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Review

Sustainable Ecosystem Services Framework for Tropical Catchment Management: A Review

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Abstract: The monsoon season is a natural phenomenon that occurs over the Asian continent, bringing extra precipitation which causes significant impact on most tropical watersheds. The tropical region's countries are rich with natural rainforests and the economies of the countries situated within the region are mainly driven by the agricultural industry. In order to fulfill the agricultural demand, land clearing has worsened the situation by degrading the land surface areas. Rampant land use activities have led to land degradation and soil erosion, resulting in implications on water quality and sedimentation of the river networks. This affects the ecosystem services, especially the hydrological cycles. Intensification of the sedimentation process has resulted in shallower river systems, thus increasing their vulnerability to natural hazards (i.e., climate change, floods). Tropical forests which are essential in servicing their benefits have been depleted due to the increase in human exploitation. This paper provides an overview of the impact of land erosion caused by land use activities within tropical rainforest catchments, which lead to massive sedimentation in tropical rivers, as well as the effects of monsoon on fragile watersheds which can result in catastrophic floods. Forest ecosystems are very important in giving services to regional biogeochemical processes. Balanced ecosystems therefore, play a significant role in servicing humanity and ultimately, may create a new way of environmental management in a cost-effective manner. Essentially, such an understanding will help stakeholders to come up with better strategies in restoring the ecosystem services of tropical watersheds.

Keywords: anthropogenic; land use; deforestation; erosion; sedimentation; ecosystem services; catchment; watershed; tropical; forest; monsoon

1. Introduction

Forests are one of the major terrestrial ecosystems within the biosphere [1] and are vital for all living processes. It is estimated that approximately more than 4 billion hectares, roughly 30 percent of the total global land area are covered by forests and more than 1.5 billion hectares, about 12 percent is used for crop production [2]. The alteration of land cover has caused deforestation, one of the biggest issues in recent decades. Deforestation has had significant impact on the earth's surface, especially on soil degradation [2]. As identified [3], tropical forests exert more influence on the climate cycle and other biodiversity processes compared to other terrestrial biomes.

Forests play significant roles in balancing ecosystem services globally. Based on scientific findings, forest ecosystem services are crucial for human survival as they provide services of many different functions such as supporting soil development, supporting the nutrient and water cycle, providing fresh water supply, regulating erosion, and water purification [4,5]. Supporting services are an interrelated system of the process of nutrient cycling involving nitrogen cycles, water cycles, and soil formation which can thus exert quantitative and qualitative effects on particular ecosystem processes [6]. Accumulation of organic matter from decomposition and decaying plant matter from leaf litter within the soil surface contribute to the major nitrogen sources in soil development [7] which offer essential nutrients to the soil [8]. Forests are essential in reducing surface runoff and soil erosion as they have vegetation cover, hence they reduce the transportation of sediments as well as nutrient pollution to the river and protect the water quality of the river [9,10]. In the United States, about 80 percent of freshwater resources are from forested watersheds [11,12]. Thus, forest conservation can be considered vital in protecting water quality in a cost-effective way by reducing the water treatment costs [13,14].

However, the importance of forests to ecosystems is often taken for granted. Over the last three centuries, the world forests have been reduced rapidly by humans as food demand increases [15]. According to [4], the total global forest area has been estimated to have been reduced by 50 percent. The clearing of tropical forests can result in many negative effects such as soil degradation, climate change, and loss of biodiversity [16]. In this review, we highlight the important components that determine the vulnerability of ecosystems service in benefiting the environment and the implications of tropical land clearing.

2. The Tropical Monsoon in the Southeast Asian Region

Global warming and climate change are issues affecting the tropical environment which are currently heavily discussed by researchers. One of these effects is on the ecosystem services such as provisioning and regulating services which are altered especially by weather related disturbances [17]. Furthermore, changing climate conditions worldwide have affected the global water cycle with severe repercussions on major watersheds [18,19]. These changing climate conditions involve precipitation and evaporation processes, thus affecting rainfall patterns [20], which in the worst cases result in drought or flood events. As identified by [20], the water holding capacity of air increases about seven percent per degree Celsius increase, resulting in increase of water vapor release and therefore producing extra precipitation events. Hence, this will further bring unpredictable weather changes thus increasing flood risk.

Climate change is a natural phenomenon that is unavoidable and persistent in its nature [21]. The monsoon seasons are one of the factors that influence climate regulation [22]. The word "monsoon" comes from the word "mausam" meaning 'season' [23–25] and it is an annual phenomenon. The monsoon system is believed to be the result of seasonal land heating [26]. Briefly, the monsoon is a seasonal process change in atmospheric movement and precipitation connected with the unpredictable heating of the earth and ocean [27]. The changes in land and sea temperatures determine the condensation rate which results in an amount of precipitation. Warmer temperature indicates more condensation of water vapor and extra rainfall development and vice versa. It often has devastating impacts including famine, food insufficiency, land dryness [28], and extra precipitation [22,29].

In tropical countries situated near the equator, natural hazards such as the monsoon always occur in the zone where the trade winds of the Northern and Southern Hemispheres converge, also known as the Intertropical Convergence Zone (ITCZ). Intense sunlight in the ITCZ heats the air and water resulting in increased air humidity. Seasonal changes in the ITCZ drastically affect the amount of precipitation in the countries that are located within the equatorial region [30] causing tropical areas to experience wet and dry seasons. Different latitude positions and ITCZ structure also affect tropical climate [31]. Long term changes in the ITCZ can result in severe droughts and flooding in tropical countries [30]. Based on studies of paleoclimate history, changes in the latitudinal position of the ITCZ during the Holocene epoch were also accompanied by significant changes in the hydrological cycle [32–34]. The Holocene shows the growth and impact of human activity worldwide, where one of the global significant effects has been on natural ecosystems. The Holocene also encompasses the growth and impacts of the human species worldwide, including all its written history, development of major civilizations, and the overall significant transition towards current urban living. Human impacts on modern-era Earth and its ecosystems may be considered of global significance for the future evolution of living species, including approximately synchronous lithospheric evidence, or more recently atmospheric evidence of human impacts.

The monsoon phenomenon particularly affects several tropical countries in Southeast Asia including Indonesia, Thailand, Malaysia, Philippines, India, Pakistan, Sri Lanka, and some African countries [35] as well as several Oceania countries. However, in this review the focus will be on Southeast Asia countries. Recently, the monsoon phenomenon has increased in severity due to changes in global climate. In Southeast Asia, global warming has caused changes in the seasonal atmospheric flow during the monsoon season, resulting in erratic temperature patterns [21]. According to [21], from the late 1970s onwards, an increase in global temperature anomalies corresponded with an increase in global precipitation. Furthermore, it was demonstrated that changes in the summer monsoon in India affected the volume of rainfall in the Philippines, Thailand, Malaysia, Bangladesh, and other Southeast Asia countries areas as well. It has also been predicted that the monsoon season will be delayed 15 days in the future, based on analysis of changes in rainfall patterns and time of the monsoon occurrence in Southeast Asia [21].

