Groundwater management in coastal areas through landscape scale planning: A systematic literature review

Abstract

Groundwater is one of the main resources for society and ecosystems. As part of the total water cycle and deeply connected with land use, many difficulties are present in groundwater management, especially in coastal areas. Landscape Scale Planning is an emerging approach for land use planning providing a framework for management based on evidence, given that landscapes have physical and information flows. Landscape Scale Planning embraces three dimensions: i) the spatial dimension centres on the recognition of distinct landscape units; ii) the temporal dimension entails the first use of a landscape through to its sustainable use by future generations; and iii) the modification dimension involves the anthropogenic alterations that affected and will affect the landscape and its features along the spatial and temporal dimensions. Through a systematic literature and the application of Landscape Scale Planning analytical framework, this paper seeks to analyse if groundwater management can be improved through Landscape Scale Planning. Twenty-eight selected publications were analysed focusing on (i) analyse existing evidence that can underpin groundwater management approaches that take into account the spatial, temporal and modification dimensions; and, (ii) analyse the implications of Landscape Scale Planning for groundwater management. The results show Landscape Scale Planning can be applied as an integrative framework for groundwater management. Landscape units based in many aspects such as geology, topography, cultural, and socio-economics can aid groundwater management that takes into account the different spatial and temporal characteristics of the aquifer. Furthermore, through the application of the Landscape Scale Planning analytical framework, it was identified that the need for the inclusion of the dynamical aspects of land use changes in the processes of groundwater management. Therefore, applying a Landscape Scale Planning approach can produce more comprehensive outcomes to improve the process of groundwater management.

1. Introduction

Groundwater is the water supply for a large part of the world's population and has a fundamental role in ecosystem health and conservation (Gorelick and Zheng, 2015). Its unrestricted use has led to overexploitation, especially when the natural recharge is incompatible with increased anthropogenic demands (Molle et al., 2018). Groundwater systems encompass the aquifer, including the flow boundaries, sink (discharges and withdrawal) and sources (recharges) (Alley et al., 2002). There is an ongoing debate about how thresholds should be determined to guide groundwater extraction (Molle et al., 2018), whilst sustaining a healthy ecological status of surrounding terrestrial ecosystems (Ross, 2016). While the primary source of recharge to aquifers is precipitation, groundwater management requires consideration of the total water cycle because this is affected by both anthropogenic pressures and landscape characteristics (Minnig et al., 2018). Hence, the concepts of groundwater recharge, availability, and sustainability are at the core of groundwater management. Jakeman et al. (2016), taking an Integrated Water Resources Management

(IWRM) perspective, suggest one of the priorities of groundwater management is balancing groundwater exploitation with demand of natural processes, as well as economic and social welfare of society. Intrinsically related to IWRM is the concept of groundwater sustainability, defined by Alley and Leake (2004 p.13) as the "development and use of groundwater in a manner that can be maintained for an infinite time without causing unacceptable environmental, economic, or social consequences".

Coastal regions are of paramount importance to the water cycle. These regions comprise many water systems such as rivers, wetlands, floodplains and estuaries, often connected by aquifers (Momtaz and Shameem, 2016). More than half of the human population and activities are concentrated in these regions (Chatton et al., 2016). Consequently, coastal regions have been strongly influenced by social and economic development which affects the sustainability of groundwater systems (Chatton et al., 2016). Generally, in highly urbanised areas, anthropogenic pressures may affect the aquifers in many ways, namely: altering the recharge due to impermeable surfaces; point source contamination due to leaks; and overexploitation due to the uncontrolled increase of extractions (Minnig et al., 2018; Tam and Nga, 2018). Other groundwater related issues challenging coastal urbanised regions include saltwater upconing, saltwater intrusion and reduction of submarine discharge to ecosystems (Michael et al., 2017; Petelet-Giraud et al., 2018). These regions are then complex landscapes that require more integrated management approaches.

Changes in the biophysical cover affects the recharge process and available groundwater for human consumption and environmental functions (Tam and Nga, 2018). While there is a connection between how land use influences and is influenced by groundwater systems, land use is generally planned and managed following anthropogenic rather than natural criteria. Thus, to achieve groundwater sustainability, groundwater management and land use planning must be integrated (Foster, 2018). Landscape Scale Planning is an emerging approach that takes a holistic view of land use planning and management. It focuses on landscapes altered by human intervention and is built upon the concepts proposed by the European Landscape Convention[1] (Council of Europe, 2000). Selman (2006) suggests landscapes comprise a multipurpose arena where different disciplines can be combined, moving beyond from a static spatial dimension to also include a temporal and a modification dimensions.

Planning at the landscape scale offers an opportunity for the integration of cross-sectoral policies using the landscape as a unit of analysis to achieving sustainable resource management (Selman, 2006). This includes making decisions based on information that takes into account competing land use interests but also their multiple functions, values and ecosystem services (Antrop and Van Eetvelde, 2017; Plieninger and Bieling, 2012; Selman, 2009). Landscape Scale Planning embraces three dimensions: i) the spatial dimension centres on the recognition of distinct landscape units, these landscape units can be defined as integrative units that have more internal resemblance than with the surrounding regions; ii) the temporal dimension entails the first use of a landscape through to its sustainable use by future generations; and iii) the modification dimension involves the anthropogenic alterations that affected and will affect the landscape and its features along the spatial and temporal dimensions (Selman, 2006). Hence, Landscape

[1] Landscape can be defined as "an area, as perceived by people, whose character is the result of the action and integration of natural and/or human factors" Council of Europe, 2000. European Landscape Convention, Report and Convention Florence, p. 8.

Scale Planning enables integrated planning for differing systems (natural, forest, agricultural, urban), their conflicts and changes that happen within them.

