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Integrated modeling of hydrological processes and groundwater recharge based on land use land cover, and climate changes: A systematic review

Jacob Kofi Mensah [a,b,c,*], Eric A. Ofosu [a,c], Sandow Mark Yidana [d], Komlavi Akpoti [a,e], Amos T. Kabo-bah [c]

[a] Regional Center for Energy and Environmental Sustainability, University of Energy and Natural Resources (UENR), Sunyani, Ghana
[b] Department of Water and Sanitation Engineering, Tamale Technical University, Tamale, Ghana
[c] Department of Civil and Environmental Engineering, University of Energy and Natural Resources (UENR), Sunyani, Ghana
[d] Department of Mathematical and Physical Earth Sciences, University of Ghana, Legon, Ghana
[e] International Water Management Institute (IWMI), Accra, Ghana

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ABSTRACT

Groundwater is the main available freshwater resource and therefore its use, management and sustainability are closely related to the Sustainable Development Goals (SDGs). However, Land Use Land Cover (LULC) and climate change are among the factors impacting groundwater recharge. The use of land-use and climate data in conjunction with hydrological models are valuable tools for assessing these impacts on river basins. This systematic review aimed at assessing the integrated modeling approach for evaluating hydrological processes and groundwater recharge based on LULC and climate change. The analysis is based on 200 peer-reviewed articles indexed in Scopus, and the Web of Science. Continuous research and the development of context-specific groundwater recharge models are essential to increase the long-term viability of water resources in any basin. The long-term impacts of natural and anthropogenic drivers on river basin interactions require integrating knowledge and modeling capabilities across biophysical responses, environmental problems, policies, economics, social, and data.

1. Introduction

Global freshwater extraction was estimated at 3.99 trillion m^3 in 2014 (Ritchie and Roser, 2017). Many semi-arid and dry countries, including the Middle East and North Africa (MENA) region, depend largely on groundwater for their freshwater demands (Jakeman et al., 2016). The primary causes of groundwater depletion in Africa between 2003 and 2009 were drought and overexploitation estimated at 143.6 km^3 (Atawneh et al., 2021). Effective groundwater management is hindered by climate change and anthropogenic processes resulting in poor water quality and low water levels. Groundwater availability is decreasing owing to climate change and pollution, while population growth and expansion in irrigated agriculture are causing a significant rise in demand and therefore aquifers would undoubtedly diminish (Wada et al., 2016). While global population, Gross Domestic Product (GDP), and water demand would be uneven, thereby causing challenges to about 30% of the major groundwater systems of the world (Richey et al., 2015), groundwater extraction for irrigation will increase by 39% by 2050 (Wada et al., 2016). While increasing irrigation water usage may increase basin-wide water depletion (Huffaker, 2008), many regions have no idea of the quantities of groundwater in these basins. Therefore, the increase in the usage of this invaluable resource without knowing its status is a recipe for future water crises (Richey et al., 2015; Scanlon et al., 2016).

Cuthbert et al. (2019) noted that climate change would present challenges to approximately 44% of aquifers across the world to recharge in the next century, particularly the shallow groundwater wells. They predicted that the consequences of current climate change on groundwater will be seen in most parts of the globe and therefore understanding aquifer recharge is critical for analyzing climate impacts. Dragoni and Sukhija (2008) defined groundwater recharge as a residual flow of water contributed to the saturated zones due to evaporation, evapotranspiration and runoff losses of precipitation which sometimes happens through diffuse infiltration. Climate change, LULC, geology, and slope all affect groundwater recharge.

Groundwater recharge and sustainability are critical challenges for the world's fastest-growing population areas, particularly the arid and semi-arid regions that depend on the resource for domestic, industrial,

* Corresponding author at: Regional Center for Energy and Environmental Sustainability, University of Energy and Natural Resources (UENR), Sunyani, Ghana.

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and agricultural needs. Therefore, the establishment of good groundwater management systems is crucial to achieving the SDGs. However, the effects of urbanization have been experiential in numerous ways such as runoff changes and drought, recharge of groundwater, scarcity of water due to increasing demand and others (Lamichhane and Shakya, 2019). Management of LULC is essential for sustainable use of groundwater resources, as well as climate change adaptation and mitigation. To accomplish this, an integrated approach to groundwater recharge is essential to guarantee a correlation between recharge and abstraction and also to understand the influence of LULC and climate change on the spatiotemporal distribution of recharge (Götzinger et al., 2008; Rukundo and Doğan, 2019; Yifru et al., 2020; Zomlot et al., 2017). The locations, volumes, and timing of groundwater flow and recharge are changing globally as a consequence of growth in agriculture, industry, population and climate change (Han et al., 2017; Manna et al., 2019). This tends to have an unavoidable impact on groundwater quality (Tweed et al., 2011; Xu et al., 2021) and also its availability. Groundwater depletion in some parts of the world owing to rising anthropogenic activities has presented a danger to regional water supplies, particularly in river basins with substantial irrigated agriculture (Liu et al., 2018; White et al., 2014; Zhang et al., 2014). To be able to predict and manage groundwater systems and the continuous increase in water supply, groundwater recharge dynamics and drivers are vital to understanding the resource. (Han et al., 2017; Shuler et al., 2021).

Climate change is one of the recent key hydrological research problems (IPCC, 2014). An ensemble of climate change scenarios has become the standard practice for analyzing the effects of climate change on hydrological systems and water resources availability due to high uncertainties in climate forecasts (IPCC, 2014; Stoll et al., 2011) and the unknown future greenhouse gas emissions. Thus, "*very little research has been done on the influence of climate change on groundwater, or how land-use and land-cover modify the hydraulic relationship between surface waters and aquifers*" (Pachauri & Reisinger, 2007). It is also difficult to get a broader perspective of the groundwater response to climate change due to human-induced changing land use and excessive utilization. However, the issue of generalizing hydrological processes in structural models (land use, soil, slopes) has been overlooked (Dams et al., 2008; Refsgaard et al., 2016). The challenges of structural uncertainties in hydrological models may be overcome by using an ensemble of models with similar boundary conditions. However, multi-model ensemble studies in hydrology are uncommon unlike studies in meteorology and climatology (Dams et al., 2015). Nonetheless, for appropriate groundwater development, there have been disagreements about models that simulate recharge and at the same time properly evaluate a basin's hydrology (Gosling et al., 2011; Ludwig et al., 2009). There are many challenges when trying to build relatively low strategy and water resource security without a proper grasp of hydrologic components, which may cause serious problems and incorrect predictions. Besides, some groundwater recharge assessment models are not appropriately connected to surface water analyses and hence the impact of LULC and other hydrological processes are ignored (Kim et al., 2008). It is critical to recognise that each model has its benefits and limitations for modeling biophysical processes. While some models only simulate surface and shallow groundwater dynamics, others simulate flow processes at a continuous volume defined by three-dimensional cells and hydrogeological characteristics (Arnold et al., 2012).

A detailed understanding of groundwater inputs and outputs is required to guide water management choices for future planning and policy. In addition to analytical regression equations (Shade and Nichols, 1996), surface water models (Arnold et al., 1998) and coupled saturated and unsaturated zone models are prominent approaches for estimating groundwater recharge (Westenbroek et al., 2016). Land-cover change uncertainty complicates water supply modeling, and its changes have influenced the hydrologic cycle (Abbott et al., 2019). Due to population growth and its implications on built-up expansion, impermeable surfaces turn to reduce groundwater recharge and other hydro-climatic components (Chithra et al., 2015; Izuka et al., 2018). However, it is difficult to estimate land-use patterns due to the influence of social, environmental, and economic factors (Veldkamp and Lambin, 2001; Han et al., 2015). Scenario-based techniques to predict LULC and climate change are extensively employed to account for this uncertainty and estimate groundwater recharge (Kepner et al., 2012; Brewington et al., 2017). Moreover, the long-term impacts of natural and anthropogenic drivers in river basin interactions require integrating knowledge and modeling capabilities across biophysical responses, environmental problems, policies, economics, data, and computer capabilities (Guzman et al., 2015). Model integration aims to increase the quantitative capability to rigorously analyze hypotheses and system behavior under dynamic circumstances (Arnold et al., 2012). Continuous study and the development of context-specific groundwater recharge models are essential to increase the long-term viability of water resources in any basin. Several review studies have been conducted to assess the impact of climate change on groundwater recharge (Amanambu et al., 2020; Atawneh et al., 2021; Bovolo et al., 2009; Castillero et al., 2021; Costa et al., 2021; Dragoni and Sukhija, 2008; Holman et al., 2012; Hu et al., 2019; Jia et al., 2020; Niu et al., 2014; Taylor, Todd, et al., 2013).

