Impact of Climate Changes and Landuse/Land Cover Changes on Water Resources in Malaysia

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Abstract This study explored various research conducted on the impact of climate change, land use, and cover change (LULC) on Malaysia's availability of water resources. The country has abundant surface water reservoirs with adequate annual rainfall, which has been projected to be higher in the future. However, climate change and LULC have been global issues with consequences on water resources everywhere. The rate of rainfall erosivity in Malaysia was increased considerably as climate change continued increase caused by global warming. Several parts of the country have reported cases of increasing flash floods and soil degradations such as soil erosion and sedimentation. Moreover, the LULC has shown a serious effect on water availability for domestic uses in several regions of the country. For instance, Selangor has consumed the largest volume of water in excess of about 4,000 MLD, which has been increasing on an annual basis. However, the supply has no longer meet the water demand with occasional interruptions due to sudden water pollution. This phenomenon has been attributed to variation in climate parameters, leading to frequent occurrences of flash flood, severe soil erosion, and sedimentation. Ultimately, the domestic water supplies are affected which depend mainly on river water resources and thus, changes in climate will indirectly influence the resident and industrial water supplies. Additionally, LULC has indicated that more lands are highly becoming erosion potentials by surface exposure due to conversion of forestlands to other forms of land use such as agriculture and developments. The combined effect of climate change and LULC is undoubtedly increasing soil erosion and sedimentation

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of water reservoirs. Thereby, causing water quality deterioration and reducing water storage volumes by reducing water reservoirs' carrying capacities.

Keywords Flash flood · Climate change · Water quality · Lan use change · Sedimentation · Water availability

1 Introduction

Climate change and land-use change are among the significant factors influencing water resources and the regional hydrological cycle. Change of land use affects water resources quality, availability and hydrological processes by changing surface roughness, canopy cover, soil properties, and rate of evapotranspiration, whereas change in climate alters main components of hydrological cycle such as evaporation, precipitation, groundwater availability, soil moisture, quantity and timing of runoff [1]. Understanding the possible implications of land use change and climate change on water quantity and quality on a regional scale is critical for long-term water resource management and planning. Land use and climate change's hydrological implications have received growing attention from water resources experts and decision-makers as water scarcity, droughts, and floods have become more common [2]. Alteration in the local and regional hydrological cycle may increase intensity and frequency of storms, floods, and droughts [3]. It is critical to dynamically evaluate the simultaneous hydrological effects of land use change and climate change in order to optimally manage the quantity and quality of water resources in response to development and population growth. This will further help to optimally manage quantity and quality of water resources in response to development and population growth.

In a worldwide setting, there is a growing interest in understanding how land use change and climate change affect water supplies, including in Malaysia. Malaysia is a country in Southeast Asia that is divided into two regions: Malaysian Borneo and Peninsular Malaysia. In 2017, the country's population was predicted to be over 32 million people, with a total land area of 330, 803 km^2 [4]. Because of anthropogenic activities such as urbanization, agricultural growth, and deforestation, Malaysia has seen significant land use and cover changes. Furthermore, the country has an equatorial climate characterized by hot and humid weather throughout the year, as well as rainfall inconsistencies in recent decades. As a result, various research on the effects of land use change, climate change, and both land use change and climate change on water resources in Malaysia have been done Tang [3] and Tan et al. [4]. According to Nainar et al. [5], the forest catchment converted to oil palm catchment exhibited highly variable discharge, quick reactions during storm events, but extremely low baseflow at all times. According to the study, the primary forests also supported the highest stream baseflow and good runoff control. Another study by Saadatkhah et al. [6] found that the increase in severe water flow in the Kelantan River basin is a result of urbanization and the conversion of forest lands to low-canopy plantations like oil palm, rubber, and mixed agriculture. Malaysian rivers have also been contaminated as a result of increased industrial growth, forest degradation, and agricultural expansion, resulting in unregulated and uncontrollable LULC. As a result, ongoing developments have resulted in a worsening of water quality [7]. According to Camara et al. [8], agricultural and logging activities had a greater impact on water quality due to their significant positive correlation with chemical and physical indicators of water quality, whereas urbanization had a greater impact on water quality due to changes in hydrological processes such as erosion and runoff. In addition to the effects of land use change and climate change, studies of the combined effects of land use and climate change on Malaysia's water resources have been conducted. Tan et al. [3] investigated the effects of land use change and climate change on the hydrological components of the Johor River basin. The authors determined that the combined effects of land use and climate change cause an increase of 4.4 and 1.2% in annual streamflow and evaporation, respectively. Adnan and Atkinson [9] discovered that climate and land use change enhanced streamflow in the wet season and lowered streamflow in the dry season in the Kelantan River basin.