In addition to land use planning (Hawkins and Selman, 2002), landscape approaches have been used in environmental management (Andersen et al., 2019), and in conjunction with other approaches such as the ecosystem approach (Morrison et al., 2018). To date, not many applications of landscape approaches have been found in groundwater management. This paper investigates if the multiple dimensions involved in Landscape Scale Planning (spatial, temporal and modification) have the potential to provide the much needed data and evidence to inform groundwater management decisions (Vadiati et al., 2018) under both a total water cycle and IWRM perspectives. To this end, the paper uses a systematic literature and applies a Landscape Scale Planning analytical framework to: (i) analyse existing evidence that can underpin groundwater management approaches that take into account the spatial, temporal and modification dimensions; and, (ii) analyse the implications of Landscape Scale Planning for groundwater management.

2. Methods

Systematic review (SR) is a method for locating, appraising and summarising evidence on a given topic. It started in the Health Sciences but its application has extended to other fields due to the wide range of published articles available (Haddaway and Bilotta, 2016). While there is a raft of methods to carry out systematic reviews of literature (Haddaway and Bilotta, 2016), this paper adopts the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009) which has been applied to many investigations concerning environmental management (Baum and Bartram, 2017; Tseng et al., 2019) and spatial planning (Boulton et al., 2018; Song et al., 2018). Following the PRISMA method, the following steps were used to carry out the review: search strategy; screening and eligibility criteria; content and result analysis (Moher et al., 2009).

2.1. Search strategy

Searches using the combination of the terms "Groundwater Management" and "Landscape Scale" did not return any results. Consequently, the two concepts were further unpacked to derive other search terms, including proxies. Relative to "Groundwater management", proxy was "Groundwater Recharge". Relative to "Landscape Scale Planning" proxies were: "landscape scale", "land use planning", and "land use change". These keywords were joined in the query searches using Boolean operators ("AND", "OR"). The protocol for conducting the searches involved queries in the Web of Science (category: "Topic") and Scopus (category: "Title, abstract, and keywords") databases, in peer-review journals and book chapters, published in the English language up to December 2018. This resulted in 480 publications. Afterwards, a search among the results was conducted using the keyword "coast*" to narrow down the results to those related to coastal areas. This resulted in 55 publications. More information on the delimitation of the keywords can be found in the Supplementary Material.

2.2. Screening and eligibility criteria

The screening of search results followed three steps. Firstly, the duplicate articles or those that did not have a full-text available were removed. Secondly, a screening of the title and abstracts was carried out to remove publications unrelated to the research aim guiding the paper – that is, if the multiple dimensions involved in Landscape Scale Planning (spatial, temporal and modification) have the potential to provide data and evidence to inform groundwater management decisions under both a total water cycle and IWRM perspectives. The screening evaluated whether: (i) analysis or provision of information to groundwater management was one of the objectives of the article; and (ii) land use patterns or changes were analysed. Finally, articles that passed this first screening were then analysed for content if:

- at least one of the three Landscape Scale Planning dimensions was analysed in the paper (i.e. spatial, temporal and/or modification dimensions), and/or
- type(s) of land use covered by the paper had at least one non-natural use (urban, agricultural, forest).

2.3. Content and result analysis

In total, 28 publications passed the screening phase. These were analysed to identify the countries where the studies were developed and other general aspects such as date of publication. Publications were then classified based on: (i) which dimensions of the Landscape Scale Planning approach they were related to; (ii) what methods were used to investigate such dimensions, given that this represents the procedure used to transform raw data into information for the management process; (iii) and, how the paper can contribute to the objectives of this study. An in-depth content analysis was then carried out to investigate how spatial, temporal and modification dimensions aspects were addressed, how land use changes were considered, and methods used for these (see Table 1). Methods used by the publications were considered in the analysis to explore the extent to which they support the investigation of spatial, temporal and/or modification dimensions. Analysis results were then constrasted with the existing literature on groundwater management and landscape approaches.

Table 1 – Criteria used to classify the publications and analyse content.

Criteria	Description of the classification criteria of the publications
Country/continent	The location where the study was conducted
Spatial Dimension	Study site, catchment or hydrogeological unit
Temporal Dimension	Past, present or future analyses
Modification Dimension	Current land uses or land use changes across time (past and future)
Methods applied	The methods applied in each publication to address differing dimensions

3. Results

3.1. Overview

Among the 28 selected publications, eight were from the Americas (seven in North and one in South America), seven from Asia, six from Africa, six from Europe and three from Oceania (Figure 1). Within these, only one publication had case study areas from multiple countries. The timespan of the publications ranged from 2001 to 2018. The year with the highest number of publications was 2012. However, there was no significant trend in the number of publications per year. The spatial dimension, through its different types of boundaries, was identified in all selected papers. The modification dimension regarding current land use and land use changes was present in 23 papers and the temporal dimension in only 16. A complete list of the selected publications can be found in the Supplementary Material (Table 5). With respect to methods, the majority of papers adopted some sort of modelling, followed by an analysis of groundwater quality or quantity through chemical methods (see Table 6 at the supplementary material). Other methods included conceptual approaches, spatial analysis, multicriteria analysis, physical methods, and sensitivity analysis. 21 publications presented potential evidence to inform groundwater management based in at least one dimension of Landscape Scale Planning, while 16 showed perspectives that could lead to a better understanding of groundwater management issues. The content analysis revealed publications predominantly focused on two emerging groundwater management issues: alterations in groundwater recharge and groundwater contamination. A general overview of the connection between the Landscape Scale Planning dimensions and these issues can be found in Table 2.

Figure 1 - Location of the study cases found in the selected publications.