Using a bibliometric review technique, Castillero et al. (2021) projected the global attention and advancements in climate change and aquifer recharge. They established that temperature rises have caused the fast melting of snow and glaciers at regions of high elevations, thereby leading to an increase in recharging capacity. On the other hand, the worst estimates for losses in recharge were found in arid and semi-arid regions. Atawneh et al., (2021) provided a systematic review of climate change and its projected values on the impact of groundwater recharge. Results show that climate change may directly affect future groundwater recharge. Based on groundwater recharge projections, an overall negative impact on groundwater recharge emerged, regardless of emission scenarios or time horizons used. Amanambu et al. (2020) investigated the status of groundwater systems and the potential consequences of climate change. They also assessed the coupling of groundwater and climate change models used in groundwater hydrologic processes for improving existing insights into climate/groundwater interactions. They established that most models predict declines in groundwater levels, recharge and storage, particularly in arid/semi-arid regions. Jia et al., (2020) studied the global engagements in the development of sustainable groundwater during the last 40 years (1978 to 2017) using the bibliometric review method. They found a 10% yearly increase in groundwater research output throughout their investigation. Taylor et al. (2013) assessed the consequences of climate change on groundwater, by both natural and anthropogenic processes. They discussed the value of groundwater services in climate adaptation and the paucity of groundwater observations that limits understanding of groundwater-climate interactions. Holman et al. (2012) reviewed the use of climate model projections, advances in hydrogeological coupling and the inclusion of socioeconomic aspects as best practices for understanding the connections between groundwater and climate change. They made the following suggestions: (1) reduce model uncertainty by combining several climate scenarios from Global Circulation Models (GCMs) or Regional Circulation Models (RCMs); (2) use different emission scenarios from the Intergovernmental Panel on Climate Change (IPCC) Special Report; (3) consider the consequences of downscaling; (4) incorporate systemic inaccuracies and model uncertainties in hydrogeological models, and (5) ensure ensembles of climate forecasts and maintain hydrogeological models are combined. Bovolo et al. (2009) found in their review that implementing strategies to respond to climate-driven hydrologic changes, as well as additional pressures from LULC changes and population growth, will be the challenge for groundwater management in the twenty-first century. A study by Dragoni and Sukhija, (2008) investigated the relationship between groundwater and climate change, as well as a summary of current insights into the links between climatic fluctuations and groundwater resources. They found that discrete resource management requires

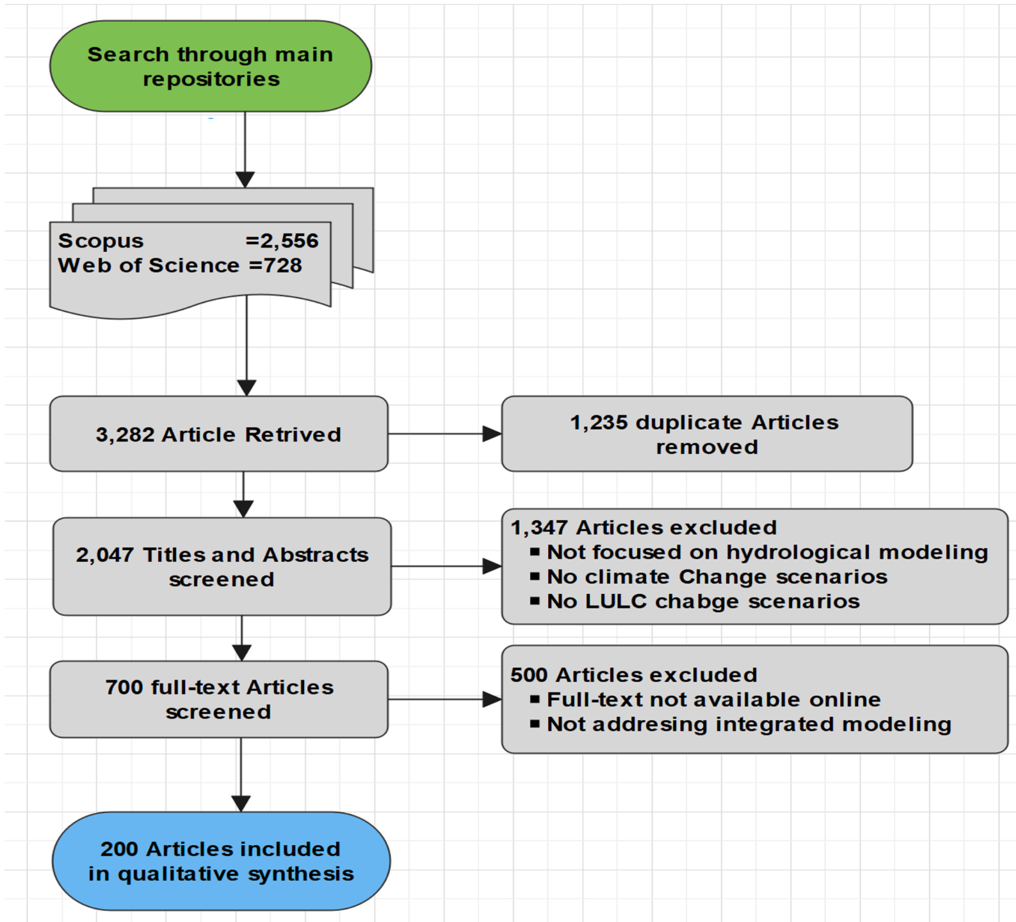

Fig. 1. Process flow diagram for the selection of studies using PRISMA.

comprehensive research that incorporates all the critical aspects that influence the occurrence and geographical distribution of resources. Among the several studies conducted on the impact of climate change and groundwater recharge only Mohan et al. (2018), and Owuor et al. (2016) provided a global meta-study on predicting groundwater recharge for varying land cover and climate change conditions. Mohan et al. (2018), examined 715 locations globally and created a groundwater recharge map with values ranging from 0 to 1375 mm/yr, with dry areas in Australia, the Middle East, and the Sahara experiencing the least recharge (1 mm/yr). However, no future groundwater recharge values were projected in this investigation. Owuor et al. (2016) reviewed 27 studies to determine how LULC affects groundwater recharge and surface runoff (2 modelings and 25 experimental). Overall, compared to other land uses in semi-arid tropical/subtropical environments, forests cover has lower groundwater recharge and discharge rates. Restoration of bare land reduces groundwater recharge from 42% of rainfall to 6% and 11% contingent on the absolute LULC.

Groundwater recharge is controlled by a variety of elements including climate, vegetation, unsaturated area, flow mechanism and thickness of the aquifer (Walker et al., 2019; Wang et al., 2020). Therefore, this systematic review seeks to examine the impacts of climate change and LULC on groundwater recharge. It also examined the modeling approaches for measuring groundwater recharge under changing LULC and climate change. There are four sections to the systematic review: A short overview of climate change and anthropogenic activities, as well as their influence on hydrological processes and groundwater, is provided in Section 1, which also includes previous research, methodologies employed, and their aims and conclusions. Section 2 provides an overview of the materials and methods used, the research design, and the creation and summary of the literature catalogue. Section 3 contains the results and discussions, including key findings such as the impact of LULC and climate change on groundwater recharge and the current state of recharge globally, while Section 4 concludes the findings.

2. Materials and methods

2.1. Design of the study

A systematic literature review was conducted to determine the usefulness of an integrated modeling strategy for predicting groundwater recharge under changing climate and land use land cover changes. The Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) was employed based on Page et al. (2021). It is a method of study that summaries and synthesizes the findings of existing literature on a certain research subject or field, providing a chance to discover significant ideas, research gaps, forms of evidence to influence practice, and policymaking (Akpoti et al., 2019; Donthu et al., 2021). It also highlights the scientific evidence of the link between variables while revealing correlations that have not been investigated. Besides, the systematic review was employed due to the specific nature of the scope of the review.

2.2. Summary of literature selection

The systematic review process captured articles through some of the main repositories including, the Web of Science and Scopus. For the preliminary investigation, Boolean search in scientific research engines

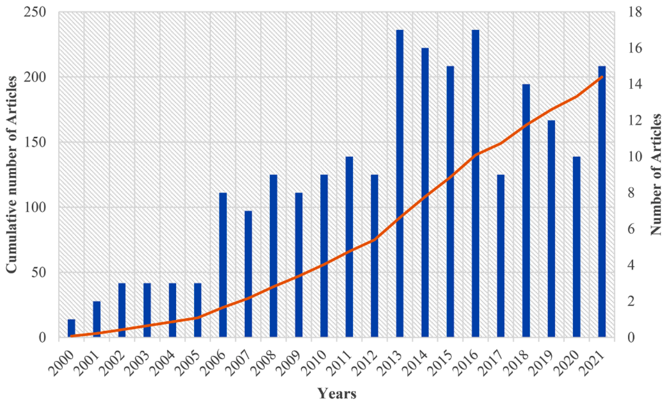

Fig. 2. Between 2000 and 2021, the number of publications is projected to increase. The bar graph depicts the number of articles read per year, while the line graph depicts the total number of articles reviewed over time.

and platforms were utilized, with an emphasis on keywords such as integrated modeling, land use and land cover change, hydrological responses, climate change, groundwater recharge, and other specific known techniques (GIS, SWAT, MODFLOW, WETSPAS, and so on) at the local, regional, national, and global levels. In all, 3282 articles were obtained because of the searches executed through all sources. After excluding 1235 duplicate articles, a total of 2047 articles were left for screening, and a further 1347 articles were deleted after filtering titles and abstracts. The complete texts of 700 possibly suitable articles were reviewed to determine their relevance. After this stage of filtering, 500 papers were eliminated, allowing 200 for inclusion in the review. Articles that were more than 10 years of age were largely omitted from the list, with a focus on those connecting future land use and land cover changes and groundwater recharge to climate change, in keeping with the objectives of the review. The PRISMA flow chart (Fig. 1) summarizes the screening procedure.

