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RIVERS AND RIVER ESTUARIES IN SRI LANKA: AN INTERPRETATION

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ABSTRACT

Sri Lanka's river systems are essential to the nation's geomorphological, ecological, and socio-economic fabric. Despite their significance, the country's river classification and drainage mapping have long been misrepresented, particularly the misconception that Sri Lanka possesses 103 river basins flowing radially from the Central Highlands. This study addresses this critical research gap by revaluating and redefining Sri Lanka's true drainage systems, origins, and outflow characteristics through comprehensive geomorphological and hydrological analysis. The primary aim of this research is to provide an accurate interpretation of rivers and river estuaries in Sri Lanka by integrating field investigations, geomorphic mapping, and digital elevation models (DEMs). The specific objectives are to (1) correct long-standing misinterpretations regarding river basin classification and drainage patterns, (2) identify the true number and distribution of rivers that directly discharge into the Indian Ocean, (3) categorize the types of river estuaries based on geomorphological and hydrological parameters, and (4) examine the implications of human interventions, such as dams and diversions, on natural flow regulation and estuarine dynamics. Using SRTM derived DEMs, topographic contour analyses, and field validation across 29 major river outlets, the study reveals that Sri Lanka comprises 94 true river basins, of which only 29 rivers directly discharge into the Indian Ocean. These outlets form five distinct estuarine types: drowned river valleys, bar-built perennial, bar-built seasonal, perennial delta, and seasonal delta estuaries. Contrary to previous literature, only eight of these rivers originate above the 1200 m contour line of the Central Highlands, while the majority emerge below it. The findings underscore the necessity of reinterpreting Sri Lanka's fluvial and estuarine systems for accurate hydrological assessment, policy formulation, and sustainable water management. Recognizing the spatial and functional diversity of these systems is vital for ecological conservation, flood control, agricultural planning, and the preservation of cultural heritage linked to ancient hydraulic civilizations. This reinterpretation provides a scientifically grounded framework to guide future research and national resource management strategies concerning Sri Lanka's riverine landscapes.

Keywords: *Estuaries, perennial rivers, river basins, seasonal rivers.*

INTRODUCTION

Rivers are the basis of human civilization. Heavy rainfall resulting from storms can lead to rapid run-off, causing the volume of water in a river channel to quickly increase. Rivers that do not flow continuously throughout the year are called nonperennial rivers. Rivers in the areas of intermediate and dry zones with dry climates in the country have a low discharge, as low amounts of water entering the channel can be designated as seasonal rivers. Seasonal rivers, also known as intermittent or ephemeral rivers, are rivers that do not flow continuously throughout the year. They either flow intermittently every year or at least twice every five years; they flow abundantly during certain seasons, such as the monsoon season. They are found in mainly dry and semiarid areas, and they drain particularly in dry zones. Water may flow for hours or even days but rarely longer. Jacobson (1997) defines an ephemeral river as one in which measurable discharge occurs for less than 10% of the year. Over time, a particular river can change from perennial (where water flow is continuous) to ephemeral, or vice versa, depending upon climatic and environmental circumstances.

The rivers are different in origin, and as they travel, they often merge with other bodies of water via flow. Accordingly, a river is a ribbon-like body of water that flows downhill due to the force of gravity. A river can be wide and deep or shallow enough for a person to wade across. A flowing body of water that is smaller than a river is called a stream, creek, or brook. Accordingly, a natural stream of water of considerable volume flows larger than a brook or creek. Rivers are the causes of waste most visible to us and are most obviously capable of producing great effects. It is not, however, in the greatest rivers that the power to change and wear the surface of the land is most clearly seen. It is at the head of rivers and in the feeders of the larger streams, where they descend over the most rapid slope and are mostly irregular or temporary. It is at the head of rivers, and in the feeders of the larger streams, where they descend over the most rapid slope and are most subject to irregular or temporary increases and decreases, that the causes that tend to preserve, and those that tend to change the form of the Earth's surface, are farthest from balancing one another and where after every season, almost after every flood, we perceive some change produced, for which no compensation can be made, and something removed that is never to be replaced. When we trace rivers and their branches toward their source, we come at last to rivulets, which run only in times of rain and are dry during other seasons (Playfair in 1802). Renowned geomorphologist William Morris Davis (1969) noted in Water, Earth, and Man that “the river is like the veins of a leaf; broadly viewed, it is like the entire leaf. There is, however, one critical difference. In the leaf, the flow of water and nutrients occurs primarily from larger to smaller veins. The river basin, as part of the hydrologic cycle, is increasingly an eco-technological and social system. For the United States, an estimated 10% of the national wealth is devoted to structures involving the movement of water, including dams, irrigation systems, water supply networks, and sewers, with increasingly sophisticated controls. A river and all its tributaries within a single basin are termed a drainage system, and in combination, several drainage systems form a variety of drainage patterns.

The comprehensive river system consists of not only the river itself but also all of its converging tributaries. Estuaries and their surrounding wetlands are bodies of water usually found where rivers meet the sea. Thus, “rivers” and “estuaries” are closely related to the natural environment. Estuaries are home to unique plant and animal communities that have adapted to brackish water, a mixture of fresh water draining from the land (rivers) and saltwater. Accordingly, a river is a naturally flowing watercourse, usually freshwater, that flows toward an ocean, sea, lake or other river. An estuary is a partly enclosed coastal body of water in which river water is mixed with seawater. Estuaries are transitional environments that meet the needs of land, freshwater and marine ecosystems (Thrush et al 2014). The term estuary is derived from the Latin words aestus (“tide”) and aestuo (“boil”), indicating the effect generated when tidal flow and river flow meet.

A river that flows throughout the year is called a perennial and empties into the ocean or bay/lagoon, forming an estuary or estuarine delta. Additionally, an intermittent stream is a stream or part of a stream that has flowing water during certain times of the year when groundwater provides water for stream flow. The water table is located above the streambed for only part of the year, which means that intermittent streams may not have flowing water during dry periods. Ephemeral streams only flow after a precipitation event, such as a heavy rainstorm. An ephemeral stream has flowing water only during, and for a short duration after, precipitation events in a typical year. Ephemeral streambeds are located above the water table year-round. Groundwater is not a source of water for streams. Runoff from rainfall is the primary source of water for stream flow.

