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# Role of Vegetation for the Protection of Phewa Watershed, Kaski, Nepal

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**Abstract** Natural resources as well as watersheds are vulnerable all over the world by a variety of natural and anthropogenic activities. Mountain watersheds in the Nepal Himalaya are severely degraded due to active tectonics and Asian Monsoon. The Phewa watershed is one of the vulnerable watersheds in this region, which is also included in the Ramsar sites. This watershed has degraded due to soil erosion, weak geology, fragile landscape, encroachment and climate change. Therefore, this research focuses on the status of the watershed and the role of vegetation for preserving it from further degradation. Protecting and conserving water, vegetation, and soil, as well as reforesting, have been the most common means of preventing watershed risks. Vegetation can help with slope stability, velocity reduction of water, and surface roughness, as well as soil infiltration, better soil structure, and increased soil strength. Species that are native to the area offer superior erosion control because of their fast growing properties and the ability to reproduce quickly, which are important for the watershed's protection.

**Keywords** Eutrophication, Soil Erosion, Sedimentation, Invasive Species, Ecological

## 1. Introduction

A watershed is a section of a land that drains precipitation into a single point, typically the basin's exit, wherein the water can flow into other water bodies as in a river, wetland, lake, reservoir, marsh, sea, or ocean [1, 2]. It refers to source of water for a particular drainage system. According to the DFRS [3], a total of 690 watersheds covering 147181 sq km were created across Nepal. Out of 690, 88 watersheds are located in the Gandaki Province, Nepal. There are 10 Ramsar sites in Nepal, one of which being the Lake Cluster of Pokhara Valley including the Phewa Watershed. In 2016, the site was declared to safeguard regional biodiversity and preserve natural resources for tourism. The Phewa watershed extends from $83^{0}48'1.93''$ to $83^{0}58'13.18''$ east and $28^{0}11'37.83''$ to $28^{0}17'27.30''$ north (Fig. 1). It is located in the humid subtropical climate with an average rainfall of 3,710 mm [4]. With a population of 65,256 [5], the watershed is located in Nepal's mid-hill zone and includes Pokhara Metropolitan City wards 2, 4, 5, 6, 7, 8, 19, 22, 23, 24, and Annapurna Rural Municipality wards 1, 2, 3 and 4. This watershed is developed between 25 and 65 million years ago, during the Tertiary Period [6]. The watershed area constitutes a unique geographical entity and exhibits the usual traits of the highland environment with a wonderful panoramic perspective of temperate High Peak in the north and humid warm climate of Terai in a conical peculiar valley landscape of mid-hill Pokhara. The altitude ranges from 793 meters to 2508.81 meters. The watershed is in a vulnerable physiographic zone that receives substantial monsoon rainfall. The watershed region is made up of 44% woodland, 39% agricultural areas, 5% residential and marshland area, 5% grass and barren land, 4% lake, and 3% shrub area [7]. Bhandari et al. (8) compiled a checklist of flowering plants in this region, documenting 613 species from 111 families. Similarly, Tamrakar [9] explored 60 aquatic plant species, 203 terrestrial plant species, 28 fish species, 11 frog species, 28 reptile species, and 36 mammals on the Pokhara Lake clusters including the common otter, which is listed on Appendix I of the CITES. Ten of the 168 bird species are listed in the CITES Appendix, while five are listed in the IUCN's various threat categories.

Due to geological and climatic circumstances, the watershed is particularly prone to rainfall induced landslides. Watershed ecosystems are typically stable and sturdy. Because of the naturally weak geological characteristics of rocks and soils, the Himalaya is an extremely fragile mountain [10]. Due to periodic monsoon rains and intense yet inefficient land use methods for farming and development, the Phewa watershed is one of Nepal's most unstable ecosystems. Each of Nepal's physiographic zones is very dangerous due to the country's high peaks, steep slopes, weak rock, and heavy soil cover over intact bed rock, as well as the monsoon climate. Larger wetlands are uncommon in the region due to the region's mountainous physiography [11]. Watershed management is the process of implementing strategies, programs, and initiatives to maintain and improve watershed roles in regulating flora, fauna, and human populations within the boundaries of a watershed to ensure the sustainability of the watershed [12]. Watershed management began with the primary goal of avoiding erosion, floods, and maintaining the long-term durability of useable water supplies [13]. Catchments are always changing and these changes must be factored into management. Since the twentieth century, however, unsustainable development has presented a danger to the ecology of watersheds in many parts of the world. Slope failures, erosion, floods, ecological imbalance, and excessive water extraction and agricultural activities all contribute to the degradation of the watershed. Particularly, the Phewa-lake has changed from oligotrophic to mesotrophic to eutrophic throughout the 1970s, 1980s, and 1990s [6]. Phewa Lake has a water surface size of 1.793 Square Kilometer and a maximum depth of 23 meters [14]. Even though biodiversity threats are a critical concern, watershed management has paid little attention to them.

