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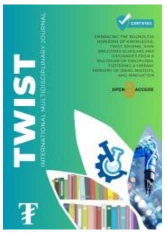

Impacts of Land Use and Land Cover Changes on Hydrological Response:
A Review of Current Understanding and Implications for Watershed and Water Resources Management

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Abstract

Land use and land cover (LULC) changes have far-reaching implications for hydrological response, making them a critical consideration in watershed management and water resources management. This review paper synthesizes key findings from the literature on the impacts of LULC changes on hydrological processes. The analysis highlights that LULC modifications can significantly alter critical hydrological components, such as surface runoff, groundwater recharge, infiltration, interception, and evaporation, with immediate or long-lasting effects at local and regional scales. Regional-scale hydrological models are valuable tools for simulating the impacts of potential LULC changes and identifying strategies to improve the adaptive capacity of river basins. However, the complexity of hydrological modelling, including spatial and temporal variability and calibration challenges, warrants careful consideration. Further research is needed to comprehensively evaluate the combined impacts of LULC changes on hydrology and water quality, as well as the differential effects of various LULC types on hydrological processes. Advances in technology, such as remote sensing and modelling tools, have facilitated the monitoring and understanding of LULC dynamics, providing valuable insights for effective natural resource planning and management. Continuous questioning and updating of our understanding of land-water interactions are essential for informed decision-making in land use planning and water resources management, with the ultimate goal of achieving sustainable land and water management practices. In conclusion, assessing the impacts of LULC changes on hydrology is crucial for watershed management and development, and provides valuable insights for sustainable land and water management practices.

Keywords

Hydrological response, Land Use, Land Cover, Water management

INTRODUCTION

Land-use change refers to the conversion of one type of land use to another, such as from forest to agriculture or from grassland to urban development [1]. This can have a significant impact on the hydrological cycle because different land uses have different effects on the way water moves through the environment [2]. For example, urbanization typically involves the construction of impervious surfaces such as roads and buildings, which can lead to increased runoff and reduced infiltration [3,4]. Agricultural land use, on the other hand, often involves the clearing of vegetation, which can lead to increased soil erosion and sedimentation of water bodies [5]. The effects of land use change on hydrology can also be influenced by other factors, such as climate change and land management practices [6,7].

Hydrologic response refers to the way water moves through the environment, including its distribution, quality, and quantity [8]. Land use change can have a significant impact on the hydrologic response, as it can alter the natural flow of water and the processes that regulate it [9]. For example, deforestation can lead to a reduced interception of rainfall by vegetation, resulting in increased runoff and reduced soil moisture [10]. Urbanization can lead to changes in the timing and amount of water reaching streams and rivers, and increased levels of pollution due to runoff from impervious surfaces [11]. These changes have significant implications for water resource management, including water supply, flood control, and ecosystem health.

Land use change can directly impact the hydrological cycle by altering the amount and timing of precipitation, the infiltration and percolation of water through soils, and the discharge of water into streams and rivers [12]. These changes can lead to altered water availability patterns, increased flood risk, and degraded water quality [13]. In addition, land-use change can indirectly affect the hydrologic response by altering the physical, chemical, and biological properties of the landscape, such as vegetation cover, soil characteristics, and land management practices [7]. These changes can affect the way water moves through the environment and the processes that regulate it, further impacting water resources and ecosystem health [14]. Therefore, understanding the relationship between land-use change and hydrologic response is crucial for effective water resource management and sustainable land-use planning [15,16].

The term "hydrological response" refers to how various processes involved in the hydrologic cycle, such as infiltration, groundwater recharge, base flow, and surface runoff, can change and vary [17]. Typically, researchers examine these changes at the Hydrologic Response Unit (HRU) scale, which is a method for dividing a drainage basin into smaller units. By studying the dynamics of hydrological responses, scientists can gain insight into the overall health of a watershed or river basin. These dynamics can be influenced by a variety of factors, including changes in land use and climate [18]. Land use and land cover change can have far-reaching effects on the physical characteristics of the basin, such as its geomorphology and soil properties, as well as on hydrological processes, water quality, and ecological integrity of the aquatic ecosystems in the area. These effects can be felt at local, regional, and global scales [19].