Table 2 – Connection between the Landscape Scale Planning dimensions and the main groundwater management issues found in the publications

Dimension	Alteration in recharge	Contamination of aquifers
Spatial	o The recharge happens in different intensities within the aquifer, this depends on the topography, location and land use (Calderon and Uhlenbrook, 2016; Guinn Garrett et al., 2012). o Hydrogeological units have uncertainties, such as spatial boundaries of or hydrogeological characteristics, that needs to be taken into account in the estimates of recharge. (Gondwe et al., 2011; Priyantha Ranjan et al., 2006).	o The contamination mainly depends on the physical aspects such as vadose zone depth, hydraulic conductivity or topography (Allouche et al., 2017; Hu et al., 2018). o Groundwater flow direction and precipitation can spread the contaminant to rivers through baseflow (Aquilina et al., 2012).
Temporal	o Temporal variability needs to be taken into account in groundwater management, because the recharge process does not happen equally throughout the year (Calderon and Uhlenbrook, 2016; Daraio, 2017). o Climate change can lead to alteration in the recharge process due to changes in precipitation pattern and evapotranspiration (Daraio, 2017; Ragab et al., 2012).	o Due to the physical characteristics of groundwater systems, contamination from agricultural land uses can take up to 25 years until it starts to be detected in the rivers (Aquilina et al., 2012). o The time required for mitigation of contaminant depend on the hydrogeological setting. Hence, it is necessary constant monitoring to understand the behaviour of different parameters (Melloul and Collin, 2003).
Modification	o Changes in land use directly affect the recharge of the aquifer altering processes of the water cycle such as evapotranspiration and infiltration (Brauman et al., 2012; Tsutsumi et al., 2009). o Urban land uses can provide indirect sources of recharge as leakage of pipe systems (Callahan et al., 2012), whereas, the increase of impervious cover minimises infiltration and can lead to a decrease in the recharge (Guinn Garrett et al., 2012).	o Agricultural land use can cause the degradation of groundwater quality due to chemical fertiliser (Koh et al., 2017) and cause alteration in salinity levels due to the leaching of irrigation (Kurtzman and Scanlon, 2011). o Urbanisation can bring a positive effect to contamination if the change in land use was from agricultural (Koh et al., 2017). However, there is also the possibility of degradation due to untreated waste disposal, usage of landfills and other urban anthropogenic activities (Mattas et al., 2014).

3.2. Spatial dimension

All the 28 selected publications covered one or more case study areas. In total, 50 case study areas were identified, some papers analysed multiple case studies. Three types of case study areas were found: i) study site refers to a point or local sites such as boreholes, wetlands (four publications); ii) catchments are defined by the topography of a region (9 publications); and iii) hydrogeological units correspond to geological formations capable of storage and transfer water (15 publications). The delimitation of 43 case studies was mostly influenced by natural aspects that are visible to society, such as their geomorphology. Of the 28 publications, 10 included coastal features or processes as criteria to define the study area.

The importance of analysing study sites at a local level from a spatial dimension perspective is that these are essential starting points to understand changes across larger spatial levels. All four publications had evidence of the relationship of the spatial dimension of Landscape Scale Planning with groundwater systems and groundwater management (e.g. effects of upstream land use changes can be identified in downstream discharge areas). Two studies used wetlands as a representative outlet of groundwater flow. Rodríguez-Rodríguez et al. (2011) and Zhu et al. (2017) applied a water balance to analyse the dynamics between water bodies and the aquifer. Other two publications analysed study sites that had specific characteristics that could be used to define landscape units: Kurtzman and Scanlon (2011) studied a typical soil type of the Israeli Coastal Aquifer, and Brauman et al. (2012) studied different land cover types in Hawaii. Both publications focused on the physical recharge process.

Catchments are the spatial unit through which hydrological processes can be analysed and modelled, including groundwater systems. Of the nine publications that focused on one or more catchments as their study area, two had groundwater as the main objective: Callahan et al. (2012) analysed groundwater recharge, and Guinn Garrett et al. (2012) analysed the river-aquifer interaction. The other seven publications studied groundwater systems processes as one of their objectives, but they were not the primary topic of the publication. Hence, catchments were generally adopted as the spatial boundary when other factors were also taken into account such as streamflow (Ragab et al., 2012) or surface runoff (Calderon and Uhlenbrook, 2016). Among these seven publications, only Guan et al. (2010) took into account the possibility that a subsurface flow between catchments might occur. Groundwater recharge (Calderon and Uhlenbrook, 2016; Tsutsumi et al., 2009), assessment of groundwater quality (Aquilina et al., 2012) and climate change impacts (Daraio, 2017; Ragab et al., 2012) were analysed to provide information for groundwater management. The size of the catchments studied varied between 0.25km² to 10,400km².

As expected, most publications adopted hydrogeological units, or part of it, as their spatial boundaries. As these hydrogeological units generally are large formations that can extend across several catchments (Dawes et al., 2012; Gondwe et al., 2011), other characteristics were used to define the spatial boundary. For example, He et al. (2008), Hu et al. (2018) and Righini et al. (2011) delimited their study areas by using the intersection of the hydrogeological unit with the overlying coastal plain, and Collin and Melloul (2001) combined the hydrogeological unit with social aspects. Koh et al. (2017) and Mair et al. (2013) conducted their studies on an island (i.e. Jeju Island, Korea). Mair et al. (2013) studied the occurrence and recharge of groundwater and Koh et al. (2017) the effects of land use change on groundwater quality. While both studies described Jeju Island having several catchments in the hydrogeological unit, analyses did not consider individual catchments.

3.3. Temporal dimension

Evidence of the temporal dimension was found in 16 publications. Past analyses of land uses was done in 13 publications. The identification of which publications carried out past analyses took into account not only the timespan of the data set but also if the data were discussed or correlated with the modification that had happened in the study area. Future estimates were analysed in 5 publications. Only Dawes et al. (2012) and Aquilina et al. (2012) considered both past and future land use changes.

In the publications that analysed past data, the time length used varied according to the objective of the study. While Calderon and Uhlenbrook (2016) used a short period of three years to analyse groundwater recharge and climate water balance in a catchment, Aquilina et al. (2012) analysed a nitrate concentration series of 38 years to evaluate the alterations due to agricultural land use in Brittany. Both analysed groundwater systems and the implication of these processes to groundwater management. Koh et al. (2017) analysed 11 years of data using chemical methods to evaluate the effectiveness of groundwater management measures to prevent saltwater intrusion. The results started to become visible after six years of implementation. When analysing a sparse time series, other publications could go even further back. The longest analysis was made by Kurtzman and Scanlon (2011) who compared the changes in chloride levels between the years of 1935 and 2007 due to extensive settlements and modern cultivation on an Israeli coastal aquifer. These publications analysed aspects or measures of groundwater management under a historical perspective based on past data.