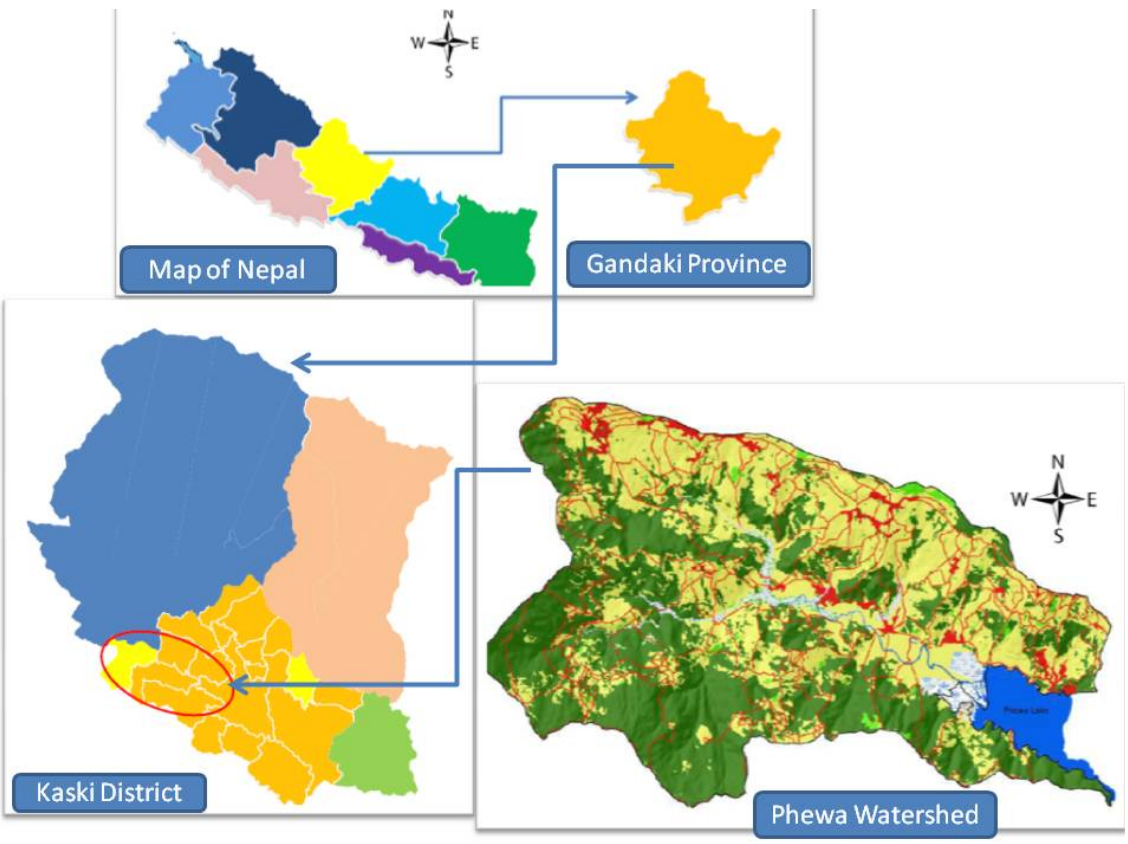


**Figure 1.** Study area

Therefore, this study aims to analyze the condition of the Phewa Watershed. The study then focuses on identifying potential explanatory variables such as soil erosion, landslides, sedimentation, and plant invasion, as well as how to manage them utilizing vegetation. The Phewa Watershed is under threat from a multitude of factors, including landslides, soil erosion, eutrophication, alien species, road construction, and encroachment, according to the research premise.

## 2. Methodology

This study focuses on the biodiversity threat, watershed, Phewa Lake, watershed management, and plant cover from the information available in the scientific journals, academic publications, conference papers, textbooks, and unpublished reports. Altogether, 113 articles focused on vegetation as a threatened mitigation measures from journals, academic publications, conference papers, textbooks, and internet assets (see Table 1) are used for this study. This study mainly focused on the threats to the Phewa watershed and possible mitigation measure using vegetation to protect it from future deterioration.