Several studies have investigated the relationship between land use and land cover (LULC) and hydrology, and they have discovered a strong association between land use and water quality at the watershed level [20]. Although research on surface water quality and the implications of LULC changes on surface water is growing more common [21], and there is still a great deal to discover the impact of LULC changes on subsurface aspects and mechanisms, such as base flow, within a watershed [22]. Changes in land cover and management practices are among the key factors driving changes in hydrological systems, leading to differences in runoff such as peak flow frequency, discharge volume, and water quality [23]. Human activities that intensify as land use changes can significantly impact water quality, leading to degradation [24].

The relationship between land use and water quality has become a relevant topic of discussion, as anthropogenic activities in watersheds continue to increase [13]. When land cover changes to impervious land use and land cover (LULC), the hydrological cycle is affected by factors such as increased storm runoff, reduced vegetation cover, and increased sediment transport to streams, which can further impact the water quality [25]. For instance, the conversion of forestland, agricultural land, and wetlands to built-up urban land use can increase the area of impervious surfaces [26–28], which disrupts the natural hydrological conditions within the watershed by increasing the rate of runoff and sometimes nonpoint source (NPS) pollution that affects hydrological quality [29,30].

METHODS

Search Strategy and Selection Criteria

To identify relevant studies, a comprehensive search was conducted using the Web of Science, Scopus, and Google Scholar databases. A combination of keywords, including "land use change," "land cover change," "hydrology," "watershed," and "hydrologic response" ecosystem services were used. Inclusion criteria for selecting studies were: (1) published in peer-reviewed journals, (2) empirical studies that directly measured the impact of land use change on hydrologic response, (3) studies that investigated the effect of land use change on hydrologic response in a watershed or catchment context, (4) studies that compared hydrologic response between different land-use types or land-use change scenarios, and (5) studies published in the English language. The exclusion criteria were as follows: (1) studies that did not focus on the impact of land use change on hydrologic response, (2) studies that focused on individual components of the hydrologic cycle rather than overall hydrologic response, (3) studies that were not published in peer-reviewed journals, and (4) studies published in languages other than English.

Data Sources and Analysis Methods

Data was extracted from the selected studies using a standardized approach. The data extracted included study location, land use types or change scenarios, hydrologic response variables measured, and methods used to measure hydrologic response. To analyse the data, we used both quantitative and qualitative synthesis methods. Meta-analysis was used to quantitatively synthesize the results of multiple studies, while narrative synthesis was used to qualitatively summarize and interpret the findings. GIS and statistical software were used to map and analyse the spatial and temporal patterns of land use change and hydrologic response**.**

Limitations and Potential Biases

We acknowledge several limitations and potential biases of our review. First, the search strategy may not have captured all relevant studies, and the inclusion/exclusion criteria may have excluded some relevant studies. Second, inconsistencies in study design and measurement methods may limit the comparability of the results. Third, the generalizability of the findings may be limited by the geographic and temporal scope of the studies included in the review. Finally, publication bias and language bias may have influenced the selection of studies. To minimize these limitations and biases, we used a rigorous search strategy, clearly defined inclusion/exclusion criteria, and carefully evaluated the quality and relevance of the studies included in the review. We also acknowledge the limitations and potential biases in the interpretation of the results and identify areas for future research to address these limitations.

OVERVIEW OF LAND USE CHANGES AND HYDROLOGIC RESPONSE

Land use changes have significant impacts on the hydrologic response of watersheds and catchments. Changes in land use alter the physical characteristics of the landscape, such as vegetation cover, soil structure, and impervious surfaces, which affect the hydrologic cycle in complex ways. Understanding the impacts of land use change on hydrologic response is essential for sustainable land use planning and management.

Types of Land Use Changes

Land use changes can be categorized into several types, including conversion of forests to cropland, urbanization, deforestation, afforestation, and reforestation. Each type of land use change affects the hydrologic response of watersheds and catchments differently. For example, urbanization leads to an increase in impervious surfaces, which increases surface runoff and reduces infiltration, while afforestation can increase evapotranspiration and reduce surface runoff.

Hydrologic Response Mechanisms Affected by Land Use Changes

Land use changes affect several hydrologic response mechanisms, including infiltration, evapotranspiration, surface runoff, and groundwater recharge. Changes in vegetation cover affect evapotranspiration rates and interception, which can lead to changes in the amount and timing of rainfall reaching the ground. Changes in land cover also affect infiltration rates, which can affect groundwater recharge and baseflow. The amount and timing of surface runoff can also be affected by land use changes, especially changes in impervious surfaces.

