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Research paper

Investigating the knowledge gap in research on climate and land use change impacts on water resources, with a focus on groundwater resources in South Africa: a bibliometric analysis

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Climate and land use change (CLUC) impact studies on water and groundwater resources have evolved in recent years. To determine whether all research gaps have been or are being addressed through the current intellectual structure, a bibliometric analysis, as well as a record review, was enacted to determine the intellectual structure of CLUC impacts on water resources, with a particular focus on the implications for groundwater resources research in the Breede Gouritz Water Management Area (BGWMA) in South Africa. Methods applied included publication-related trends and science mapping. This study found that CLUC impact research being published has increased by 600% between 2014 and 2021, localised research is being done in 95 countries, and land use change (LUC), specifically urbanisation, is being considered more often as a variable. However, a few gaps in the research remain, including smaller spatiotemporal scales in more locations, a stronger focus on LUC in all its forms, LUC versus climate change (CC) impact studies, and multi-modal approaches to related research. CLUC impacts on water and groundwater resources research have made significant progress over the years, but more research is necessary to make this a robust area of research.

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INTRODUCTION

The impacts of climate and land use change (CLUC) on water resources, including groundwater resources, persist globally. Global reliance on groundwater resources is increasing, albeit not always at sustainable rates, especially in areas where surface water availability is declining (Amanambu et al., 2020; Taylor et al., 2013). To understand the future of our water resources from a sustainability point of view, it is therefore imperative that impact studies, specifically CLUC impacts on water and groundwater resources, be executed locally (for example, Wang et al., 2018).

The Breede Gouritz Water Management Area (BGWMA) is an important water management area (WMA) in South Africa (Breede Gouritz Catchment Management Agency, 2020) and is currently being studied more intentionally regarding its groundwater resources. Although effort has been made to delineate surface and groundwater quaternary catchments, and monitor water levels (DWS, 2017; Van der Berg, 2017), no CLUC impact study has been done in the catchment to determine the sustainable use of surface and groundwater in the future. This review is a starting point for CLUC impact studies in the BGWMA. Although CLUC impact studies have been on the rise in recent years, a knowledge gap, where the magnitude of these perturbations is studied on a local scale, is still evident from the research assessed. This is the case for the BGWMA.

CLUC impact studies have been on the rise in recent years, especially since the International Panel on Climate Change (IPCC) fifth assessment report, which published the latest knowledge, revealed new results on climate change (CC) research and called for papers on studies explicitly relating to CC and the groundwater system (Smerdon, 2017). Amanambu et al. (2020) wrote a review summarising over 300 articles about CC impacts on groundwater. They reviewed global CC, assessed the present impact of CC on groundwater, reviewed groundwater models, climate-induced future groundwater changes, and groundwater feedback to the climate system, and determined vital considerations regarding research in this field. Regarding the sustainable use of groundwater, it is clear from the literature, according to Amanambu et al. (2020), that the physical and socio-economic aspects must be incorporated and integrated into such research endeavours. What is also apparent from their findings is that CLUC impacts the groundwater system and that land use change (LUC) is intricately linked to CC. The main focus of CLUC impacts on groundwater studies has been on the impact of CC. Amanambu et al. (2020) recommend that LUC be considered in future water resource-related studies. A few studies were found on a global scale that looked at the combined effects of CC and LUC on some parts of the hydrologic system (Cochand et al., 2021; Nkhoma et al., 2020; Van Huijgevoort et al., 2020; Olivares et al., 2019; Osei et al., 2019; Shrestha et al., 2018; Tamm et al., 2018; Zhang et al., 2018; Ahiablame et al., 2017; and Ponpang-Nga and Techamahasaranont, 2016). A number of these studies focused on the groundwater system specifically.

To the authors' knowledge, no CLUC impact studies on the groundwater system have been conducted in South Africa, although there are a few studies studying a particular aspect of the groundwater system. For instance, two indices were created; Van Rooyen et al. (2020) created a groundwater quantity and quality vulnerability model, which was applied to the 19 WMAs in South Africa. These authors found that, in general, groundwater resources are more vulnerable in the west, with a few exceptions, including the Breede WMA. The central regions will likely experience higher vulnerability in the future, whereas groundwater resources in the Western Cape and southern coast will experience a moderate vulnerability increase. Groundwater vulnerability is mainly sensitive to the following parameters, in decreasing order: mean annual temperature, aquifer type, terrain slope, mean annual precipitation, tritium distribution in groundwater, electrical conductivity, cultivated land use, and population density. A decade earlier, Dennis and Dennis (2011) created the DART index as a regional screening tool to determine the impact of CC on South African aquifers. DART is an acronym for depth to water level change, aquifer type (storativity), recharge and transmissivity. Monthly DART index calculations revealed a robust spatiotemporal control on recharge.

Nkhonjera and Dinka (2018) conducted a literature review of climate change's direct and indirect impacts on groundwater resources in the Olifants River basin. A significant study by Albhaisi et al., (2013) was done where the impacts of LUC on groundwater recharge in the upper parts of the Berg Catchment. The catchment had undergone many changes before the study; a dam was built, and non-native hillslope vegetation was cleared in the upper reaches of the Berg River. Albhaisi et al. (2013) used time-series land use data with the Wetspa hydrological model and determined whether evapotranspiration would decrease and recharge would increase under the aforementioned land use changes. They found that the distribution and location of the different types of land use (or classes in the study) determined the quantity of groundwater recharge with significant spatiotemporal variability of recharge. Furthermore, an 8% increase in recharge was observed over 21 years because of alien hillslope vegetation clearing. It was recommended that a similar study be repeated in other catchments and that the impact of LUC is included.