A random selection of review articles released in the last decade (2000–2021) were those considered for the analyses, it does not however include conference proceedings. The search was restricted to English-language peer-reviewed journal papers. The journals chosen had enough material regarding GW recharge modeling in connection to LULC, the majority of which indicated the possibility of modeling GW recharge or surface-groundwater interactions, as well as hydrological modeling. The collection included a total of 200 scholarly articles as shown in (Fig. 2).

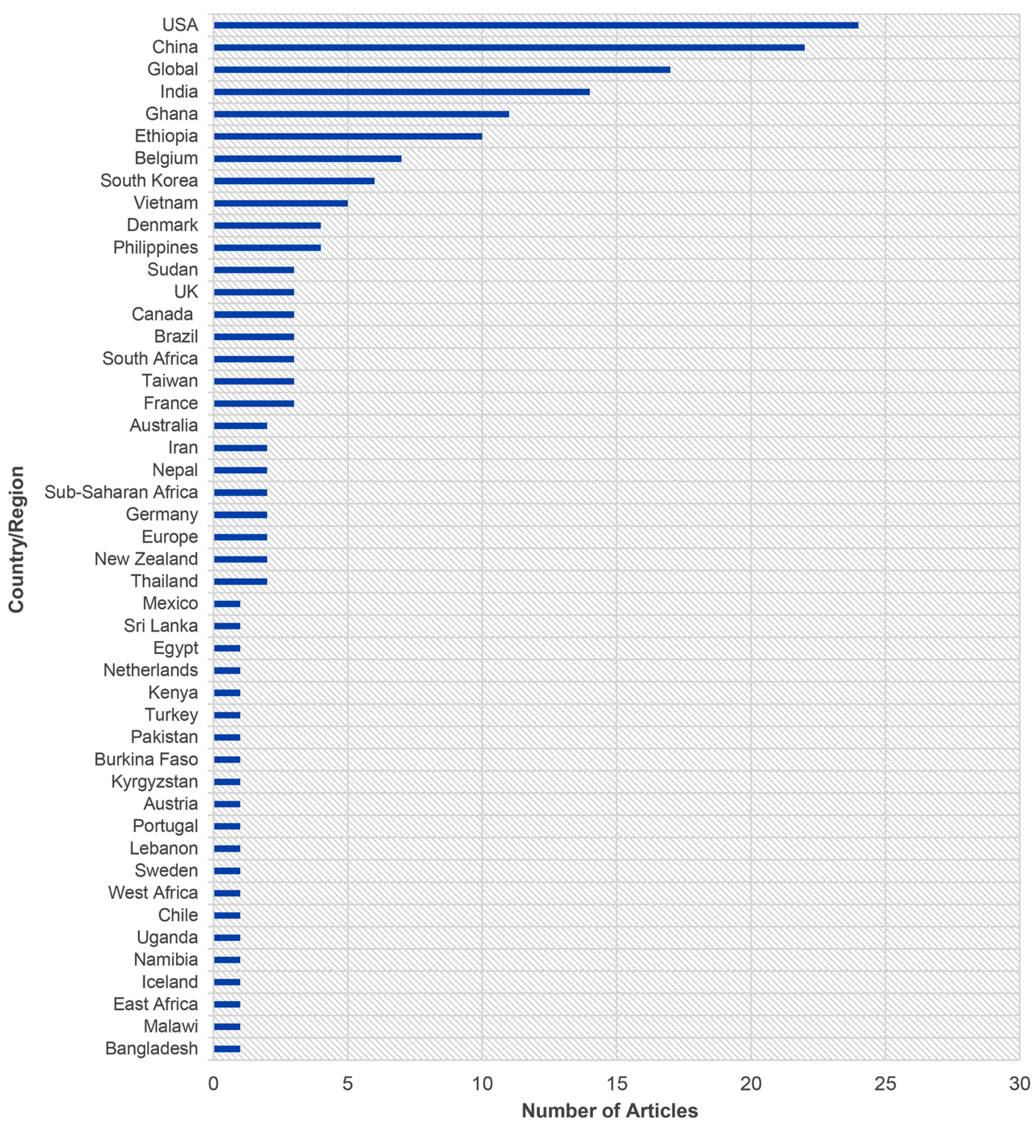

Fig. 3. Number of publications per country (2000 to 2021) for this study.

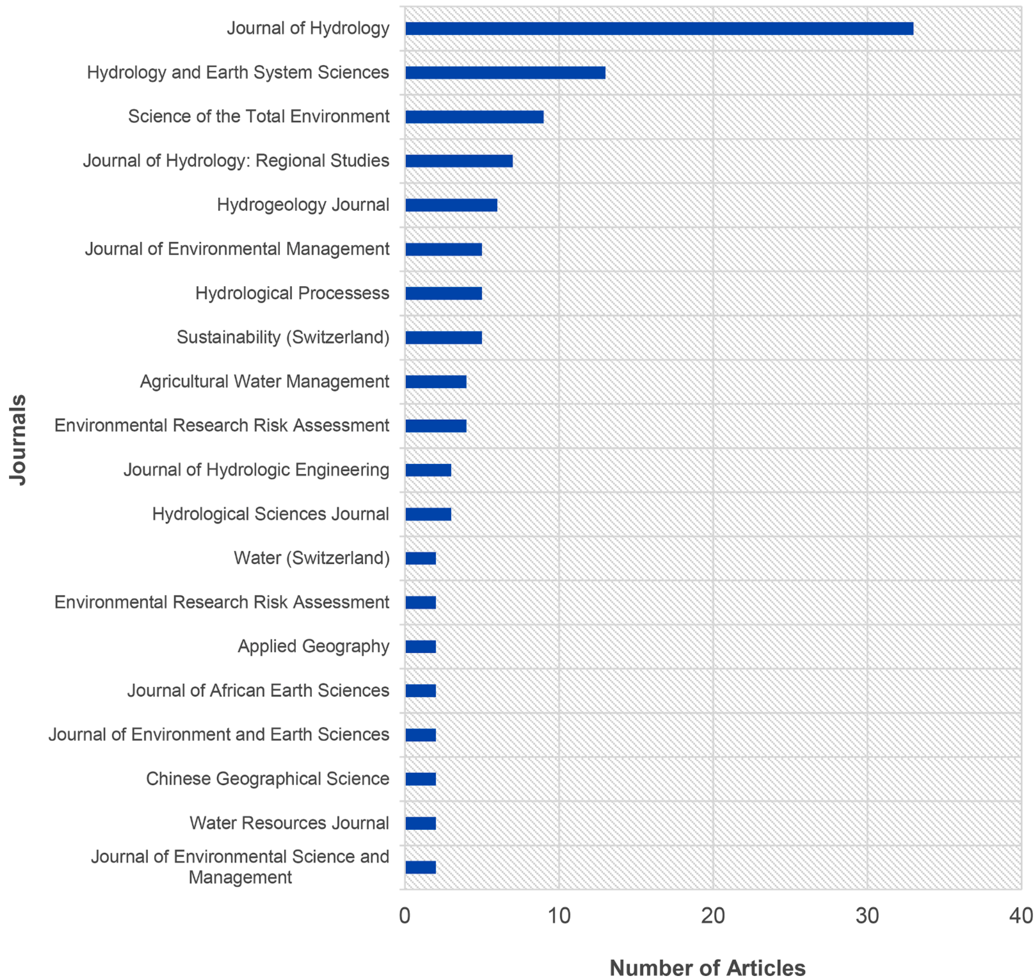

Fig. 4. Journal publications reviewed (Displayed are Journals with more than one paper reviewed).

2.3. Summary and development of a catalogue

The number of scientific articles reviewed for this publication is from America, Africa, and Asia. Over 50 countries contributed 180 peer-reviewed publications, with 61 from Africa, 49 from Asia, 43 from America, 24 from Europe, and 2 from Australia. Furthermore, there were 11 publications examined from Ghana, with 24, 21, 10, and 14 from the United States, China, Ethiopia, and India respectively. Fig. 3 displays the complete list of countries from which journals were collected for this study's analysis.

Between 2000 and 2021, the sum of published literature on the use of hydrological models to estimate land use land cover and climate change impact on the recharge of groundwater has seen an exponential rise (Fig. 2). These articles were included in 120 journals related to hydrology, hydrogeology, environment, and related topics. Fig. 4 displays the complete list of Journals that were accessed, and the number of articles accessed from each outlet.

3. Results and discussions

3.1. Impact of Land Use Land Cover (LULC) and climate changes on hydrological processes

The two most important occurrences impacting water regimes globally are land-use and climatic changes (Brown et al., 2014; Chung et al., 2011). Urbanization is the second leading cause of land-use change, impacting ecosystems after agriculture (Paul and Meyer, 2001). However, increased urbanization has resulted in impermeable surface development, which affects the hydrologic features of watersheds globally (Schueler et al., 2009; Wagner et al., 2013). In addition, these impermeable surfaces created inside watersheds often affect hydrologic stability and the individual water balance components (Chen et al., 2017). That notwithstanding, Sathish Kumar et al. (2013), Sunde et al. (2016), and Wu et al. (2015) have recognized urbanization and impermeability development would alter streamflow, surface runoff, and baseflow, resulting in evapotranspiration decreases (Miller et al., 2014; Sunde et al., 2016). Several previous investigations have endeavored to address the issue of how hydrologic systems adapt to urbanization and agricultural growth (Choi and Deal, 2008; Lin et al., 2008).

