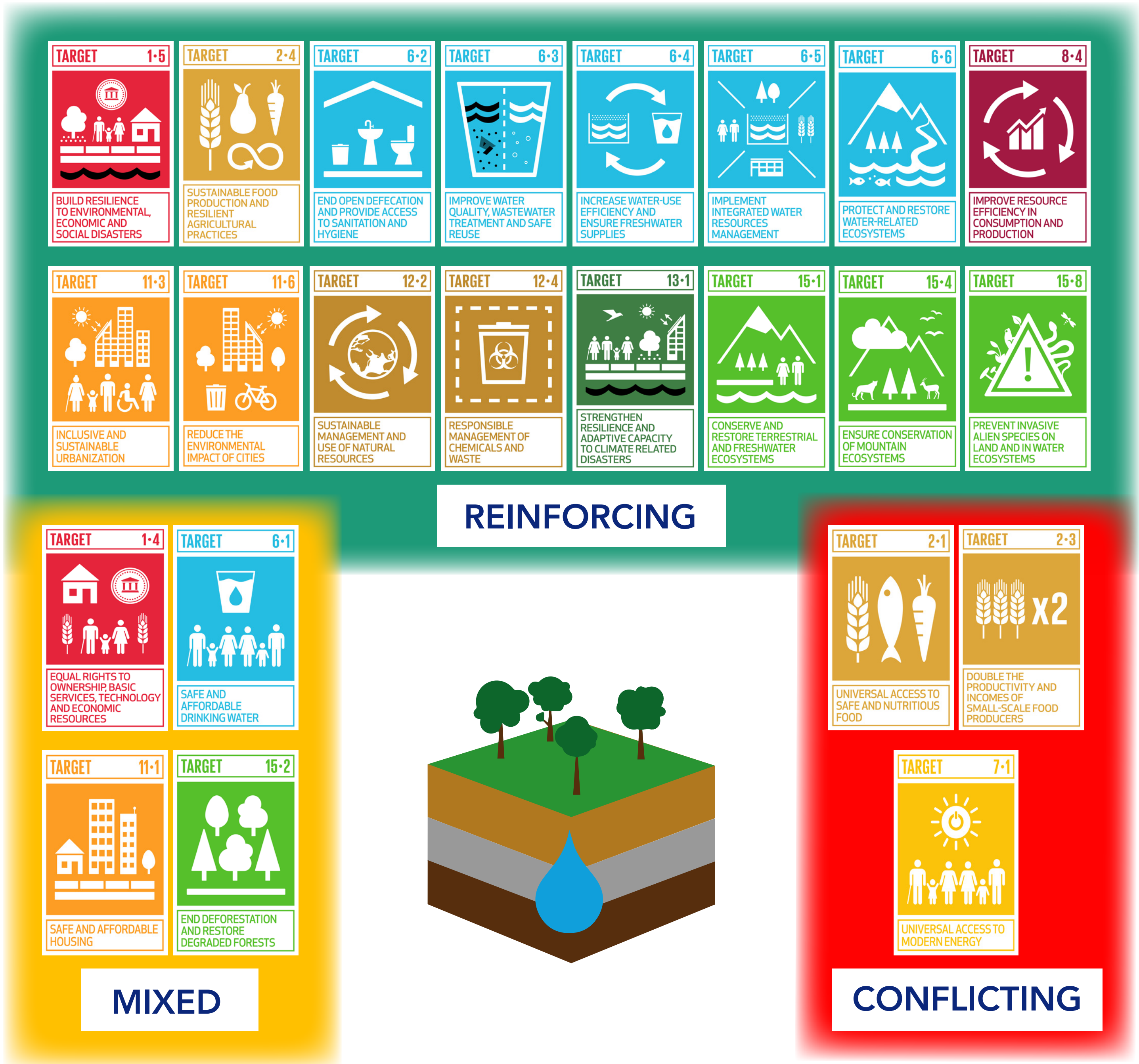

Figure 2. Categories of primary interlinkages between groundwater and SDG targets. (Source of icons: https://www.globalgoals.org/resources)

critical that groundwater resources and their services are managed and protected in order to sustain the resilience of increasing populations in the face of climatic and socio-economic change.