Many researchers agree that climate change results in rising global temperatures, which in turn impact the amount of monsoon rainfall [36–38]. Therefore, countries in regions which are at risk of being affected by monsoon phenomena should be prepared by having disaster mitigating plans. Southeast Asian countries which are affected by the monsoon season include Malaysia, Singapore, Thailand, Philippine, Vietnam, Laos, and other neighboring countries [21], as illustrated in Figure 1.

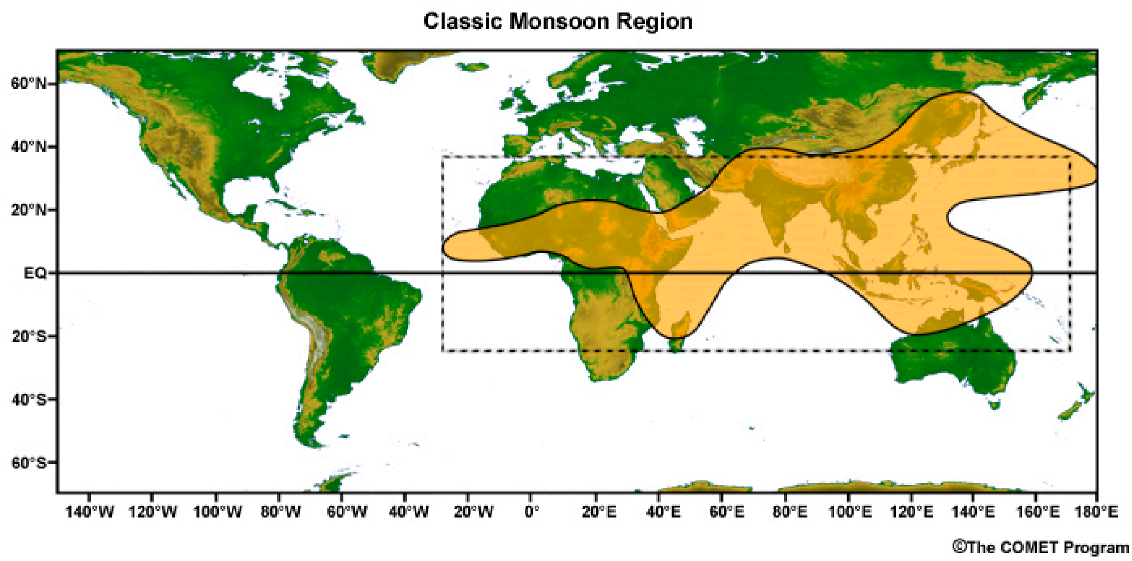

Figure 1. Map of monsoon region. Retrieved from [39].

The monsoon occurs when there is a thermal contrast between land and ocean [24]. This occurs when large land areas such as Asia, Australia, and Africa increase in temperature during the spring and summer seasons. As oceans have higher thermal inertia compared to land areas, continents therefore respond much faster to the seasonal cycle in solar heating, thus setting up big temperature gradients. Hot land areas receive humid air from the oceans. When moisture-laden air reaches the warm land, the moisture condenses and rainfall occurs. During the autumn and winter seasons, the large land areas become cooler faster compared to the surrounding oceans, which results in dry air flowing from the land areas out through the ocean [24].

3. Water Input in Tropical Watersheds

The water cycle is a continual process (Figure 2) powered by solar energy [40]. During the monsoon season, hot weather heats the air and water in the ITCZ resulting in increased air humidity which in turn promotes increased cloud formation [30,41]. The condensation process converts water vapor into liquid [42] followed by the process of raindrops falling from the atmosphere to the ground surface, which is known as precipitation, (P) [43].

An amount of 15–50% of precipitation undergoes the interception, (I_n) process, as raindrops from rainfall evaporate as drying just after raining occurs [44]. This interception process is influenced by factors such as types of land cover, amount of rainfall, and demand on the evaporation process [44]. Interception also can occur in urban area as raindrops land on rooftops, rough surface parking lots, or other surfaces that can hold the raindrops [45]. Rainfall that is not evaporated from interception processes undergoes the infiltration process.

As explained by [46], when water reaches the ground, it undergoes the infiltration process by moving through the boundary area to be absorbed and stored in the soil, forming ground water, (G) [47]. Forests are good water filtration systems as tree roots create large channels in the soil which facilitate infiltration of underground water. Within the water cycle, forests function to receive rainfall and clean and replenish the water supply [48]. Forest ecosystems also help to filter water, especially organic waste from decomposition processes [4]. Furthermore, forests improve water quality [49] by slowing down the rate at which the rain falls to the land surface thus inhibiting soil erosion and soil runoff [50,51].

Forests not only reduce soil erosion from occurring, but also reduce soil movement in waterways. By lowering sediments yield, forests can therefore lessen the risk of flood events arising. Forests and trees serve as a natural water filter which can protect river basins, lakes, and estuaries [50]. Water pollution increases when there are no trees as the soil is easier to detach and erosion tends to occur [4,36–38]. Without forest cover, the water droplets will directly fall onto the ground surface when rainfall occurs, thus eroding away the land and increasing sedimentation in the river [50]. The presence of sedimentation in rivers degrades water quality. Forests are therefore crucial in dictating water quality and balancing the earth's water cycles [52].

After the precipitation process, the water is discharged to a river through a channel. Water discharge, (Q) to river is influenced by precipitation, evaporation, and storage in ground water [53]. River discharge is equal to precipitation minus evapotranspiration plus minus changes in water storage [54].

$$\text{River discharge} = \text{Precipitation} - \text{Evapotranspiration} \pm \text{Water storage}$$

The process of the water cycle continues with plant uptake processes, where groundwater and soil moisture are absorbed by plant root systems [55]. Only one percent of water absorbed by plants is utilized for photosynthesis and cell development while the remaining ninety-nine percent is passed back to the atmosphere through the plant stomata by the transpiration process [56–58]. In this process, water is vaporized and carbon dioxide is absorbed thus photosynthesis occurs [59]. As the plant dies, the decomposition process occurs and the nitrogen cycle is involved in this mechanism [60]. Nitrogen compounds in the organic matter are released to the soil as they are broken down by the aid of microorganisms, a process known as decomposition. Afterwards, ammonia is produced, which then undergoes the nitrification process involving the conversion of ammonia into nitrite and nitrate [61]. All these compounds such as nitrate, nitrite, ammonia, and ammonium are taken up from soils by plants and the cycles continue naturally [62]. All cycles (water cycle, nitrogen cycle, and carbon cycle) are symbiotic and complete the life cycle.

Transpiration in the Amazon rainforest produces about 50–80% of its rainfall [63]. Deforestation can alter rainfall distribution by changing wind and oceanic flow patterns. Forests regulate climate by trapping moisture and cooling the land surface [64].