Climate change may affect watershed hydrologic systems by altering temperature and precipitation regimes (Arnell and Gosling, 2016; Siabi et al., 2021; Yeboah et al., 2021). Extreme precipitation occurrences have risen during the last century in the Midwest, according to Richmond and Yohe (2014), contributing to surface runoff and streamflow increases (Georgakakos, 2014; Jiménez Cisneros et al., 2014). Moreover, as climate projections indicate, both the rate and magnitude of such extremes may continue to rise in the future decades (Sun et al., 2016; Walsh et al., 2014). These temperatures are now increasing over West Africa, and climate estimates show that they will continue to rise throughout the coming years (Romero-Lankao et al., 2014; Sun et al., 2016). It is projected that these temperature increases would lead to increased evapotranspiration (ET) and reduced soil moisture, impacting infiltration over much of the Midwest region of the United States (Walsh et al., 2014). Some of these hypothetical changes have been studied in past research, especially in developing countries where climate model forecasts have been combined with hydrologic models to assess potential climate change effects on water systems (Chien et al., 2013; Hayhoe et al., 2010; Jin and Sridhar, 2012; Mohammed et al., 2015; Vo, Ngoc Duong, Gourbesville et al., 2016; Xu et al., 2013).

Climate change impacts on hydrologic processes such as surface runoff, streamflow, baseflow, and evapotranspiration have been documented in most parts of the world. (Dams et al., 2015; Ficklin et al., 2010; Joh et al., 2011; Ouyang et al., 2015). There are many catchments in which both land use and climate change are taking place simultaneously, making it difficult to ascribe observed changes in water regimes to either of these stresses since their relative influences differ (Giri et al., 2020; Mishra et al., 2014; Persaud et al., 2020; Praskievicz and Chang, 2009). Most researchers have used integrated modeling methodologies employing LULC change, climate, and hydrologic models to evaluate the discrete and coupled hydrologic implications on groundwater recharge and sustainability. Climate change has been shown to have a greater influence on water regimes than land-use changes in certain areas (Arfanuzzaman and Atiq Rahman, 2017).

Integrated modeling is needed to better understand how future climate and land-cover changes may affect watersheds in different regions. Most urban watersheds might benefit greatly from the use of fine-scale urban development predictions, downscaled climate projections, and process-based hydrologic models to produce insights for water resource managers. Simplified and integrated hydrological modeling, or distributed and theoretical modeling, are the integral parts of these approaches. (Thanapakpawin et al., 2007), used a distributed hydrology model to simulate crop-to-forest reversal and forest-to-crop expansion scenarios based on land-cover transitions detected from 1989 to 2000. All previous approaches have used similar models, and the use of physically-based, comprehensive, distributed hydrological models differs from earlier techniques (Niehoff et al., 2002; Oogathoo, 2006). The MIKE-SHE model was used by Im et al. (2009) to investigate a watershed's reaction to changes in land use. Using Landsat images and five land-use classes, they found a link between an increase in urbanization (10%), an increase in total runoff (5.5%) and overland flow (24.8%).

Tam and Nga (2018), assessed the impacts of urban developments on groundwater resources. The objectives of their assessment included change in land use and groundwater abstraction increases owing to the growth of the urban population, climate, land use, and other parameters were used in conjunction with WETSPA and MODFLOW, which are integrated hydrological simulation models. Rainfall infiltration accounts for 53.6% of groundwater recharge systems, 31% from seepage of rivers and lakes, and leakage from municipal water supply networks accounted for the remaining 15.4%. General abstraction of groundwater and urbanization-caused impervious areas was identified as triggering the reduction in groundwater levels and an insignificant reduction of groundwater recharge respectively. Awotwi et al. (2015) used SWAT to assess the hydrological influences of changes in LULC on water balance. The findings show that decreasing land cover reduces surface water and base flow while increasing evapotranspiration (ET) increases annual water yield under different LULC. Wagner et al. (2013) used the SWAT hydrologic model, to investigate the impacts land use changes on runoff and evapotranspiration in the catchments of Pune and concluded land use impact on water resources. The research investigated historical land-use changes and their consequences on hydrology between 1989 and 2009 and found that land-use change drives rapid socio-economic development. The researchers linked two model runs using 1989/1990 and 2009/2010 land use categories. The primary land-use changes identified were an increase in urban area from 5.1% to 10.1% and farmland from 9.7% to 13.5% during the 20 years. Nonetheless, urbanization increased water yield by 7.6% at the sub-basin scale, while increasing farmland resulted in a 5.9% rise in evapotranspiration.

The MIKE-SHE model was used by Oogathoo (2006) as a means of examining the influence of different watershed scenarios management on hydrological systems by utilizing land-use increase or decrease percentages (increase urbanization from 0.2% to 2%). There was a considerable increase in deforestation (11%) whereas, with tile drainage application, the results obtained showed a decrease in high runoff peaks. The same approach was used by Niehoff et al. (2002) for the prediction of change in land use scenarios, wherein a percentage increase in the existing land-use composition was used to examine the influence of these changes on hydrological processes (WaSiM-ETH).

Fohrer et al. (2005), used the IOSWAT model to investigate the impact of diverse and distinct average agricultural lands provided by the ProLand model on hydrological processes. Their analyses outlined that improving the evaluation of future land-use changes on hydrological processes requires accurate forecasting, considering prevalent regional land uses. Analogously, the features of the physical catchment that may be influenced by the changes might be investigated using a regionally distributed, physically based hydrological model. Moreover, the authors concluded that complete hydrology should be included throughout the examination to achieve an enhanced, accurate, and comprehensive understanding of the catchment. Spatially explicit land-use change models may be used to model confined land-use changes with time that demonstrate substantial modifications in landscape configurations (Wakode, 2016; Wijesekara et al., 2012). Besides, comparing a spatially distributed hydrological model that operates on both land-use-based and non-land-use-based physical parameters would provide more comprehensive and presumably more accurate results than a lumped-level model (Jens Christian Refsgaard, 1997). A distributed hydrological model WETSPA was used by Albhaisi et al. (2013), to analyse land-use impacts of change and its prediction on groundwater recharge. The results revealed that changing land cover increased groundwater recharge. Mengistu et al. (2019), employed SWAT and HSPF models to analyze hydrological responses to changes in LULC and management strategies and identified that the change in LULC pattern modified the rainfall-runoff relationship and significantly increased runoff.

Existing information on LULC's long-term consequences on hydrology has been revealed by the use of hydrological models (Fletcher et al., 2013). These models allow the effects of temporal and spatial changes to be established on the simulated hydrological response, including LULC influences and impervious cover expansion. The impermeability of the urban landscape is commonly ignored in model-based investigations of LULC effects (Gerard et al., 2010; Tavares et al., 2012). It is consequently common that hydrological models typically parameterize land use at incorrect geographical and temporal scales (Dams et al., 2008), meanwhile, effective impervious area and spatial connectivity have been demonstrated to be significant hydrological modeling elements (Han and Burian, 2009; Mejia and Moglen, 2009).

3.2. Groundwater recharge under changing LULC and climate

Climate patterns and land-use changes have the potential to significantly alter hydrological processes, hence affecting groundwater supply and quality. While hydrological conditions will be modified by climate change, it will also affect groundwater resources indirectly via their interaction with surface water bodies (Jyrkama and Sykes, 2007). Thus, the effects of climate change on groundwater measurements entail forecasting the interaction of groundwater systems and the development of hydrological variables. However, a good evaluation of these variables is challenging, since they are dependent on many physical parameters that are highly spatiotemporal. A rise in temperature and evapotranspiration in the Mediterranean according to climate and land-use analyses points to these variabilities (Chaouche et al., 2010; Molina-Navarro et al., 2014). While not all research agrees on evidence of a declining trend in annual precipitation, some agree on a shift from the precipitation pattern (Chaouche et al., 2010; Molina-Navarro et al., 2014). Together with land-use changes, these altered patterns will result in a reduction in recharge to aquifers (Ertürk et al., 2014). Therefore, there are reductions in water levels and groundwater discharges, which may harm water supplies and ecosystems depending on groundwater

(Kløve et al., 2014). These consequences would be more pronounced in closely coupled groundwater basins and worsened by increased water abstraction to meet rising demand. Hence, understanding future recharge and discharge patterns because of these stresses is crucial for integrated water management. A watershed's surface processes may be analyzed using numerical hydrological models that take into account the consequences of global warming (Caballero et al., 2007; Mango et al., 2011; Shrestha et al., 2013). These models are also effective for addressing uncertainty regarding climate change's influence on hydrological systems (Xu et al., 2011). Groundwater systems (climate, land use, water needs, adaptability, etc.) can only be accurately predicted if hydrogeological processes are linked together (Holman et al., 2012; Pulido-Velazquez et al., 2015). Nevertheless, developing integrated models is challenging, since it necessitates making assumptions that exclude comprehensive analyses of some variables. Groundwater quantity and quality effects are analyzed using groundwater flow and transport models, which are often used in conjunction with hydrological models capable of simulating the land phase of the hydrological cycle (Ali and Mubarak, 2017). Using a control system, some of the hydrological model outputs are used as inputs in the groundwater models. As a result, systematic coupling preserves sufficient information in the system's critical activities while giving a complete description of how those processes are related.