The fundamental motivation for this research is that climate change and anthropogenic activities such as deforestation, agricultural development, and urbanization have continually worsened the state of Malaysia's lands and water resources throughout the country. Despite the fact that there has been a lot of study done to address the issues described above, this review was important to incorporate the major findings of the previous studies to help policymakers identify specific basins that need to be improved and prioritized. As a result, this review aims to highlight the most recent trends and potential impacts of land use change, climate change, and combined land use and climate change impacts on water quantity and quality in various parts of Malaysia and identify the major sources of water resource degradation. Based on the current study's findings, the review also suggests mitigation and adaptation strategies for managing water resources.

2 Impact of Climate Changes on Malaysian Water Resources

2.1 Introduction to Climate Change

The climate system results from a complex interrelation of atmosphere, ocean, land surfaces, cryosphere, biosphere and lithosphere [10, 11]. The cryosphere comprises land surface covered by ices (ice shelves and glaciers), snow and sea ice. The biosphere refers to all living organisms on the planet that spread throughout the ocean and land surfaces. The role of land surfaces as a climate system component is more pronounced by major impacts of green vegetation. The solid earth portion is regarded as lithosphere which facilitates the distribution of ocean basins, mountain ranges, including the incidence of volcanic eruption [12]. The chemical composition in the atmosphere can be considered as component of climate change. Both internal undercurrent and external factors influence climate system. The forcing mechanisms usually refer to external factors, including natural phenomena such as volcanic eruptions, solar variations, and human-induced factors. Human factors include continuous burning of fossil fuels and the depleting natural vegetation cover, both actions lead to changes in atmospheric composition. The amount of solar radiation entering the earth's atmosphere and surface has been in balance with the amount of energy emitted. The latter is made up of shortwave and longwave components in each case. Meanwhile, the earth's surface absorbs roughly half of the incoming radiation; this energy is transported back to the atmosphere, warming the air in contact with the surface (sensitivity heat), evaporating water (latent heat), or absorbed by clouds and green gases. Long wave energy is eventually radiated back to the planet as well as out into space by the atmosphere [13].

Nowadays, climate change is one of the most severe challenges facing humanity around the world [14, 15]. This problem drew the attention of international and multidisciplinary researchers and organizations to direct their efforts towards global environmental sustainability. Among these organizations are Intergovernmental Panel for Climate Change (IPCC), United Nation Environment Program (UNEP) and World Metrological Organization (WMO). The main objective of establishing these organizations was to provide the world with clear idea of current knowledge on climate change and its potential impact on the environment and global socioeconomic activities. Both global and regional climate changes are complex phenomenon which human activities are the major influencing factors for their changes [10]. The studies conducted by IPCC working groups show that, change in climate have indicated positive and negative consequences in future. However, the negative effect will prevail with large rates of climate change to be observed globally. Among the anticipated adverse impacts of climate change are excessive changes in extreme rainfall and temperature events [16]. Moreover, the patterns in some climate system variables were expected to include more hot days and heat waves in some regions, while in other regions, there were fewer cold days and cold waves. Eventually, it may lead to rise in global precipitation, a greater number of severe events (flood and drought) and a catastrophic overall ecosystem [12]. There are clear convictions that the global environment is already changing and that more changes are inevitable. For example, the average global temperature rose by about 0.74 °C over the last century from 1906 to 2005 [16].

The IPCC recently released studies that showed solid evidence of rising global average sea level. The melting of snow cover and mountain glaciers is thought to have caused a total worldwide mean sea level rise of 12.22 cm during the twentieth century [17]. It was also discovered that there have been changes in the amount, intensity, frequency, and types of precipitation over the last century [18]. Furthermore, it was predicted that by the year 2100, the earth's surface temperature is expected to rise by 1.1–6.4 °C. Latest evidence has revealed that the climate system has been steadily heating since the 1950s, with more spectacular observable changes spanning decades to millennia.

Similarly, increased warming has been observed in both temperature and ocean water while the amount of snow and ice have reduced and both sea level and concentration of GHG have increased. In addition, the earth has been successively warmer in each of the last three decades at the surface of the earth than any preceding decade since the year 1850. Energy stored in the climate system has been dominated by ocean warming, accounting for more than 90% of the energy accumulated between the year 1971 and the year 2010 [19]. Recent studies have shown that, there have been reductions in the mass of the Greenland and Antarctica ice sheets during the last two decades. This indicates a worldwide shrinkage of glacier with both Arctic Sea ice and Northern Hemisphere spring snow cover have continued to reduce in sizes. Similarly, the rate of sea level rise since the mid-nineteenth century has been larger than the mean rate during the two previous millennia.