The landmass of Sri Lanka has a total area of 65,610 square kilometers (25,330 sq mi), with 64,630 square kilometers (24,950 sq mi) of land and 980 square kilometers (380 sq mi) of water. Sri Lanka, an island country lying in the Indian Ocean, is separated from peninsular India by the Palk Strait. It is located between latitudes 5°55′ and 9°51′ N and longitudes 79°41′ and 81°53′ E and has a maximum length of 268 miles (432 km) and a maximum width of 139 miles (224 km). Morphologically, Sri Lanka would have been nearly flat land because of its Proterozoic high-grade rocks. However, the geomorphology of the island is very complex, is controlled by structures and tectonics (Vitanage, 1970, 1972), and consists of many high mountains and plateaus. More than 90% of the country's geology consists of crystalline rocks of Precambrian age. The Precambrian basement has been divided into three zones: the highland complex (HC), Vijayan complex (VC) and Wanni complex (WC). The Kadugannawa complex (KC) is a minor zone located again in WC. Owing to their geomorphology and geology, drainage rivers have several common types of drainage patterns, such as dendritic, deranged, centripetal and trellized. Sri Lanka's few rivers rise in the Central Highlands, from 2400 m or greater in elevation. However, they do not flow in a radial pattern toward the sea, as mentioned by many scientists (Katupotha and Gamage, 2020).

In Sri Lanka, the tributaries are connected to rivers designated *Oya, Ela, Odai*, *Ara* or *Aru* according to flow patterns and size as recognized by the local dialect. The synonyms are stream, streamlet (a small stream), rivulet (a very small river or stream), rill (a shallow channel cut in the surface of soil or rocks by running water), brooklet, runnel or runlet (a small stream), creek (a narrow, sheltered waterway, especially an inlet in a shoreline or channel in a marsh), and tributaries (a stream that flows to a larger stream or other body of water). Stream order is a system used in geomorphology and hydrology to categorize streams and rivers on the basis of their branching structure. Stream order helps geographers, geologists, and hydrologists study and measure the size and complexity of waterways, which is important for understanding river systems and their behavior. Horton's successors, A.N. Strahler, defined streams of different orders. All the initial, unbranched source tributaries he called first-order streams. When two first-order streams join, they form a second order; when two second-order streams merge, they form a third order; and so on (Waugh 2009. The largest river in the world, the Amazon, is a twelfth-order waterway. Drainage orders in the western and southern parts of Sri Lanka were identified by Katupotha (1994).

As mentioned earlier many local and foreign researchers and scientists address the drainage pattern and drainage system in Sri Lanka, depicting rivers that begin from the Central Highlands and flow radially toward the sea”. However, this statement is incorrect. Therefore, this work aims to reveal the proper drainage pattern and system, emphasizing the geology, geomorphology, elevation and behavioral characteristics of the Central Highlands, Midlands and Lowlands.

MATERIAL AND METHODS

The current study is a combination of field works and literature surveys. Journal articles, maps, and different interpretations in scientific papers and fieldwork were performed on the lowlands of the 29 rivers and estuarine delta areas in 2017, with experience in reaching conclusions, which is highly significant. Since river basin maps are crucial for examining the true nature of the river basin concept, base maps developed by the Survey Department of Sri Lanka were used to create necessary maps. Furthermore, contours (< 150 m, 300 m, 600 m, 1200 m and > 2400 m) were added to categorize each river’s basins and rivers according to the origin area to understand whether each river starts from the Central Highlands, as most of the literature claims. Digital elevation models (DEMs) are computer-generated representations of the elevation of terrain. With the DEM representation of the Central Highlands, river flow patterns can be easily understood. Therefore, to develop a DEM for Sri Lanka and the central highlands, freely available Shuttle Radar Topography Mission (SRTM) data were used and processed in the ArcMap 10.4.1.

RESULTS AND DISCUSSION

Rivers in Sri Lanka

The interpretation of the river basin concept was first attempted in Sri Lanka by Hunting Survey Corporation Limited, Toronto, Canada, and Surveyor-General of Ceylon (Sri Lanka) in 1962. Arumugum (1969) reported that Sri Lanka can be divided into 103 components of natural river basins. Unfortunately, misunderstandings of river basins with rivers have been reported for decades and are worthy of study, even in the Sri Lankan educational system. Most have misinterpreted the number of rivers in Sri Lanka as 103 and mentioned that they flow radially from the Central Highlands to the sea. River basin maps and digital elevation models have been developed to understand river basins, river origin locations and flow patterns in Sri Lanka (Katupotha and Sachith 2020). These data coupled with previous field observations were then used to critically evaluate the existing scientific literature. Accordingly, 29 rivers (15 out of 29 perennial rivers and 14 seasonal rivers) flow directly to the sea. These river estuaries were categorized as drowned river valleys, bar-built perennials, bar-built seasonal estuaries, perennial delta estuaries, and seasonal delta estuaries. Considering the origin of these 29 rivers, only 8 rivers begin from the central highlands and margins (>1200 m contour line), and most rivers/Oya emerge below the 1200 m contour line. Another 64 rivers/Oya were emptied into lagoons even though they are traditionally classified as flows directly to the sea. Four rivers/streams, namely, Mahsilawa, Katupila Ara, Pallakutti Ara and Rathmal Oya, connect to other rivers or salt marshes, whereas Bolgoda Lake, MaduGanga, Madampe Lake, Telwatte Ganga, Rathgama Lake and Koggola Lake are back-barrier coastal lagoons mistakenly identified as rivers in the traditional classification by Arumugam (1969) and others. All these originate below the < 100 m contour line. Hence, some misreadings of river basins and rivers clearly exist in existing scientific studies. As this information is valuable in many ways to the country, misreading of these subject matters must be corrected immediately (Katupotha and Gamage 2020).

In Sri Lanka, the river source may be a spring or overflowing reservoir. Surface runoff and groundwater also largely contribute to river flow. While a river flows in its channel, it receives more water from streams and other rivers and from rainfall. At the end of a river is its outlet, where the water empties into a lagoon or into the ocean. Sri Lanka has no river that empties into a large river or a lake. However, dams, barrages or anicuts for the purpose of irrigation or hydropower generation have arrested almost all rivers. Many barrages of the wet zone and intermediate zone have also been constructed to prevent the upstream intrusion of tidal water. These are called salinity barrages. The oldest salinity barrage on a Sri Lankan river dates back to 1904 on Karambalan Oya and was constructed 6.5 km upstream of its marine entrance to prevent tidal water intrusion to the Thinipitiya Irrigation Tank. Modern salinity barrages are common in front of water intakes for drinking purposes after conventional treatment. Classic examples are salinity barrages on the Gin Ganga and Walawe Ganga. River flow regulation for trans-basin diversion is a traditional practice in Sri Lanka that dates back to hydraulic civilization.