Spatial and Temporal Scales of Impact

Examining the consequences of alterations in land use and land cover (LULC) on hydrological conditions is crucial for the effective management and advancement of watersheds [31–33]. Modifications in land use and land cover (LULC) have the potential to significantly influence the trajectory of rainfall, impacting essential hydrological elements including surface run-off, groundwater recharge, infiltration, interception, and evaporation [34,35]. The impacts of LULC changes on the relationship between rainfall and run-off can be substantial. However, quantifying these effects becomes a greater challenge when dealing with large basins, as the interplay between LULC, climate characteristics, and underlying hydrological processes is intricate and dynamic [8].

Numerous studies have been conducted to evaluate the impact of land use and land cover (LULC) changes on hydrological systems across various spatial and temporal scales [1,10,17,24,36,37]. LULC modifications can affect hydrological response at different spatial and temporal resolutions. At the local level, alterations in land use can impact the hydrology of smaller catchment areas, leading to changes in the quality and quantity of water supply [38,39]. Similarly, at a regional scale, changes in land use can have an effect on the hydrology of entire watersheds or river basins, ultimately influencing the downstream water supply and quality [40–42]. The magnitude and duration of the impact on hydrological response may vary, with some changes being immediate and others persisting over longer periods [4,43,44].

Purpose and scope of the literature review

Watershed process are highly dynamic in both space and time [8,45]. It is essential to continuously scrutinize general assertions about land-water interactions to ascertain their accuracy and relevance as the best available information. Furthermore, evaluating whether the existing information aligns with sustainable decision-making processes for developmental activities is crucial [46]. Regional-scale hydrological models serve a crucial role in effective river basin management. These models enable the simulation of potential impacts resulting from future changes in LULC, thereby aiding in the identification of measures that can enhance the adaptive capacity of river basins [47]. Various environmental conditions, such as land use and cover (LULC) and climate, exert influences on the hydrological processes within a watershed. LULC plays a crucial role in controlling the hydrologic response of watersheds in several ways [48]. Hence, to manage natural resources optimally, it is necessary to understand the impacts of LULC change on the hydrologic cycle [13,49,50].

By way of definition, [51], define land use and land cover change (LULC) as the alteration of land use resulting from the interaction between humans and the physical environment. Land cover pertains to the biophysical properties of the Earth's surface, including the distribution of vegetation, water, soil, and other physical characteristics, while land use relates to the way in which humans have utilized the land for economic activities [3,52,53]. The comprehension of LU/LC transformations is essential for effective natural resource planning and management [54], and advancements in technology have facilitated the monitoring and study of natural resource dynamics for environmental purposes [55].

HYDROLOGICAL MODELLING

When highly variable changes occur within a catchment, the hydrological processes at the catchment scale are no longer stationary [33]. A multitude of models exist for solving hydrological problems, and among them, predicting rainfall-runoff (RR) is considered one of the most intricate processes in environmental modelling. The complexity arises from the spatial and temporal variations in topographical characteristics, rainfall patterns, and the numerous parameters that need to be determined during the calibration process [6,56].

MODELLING LULC AND HYDROLOGIC RESPONSE: METHODOLOGICAL REVIEW

The investigation of LULC (Land Use and Land Cover) change holds significant importance in research, given its connections to climate change, urbanization, agriculture, forestry, geology, hydrology, and other ecosystem services. Gaining a comprehensive understanding of how LULC change affects hydrology and water quality is crucial for informed decision-making in watershed management and the development of ecological restoration strategies. While previous studies have predominantly concentrated on assessing alterations in channel discharge resulting from LULC change over extended periods, there is a need for further exploration in this field. Certain research studies have also focused on analysing the interconnected effects of both land use and land cover (LULC) changes and climate change on water quantity. These investigations utilize calibrated hydrologic models that incorporate future climate predictions and projections of LULC. For example, [57] employed the Soil and Water Assessment Tool (SWAT) to assess the vulnerability of freshwater availability in the Brahmaputra basin in South Asia in response to projected changes in land use and land cover (LULC) and climate. Their study revealed that alterations in precipitation patterns have significant implications for stream flow and groundwater recharge. Additionally, variations in CO_2 concentration and temperature were observed to influence average annual evapotranspiration levels.