Other studies conducted in South Africa include the work by Varet et al. (2009), who studied the impact of LUC on groundwater resources in Lake St Lucia. These authors confirmed that groundwater is an essential contributor to streamflow during drought, especially in prolonged drought conditions, as was the case in this area. Manipulation of vegetation was enacted to increase groundwater recharge and decrease groundwater use. Pine plantations were replaced with grasslands; consequently, there was a rise in the water table and an increase in discharge. LUC, however, is not the only reason for changes in groundwater resources; sea-level rise, saltwater encroachment, and a decrease in rainfall also play a role. Furthermore, LUC significantly affects the observed water table level more than precipitation. The introduction of grasslands around Lake St Lucia changed the vegetation's rooting depth, consequently decreasing evapotranspiration rates. The rate at which groundwater is lost to evapotranspiration is a function of rooting depth to groundwater depth; changes in the water-table elevation will determine how much the root system is in contact with the groundwater zone and, therefore, the actual evapotranspiration. Changes in the water table levels will determine how much groundwater will be lost through evapotranspiration, especially in shallow groundwater tables. The authors also reflected on removing the pine trees, which improved river water flow.

A bibliometric analysis is becoming increasingly robust in most areas of research (Donthu et al., 2021; Meija et al., 2021; Zhao et al., 2019). A bibliometric analysis is a general term (Meija et al., 2021) for an objective study that includes a spatiotemporal analysis of large volumes of scientific data (hundreds to thousands) in a specific field (Donthu et al., 2021). Other terms like scientometrics and informetrics are used interchangeably with that of bibliometric analysis (Meija et al., 2021). A bibliometric analysis, however, enables the author to do a quantitative literature study and explore the intellectual structure of a chosen field by investigating the emerging trends, article and journal performance, collaboration patterns and research constituents in this specific field (Donthu et al., 2021a; Verma and Gustafsson, 2020). It allows the author to make sense of a more extensive data pool by evaluating and understanding collective scientific knowledge, exploring evolutionary trends, identifying knowledge gaps and making informed decisions regarding future research in a chosen field (Donthu et al., 2021). With more accurate and comprehensive results on the intellectual framework of this field, a more informed decision on the research priorities in the BGWMA can be made.

This paper is the first in a series of papers pertaining to a CLUC impact study on the groundwater system of the BGWMA. The aim is to first analyse the global intellectual and research structure of CLUC impact studies on water and groundwater resources by presenting a bibliometric analysis supported by a record review. From this, the current trends in the research can be determined, and a gap analysis can be performed. Furthermore, the key findings of this study will serve as an indicator of research focus points for CLUC in future groundwater studies in general and for the specific context of the BGWMA.

METHODS

The methods applied to this study consisted of, firstly, the bibliometric analysis, which was followed by the record review. Details regarding both methods will be discussed in the following paragraphs.

Bibliometric analysis

A bibliometric analysis is an essential step in determining the intellectual framework of a specific field. A bibliometric analysis was conducted using Mendeley as the reference database in this study. Software packages that were used were Excel, Bibexcel and VOSViewer.

The data were obtained through a few steps (see Fig. 1). References, including books, articles, conference proceedings, theses and reports, were downloaded in Mendeley in two rounds using the following whole expressions, respectively:

1. 'Climate change and land use change impact analysis on groundwater resources.'
2. 'Climate change and land use change impact analysis on water resources.'

Articles on water resources in general and groundwater resources specifically were sourced for two reasons: to solicit a more extensive dataset including surface waters, and to verify whether surface waters or groundwaters are currently the focus point in CLUC impact studies. Regarding Fig. 1, as stated above, 5 databases were consulted for academic references, 685 articles were found, 193 duplicates were removed, and 2 records were removed by an automation tool. Next, each entry was scanned, and only entries with CC, LUC, or both in the title were kept. Furthermore, each entry was manually checked for data completeness and consistency (were all the individual items of each reference listed, i.e., authors, title, keywords and so forth?), and missing information was accounted for where applicable. Lastly, 121 records were removed because the focus was more specifically on either water quality or bioenergy and other aspects of water resources that did not match the focus of this study (refer to Fig. 1). A final database with 369 entries between 2001 and 2021 was used for the analysis (Fig. 1).