The five publications that analysed future conditions investigated the response of groundwater systems to determine changes. Four publications applied scenarios related to climate change and Global Climate Models - GCM. Starting from past data analysis, Dawes et al. (2012) analysed future scenarios including climate and land use change up to 2030 and Ragab et al. (2012) analysed land use and climate change scenarios until 2100. Zhu et al. (2017) and Daraio (2017) applied scenarios of climate change until 2100. Aquilina et al. (2012) were the only ones to approach the water quality aspect under a future perspective. These futures estimates were based on trends detected. The future scenarios analysed did not include changes due to other factors such as socio-economic pressures.

3.4. Modification dimension

Aspects of anthropogenic modification of land use were present in 23 of the 28 selected publications. For example, three main types of land use changes were shown in the publications: agricultural, urban and forestry. While agricultural land use was present in all 23 publications, urban land use was in 18 publications, and forestry land use was in 15 publications. These publications connected the impacts of these land uses with groundwater quantity (Brauman et al., 2012; Callahan et al., 2012) and quality (Hu et al., 2018; Koh et al., 2017). The current land uses within the study area were analysed by ten publications, whereas past land use change processes were analysed in 15 publications. Only Collin and

Melloul (2001) and Dawes et al. (2012) analysed both the current and the impact of land use changes on groundwater resources.

When current land uses were evaluated, the publications studied mostly agricultural or urban land uses and their impacts on groundwater systems as well as possible implications for groundwater management. The main anthropogenic impact detected was the contamination of aquifers, especially due to agricultural activities. This included presence of nitrate (Allouche et al., 2017; Mattas et al., 2014) and phosphate (Mattas et al., 2014) above the desired levels for drinking water consumption. Issues directly related to coastal areas were not much explored. Only four papers studied directly land use changes and saltwater intrusion. For example, Priyantha Ranjan et al. (2006) estimated the correlation between deforestation and aridity index losses in fresh groundwater due to saltwater intrusion. Where the impacts of urban land uses were investigated, high levels of chloride were detected in groundwater (Melloul and Collin, 2003). The main type of land use change observed was from pre-development (natural) conditions to agriculture and from agricultural to urban (residential) uses. These land use changes were found to alter groundwater recharge (He et al., 2008), water quality (Aquilina et al., 2012) and aquifers dynamics (Guan et al., 2010). Saltwater intrusion and overexploitation of groundwater were also related to changes in land use (McFarlane et al., 2012; Melloul and Collin, 2003).

3.5. Methods applied by publications

Modelling was the most applied method by the publications to analyse the spatial dimension. At the site level, Kurtzman and Scanlon (2011) analysed recharge through physical methods and modelling, and Brauman et al. (2012) used water balance to identify the primary components of the recharge. At the catchment level, six out of the nine publications applied some modelling technique, with three applying scenario analysis. Regarding hydrogeological units, the most common method applied was also modelling. Numerical models were applied to analyse alteration in recharge (He et al., 2008), effects of climate change on groundwater resources (Dawes et al., 2012), the uncertainty to define the actual hydrogeological areas (Gondwe et al., 2011), and to evaluate alteration in groundwater quality (Priyantha Ranjan et al., 2006). Other methods were spatial analysis (Righini et al., 2011), multicriteria analysis (MCA) (Melloul and Wollman, 2003), and case study analysis using a conceptual approach (McFarlane et al., 2012).

Modelling was used by 11 publications to analyse the temporal dimension, including scenario analysis (7 publications). Models based on the water balance equation were the mostly used. Modelling based on past data was used by Mair et al. (2013) (18 years of data) and Calderon and Uhlenbrook (2016) used (3 years of data). Chemical methods were used in eight publications. The shortest period used for the application of chemical methods was nine years (Guan et al., 2010). Chloride and nitrate were the most used indicators for chemical methods (e.g. Calderon and Uhlenbrook, 2016; Guan et al., 2010). Other methods applied were case study analysis through a conceptual approach (Mattas et al., 2014; McFarlane et al., 2012), spatial analysis with remote sensing (Righini et al., 2011), and physical methods (Aquilina et al., 2012; Hu et al., 2018). Analysing future conditions, five publications applied modelling techniques to simulate future scenarios. Aquilina et al. (2012) were the only ones to approach the water quality aspect under a future perspective.

To investigate the modification dimension, thirteen publications applied modelling to analyse land use impacts on groundwater resources, including scenario analysis (8 publications). Models based on the water balance equation were applied eight times. Models based on the flow equation were applied in four publications (Dawes et al., 2012; Kurtzman and Scanlon, 2011). While the water balance based models were generally applied to evaluate impacts on groundwater recharge due to changes in land use, flow equation models were applied to analyse impacts not only on recharge but also on the behaviour of the aquifer. Only Daraio (2017) applied a surface hydrologic model. He analysed the groundwater component of the water cycle taking into account the current land uses in the study area. Another frequent method applied was the analysis through chemical methods, used in ten publications (e.g. Allouche et al., 2017; Rodríguez-Rodríguez et al., 2011). Through this method, alterations in groundwater recharge and evaluate contamination of aquifers were estimated. Chloride, nitrates, and electrical conductivity were the indicators most often used. Other methods used were spatial analysis (Dawes et al., 2012; Mair et al., 2013), physical methods (Callahan et al., 2012; Kurtzman and Scanlon, 2011), conceptual approaches (Mattas et al., 2014; McFarlane et al., 2012), MCA (Collin and Melloul, 2001; Hu et al., 2018), sensitivity analysis (Allouche et al., 2017) and statistical methods (Daraio, 2017; Koh et al., 2017).