To simulate the hydrologic response of Canagagigue Watershed in southern Ontario, Canada [58], three Geographic Information System (GIS)-based watershed simulation models, namely MIKE SHE, APEX, and SWAT, were compared to assess their efficiency. The models were calibrated and validated over a four-year period, and it was observed that all three models produced similar simulated flows that closely matched the observed flows. However, it was noted that MIKE SHE provided a more accurate simulation of mean daily/monthly flow at the watershed outlet during both the calibration and validation phases, particularly emphasizing the calibration results. The authors of the study suggest that conducting field tests on watersheds can assist researchers in selecting the most suitable model for their specific requirements.

Furthermore, [29] conducted a comprehensive assessment to examine variations in water quality resulting from land use in the upper transboundary catchment of the river Nisa, which spans across the Czech Republic, Germany, and Poland, covering an area of 694 km^2. The study involved the collection of weekly water samples from the river and its tributaries at 29 sampling sites. Each sampling site represented a distinct hydrological response unit (HRU) characterized by a specific combination of eight land-use categories. To categorize the HRUs effectively, cluster analysis was employed, resulting in the identification of five land-use classes. The outcomes of the cluster analysis revealed six groups of sampling sites that exhibited similar chemical water compositions, which correlated with the corresponding land use regardless of sub-catchment size. The study revealed that water quality was significantly influenced by the proportions of settlement areas and arable land. HRUs predominantly covered by forests (with over 70% forest cover) displayed the lowest concentration levels for most of the monitored parameters, except for Cd, Mn, and SO4. These findings highlight the impact of land use, particularly settlement areas and arable land, on water quality within the studied transboundary catchment.

Utilising the MIKE SHE model, [59] conducted a study to estimate aquifer recharge in the Ogun and Osun Basins, located in Nigeria. Within each basin, two cities, Abeokuta and Oshogbo, were selected as study areas. The model input components were categorized into two zones: the atmosphere zone and the unsaturated zone. In the atmosphere zone, data related to rainfall and potential evapotranspiration were considered. For the unsaturated zone, geological information was taken into account. The MIKE SHE model was utilized to simulate groundwater recharge, utilizing daily records of rainfall from climate stations in Oshogbo and Abeokuta. The simulation results indicated that daily groundwater recharge varied in response to rainfall. Recharge rates ranged from 0 mm/day in January, due to insufficient rainfall, to 10.89 mm/day in Abeokuta and 29.85 mm/day in Oshogbo in August, when the soils were at field capacity. The study also revealed that daily groundwater recharge was higher in the Osun basin compared to the Ogun basin. This difference was attributed to greater precipitation, lower evapotranspiration, and the presence of sedimentary soil in the Osun basin, facilitating increased water movement into the aquifer.

1. Remote Sensing and Modelling Approaches

Many studies have employed remote sensing and modelling tools to assess the impact of LUC on hydrologic response. For example, [14] used remote sensing data and the Soil and Water Assessment Tool (SWAT) to investigate the impact of LUC on runoff and sediment yield in a watershed in China. Similarly, [60], applied the SWAT model to analyse the effect of LUC on water balance components in a Brazilian watershed. In analysing the hydrologic effects of forest loss across tropical regions, modelling shows reductions in precipitation recycling, surface roughness, evapotranspiration and dry season flow along with increases in runoff and downstream drought risks [61]. Furthermore, [62] projected by estimating significant impacts of global agricultural expansion on hydrology including resulting in a 47% increase in average runoff and 40% decrease in groundwater recharge by 2100 based on simulations.

Similarly, [16] conducted a study using ArcGIS 10.2 interfaced with ArcSWAT 2009 to evaluate the influence of land use/land cover (LULC) changes on hydrological parameters, specifically streamflow and sediment yield, in the

Kangimi Catchment located in Kaduna, Nigeria. The catchment was divided into ten sub-basins, and the development of hydrological response units (HRUs) involved creating 39 HRUs through a multiple HRU approach. The SWAT model plugin in ArcGIS was calibrated and validated, with satisfactory performance indicated by R2 values of 0.92 and 0.82, and NS values of 0.93 and 0.86 for calibration and validation, respectively. The calibrated model was then used to assess the impact of LULC changes on hydrological parameters. The model results demonstrated that the expansion of agriculture and the increase in bare surfaces resulted in elevated annual streamflow and sediment yield within the Kangimi catchment. The study found that streamflow increased by 28.23% (from 345.2 m^3/s to 387.37 m^3/s) due to agricultural growth and the presence of increased bare surfaces. Similarly, sediment yield increased by 33.31% (from 60.03 to 90.02 t/ha) as a result of the combined effects of LULC changes and climate dynamics. These findings highlight the significant influence of LULC changes on hydrological parameters and emphasize the importance of considering such changes when assessing the impact on streamflow and sediment yield in the Kangimi Catchment.