6.2 *By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations*

Ending open defecation and increasing safely managed sanitation is critical to human health as well as groundwater quality. Faecal contamination is at the root of many waterborne diseases. However, prevalent solutions, like pit latrines, are often poorly constructed or managed, leading to contamination of groundwater. Countries where pit latrine use is prevalent also tend to have high rates of groundwater use (Tillett, 2013), typically in rural or peri-urban areas indicating the close linkage between sanitation and groundwater. The poor design and construction of wells, bores and springheads can also mean a risk of faecal groundwater contamination from humans or animals. Hence, it is critical to develop water and sanitation technologies, as well as waste handling and recycling of waste with risk to groundwater in mind. This will synergistically protect groundwater and human health.

6.3 *By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*

12.4 *By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment*

There are many pollutants that negatively impact groundwater, including nitrate and pesticides from agriculture, arsenic from inherent sediment and aquifer sources, and syntheticorganic compounds including so-called 'emerging' contaminants from a host of sources, including domestic and industrial wastewater and solid waste.

Although groundwater is perceived to be, on the whole, less vulnerable to pollution than surface water, this is not true in many contexts. The generally slow groundwater flow rates and the 'trapping' nature[10] of the aquifer itself implies that once an aquifer is polluted, it can be time-consuming to recover it naturally or prohibitively expensive and difficult to treat by available technologies. Groundwater may have inherent characteristics that support natural remediation of some contaminants, but pollution prevention is always the most cost-effective and sustainable solution. Once polluted, an aquifer may be unusable for years, decades or longer[11].

Further, the health of recharge and discharge zones will impact the status of aquifers that are actively recharging. Even fossil groundwater – which can be defined as that recharged prior to the beginning of the Holocene epoch - has been shown to be sensitive to modern pollutants (Jasechko *et al.*, 2017).

Overall, understanding the characteristics and vulnerability of local groundwater resources and prioritising targeted anti-pollution action, like informed land-use planning, proper sanitation and waste management, and protection of abstraction wells and their catchment areas will lead to reinforcing interlinkages (GW-MATE, 2002).

6.4 *By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity*

12.2 *By 2030, achieve the sustainable management and efficient use of natural resources*

Although having different focus, targets 6.4 (water) and 12.2 (consumption) overlap substantially in the aim of sustainably managing and efficiently using groundwater resources.

Agriculture accounts for approximately 70% of all freshwater use, and groundwater provides an estimated 43% of irrigation water globally (Siebert *et al.*, 2010). To meet growing food demands, irrigated area will need to expand by an estimated 17% by 2050 (Bruinsma, 2009); a large share of this increase will have to take place in developing countries. Particular focus is on Africa where only about 6% of cultivated area is currently irrigated (You *et al.*, 2010). As the largest water user, it is clear that agriculture needs to become more water-efficient.

The introduction of hi-tech irrigation systems may reduce overall water application in the fields, but also reduces return flows that recharge aquifers or contribute to downstream river flows. Hence, efforts to increase water-use efficiency in agriculture have not always led to gains in groundwater quality and quantity (FAO, 2017).

[10] An aquifer can withhold and attenuate the movement of contaminants significantly, due to sorption, filtering, by-pass flow mechanisms and other processes

[11] Pollution of Groundwater. http://www.waterencyclopedia.com/Oc-Po/Pollution-of-Groundwater.html

Furthermore, while pressurised (drip) irrigation effectively improves agricultural water productivity and reduces unit groundwater pumping cost, they may encourage farmers to irrigate larger areas of land and may result in overall increase in water consumption, rather than reduction. Therefore, action under these targets in the agricultural sector needs to be considered, not only in terms of efficiency, but also in terms of the absolute amount of groundwater withdrawn from aquifers and the risk of water scarcity it may create. Policies and targets to control acreage of irrigated crops and to cultivate less water–consuming crops are needed. To address these complexities, it is critical to assess the trade-offs, which are well-captured by the coherent set of indicators under target 6.4 on "water efficiency" and "water stress". The latter critically brings in environmental flow allocations, i.e. the concept of sustainability of water resources (including groundwater).

In other sectors – including water for domestic and industrial use – water reform can be equally complex. Between now and 2050, water demands are expected to increase by 400% from manufacturing, and by 130% from household use (OECD, 2012). It has been estimated that there may be a 40% gap between water demand and water available by 2030, which will impact groundwater resources in many regions (2030 Water Resources Group, 2009). While the industrial, and to some extent the domestic, sector generally is having more success with water-saving approaches, including recycling of water, much more can still be done in these sectors, especially in developing countries.