**Table 1.** Literature reviews list

| SN | Type | Number |
|---|---|---|
| 1 | Scientific Journals | 50 |
| 2. | Book Chapter | 22 |
| 3 | Reports | 26 |
| 4 | News paper | 2 |
| 5 | Thesis | 3 |
| 6 | Conference/proceeding Paper | 8 |
| 7 | e-portal | 2 |

## 3. Existing Problems

### 3.1. Threat

Natural resources are under jeopardy all around the globe. According to Millennium Ecosystem Assessment [15], just four ecosystem services have improved in the last 50 years, fifteen are in significant decline, and five are stable in general but under threat in specific regions of the world. Land degradation is a global problem that affects over 8 million Square Kilometer of land and threatens the livelihoods of over 1 billion people [16]. Despite the fact that watersheds are endangered by a range of natural sources, the majority of the problems stem from direct or indirect human involvement with them. As a sociopolitical-ecological entity, the watershed is vital in providing dietary, societal, and income security, along with critical life support services to assist stakeholder activities in the catchment [2]. The interaction of physical, biophysical, and human activities in Himalayan watersheds has resulted in a complex physiography. Due to geological and climatic factors, as well as extensive but inefficient land use methods for farming and habitation, the Nepalese Himalayas are one of the world's most vulnerable ecosystems. According to [17], severely degraded watersheds cover around 10% of Nepal's area whereas extremely good condition watersheds cover just 33% of the territory. The majority is defined by steep hills, large height differences over short distances, scarring river and stream banks from landslides and gullies, massive rocks in limited watercourses from massive dumping and floods, sparse vegetation, farmlands, and dispersed human settlement. The watershed is threatened by encroachment, eutrophication, landslides and sedimentation, invasive species; toxic pollution, overfishing, water diversion, acidification, and climate change [18]. Flowing processes and complicated interactions develop throughout valleys as a result of natural dams created by landslides or debris-laden flows caused by streams, culminating in the formation of lakes [19]. It indicates that the watershed region is vulnerable to soil erosion and landslides due to its current conditions. According to the Ministry of the Environment, the Kaski district is severely vulnerable to landslides [20]. The Phewa watershed is one of the most susceptible due to folded, faulted and fractured meta-sedimentary rocks [21]).

According to aerial images and field observations in 1977, approximately half of the area in the Phewa watershed was in terrace, 28% unmanaged forest, 11% grassland and pastureland, 7% deteriorated scrub and 1% gullies or slides [22]. According to Poudel and Mandal [23], degraded land occupies 0.3 percent of the Phewa watershed, whereas forest, agricultural, built-up, and water bodies cover 52.98 percent, 27.90 percent, 16.40 percent, and 2.40 percent, respectively. Although forest cover benefits both physical and environmental elements, soil erosion and sedimentation are the most pressing challenges in the Phewa watershed. The Phewa watershed is commonly endangered by landslides, soil erosion, exotic species invasion, climate change and pollution, and upstream and downstream sedimentation (Fig. 2). The fundamental sources of debris and slides include the thermoplastic phenomena as well as external environmental variables such as climate, soil type, earthquake frequency, road construction and slope. As a result of nutrient loading from agriculture, landslides and increased development in the surrounding region, the lake is mesotrophic and presently experiencing serious environmental difficulties [24]. In 2014 and 2015, the average sediment flux of Phewa Lake was 16 and 17 tons per acre per year, respectively [25]. Rapid eutrophication is increasingly prevalent [4, 26] and the lake is also seasonally oligotrophic as a result of high rainfall in its catchment area [27]. Extreme lake-area encroachment, increased eutrophication, invasive species, water diversion, toxic contamination, acidification, unregulated fishing, sedimentation, hotel water pollution and the effects of extreme weather occurrences are just a few of the major threats to Phewa Lake [26]. The introduction of non-native plants into the wetland, the removal of buffering vegetation, and upland forest deterioration are the main causes of vegetation loss [28]. According to Friedrichsen [29], urbanization may be the most serious long-term threat to watersheds because the eastern and northern parts of the Phewa watershed are rapidly developing and encroaching on metropolitan centers.