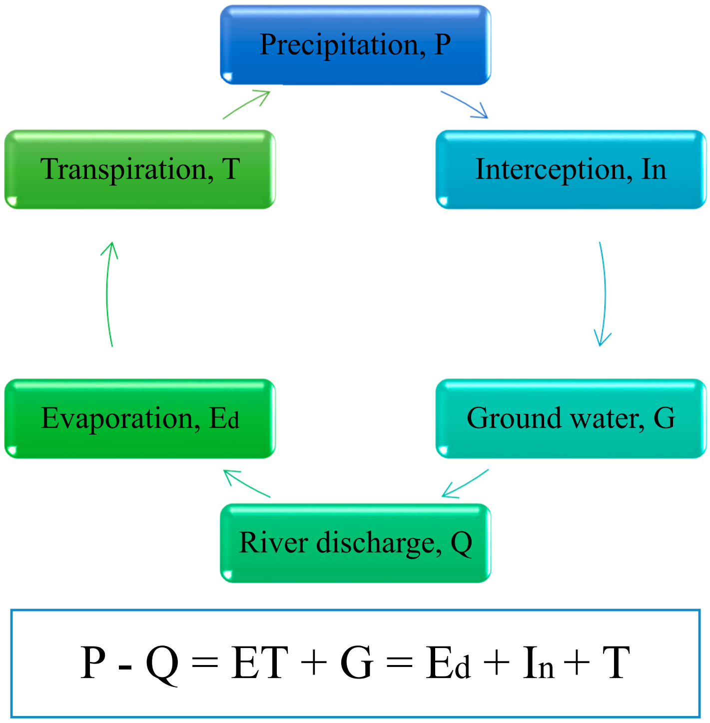

Figure 2. The water cycle.

The water cycle process continues further by converting liquid water to its gaseous state via the evaporation process. According to [65], through evapotranspiration, water is recycled more efficiently in the forest canopy compared to sparsely-vegetated land such as crop fields. Evapotranspiration, (ET) is the combination of two processes of evaporation, (E_d) and transpiration, (T) from plants to the atmosphere. However, deforestation weakens the hydrological cycle and alters the land temperature due to changes in the land surface. This alteration of land temperature affects global rainfall patterns [66]. Tropical deforestation is seen as the cause of the increase of the local surface albedo [67] and reduction of the evapotranspiration rate [68]. Evapotranspiration reduction is responsible for about 16 percent of the global land warming and the rise in temperature [69] and results in extreme rainfall events [70]. Large scale anthropogenic activities could change rainfall patterns in a radius of hundreds to thousands of kilometers away from the deforestation area, which could result in droughts and affect water supply [71,72].

Deforestation alters the hydrological cycle by disrupting the evapotranspiration process of the trees [3]. Based on the finding of [73], in some cases the rate of rainfall represents about 80 percent of its evapotranspiration. Deforestation also influences the albedo effect and includes climate temperature, cloudiness, and air movement [74]. Within the earth's energy cycle, evapotranspiration is one of the main processes that is driven by the sun [75]. Solar radiation affects cloud formation and thus influences evapotranspiration and precipitation fluxes [76]. When clouds are high in water content, their albedo effect is correspondingly high, thus cooling the climate [76]. The overall interaction of solar radiation, water vapor, and cloud formation creates a positive feedback, thus an increase in water vapor increases the greenhouse effect [77] which can alter the earth's energy balance.

Watershed areas that are encroached upon by land use activities can negatively affect the ecosystem services, especially the water cycle. Alteration of the earth's surface disrupts the water cycle process by decreasing the rate of water infiltration to the ground as well as increasing the surface runoff, thus increasing flood magnitude [78]. Increasing human population numbers have driven land use activities, changing land cover, and altering the hydrology process, thus aggravating the ecosystems involved in watershed management [79].

The implication of the monsoon season can result in two conditions; either dry or wet. Countries affected by the monsoon will usually face a rainy season followed by a dry season, or a failure of the monsoon which will result in a drought [28]. If the rainfall received is below the usual amount, then the country will be faced with water shortage. Absence of rainfall for a certain duration of time can cause soil cracking and crop failure. Thus, some flora and fauna might be threatened due to these phenomena [28,80]. However, continuous rainfall during the monsoon season can lead to flood disaster [81–83]. Many flood events have occurred in Southeast Asia due to monsoon phenomena (Table 1) such as in Nepal, Indonesia, Sri Lanka, Bangladesh, Thailand, India, and Malaysia.

Table 1. Major flood cases in Southeast Asia from 2003 to 2007.

Year	Country Affected	Impact
2003	Nepal	239 killed 284 injured 15,575 homeless 43,395 affected
	Indonesia	241 killed 30 injured 1468 affected
	Sri Lanka	235 killed 695,000 affected US$29,000 damage
2004	Bangladesh	730 killed 36,000,000 affected US$2,200,000,000 damage
	Nepal	185 killed 15 injured 800,000 affected
2005	India	1200 killed 55 injured 20,000,000 affected US$3,330,000,000 damage
2006	Thailand	280 killed 2,555,308 affected US$34,940,000 damage
	Indonesia	236 killed 56 injured 670 homeless 28,505 affected US$55,200,000 damage
	Sri Lanka	25 killed 2 injured 333,000 affected US$3,000,000 damage
	India	350 killed 65 injured 4,000,000 homeless US$3,390,000,000 damage
2007	Indonesia	40 killed 1 injured 400,000 affected US$695,000,000 damage

Source: EM-DAT: The OFDA/CRED International Disaster Database [84].

Major flood cases occurred in Malaysia from the year 2000 until 2016 (Table 2). This can occur when too much rain is received continuously to the point where the soil cannot retain the water anymore. However, the impact can be minimized if land and watershed management are in good condition in the context of forest ecosystem. Forests are the best agents in helping to reduce flooding, and most flooding cases have been partly blamed on deforestation activities [85,86].

In Malaysia, there are two monsoon seasons, which are the Southwest Monsoon (SWM) (which occurs annually from May to September) and the Northeast Monsoon Season (NEM) (which occurs annually from November to March). Pronounced extra rainfall occurs in the East coast of Malaysia during the NEM [87,88], which affects Kelantan, Terengganu, and Pahang states. As happened in Kelantan, the recurrent flood event was believed to be due to extra precipitation during NEM, however, in 2014, massive flood events occurred there, with an estimated loss of MYR 1 billion [89]. This event is believed to have been caused by uncontrolled development activities and also a high amount of rainfall due to the monsoon seasons [89]. Unsustainable development and rapid settlement have been seen as the factors that promote the hazards which lead to extreme flood events. Other factors stem from geomorphology, topography, drainage pattern, and mechanical factors [90].

Table 2. Flood cases in Malaysia from the year 2000 until 2016.