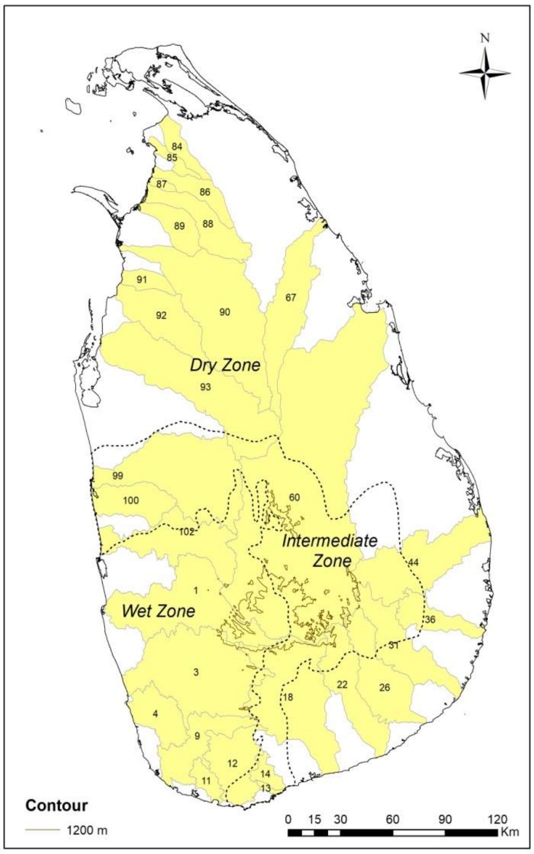

Figure 1: Twenty-nine river basins flow up to the ocean, and the same river basins, which begin above 1200 m (Katupotha and Gamage, 2020)

Ancient Lanka (Ceylon or Sri Lanka) was reputed for her hydraulic civilization, which was achieved through transbasin diversions and the construction of irrigation tanks beginning in the pre-Christian era. The hydraulic civilization of ancient Ceylon has direct bearings with early human settlements in the dry zone (Dharmasena 2017). The ten divisions are as follows: 1) Kevesastha (Northern), 2) Neelagiri (Modaragam Aru), 3) Kawasthalabba (Yan Oya), 4) Rakungiri (Malwatu Oya), 5) Chalaka (Mi Oya), 6) Upulwangiri (Kala Oya), 7)

Dummaka Kadeera (Deduru Oya), 8) Agni (Kumbukkana Oya, Menik Ganga, Kirindi Oya, 9) Mahagiri (Samanala Mountain Area; Kelani, kalu, Walawe and mahaweli), and 10) Indra (Maduru Oya, Mundeni Aru, Gal Oya. However, two types of ancient systems were prominent:

1. Partial diversion of some major rivers achieves interbasin transfer.
2. Storage tanks were created to feed the downstream command areas of the rice paddies.

A few classic examples are as follows:

a. Diversion of Amban Ganga at Elahera through so-called Amuna (anicut or weir) and convey water through a massive canal (Elahera-Minneriya Yoda Ela) to feed a series of major storage tanks (e.g., Minneriya, Giritale, Kaudulla, and Kantale)
b. Transfer of water from Amban Ganga further downstream at Angamedila to feed Parakrama Samudra
c. Interlinking of the Kala Oya and Malwattu Oya Basins through a 53 km long giant canal called Jaya Ganga, which conveys water from the Kala Wewa to a series of major tanks on the Malwattu Oya (Aruvi Aru) Basin (viz., Nachchaduwa tank, Nuwera Wewa and Tisa Wewa).

The ancient water resource development in the southern Dry Zone was confined to the Kirindi Oya and Menik Ganga basins (e.g., Tissa Wewa, Yoda Wewa, and Yodakandiya Wewa), although scholars argue that there are bits and pieces of ancient types in the Walawe River and Malala Oya basins. These schemes involve medium-scale storage tanks fed by diverting water without complicated link channel systems.

Types of river outfalls

Rivers are the main transporting agent in the fluvial cycle. A river and all its tributaries within a single basin are termed a “drainage system”, and in combination, several drainage systems form a variety of drainage patterns. Additionally, a river flows in a channel from high ground to low ground and ultimately to a lake or the sea. It receives more water from streams and other rivers and from rainfall or snowfall. The end of a river is its mouth or outlet where the water empties into a large river, a lake, a lagoon or an ocean. Rivers vary greatly in size; some are so small that they dry during the hot, dry season. River water comes from a combination of precipitation, lakes, springs and smelting ice and snow. The various streams that flow from the river’s source are called headwaters. Rivers can discharge directly into the sea through outlets or estuaries. An estuary is a place where fresh saltwater mixes, such as a bay **or** salt marsh, or where a river enters an ocean (Water Science Glossary 2018). As water moves through estuaries, the chemical composition of nutrients and other ions changes, which *can* have broad impacts once the water reaches the ocean.

Since ancient times, the population of Sri Lanka has depended on the island’s vast network of river basins. It was crucial to their survival, and human civilization evolved around them. Over time, human lifestyles have become more complicated, and the environmental stress induced by human activities has become more severe. Therefore, the need has arisen to understand the subject of achieving related policy-making, development, conservation and management goals (Katupotha and Gamage 2020).

The drainage pattern, which is formed by streams, rivers, and lakes, is a peculiar lattice in a drainage basin. They are governed by the topography of the landscape, whether a particular region is dominated by hard or soft rocks and the gradient of the land. Geomorphologists and hydrologists often view streams as being part of drainage basins. Thus, a drainage basin is a topographic region from which a stream receives runoff through overland flow and groundwater flow. Geomorphologists and hydrologists often view streams as being part of drainage basins. A drainage basin is the topographic region from which a stream receives runoff, throughflow, and groundwater flow. Drainage basins are divided from each other by topographic barriers called watersheds. Drainage basins lose water and sediment through evaporation, deposition, and streamflow. A number of factors influence the input, output, and transport of sediment and water in a drainage basin. These factors include topography, soil type, bedrock type, climate, and vegetation cover (Pidwirny 2006). The number, size, and shape of the drainage basins found in an area vary with the scale of examination. Drainage basins are arbitrarily defined on the basis of the topographic information available on a map. Thus, a drainage basin is an area of land where water from rain or snow melt drains downhill into a body of water, such as a river, lake, wetland or ocean. The drainage basin includes both streams and rivers that convey water as well as the land surface from which water drains into those channels. Geomorphic surfaces in the Deduru Oya, Kelani, Kalu, and Walawe River Basins in Sri Lanka have been identified, with emphasis on absolute altitude, slope, gradient, and other characteristics. The drainage density and drainage pattern on each geomorphic surface depend on the geology, structure, and characteristics of the terrain as well as the prevailing climate (Katupotha 1991). Katupotha (1991) identified seven geomorphic terrains in the above river basins of Sri Lanka as follows:

(i) Flat terrain (Lowland I, <30 m),
(ii) Flat to Slightly Undulating Terrain (Lowland II, <30 m),
(iii) Undulating terrain (Lowland III, 30–150 m),
(iv) Rolling and Hilly Terrain (Upland I, 150–460 m),
(v) Dissected rolling and hilly terrain (Upland II, 460–930 m),
(vi) Steeply dissected Rolling and Hilly Terrain (915–1830 m), and
(vii) Mountainous terrain (1830 m or more).