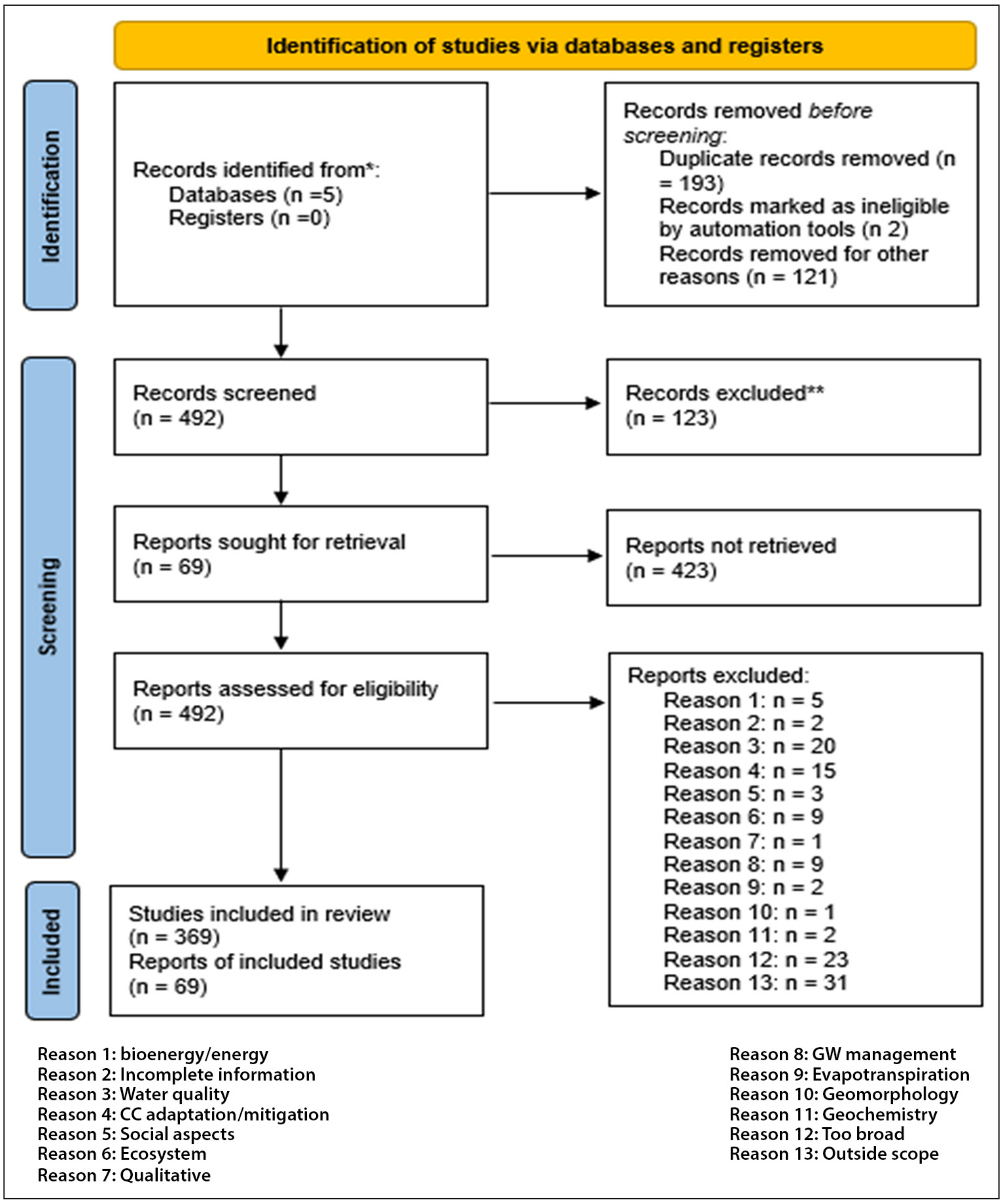

Figure 1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) 2020 flow diagram (from Page et al., 2021)

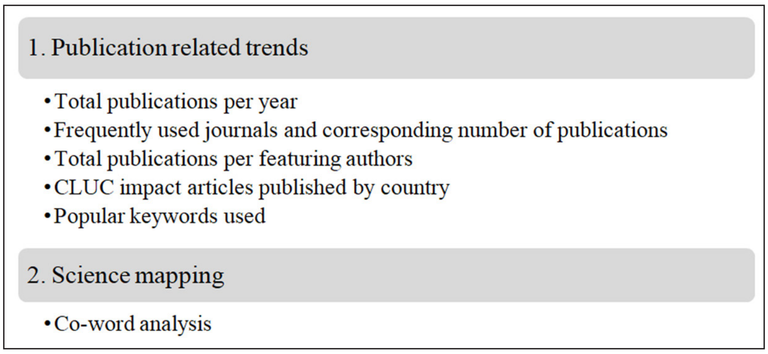

Figure 2. Proposed techniques to perform bibliometric analysis

The following techniques were chosen (Fig. 2) to determine the evolution of CC and LUC impact research and which knowledge gaps still need to be addressed. Publication-related trends pertain to the spatiotemporal trends of CLUC impact studies on water and groundwater resources by determining the trends of publications over time, journals most frequently employed, most common authors in this field, countries where related research is undertaken, and keywords most frequently used (Donthu et al., 2021). Science mapping explores the content of publications to determine relationships amongst keywords and assumes that words that consistently appear together have a thematic connection to one another (Donthu et al., 2021).

Record review

An extensive literature search was conducted on various platforms. Search platforms included the University of the Western Cape's (UWC) online library, Google Scholar, ScienceDirect, Elsevier and Scopus. Other sources consulted were reports by the Breede Gouritz Catchment Management Agency and the Water Research Commission. The focus and keywords first used were 'climate change and groundwater'. After that, the phrase 'land use change and groundwater' was added. Articles that considered CC and LUC impacts on water resources were part of the filtered results of the two main search phrases used and stated above.

A few methods were applied to filter the substantial volume of material available. Firstly, a cut-off date was selected. The most recent articles on CC, LUC and groundwater-related research were mainly written after 2015; the chosen publications were published between 2015 and 2021. Older articles were included if deemed to be bringing significant findings on CC and LUC impacts that would contribute to this study. Secondly, abstracts were read as the second round of filtering. Thirdly, all articles on groundwater resources were selected, representing worldwide areas. The final list of articles was studied intently by summarising them in paragraph form according to the author, year, title, aims and objectives, data collection methods, data analysis methods, results, discussion, and conclusions. A summary of significant findings from these studies was included to support the results of the bibliometric analysis.

RESULTS

The results of the bibliometric analysis and the record review will be discussed separately in the following paragraphs.

Bibliometric analysis

The bibliometric analysis has been performed by first exploring publication-related trends to determine the contributions to the field of CLUC impact studies on water and groundwater resources. Science mapping followed, in which any relationships between keywords were assessed. These methods were followed to determine if gaps in the research field remain. More information can be found in the following paragraphs.

Publication-related trends

Total publications per year

The total publications per year for CLUC impact studies on water resources have increased substantially since 2007 (Fig. 3). Almost zero studies were published in this field (before 2007) to 2020 and 2021, when 74 and 60 articles were published, respectively. A surge in publications was observed after 2014 (by 600% in 2021) when the IPCC called for more research on CC impacts on groundwater (Bates et al., 2008; Smerdon, 2017). It is evident that CLUC impact studies have been given more attention in the last couple of years.

Frequently used journals and corresponding number of publications

The journal that published the most related articles is *Water* (Table 1). The top 10 journals are based mainly in Europe, America, and the United Kingdom. Most journals that published articles in this field pertain to water, hydrology, or sustainability.