Groundwater recharge can be estimated experimentally using isotope tracers (Addai et al., 2016; Panda et al., 2019; Wang et al., 2008), statistically using water-table fluctuation (WTF) analysis (Moon, et al., 2004), or numerically via water balance simulations ((Anuraga et al., 2006; Batelaan et al., 2003; Carrera-Hernández and Gaskin, 2008). Groundwater recharge may be assessed at the regional scale using a distributed water balance simulation model that is split into grid cells and each cell is assigned a land-use category. A simple daily Soil-Water Balance (SWB) model was developed by Carrera-Hernández and Gaskin (2008), and found that recharge had diminished as a result of urban growth. Hydrological processes are examined from the perspective of the consequences of land-use change effects on the recharge of groundwater using the WETSPASS model. According to Batelaan et al. (2003), WETSPASS, provides a great alternative for long-term spatial patterns of groundwater recharge by calculating water balance while accounting for the proportions of vegetation, water, and impermeable land. WETSPASS model applications for groundwater recharge estimation can be found in Tilahun and Merkel (2009), Woldeamlak et al. (2007), and Dams et al. (2008). It has also been applied in China for land use impact analysis (Moiwo, 2006) and also with good results in groundwater simulation (Moiwo, et al., 2010).

Globally, remote sensing and GIS, and other approaches for groundwater assessment have been used for groundwater flow, and quantity (Goodchild, et al., 1993). Hydro-geological data may be stored in GIS together with geographical settings in an interactive catalog, allowing for objective spatial data analysis utilizing multiple logical criteria (Shahid, et al., 2000). GIS has received attention for large-area spatial hydrological and hydro-geological modeling, proving to be a useful tool in groundwater investigations. These include the assessment of indirect groundwater recharge and storage potential (Shaban et al., 2006; Srinivasa Rao and Jugran, 2003), mapping of topographical phenomena (Epstein et al., 2002; Jat et al., 2009; Sudhira et al., 2004), detecting change studies (Kumar et al., 2018), and for several hydraulic and hydrologic models parameterization (White and Greer, 2006). These competencies have also been utilized extensively to analyze the influence of urbanization on groundwater quality (Mapani, 2005; White and Greer, 2006; Woldeamlak et al., 2007). Some studies (Shaban et al., 2006; Shahid et al., 2000) used statistical weighting systems to assess groundwater recharge, rainfall potential, and urbanization effect, and simple overlay analysis of several themes are inter-related in GIS (Mapani, 2005). Hydro-geological data (hydrology, etc.) are required for the evaluation of groundwater in these methods. However, since their conclusions are mainly based on qualitative observations, subjectivity is high, lowering accuracy, and validation of results might be challenging. Some studies have employed remote sensing and GIS to parameterize hydrological and hydro-geological models (MODFLOW, SWAT, HEC-HMS, WETSPASS, etc.) (Canters et al., 2011; White and Greer, 2006). The use of these modeling approaches for groundwater assessment is precise. However substantial hydrogeological data is required, including Well lithologies, aquifer boundaries, pumping test data, soil maps, water levels, discharge, and many more, which are sometimes not readily accessible, especially in developing nations due to data paucity. The effect of urbanization and land use land cover changes on groundwater recharge may be estimated using basic methods in the absence of extensive hydro-geological data. The water balance technique is a straightforward way to estimate groundwater potential and recharge. The research found groundwater depletion for agricultural and industrial usage has surpassed recharging in most Indian states (Jat et al., 2009). In urban areas, groundwater outflow increased while recharge decreased owing to the conversion of pervious to impervious regions and shifting of groundwater faults and zones.

Pan et al. (2011), investigated land-use change impacts on groundwater recharge based on water balance modeling. The WETSPASS simulation data were combined with GIS spatial analysis to achieve a regional evaluation impact. Considering the precipitation values in the basin, groundwater recharge accounted for 21.16%, whereas (evapotranspiration) constituted 72.54%. The annual-lumped groundwater recharge rate decreased in farmland, grassland, urban areas, and forest. They also discovered that land-use change reduced groundwater recharge by 4×10^6 m^3 per year, with an average rate of 100.48 mm/yr in 1980 and 98.41 mm/yr in 2005. The principal reason for the variation is because of an increase in urban and rural settlements. Understanding how land-use change affects groundwater recharge in locations experiencing fast urbanization and limited surface water availability is critical to ensuring that groundwater supplies are adequately replenished. Several factors govern surface runoff and these may include land use land cover, river network, and topography (Xu and Zhao, 2016). Nevertheless, increases in surface runoff can be attributed to anthropogenic activities such as deforestation, urbanization, and overgrazing in a watershed (Fohrer et al., 2005). The vegetation cover decline leads to a reduction in the interception and alteration of the structure of the soil physically, which decreases infiltration capacity thereby reducing groundwater recharge (Koster, 2013).

Martínez-Retureta et al. (2020) also used the SWAT model to examine the impact of LULC changes on hydrology. Over 30 years (1984–2013), three LULC scenarios (1986, 2001, and 2011) were compared, which showed a considerable reduction in total yearly flows. The yearly flows of 25.05 m^3/s differed between LULC 1986 and 2011. On a monthly and seasonal basis, evapotranspiration and surface flow increased while infiltration and lateral flows decreased. These changes and their impacts are critical for long-term sustainable groundwater management. (Usman et al., 2020) used a 3-D dimensional groundwater flow model FEFLOW, remote sensing data, actual LULC patterns, and statistical downscaling of climate data to explore groundwater dynamics in Pakistan's Lower Caleb Canal. They found that improvements in rice cultivation had a considerable impact on groundwater levels, whereas decreases in rice, cotton, and sugarcane fodder areas had a negative impact. Also, groundwater levels are expected to fall under H3A2 and H3B2 climate scenarios. (Shuler et al., 2021) utilized the Soil Water Balance 2 (SWB2) model to evaluate groundwater recharge in the Tutuila basin under several climate changes and land-cover scenarios. To anticipate future recharge, the calibrated model was integrated with dynamically downscaled GCM forecasts under RCP 4.5 and RCP 8.5, as well as future land-cover scenarios. On average, the RCP8.5 and RCP4.5 scenarios predicted 11% and 18% increases in yearly precipitation respectively, resulting in 8% and 14% increases in groundwater recharge. Increase in surface runoff was up to 50% higher than the increase in recharge, illustrating that precipitation drives groundwater recharge. Urbanization may reduce local recharge by up to 20%,

Table 1
Groundwater recharge under changing LULC and climate change.

Reference	Main Purpose of the study	Major Criteria considered	Method/ Model Used	Climate Scenario/ GCM	Gaps Identified
Guzha et al. (2018)	Impacts of land use and land cover change on surface runoff, discharge, and low flows (East Africa)	Land use, soil map, streamflow, temperature, mean annual discharge, Peak discharge, surface runoff, baseflow	SWAT	Not considered	To enhance model parameterization, extensive parameter sensitivity analyses must be performed.
Thieken et al., 2016	Land Use/Cover Change on the Hydrological Response	DEM, Land use, soil map, streamflow, temperature, rainfall, potential evapotranspiration, surface runoff	SWAT	Meteorological data CHIRPS was used as a climatic database	Results did not properly represent the extreme rainfall values, overestimating the precipitation in the study area
Osei et al., (2019)	Impact of climate and land-use changes on the hydrological processes	DEM (SRTM), Land use, soil map, streamflow, temperature, rainfall, Evapotranspiration, surface runoff	SWAT	RCP2.6, RCP4.5, and RCP8.5	The study failed to consider the relationship between surface and groundwater baseflow in the simulation of land-use practices.
Martínez-Retureta et al. (2020)	Land Use/Cover Change on the Hydrological Response	DEM, Land use, soil map, streamflow, temperature, rainfall, potential evapotranspiration, surface runoff	SWAT	Meteorological data CHIRPS was used as a climatic database	Results did not properly represent the extreme rainfall values, overestimating the precipitation in the study area.
Erena and Worku, (2019)	Land use land cover and resulting surface runoff management for environmental flood hazard mitigation	Satellite image, Digital Elevation Model (DEM), surface runoff, land use land cover	Rational Model surface runoff	Meteorological data	Not able to simulate land-use changes on infiltration. Streamflow, soil maps and water balance not considered hence results at variance with other similar researches

according to land-cover scenarios.