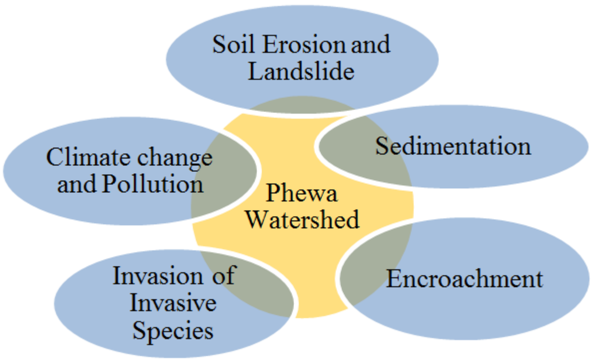


**Figure 2.** Threatened of Phewa watershed

### 3.2. Soil Erosion and Landslide

Landslides, surface runoff, floods, ecological imbalance, and excessive water collection for farming activities are the primary causes of watershed damage [30]. Individual soil particles split from the soil mass are moved by erosive agents such as flowing water and wind and these sediments are deposited to the river bed. Globally, the leading causes of soil degradation are deforestation and loss of natural vegetation (43%), overgrazing (29%), insufficient farming practices (24%), and overexploitation of natural vegetation (4%) [31]. Abandoned terraces are more prone to erosion as a result of labor migration from the highlands to urban areas [32]. Because of heavy land use without appropriate consideration of conservation measures coupled with excessive rainfall, the erosion process in the watershed has transported a large amount of silt to the lake diminishing its capacity [33]. Water erosion itself has destroyed 1094 million hectares of land globally, with 751 million hectares severely impacted [34, 35] and 3 million hectares of agricultural land lost per year due to erosion [34, 35, 36]. Himalayan countries are particularly prone to soil erosion due to their steep topography and thin soil thickness [37]. The intensive rainfall mostly dominates the soil erosion in the Asian highland [38]. The ultimate impacts of watershed degradation, such as soil erosion, landslides, high sedimentation, water pollution, floods and droughts, must be detected as soon as feasible in order to protect watersheds. Anthropogenic (indiscriminate deforestation, road construction, mining, poorly regulated diversion, logging, and improper farming) and natural (landslides, wildfires, and floods) elements may emerge at any time and degrade the landscape in future.

Increased soil erosion deteriorates the watershed's ecosystem by causing sedimentation, deteriorating water supplies, diminishing forest production and compromising other vital environmental services [39]. Landslides are characterized as processes that cause the downward and outward movement of slope-forming substances composed of natural rocks, soil, manmade fill, or mixes of these elements [40, 41]. Between 2004 and 2010, landslides killed around 4500 people worldwide (excluding seismically caused landslides) [42]. The most human lives are lost in India, China, the Philippines, and Nepal, with landslides wreaking havoc on populations and infrastructure [43]. A total number of landslides were found to be 4351 causing 5437 of recorded death tools from 1971to 2019 [44, 45] in Nepal. These numbers of landslides and death tolls are different in different physiographic regions due to the variation of geomorphology and microclimate [46].

The maximum and lowest mean monsoon rainfalls are 1,236 mm and 506 mm, respectively [47]. According to an IPCC report [48], meteorological factors will alter due to climate change in future directly contributing landslide generation. There is also a correlation between rainfall intensity, rainfall duration and landslide incidents [49]. This rainfall acts differently in different slope gradients. Around 10 percent of the watershed is plain to rising (0–10% gradient), 60 percent has slopes ranging from 20% to 60%, and 15 percent is exceptionally sharp (60–100% gradient) [22, 27] in this watershed. Basnet et al. [50] explained that the landside density is 0.44 per $km^2$. The gradients of the watershed to the south are softer (approximately 30 to 50%) than those to the north (above 50%). The soils in the Phewa watershed area are generally well drained and have a high surface erosion potential, which can lead to gullies and, as a result, landslides [51]. The hill system is broken through by a series of irregular ridges and elevations. Furthermore, anthropogenic activities such as unplanned rural road construction in this watershed has been contributing for increasing soil erosion and land sliding, that has resulted sedimentation in the Phewa lake [52, 53]. Upslope, shallow landslides and soil loss can result in substantial sediment outputs, which can contribute to downstream issues including reservoir sedimentation and pollution. Rapid bedrock uplift and river incision rates are induced by tectonic and climatic forces, earthquakes, increasing precipitation [54].

Soil erosion is prevalent over two-thirds of the area in the Phewa lake watershed with an annual average erosion rate of 29.3 (t/ha/yr) as per 2007 and reduced to 25.4 (t/ha/yr) in 2017 [55]. According to CBS [56], protected pasture of Phewa watershed had 920 ton/sq km/yr soil erosion, overgrazed grass land had 2200-34700, and gullied overgrazed grass land had 2900 ton/sq.km/yr soil erosion. According to Fleming [57], the soil erosion rate threshold for Nepal is 10-20 tons per hectare per year. This process clogs the rivulets and streams causing major landslides. The vegetation in the watershed slopes protects against rainfall-induced erosion; however, the rate of soil losses incurred by sheet and rill erosion on farmland and barren land is relatively high. The aforementioned condition is discreetly available where 39% agriculture land, 5% barren land and nearly 40% sloppy areas occupy the whole watershed [7, 22]. Abandoned agricultural land due to population shifts in the upper levels of the watershed [5] is causing the creation of gullies, which eventually results in soil erosion and landslides.