Carbon dioxide (CO_2), methane (CH_4), and nitrogenous oxide (NO_2) concentrations in the atmosphere have also surged to levels not seen in at least 800,000 years. Carbon dioxide concentrations have risen by 40% from pre-industrial times, owing largely to fossil fuel emissions. Although the ocean absorbed around 30% of the produced anthropogenic carbon dioxide, the alterations have triggered land use emissions changes, leading to ocean acidification [20]. Natural and manufactured chemicals and processes that modify the earth's energy budget are main component climate change drivers [14]. According to Nasidi et al. [21], climate drivers are the elements that contribute to GHG emissions directly or indirectly. Interaction of the climate system components can lead to important climate processes. This may lead to a possible imbalance in the earth ecosystem with a global consequence requiring other components to respond accordingly.

2.2 Impact of Climate Change on Water Resources in Malaysia

Several studies were conducted with respect to climate change, land use/cover change (LULC), and available water resources. These studies have revealed changes in climate variables, increased rainfall frequency and expansion of surface water storage. For example, Amin et al. [22] reported an increase in future temperature of Malaysia by 36.3% from baseline condition for the twenty-first century with a corresponding change in precipitation of 45.4% due to climate change. This agrees with Tan and Nying [23] where high temperature and precipitation are projected to occur due to climate change at Pahang in 2069 period. The study also highlighted the need to follow management control guidelines to curtail erosion and landslide problems that affect water resources quality. Moreover, earlier studies have reported the significance of restricting any unsustainable agriculture practice because of its severe impacts on the environment, wildlife, tourism, and humans. Their impacts are further impinging on quality and quantity of water supplies from upstream down to the surrounding lowlands regions of Malaysia. Similarly, Razali et al. [24] conducted review on land use change in highlands and its impact on river water quality and reported considerable water quality deterioration due to change of land use which largely caused by development and agriculture activities.

2.3 Water Quality and Quantity Changes Due to Climate Change

Peninsular Malaysia has a rich network of rivers and streams that produce approximately 150 major river basins. The Pahang River is the longest, running for 434 km before reaching the South China Sea. The drainage catchment area is approximately 29,000 km^2. The Kelantan, Terengganu, Dungun, Endau, and Sedili rivers all drain into the South China Sea in a similar manner [25]. The major river basins in the east of Malaysia are larger than those in Peninsular Malaysia. The Rajang River in Sarawak, eastern Malaysia, has the longest river in the country at 563 km. The quality and quantity of water in these rivers kept changing over considerable time [26, 27]. Climate change has significantly affected the variability of water received from the atmosphere, consequently influencing environmental sustainability.

Similarly, the quality of available water has been affected considerably that causes intermittent disruption of domestic water supply in several states, for example Selangor and Kedah [28]. Nasidi et al. [18] reported that increased rainfall in most parts of Malaysia is the main reason for increasing water contamination from high inflow of soil erosion and sedimentation. The study has further connected high erosive rainfall with influence of climate change on climate variables. Thus, it leads to increasing contamination of surface water storage such as dams and riverbanks. Consequently, affect the quality of domestic water supply in most towns and cities of Malaysia. Furthermore, Ismail [28] assessed the availability of water resources in Perak which shared a boundary with Pahang from west and correlated it with land degradation. The results showed a clear agreement between the volume of water received and soil erosion. Abdullah et al. [27] has further evaluated the rainfall received in Pahang state of Malaysia and found the average rainfall received has been increased by 26% of the past three decades. The disadvantage of this study is that, since erosivity is reported yearly, two months erosivity is insufficient to conclude soil erosion for a particular study location.

For instance, Nasidi et al. [26] conducted a study on the impact of climate change on erosion severity, water resources, and corresponding area coverage under different emission scenarios (Fig. 1). The study selected two future periods for the impact assessment (2050s and 2080s). The results revealed a progressive increase in degree of erosion which translates into high rate of water contamination. Reference with baseline period (1976–2005), future scenarios indicate more areas to be affected by high soil erosion intensities under each Representative Concentration Pathway (RCP). In addition, high area extent was found to experience more intense soil degradation and water contamination in 2080s than the corresponding period in 2050s.