6.5 *By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate*

Groundwater is often taking second-stage in integrated water resources management (IWRM) and international water cooperation partly due to the inconspicuous character of the resource and its access point (wells, etc.) on the ground surface. Nevertheless, missing out on the groundwater component as part of integrated approaches will in most contexts result in suboptimal solutions in the long term. There are an estimated 592 transboundary aquifers globally (IGRAC, 2015). Transboundary aquifers, extending across two or more countries, have been increasingly recognised in international water negotiations. However, there is still a paucity in concrete rules in international water law to govern relations and cooperation around these resources (Eckstein, 2011), and resources still tend to be addressed individually and by separate regulations (Mechlem, 2016).

If groundwater is explicitly considered as part of IWRM, and transboundary aquifers become an integral component of transboundary agreements, target 6.5 may reinforce and advance groundwater sustainability substantially.

6.6 *By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.*

15.1 *By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements*

These targets are similar in terms of focus on ecosystems and interlinkages to groundwater. Humankind has become heavily dependent on groundwater abstraction for domestic, agricultural and industrial uses over the last generation (Shah et al., 2007), and groundwater depletion and degradation is an increasing and development–threatening issue in parts of the world, with implications propagating to the global level (Famiglietti, 2014). Non-renewable, or fossil, groundwater resources provide a particular challenge (Foster and Loucks, 2006). In order to achieve socially and environmentally sustainable use of groundwater, the interlinkages with ecosystems and their beneficial services to humans have to be accounted for. Benefitting from the resource for economic development needs to be weighed against the potentially negative consequences on the natural services that groundwater also provides (WLE, 2015).

Groundwater-dependent ecosystems (GDEs) (Griebler and Avramov, 2015) are ecosystems, which require access to groundwater to maintain their composition, structure and function (Kløve *et al*., 2011). Aquatic GDEs include springs, wetlands, rivers, lakes and lagoons. Coastal GDEs can include estuaries and nearshore environments. GDEs also exist internally in aquifers, e.g. in caves. Important terrestrial GDEs, often neglected, are riparian zones and semi-arid vegetation tapping groundwater. Adequate and good quality groundwater resources normally support GDEs, while GDEs are negatively impacted by worsening groundwater quality. Even moderate increases in groundwater pollution (e.g. from pesticides or nutrients), or changes in groundwater level dynamics, can impact ecosystem structure, resulting in the loss of key species or GDEs altogether (IAH, 2016).

The ecosystem services that groundwater provides to GDEs and to humans are critically important. Besides relying on GDEs, like springs and wetlands, humans also benefit from the internal ecosystem services provided by groundwater, in terms of storage and purification of water. These are increasingly taken advantage of through nature-based solutions like managed aquifer recharge (MAR) and in-situ bioremediation (GRIPP, 2018; WWAP, 2018). Achieving the ecosystem-centric targets of 6.6.

and 15.1 will require strong political will and vision to support control of abstractions, while to a larger extent relying on sustainable groundwater-based solutions.

8.4 *Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead*

Groundwater provides food and clothes for human consumption, through irrigated cultivation of food, fodder and fibre. Significant staple crops, like rice, wheat and maize, as well as cotton and 'luxury' crops, like sugar, are grown with groundwater, and increasingly through groundwater depletion (Villholth et al., 2016). In order to decouple economic growth associated with groundwater use from environmental degradation, the interlinkage between groundwater irrigation and unsustainable consumption needs to be better understood, and international thinking, awareness raising among consumers and trade regulations are needed to take these critical aspects into account based on a water footprint approach (Hoekstra *et al*., 2017).