Start Date	End Date	Locations	Disaster Type	Total Deaths	Total Damage Affected
21 November 2000	1 December 2000	Kuala Krai, Pasir Putih, Kota Bharu, Pasir Mas, Tumpat Districts (Kelantan Province), Kubang Pasu, Kota Setar, Padang Terap Districts (Kedah Province), Besut District (Terengganu Provice)	Flash flood	12	8000
19 August 2001	19 August 2001	Teluk Ipil Area (Seberang Perai Selatan District, Pulau Pinang Province)	Flash flood	-	10,000
29 October 2001	30 October 2001	Inanam Borough (Kota Kinabalu District, Sabah Province) Beaufort, Papar, Penampang, Tuaran Districts (Sabah Province)	Flood	-	5000
30 October 2001	30 October 2001	Kuala Lumpur Province	Flood	-	200
22 December 2001	3 January 2002	Pahang, Kelantan, Terengganu Provinces	Riverine flood	11	18,000
31 January 2002	31 January 2002	Simunjan District (Sarawak Province)	Landslide	10	
29 November 2003	2 December 2003	Kuala Terengganu, Kemaman, Marang, Dungun Districts (Terengganu Province), Kota Bharu District (Kelantan Province), Kuantan District (Pahang Province)	Flash flood	5	3000
17 December 2003	5 January 2004	Kampong Pengkalan, Buang Saying, Muhibbah Hujung, Muhubbah Baru, Sinar Baru, Lokan, Sritanjung Areas (Kinabatangan Districts, Sabah Province), Beluran Area (Labuk & Sugut District, Sabah Province), Kota Marud District (Sabah Province)	Riverine flood	-	2000
3 October 2004	25 October 2003	Kedah, Pahang, Perak Provinces	Riverine flood	3	13,800
24 January 2004	3 February 2004	Kuchung, Bau, Mkah, Sibu, Samarahan Districts (Sarawak Province), Johor Baru, Pontian, Kota Tinggi Districts (Johor Province)	Riverine flood	3	6900
8 March 2004	11 March 2004	Johor Province	Riverine flood	-	9138
10 December 2004	18 December 2004	Bera Area (Temerluh District, Pahang Province), Kuantan, Pecan District (Pahang Province), Kota Bharu, Gua Musang, Kuala Krai, Tanah Merah, Pasir Mas, Machang, Tumpat Districts (Kelantan Province), Dungun, Kemaman, Julu Terenggau, Besut, Setiu Districts (Terengganu Province)	Riverine flood	13	15,000
17 July 2005	19 July 2005	Telipok Village (Tuaran District, Sabah Province), Menggatal Area (Kota Kinabalu District, Sabah Province)	Flash flood	4	600

Table 2. *Cont.*

Start Date	End Date	Locations	Disaster Type	Total Deaths	Total Damage Affected
23 November 2005	12 Janauary 2006	Kelantan, Terengganu, Kedah, Perlis, Perak Provinces	Flash flood	9	30,000
9 January 2006	9 January 2006	Johor Province	Riverine flood	-	1112
10 February 2006	18 February 2006	Terengganu, Pahang, Kelantan Provinces	Riverine flood	-	4906
20 April 2006	21 April 2006	Kampong Manjoi Borough (Ipoh City, Kinta District, Perak Province)	Riverine flood	-	500
19 December 1006	20 December 2006	Melaka, Negeri Sembilan, Pahang, Johor Provinces	Flash flood	6	100,000
11 January 2007	1 February 2007	Johor, Pahang Provinces	Riverine flood	17	137,533
7 December 2007	21 December 2007	Johor, Kelantan, Pahang, Terengganu Provinces	Riverine flood	29	29,000
1 December 2008	4 December 2008	Cherating Area (Kuantan District, Pahang Province), Kelantan, Terengganu Provinces	Riverine flood	-	2000
28 December 2008	19 January 2009	Pahang, Kelantan, Terengganu, Sarawak Provinces	Flash flood	-	6000
23 November 2009	26 November 2009	Kedah, Terengganu, Kelantan, Perak Provinces	Riverine flood	-	1793
20 November 2009	27 December 2009	Hulu Terengganu, Besut, Setiu, Dungun, Marang, Kemaman Districts (Terengganu Province)	Riverine flood	-	9082
28 January 2011	31 January 2011	Johor Province	Riverine flood	2	20,000
21 May 2011	21 May 2011	Ulu Langat District (Selangor Province)	Landslide	16	6
1 December 2013	8 December 2013	Kuala Lumpur, Pahang, Terengganu, Johor, Kelantan Provinces	Riverine flood	4	75,000
16 December 2014	30 December 2014	Sabah, Kelantan, Pahang, Terengganu, Perak, Johor, Selangor, Perlis Provinces	Riverine flood	17	230,000
14 January 2015	20 January 2015	Sarawak Province	Riverine flood	1	3000
19 February 2016	24 February 2016	Johor, Melaka, Negeri Sembilan, Sarawak Provinces	Flood	-	6000
18 July 2016	19 July 2016	Yan, Baling Districts (Kedah Province), Penang City (Timur Laut District, Pulau Pinang Province)	Flood	-	441
28 November 2016	7 December 2016	Terengganu Province	Flood	-	400

Source: EM-DAT: The International Disaster Database [84].

4. Flood Event

Flooding can be caused by nature or by a combination of natural and anthropogenic factors [91]. The magnitude of a flood event is influenced by flood depth, velocity, and duration [91]. River overflow occurs due to excessive rainfall, but can be avoided if the watersheds have good catchment management practices of making sure they are pristine, undisturbed, and forested, as the whole ecosystem plays its role in servicing the benefits [4]. Alteration of the natural landscape is the main key in conversion of natural hazards to actual disasters [91]. Increase in human population with subsequent increase in demand for agriculture and land settlement drives deforestation and changes in land use [92,93]. These changes have destroyed the function of ecosystems as a flood regulator. Increase in deforestation activity has resulted in increased erosion process and sediment transport. Further, inadequate catchment management practices of watersheds have resulted in vulnerable rivers, which are sensitive to natural disasters especially during the monsoon season which brings extra rainfall [94]. So, when high rainfall occurs, rivers tend to overflow as the watershed cannot hold the increase in water flow rate [95].

5. Ecosystem Services of Tropical Forest

Forest is very crucial in avoiding natural disaster especially in flood and erosion management. The 'Global Forest Resource Assessment' defined "forest" as an area of land having more than 0.5 hectare of trees higher than five meters, with more than ten percent canopy cover [96]. Forests provide various types of ecosystem services which include supporting services such as nutrient cycling and water cycling; provisioning services by obtaining fresh water quality, and regulating services such as carbon sequestration, erosion, water purification, and natural hazard regulation [4]. Alteration of forest landscapes can change natural ecosystems and affect the efficiency of services which the systems provide [64,79]. Here we want to highlight two main roles performed by forests, which are flood and erosion regulation.

5.1. Flood Regulation

Increase in erosion processes and subsequent transportation of sediments to rivers make watersheds shallower and increase flood risk. Floods are one of the most dangerous natural events that threaten most tropical countries in monsoon seasons [81,82,97]. Forests, via ecosystem services, can act as a natural hazard regulator, which is crucial in mitigating natural disasters and their impacts, particularly in the Asia Pacific region where they function as protection against natural disasters of various types and degrees [98,99], from minimal land degradation up to flood disaster [100–102]. All of these give a significant impact on the watershed area. Although forests cannot directly reduce the total quantity of rainfall, they help by bringing down the degree of flood events and flood damage [4,98]. Furthermore, the presence of forests can improve infiltration, interception, and storage capacity of local lands. Evapotranspiration carried out by trees within forests stabilizes soil moisture content, thus resulting in a substantial buffer against flooding when rainfall occurs [98]. Overall, the presence of forests can significantly reduce the sediment flow to rivers, reduce the frequency of floods and drought events, and lead to better ecosystem conditions [103].