These geomorphic surfaces of river basins can be compared with the concept of planning surfaces (Katupotha 2013). Planation surfaces are large-scale land surfaces that are almost flat, with the possible exception of some residual hills. The processes that form planation surfaces are collectively labeled "planation" and are exogenic (surface-related). Common examples include pediments, pediplains, etchplains, and peneplains. Planation surfaces often represent unconformities (past breaks in sedimentation, often accompanied by widespread erosion) that have been buried and subsequently exposed (or exhumed) owing to uplift and renewed erosion. Hard rocks such as basement rocks, volcanic rocks, and lithified sedimentary rocks. Nearly flat surfaces with a rectilinear to slightly concave profile. They can have undulations with wavelengths ranging from tens of kilometers to thousands of kilometers. Marine abrasion can contribute to the planation of rock surfaces. Fluvial erosion can lead to the formation of planation surfaces. Glacial erosion can also contribute to the formation of planation surfaces. Gently undulating, almost featureless plains formed by prolonged fluvial erosion. Plains where the bedrock has been subject to considerable "etching" or subsurface weathering. Broad, relatively flat rock surfaces formed by the joining of several pediments are often found in arid or semiarid climates. Planation surfaces can be used to understand the history of erosion and paleo-uplifting in an area, and they can also be used to identify potential resources with paleo-river systems.

According to the watershed and river basin definition, the number 103 demarcated by Arumugam (1969) can be summarized as follows by Katupotha and Gamage (2020):

1. Six water bodies are located in back-barrier coastal areas	06
2. There are 64 rivers / Oya flowing to coastal lagoons	64
3. Twenty-nine rivers directly flow into the sea	29
4. Four empty into wetlands or salt marshes,	04
Total	**103**

The above data indicate that 29 rivers (Katupotha and Gamage 2020) flow directly to the Indian Ocean, and their estuaries are categorized as drowned river valleys, bar-built perennials, bar-built seasonal estuaries, perennial delta estuaries, and seasonal delta estuaries.

Physical background and water resources

There are three sources of water. a) Groundwater: underground water exists between the pores and gaps of rocks and dirt. It is commonly found in aquifers. Seepage from surface water is a natural source of groundwater. It is the primary source of public water supply since it is less expensive and less polluting than surface water. b) Surface water: Surface water includes bodies of water such as lakes, rivers, ponds, and Stearns. Rainfall is the natural supply of surface water. It is the primary source of fresh water in the area. c) Rainwater: Rainwater can be collected from rooftops and other surfaces and utilized. It can be used by reusing water that has been saved on roofs and surfaces. It is a very small water source. The tropical island of Sri Lanka can be divided into three geographic zones corresponding to elevation: the central highlands, the lowland plains, and the coastal belt. The central mountainous mass somewhat south of the center includes numerous mountains, plateaus, and valleys surrounded by broad plains.

The annual average rainfall varies. 900 mm to 5,000 mm. The precipitation regime in Sri Lanka is divided into three different zones: the wet zone, the intermediate zone, and the dry zone. The wet zone, which is located in the southwest, receives a mean annual rainfall of over 2,500 mm, with a strong contribution from the southwest monsoon. The dry zones, which are located in southern and northwestern China, receive less than 1,750 mm. The intermediate zones found in the eastern and central regions receive between 1,750 mm and 2,500 mm, primarily from the northeast monsoon.

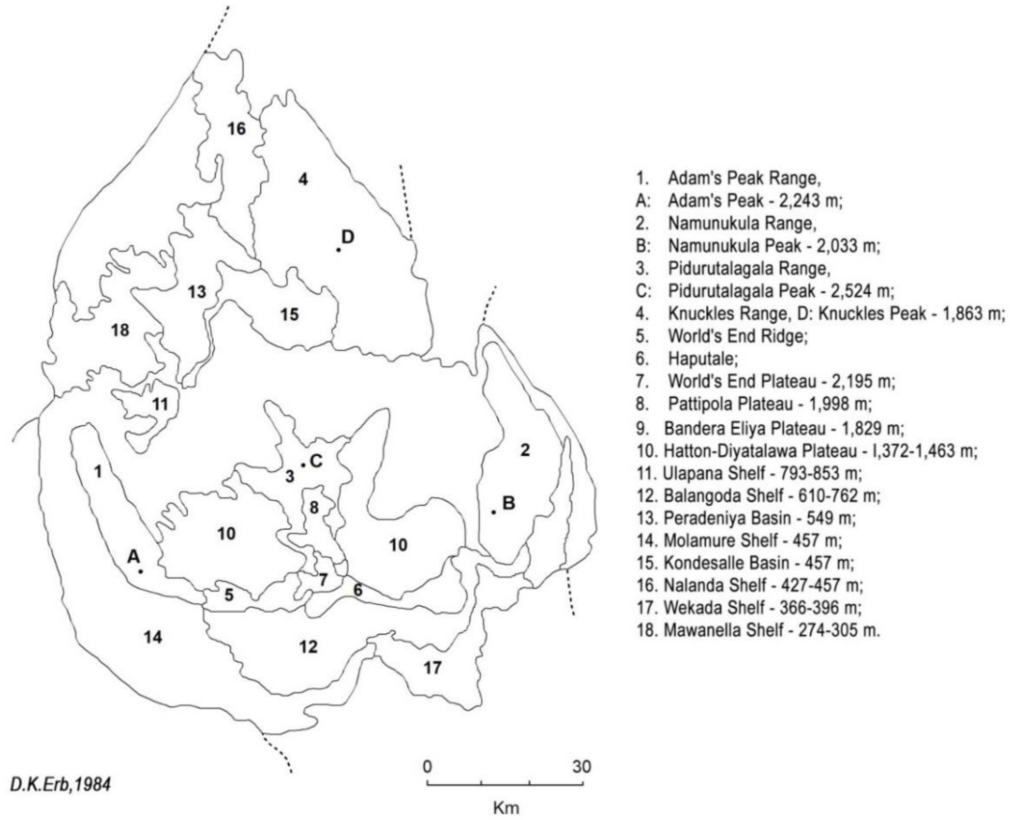

Figure 2: The central mountainous mass somewhat south of the center, including numerous mountains, plateaus, and valleys surrounded by broad plains (Katupotha and Gamage, 2020)

The southwest slopes of the central hills are known to reach as high as 5,000 mm annually, and annual rainfall can vary by more than 1,000–2,000 mm over distances of less than 100 km. All the regions receive steady rainfall during the intermonsoon season. Inland water bodies of 2,905 sq. km cover surface water. In total, 94 river basins are included (Katupotha and Gamage 2020). Among these 94 river basins, 09 rivers flow from the Central Highland (Figure 5). These are six major aquifer types; shallow karstic aquifers and coastal sand aquifers are related to groundwater in Sri Lanka. The geomorphic perspectives of these aquifers are described in detail by Panabokke (2007) and Dharmasena (2024).