11.3 *By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries*

11.6 *By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management*

According to the SDG 11 Synthesis Report (United Nations, 2018), there is enough evidence that the rate of urban population growth globally is unprecedented and most pronounced in developing countries. The consequences of excessive, often unplanned, urban expansion include, amongst others, increased demand for infrastructure, increased energy consumption, environmental degradation and increased cost of providing basic services per capita, including water, sanitation and drainage. This has direct relevance to groundwater. Cities that plan land use more efficiently are in a better position to provide and maintain water services at a lower cost, and to manage waste and wastewater better, thus limiting adverse impacts on groundwater availability. Many cities in developing countries, like in tropical Africa (Foster, 2017), increasingly depend on groundwater, while the capacity to plan and manage the services does not cope. Informal peri-urban settlements tend to be particularly left behind in terms of water and waste handling services. This implies local contamination of groundwater with subsequent health risks for the poorest who often rely on shallow groundwater. Self-supply, where citizens or industries get access to groundwater through own means, like wells, can alleviate lack of access. Yet, in many cases, this also creates challenges in terms of integration into municipal systems for planning, maintenance and cost-recovery. Finally, poorly managed municipal solid waste systems have severe environmental consequences in often densely populated urban informal settlement areas, where urban infrastructure and services are inadequate (UNEP, 2015). Uncollected waste obstructs urban drainage resulting in the spread of infectious diseases, and leachate generated from uncontrolled dumpsites pollutes both surface and groundwater (Adeyi and Maiolagbe, 2014).

Certain cities are prone to land subsidence under intensive groundwater pumping scenarios, like Mexico City as well as Bangkok, Singapore, Jakarta, and Ho Chi Minh City lying in old delta areas, where this gives rise to costly infrastructure and drainage problems (DELTARES, 2013). As many nuclei for megacities are located along coasts, groundwater dependence also increasingly results in saltwater intrusion (White and Kaplan, 2017; Ferguson and Gleeson, 2012).

Progress towards both these targets related to sustainable urban development will therefore have a reinforcing positive impact on groundwater quality, availability and sustainable use.

15.4 *By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development*

Mountainous areas are particularly important for the provision of freshwater. The ten largest rivers originating in the Hindu Kush Himalayas alone supply water to over 20% of the global population. About 40% of the world's irrigation is supported by flows originating from large mountain systems[12]. Although snow and glacier melt generally dominate mountain hydrology, groundwater contribution to runoff can be significant during the dry season (Andermann *et al*., 2012). Also, groundwater-dependent mountainous ecosystems, importantly springs, provide a diverse range of ecosystem services and products to humans. Preserving mountainous ecosystems will support the protection of underlying aquifers essential for maintaining these services.

[12] http://www.fao.org/fileadmin/templates/mountain_partnership/doc/POLICY_BRIEFS/SDGs_and_mountains_water_EN.pdf

15.8 *By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species*

Reductions in groundwater recharge rates, availability and quality have been attributed to the spread of invasive species, which typically have higher evapotranspiration rates than indigenous species (Chamier *et al.*, 2012; USDA, 2009; Gorgens and Van Wilgen, 2004). For example, the *Prosopis* (mesquite), *Eucalyptus globule, Acacia and Tamarix* – each of which is amongst the 100 worst invasive species listed on the global Invasive Species Database[13]- have been demonstrated to increase above-ground biomass and higher transpiration rates than native species, resulting in reduced shallow groundwater availability. This has been reported as a source of concern in e.g. South Africa, Australia and the USA.

Dzikiti *et al.* (2013) demonstrated groundwater savings of up to 70 m^3/ month per hectare of Prosopis cleared. Invasive species have also been linked to increased nutrient and pollutant concentrations in groundwater (Chamier *et al.*, 2012), with a quadrupling in groundwater salinity (to 10,000 mg/l) attributed to invasions of Tamarix chinensis in a South African area (Scott *et al.*, 2008). Whilst the degree to which invasive species influence groundwater quantity and quality is uncertain and vary significantly, measures to prevent and eradicate invasive species would likely increase available groundwater resources and prevent quality degradation in many specific contexts.

Conflicting interlinkages

When planning and implementing work to address targets that have primary and conflicting interlinkages with groundwater, groundwater must be considered at all stages in order to prevent unwanted and negative outcomes. In this evaluation, three targets have been identified: 2.1, 2.3 and 7.1. The first two relate to eradication of hunger and agricultural livelihoods and the latter to energy access.

2.1 *By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round*

2.3 *By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment*

Irrigated agriculture in many arid and semi-arid areas is based on groundwater, as groundwater enables a year-round crop production, and achievement of higher yield and more uniform crop quality. This incentivises farmers to grow high-value crops (IAH, 2015). Groundwater currently provides almost half of irrigation water globally (Siebert *et al.*, 2010), and since 1960, there has been a 300% increase in groundwater extraction for irrigation, with millions of small farmers taking advantages of low-cost pumping technology (IAH, 2015).