Regional effects on seasonal flow patterns, flooding/drought risks and water pollution are worthy of note [63]. Hence, in analysing agricultural expansion and its impact of hydrological response, [64] estimated that agricultural expansion could increase global runoff by 8-22% and decrease evaporation by 10-17% by 2100 based on scenario modelling. Impacts include shifts in seasonal flow patterns, increased flooding and water pollution risks, particularly in tropical regions. This position was supported in a study by [65] using modelling and satellite data they determined the impact of deforestation on higher surface temperatures and changes in precipitation patterns across tropical South America, leading to large-scale effects on regional climate and hydrology.

2. Urbanization and Impervious Surfaces

Urbanization has been a major driver of LUC, leading to increased impervious surfaces and altered hydrologic responses. In a study on the impact of impervious surfaces on the hydrologic response in a watershed [27] found that increased imperviousness led to higher runoff rates and reduced groundwater recharge. In a related study, [66] found that urbanization increased the frequency and magnitude of flood events in a Brazilian catchment [67]. Urbanization leads to impairment of water resources across multiple scales via increased runoff, flooding risks, water quality issues, hyper-salinization, loss of aquifer recharge and species endangerment in rivers and wetlands receiving urban flows. Policies and strategies for mitigating impacts are discussed [68].

In investigating the impact of LULC on Hydrological response, [2] conducted a study to examine the impact of land use and land cover changes (LULC) on stream flow in the upper Gidabo Watershed in Ethiopia. The LULC analysis identified seven types of land uses, with agroforestry being the dominant land use. The analysis revealed that agricultural land and urban settlements had increased by 59.8% and 28.7%, respectively, at the expense of forest and grassland. The study further utilized a model to assess the effects of these LULC changes on hydrological processes. The model's impact analysis indicated a 9.2% increase in the volume of surface runoff and a 1.7% increase in evapotranspiration as a result of the observed LULC changes. These findings highlight the significant influence of land use and land cover changes on stream flow within the upper Gidabo Watershed. The expansion of agricultural land and urban settlements has contributed to changes in hydrological processes, leading to increased surface runoff volume and evapotranspiration.

Going further, [69] summarized how major land use changes like urbanization, deforestation, and agriculture have altered hydrologic response at local to global scales with respect to water quality and aquatic living, pointing out fluctuations in flow volumes and timing, increased flooding and drought risks, as well as other water quality issues. In agreement, [70] and [56], both stated that agricultural expansion was responsible for a sharp increase in global runoff coefficients and a current decline in evaporation during the 20th century based on model simulations.

In Tigray regional state, northern Ethiopia, [3] conducted a study to investigate the combined impact of land use/land cover changes and climate change on hydrology in the Aynalem catchment, considering their global significance. The study focused on analyzing historical land cover changes between 1995 and 2015 within the catchment and their effects on runoff. The analysis revealed notable land cover changes during the studied period. The urban area expanded from 1.39% to 7.50%, cropland increased from 54.03% to 65.69%, and water bodies saw an increase from 0.14% to 0.42%. However, the area covered by planted forests decreased from 3.61% to 2.92%, grassland decreased from 2.22% to 1.90%, and open shrub lands reduced from 38.61% to 21.53%.

3. Agricultural Expansion and Deforestation

Agricultural expansion and deforestation are other significant drivers of LUC and have significant implications for hydrological processes. In Indonesia, [23] studied the impact of deforestation on the hydrological response of a tropical watershed and found that deforestation led to increased runoff and decreased evapotranspiration. In an Ethiopian watershed, [71] explored the effects of agricultural expansion on the hydrologic response, demonstrating that increased agricultural land use led to decreased infiltration, increased runoff, and altered streamflow patterns [5]. Measuring hydrologic response to selective logging in intact tropical rainforest using field data and models, [72] presented results that show that substantial post-logging decreases in rainfall interception (up to 60%), transpiration (up to 45%) and dry season flows (25-40%) due to changes in canopy cover, soil structure and undergrowth vegetation. Agricultural expansion may alter flow regimes by shifting the timing and magnitude of floods, increasing high flows and stream salinity while reducing low flows and water availability during dry seasons due to complex and synergistic impacts on soils, vegetation cover and geology [34,73].