### 3.3. Sedimentation

The watershed consists of 19 sub-watersheds and the Firke Khola and Seti canal drain the water to the Phewa Lake where the Harpan Khola accounts for 70% of the total water intake. The Harpan Khola has mean flows of $5.58m^3$/second [58]. The tributaries or seasonal streams of the Harpan Khola are Hadi, Khahare, Lauruk, Thotne, Thado, Betani, Bhakunde, Faure, Kutuje, Orlan, Kamni, and Turung kholas (khola means small rivers in Nepali). The rainfall fluctuates over the years but the rainy season *i.e.* June to September accounts 80 percent of yearly rainfall. This flow has frequently been unable to be retained by the watershed due to different pre-disposing conditions. Therefore, this runoff triggers the soil erosion and deposits the sediments to the lake. The yearly sediment deposit at Phewa Lake is $175{,}000\text{-}225{,}000m^3$ [59], which is consistent with Laban's [60] finding that sedimentation rates in highly damaged mountain slopes vary from $16800m^3/km^2$/year to $368m^3/km^2$/year in protected meadows. If this pace of sedimentation is continues, the lake will be gone in 135-175 years, presuming 80 percent loss of water content. In the last five decades, siltation has reduced the size of Phewa by more than half [61]. Watson et al. [62] estimate that the lake will lose 80% of its storage capacity in the next 110–347 years based on the pace of areal decline and sediment intake. According to CBS [56], the Phewa watershed has a sediment production of 8.9 tons per hectare per year.

### 3.4. Invasion of Invasive Species

Despite its small size, Nepal is abundant in flowering plants. Nepal is home to 6,973 Angiosperm species, 26 Gymnosperm species, 534 Pteridophytes species, 1,150 Bryophytes species, 1001 Algae species, 1822 Fungi species, and 465 Lichen species, with 284 blooming as endemic plants [63]. In Nepal, there are 25 invasive and alien plant species classified into 13 families [64], while at least 219 alien flowering plant species are becoming natural [65, 66]. Since the Annanpurna region is intimately related with the Phewa watershed and is heavily influenced by high rainfall, broad leaf species predominate as vegetation in this region [67]. In the Panchase forest, which encompasses the Phewa watershed, there are *Schima wallichii-Castanopsis indica*, hill sal forests, pine forests, *Quercus semicarpifolia-Quercus lamellosa-Rhododendron arboretum*, and *Daphniphylum himalense* forests [63]. Furthermore, the Panchase forest is home to rare, threatened, and unique plant species, including six endemic and three threatened orchid species [68, 69, 70, 71].

The introduction of invasive species is a growing problem in this watershed. The invasive plants such as *Eichhornia, Eupatorium, Ageratum* species threaten the quality of the watershed. Invasive species are actively invading, creating a danger to increasing agricultural operations, forest, culture, transportation, trade, power production, recreation, and fisheries by eradicating and substituting native biodiversity. Due to sedimentation caused by soil erosion, landslides, and significant water hyacinth invasion, the lake and its watershed have been under intense and exhausting pressure for the last several decades [26]. The loss of aquatic biodiversity has been exacerbated by the challenges posed by invasion like water hyacinth, and the similar situation exists in terrestrial plants due to *Ageratum and Eupatorium* species. According to Pathak et al. [72], invasive species at Phewa Lake are *Alternanthera philoxeroides, Eichhornia crassipes, Ipomoea carnea ssp. Fistulosa, Leersia hexandra, and Pistia stratiotes*. Similarly, Acharya [73] reported water hyacinth, parthenium, morning glory and lantana camera on this watershed. All of these aforementioned non-native species, *Eichhornia crassipes*, are classified as a highly aggressive and troublesome foreign species in the Phewa watershed [74]. Nine of the 14 worst species were found in former Bhadaure Tamagi VDC of Phewa watershed, *Parthenium* with *Ageratum and Ageratina species* being the most troublesome [75]. Abandoned agricultural land as a result of population shifts is allowing non-native species to thrive at the watershed. Salinity, nutrients, disturbance, temperature, competition from other associated plants, and natural enemies appear to be the major elements that limit water hyacinth infestations [76]. It was believed that the threat of invasive species would be much lower in natural habitats as compared to disturbed habitats. A pH of 6 to 8 [77] and a temperature of 28 to 30 degrees Celsius are ideal for the growth of water hyacinth [78]. The Phewa Lake has circum-neutral pH (6.83±0.76) [79] and the annual water temperature ranges from 15° to 30°C [62]. This invasive species thrives due to upstream soil erosion and sedimentation as well as a lack of natural enemies and an allelopathic impact to compete with other plants. Plant invasions alter the soil microbial community, soil physicochemical characteristics and litter decomposition rates. These activities boost the nitrogen cycle and releasing extra nitrous oxide ($N_2O$) into the atmosphere, fostering global warming and affecting in the geographic ranges of some invasive species [80].

### 3.5. Climate Change and Pollution

The average maximum and lowest temperature trends grew by 0.008 and 0.026 degrees each year, respectively. Furthermore, the average total annual precipitation from

1980 to 2016 was 3863.29 mm, with July receiving the most precipitation and December receiving the least [73]. Over the previous 30 years (1981-2011), the maximum and lowest average temperatures in the Phewa watershed have risen by $0.81^0$C and $0.2^0$C, respectively [47]. Kaski district has a moderate vulnerability rating (*i.e.* 0.356-0.600) [20]. Phewa Lake is subjected to non-climatic stresses such as pollution [81], 310 Km poorly constructed roads [52], and a variety of local development and human settlements [58]. Traditional farming practices are used by the majority of farmers in watershed areas to cultivate agronomical, legume, spice, vegetable, and fruit crops. The key concerns are the tiny size of land without irrigation infrastructure, the large distance between irrigated land and residential areas, and the soil's high acidity. The effect of climate change in the Himalayas is enormous because it is projected that the temperature will increase at least 1–2 °C degree centigrade by 2050 [82].