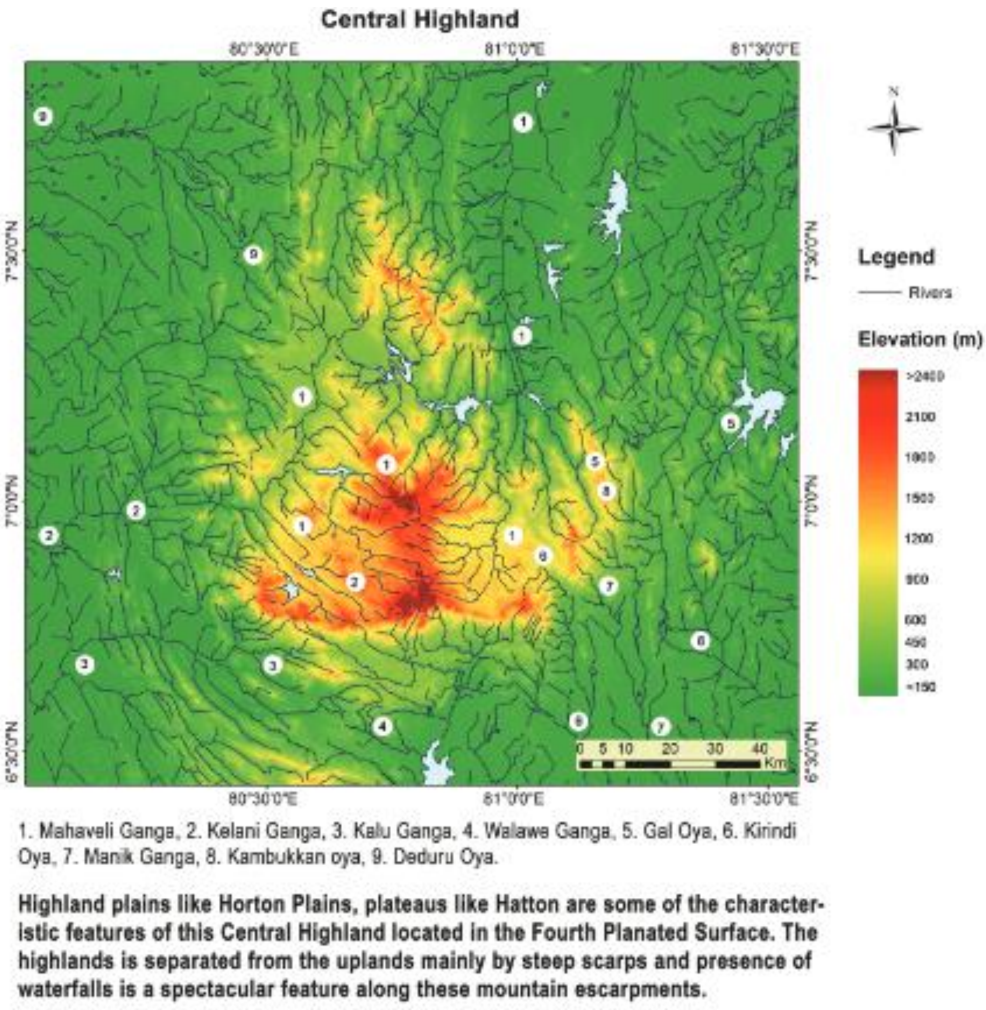

Figure 3: Morphological features of the central highlands (Katupotha and Gamage, 2020)

These aquifers are (1). Shallow karstic aquifer of the Jaffna Peninsula, (2). Deep Confined Aquifers, (3). Coastal Sand Aquifers, (4). Alluvial Aquifers, (5). Shallow Regolith Aquifer of the Hard Rock Region, and (6). South Western Lateritic (Cabook) aquifer. All these water resources in Sri Lanka are interconnected into two main agricultural seasons: The Maha season triggered by the northeast monsoon (September–March) and the Yala season activated with the onset of the southwest monsoon (May–August).

Flow regulation

Flow regulation is the alteration of the natural flow regime via the construction of dams or diversions (Ellen Wohl 2018, 2021). Environmental flow describes the stream flow (quantity and regime) required to sustain upstream and downstream habitats, riparian vegetation, human livelihoods and wildlife. When natural rivers or tributaries are held back by weirs, anicuts, barrages or dams, for a variety of purposes, such as diversion for irrigation, hydropower generation or flood control, the downstream flow requirement is often ignored or neglected (Silva et al. 2014). The ancient hydraulic civilization in Sri Lanka collapsed around the twelfth century AD, and the reasons that led to the collapse remain vague. Water flow regulation in ancient Sri Lanka was used mainly for water management, especially for food production; domestic needs (for settlement, drinking purposes, bathing, recreation, etc.); rainwater harvesting; the existence of fauna and flora; the use of administrative boundaries; landscaping and ancient city planning; and the mitigation of natural disasters. Attempts have been made to compromise the collapse in relation to several factors, such as Tamil invasions and the subsequent loss of hydraulic experts, impairment of soil fertility, epidemics and famine. Nevertheless, the cleverness of water engineering in ancient Ceylonese gradually disappeared with the shifting of kingdoms from the dry zone to the wet zone. Portuguese and Dutch (1505--1795) constructed canal networks for flood protection and navigation confined only to urban areas in Colombo and the western and northwestern coasts. Today, most of them have deteriorated into grimy waterways. Hydrologic changes resulting from the construction of the Old Dutch Canal gradually transformed Muthurajawela, once very fertile rice fields, into a saline marsh. During the early period of British rule (1815--1857), the maintenance of ancient irrigation works was much neglected. Nevertheless, many ancient irrigation systems were restored or new systems were constructed following the establishment of the Irrigation Department in the early 1900s under British rule. The British also built Liyangasthota uncut or regulatory weirs on the Walawe River, Budulu Oya anicut on the Badulu Oya, Bowatenna anicut on Amaban Ganga and several irrigation systems in the southern province, such as the Kirama Oya and Urubokka Oya irrigation schemes, which comprised several diversions and anicuts.