Total publications per frequent authors

The author with the most publications is Sangam Shrestha (Table 2) from Thailand's Asian Institute of Technology. Shrestha has been focusing on the integrated impacts of CC and LUC on water resources since 2016 (Shrestha et al., 2018). He has published 152 documents, been cited 3 579 times and has an h-index of 32 (Scopus, 2022h; ORCID: 0000-0002-4972-3969). He is followed by Bernd Diekkrüger from Bönn University in Germany, who published 157 documents and co-authored many articles regarding case studies worldwide, including in East Africa and Thailand, for example (Gabiri et al., 2020). He has been cited 3 462 times, and his h-index is 33 (Scopus, 2022a; ORCID: 0000-0001-9234-7850). Four of the top 10 authors are from Germany, but the countries in which most of the research has been done are China and Uganda (Table 2). The topics or subject areas most commonly contributed are streamflow and non-point source pollution, river basins and agriculture (Scopus, 2022a–j). According to Table 2, 4 authors also focused on climate change or climate models, whereas land cover is a contribution topic for two of the listed authors.

Table 1. Journals that are most frequently used to publish CLUC impact-related articles and their corresponding quantity of publications

Journals	No. of publications
Water (Switzerland)	38
Journal of Hydrology	22
Science of the Total Environment	20
Hydrology and Earth System Sciences	14
Journal of Water and Climate Change	14
Water Resources Research	14
Sustainability	13
Journal of Hydrology: Regional Studies	12
Hydrological Sciences Journal	7
Water Resources Management	7

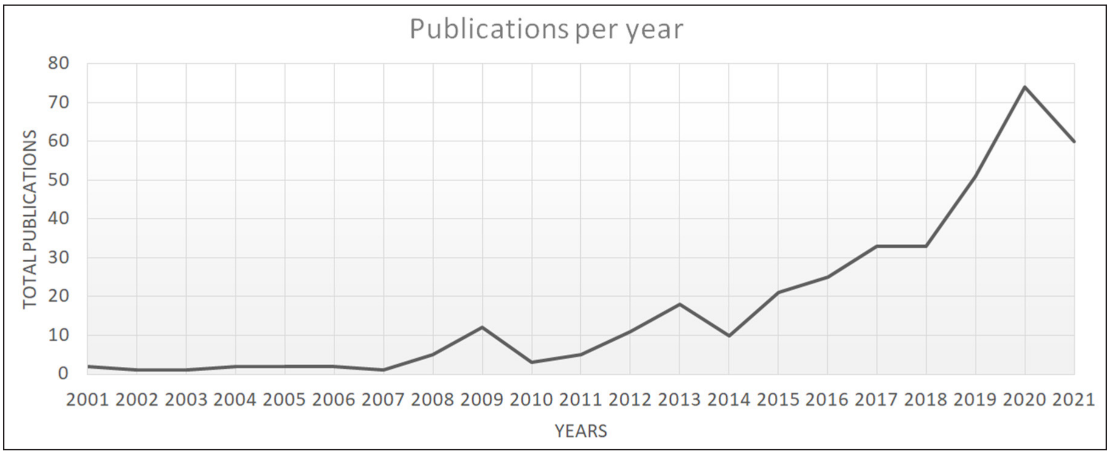

Figure 3. Total publications per year regarding CLUC impacts on water resources

Table 2. Frequently occurring authors, their countries of origin, the corresponding number of publications, focus countries or regions for their respective research and focus areas of research or common research topics per author (Scopus, 2022 a–j).

Authors	Country originating from	No. of publications	Country(s)/region(s) of research focus	Most contributed topics 2016–2020
Shrestha, Sangam	Thailand	7	Thailand China Cambodia Bhutan India Nepal Pakistan Myanmar	River basins Non-point source pollution Streamflow Climate change Regional climate Climate change adaptation Urban climate Resilience
Diekkrüger, Bernd	Germany	6	Burkina Faso Uganda East Africa West Africa Tanzania Togo	Climate models Regional climate River basins Non-point source pollution Streamflow Agriculture
Näschen, Kristian	Germany	4	Burkina Faso Tanzania Uganda	Rice production Seasonal wetlands Agriculture River basins Non-point source pollution Streamflow
Döll, Petra	Germany	4	Global scale	Gravity Recovery and Climate Experiment (GRACE) Groundwater Water storage Water–energy nexus
Kløve, Bjørn	Finland	4	Iran Afghanistan	Usable area Instream flow Ecosystems Peatlands Soil
Zhang, Lu	China	3	China Australia	Streamflow Sediment yield Hydrologic models Runoff
Nistor, Mărgărit Mircea	United Kingdom	3	China Singapore United Kingdom France	Climate change Aridity Evapotranspiration Glacial lakes Ice cover Penman-Monteith Equation
Gabiri, Geofrey	Uganda	3	Uganda East Africa	Rice production Seasonal wetlands Agriculture Landsat Land cover Remote sensing River basins Non-point source pollution Streamflow
Leemhuis, Constanze	Germany	3	Uganda Tanzania East Africa	Rice production Seasonal wetlands Agriculture River basins Non-point source pollution Streamflow Landsat Land cover Remote sensing
Sun, Ge	America	3	China America	Eddy covariance Net ecosystem exchange Ecosystems Remote sensing Latent heat flux Crop coefficient Streamflow Sediment yield

CLUC research by country

CLUC impact studies on water and groundwater resources have been underway in many countries. However, CLUC research in China supersedes research in other countries or regions (Table 3). According to the countries mentioned in the references' titles or abstracts in the final database, 95 countries are mentioned. Thus, CLUC impact studies on water and groundwater resources are ongoing in 95 countries. After China, articles with a 'global' focus follow, including articles with a general focus where no specific country was mentioned, articles with general observations, or where the findings are intended to be used as a general tool. In Africa, a few 'general' articles and West and East Africa are often mentioned in titles and abstracts, including countries like Ethiopia, Uganda and Kenya (Table 3). Several references were pooled in a continent group since a mountain range or a river that cut across multiple countries was studied, for example, in Asia or Europe. The most studied regions in China included the Loess Plateau in the Yellow River basin (Yan et al., 2018). The results from Tables 2 and 3 are consistent because China and East Africa (Uganda) are highlighted.