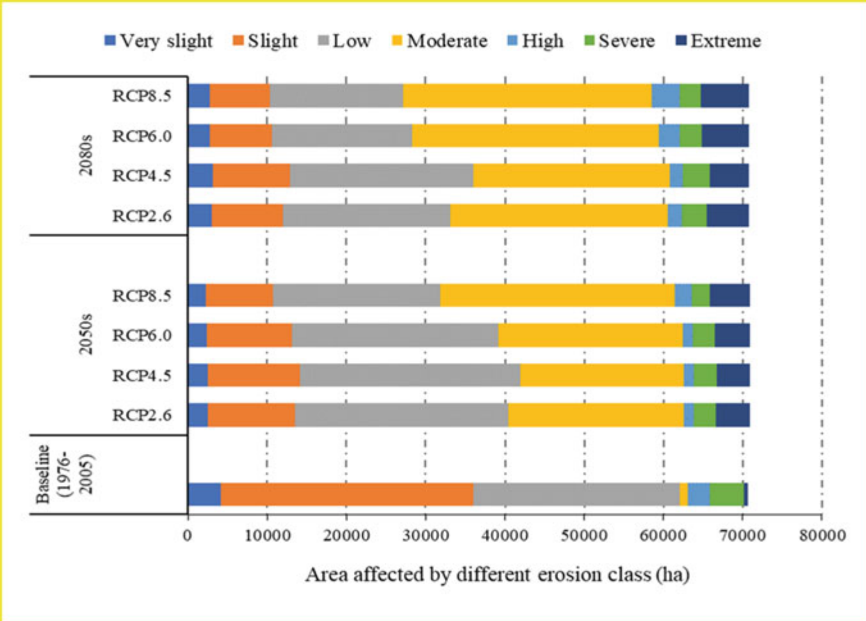

Fig. 1 Soil erosion severity change due to climate change [18]

However, both climate change projection periods have shown considerable increase of soil erosion relative to the baseline condition.

However, the demand for water use in Malaysia rises annually due to a rise in population and economic growth, resulting in a water deficit experienced since 2010. Perlis, Kedah, Pulau Pinang, Selangor, and Melaka are among the states in Peninsular Malaysia that are affected [25]. In 2010, severe water scarcity was recorded in Kedah and Selangor, with deficits of 1,852 Mm^3 and 1,278 Mm^3, respectively. Water shortfalls are expected to rise until 2050, according to projections. According to the Water Resources Study undertaken for the period 2015–2050, the Northern States, especially Perlis, Kedah, and Penang, have been experiencing water shortages of around 246–221 Mm^3. Selangor and Melaka are next, with estimates of over 1,000 Mm^3 and about 200–336 Mm^3 respectively. Despite the fact that Selangor's population has been growing over the years, the state faced a water crisis in 2014 due to a drought season that led the dam level to drop. The main factor responsible for this scarcity of water resources was attributed to the climate change. Figure 2 shows change of domestic water consumption in Malaysia in million liters per day (MLD). With the increase in climate variability, these figures might have increased by now and will continue to increase.

Moreover, roughly 360 km^3 of the entire annual rainfall volume of 990 km^3 is lost to evapotranspiration [25]. Similarly, total surface runoff is 566 km^3, and groundwater recharge is about 64 km3 (about 7% of total annual rainfall). Despite this, about 80%

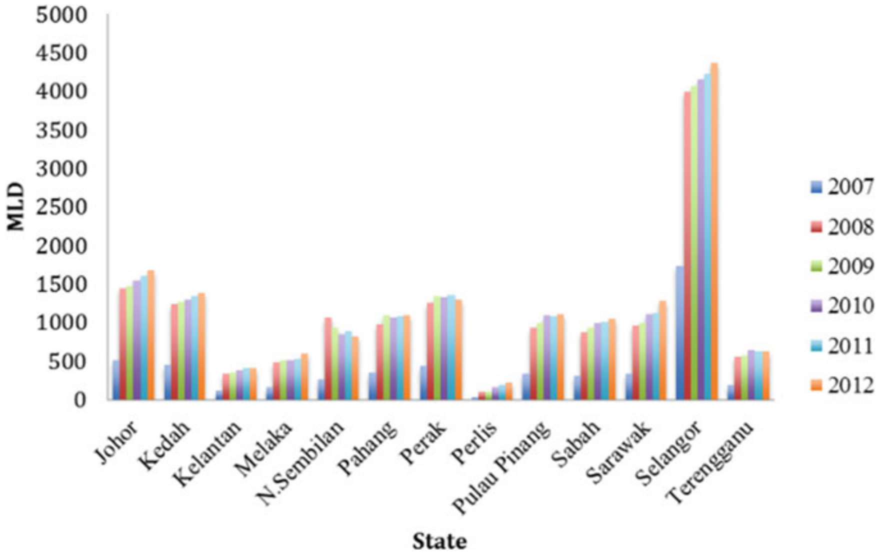

Fig. 2 Water resources in Malaysia from 2007–2012 [25]

of groundwater is returned to rivers and is not considered a separate resource. As a result, Malaysia's total internal water resources are projected to be 580 km^3 per year.