### 3.6. Land Encroachment

The storage capacity of the lake was increased in the early 1960s when a dam was built at the Pardi outlet [47]. In 1975, a structural breakdown ruined the dam forcing it to be reconstructed. After the dam failed, exposing land near the lake, landlords used political and other influence to have the land recorded in their names. The likelihood of encroachment for built-up purposes on 33.79 ha of barren land near Phewa Lake is 33.79 percent [23]. The analysis demonstrates that the forest area, shrub-land, grassland, and built-up area in the watershed were increased whereas agricultural land, surface area of the lake, and barren land were decreased [83].

## 4. Watershed Management

A watershed offers ecological services and water supplies to flora and fauna, as well as agricultural and cultivation activities. Water strength, water capture, and water release are the three fundamental functions of a watershed [84]. EPA [85] estimates that clean and healthy watersheds are responsible for more than $450 billion in food, manufactured goods, fiber, and tourism. Micro level precise mapping on the surface of characteristics like surface morphometry, land use, land cover resources, and population parameters is typically a huge difficulty in mountain geography but it is required for watershed management [30]. Sustainable human activities are essential to the ecological balance of watersheds. The water, biota, surrounding watershed, and atmosphere are all interrelated components of the ecosystem; humans are regarded an intrinsic element of this system [86].

To manage vulnerable watersheds, strict adherences to national legislation including the utilization of vegetation on an as-needed basis are required (Fig. 3).

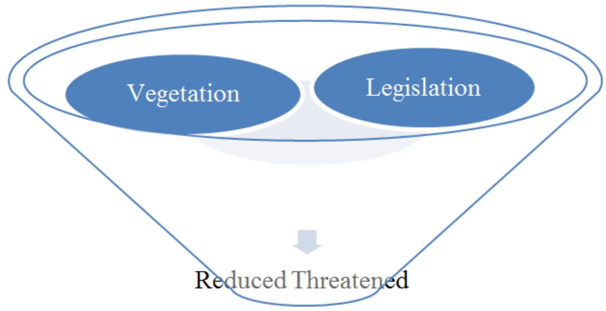


**Figure 3.** Management of threatened

Watershed management in Nepal is governed by laws such as the Soil and Watershed Conservation Act of 1982, the Land Act of 1964, the National Parks and Wildlife Conservation Act of 1973, the Environmental Protection Act of 1996, the Forest Act of 1993, the Water Resource Act of 1992, and the Local Self-Government Act of 1999. The Soil and Watershed Conservation Act of 2039 (1982) defines how to safeguard or save any place from being devastated by natural catastrophes like as flood, soil-erosion, and landslide, as well as how to maintain cleanliness by preventing muddy water flow. Later in 1985, the Conservation Act was followed by the Soil and Watershed Conservation Regulation provides the government the authority to designate any watershed as a "Protected Watershed" and to introduce improvement conservation initiatives in these areas. The Solid Waste Management and Resource Mobilization Center Act of 1987 established a center as the solid waste management regulatory body. The act is concerned with the pollution of water caused by solid waste. The Water Resources Act of 1992 regulates the use of water; water contamination is prohibited and that governs water resource management as a whole. The Forest Act of 1993 stipulated that trees cannot be destroyed in a manner that has a significant negative impact on the environment, causes public harm or loss, or causes soil erosion in the watershed region. The Water Resource Regulation 1993 (2050 BS) oversees water resource management. The Environment Protection Regulation of 1997 (2054 BS) has a list of water-related projects that require an Environmental Impact Assessment (EIA) or Initial Environmental Examination (IEE). The Local Self-Government Regulation of 1999 established the authorities, functions, and responsibilities of the Village, Municipality, and District Development Centre in the area of water and sanitation. When using water for irrigation from any river/rivulet, the Irrigation Regulations 1999 (2056 BS) mandates that only the leftover water be utilized for irrigation after determining that it will not impair local biodiversity. According to the National Wetland Policy of 2003, wetlands are permanent water basins that receive water from underground sources or precipitation. The Nepal National Water Plan, 2005 and Water Resource Strategy, 2002 include management of ecosystem and develop action plans for water-induced tragedies, an environmental plan of action for watersheds and water ecosystems, water delivery, and sanitation. The Nepalese Constitution of 2015 (2072 BS) governs the country and includes provisions for natural resource protection, management, and use regulations, as well as rights to a healthy environment.