5.2. Erosion Regulation

Forest, trees, and other vegetative covers are crucial for stabilizing and retaining soil and preventing landslides [4,104]. Forest canopy reduces the impact of heavy rainfall on the soil and thus helps in reducing soil detachment. Forest floor which is covered with leaves and debris can lower the rate of water flow and prevent soil runoff. Elliot et al. [105] found that Pristine forests have a hydraulic conductivity of 15 mm/h with an erosion rate of less than 0.1 mg/ha^{-1}, while in disturbed forests the conductivity can drop to 5 mm/h and erosion rates can exceed 20 mg/ha^{-1}. This is due to the fact that when the forest floor is disturbed, the rate of soil erosion and runoff are increased by order of magnitudes.

Maintenance of water quality is one of the most significant contributions of forests to the hydrological cycle. Forests help filter pollutants from entering water bodies by minimizing soil erosion processes and thus minimizing sediment transportation [104]. Furthermore, natural forests give the most efficient barrier for reducing soil erosion and detachment since they possess large canopies [64,104,106]. Erosion processes are highly correlated with increased sediment production and siltation of water bodies [104]. Pristine forests provide the best services by ensuring clean water quality which is free from other possible pollutants [104].

When there are no trees and therefore less roots or debris on the forest floor, the infiltration process is disrupted [52]. This allows the effect of raindrops to increase soil detachment and causes soil erosion. Conversion of forest areas to agricultural land use results in high rates of erosion [107]. In higher slopes, cutting down trees can increase erosion rates and sediment transportation yield, which in turn increases the risk of flooding and land slide events occurring [52,104,108]. Forest removal and alteration of land use systems leads to increase in erosion processes unless proper management of soil conversion is carried out [104].

6. Soil Erosion and Sedimentation Process

Soil erosion is one of the effects of land use activities that can cause damage to watersheds. Soil erosion can be defined as: (1) Material that is detached from the soil surface by the act of water and/or wind under natural situations [109]; (2) A natural process that occurs through geological time and is crucial for soil formation [110,111]; (3) Movement of soil through wind and water action. Erosion rates increase with increases of slope [112]. The rate of erosion also depends on erosivity (the energy of erosion) and the friction of soil erosion [111].

Erosion processes lead to accumulation of sediments in rivers. The term 'sediment' usually refers to the soil particles transported by stream flow and deposited in a river channel [113]. It is a predominant source of suspended material. In turn, sedimentation is the process of transportation and deposition of soil particles in the stream flow with the aid of water and wind [113,114]. Both erosion and sedimentation alter the morphology of the land structure over time. Anthropogenic activity such as deforestation, agriculture, mining, land settlement, and industrial activities increase the rate of transportation and sedimentation of particulate material in rivers, which may deteriorate the ecosystem and result in shallower rivers [115]. Sedimentation can degrade the water quality, affect the aquatic population, and decrease the light intensity for growth of aquatic plants [116].

7. Mechanism of Soil Erosion and Sedimentation

Erosion processes will not occur without the presence of water or wind. Rainfall acts as the main driver in enhancing erosion processes. Soil erosion consists of four main steps (Figure 3). As rainfall occurs, the rain drops onto the soil surface and makes first contact with the soil. The detachment process takes place when soil particles disengage as the rain touches down on the soil. Afterwards, the soil particles are transported by rolling, splashing, or dragging and translocate to another place [117]. Finally, the soil particle is deposited at some other place at a lower elevation [117]. If the soil particle is deposited in a river, then it is known as a sedimentation process. Uncontrolled sedimentation in rivers can cause water degradation, destruction of aquatic habitat, shallower rivers, and thus an increase in flooding risk due to reduction of water storage capacity within a catchment [118–120].

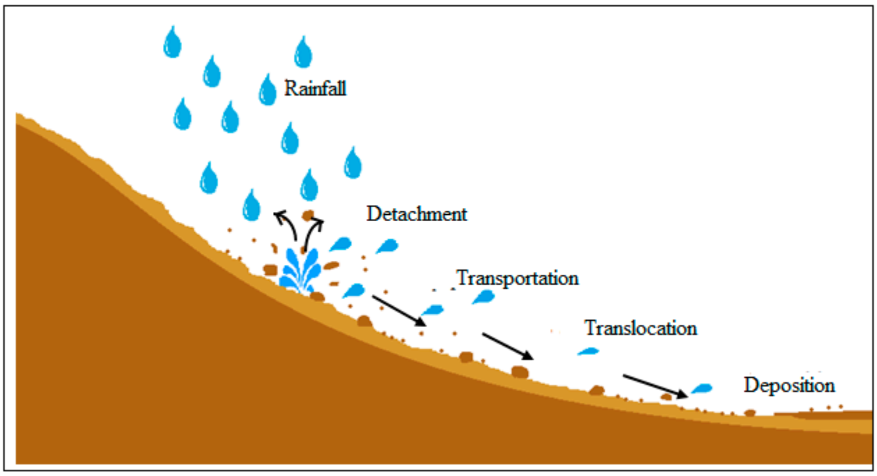

Figure 3. Mechanism of water erosion [117].

8. Impact of Land Clearing Activities on the Watersheds

Rapid land clearing has had a great impact on watersheds especially on erosion and sedimentation. There are several anthropogenic activities that can enhance soil degradation and lead to soil erosion (Figure 4). As erosion occurs, soil particles are transported into water bodies and deposited at river beds [117]. Continuous transportation of sediments to rivers results in shallower rivers and renders them vulnerable to natural hazards [121]. This results in high flood risk when extra rainfall occurs especially at the change of the monsoon seasons. Increase in sedimentation can also cause the deterioration of water quality and harm aquatic organisms in the river basin [122]. The major land use activities that degrade soil structure are deforestation, agriculture, mining, and development of urban or rural residential areas [115].

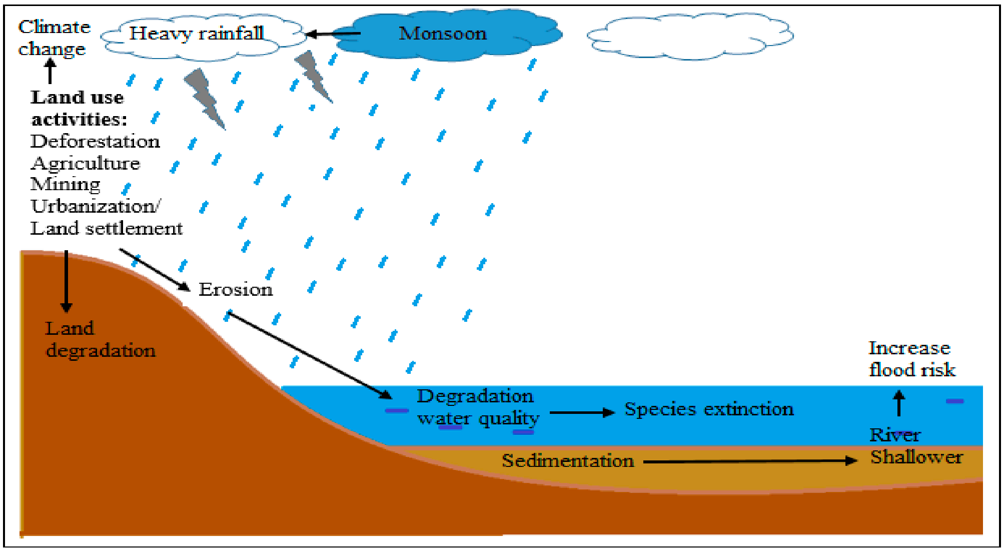

Figure 4. Land use activities and their impact on the environment.