Since Sri Lanka was independent in 1948, Sri Lanka has accomplished several major hydropower and multipurpose reservoir schemes by damming and diversifying upland rivers, creating new reservoirs and augmenting existing reservoirs. Major developments in the Kelani River resulted in two hydropower reservoirs, namely, Castlereagh and Maussakelle, in the upper watershed. Senanayake Samudra, the largest surface water body in the country (7,760 ha), was created in 1951 by damming the Gal Oya at Inginiyagala. The Chandrika Wewa Reservoir and Udawalawa Reservoir were built on the Walawe River from 1963--1968 by damming Hulanda Oya and the mainstream of the Walawe River, respectively. The upstream region of the Walawe River was arrested by a hydro dam, creating the Samanalawewa. The construction of the Lunugamvehera Reservoir on Kirindi Oya, upstream of the existing ancient reservoirs, was completed in 1986 to transfer water via the ancient Badagiriya tank for downstream irrigation. The Mau Ara Reservoir was constructed by interlinking Malala Oya and Mau Ara, a left bank tributary of the Walawe River, in 2003. The most recent water resource developments in the country were the completion of the Handapanagala and Weheragala reservoirs in the Kirindi Oya basin of the southern province in 2009. The Rambaken Oya Reservoir, a multipurpose reservoir (56 MCM) constructed in Maha Oya Divisional Secretariat Division on the MundeniAru Basin, was commissioned in July 2013, whereas the Deduru Oya Reservoir (2000 ha) on Deduru Oya at Thunmodera, approximately 15 km away from Wariyapola, was commissioned in November 2014. The Moragahakanda and Kalu Ganga multipurpose projects were completed at Amban Ganga at the beginning of 2018. In addition, several river water development projects are ongoing in Sri Lanka at different stages of progress (e.g., the Yan Oya, Uma Oya Diversion Project, and Broadband Hydropower Project on the Kelani River), some of which are major multipurpose and transbasin schemes. Like Uma Oya, the branch of the upper Mahaweli diverted to southern Sri Lanka through a tunnel, which is also a multipurpose and transbasin scheme. In all these projects, trunk streams of the river are arrested by massive concrete dams, sometimes with additional saddle dams.

Among the 29 rivers in Sri Lanka that directly discharge into the Indian Ocean, only three major rivers (<1000 sq km), namely, Kumbukkan Oya and Maha Oya, have not been regulated or diverted to date. However, 204 river kilometers of the total river length of fifteen regulated rivers (2077 km) have been inundated into reservoir ecosystems, whereas another 254 river kilometers are either completely dead or badly degraded to a greater extent because of the nonrelease of environmental flows below the dams. Only the Walawe River below the dam of the Samanalawewa Reservoir is fortunate to have downstream flow due to natural leakage. Only flood water, spilled water or return flows flow along the main river channels, which are subjected to flow regulation of the mainstreams. In addition, many medium and large reservoirs are fed by the lateral tributaries of major rivers. The headwater tributaries of major rivers (viz., the Mahaweli, Kelani, Kalu, and Walawe rivers; Kirindi Oya; and Maha Oya, which drain the Central Highland in Sri Lanka) have been regulated by small weirs to generate less than 10 MW of electricity installed capacity as mini hydropower projects. There are approximately 200 mini hydropower projects in the Central Highland with installed capacities over 300 MW, of which more than 64 mini hydro schemes are located in the upper Mahaweli River basin. Almost all potential headwater streams of the Kelani, Kalu and Walawe rivers have already been tapped for small hydropower generation. Certain sites of Maha Oya and Kirindi Oya have also been exploited for small hydropower generation. Silva et al. (2016) reported that approximately one kilometer of stream length will be dried off below a weir, which has an installed capacity of one megawatt of electricity if the environmental flow is not properly maintained. In addition, the ultimate extinction of several freshwater fishes endemic to Sri Lanka, whose habitats are essentially hill streams, is unavoidable. River systems are excellent natural resources that provide a variety of goods and services.

Classification of the river outlets of Sri Lanka

The total landscape of Sri Lanka is divided into 94 drainage basins (Katupotha and Gamage 2020). Arumugam (1969) mentioned that 103 river basins, followed by Manchanayake and Madduma Bandara (1999), the National Atlas (2007) and many others, all misunderstood the concept of the river basin. They confuse some lagoons and short streams, such as river basins. Six small coastal lagoon basins in the Wet Zone of the island that possess their own local watershed, namely, Bolgoda Lake, Madu Ganga, Madampa Lake, Telwatta - Hikkaduwa Ganga, Ratgama Lake and Koggala Lake, are not distinct lagoon basins (Silva et al., 2013); they are back barrier lagoons with their own small watersheds formed during the mid-Holocene sea level fluctuations. Some of these lagoons have substantial tidal inlets with or without sand barriers, which formed during mid-Holocene sea level rise. Beira Lake is also a coastal lagoon that has been converted into a freshwater body by human interventions, mainly due to the modification of the hydrological network for flood control and navigation by Portuguese and Dutch colonizers (Silva 2017; Katupotha, 2003). The remaining drainage basins or true rivers discharge into the Indian Ocean only during the rainy season since they are not connected to saturated groundwater aquifers. Only the Sinimodara Oya basin, which lies in the intermediate and dry zones of the Hambantota district, is fed by groundwater springs and maintains perennial flow throughout the year.

Of the 94 river basins demarcated in Sri Lanka’s landscape, only 29 rivers emptied directly into the Indian Ocean, forming prominent estuaries or direct land–ocean interfaces (Figure 2.1 and Table 2.1). Interestingly, approximately sixty-four rivers directly enter lagoons or other sources. For example, Katupila Ara (River Basin No 27), which drains a small area in Yala National Park in the southern dry zone, empties into the shore parallel channel of Menik Ganga, whereas the Mahasilwa Oya basin (Basin No 24), which is also confined to Yala National Park, is closer to Menik Ganga and discharges into a water hole. Basin No. 66, marked as Pulakutti Aru in the river basin map (Arumugam, 1969; Manchanayake and

Madduma Bandara 1999; National Atlas, 2007), is apparently the tightest channel of Yan Oya. Accordingly, the true river basin number in Sri Lanka was corrected to 93. An approximately 32 km long coastal stretch from Pooneryn to Mantai, where there are no lagoons, receives freshwater from six shorter seasonal rivers, which are confined to the western segment of the northern dry zone.

Five types of estuaries

Estuaries can be classified by their formation and water circulation, leading to types such as coastal plain, bar-built, tectonic, and fjord estuaries, as well as vertically mixed, partially mixed, and highly stratified estuaries. The estuarine characteristics of the twenty-nine rivers discharging into the Indian Ocean that form estuaries in Sri Lanka differ from their estuarine characteristics, such as the form and shape of the marine entrance, discharge patterns, geomorphology of the river mouth, intertidal zones, etc. Sand bars develop at the marine entrance due to marine and fluvial sediment transport and accretion resulting from wave actions and tidal and river fluxes. The Kelani River, which drains the wet zone of Sri Lanka, has no prominent sand bar development at the marine entrance. The marine entrance is relatively deep, and sediment transport and littoral drift have been reduced because of the construction of Colombo Harbor. This type of estuary is called a drown river valley estuary. Sand bars develop river water flow through as a result of high river discharge, keeping the marine entrance open throughout the year. These estuaries are called bar-built or barrier-built perennial estuaries. If river mouths open seasonally and coincide with basin rainfall, they are bar-built or barrier-built seasonal estuaries. There are river mouths without sand bars. For coasts with low wave energy, fine sediment is deposited on riverbanks within intertidal areas, forming river deltas. There are two types of delta estuaries depending on the discharge volume and flow pattern (seasonal or perennial). Accordingly, five distinct estuaries are present in Sri Lanka, as outlined below.