In less developed regions, like sub-Saharan Africa, the potential of irrigation with renewable groundwater is yet to be realised (Pavelic *et al.*, 2013; Altchenko and Villholth, 2015), but could enhance food security substantially. However, 'doubling agricultural productivity' could induce the risks of groundwater depletion, and decreasing groundwater quality through nutrient and pesticide leaching and salinization. Furthermore, intensive water use for agriculture could jeopardise other economic, social and environmental activities that draw from the same aquifer systems.

There is some evidence that poor people and vulnerable groups (especially women) experience decreased access to groundwater, and, in some cases, groundwater access patterns may exacerbate inequalities (Baguma *et al.*, 2017). Where groundwater is already heavily exploited or degraded, the smallholder production may be threatened by resource constraints or elite capture. Hence, achieving targets 2.1 and 2.3 on food security and agricultural productivity and livelihoods could imply antagonistic impacts in terms of sustaining ecosystem services from groundwater and securing equal access to water for productive use. It is critical, therefore, that the progress towards the targets 2.1 and 2.3 is coordinated with target 1.4 (basic services), 5.5 (gender) 6.1 (universal water supply), 6.3 (water quality), 6.4 (water use efficiency), and 6.6 (water-related ecosystems).

7.1 *By 2030, ensure universal access to affordable, reliable and modern energy services*

Energy supply presently accounts for approximately 52 billion cubic meters of freshwater consumption annually (Spang *et al.*, 2014), nearly 1.5% of global freshwater withdrawals. It has been estimated that by 2050, the demand for energy will almost double globally[14]. The extraction and processing of fossil fuels such as oil sand, and hydraulic fracturing for natural gas and oil, are known

[13] http://www.iucngisd.org/gisd/species.php?sc=72, Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission
[14] https://www.climategate.nl/2011/09/the-worlds-energy-supply-in-2050/

to present a risk to groundwater in terms of pollution, with potential implications for water availability, if not properly managed (Vengosh *et al.*, 2013).

On the other hand, with presently increasing use of certain types of renewable energy sources, often perceived as clean, and in particular solar energy, groundwater may be subjected to accelerated pressure from abstraction, as the tendency to move away from fossil fuels is gaining pace. Intelligent incentive structures are required to manage these trade-offs (FAO, 2018).

Energy is essential for groundwater extraction, treatment and distribution. Disruptions in energy services can have direct implications for water security in groundwater-dependent regions and irrigation schemes. Volatile energy prices can also impact the affordability of groundwater supplies (Shah *et al.*, 2012). Hence, as dependence on groundwater increases, the dependence on reliable energy also increases.

The challenges of managing the conflicting risks from achieving target 7.1 with respect to groundwater are manifold. Firstly, since, energy development, especially in rural areas is often linked to groundwater irrigation development, either by policy implication or by default, expansion of electrification or solar power access will result in acceleration of groundwater development for irrigation (Shah *et al.*, 2018). While facilitating the achievement of the goals of food security of large populations, especially in sub-Saharan Africa and parts of Asia, depletion and degradation risks of groundwater are real.

Secondly, a feedback loop to the energy sector is foreseeable as groundwater levels drop and larger energy requirements are needed to pump the same amount of groundwater. The energy-groundwater nexus is already very pertinent in parts of South Asia and China, and while there is still scope for expanding and improving energy access to enhance domestic energy use, it comes with an in-built risk to groundwater as irrigation coincidentally follows. These interlinkages need to be acknowledged and accounted for in achieving target 7.1.

Mixed interlinkages

Primary mixed interlinkages may need the most detailed consideration before implementation. Four targets have been identified in this category: 1.4 (access to basic services), 6.1 (drinking water), 11.1 (safe and affordable housing) and 15.2 (forests).

1.4 *By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance*

11.1. *By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums*

Both targets are similar in groundwater context, with the exception that 11.1 focuses on urban populations. Access to basic household services links the two targets to groundwater in two ways. First, groundwater can be a preferred source of drinking water and is a source for domestic and municipal water supply in many regions. Second, a lack of basic services such as sanitation can negatively impact groundwater quality. In densely populated areas, the lack of adequate sanitation facilities almost inevitably leads to pollution and contamination of the available water resources. Some 24% of the world's urban population currently live in slums, and by 2030, about 3 billion people will be in need of formal and adequate housing with basic services[15].