8.1. Deforestation Activities

Deforestation is the process of alteration of forest area into an area of non-forested land for human use such as agriculture, urbanization, industrial, or grazing area [123,124]. It is one of the activities that contributes to the major portion of sedimentation in the river basin. Recent studies in New Zealand show that extensive deforestation has increased the rates of erosion due to the dominance of steep slopes, high rainfall, erodible rocks, and common high-intensity rainstorms [125]. Over 800 years, an increase in the human population in New Zealand has led to about half of the forest being cleared and with the addition of recent activities the erosion problem has worsened [126]. Previous studies conducted at the Krachan National Park in Thailand concluded that as land cover decreases, the soil loss increases [127].

The process of deforestation comprises the cutting down of trees and clearing the space of the presence of plants. The absence of trees has caused the loss of roots to hold the soil from soil erosion, thus increase erosion rates. Reference [63] reported that Costa Rica has lost about 860 million tons of topsoil per year, followed by Madagascar which has lost approximately 400 tons per hectare due to deforestation activities, which in turn has resulted in rivers discharging into the Indian Ocean becoming reddish-brown. Heavy rainfall in tropical regions with an absence of trees has caused soil run off and carried soil into the local rivers, causing increased siltation in water bodies and a rise in the height of river beds. Cascading effects of river basin degradation and other disturbances of water resource from agriculture and urban areas are also sources of sediment loading [128]. Deforestation also makes the area become drier due to a decrease in water-holding capacity. Case studies show that rapid human development has driven deforestation activity in the Brazilian Amazon since the1980s [129].

In the case of Malaysia, deforestation is due to land conversion of virgin forest for agriculture activities, especially oil palm plantation [130,131]. As stated by [131], in Peninsular Malaysia only 20.6% of Johor states are covered with forest while approximately 35% which was 717,398 ha in 2011 [132] is for oil palm plantation. The alteration of the original vegetation cover tends to increase erosion processes [133]. In the process of turning from forest to agriculture area, the selected area needs to be cleared and the bare soil is thus exposed to the rainfall. Removing vegetation by land clearing can cause soil to detach thus resulting in erosion process and surface runoff [134,135]. Absence of cover crops can also enhance the occurrence of soil erosion [136,137].

8.2. Agriculture Activities

The increase in global human population has resulted in a high demand for agricultural production, which in turn has driven stakeholders to develop new plantation areas to start agricultural activities [92,126]. Deforestation takes place directly before a new of plantation area is developed. Clearing land activities expose the soil to erosion when heavy rainfall occurs [123]. Terracing processes for cultivation purposes have also caused land degradation before the land can fully recover by having cover crops [138]. At this stage, the percentage of soil erosion during heavy rainfall is very high especially for lateritic soil, the effect of which can be directly ascertained by observing the river color [95].

Alteration of land use due to the construction of terrace systems on catchment areas has resulted in storm runoff [139]. Abandonment of terrace systems can over time increase gully erosion thus causing terrace failure [140–142]. The impact of abandoned agricultural areas vary based on the slope gradient. If the slope gradient is steep, then the rate of soil erosion rises significantly after abandonment due to changes in surface cover crops characteristics [143]. Abandonment of terrace sites negatively impacts hydrological infrastructures mostly due to land degradation problems, caused by water erosion and nutrient loss [144]. It has been suggested that in the terracing area, soil particles are detached and transported in phases via diverse pathways. In addition, soil and vegetation parameters influence the factors of erosion losses [145]. Erosion and runoff processes are also strongly correlated with kinetic energy from precipitation phenomena. Therefore, rain intensity can be used to predict erosion rates [146]. Additionally, poor design and maintenance of terraces are the factors which contribute to significant sediment loading [147,148]. Originally, terraced areas were constructed in order to increase water and soil retention and to improve irrigation, hence reducing both hydrological connectivity and erosion, [142,149,150]. Terraces also reduce the slope gradient which results in increased water infiltration [151] and increased water flow control thus reducing soil erosion [152,153]. However, terracing does not completely alleviate the erosion process because in some cases, there is a slope gradient between two successive terraces which triggers the detachment of soil particles thus leading to erosion [143,154–157].

In Thailand, the land underwent drastic change between 1960 and 1970 due to conversion of the former landscape to agricultural landscape influenced by cash crop culture for the purposes of social economy development [158]. The conversion of land to agriculture use by replacing forested area with cash crop fields cassava, corn, rubber, paddy, kenaf (*Hibiscus cannabinus*), and sugar cane and other oil crops [159–161] has an extreme impact on the ecosystem, including soil erosion problems to rain-fed paddy fields in the lowlands and crop fields in the uplands [158].

In Ethiopia, land degradation such as soil erosion is one of the major causes of rural poverty, decrease in agricultural productivity and unstable food insecurity [93]. The main factors that contribute to land degradation are increase in population, deforestation activities, and loss of vegetation cover, as well as additional causes such as topography and soil type. All these factors have an impact on water quality and biodiversity loss [93]. Suspended solids from erosion processes which contain nutrients and agricultural chemical are being washed out down to water bodies resulting in pollution in river downstream [162]. Excessive nutrient concentration in the river can cause eutrophication and affect the aquatic species in the river ecosystem hence causing fatalities in the worst cases [163]. According to [164], the land degradation in Ethiopia occurred because of biological processes driven by socioeconomic and political factors. While [165] stated that manipulation of forest land for subsistence agriculture is the main cause of land degradation. A study by [166] in the Dera District of Ethiopia pointed out that land degradation was a result of increase in human population in the area. In addition, [165] reported that the heavy reliance of some 85% of Ethiopia's growing population on an exploitative kind of subsistence agriculture is the major reason behind the current state of land degradation.

8.3. Mining Activities

Sand is very important in maintaining and protecting the river ecosystem, as well as a habitat for aquatic species, but at the same time it is widely used for making concrete [167]. In the past few decades, sand demand has increased due to the rapid development of the construction of buildings [167,168]. This leads to stakeholders continuing mining activities to the point where it becomes an environmental issue. Sand mining activity can be defined as the process of removing sand and gravel from its original place for industrial demand [167]. However, mining is a very severe and destructive activity which can have the same erosion impact as agricultural activities [169–171].