Further, [74] in a study measured and modelled hydrologic response to deforestation within tropical rainforest in Southeast Asia. The results show that even selective logging reduced rainfall interception by up to 60%, transpiration by 45% and dry season flows by 25-40% due to loss of canopy cover and changes in soils and undergrowth vegetation. Supporting the work of [72] who assessed hydrologic response to deforestation simulated that between the wet and dry years, the hydrological conditions or responses were different. The impact of antecedent soil moisture on runoff production and baseflow recession rates in a semi-arid region and direct runoff production from storms that occurred during dry periods were obvious.

In Iran, [75] assessed changes in the land cover of the eastern sub-basins of Lake Urmia basin. They used classification and statistical analyses to aid in their evaluation. The results of the land cover classification analysis revealed that in 1976 and 2011, pasture land covered 41.4% and 27.2% of the study area, respectively. The decrease in pasture land was significant and was mainly due to the expansion of agricultural land. Over the last 35 years, crop land, horticultural land, and rain-fed land increased by 412%, 333%, and 672%, respectively. The researchers also used trend analysis to identify an increasing temperature trend throughout the region and a precipitation trend specific to the area. The trend tests confirmed a general decreasing trend in stream-flows throughout the region, which was more noticeable in downstream stations, suggesting that changes in land cover had a greater impact on streamflow than temperature, as evidenced by the correlation between changes in streamflow and simultaneous changes in climatic variables and land cover.

4. Wetland Loss and Restoration

Wetlands are critical for maintaining hydrological balance and mitigating the impacts of LUC [9]. In investigating the effects of wetland loss on surface water hydrology in a Canadian watershed, wetland loss was discovered to have led to increased runoff and flood risk [9]. Conversely, assessing the hydrologic implications of wetland restoration in an agricultural landscape in the United States, demonstrating that restored wetlands contributed to increased water storage capacity and reduced peak flows. Evidence show that LULC influences regional and global hydrological cycles through major influences on the existing rainfall patterns, evapotranspiration, and the water balance of rivers and wetlands [76]. Threats to ecosystems, water security and climate resilience are not excluded [10].

In the Anzali wetland catchment, Iran, [77], conducted a study to analyze the hydrological consequences of dynamic land use and land cover (LULC) changes. The study utilized the Soil and Water Assessment Tool (SWAT 2012) model to assess the impacts on evapotranspiration, water yield, and sediment yield. Two model runs were performed, one using static LULC inputs and the other using dynamic LULC inputs, to evaluate the effects of LULC changes between 1990 and 2013 on hydrologic response. In the static model, the LULC map of 1990 was employed, while in the dynamic model, a gradual change in LULC distribution was interpolated from the available 1990, 2000, and 2013 LULC data. The findings indicated that at the Hydrological Response Unit (HRU) scale, an increase in agricultural land use resulted in a rise in evapotranspiration, water yield, and sediment yield by up to 8.3%, 7%, and 169%, respectively. On the other hand, urban expansion led to a decrease in evapotranspiration, water yield, and sediment yield by up to -3.5%, -2.3%, and -9.4% respectively.

5. Climate Change Interactions

Alluding to links between climate change and hydrological response within the context of LULC, climate change can exacerbate the hydrological impacts of LULC [78] examined the combined effects of LULC and climate change on the hydrologic response, They discovered that these two factors interacted to increase runoff and decrease groundwater recharge in the watershed of study [44]. Furthermore, [17] also investigated the interaction between LULC and climate change in a Mediterranean catchment, revealing that the combined effects led to increased flood risk and reduced water availability.

In the work of [79] the combined impact of climate and Land Use/Land Cover (LULC) changes was investigated. An evaluation of the combined impact of along with and without water storage structures on water balance components of the Krishna river basin, India under present and future scenarios with the help of Soil Water and Assessment Tool (SWAT). The coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) values obtained during the calibration period were 0.63 and 0.61, respectively, whereas, in validation, these values were found to be 0.61 and 0.56, which are indicative of a satisfactory result. The results showed that the model simulations and performance were significantly influenced by the presence of water storage structures, whereas the LULC changes were effective at the sub-watershed level.