Popular keywords used

The most common keyword used is climate change (Table 4). Groundwater recharge follows, on par with the SWAT model, consistent with the record review results (Osei et al., 2019). Emerging keywords are land use and LUC and irrigation and urbanisation. These results confirm that more studies are starting to focus on the impact of land use and land use change. However, the focus is still predominantly on CC. Studies have shown that it is crucial to incorporate the impacts of land use change in conjunction with CC; therefore, this finding demonstrated the prevailing research gap on land use change as a variable in water resource perturbations (Adhikari et al., 2020).

Table 3. Countries where CLUC research is being enacted and their number of occurrences in the database used for this study[1]

Countries	Count
China	70
Global*	39
America	36
India	23
Ethiopia	17
Africa*	15
Italy	9
Spain	7
Canada	7
Vietnam	7
Iran	7
South Africa	6
Europe*	6
Pakistan	5
United Kingdom	4
Kenya	4
Uganda	4
Bangladesh	4
Taiwan	4
Thailand	4

[1]Global pertains to general research. Continents (*) refer to general research on the specific continent or to regions such as mountain ranges or rivers that cut across multiple countries in the specific region.

Science mapping

The co-word analysis confirms that CC is the most commonly used keyword (Fig. 4). It further illustrates how often the term CC is used with other co-words such as groundwater and groundwater recharge, SWAT, land use change, and hydrological modelling. Undoubtedly, CC has been the most studied variable regarding water and groundwater resources.

Record review

Extensive research has been undertaken regarding CC and groundwater, and many knowledge gaps have been addressed. Clearly, from the literature, CC, in a general sense, will exacerbate the hydrologic cycle; typically cold places will become colder, humid and wet places will become more humid and wet, and so forth (for example, Hegerl et al., 2019). These findings will consequently impact variables related to water resources, such as streamflow and recharge. CC generalisations or large-scale climate models are often too broad and sometimes irrelevant (Trzaska and Schnarr, 2014); the magnitude of the impact needs to be assessed on regional scales regarding CC (McGregor, 2018; Kundu et al., 2017). Furthermore, CC impacts are rarely linked to LUC impacts, and the combined impact of CLUC is not often evaluated for groundwater resources (Amanambu et al., 2020).

Across the board, according to reviewed papers, the recommendation is to include LUC in groundwater impact studies and localise groundwater studies to a catchment level (Amanambu et al., 2020; Van Huijgevoort et al., 2020). Land use and land cover changes influence evapotranspiration rates and the interception of water, which will influence runoff and recharge in the case of groundwater (Tamm et al., 2018). Another good example is afforestation and deforestation, which affects streamflow, discharge, and runoff by decreasing (afforestation) and increasing (deforestation), respectively (Nkhoma et al., 2020). This information is site-specific, and it is not easy to ascertain whether these findings would have similar or different outcomes elsewhere.

In the context of groundwater research, groundwater recharge is the most widely understood variable and most studied (Adhikari et al., 2020). Recharge is generally directly associated with precipitation but can also be influenced by local geological formations, topography and land use (Fu et al., 2019; Mote et al., 2013; Zhou et al., 2010; Dragoni and Sukhija, 2008); however, the rising temperature will increase evapotranspiration which could offset the role of precipitation in recharge (Bellot and Chirino, 2013; Touhami et al., 2013; Scanlon et al., 2005). Groundwater recharge is expected to decrease up to 19.6%, depending on the area. It is still poorly understood as a groundwater variable (Moeck et al., 2020).

Table 4. Most popular keywords and their corresponding number of occurrences

Keywords	Frequency
Climate change	30
Groundwater recharge + recharge	12
SWAT + SWAT model	12
Land use + land use change	8
Hydrological modelling	5
Groundwater	5
Water resources	3
MODFLOW	3
Irrigation	2
Urbanisation	2