Mining and land degradation are strongly interconnected. They lead to severe environmental problems in river basin ecosystems that need immediate attention for conservation and restoration. Sand mining imposes stress on biological communities in rivers due to destruction of the riparian zone, which leads to loss of plant and animal habitat [172]. Riparian flora and fauna can be damaged due to channel incision, river bank slumping and lowering of the water table [168,173,174]. Besides that, it also degrades the geography of the river landscape leading to topological disorder, thus damaging the land use pattern around the mining area [175].

A study in Tamil Nadu pointed out that sand mining adversely affects the environment through depletion of ground water, destruction of existing vegetation and soil profile, damage of top soil, instability of the landscape, and changes in river bed form and sediment characteristics [167]. Apart from that, mining activities have been seen as one of the driving factors that have led to deforestation activity as can evidenced by loss of forest area in Guyana [176], Philippines [177], Michoacán, Mexico [178], and Nyamagari, India [179].

8.4. Urban and Rural Residential

'Urban' is a broad term that can be found throughout social and scientific sentences. Reference [180] defined 'urban' as a place-based characteristic that integrates elements of population density, social and economic body, and the revolution of the natural environment into man-made areas. Similarly, reference [181] states 'urban' as the conversion of ecosystems into human settlements and associated activities. During the development process, rivers are generally modified. These changes lead to the physical alteration of rivers which possess unique hydrological and physical properties [182]. Urbanization has altered the landscape by carrying out development near the river basins, destroying the ecosystem near the basin in the process. Disturbance near the basin area also leads to erosion as soil becomes loose and easy to leach out into the river [4].

In Thailand, erosion also occurs due to development processes driven by the increase in population growth, in addition to natural factors such as rainfall and topography. The wave of agricultural expansion rapidly changed Thailand's landscape at the end of the 1960s [183]. As a result, it has become one of the major problems contributing to erosion problems in Northeast Thailand [158].

On the whole, the erosion process occurs due to land use activities. The major land use activities that have been mentioned in all three countries are deforestation, agriculture, human development, and mining activities. All these activities are correlated with forest loss where the first step in all the activities mentioned begins with land clearing. As forests are destroyed, the ecosystem services are disrupted and fail to provide their benefits in maintaining the environment.

9. Erosion Mitigation

Erosion management is very important in protecting watersheds. There are two types of erosion mitigation, natural and also man-made. In natural erosion mitigation, forests and riparian zones are the barriers in controlling direct sediment transport to the river. Man-made mitigation can be divided into several types such as building retaining walls or terraces for steep slopes, adding mulch or rocks, and conducting sustainable farming to minimize the impact of erosion.

9.1. Natural Erosion Mitigation

According to reference [184], riparian zones can be defined as three dimensional zones interrelated between fresh water and terrestrial ecosystems. It was further described by [185] that three dimensional zones include groundwater, the forest canopy, the floodplain, slopes near the water body, and the terrestrial ecosystem alongside the water course. Riparian zones are one of the main components in controlling the process of sedimentation in the river [186]. As rainfall occurs, water flows from upstream (higher slope) to downstream (lower slope) [187]. Figure 5 shows the differences between forested and deforested areas. The mechanism of soil erosion is less severe in the forest area and high in the deforested area as there is no soil cover [104]. After forests, the riparian zone plays an important role in mitigating the transfer of sediments to rivers.

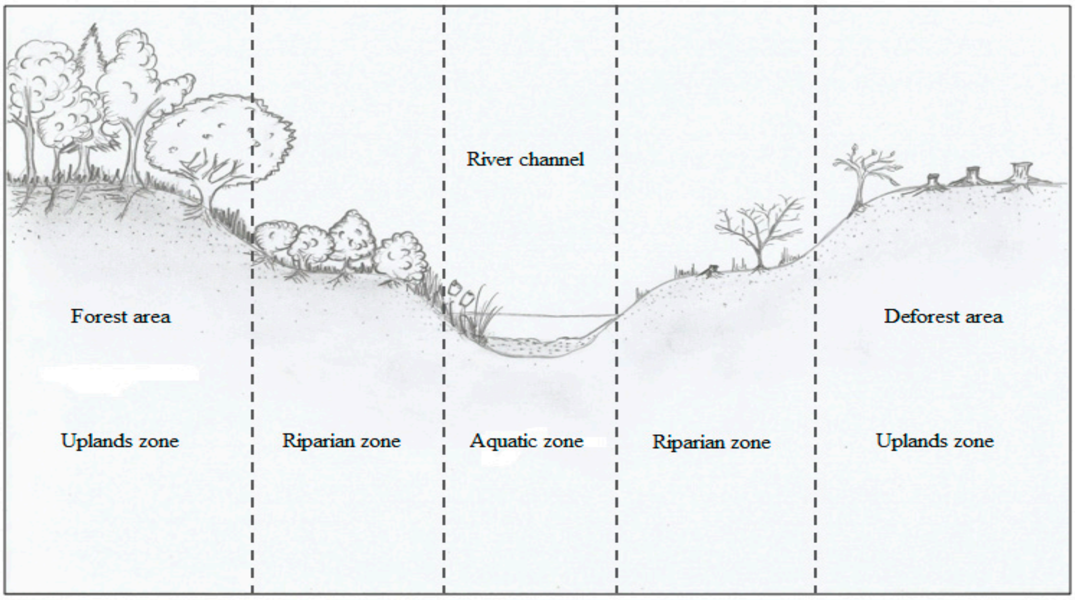

Figure 5. Riparian ecosystem.

The main function of the riparian zone is to minimize the overland transport of sediment [188]. The vegetation near rivers has the ability to stabilize the river channel thus acting as a sediment trap during overbank flow [189]. It also acts as a good obstacle in stopping sediments from flowing to the river. Alteration of land use and riparian zone degradation not only causes sedimentation in rivers, but also greatly influences water quality on different spatial scales [190–192]. This is due to the increase in sedimentation transport, nutrient, and pollutant concentration, which can thus change the hydrological pattern [190,193].

As the riparian zone is removed or destroyed, the sediment loads within the river channel change. The vegetation zone is very important in regulating the sediment transport. Furthermore, within rivers in land areas that are dominated by pasture activity, and which have less riparian vegetation, the total nitrogen concentration and electric conductivity is higher [192]. This indicates that river water quality is influenced by the interaction between land use and riparian zone. Different types of vegetation cover at the riparian zone result in different nutrient transport, physical characteristics, and also energy balance [194–197]. The riparian zone affects the breakdown rate of leaf matter and coarse particulate organic matter [192,198].

However, river systems can be protected by the riparian zone as it influences the process of soil runoff, river bank erosion, sediment transport, nutrient and pollutant transfer, and also the aquatic ecosystem [199–202]. Therefore, the quality of river water cannot be ensured without the presence of the riparian zone.