This review considers the different models and techniques that have been used in assessment of hydrologic response within various river basin systems across the globe. Upon careful selection of the articles reviewed, the location and tool(s) utilised were drawn out and presented in Table 1.

SYNTHESIS AND FUTURE DIRECTIONS

Remote sensing and modelling tools have become indispensable in studying the impact of land use – land cover change (LULC) on hydrologic response. Modelling results have revealed that LULC, such as deforestation, agricultural expansion, and urbanization, can have profound effects on various hydrologic parameters, including runoff, sediment yield, water balance components, evapotranspiration, and groundwater recharge. For instance, agricultural expansion has been found to increase global runoff and decrease evaporation, resulting in shifts in seasonal flow patterns, increased floo-

Table 1 Review of Studies and Methods employed

Location of Study	Tool used	Major Application	Author(s)
Vietnam	MIKE SHE	Watershed hydrology simulation	[80]
Malaysia	SWAT	Hydrological modelling for flood forecasting	[81]
Mexico	SWAT	Land use change impact on Groundwater quality	[82]
Spain	SWAT	Streamflow estimation for water-resources planning and management	[83]
Spain	SWAT	Hydrological modelling of Flash floods	[84]
Colombia	SWAT	Hydrological modelling of streamflow response to drought.	[85]
United States	MIKE SHE	Climate change impact on hydrological response water resources	[73]
China	SWAT	Soil erosion control	[18]
India	SWAT	Watershed management planning	[86]
Brazil	MIKE SHE	Watershed hydrological modelling	[60]
China	SWAT	Agricultural drought forecasting	[44]
Iran	SWAT	Climate change impact on hydrology	[75]
China	MIKE SHE	Water resource management	[87]
Ethiopia	SWAT	Impact on runoff and evapotranspiration	[2]
China	SWAT	Simulating the effects of land use changes on runoff and nitrate loading	[64]
China	MIKE SHE	Impact on runoff and evapotranspiration	[36]
Ethiopia	SWAT	Modelling land use changes and their impact on water resources	[8]
Ethiopia	MIKE SHE	Water balance simulation	[3]
Nigeria	SWAT	Estimating the impact of land use change on water balance	[53]
Nigeria	MIKE SHE	Estimating the impact of land use change on groundwater recharge	[59]
Nigeria	SWAT	Simulation of water quantity and quality variables	[62]
Nigeria	SWAT	Runoff simulation and water resources management	[88]
Nigeria	SWAT	Modelling and prediction of sediment yield and concentration	[89]
Malaysia	WEAP	Water resources management and watershed management	[90]
Zimbabwe	SWAT	Evaluating impacts of land use and climate change on streamflow	[20]
Burkina Faso	SWAT/WaSIM	Assessing the impacts of climate change on water resources	[91]
Ethiopia	SWAT	Modelling land use changes and their impact on water resources	[8]
South Africa	SWAT	Flow rate response to land use	[92]
Tanzania	WEAP	Modelling Water Demand and Water Resource Management	[93]
Kenya	SWAT	Simulating the impacts of land use changes on streamflow and sediment yield	[94]
Sudan	SWAT	Assessing quantitative estimation of water balance components Modelling the impact of land use changes on water resources	[95]
Ethiopia	MIKE SHE	Water balance simulation	[3]
Uganda	SWAT	Evaluating the impacts of land use changes on water resource availability	[7]
Ghana	SWAT	Assessing the impacts of land use on surface runoff	[96]

-ding, and water pollution risks, particularly in tropical regions. Similarly, urbanization and impervious surfaces have been identified as significant drivers of LULC, leading to increased runoff rates, reduced groundwater recharge, heightened frequency and magnitude of flood events, and impairment of water resources across multiple scales. Such changes in land use and land cover have been observed to impact stream flow, surface runoff, and evapotranspiration, with subsequent consequences for water quality, aquatic life, and water availability.

Climate change and LULC are global issues that can interact and exacerbate hydrologic response in catchments and watersheds, with potential regional climate and hydrological consequences. Consequently, policies and strategies for mitigating the impacts of LULC on hydrologic response have been discussed in various studies, emphasizing the need for sustainable land management practices, conservation measures, and urban planning to minimize adverse hydrological impacts. Remote sensing and modelling tools have played a crucial role in assessing the impacts of LULC on hydrologic response, providing valuable insights for understanding the complex interactions between land use change, hydrology, and climate change, and informing decision-making for sustainable land and water management practices.