The Ninth Plan placed a strong emphasis on managing water flow by building reservoirs, in order to reduce flood damage and maximize the benefits of water resources [87]. Integrated watershed management activities are given top attention. Priority is given to comprehensive watershed management to protect underground water and soil in the Chure-Bhawar and Terai areas in the Tenth Five Year Plan (2002–2007). Despite the fact that the plan only addresses the Chure Hills and Terai, it strongly advocates for an integrated watershed management strategy. Several watershed management initiatives, including landslide danger zone repair, river training works, eco-zoning-based land use planning along the Lake Coast, and solid waste management, were completed in the Phewa watershed [88]. The traditional maintenance of Nepal's watersheds included the creation of terraced areas for crop cultivation. In 1974, Nepal formed the Department of Soil Conservation and Watershed Management, which marked the beginning of systematic watershed management in the country. For three years (1975–1977), the Nepal Government operated the first effort focusing on integrated water catchment management in the Phewa watershed [56]. A collaborative and integrated strategy to watershed management was formed in the second half of the 1990s. This includes boosting livelihoods and human development at the farm household, local, or watershed level through the use and conservation of land, water, and forest resources [89].

The best safeguard against extreme weather is a healthy watershed. Watersheds are useful units for natural resource management due to their diverse biophysical and, in most cases, socioeconomic characteristics. According to the 2011 national census, the watershed region of Nepal is home to approximately 590,000 people. It is necessary to maintain a balance between economic development and land and water resource conservation. During a drought, vegetation can hold water, lowering the risk of fire and giving wildlife habitat, and it can also seek out extra water during heavy rains, minimizing erosion and runoff. The most typical ways to prevent watershed threats have been reforestation and displacement of local populations from important places such as steep slopes, forest and wetlands. Increased usage of trees and shrubs can collect and slow down water runoff by 10% to 20%, allowing water to be conserved before it reaches streams, rivers, and lakes [90]. This method also helps to reduce soil erosion, landslide and sedimentation. Grazing control by social fencing and stall feeding was significantly more effective in reducing erosion and increasing grass and fodder leaf output. Over the next three decades, as a result of the national government's policy of delegating forest management to local people in the Phewa watershed, forest productivity doubled and grass and feed output grew fivefold [22].

Several studies explained the role of vegetation in hazardous events such as landslides, rock falls, and debris flows [91, 92, 93]. The soil is protected from the effects of rainfall by natural vegetation and aids in the infiltration and replenishment of underground water sources. Infiltration capacity is reduced when vegetation cover is displaced [94]. The soil is exposed to extreme precipitation due to a lack of natural vegetation resulting in weak structure and enhanced runoff dissociating the soil particles that promotes soil erosion. Litter and plant cover improved downstream flow, velocity reduction, and surface quality encouraging soil absorption through increased macro-pore density as well as improving soil composition by adding nutrients [95]. According to Igwe et al. [96], preserving existing natural vegetation and tree planting where land has been barren just provide required assistance for soil erosion prevention for the preservation of the global ecosystem. In order to increase slope stability, upslope areas of a site or watershed must have long-term control of soil erosion and sediment generation. Maintaining and improving vegetation cover can help with slope stability, sloughing off rain before it infiltrates, directing water away from unstable slopes, and increasing soil strength [97, 98]. According to Hasnawir et al. [99], deep-rooted, lateral-spreading species have exhibited stronger pull-out resistance and are regarded ideal for erosion control and reducing negative impacts on forest slopes, such as surface erosion and shallow landslides. They discovered that plant morphological variety hampered sediment retention, and that grass barriers were the best at retaining sediment. Indeed, their findings imply that employing native grass species barriers to begin ecological restoration of eroded gullies is the optimal method. The most important component in encouraging short-term sediment deposition and gully stabilization is gully bed vegetation. Topographical impacts are only noticeable in nearly vegetated gullies: in the apparent lack of any ground natural vegetation, naked steep gullies become really efficient soil infiltration pathways, and deposition rate occurs only when the silt mobility gets lower due to a large reduction in nearby gully steep hill [100]. According to Rehman et al. [101], research in Pakistan on the influence of steep slope and vegetation cover on erosion and sediment production in hilly areas, increasing different vegetation results in a considerable reduction in sediment flow.

The chosen plant should have a deep and extensive root system, as well as be hardy, quick-growing, and suckering [102]. To mechanically maintain a gradient Vs a modest landslide, vegetation must pass through the surface morphology that can be close to 2m underneath the surface of the ground [103]. Strong roots act as soil nails on slopes. Large trees can serve as a level in high winds, causing them to break or uproot, affecting the mechanical integrity of the slope [104]. According to Istanbulluoglu and Bras [105], plant instability might result in a sharply fragmented topography with substantially lower elevation than landscapes originating from stable, uninterrupted vegetation. Once a plant's suitability for a certain habitat has been determined, above and below ground plant attributes should be considered. Fine root density, stem bending stiffness, stem density, erosion control potential, and debris blockage potential are all factors to consider. Vegetation aids with water logging, underlying soil stability, hardness and fertility, and the enhancement of soil microbes. Ground surface protection has been aided by the presence of herbs, shrubs, and perennial plants with a united root system. Additionally, vegetation improves water quality, reduces storm water runoff, improves wildlife and fishery habitat, and inhibits the establishment of noxious weeds.