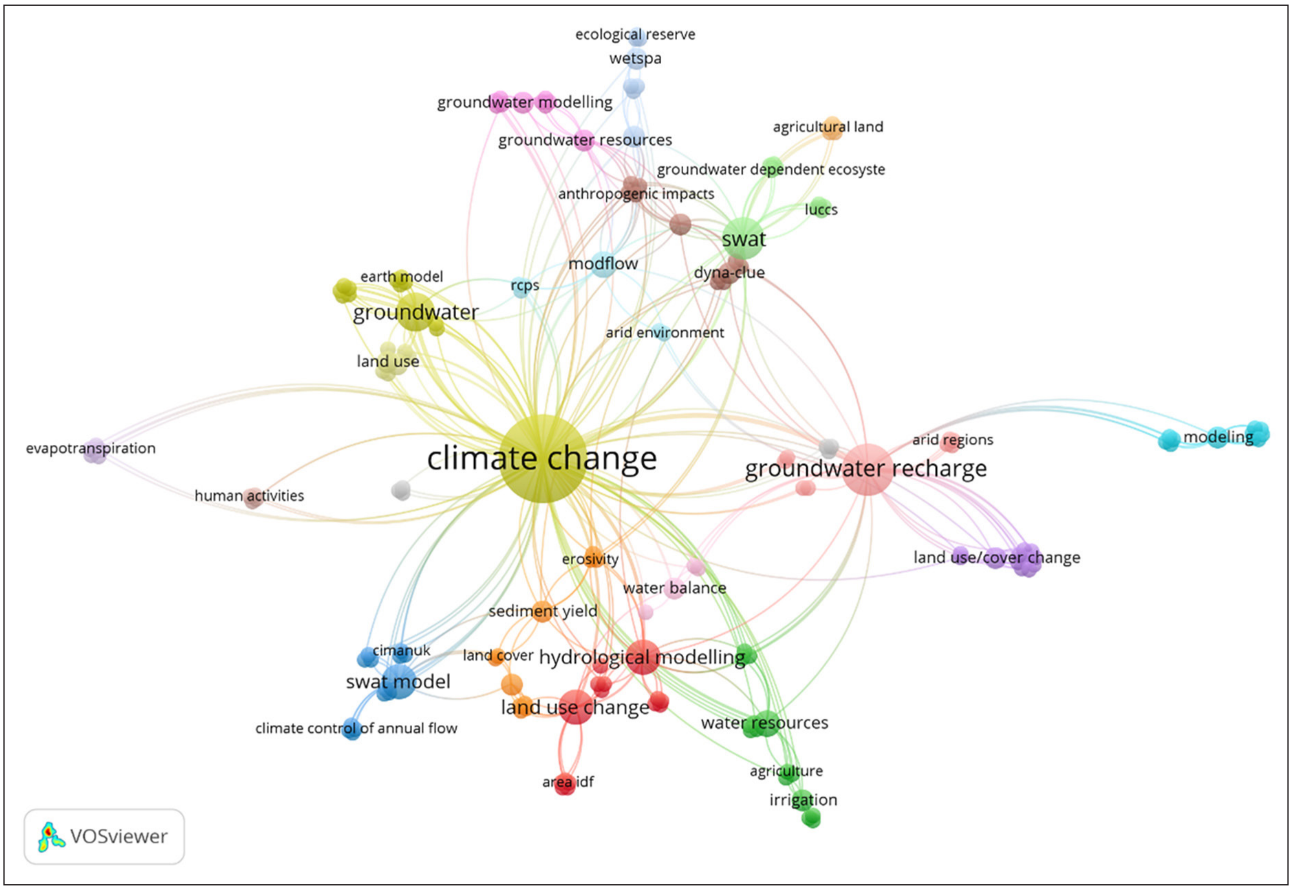

Figure 4. A visually depicted co-word analysis. CC is the most common keyword in studies relating to CLUC impacts on water and groundwater resources.

Other sub-focus areas in groundwater research, such as discharge, groundwater flow and storage, groundwater quality, and groundwater-surface water interaction, are still poorly understood. What is known is that discharge is influenced by precipitation and temperature (Kurylyk et al., 2013, 2015; Gunawardhana and Kazam, 2012). Groundwater flow and storage are less vulnerable to the effects of CC (Pohkrel et al., 2013; Taylor et al., 2013); however, groundwater availability is expected to decrease, especially in arid and semi-arid environments (Amanambu et al., 2020). Moreover, shallow aquifers can be replenished, whereas deep-seated aquifers cannot (Van Rooyen et al., 2020). Alluvial aquifers, for example, are influenced by the effects of surface vegetation cover (Le Maitre et al., 1999). Both CC, LUC and anthropogenic factors influence groundwater quality; anthropogenic influences include over-abstraction of groundwater (Tamm et al., 2018; Bighash and Murgulet, 2015; Klove et al., 2014; Schmidt and Garland, 2012; Earman and Dettinger, 2011; Gurdak et al., 2011; Dragoni and Sukhija, 2008; Gurdak et al., 2007), but it is an area that is still poorly understood (Amanambu et al., 2020). The groundwater-surface water interaction is influenced by CC and landform, geology, and other living biological factors (Sophocleous, 2002); however, more information and research are needed.

In conducting the record review, some other research gaps have been identified:

- The scale of the study in terms of space should ideally be at the plot scale when it comes to assessing groundwater recharge (Moeck et al., 2020) as opposed to catchment scale in the case of streamflow response (Guzha et al., 2018). CC impact studies are best applied on a regional scale (McGregor, H., 2018). LUC studies should be done on a catchment to local/plot scale (Wang et al., 2018).
- The study's time scale needs to be considered; short- to medium-term forecasts will best limit uncertainties (Amanambu et al., 2020; Moeck et al., 2020).
- Combining CC and LUC effects on the groundwater system (Adhikari et al., 2020).
- Variations below the surface also need to be included (Amanambu et al., 2020), such as aquifer features, definition and quantification of boundary conditions, and a better understanding of the dynamics of an aquifer (Viaroli et al., 2019).
- Feedbacks from the groundwater system to CC also need to be incorporated in future studies (Amanambu et al., 2020), for example, vegetation feedback on the water balance.
- Using more field data (Guzha et al., 2018), such as abstraction data and river flow information, is to be encouraged (Touhidul-Mustafa et al., 2019).
- Groundwater modelling also requires integrating surface-groundwater interaction in the unsaturated zone (Amanambu et al., 2020).
- A multi-model approach is strongly recommended when it comes to hydrological modelling (Touhidul-Mustafa et al., 2019).
- Future studies should use different calibration and validation techniques and perform a sensitivity analysis. The last step is necessary to identify and discriminate between the influential and non-influential parameters, which can help reduce uncertainty and simplify the modelling process (Nkhoma et al., 2020; Touhidul-Mustafa et al., 2019).
- Multiple CC, regional climate models (RCMs), and LUC scenarios should be considered in the hydrological modelling phase (Touhidul-Mustafa et al., 2019). Moreover, multiple emissions scenarios should also be considered (Guzha et al., 2018). These methods are needed to make the best possible predictions for future water use under realistic scenarios.

DISCUSSION

This review shows a positive development in CLUC impact studies on water resources, focusing on groundwater specifically. The record review revealed a gap in the research where, amongst other gaps, more localised studies should be done, and fewer generalisations and extrapolations in terms of CC and LUC should be made (Moeck et al., 2020; Guzha et al., 2018; McGregor, 2018). Therefore, a 600% increase in related publications from 2014 (to 2021) (Fig. 3) and ongoing research in 95 countries is significant.