4. Discussion

Balancing groundwater exploitation with demands from natural processes and anthropogenic uses comprises the key challenge for groundwater management (Jakeman et al., 2016). Challenge is further compounded by ongoing population and urbanisation growth (Tam and Nga, 2018), along with climate change impacts (Cuthbert et al., 2019). The search for a framework capable of dealing with such aspects is still a challenge that needs to be overcome for groundwater management (Vadiati et al., 2018). Additionally, coastal urbanised areas relying on groundwater supplies present a set of issues that are both complex and difficult to address without a more holistic perspective to groundwater management (Michael et al., 2017). One such holistic perspective is the Landscape Scale Planning approach (Selman, 2006), which not only takes into consideration the distinctive features and characteristics of landscape units but also spatial and temporal changes in land uses and inherent impacts caused on groundwater resources. The implementation of the Landscape Scale Planning approach however, requires groundwater resources related information that can adress the complexitity of issues affecting them - especially information that sheds light on the spatial, temporal and modification dimensions. Findings from this study proved that there is a long way to go for current groundwater science to deliver this much needed information.

Fisrtly, findings indicated that from the spatial dimension, groundwater systems are usually studied and managed at only one level, as the catchment or hydrogeological basin, in an attempt to analyse the region into self-contained units. However, according to Sanz et al. (2016), the occurrence of groundwater does not always coincide with these units. Part of what forms a landscape are the spatial differences. These differences such as topography, geology and land use can influence the aquifer, and as consequence, the recharge process or the contaminant path in the aquifer. Although evidence of this relationship was present in selected publications (Calderon and Uhlenbrook, 2016; Hu et al., 2018), many times, these differences within the study area were disregarded. Recently, other scholars (Fan et al., 2018) have also shown that different parts of the hydrological system, including groundwater, have differing spatial characteristics which need to be taken into account. This implies that the knowledge required for managing groundwater systems needs to be built from the local to the landscape scale. Therefore, the use of landscape units underpinned by physical, socioeconomic, cultural and other factors, can aggregate similar spatial characteristics which are also important for informing groundwater management. One of the benefits of considering the Landscape Scale Planning approach would be the possibility of connecting multiple features of coastal landscapes such as shorelines, beaches and estuaries to the whole groundwater management. Submarine groundwater discharge, base flow in estuary regions and saltwater intrusion are coastal groundwater management issues that affect such features but had little attention in the selected publications.

Secondly, from a temporal dimension, a significant amount of publications focused only on the current state of a groundwater system, or on the provision of information for groundwater management for the current situation. When analysing the temporal dimension, many publications sought to establish an average situation of the system based on past data as a baseline (Mair et al., 2013) and identified additional disturbance as external drivers (Mattas et al., 2014). Building on this information, some publications developed future scenario analysis based on detected trends (Zhu et al., 2017) or future drivers (Aquilina et al., 2012). Consideration of future changes to groundwater systems however, was not a predominant trend in the publications analysed. This presents a considerable gap in knowledge because these systems are, and will continue to be, confronted with future uncertain changes in rates of population and urbanisation growth, demands from natural processes and climate change impacts.

Thirdly, from a modification dimension, the publications gathered accounted for many analyses of land use changes but without fully considering more dynamic aspects. While some of these dynamics were included in analyses of groundwater management issues based on the historical evolution (Mattas et al., 2014), they were not considered in analyses exploring future situations. The manner by which different pressures alter land use patterns and groundwater systems under a longer planning horizon is often disregarded, despite its importance. For instance, from Gashaw et al. (2018) and Kundu et al. (2017), it can be seen that when the process of change is taken into account throughout the planning horizon, the difference can be of up to 20% of the groundwater balance. Teklay et al. (2019) found that management approaches considering the dynamic nature of land use change can significantly result in differing outcomes, given that it can increase the spatial and temporal accuracy of the hydrological information provided. Landscape can be formed through a matrix of different and competing land use patterns. Thus the dynamic aspect of changes needs to be acknowledged as well as the relationships between these land uses (Mercau et al., 2016) not only regarding their physical aspects but also the socioeconomic or cultural ones. Coastal areas have become centres with high levels of urbanisation, agriculture, and seasonal population increases due to tourism. These drivers are causing an increase in saltwater intrusion, alterations in groundwater levels and its quality. Including these dynamics in groundwater management can support a move towards a more interdisciplinary approach - one of the objectives of the IWRM (Foster and Ait-Kadi, 2012).

Finally, findings from this study indicate that most of the limitations associated with providing information for managing groundwater under a Landscape Scale Planning approach appear to be related to existing methods of analysis. However, different methods have the potential to overcome some of these limitations. For example, to address the spatial dimension, water table fluctuation can be spatialized to a broader scale (Healy, 2010), while groundwater flow models can be applied to understand the behaviour of the whole aquifer (Anderson et al., 2015). Chemical or physical methods have both been applied to increase the understanding of the study area characteristics and problems. Although these methods are point-based, they can serve as part of a monitoring effort to provide information through the detection of alteration in groundwater quality and quantity serving as a basis for management (Rohde et al., 2017; Thomas, 2018). For this, their outputs need to be scaled up from a point-based to the whole landscape. Similarly, they can deal with different spatial levels and provide information and support to management processes (Pezij et al., 2019). From a temporal perspective, these methods cannot simulate future conditions. In order to do that, the application of models is necessary and they can be underpinned by chemical or physical methods. However, the uncertainty inherent to all these methods cannot be removed and this needs to be acknowledged by management processes (Neuendorf et al., 2018). Regarding the modification dimension, there have been proposed methods capable of encompassing the dynamics of change in land use for future scenarios (Dang and Kawasaki, 2017; Guan et al., 2011; Han et al., 2015). However, these methods have not been widely used, especially to inform groundwater management.