In the context of target 1.4, it is noteworthy that in many regions, despite prevalent state custodianship of water (including groundwater) (van Koppen and Schreiner, 2018), groundwater access is still tied to land tenure and control. This gives rise to inequitable access or lack of investment in livelihoods based on groundwater, due to tenure insecurity (Sugden, 2014).

Depending on groundwater characteristics, regulations on its access and the solutions implemented for basic services, interlinkages with groundwater in targets 11.1 and 1.4 can be reinforcing or conflicting in groundwater-dependent regions.

6.1 *By 2030, achieve universal and equitable access to safe and affordable drinking water for all*

Groundwater is the preferred source of drinking water worldwide. Depending on demand for supply, groundwater and aquifer characteristics, and the sustainability of groundwater management, achieving target 6.1 can have reinforcing or conflicting impacts on groundwater.

Although numbers are uncertain, it has been estimated that groundwater is the main source of domestic water for more than 2.5 billion people globally (WWAP, 2015). In some areas, groundwater dependence approaches 100% (Howard, 2015). The majority of people in rural sub-Saharan Africa, where adequate access to drinking water is relatively low, source their drinking water from groundwater. Around half of the population in

[15] https://unhabitat.org/urban-themes/water-and-sanitation-2/

sub-Saharan Africa use groundwater point sources and an additional but unknown number are served by groundwater-fed piped supplies (Baguma *et al.*, 2017).

Groundwater can naturally offer higher quality water than surface water. This is because water percolates down through a soil profile as it recharges aquifers. The profile can retain and eliminate faecal parasites, bacteria and viruses from the water. In addition, water can be stored in aquifers for long periods of time (decades to millennia), and the subsurface survival of pathogenic organisms is rarely longer than 300 days. Therefore, aquifers naturally provide the functions of water-supply filtration, storage and protection. Well-managed groundwater resources can therefore reinforce SDG 6.1 and provide a safe water source.

However, the assumption that groundwater is 'clean' has led to adverse consequences. It is estimated that at least 140 million people in 50 countries have been drinking water containing arsenic at levels above the WHO provisional guideline value of 10 ppb for many years; and nearly 50 million - in south and east Asia - have, for decades, consumed water contaminated with arsenic at levels above the previous WHO standard of 50 ppb (Ravenscroft *et al.*, 2009). Other groundwater contaminants are increasingly evident in drinking water from unprotected drinking water sources or aquifers[16].

'Safely managed drinking water services' have been defined as water that is free of faecal contamination and priority chemical contaminants, including arsenic. To ensure this is rigorously adhered to, assessing groundwater 'safety' must be a priority and will require protocols and practices for assessing access point construction integrity, groundwater quality testing and protection, and yield security in droughts (IAH, 2017; WHO and UNICEF, 2017).

Over-exploitation of groundwater could be a risk to water supply in many groundwater-dependent areas, both from a quantity and quality perspective. Often, demand for domestic supply is relatively small, and threats to drinking water are mostly related to water quality degradation (e.g. pathogenic microorganisms, arsenic, waste-related contaminants), or come from intensive exploitation for nearby irrigation or industries. When groundwater is not safe to drink and is overused, progress towards target 6.1 may be compromised. Achieving other "water-related" targets, such as 6.3 (water quality) and 6.4 (water efficiency), should ensure sustainability and good quality of the resource base for drinking water.

15.2 *By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally*

The sustainable management of forests must include sustainable management of groundwater in forest areas. In this sense, the interlinkage between groundwater and target 15.2 is reinforcing. However, changes in forest cover and quality can have complex effects on groundwater systems and can lead to different impacts in different contexts.

A key challenge is how to optimise the trade-offs between water consumption, water yield in terms of runoff from forested areas, forest products and the wider range of water-related ecosystem services provided by forests (FAO, 2014). Effect of afforestation or deforestation on groundwater recharge rates is a topic of continuous scientific debate (Ellison *et al.*, 2017; Farley et al., 2005). Forests often have a dampening impact on runoff and increase of infiltration rates, but also larger interception and evaporation losses.