The journals publishing the most CLUC impact articles are primarily based in Europe, America and the United Kingdom (Table 1). However, authors from countries like Thailand, Germany, Finland and America are publishing CLUC impact articles (Table 2) that have been enacted all over the globe (Tables 2 and 3). From the database used for this review, 95 countries were mentioned as sites for research. China has been doing the most local research, followed by India and Ethiopia. Furthermore, many CLUC impact articles have a general or global focus. Regional research in America, Africa and, to a lesser degree, Europe is also evident. East Africa is a hotspot in Africa, specifically Uganda, Ethiopia, Kenya, and Tanzania (Table 3). The results from the authors' details in Table 2 and the listed countries in Table 3 are consistent since China and East Africa are popular areas for research evident from both searches. More attention is paid to local site-specific examples worldwide, which was identified as a literature gap. The localised experiments are now addressing the gap – moving away from very generalised discourse about CC and LUC to more specific applications of CC and LUC. However, localised research to plot scale for groundwater (Moeck et al., 2020) and land use change studies (Wang et al., 2018), catchment scale for streamflow (Guzha et al., 2018) and regional scale for CC (McGregor et al., 2018) still needs to be addressed in other places around the globe, predominantly arid to semi-arid environments.

According to the authors' most contributed research topics, streamflow, non-point-source pollution, river basins, and agriculture are the most researched (Table 2). CC is a research topic for 4 of the top 10 authors listed, followed by LUC, a topic of contribution for 2 listed authors (Table 2). LUC studies are becoming more important as a variable in water impact studies.

Hydrological modelling is frequently used to characterise hydrological processes, whether surface or underground, through physical models, mathematics, and computer technology (Allaby and Allaby, 1999). These developed models can subsequently determine future scenarios wherever they are implemented (Osei et al., 2019; Guzha et al., 2018) and inform mitigation and adaptation measures to prioritise groundwater recharge, for example (Mamo et al., 2021). Various existing models have already been developed and refined; for example, the most common SWAT model (Osei et al., 2019). According to the record review, a multi-model approach is advised, which also considers variations below the surface, such as groundwater flow and storage (Taylor et al., 2013; Amanambu et al., 2020). As evident from the most popular keywords, SWAT and MODFLOW are two models frequently utilised for hydrological modelling. These models have been applied separately in different scenarios or coupled, in which surface and underground water processes were considered. Multiple hydrological models are highly recommended for the most accurate simulation and results (Touhidul-Mustafa et al., 2019). This finding is therefore encouraging. However, surface hydrological models like SWAT cannot always account for groundwater processes and are mainly used for surface hydrological responses to land use and land cover changes (Yan et al., 2018), land degradation (da Silva et al., 2018) and water balance (Osei et al., 2018).

In the context of modelling, there is a research gap regarding groundwater modelling, which is apparent from the lack of keywords in the literature revealed through this study. Groundwater modelling is becoming more common, including variations below the surface and defining aquifer features, as mentioned in the record review results as a knowledge gap. Aquifer features include defining and quantifying boundary conditions and understanding an aquifer's dynamics (Viaroli et al., 2019). The most common model, listed in the most popular keywords, is MODFLOW, created by the United States Geological Survey (USGS) and can illustrate groundwater elements such as flow and storage (Mamo et al., 2021; Amanambu et al., 2020). Other groundwater models include GSFLOW, PRMS (Hunt et al., 2008; Markstrom et al., 2008), and HydroGeoSphere (Maxwell et al., 2015; Brunner and Simmons, 2012). A newer version of SWAT, called SWAT+, is available for use. It is advantageous due to enhanced model performance (Bailey et al., 2020). Physically realistic groundwater flow gradients, fluxes and interactions with stream models (water supply and conservation applications) can be obtained through SWAT+ (Bailey et al., 2020). Additionally, a new groundwater flow model that can be coupled with SWAT+ was also recently developed, called gwflow (Bailey et al., 2020). Gwflow has many advantages, including not needing other groundwater modelling codes like MODFLOW; for example, it does not increase the simulation run time in SWAT+ and is computationally not as complicated and compatible with SWAT+. It is used to understand groundwater flow in watershed hydrologic processes better. Gwflow has been developed very recently, and although it has worked successfully in a case study in the U.S., it has not been calibrated yet (Bailey et al., 2020).

Land use change modelling has been developed over the years but not readily incorporated into research endeavours, according to the lack of keywords. Models such as Dyna-CLUE (Adhikari et al., 2020; Shrestha et al., 2018), Azure (Van Huijgevoort., et al., 2020) and FORE-SCE (Ahiablame et al., 2017) can be used to generate relatively realistic future land use scenarios. Depending on the research, they can also consider land use scenarios such as deforestation, afforestation or urbanisation. Furthermore, land use change detection can be done with time-series satellite imagery that generates 'change' versus 'no change' maps (Albhaisi et al., 2013). These maps are generated with historical data. The best data to use when it comes to collecting land use data is satellite remote sensing data (Gautam et al., 2003), as it provides more layers of information and is a low-cost and time-saving manner to assess LUC on a regional scale (Albhaisi et al., 2013; Rogan and Chen, 2004; Kachhwala, 1985). Geographically weighted regression (GWR) models have been used in one study coupled with a hydrological model (Wang et al., 2018), which made it possible to measure the hydrological response of a catchment to CC and/or LUC down to each pre-defined hydrological response unit. This method takes local hydrological variations such as discharge (Rennermalm et al., 2012), mean annual precipitation (Yue et al., 2013), annual runoff (Chang et al., 2014) and, lastly, surface water quality (Chen et al., 2014; Tu and Xia, 2008) into account. However, no such study for groundwater has been found.

As reflected in the bibliometric analysis, more recent studies show that CC and LUC are now more explicitly linked with a focus on water (Table 1). Furthermore, a greater focus on LUC linked with CC is evident (Table 4 and Fig. 4) from the keywords most frequently used, particularly land use and land use change, irrigation, urbanisation, and human activities. It seems that LUC and urbanisation are most frequently linked, which is unsurprising given the rate at which built-up impervious surfaces are increasing around the globe. The urbanisation percentage is currently at 56% in December of 2021, which denotes the number of people living in urbanised areas, i.e. cities (Szmigiera, 2021). This percentage is on the rise.