5. Conclusion

Using a systematic literature review, this paper sought to analyse how the current state of groundwater management in coastal areas could be improved through the application of a Landscape Scale Planning approach. From the selected publications, it could be noted that the spatial, temporal, and modification dimensions have an intrinsic connection with groundwater management. This connection is confirmed from the evidence supporting that each dimension can be connected with characteristics of groundwater systems, such as the different spatial and temporal distribution of recharge as well as the strong influence that land use modification causes on the aquifer. Furthermore, through the application of the Landscape Scale Planning analytical framework, it was possible to identify gaps between the relationship of land use with the applied approaches for groundwater management, such as the lack of consideration regarding the dynamical aspects of land use change in the current management measures. This consideration is important because it can provide more accurate information to the management process. Applying a Landscape Scale Planning approach to frame this connection can produce more comprehensive outcomes therefore improving the process of groundwater management.

Landscape Scale Planning can be applied as an integrative framework because it connects different sectors and perspectives. Bottom-up management can be promoted using Landscape Scale Planning through landscape units based on many aspects such as geology, topography, cultural, and socio-economics. This can aid groundwater management that takes into account the different spatial and temporal characteristics of the aquifer. Two main issues that emerged from the review were alterations in recharge and contamination of the aquifer. These issues happen in a heterogeneous way within the aquifer and are influenced by the several aspects such as topography, geology and land use. Landscape units can bring together these distinct aspects and characteristics of the aquifer into different zones to improve groundwater management. While this could aid the identification of their complementarities, it could also facilitate the provision of information for decision making. Additionally, the modification dimension could be more easily considered if the dynamics of land use change were evaluated over more uniform regions, such as landscape units, instead of the highly complex landscape such as coastal catchment with different land uses. Using landscapes as an integrative platform for planning can improve the connection of land use change and groundwater management with other topics, especially in coastal regions. Issues such as saltwater intrusion and submarine groundwater discharge had little attention in the publications gathered. These issues could be better addressed under a Landscape Scale Planning approach because it enables the integration with other sectors, such as estuarine planning.

Suggestions for further research include the evaluation of groundwater management strategies underpinned by all the three dimensions of Landscape Scale Planning. Other studies could analyse the effects of the dynamics aspects included in the modification dimension on typical coastal groundwater management issues such as saltwater intrusion.

References

Alley, W.M., Healy, R.W., LaBaugh, J.W., Reilly, T.E., 2002. Flow and Storage in Groundwater Systems. Science 296, 1985.

Alley, W.M., Leake, S.A., 2004. The Journey from Safe Yield to Sustainability. Ground Water 42, 12-16.

Allouche, N., Maanan, M., Gontara, M., Rollo, N., Jmal, I., Bouri, S., 2017. A global risk approach to assessing groundwater vulnerability. Environmental Modelling & Software 88, 168-182.

Andersen, P.S., Andersen, E., Graversgaard, M., Christensen, A.A., Vejre, H., Dalgaard, T., 2019. Using landscape scenarios to improve local nitrogen management and planning. J Environ Manage 232, 523-530.

Anderson, M.P., Woessner, W.W., Hunt, R.J., 2015. Chapter 2 - Modeling Purpose and Conceptual Model, in: Anderson, M.P., Woessner, W.W., Hunt, R.J. (Eds.), Applied Groundwater Modeling (Second Edition). Academic Press, San Diego, pp. 27-67.

Antrop, M., Van Eetvelde, V., 2017. The Holistic Nature of Landscape – Landscape as an Integrating Concept, in: Antrop, M., Van Eetvelde, V. (Eds.), Landscape Perspectives: The Holistic Nature of Landscape. Springer Netherlands, Dordrecht, pp. 1-9.

Aquilina, L., Vergnaud-Ayraud, V., Labasque, T., Bour, O., Molenat, J., Ruiz, L., de Montety, V., De Ridder, J., Roques, C., Longuevergne, L., 2012. Nitrate dynamics in agricultural catchments deduced from groundwater dating and long-term nitrate monitoring in surface- and groundwaters. Sci Total Environ 435-436, 167-178.

Baum, R., Bartram, J., 2017. A systematic literature review of the enabling environment elements to improve implementation of water safety plans in high-income countries. Journal of Water and Health 16, 14-24.

Boulton, C., Dedekorkut-Howes, A., Byrne, J., 2018. Factors shaping urban greenspace provision: A systematic review of the literature. Landscape and Urban Planning 178, 82-101.

Brauman, K.A., Freyberg, D.L., Daily, G.C., 2012. Land cover effects on groundwater recharge in the tropics: ecohydrologic mechanisms. Ecohydrology 5, 435-444.

Calderon, H., Uhlenbrook, S., 2016. Characterizing the climatic water balance dynamics and different runoff components in a poorly gauged tropical forested catchment, Nicaragua. Hydrological Sciences Journal 61, 2465-2480.

Callahan, T.J., Vulava, V.M., Passarello, M.C., Garrett, C.G., 2012. Estimating groundwater recharge in lowland watersheds. Hydrological Processes 26, 2845-2855.

Chatton, E., Aquilina, L., Pételet-Giraud, E., Cary, L., Bertrand, G., Labasque, T., Hirata, R., Martins, V., Montenegro, S., Vergnaud, V., Aurouet, A., Kloppmann, W., Pauwels, 2016. Glacial recharge, salinisation and anthropogenic contamination in the coastal aquifers of Recife (Brazil). Science of The Total Environment 569-570, 1114-1125.

Collin, M.L., Melloul, A.J., 2001. Combined land-use and environmental factors for sustainable groundwater management. Urban Water 3, 229-237.

Council of Europe, 2000. European Landscape Convention, Report and Convention Florence, p. 8.

Cuthbert, M.O., Gleeson, T., Moosdorf, N., Befus, K.M., Schneider, A., Hartmann, J., Lehner, B., 2019. Global patterns and dynamics of climate–groundwater interactions. Nature Climate Change.

Dang, A.N., Kawasaki, A., 2017. Integrating biophysical and socio-economic factors for land-use and land-cover change projection in agricultural economic regions. Ecological Modelling 344, 29-37.