To avoid erosion and manage water on the hillslopes, most croplands must be converted to a sophisticated system of terraces due to the steep slopes and heavy rainfall. Because of the higher expense and technical difficulties associated with steep terrain, hardware constructions alone are not acceptable. The use of purely vegetative structures to limit erosion in a short period of time may not be effective, hence a combination of structural and vegetative methods is recommended for slope management [106]. Compared to an earth retaining structure or other geological protection systems, vegetation treatment is the most cost effective. When it comes to species selection, the chosen species should have a deep, strong and wide root system, as well as be indigenous, fast-growing, and bushy type. Restoring the most valued plant communities on engineering building sites will also save long-term maintenance costs, reduce erosion and landslide rates, and improve water quality. Reduced landslide risk can benefit downstream by reducing the amount of sediment that reaches rivers, as well as locally by reducing fatalities and infrastructure damage. Because of the weak geology, naturally high levels of erosion, and mass movements, erosion and sedimentation are a top priority, and this area is particularly prone to land management impacts. Species native to the location, with colonial behavior, suited for the site, have a large biological amplitude of adaptability, a dense and deep root system superior erosion control value, excellent root spread and strength, a fast growing nature, and be commercially available or ability to propagate quickly are needed to protect watershed from landslide, soil erosion, sedimentation, invasive species invasion and reduce or adapt climate change.

Land encroachment and solid waste disposal from hotel, domestic uses and agricultural run-off cause severe trouble to the lake. Phewa is the most contaminated lake diseases germ like *E. coli* readings in the lake ranging from 39 to 123 units per 100 ml, despite the fact more than 100 kg of soaps and detergents from washing activities [58]. Now several governmental policies, laws and legislation are building up.; they are needed to strongly implement to manage the problem of land encroachment and pollutant. According to Bo et al. [107], the types of slopes that are most sensitive to climate change changing vegetation and ground and surface water levels would alter the stability of slopes. To counteract climate change, ecological base adaptation is the best option where vegetation growth is required.

Prevention, eradication, and control are the three main tactics for dealing with invasive species [108]. Local women's groups in the Pokhara valley have used the biomass of *E. crassipes* to make handcraft items (e.g., pen holders, dust bins, handbags) [109]. Ecosystem-based Adaptation (EbA) is gaining traction as a cost-effective and environmentally benign way to safeguard human and ecological populations against climate change and biological invasion [110]. In Nepal's initial Biodiversity Strategy [111], alien invasive species were recognized as a threat to all biodiversity, but no management strategy was specified. In the second iteration of the National Biodiversity Strategy and Action Plan 2014-2020, the threats posed by alien species to biodiversity in marshes, agricultural, grasslands, and other ecosystems have indeed been adequately recognized [63]. When an invasive species establishes itself in a new area, it can quickly overtake native species, resulting in a monoculture throughout the landscape. The diversity of macro-invertebrates was favorably connected to water hyacinth, however the impact of water hyacinth on hydro power generation is likely to be limited [112]. Water hyacinth has previously been shown to be a promising plant with a wide range of wastewater treatment uses [113]. To avoid invasive species invasion, it is preferable to convert agricultural land to grassland or forest rather than keeping it barren, which indicates by growing vegetation can reduce penetration of some invasive species. Ornamental value, animal fodder, fish feed, fertilizers, biomass energy (Charcoal Briquetting, Bio Gas), raw materials for building, handcraft manufacturing, paper and board, and as a pollution filter are just a few of the possibilities for the invasive plant.

# 5. Conclusions and Recommendation

Soil erosion, landslides, invasion, and sedimentation are the most serious problems in the Phewa watershed. The anthropogenic effect and natural components have had a significant impact on the watershed. As the Ramsar site's indication authority, it is required to state that it is desirable to apply ecological techniques to decrease soil erosion, sedimentation, climate change and invasion of the non-native plants. To safeguard the watershed, species that are adapted for the site, have a superior erosion control value, a fast growing habit, and the ability to propagate quickly are required. Above and below ground plant features should be examined once a plant's suitability for a specific ecosystem has been determined. The soil is protected from the effects of rainfall by natural vegetation. It aids in the absorption and replenishment of underground water and has a significant impact on slope stability.

Invasive plants such as *Eichhornia, Eupatorium, and Ageratum sp*. pose a serious threat to this watershed and must be managed.

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