Pulido-Velazquez et al. (2015), employed an integrated modeling framework consisting of the SWAT hydrological model, the MODFLOW groundwater flow model, and the MT3DMS mass-transport model. The SWAT model outputs were utilized as Inputs to MODFLOW for modeling variations in groundwater flow and storage implications on surface-groundwater interactions. For emission scenario, A1B, three General Circulation Models (GCMs) were investigated. The examination of historical patterns and main dynamic mechanisms helped describe LULC changes, whereas future trends were quantified using Markov chain and Cellular automata to simulate future LULC maps. The findings established a decrease in groundwater recharge and a rise in nitrate concentrations due to climate and Land Use Change. The influence of LULC and climate change on surface water output and groundwater recharge was investigated using SWAT-MODFLOW (Yifru et al., 2021). The LULC change was evaluated using cellular automata which showed the majority of LULC is cultivated land, with 5% forest and grassland. Temperatures and precipitation are projected to increase by 8–11% and 3–6%, respectively. The results from their analyses indicated climate change has a considerable influence on water yield and groundwater recharge distribution, but LULC change has little effect. A 10% recharge was expected under the baseline scenario, however, a reduction of 47–53% of recharge is expected because of climate change. Besides, the authors reiterated a 48% expected reduction in water yield and conversion of perennial rivers to intermittent water bodies causing water supply shortages because of climate change. Groundwater level fluctuations using statistical analyses to identify groundwater level changes and non-stationarity in seven heavily inhabited secondary cities in India and the impact of rainfall and LULC on the groundwater was also investigated by Mohanavelu et al. (2020). Overall, the groundwater level varied between 10 cm/yr in most of the wells. An influence of rainfall and LULC owing to climatic variability and human activities on groundwater change dynamics was also identified. Statistical correlation revealed that climatic variability may have a role in influencing rainfall and groundwater recharge. Climate change's impact on expected streamflow and groundwater recharge levels was examined using the Dyna-CLUE model by Sahoo et al. (2019). For twelve future climate change scenarios, RCM data [RCP 2.6, 4.5, 6, and 8.5] were evaluated using five bias correction approaches linear scaling, local intensity scaling, power transformation, distribution mapping, and variance scaling (4 RCPs in each year for 2030-2050-2080). From 2016 to 2030 through 2050 and 2080, groundwater recharge increased significantly for all sub catchments in all the RCPs. Streamflow uncertainty was characterized as exceedance probability and recurrence interval, and all the scenarios showed a significant increase in groundwater recharge. Sustainable water resource management has often been interlinked with LULC changes affects groundwater recharge and surface runoff. However, there is a paucity of quantitative information on how LULC changes influence underground elements of the hydrologic cycle, notably groundwater recharge. A summary of the main purpose of each study considered, methods/models used with climate scenarios, and the weaknesses and gaps are presented in Table 1.

3.3. Change of LULC and their impact on hydrologic characteristics

Rainfall and groundwater base-flow influence streamflow, which is crucial for flood management (Lofgren and Gronewold, 2014). Several investigations have revealed land degradation has had an impact negatively on river systems (Ayivor and Gordon, 2012). However, little is said in the research of Ayivor and Gordon about their negative impact also on groundwater resources. Adjei et al. (2014) concluded that changes in land use have decreased the area of water coverage at Lake Bosomtwe Basin at a pace of 0.03% per annum between 1986 to 2008.

Li and Fang (2021) used the Delta downscaling approach to examine climate change impacts on streamflow. Calibration of the model predicts projected minimum monthly temperature rises of 1.5 °C, 2 °C, and 3 °C for all RCPs (2.6, 4.5, and 8.5) respectively. Rainfall is expected to decline in the 2030s and then rise to 8.9%, 12.89%, and 13.9% in the three scenarios, while streamflow is anticipated to increase by 10.5%, 20.1%, and 23.2% from 2020 to 2093 under the three RCP scenarios. The authors reiterated dry season streamflow is also expected to decline by 1.1% and rise by 3.2% in the rainy season. Lopes et al. (2021) used the SWAT model to predict the water balance, including runoff potential, evapotranspiration, tangential flow, and groundwater flow under various LULC scenarios. The model performance correctly matched the basin's flow regime. From 1986 to 2014, the basin's surface runoff grew by 30.8% while its groundwater contribution dropped by 5.29% due to forest conversion. Between 1986 and 2006, a 5% forest transition changed runoff by 17% (9.2 mm), producing 6.5% of the basin's total runoff. They concluded changes in LULC have impact on a river basins hydrology and therefore water resource management and land use planning need knowledge of the link between hydrologic response and LULC. A balance between these two conflicting LULC transition scenarios is vital for the catchment and the ecosystem. Briones et al. (2016)

Table 2
Groundwater recharge under changing LULC and climate change.

Reference	Main Purpose of the study	Major Criteria considered	Method/Model Used	Climate Scenario/ GCM	Gaps Identified
Guzha et al. (2018)	Impacts of land use and land cover change on surface runoff, discharge, and low flows (East Africa)	Land use, soil map, streamflow, temperature, mean annual discharge, Peak discharge, surface runoff, baseflow	SWAT	Not considered	To enhance model parameterization, extensive parameter sensitivity analyses must be performed.
Thieken et al. (2016)	Land Use/Cover Change on the Hydrological Response	DEM, Land use, soil map, streamflow, temperature, rainfall, potential evapotranspiration, surface runoff	SWAT	Meteorological data CHIRPS was used as a climatic database	Results did not properly represent the extreme rainfall values, overestimating the precipitation in the study area
Osei et al. (2019)	Impact of climate and land-use changes on the hydrological processes	DEM (SRTM), Land use, soil map, streamflow, temperature, rainfall, Evapotranspiration, surface runoff	SWAT	RCP2.6, RCP4.5, and RCP8.5	The study failed to consider the relationship between surface and groundwater baseflow in the simulation of land-use practices.
Martínez-Retureta et al. (2020)	Land Use/Cover Change on the Hydrological Response	DEM, Land use, soil map, streamflow, temperature, rainfall, potential evapotranspiration, surface runoff	SWAT	Meteorological data CHIRPS was used as a climatic database	Results did not properly represent the extreme rainfall values, overestimating the precipitation in the study area.
Erena and Worku (2019)	Land use land cover and resulting surface runoff management for environmental flood hazard mitigation	Satellite image, Digital Elevation Model (DEM), surface runoff, land use land cover	Rational Model surface runoff	Meteorological data	Not able to simulate land-use changes on infiltration. Streamflow, soil maps and water balance not considered hence results at variance with other similar researches
Baker and Miller (2013)	Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources	GIS, DEM, Land use maps, soil map, surface runoff, groundwater recharge, streamflow	Automated Geospatial Watershed Assessment (AGWA) tool, and SWAT	Meteorological data from the weather station at the basin	A detailed land cover analysis is needed for the rainfall-runoff period to establish a statistically valid link between rapid changes (annual) in land cover and observed hydrologic response to allow for monthly model calibration to determine land management practices.
Pan et al. (2011)	Impact of land-use change on groundwater recharge in Guishui river basin in China	DEM, Land use, soil map, streamflow, temperature, rainfall, potential evapotranspiration, surface runoff	WETSPASS and GIS	Meteorological data from the weather station at the basin	The analysis did not include runoff and its impact on groundwater recharge as a result of land-use changes
Usman et al. (2020)	Numerical modeling and remote sensing-based approaches for investigating groundwater dynamics under changing land use and climate in the agricultural region of Pakistan	DEM (SRTM), Land use, rivers, Well logs, temperature, rainfall, Evapotranspiration, Solar Radiation, Relative humidity, Wind speed, LULC (MODIS NDVI)	FEFLOW	H3A2 and H3B2; A2 and B2 under HadCM3	FEFLOW does not adequately account for the effects of surface and streamflow. Another alternative is to use a spatially distributed hydrological model, such as the SWAT model, but there were limitations due to the lack of streamflow data in the study area
Shuler et al. (2021)	A participatory approach to assessing groundwater recharge under future climate and land-cover scenarios, Tutuila, American Samoa	Precipitation, PET, AET, LULC, Soil Types, Infiltration, Surface runoff.	Soil Water-Balance 2 (SWB2)	RCP4.5, and RCP8.5	A single Regional Climate Model (RCM) was used for the climate change scenario. A combination of several models could have given reliable results based on the no stationarity of precipitation outputs.

used the SWAT model to assess the impact of LULC on the Palico basin's hydrology. The model employed LULC maps from 1989 and 2013, as well as climatological and hydrologic data. It was discovered that reduced forest and grassland cover increased surface runoff while reducing baseflow and groundwater recharge while changes in LULC altered both the volume and timing of water. During the wet seasons, the sub-basins increase forest cover increased groundwater recharge by (22%), grassland increased baseflow (1%), and reduced streamflow (7%). Another sub-basin with forest loss (54%) had a pronounced rainfall-runoff response, with reduced baseflow (11–17%), and higher streamflow (4–24%). Awotwi et al. (2021), considered climate change influence of on streamflow using the SWAT model and climatic data for RCMs (RCP4.5 and RCP8.5). Annual streamflow is estimated to rise between 4% and 11%, however the RCP4.5 scenario predicts a decline by the mid-century. RCP8.5 simulation results showed increased streamflow in the 21st century using the top performing models. The monthly streamflow changes for RCP4.5 were −15% to 23% and for RCP8.5 were −24% to 24%. The inclusion of anticipated climate and LULC change in hydrological impact assessments is highly beneficial in creating regional adaptation and mitigation measures.