2.4 *Factors Affecting Water Demand and Supply in Malaysia*

Globally, studies have reported that climate change influences the demand and supply of water e.g. [29–31]. Similarly, according to a Malaysian assessment, climate change is a major contributor to changes in water demand and supply, including reservoir operations, water quality, hydroelectric generation, and navigation [18, 25]. During dry seasons, the demand for water in agriculture activities tends to increase. As a result of climate change, water supplies are becoming increasingly scarce and expensive. Population, affluence, as well as the expansion of the ecology system and recreational usage, all influence water demand. As a result, water consumption efficiency must strike a balance between water supply constraints and rising demand.

3 Land Use Change Impacts on Quality and Quantity of Water

3.1 Land Use Change Trends and Implications

Land use and land cover change (LULC) management is still a major environmental issue that society must solve. LULC is one of the key causes of environmental change, with substantial consequences for human livelihoods, in addition to ecosystem fragility. Hydrological, climatological, and biodiversity responses all show such changes [32]. Over the world, expansion of cropland and urban areas is at the expense of forest and grasslands [33]. LULC change is one of the important driving factors forcing environmental changes at spatiotemporal scales, significantly contributing to earth surface processes and forest fragmentations. In addition, the hydrological response of watershed is notably changed due to LULC alterations [34]. An example of this phenomenon is a study by Gyamfi et al. [35] who reported that groundwater flow is higher and surface runoff is lower in the vegetative lands due to the greater percolation of rainfall into the shallow and deep aquifer. While vegetation is absent in the cleared lands, groundwater flow is lower and surface runoff is higher. Urbanization, deforestation, and other human land use activities can significantly change seasonal and annual distribution of stream flow. Understanding how these changes impact water quantity will enable policymakers and planners to formulate plans towards minimizing the negative effects of projected land use changes on runoff rate and stream flow patterns. The situation is more critical in high rainfall regions like Malaysia [36].

In Malaysia, population growth and human activities have increased pressure on land, forests, and water resources causing misuse of the land use. In the last decades, Malaysia has experienced intensified and rapid urbanization since its independence because of high economic growth [37]. Agricultural productions are still critical to the country's economic development, even though the country's development policy has shifted from the agricultural to the manufacturing sectors since the 1980s [38]. Consequently, most of the forestland has been turned to cropland, especially oil palm and rubber plantations. Furthermore, the development of wood and non-timber resources that provide the country with socio-economic benefits has resulted in the loss of most of Malaysia's forested land (Table 1). The land use change trends of intensified rubber and oil palm crops over the last century have altered the features of Malaysia's landscape. Accordingly, forest land has been converted to rubber and oil palm lands until the mid of 1990s, thereafter not only forest land rather rubber and oil palm plantation areas were converted to urban and built-up areas due to industrialization in the region [39]. These findings revealed that the rapid industrial development remarkably increased the rate of urban and built-up area. Such fragmentation, landscape pattern changes and heterogeneity have affected the integrity of different ecological systems including water quantity and quality. Several studies such as Olaniyi et al. [40] and Pourebrahim et al. [41] have confirmed that land use transition was made in Malaysia mainly due to agricultural productions up to

Table 1 A summary of numerous studies conducted on land use/cover change extent in various parts of Malaysia

Target	Observations/results	Location	Studies
Hydrologic characteristics and land use assessment	Built-up and oil palm area were increased at the expense of forest area	Tasik Chini's Feeder Rivers/Pahang	[36]
Changes in agricultural landscape pattern and its relationship with forestland	(1966–1981) the total area of oil palm was increased 4.7% per year, while total area of forest declined 0.2% per year	Selangor, Peninsular	[38]
Generating insights on the changing process of land use/land cover and landscape pattern	(1966–1995) the total area of oil palm plantation was increased from 866 (ha) to 6967 (ha), while total area of forests was reduced from 2137 (ha) to 2087 (ha)	Selangor State	[42]
Relationship between landscape pattern and landscape type response to changes in land use	Recently, land use conversion has been more associated with urbanization than using to crop lands	Selangor State	[39]
Assessment of Drivers of Coastal Land Use Change	Between (1980–2000) Urbanized area was increased from 26.1% to 33.7% whereas mangrove forested area was increased by 4.6%	Perak State	[40]
Land cover and industrial plantation distribution in The Peatlands of Peninsular Malaysia, Sumatra, and Borneo	Between (2007–2015) deforestation rate of 4.1% per year was performed. Industrial plantation was the major reason for the change	Sarawak State	[43]
Determination of land cover changes in the city of Seremban	Between (1990–2010) non-vegetative land was increased from 3.55 to 7.25%	Negeri Sembilan State	[44]