Daraio, J.A., 2017. Potential Climate Change Impacts on Streamflow and Recharge in Two Watersheds on the New Jersey Coastal Plain. Journal of Hydrologic Engineering 22.

Dawes, W., Ali, R., Varma, S., Emelyanova, I., Hodgson, G., McFarlane, D., 2012. Modelling the effects of climate and land cover change on groundwater recharge in south-west Western Australia. Hydrology and Earth System Sciences 16, 2709-2722.

Fan, M., Shibata, H., Chen, L., 2018. Assessing high impacts of climate change: spatial characteristics and relationships of hydrological ecosystem services in northern Japan (Teshio River watershed). Mitigation and Adaptation Strategies for Global Change 23, 525-552.

Foster, S., 2018. Is UN Sustainable Development Goal 15 relevant to governing the intimate land-use/groundwater linkage? Hydrogeology Journal 26, 979-982.

Foster, S., Ait-Kadi, M., 2012. Integrated Water Resources Management (IWRM): How does groundwater fit in? Hydrogeology Journal 20, 415-418.

Gashaw, T., Tulu, T., Argaw, M., Worqlul, A.W., 2018. Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. Sci Total Environ 619-620, 1394-1408.

Gondwe, B.R.N., Merediz-Alonso, G., Bauer-Gottwein, P., 2011. The influence of conceptual model uncertainty on management decisions for a groundwater-dependent ecosystem in karst. Journal of Hydrology 400, 24-40.

Gorelick, S.M., Zheng, C., 2015. Global change and the groundwater management challenge. 51, 3031-3051.

Guan, D., Li, H., Inohae, T., Su, W., Nagaie, T., Hokao, K., 2011. Modeling urban land use change by the integration of cellular automaton and Markov model. Ecological Modelling 222, 3761-3772.

Guan, H., Love, A.J., Simmons, C.T., Hutson, J., Ding, Z., 2010. Catchment conceptualisation for examining applicability of chloride mass balance method in an area with historical forest clearance. Hydrology and Earth System Sciences 14, 1233-1245.

Guinn Garrett, C., Vulava, V.M., Callahan, T.J., Jones, M.L., 2012. Groundwater-surface water interactions in a lowland watershed: source contribution to stream flow. Hydrological Processes 26, 3195-3206.

Haddaway, N.R., Bilotta, G.S., 2016. Systematic reviews: Separating fact from fiction. Environ Int 92-93, 578-584.

Han, H., Yang, C., Song, J., 2015. Scenario Simulation and the Prediction of Land Use and Land Cover Change in Beijing, China. Sustainability 7, 4260-4279.

Hawkins, V., Selman, P., 2002. Landscape scale planning: exploring alternative land use scenarios. Landscape and Urban Planning 60, 211-224.

He, B., Wang, Y., Takase, K., Mouri, G., Razafindrabe, B.H.N., 2008. Estimating Land Use Impacts on Regional Scale Urban Water Balance and Groundwater Recharge. Water Resources Management 23, 1863-1873.

Healy, R.W., 2010. Estimating Groundwater Recharge. Cambridge University Press, Cambridge.

Hu, X., Ma, C., Qi, H., Guo, X., 2018. Groundwater vulnerability assessment using the GALDIT model and the improved DRASTIC model: a case in Weibei Plain, China. Environ Sci Pollut Res Int 25, 32524-32539.

Jakeman, A.J., Barreteau, O., Hunt, R.J., Rinaudo, J.-D., Ross, A., Arshad, M., Hamilton, S., 2016. Integrated Groundwater Management: An Overview of Concepts and Challenges, in: Jakeman, A.J., Barreteau, O., Hunt, R.J., Rinaudo, J.-D., Ross, A. (Eds.), Integrated Groundwater Management: Concepts, Approaches and Challenges. Springer International Publishing, Cham, pp. 3-20.

Koh, E.-H., Lee, S.H., Kaown, D., Moon, H.S., Lee, E., Lee, K.-K., Kang, B.-R., 2017. Impacts of land use change and groundwater management on long-term nitrate-nitrogen and chloride trends in groundwater of Jeju Island, Korea. Environmental Earth Sciences 76.

Kundu, S., Khare, D., Mondal, A., 2017. Past, present and future land use changes and their impact on water balance. J Environ Manage 197, 582-596.

Kurtzman, D., Scanlon, B.R., 2011. Groundwater Recharge through Vertisols: Irrigated Cropland vs. Natural Land, Israel. Vadose Zone Journal 10.

Mair, A., Hagedorn, B., Tillery, S., El-Kadi, A.I., Westenbroek, S., Ha, K., Koh, G.-W., 2013. Temporal and spatial variability of groundwater recharge on Jeju Island, Korea. Journal of Hydrology 501, 213-226.

Mattas, C., Voudouris, K., Panagopoulos, A., 2014. Integrated Groundwater Resources Management Using the DPSIR Approach in a GIS Environment Context: A Case Study from the Gallikos River Basin, North Greece. Water 6, 1043-1068.

McFarlane, D., Strawbridge, M., Stone, R., Paton, A., 2012. Managing groundwater levels in the face of uncertainty and change: a case study from Gnangara. Water Science and Technology: Water Supply 12, 321-328.

Melloul, A., Wollman, S., 2003. Qualitative hydrological and land-use planning tool for the Israel Coastal aquifer. The Science of The Total Environment 309, 1-17.

Melloul, A.J., Collin, M.L., 2003. Harmonizing water management and social needs: a necessary condition for sustainable development. The case of Israel's coastal aquifer. Journal of Environmental Management 67, 385-394.

Mercau, J.L., Nosetto, M.D., Bert, F., Giménez, R., Jobbágy, E.G., 2016. Shallow groundwater dynamics in the Pampas: Climate, landscape and crop choice effects. Agricultural Water Management 163, 159-168.

Michael, H.A., Post, V.E.A., Wilson, A.M., Werner, A.D., 2017. Science, society, and the coastal groundwater squeeze. Water Resources Research 53, 2610-2617.