Getachew et al. (2021) modeled hydrological reactions to projected climate and LULC. Their study focused on the consequences of climate and LULC change on water balance. Calibration, validation, and uncertainty assessments were carried out using SWAT and IPEAT (Integrated Parameter Estimation and Uncertainty Analysis Tool). The CanESM2 GCM and three RCP (2.6, 4.5, and 8.5) scenarios, were utilized. The Statistical Downscaling Model (SDSM) produced high precision future climate data, whereas the future LULC was created using the Cellular Automata-Markov Chain model. The basin's hydrological response was assessed by combining three scenarios: LULC change, climate change, and LULC combined with climate change. The study discovered evapotranspiration increases by 0.84%, 59.8%, and 55.5% under LULC, climate, and a combination of both under RCP8.5 by the end of the century. Streamflow is predicted to increase by 12.85%, 28.55%, and 26.4%, whereas lateral flow is also expected to increase by 9.9%, 20.035%, and 29.125% in each scenario. The SWAT model was utilized by Liu et al. (2021), to estimate catchment responses using four CMIP5 models, and two emission scenarios (RCP 4.5 and RCP 8.5). Streamflow is anticipated to rise 0.5–4 times due to early snowmelt, and snow cover will be declining at lower altitudes and increasing at higher elevations by the end of the century. The water cycle is known to be affected by LULC processes and climate change. These findings

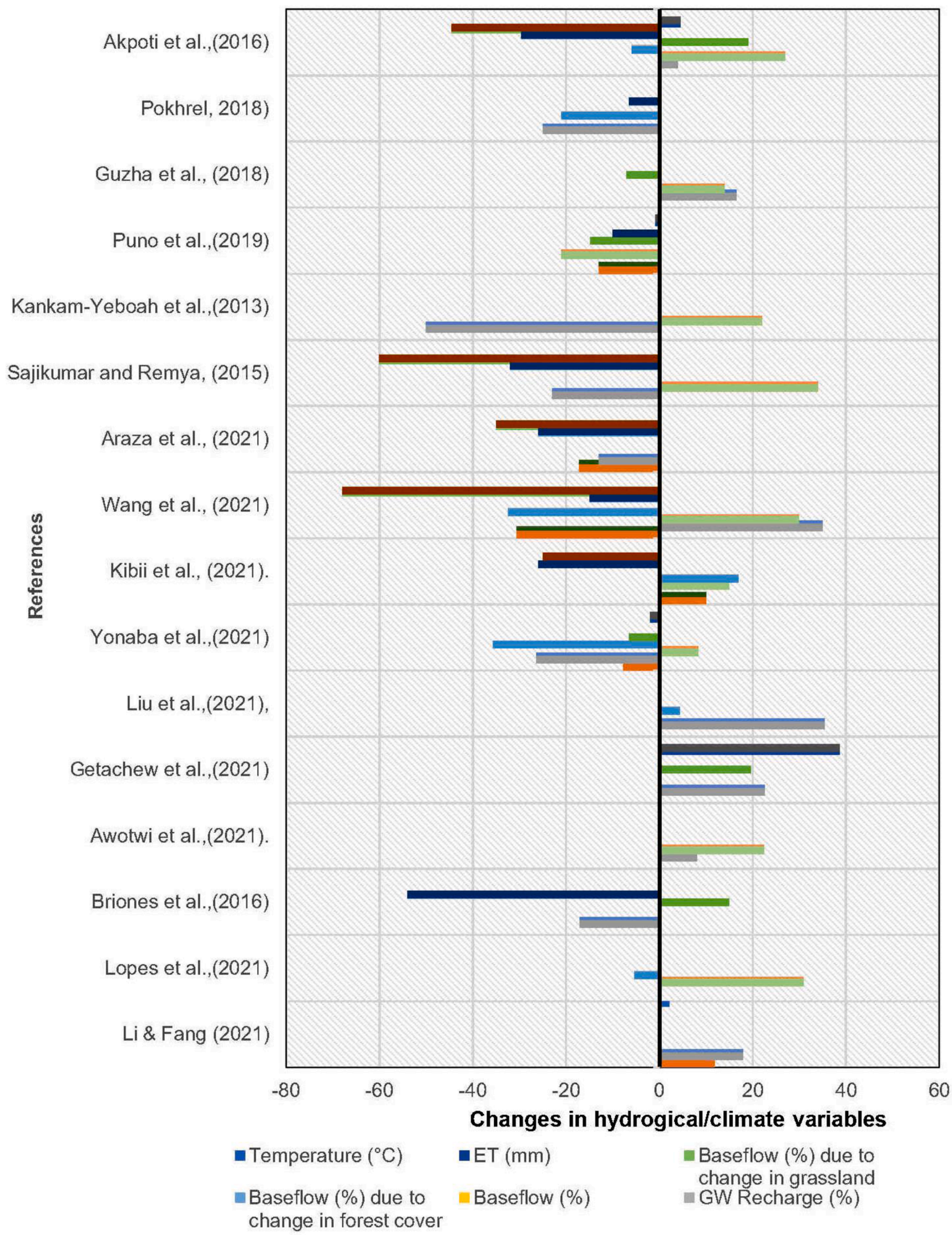

Fig. 5. Examples of changes in LULC impact on hydrologic characteristics from selected authors.

emphasize the need for optimizing LULC processes in hydrological modeling, as well as the importance of developing integrated modeling frameworks. However, hydrological modeling does not yet support LULC alterations. In light of this, Yonaba et al. (2021) also utilized the SWAT model to predict surface runoff in the Sahelian regions, using rainfall and runoff data. The DLU scenario successfully analyzed surface runoff, actual evapotranspiration, and deep aquifer infiltration. Their study found that surface runoff was impacted by both rainfall and LULC changes. Also, isolated climatic variability contributions and LULC variations on rivers demonstrated that LULC circumstances had a prominent influence.

Rapid population growth and its associated increase in water demand, and climate change have altered hydrologic responses in many river basins, including groundwater recharge. Kibii et al. (2021), employed the SWAT model to analyze climatic variability and land use impacts. Due to the high population density, land use was altered over time, reducing forest cover from 37% in 1989 to 26% in 2019 resulting in severe but decreasing rainfall occurrences in the basin. Changes in land use and climate caused excessive surface runoff and limited baseflow and groundwater recharge, culminating in severe water level fluctuations. Wang et al. (2021), employed SWAT to explore the hydrological implications of urbanization. Between 1980 and 2015, the proportion of unexploited wetlands and bare lands declined from 3.84 to 0.48%, agricultural land decreased from 71.34% to 67.9%, and forest land decreased from 14.9% to 11.7%. During the same period, urban land increased from 6.75% to 15.25% and grassland from 0.5 to 1.03.

Table 3
Climate change, land use, and land cover impact on water balance components.