a) Drown River Valley Estuaries
b) Bar-built Perennial Estuaries
c) Bar-built Seasonal Estuaries
d) Bar-built Perennial Delta Estuaries
e) Nonbarrier Delta Estuaries with Seasonal Rivers

Table 1. Types of classified river estuaries distributed in Sri Lanka

TYPE	RIVER ESTUARY Length of river in km	Stating & Ending Points
Type 1: Drown River Valley Estuary (DR)	1.1 Kelani River (145 kim)	-Colombo
Type 2: Bar-built Perennial Estuaries	2.1 Kalu Ganga (129 km) 2.2 Bentota Ganga 2.3 Gin Ganga (113 km) 2.4 Polwatta Ganga 2.5 Nilwala Ganga 2.6 Sinimodara Oya 2.7 Kirama Oya 2.8 Walawe Ganga *(138 km)* 2.9 Deduru Oya *(142 km)* 2.10 Maha Oya *(134 km)*	-Kalutara Kabaragala Mt.-Gintota Namunukula-Bundala Belihul Oya-Ambalatota Gommuna Mt.-Chilaw Rakshawa Mt.-Kochchikade
Type 3: Bar-built Seasonal Estuaries	3.1 Kirindi Oya *(116 km)* 3.2 Menik Ganga *(114 km)* 3.3 Kumbukkan *(Oya(116* km) 3.4 Heda Oya 3.5 Gal Oya *(108 km)* 3.6 Kal Aru 3.7 Modaragam Aru 3.8 Karambalan Oya	 Namunukula-Yala Hawa Eliya Mt.- Oluwil
Type 4: Bar-built Perennial Delta Estuaries	4.1 Mahaweli River *(335 km)* 4.2 Yan Oya *(142 km)* 4.3 Malwattu Oya *(164 km)* 4.4 Kala Oya *(148 km)*	Horton-Trikomalee Ritigala-Pulmoddai Inamaluwa Mt.-Vankalai Omaragolla Mt.-Gangewadiya
Type 5: Nonbarrier Delta Estuaries with Seasonal Rivers	5.1 Mandekal Aru 5.2 Pullavarayankaddu Aru 5.3 Pali Aru 5.4 Chippi Aru 5.5 Parangi Aru 5.6 Nay Aru	

a) Drown River valley estuaries

These estuaries are formed as sea levels rise and flood the lower reaches of river valleys, creating a semienclosed body of water where freshwater from the river mixes with saltwater from the ocean. The topography of these estuaries often retains the characteristics of the original river valley, with a wide, shallow area where the river meets the sea.

Among the 29 rivers, only the Kelani River empties into the Indian Ocean through a drown river valley estuary (Tables 1 and 2). The Kelani River, which drains 2278 sq km in the wet zone, experiences an average rainfall of 3802 mm/y and discharges 5579 MCM, approximately 65% of the annual rainfall volume, which is the highest percentage discharge volume in the Indian Ocean, from Sri Lankan watersheds. Several factors, such as Panadura Canyon, Colombo Fort City and Colombo Harbor and sea morphology (bathymetry), the location of submerged rock outcrops and the direction of submerged reefs, and the hills and ridges around Fort, Kotahena and Mutwal, have averted the development of the sand bar at the Kelani River marine entrance (Swan, 1983; Katupotha, 1988; Madduma Bandara, 1989; Cooray and Katupotha, 1991; Katupotha, 2003). However, the amount, gradient, and direction of littoral drift determined the shoreline characteristics between the Colombo headland and the Kelani River entrance as well as toward the north, where long uninterrupted beaches have formed, e.g., the development of Crow Island and associated sandy patches on the left bank and the development of the barrier ridge from Lansiyawatta, Hendala, and Palliaywatta to Pitipana on the right bank before colonial times. After colonial times, during the Dutch, Portuguese and British periods, the sand bar formations were completely averted due to the gradual development of Colombo Harbor and the encroachment of lands for the expansion of commercial and residential activities. These activities are also responsible for the deepening of the Kelani River marine entrance, and the sediment is not transported to trap the river for sand bar formation.

b) Bar-built Perennial Estuaries

Bar-built perennial estuaries are shallow estuaries formed by sediment bars or barriers across their mouths, trapping freshwater from rivers, and are widespread, particularly around the UK coast. The salient characteristics of bar-built estuaries are typically shallow, with the bar/barrier limiting tidal action within the estuary. They are common around coastlines, particularly in areas with significant sediment supplies and relatively stable sea levels. Over time, the bar/barrier can even lead to the formation of a lagoon, a body of water separated from the sea by a narrow strip of land.

In addition, of the twenty-eight rivers, a majority drain the wet zone and enter the Indian Ocean through bar-built or barrier-built estuaries, albeit ten rivers have perennial flows irrespective of their basin size (Tables 2.1 and 2.2). The watersheds of the perennial rivers are either confined to the wet zone or their headwaters are located in the wet zone except for Sinimodara Oya. Although the watershed of Sinimodara Oya lies between intermediate dry zones in the Hambantota District, it is the source, in addition to the rainwater being the groundwater springs located off Beliatta in Uda Ambala village. Among the ten bar-built perennial rivers, Kalu Ganga has the highest annual discharge volume of 4032 MCM, and only the Bentota Ganga, Gin Ganga, Nilwala Ganga, Walawe River and Deduru Oya discharge more than 1000 MCM into the Indian Ocean (Table 2.1). The formation of sand bars and their dynamic nature in these rivers vary from one river to another. Oceanic processes, fluvial fluxes and human interventions play vital roles in sand bar formation.

c) Bar-built Seasonal Estuaries

Bar-built seasonal estuaries are shallow lagoons or bays protected from the ocean by sandbars or barrier islands, forming an intermittent connection to the sea, and are common in tropical and subtropical locations. The connection to the ocean can be intermittent, with sandbars or barrier islands periodically closing off the estuary, leading to a "still-water" condition, and then opening again due to seasonal factors such as tides, storms, or river discharge. Bar-built estuaries support a diverse range of habitats, including backwater refuges and brackish water environments, and are home to unique plant and animal communities adapted to these dynamic conditions.