9.2. Infrastructures

Man-made erosion mitigation is the infrastructure that is built to reduce the impact of the erosion process especially in agriculture sectors. Best practice methods for erosion mitigation are discussed as follows:

The common practices that can be applied to minimize the erosion process are manage the land use properly as well as covering up the disturbed area by restoration and reclamation processes. Restoration can be done by having a green planning project such as applying cover crop on bare soil. Cover crops are generally most practical and effective in controlling soil erosion and sediment problems. However, using this method requires time to allow for sufficient growth of the cover crops. Cover crops help in absorbing the impact of raindrops and thus can reduce soil particles from detaching [203]. Bare soils have a high tendency to undergo erosion compared to covered soil. Plant roots are effective in preventing soil erosion. The roots of crops such as grass bind to the soil particles and help soil erosion mitigation. According to [204], native plant species on steep slopes and riverbanks can reduce the soil loss. For the best results, bare ground around the tress need to be covered by cover crops like grass or *Calopogonium mucunoides*. Further, cover crops also act as sediment and pollutant filters [205].

Additionally, apply some technical mitigation such as building retaining walls or terraces for steep slopes to reduce the soil detachment. Steep slopes are a typical erosion problem. Building retaining walls or constructing terraces are an option to mitigate slope erosion in hilly areas [206]. Retaining walls are structures designed to provide stability and strength to the slopes using logs or rocks [207]. If wood is used as a construction material, then preservatives need to be applied to prevent the structure from collapsing. Retaining walls are used on unstable slopes where space is limited and when the slope is too steep for agricultural activities [207]. Examples of retaining walls are cantilever walls, gravity walls, and sheet piling [208].

Besides, adding mulch and rocks can act as a buffer to the erosion process. According to [209], adding mulch can reduce the effect of soil erosion on bare soil as it holds the upper soil layer from being washed away by heavy rainfall, and also reduces the effect of heavy water flow in vegetation areas. Natural mulches that can be applied include woodchips, grass clipping, back chips, or straw. Application of these materials can absorb the impact of raindrops and reduce the disengagement of soil particles. This also protects young plants such as seedlings and grass seeds from being washed away by heavy rainfall. Mulch is usually applied during the establishment of young seedlings for temporary or permanent vegetation cover [203]. It can also function as plant protection from extreme weather. The other benefits of mulch are increasing water penetration, maintaining soil moisture and temperature, as well as increasing the organic content of soil [203]. However, organic mulch can be degraded through time as it can decompose due to its biodegradable content.

Agricultural sectors, in order to minimize erosion, practice sustainable farming such as reducing tillage and contour farming. Tilling is a common practice by farmers in order to loosen the soil for root plant aeration and help plant growth. In order to reduce the effect of soil erosion, tillage practice should be reduced according to the suitability of the soil. Having frequent tillage can increase the percentage of erosion as the top soil becomes loose after the tillage process. This can be reduced by practicing zero-tillage or changing to other deep planting methods, such as using mull-till or ridge-till methods [210].

Contour farming, also known as contour ploughing or contour bunding, can be defined as tilling and planting trees around the slopes according to the contour of the land from up to downhill [205]. It is the farming practice of ploughing or planting across a slope following its elevation contour line. This method is used to maintain the soil quality and composition. It is commonly applied to cultivation areas with slopes between 15 and 20 degrees [211]. Based on a study done by [205], contour farming can help reduce the rate of erosion rate by about 50 percent. It can also improve water quality by controlling sediment transport and runoff, thus increasing the water infiltration rate. Also, contour farming is very cost effective and is a good sustainable farming practice. Contour farming is not only productive for a farm but also helps in mitigating erosion, controlling floods, and soil conservation.

10. Conclusions

To sum up, we present our summary using a tripod beta framework (Figure 6) based on the identified chain of events (Monsoon-Watershed-Erosion-River-Sedimentation-Flood); identified barriers (Forest, Riparian Zone, Infrastructure), and scientific justification of the failure of each of the barriers. Tripod beta is a tool used to explain an analysis of an incident which results from human factors [212]. It comprises the component of agent, object, event and event-agent. Agent (hazard) is an entity with the potential to cause destruction of object upon which is acting. In this review, the agent, which is the monsoon acts on the watershed (object), defined as a component which impacted by a devastating impact caused by the hazard. The "event" is a result of the affected object due to failure of the barriers. Monsoon acts on the watershed compounded by deforestation factor (collapse of first barrier) to cause an erosion event. Ironically, if the watershed is managed with the "business-as-usual" approach, the event may evolve to agent (event-agent), acting upon the object, thus, results in a new event. In our case, the event-agent component (erosion) will in turn act on the river (object). Moreover, absence of riparian zone as a natural barrier and infrastructure as a man-made barrier will cause massive sedimentation transport to the river, consequently, results in overflow (event). Accumulation of sedimentation in the river will cause river to overflow (shallower), increase the flood risk. If there an extra precipitation, then the chances of catastrophic flood to occur are higher. Forest ecosystem plays a crucial role in mitigating natural disasters. Special consideration on the identified barriers in managing the watershed will help to reduce vulnerability of the catchment in tropical regions.

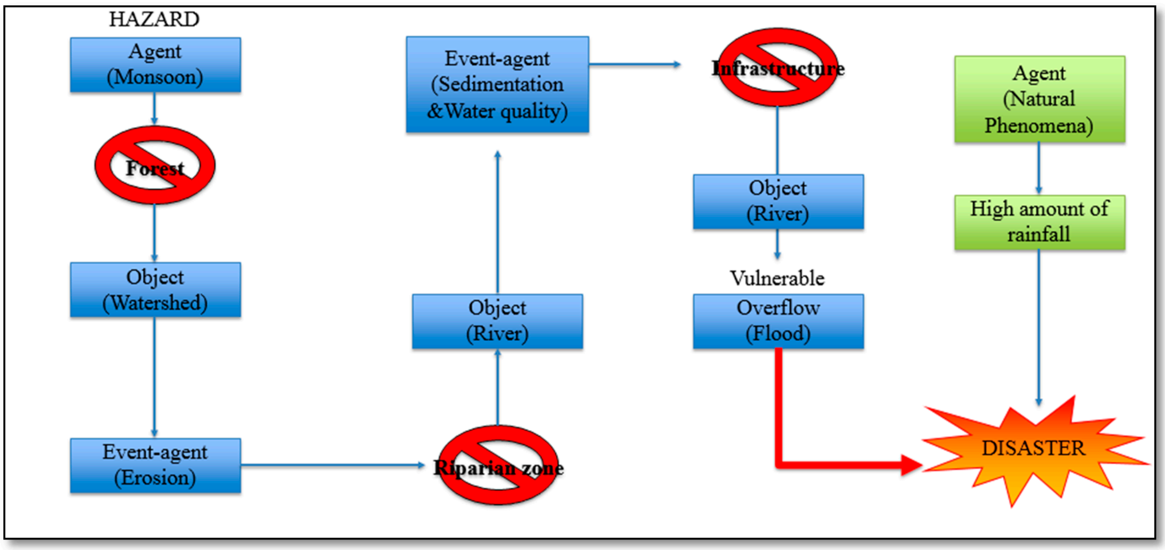

Figure 6. Sustainable Tropical Catchment Management Framework highlights three critical barriers that need serious attention in watershed management.

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