The effect of forests on groundwater quality is also context-specific. Precipitation filtered through forest catchments is commonly thought to deliver 'purified' water (Neary *et al.*, 2009) and can support payment for ecosystem services[17]. However, groundwater quality may be negatively affected by enhanced acidification and nitrification (Allen and Chapman, 2001).

Finally, climate change is potentially altering the natural cover of forests and their role in the water cycle and influencing the availability of water resources in many parts of the world. These changes, as well as efforts to conserve or expand forest cover to reduce greenhouse gas emissions, are at present difficult to measure, predict and respond to. Hence, achieving SDG target 15.2 requires good understanding of potential and actual impacts on groundwater from changes in forests.

CONCLUSIONS AND RECOMMENDATIONS

In the coming decades, sustainable utilization of groundwater resources will be critical to achieving sustainable development at large, and the SDGs of UN Agenda 2030 in particular. However, the importance of groundwater to sustainable development is currently poorly captured in SDG targets and, as was shown in this report, there is an overall lack of groundwater recognition at target level. Only one target (target 6.6 on water-related ecosystems) references groundwater explicitly in target wording. Fifty-three (53) targets

[16] http://www.worldwatch.org/node/481
[17] https://globalforestatlas.yale.edu/conservation/finance-forest-conservation-payment-ecosystem-services

have interlinkages with groundwater use, management and/or sustainability, even though groundwater was not made explicit in the target. Hence, groundwater is largely invisible in the existing SDG domain. The report attempted to unpack the links between the SDG targets of the 2030 Development Agenda and groundwater, in order to assist decision-makers' understanding to what extent groundwater must be taken into consideration when planning and implementing SDGs. This assessment suggests that:

- More than 50% of all interlinkages between SDG targets and groundwater are reinforcing; and only 3 interlinkages are conflicting. It is therefore important to draw synergies between SDG initiatives and groundwater so that reinforcing interlinkages allow leveraged results. For conflicting interlinkages, smart solutions and collaborative approaches will be required, and long-term engagement will be necessary.
- Nearly a third of all identified interlinkages were classified as 'mixed'. This means that when target activities are planned, careful consideration must be given to possible impacts on groundwater from different perspectives, in order to avoid unintended, negative outcomes.
- Primary interlinkages that constitute over 40% of all interlinkages identified may be the easiest to understand and plan for. Given the already overwhelming complexity of the SDG processes, it is recommended, for all immediate practical purposes, to focus on primary interlinkages. It can be noted, however, that this report identified even more secondary interlinkages than primary ones. This means that in some national contexts, groundwater experts need to be able to share knowledge to a wide range of actors, particularly those involved in addressing the targets classified as having secondary groundwater interlinkages. In parallel, decision makers should consult groundwater experts before action, even if linkages are not immediately apparent.

Although groundwater literature globally is substantial and growing, there is still a paucity of well-structured, globally useful, up-to-date and SDG-relevant groundwater data available. This means that making globally relevant recommendations for groundwater use, management and sustainability in the SDG era is difficult and plagued with uncertainty.

Although cognisant of the indicators and monitoring framework for the SDGs, this report focused primarily on the level of targets. Targets are normally well-formulated, but the links between targets and their indicators are often poor or simplistic. This, on one hand, could signal that all groundwater-related aspirations may not be operationalised – that is, translated to real, measurable action. This also implies that a single target can cover multiple themes and is measured by indicators that are not necessarily integrated. On the other hand, this also creates an opportunity for improvement of indicators in the future - to better match their related target. The methodology and analysis suggested in this report may help this process.

While this is not a comprehensive analysis of all possible impacts that SDG-related actions may have on groundwater, a suggested structured approach that stimulates 'groundwater-centric' thinking in the context of SDGs should be useful. It is unlikely that significant changes will be made to the already complex global SDG target and indicator framework in the nearest future. Yet, the review of this framework is a continuous process, and hence it is important to inform this process. It also important to think beyond the 2030 horizon and continuously develop evidence-based arguments for a better target and indicator system that may be adopted by UN Member States after 2030.

While the focus of this report has been global, its utility may be even more relevant within the national contexts. And the overall methodology is probably applicable to other aspects and themes of critical importance to sustainable development, that may not yet have received adequate attention in the current SDG framework.

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