1990s. Afterward, land cover changes were attributed to urbanization and the industrial sector development. All the studies in the (Table 1) concluded that urbanized area and industrial plantation are the two main driving factors contributing to forest clearance and land use change.

3.2 *Water Quantity Response to Land Use Change*

When local and regional development rise, land use and land cover shift as well. Such changes are increasingly influencing the hydrological process, resulting in water yields, streamflow, surface runoff, flow regimes, soil moisture, and evapotranspiration [44]. The land will become impervious when the forest takes over and vegetative sections are converted to built-up areas. Furthermore, forested places differ from barren fields, short crops, and built-up areas in terms of roughness and morphology. Rainfall that falls in urban areas enters waterways quickly, creating stormwater runoff and erosion [45]. Malaysia's economic transformation from an agriculture-based to an industry-based economy has rapidly expanded in developed areas in recent years [46]. For example, in Peninsular Malaysia's peatlands, forest-dominated cover had decreased to 42% by 2007, although forest cutting rates had remained high. Over a quarter of peatlands had been converted to managed land use categories, resulting in lower water table levels (11% small-holder areas and 18% industrial plantations) as reported by Miettinen [43]. As a result, quantity of water resources in Malaysia has undergone remarkable alteration. Uncontrolled urban development has negatively affected Malaysia watershed ecosystems, in particular their capacity to regulate streamflow.

However, majority of the reports indicated that logging activities and conversion of natural forests to agricultural and urban lands are the key factors changing water quantity and increasing flood risks in various parts of Malaysia. As a result, several research on the effects of changing land use and land cover on water quantity and flood events have been done (eg. Saadatkhah et al. [6] and Mansor et al. [47]). The data demonstrated that conversion of forest land to agricultural and built-up areas increased surface runoff and stream flow, trends in water discharge, and upsurges in flood volume at the watershed scale. Groundwater flow and percolation reduced dramatically compared to surface water [3]. The fundamental cause of this phenomena is that forest cover areas have higher interception and infiltration rates than other managed land uses; thus, forest clearing can boost surface flow while decreasing groundwater flow. Based on the findings, it can be concluded that increased surface water flow was recorded in cleared fields and catchments with low-density vegetation, but low surface runoff was observed in basins with forest and secondary jungle. Furthermore, urbanization and deforestation, notably the transfer of forest lands to less densely wooded areas for rubber and oil palm plantations and mixed agriculture, were revealed to be responsible for the rise in surface water flow. Urban soils, on the other hand, have a superior impermeable ground surface due to the lower rate of infiltration and less/loss evapotranspiration, resulting in excess runoff volume [6].

Nevertheless, there are some other contradictory results about the influence of LULC on water quantity. For example, Adnan and Atkinson [9] conducted a study on exploring the impact of land use change on streamflow changes in Kelantan River. They found that deforestation and urbanized area increased streamflow, and consequently increased flood events in the wet season in the downstream catchment but decreased streamflow in the dry season. Furthermore, the findings from small catchments differed from those obtained from moderate and large catchments. Ngah and Reid [48] found that a moderate-sized catchment (1000 km^2) is not straightforward and usually contradictory when compared to findings from other experimental catchments. Particularly those studies on impact of land use change on water yield in the Langat River basin in Selangor State and the Linggi River basin in Negeri Sembilan

State. Consequently, it may be deduced that forest area supports good runoff management and stream baseflow. On the other hand, urban and built-up regions enhance surface runoff and flood volume.