Minnig, M., Moeck, C., Radny, D., Schirmer, M., 2018. Impact of urbanization on groundwater recharge rates in Dübendorf, Switzerland. Journal of Hydrology 563, 1135-1146.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Group, P., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 6, e1000097.
Molle, F., López-Gunn, E., van Steenbergen, F.J.W.A., 2018. The Local and National Politics of Groundwater Overexploitation. Water Alternatives 11, 12.
Momtaz, S., Shameem, M.I.M., 2016. Chapter 4 - The Research Setting, in: Momtaz, S., Shameem, M.I.M. (Eds.), Experiencing Climate Change in Bangladesh. Academic Press, Boston, pp. 41-68.
Morrison, R., Barker, A., Handley, J., 2018. Systems, habitats or places: evaluating the potential role of landscape character assessment in operationalising the ecosystem approach. Landscape Research 43, 1000-1012.
Neuendorf, F., von Haaren, C., Albert, C., 2018. Assessing and coping with uncertainties in landscape planning: an overview. Landscape Ecology 33, 861-878.
Petelet-Giraud, E., Cary, L., Cary, P., Bertrand, G., Giglio-Jacquemot, A., Hirata, R., Aquilina, L., Alves, L.M., Martins, V., Melo, A.M., Montenegro, S., Chatton, E., Franzen, M., Aurouet, A., team, C., 2018. Multi-layered water resources, management, and uses under the impacts of global changes in a southern coastal metropolis: When will it be already too late? Crossed analysis in Recife, NE Brazil. Sci Total Environ 618, 645-657.
Pezij, M., Augustijn, D.C.M., Hendriks, D.M.D., Hulscher, S.J.M.H., 2019. The role of evidence-based information in regional operational water management in the Netherlands. Environmental Science & Policy 93, 75-82.
Plieninger, T., Bieling, C., 2012. Resilience and the Cultural Landscape: Understanding and Managing Change in Human-Shaped Environments. Cambridge University Press, Cambridge.
Priyantha Ranjan, S., Kazama, S., Sawamoto, M., 2006. Effects of climate and land use changes on groundwater resources in coastal aquifers. J Environ Manage 80, 25-35.
Ragab, R., Bromley, J., D'Agostino, D.R., Lamaddalena, N., Luizzi, G.T., Dörflinger, G., Katsikides, S., Montenegro, S., Montenegro, A., 2012. Water Resources Management Under Possible Future Climate and Land Use Changes: The Application of the Integrated Hydrological Modelling System, IHMS, Integrated Water Resources Management in the Mediterranean Region, pp. 69-90.
Righini, G., Raspini, F., Moretti, S., Cigna, F., 2011. Unsustainable use of groundwater resources in agricultural and urban areas: a persistent scatterer study of land subsidence at the basin scale, Ecosytems and Sustainable Development VIII, pp. 81-92.
Rodríguez-Rodríguez, M., Benavente, J., Alcalá, F.J., Paracuellos, M., 2011. Long-term water monitoring in two Mediterranean lagoons as an indicator of land-use changes and intense precipitation events (Adra, Southeastern Spain). Estuarine, Coastal and Shelf Science 91, 400-410.
Rohde, M.M., Froend, R., Howard, J., 2017. A Global Synthesis of Managing Groundwater Dependent Ecosystems Under Sustainable Groundwater Policy. Ground Water 55, 293-301.
Ross, A., 2016. Groundwater Governance in Australia, the European Union and the Western USA, in: Jakeman, A.J., Barreteau, O., Hunt, R.J., Rinaudo, J.-D., Ross, A. (Eds.), Integrated Groundwater Management: Concepts, Approaches and Challenges. Springer International Publishing, Cham, pp. 145-171.
Sanz, D., Calera, A., Castaño, S., Gómez-Alday, J.J., 2016. Knowledge, participation, and transparency in groundwater management. Water Policy.
Selman, P., 2006. Planning at the Landscape Scale. Routledge, London and New York.
Selman, P., 2009. Planning for landscape multifunctionality. Sustainability: Science, Practice and Policy 5, 45-52.
Song, X.P., Tan, P.Y., Edwards, P., Richards, D., 2018. The economic benefits and costs of trees in urban forest stewardship: A systematic review. Urban Forestry & Urban Greening 29, 162-170.
Tam, V.T., Nga, T.T.V., 2018. Assessment of urbanization impact on groundwater resources in Hanoi, Vietnam. J Environ Manage 227, 107-116.
Teklay, A., Dile, Y.T., Setegn, S.G., Demissie, S.S., Asfaw, D.H., 2019. Evaluation of static and dynamic land use data for watershed hydrologic process simulation: A case study in Gummara watershed, Ethiopia. CATENA 172, 65-75.
Thomas, B.F., 2018. Sustainability indices to evaluate groundwater adaptive management: a case study in California (USA) for the Sustainable Groundwater Management Act. Hydrogeology Journal.
Tseng, M.-L., Islam, M.S., Karia, N., Fauzi, F.A., Afrin, S., 2019. A literature review on green supply chain management: Trends and future challenges. Resources, Conservation and Recycling 141, 145-162.
Tsutsumi, A., Jinno, K., Berndtsson, R., 2009. Surface and subsurface water balance estimation by the groundwater recharge model and a 3-D two-phase flow model/Estimation de bilan hydrologique de surface et de subsurface à l'aide de modèles de recharge de nappe et d'écoulement diphasique 3-D. Hydrological Sciences Journal 49.

Vadiati, M., Adamowski, J., Beynaghi, A., 2018. A brief overview of trends in groundwater research: Progress towards sustainability? J Environ Manage 223, 849-851.

Zhu, J., Sun, G., Li, W., Zhang, Y., Miao, G., Noormets, A., McNulty, S.G., King, J.S., Kumar, M., Wang, X., 2017. Modeling the potential impacts of climate change on the water table level of selected forested wetlands in the southeastern United States. Hydrology and Earth System Sciences 21, 6289-6305.