KEY FINDINGS AND KNOWLEDGE GAPS

Despite significant progress, several knowledge gaps remain. For instance, agricultural expansion and deforestation have been identified as having significant implications for hydrological processes, including altered streamflow patterns, changes in rainfall interception, transpiration, and dry season flows. However, further research is needed to fully understand the extent and magnitude of these impacts, particularly in different regions and under different climatic conditions. Additionally, the effects of LULC on wetlands, including wetland loss and restoration, on runoff and flood risks, and water storage capacity, need further investigation. Furthermore, the influence of LULC changes on regional and global hydrological cycles, including rainfall patterns, evapotranspiration, and water balance, requires more in-depth study. The interactions between climate change and LULC impacts on hydrologic response also need further elucidation, including potential synergistic or antagonistic effects. Moreover, the impacts of LULC changes on ecosystems, water security, and climate resilience require more comprehensive assessment. Overall, ongoing research using remote sensing and modelling tools is crucial in addressing these knowledge gaps and advancing our understanding of the complex relationship between land use change, hydrology, and climate change, and informing effective strategies for sustainable land and water management practices.

Overall, the findings highlight the significant role of agricultural expansion, deforestation, wetland loss and restoration, and climate change interactions in influencing hydrological processes and water resources. These impacts have important implications for water availability, flood risk, and ecosystem health, and underscore the need for sustainable land management practices to mitigate the adverse effects of LULC changes on hydrological processes and water resources.

IMPLICATIONS FOR LAND USE PLANNING AND WATER MANAGEMENT

The impacts of land use and land cover (LULC) changes on hydrology have important implications for land use planning and water resources management. LULC changes can significantly alter hydrological processes, such as surface runoff, groundwater recharge, infiltration, interception, and evaporation, which in turn can affect the availability and quality of water resources in watersheds. These impacts may vary in magnitude and duration, and can occur at different spatial and temporal scales, from local catchment areas to entire watersheds or river basins, with downstream implications for water supply and quality.

Given that hydrological phenomena are very volatile in both place and time, it is critical to regularly examine the implications of LULC alteration on hydrology in order to successfully manage basins and make intelligent choices regarding land use control and water resource management. Regional-scale hydrology models may be extremely useful in modelling the effects of probable future modifications in LULC and suggesting methods to increase river basins' adaptive capacity. Recognition of the effects of LULC alterations on the hydrologic cycle is essential for the efficient handling of earth's resources, particularly water supplies.

However, hydrological modelling, particularly rainfall-runoff prediction, is a complex process due to the spatial and temporal variability of topographical characteristics, rainfall patterns, and the number of parameters involved. Therefore, there is a need for further research on the combined impacts of LULC changes on hydrology and water quality, as well as the effects of different types of LULC on hydrological processes.

Advancements in technology, such as remote sensing and modelling tools, have facilitated the monitoring and study of LULC dynamics for environmental purposes, which can aid in the comprehension of LULC transformations for effective natural resource planning and management. It is important to continuously question and update our understanding of land-water interactions to ensure that the best available information is used in decision-making processes related to land use planning and water resources management in a sustainable manner. Overall, assessing the impacts of LULC changes on hydrology is crucial for watershed management and development, and can provide valuable insights for decision-makers to make informed choices for sustainable land and water management practices.

CONCLUSION

Land-use change has significant impacts on the hydrological cycle and hydrologic response. Different land uses, such as urbanization and agriculture, can alter the way water moves through the environment, affecting water availability, flood risk, and water quality. These impacts can be direct, such as changes in precipitation, infiltration, and discharge, as well as indirect, such as alterations to landscape characteristics and land management practices. Understanding the relationship between land-use change and hydrologic response is crucial for effective water resource management and sustainable land-use planning. Although research on the impacts of land-use change on hydrology and water quality has made progress, there is still much to learn, particularly regarding subsurface aspects and mechanisms. The relationship between land use and water quality has become increasingly relevant as human activities continue to intensify in watersheds. It is imperative to consider the effects of land-use change on hydrology and water quality in land management decisions to ensure sustainable water resource management and protect ecosystem health in the face of ongoing changes in land use and climate. Further research in this area is needed to enhance our understanding of the complex interactions between land use, hydrologic response, and water quality and inform effective strategies for managing water resources in a changing world.

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