3.3 Land Use Change Impacts on Water Quality

Anthropogenic land use change negatively affects the conditions of water quality [7]. Transformation of grasslands and natural forests to croplands and built-up regions, combined with intensive agricultural activities and population increase, is a potential source of toxins from agricultural chemicals, urban sewage disposal, and landfill, all of which affect water quality [49]. Increased nitrate and nitrogen concentrations in surface and subsurface water have been a major source of concern in recent decades. This is because of a rapid agricultural, industrial, and urban development, which revealed a clear link between rising nitrate levels in water resources and increased human activities [50]. Changes in surface water quality are strongly linked to nearby land use, and the types and quantities of contaminants that flow into lakes, rivers, and aquifers are largely determined by the land use pattern [51]. Water quality is defined as a measurement of water utilization for a variety of purposes, including drinking, irrigation, industrial, recreation, and habitat, based on chemical, physical, and biological factors [52]. Water quality is extremely important to all living species on the planet. As a result, many scholars, policymakers, and water resource managers have taken notice of this viewpoint. The quality of water changes based on the time, place, climate, and pollution source. Water resources can be contaminated by point and non-point source (NPS) contamination [8]. Natural processes may cause NPS contamination, which cannot be completely avoided, but synthetic alterations can have a major impact on the rate of pollution at the source.

Pollution of water resources in Malaysia poses a severe threat to public health and the environment. According to a report published by the Department of Irrigation and Drainage in 2001 and quoted by Juahir et al. [52], about 60% of Malaysia's major rivers are regulated for domestic, industrial, and agricultural reasons. According to Rosnani [53], sewage disposal, industrial discharges, land clearance, and earthworks activities harm Malaysian rivers. Similarly, Juahir [52], 42% reported that the river basins were polluted with suspended solids (SS) from uncontrolled land use and land clearing, 30% with biological oxygen demand (BOD) from industrial discharges, and 28% with ammoniacal nitrogen (AN) from husbandry activities and urban sewage disposals in 1999. This finding showed that poorly planned land clearing activities polluted the majority of river basins (42%) the most. Numerous studies have been undertaken to investigate the impacts of land use change on water quality and their association with water quality indicators (Table 2). The findings from (Table 2) revealed that anthropogenic land use change has evidently affected water quality due to the rapid and continuous developments that Malaysia has been undergoing over the last decades. Thus, changes in landscape pattern by human developments are the source of water quality degradation in different water bodies through different processes. In Malaysia, land use is categorized into three major types namely: dominated forest land use, agricultural land use, and urbanized lands.

Natural forests would have no major negative effects on water quality without anthropogenic activities. It is obvious that trees can help to preserve the quality of

Table 2 Impact of land use change on water quality in different regions of Malaysia

Location	Objectives	Observations/results	Studies
Cameron Highlands, Pahang State	To summarize the impacts of land use change, practices-policy-management of agriculture, and agro-tourism on water quality of the river system network	Outcomes from earlier studies have highlighted that the factors such as soil erosion, agriculture activities, landslides urbanization, and unplanned developments associated with land use change have notably affected the river water quality	[56]
Nerus River, Terengganu State	To assess response of water quality in Nerus River to land use and land cover characteristics	The relationship between water quality and land use change demonstrated that urbanization was a major factor affecting the river water quality, followed by horticultural activities in rural areas close to the rivers	[57]
Malacca River, Malacca State	To determine the connection of LULC changes in contributing to pollutant sources in the Malacca River	Urbanized area significantly polluted the water through E. coli, total coliform, EC, BOD, COD, TSS, Hg, Zn, and Fe, while cropland activities caused EC, TSS, salinity, E. coli, total coliform, arsenic, and Iron pollution	[7]
Pinang River, Keluang River, and Burung River, Penang State	To investigate the interaction of land use change and water quality in rivers in Penang Island and identify the pollution sources along the rivers	The overall results showed that total organic carbon (TOC) increased due to urban sewage in Pinang and Keluang Rivers, while TOC increased due to the paddy fields in Burung River	[58]
Sabah State	To evaluate the effects of various land uses on suspended sediment dynamics	The findings demonstrated that even multiple-logged forests have high value in conserving water quality and reducing erosion in hilly terrain, while oil palm cover requires careful land management	[59]

(continued)

Table 2 (continued)

Location	Objectives	Observations/results	Studies
The states of Kedah, Penang, and Perak	To study water quality status of rivers under different managed land use activities	The rivers with industrial land use setting showed the highest level of pollution, followed by rivers with plantation pollution, while recreational and less distributed rivers recorded the lowest level of pollution	[60]
Tanah Tinggi Lojing, Kelantan State	To discover the relationship between managed land uses and water quality status	The results pointed out that land use developments have affected the water quality parameters in the Tanah Tinggi Lojing area	[61]
Gombak River, Selangor State	To establish a link between water quality and land use characteristics	The findings revealed that as the amount of activity in the river watershed rose, the water quality index (WQI) value declined. Furthermore, the anticipated WQI revealed a steady decline in water quality	[62]

surface water. For example, in a study published by Nainar et al. [50], the rainforest was found to make a few noteworthy contributions to water quality and erosion reduction. Despite their importance in safeguarding water quality, forest areas are shrinking in Malaysia. This is primarily due to the conversion of forest lands to agricultural and urban development uses. As a result, the majority of the studies analyzed in this study focused on the effects of deforestation on Malaysian surface water quality. The association between land use change and water quality characteristics revealed a significant positive relationship between changes in chemical and physical water quality indicators and forest land use.