There is still a prevailing gap in the research since urbanisation seems to be the main focus of LUC, and other significant aspects of land change are being overlooked. For example, irrigation, or in other words 'artificial discharge', is considered to be field data, and was mentioned in the list of most popular keywords, and was also recommended to be incorporated into CLUC impact studies on groundwater (Guzha et al., 2018; Touhidul-Mustafa et al., 2019). Even though this is a positive finding in light of emerging research trends, only two occurrences were mentioned, which is insufficient. A few implications for overexploitation of groundwater are that it affects recharge and groundwater levels negatively (Berhail, 2019; Touhidul-Mustafa et al., 2019; Mamo et al., 2021), can cause land subsidence in arid/semi-arid environments (Andaryani et al., 2019), and a decline in the observed water table will render shallow boreholes, hand-dug wells and springs drying up, and increase the cost of abstraction (Mamo et al., 2021). Lastly, increasing abstraction rates causes seasonal fluctuations in the water table, which could also influence pumping costs, biodiversity of aquatic ecosystems and water quality (Cochand et al., 2021). Groundwater abstractions exhibit spatiotemporal controls that follow cropping seasons and precipitation signatures and are also more prevalent in farmlands and industrial areas than forests (Touhidul-Mustafa et al., 2019). Local research incorporating irrigation and groundwater abstraction rates is crucial, which would also be the case of the BGWMA due to the extent of irrigated agricultural activity in the WMA (Van der Berg, 2017).

Other research gaps, particularly in the case of the BGWMA, are afforestation and deforestation, which are critical aspects of LUC. These forms of LUC are critically important in many parts of the globe. We have seen, for instance, that removing invasive species could increase groundwater recharge (Albhaisi et al., 2013; Le Maitre et al., 1999) and removing pine plantations can cause the water table to rise and increase discharge (Varet et al., 2009). The deeper the rooting depths of trees, the more water will be extracted from the related groundwater stores (Le Maitre et al., 1999). Furthermore, changes in vegetation can affect groundwater recharge rates and water-table depths (Le Maitre et al., 1999). More research on LUC and aspects of afforestation and deforestation is needed. Furthermore, even though LUC is now being considered as a variable more frequently than CC, CC is still the main focus, and this is despite some of the latest research that has found there are cases where LUC has a more significant impact on water resources than CC, especially around groundwater concerns (Viaroli et al., 2019). The significance of LUC cannot be underestimated.

The results of a few studies focusing on both CC and LUC impact on groundwater resources proved that both variables are important to consider when analysing the impact since their respective impacts have distinct implications. Cochand et al. (2021) found that groundwater dynamics on the Swiss Plateau, East of Lake Biel, were more sensitive to LUC than CC due to increased irrigation, and concluded that both CC and LUC should be considered when it comes to water resource studies. The impacts of CC were outweighed by LUC and abstraction impacts in the groundwater system of the Veluwe, a large strategic groundwater reservoir in the Netherlands (Van Huijgevoort et al., 2020). They also found that before the early 19th century, LUC was the most significant contributor to a decline in groundwater recharge over the entire period, after which groundwater abstraction played a more significant role in the decline of the observed recharge. Groundwater depletion due to CC, LUC and population growth in the Central Valleys of Oaxaca in Mexico was studied by Olivares et al. (2019). The authors found that climatic conditions mainly influenced groundwater recharge in the area and claimed that despite a projected increase in annual precipitation, a rise in temperature and evapotranspiration would cause a decline in recharge. Furthermore, population growth leads to an increase in groundwater abstraction. Groundwater is, therefore, a high-risk resource due to fluctuating recharge and human activities. These results are site-specific.

In South Africa and the BGWMA, no CC and LUC impact study on groundwater has been done. All the knowledge gaps need to be addressed, which include smaller scale studies in terms of time and space, and combining the effects of CC and LUC. Variations below surface and aquifer features need to be assessed and incorporated, more field data need to be incorporated, such as abstraction rates, multiple models need to be applied, and multiple CC, LUC and emissions scenarios need to be accounted for. These steps are all essential for water planning and management for the future, especially since South Africa is deemed a water-scarce country (Population Action International, 2012).

CONCLUSIONS

The results of this study were beneficial in determining the bibliometric structure of the impact of CC and LUC on water and groundwater resources and highlighting the current research gaps and recommendations for future research in this regard. Publications are on the rise, and more recent literature has shown that LUC is also being considered alongside or in place of CC. The literature also shows that more local research cases are evident since research is being enacted in more and more countries. However, despite more localised research, most of the research enacted is in China or a general context. More research is needed, keeping in mind more minor spatiotemporal scales. Multiple hydrological models are also being incorporated into CLUC impact studies, but groundwater and land use change models could be used more often. Furthermore, the need for a stronger focus on LUC has been identified; the diverse and multiple forms of land use are not yet adequately addressed. When LUC is addressed, it is usually in the urban context, and the urban implications can vary significantly from that of afforestation or deforestation and irrigation demands. The impact of CC versus LUC is relatively new, but it has been recommended to include both areas in water and water-related research. This bibliometric analysis picks up on the trend that CC and LUC studies are becoming more common, but there is still a way to go before CC and LUC become an established and robust area of research, especially in South Africa and in the BGWMA. All of the knowledge gaps identified in this study must be addressed in the BGWMA and many other WMAs in South Africa.

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AUTHOR CONTRIBUTIONS

Dr Kanyerere and Prof Jovanovic assisted as supervisor and co-supervisor, respectively. They assisted in the methodology and, with Prof Goldin, in writing, reviewing, and editing this paper. All authors have read and agreed to the published version of the manuscript.

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