Reference	Main Purpose of the study	Hydr. Model Used	Climate Scenario/GCM	Key Results
Li and Fang (2021)	Assessment of climate change impacts on the streamflow for the Mun River in the Mekong Basin, Southeast Asia	SWAT	34 GCMs under RCP2.6, RCP4.5, and RCP8.5	1) Increase in temperature under all RCPs. 2) Annual Decrease in average precipitation in the 2030s and increase from 2060s and 2080s under the three scenarios. 3) Rise in streamflow
Lopes et al.,(2021)	Hydrological regime, water availability, and land use/land cover change impact on the water balance in a large agriculture basin in the Southern Brazilian Amazon	SWAT	No GCM RCP considered	1) Conversion of forest to agricultural use influenced surface runoff increase 2) Decrease in Groundwater contribution 3) Forest transition resulted in a significant change in the runoff
Briones et al. (2016)	Hydrologic impact evaluation of land use and land cover change in Palico Watershed, Batangas, Philippines	SWAT	No GCM was considered for the study	1) Reduction forest cover and grassland 2) Increase in surface runoff 3) Decrease in baseflow and groundwater recharge 4) An increase in forest cover and grassland caused an in baseflow and decreased the streamflow 5) Significant forest loss recorded significantly lower rainfall-runoff, lower baseflow, and higher streamflow.
Awotwi et al.,(2021)	Climate change impact on streamflow in a tropical basin of Ghana, West Africa	SWAT	GCM under RCP4.5, and RCP8.5	1) Increase in annual streamflow under RCP8.5 2) Decrease in annual streamflow under RCP4.5 3) Monthly Streamflow varied between -15% and 23% under RCP4.5 4) Monthly Streamflow varied between -24% and 24% under RCP8.5
Getachew et al. (2021)	Modeling projected impacts of climate and land use/land cover changes on hydrological responses in the Lake Tana Basin, Upper Blue Nile River Basin, Ethiopia	SWAT with IPEAT	1 GCMs under RCP2.6, RCP4.5, and RCP8.5	1) LULC causing significant increases in cropland, tree cover, and urban areas 2) LULC causing increases in ET, Baseflow, and Streamflow 3) CC has an aggravating effect on Temperature 4) CC causing 25% increase in precipitation 5) CC influencing Streamflow and lateral flow
Liu et al.,(2021)	Identifying climate change impacts on surface water supply in the southern Central Valley, California	SWAT	5 GCMs under RCP4.5 and RCP8.5	1) CC causing extreme temperature increases 2) CC influencing Peak Streamflow increases
Yonaba et al.,(2021)	A dynamic land use/land cover input helps in picturing the Sahelian paradox: Assessing variability and attribution of changes in surface runoff in a Sahelian watershed, Tougou.	SWAT	Climate variables from local stations	1) LULC explains increases in surface runoff 2) Influence of LULC on a decrease in rainfall 3) The greater impact of CC and LULC on streamflow, ET, and infiltration
Kibii et al. (2021)	Evaluating the impact of land use and climate variability on the Kaptagat catchment river discharge	SWAT	Climate data from meteorological stations of the study area	1) LUC caused a decrease in forest cover and increased urbanization 2) LUC caused a decrease in rainfall 3) Increase in Surface runoff 4) A decline in baseflow and 5) Increase groundwater recharge
Wang et al. (2021)	Hydrological effect of urbanization in Yitong River Basin	SWAT	No GCM considered	1) LULC caused a decrease in wetlands and bare sands 2) LULC caused a decrease in forest lands by 11.7% 3) Increase in surface runoff
Kumar and Bhattacharjya (2020)	Evaluating two GIS-based semi-distributed hydrological models in the Bhagirathi-Alkhnanda River catchment in India.	SWAT and HEC-HMS	GCM under RCP4.5, and RCP8.5	1) SWAT performs better than HEC-HMS 2) Underestimation of peak discharge Increase in peak discharge under RCP4.5, and RCP8.5
Araza et al., (2021)	Probable streamflow changes and its associated risk to the water resources of Abuan watershed, the Philippines caused by climate change and land-use changes	SWAT	GCM under RCP4.5, and RCP8.5	1) LULC caused decreases in forest cover and grassland 2) Both CC and LULC caused a decrease in streamflow and precipitation 3) CC and LULC caused a decrease in ET and groundwater recharge
Tayebzadeh Moghadam et al., (2021)	Spatio-temporal modeling of water balance components in response to climate and land-use changes in a heterogeneous mountainous catchment in Iran	SWAT	GCM under RCP4.5, and RCP8.5	1) CC and LUC influenced an increase in precipitation and evapotranspiration 2) CC caused a significant effect on water yield 3) LUC has a significant effect on sediment yield 4) Combined CC and LUC had significant changes on both water yield and sediment yield under RCP4.5
Puno et al.,(2019)	Hydrologic responses of watershed assessment to land cover and climate change in the Muleta Watershed, Philippines	SWAT	No GCM was considered. Climatic data of study area	1) LULC caused a 10% decrease in forest cover 2) Minimal difference in precipitation among subbasins across the watershed 3) LULC and CC caused a decrease in rainfall

(*continued on next page*)

Table 3 (*continued*)

Reference	Main Purpose of the study	Hydr. Model Used	Climate Scenario/GCM	Key Results
				4) 4) LULC causes increase surface runoff and a decrease in groundwater recharge
Guzha et al.,(2018)	Impacts of land use and land cover change on surface runoff, discharge, and low flows: Evidence from East Africa			
Pokhrel (2018)	Impact of Land Use Change on Flow and Sediment Yields in the Khokana Outlet of the Bagmati River, Kathmandu, Nepal	SWAT	Local Climate data	1) LULC contributed to forest and Agric land losses to urbanization 2) 2) Decrease in streamflow and contribution to groundwater

Moreover, the same SWAT modeling results showed substantial increases in runoff from 1980 to 2000 but not from 2000 to 2015. Kumar and Bhattacharjya (2020), compared the performance of these hydrological distributed models in four Indian river basins. A comparison of the two models (SWAT and HEC-HMS) shows the superiority of the SWAT during the dry season. The models anticipate probable river discharges under different climate change scenarios will give rise to peak discharge by 27% and 47% under RCP4.5 and RCP8.5 respectively. River basin hydrology is one of the key effect sectors of climate and LULC changes, all of which negatively influence water supplies. Process-based streamflow modeling of baseline and possible scenarios may quantify changes in streamflow. Araza et al. (2021) evaluated streamflow fluctuations with a baseline model developed for two impact scenarios assessments: 1. Climate projections to 2070; and 2. Landcover degradation due to forest loss in the river basin. Peak flow simulations increased by 26% and low flow simulations increased by 63% after calibrating the parameters. The calibrated model predicted a water deficit (18.65%) during the dry season and a surplus (12.79%) in 2070. Changes in climate and land use and land cover caused water shortages, while LULC produced surpluses. Changes in climate and land use affect hydrological systems. Tayebzadeh Moghadam et al. (2021) employed the SWAT model to assess the independent and integrated effects of climate and land use changes on water balance components. The GFDL-ESM2M RCP 4.5 and RCP 8.5 GCMs were used to forecast future climate scenarios for 2020–2040. A Markov chain model anticipated the catchment's land-use shift, indicating increased precipitation and evapotranspiration. Sajikumar and Remya (2015) used watershed simulation models with a GIS framework to study the influence of LULC change on runoff characteristics of two watersheds. Their findings indicated a 60% loss in forest area and a 32% reduction in catchments. However, the increases in surface runoff are within 20% of the changes in the forest area. Similarly, the runoff maximum (peak) value increased by 15%. The less-than-expected impact might be due to the conversion of forest for agricultural reasons, with crops taking up most of the forest's features except evapotranspiration. They suggested making rain harvesting mandatory in places with significant evapotranspiration. This action will improve groundwater percolation and reduce evapotranspiration.

Changes in Land Use and Land Cover (LULC) may greatly affect a drainage basin's runoff characteristics, which in turn affects the area's surface and groundwater availability. It is noteworthy to estimate the influence of LULC change on runoff characteristics of the northern region in general and minor watershed levels (sub-basin levels) on groundwater hydrology. The SWAT model has also shown promise in analyzing the consequences of LULC change on hydrology. In East Africa, Ethiopian researchers Guzha et al.(2018), Demeke and Andualem (2018), and Welde and Gebremariam (2017) determined that degraded forest land increases hydrological characteristics. Urbanization increased evapotranspiration, baseflow, and surface runoff, according to Puno et al. (2019). Their investigation also found that increasing forest cover reduced baseflow and surface runoff. Kankam-Yeboah et al. (2013) assessed the influence of climate change on streamflow. After model calibration, they detected between 22% and 50% of streamflow loss in their study catchments for 2006–2035 and 2036–2075. Sood et al. (2013) reported a 40% decrease in river flows due to less rainfall and increased temperatures with a Nash Sutcliffe Efficiency (NSE) of −0.43 was obtained by Bair (2014) using the SWAT model. The model might be used to assess the effects of small-scale irrigation on agricultural and socio-economic activities (Worqlul et al., 2018). Akpoti et al. (2016), used the SWAT to assess rainfall variability and LULC change on streamflow in the Black Volta Basin in West Africa. Between 2000 and 2013, changes in land use and land cover rose by 1% and 6% for wet and dry season discharges, respectively. Many models (hydrological) were developed and used for rainfall-runoff processes simulation in urban areas, including SWMM, MIKE, HSPF, STORM, and IN-FOWORKS. Table 2 shows the summary of the main purpose of each study considered, methods/models used with climate scenarios, and key results. Percentage change in hydrologic characteristics of some key authors is shown in Fig. 5 (Table 3).

4. Conclusion

The systematic review examined a total of 200 papers on integrated modeling approaches and highlighted research trends, as well as the effects of LULC and climate change on groundwater recharge. This review has demonstrated that over the last few decades, advances in research have shown that groundwater recharge may be simulated using a variety of approaches and instruments. The systematic review revealed significant information on the effects of LULC, and climate change on groundwater recharge, which has implications for LULC planning. It demonstrates that the effect of climate change on aquifer recharging is reflected in declines in the water table because of temperature increases, rainfall variability, and increased evapotranspiration.

Several of the research examined used hydrological or hydrogeological models, as well as empirical statistical models and evapotranspiration models. Other researchers employed ecohydrological models to determine the relationship between climatic factors and groundwater levels. Numerous studies have been conducted that consider severe occurrences, such as the repercussions of harmful anthropogenic effects. Recent research has demonstrated the value of an integrated modeling strategy for evaluating the effect of land-use changes on water resources. The papers reviewed advocated for the use of a spatially explicit land-use simulation model in conjunction with a hydrological model as a useful tool for assessing the influence of land-use change and climate change on groundwater recharge. The reactions to LULC changes vary, indicating the need of conducting site-specific research to fully understand the consequences of LULC changes. Such research must measure the combined effects of several stressors, such as LULC, climate, landscape, and soil qualities. Finally, the findings of this research emphasize the need for integrated modeling for assessing changes in groundwater resources.

Author Contributions Statement

Research design (Jacob K. Mensah, Ofosu-Antwi Eric, Komlavi Akpoti)

Manuscript writing (Jacob K. Mensah, Komlavi Akpoti, Yidana Sandow Mark)

Manuscript review (Ofosu-Antwi Eric, Yidana Sandow Mark, Amos T. Kabo-bah, Komlavi Akpoti)

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper

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