Furthermore, according to the findings summarized in this review, forest clearance can cause more salinity problems in river basins. as Also, the sediment export and organic matter decomposition in streams, which can cause acidity issues in the basin, such as total acidity, low pH, and mobilization of dissolved heavy metals. The correlation analysis revealed a substantial positive link between increasing agricultural lands and physical and chemical water quality parameters in Malaysia. Water quality indicators (physical parameters such as temperature, electrical conductivity (EC), total suspended solids (TSS), turbidity, and total dissolved solids (TDS), as well as chemical parameters such as pH, biochemical oxygen demand (BOD), heavy metals, dissolved oxygen (DO), chemical oxygen demand (COD), and nitrate) have been the focus of major studies in Malaysia to address the impact of land use change on water quality. This is because these criteria are made up of elements used to establish the quality of various water bodies (lakes, rivers, and streams) in Malaysia using the Malaysian Marine Water Quality Standards and Index, controlled by the Department of Environment [54].

Urbanization is another type of land use which affects water quality. Several researchers have investigated the effects of urbanized land on water quality over the last decade in Malaysia. Thus, urban land use as one of the forcing factors has been the focus of numerous studies (Table 2) in dealing with water quality status in the country. The findings of the reviewed reports in this study stated that the major sources of water quality degradation in built areas involve industrial, residential, and recreational activities. As a result, urban growth has become a key predictor of water quality changes in the water resources of Malaysia. A study by Azyana et al. [55] which was conducted on water quality degradation in the Kinta River, Perak State, the results showed that land development was the best indicator for water quality degradation. The overall results of the reviewed reports illustrated that logging activities and conversion of forest land to urban and agricultural land use are the main sources of water quality degradation in Malaysia. However, comprehending the correlation between land use change and water quality can facilitate viable management of the major sources of water deterioration and the processes involved in assessing water quality status.

4 Conclusions

Malaysia is blessed with a high annual rainfall amount in almost all the regions of the country. However, studies have revealed the considerable impact of climate change on the quantity and quality of the available water resources. The climate change, which is caused by global warming, has limited the water availability for domestic uses in several regions. Many catchments are found to have higher rainfall characteristics with raise in temperatures. These increments in climate variables could lead to extreme events that cause flash flood and severe drought incidents. Since, the domestic water supplies are relying on river water resources, changes in climate will greatly influence the resident and industrial water supplies due to variation of both water quantity and quality. Moreover, land degradation is also bound to occur such as soil erosion at higher rates when rainfall erosivity is higher due to climate change.

Consequently, the higher rates of both erosion and sedimentations will directly affect the quality of river waters. In addition, higher sedimentation will eventually lead to the reduced river carrying capacity and, hence, reduces the river's water quantity or flow rates. Furthermore, this study found that the LULC due to anthropogenic activities has directly contributed to the change in quantity and quality of water resources in Malaysia. Also, the rate of deforestation for residential development showed an increasing trend, affecting the quality of river water.

5 Recommendations

1. Anthropogenic activities (e.g. deforestation, agricultural activities, residential developments, mining, landscape reforming-cutting hills, etc.) are the major causes of climate change. Optimization of these activities and recovery process such as reforestation should be emphasized to overcome the issues of human activities that trigger or induce land use and climate changes.
2. Future LULC requires proper planning, especially on expanding residential area and agricultural land for food production. Any developments should consider a conservative aspect to determine the consequences on the water resources.
3. Enforcement and campaign on the implementation of Best Management Practices (BMPs) for land use and water resources management to all stakeholders are important mechanisms to ensure that they are protected and conserved.
4. Wise management of the land and water resources by all stakeholders including the authorities and societies is necessary to ensure that it does not induce the climate change and interrupt water resources both in terms of flow quantity and river quality.
5. More studies and implementation of Integrated River Basin Management (IRBM) by the relevant authorities could minimize the effect of LULC and climate changes on water quantity and quality.

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