In the case of bar-built seasonal estuaries, sand bars may disappear completely or partially during the rainy season, particularly during the northeast monsoon season, because of high river discharge; otherwise, a part of the sand bar will be manually removed by local residents as a flood control measure. There are eight rivers in this category, of which Gal Oya has the highest watershed area and discharge volume (Tables 2.1 and 2.2). Nevertheless, some of these rivers have been subjected to massive flow regulations (e.g., Kirindi Oya, Menik Ganga, Gal Oya). Kumbukkan Oya, Kal Aru and Modaragam Aru can be considered rivers subjected to the least amount of regulation or minimum human interventions. The Karambalan Oyawhich drain the northwestern intermediate zone (Figure 2.2) was arrested by a salinity barrage in 1902 to feed the Thinipitiya Irrigation Tank.

d) Barrier-built Perennial Delta Estuaries

Perennial estuaries are those that maintain a consistent connection to the ocean, even during dry periods, unlike seasonal estuaries, which only connect during the rainy season. They are characterized by rivers with year-round flows. Four fascinating barrier-built delta estuaries in Sri Lanka, namely, the Mahaweli River, Yan Oya, Aruvi Aru (Malwattu Oya) and Kala Oya, have perennial flows, although the Malwattu Oya and Yan Oya basins lie exclusively in the dry zone (Figure 2.2). The Malwattu Oya River has the second largest watershed and receives additional water transferred from the Mahaweli River. Similarly, Yan Oya and Kala Oya were also augmented by Mahaweli River water during the first phase of Mahaweli River diversion. No information is available on whether these rivers experienced perennial flows before augmentation. The Mahaweli River, the largest and longest river basin in the country, empties into the Indian Ocean at Trincomalee Bay on the east coast through multiple channel delta entrances. Delta channels meander through the mangrove forest before emptying into Koddiyar Bay. There are three major marine entrances around Trincomalee Bay with distinct sand barriers. In addition, a braided river channel of the Mahaweli River called Verugal Aru discharges into the ocean several kilometers south of Trincomalee Bay. Yan Oya also empties into the eastern segment of the northern coast several kilometers north of Trincomalee Bay. It has a fascinating meandering delta with a lush green mangrove forest, but it enters the sea through a single channel, showing the convergent nature of delta channels.

e) Nonbarrier Delta Estuaries with Seasonal Rivers

From Poonaryn to Manwathu Oya estuary in an approximately 120 km coastal zone, it is possible to recognize a number of nonbarrier delta estuaries with seasonal rivers (Katupotha and Sachith 2024). The names of these rivers are shown in Table 1. All tidal creeks, mud flats, and estuaries create many subhabitats, e.g., sea grass meadows, beach mangrove strips, mangrove forests, intertidal mud flats, and salt marsh pockets. Seagrass meadows are underwater ecosystems formed by seagrasses. Seagrasses are marine (saltwater) plants found in shallow coastal waters and brackish waters in front of estuaries. Additionally, tidal creeks or tidal channels are narrow inlets or estuaries that are affected by the ebb and flow of ocean tides. Thus, it has variable salinity and electrical conductivity throughout the tidal cycle and flushes salts from inland soils. This has a significant effect on the study area. Beach mangrove forests are unique habitats in the study area, especially from Chippi Aru to Nay Aru in the intertidal zone. All the locations are close to most of the associated ecosystems, such as coral reefs and patches, seagrass beds, and cultural sites, e.g., St. Jamaes church, Thriketheeswaram Kovil and other temples (Katupotha and Sachith 2024).

Table 2. Twenty-nine rivers in Sri Lanka that directly discharge into the Indian Ocean

Basin No	River/Oya /Aru	Watershed (sq km)	Rainfall (mm)	RF Volume (MCM)	Discharge (MCM)	Discharge % RFV	Estuary Type
1	KelaniRiver^{W}	2278	3802	8660	5579	64.4	DR
3	KaluGanga^{W}	2720	4155	11302	4032	42.4	BB
4	BentotaGanga^{W}	629	3423	2153	1247	57.9	BB
9	GinGanga^{W}	932	3310	3085	2179	70.6	BB
11	PolwattaGanga^{W}	236	2784	657	299	45.5	BB
12	Nilwala Ganga ^{W}	971	2957	2871	1379	48	BB
13	SinimodearaOya^{ID}	39	1897	74	22	29.7	BB
14	KiramaOya^{WI}	225	1960	441	130	29.5	BB
18	WalaweRiver^{WID}	2471	1852	4577	350	7.6	BB
22	KirindiOya^{D}	1178	1506	1774	428	24.1	BB
26	MenikOya^{WD}	1287	1630	2098	484	23.1	BB
31	KumbukkanOya^{D}	1233	1572	1938	428	22.1	BB
36	HedaOya^{D}	611	1753	1071	394	36.8	BB
44	GalOya^{ID}	1873	1943	3640	1079	29.6	BB
60	MahaweliRiver^{WID}	10448	1946	20101	4009	19.9	BD
67	YanOya^{D}	1538	1610	2476	482	19.5	BD
84	MandekalOya^{D}	300	1347	404	78	18.6	DL
85	Pallavarayankaddu Aru^{D}	61	3541	216	40	18.5	DL
86	PaliAru^{D}	456	1344	613	113	18.4	DL
87	ChippiAru^{D}	67	1328	89	16	18	DL
88	ParangiAru^{D}	842	1395	1175	225	19.1	DL
89	NayAru^{D}	567	1268	719	123	17.1	DL
90	AruviAru^{D}	3284	1393	4032	192	4.4	BD
91	KalAru^{D}	212	953	202	25	12.4	BB
92	ModergamAru^{D}	943	1166	1100	169	15.5	BB
93	KalaOya^{D}	2805	1417	3974	855	21.5	DL
99	DedurunOya^{WID}	2647	1734	4589	1129	24.6	BB
100	KarambalanOya^{I}	596	1721	1026	225	24.9	BB
102	MahaOya^{WI}	1528	2760	4218	1485	35.2	BB

Basin numbers are based on Arumugama (1969). (W = wet; I = intermediate; D = dry)

No river enters the Indian Ocean directly from Pulmoddai to Pooneryn across the Jaffna Peninsula, as the coast is sheltered by several shore parallel lagoons, such as Kokkilai, Nanthikadal, Thondamannaru Chundi kulam and Jaffna.

CONCLUSIONS

In general, Sri Lanka's landmass spans a long period from Point Pedro Point (from north to south, approximately 438 km) and is approximately 227 km wide from Colombo to Sangaman Kanda Point. The country's central hills are located to the south. This order and the physiographic shifts are not compatible with the radial drainage pattern. Accordingly, the 29 described rivers also have different height levels, as mentioned by Katupotha and Gamage (2020). However, 29 perennial and seasonal rivers have formed different estuary shapes. They have different values for agriculture, settlements, fisheries, recreation, ecotourism and the variety/diversity of fauna and flora.

The rivers and estuaries of Sri Lanka play fundamental roles in the nation's hydrological, ecological, and socioeconomic systems. These water bodies support biodiversity, agriculture, hydropower, and human settlements. However, human interventions, including dam construction, irrigation projects, and urban expansion, have significantly altered natural river flow patterns, affecting both ecosystem health and water availability.

This study highlights the need for a more accurate interpretation of river basins, correcting the long-standing misclassification of 103 basins when only 94 exist. Additionally, only 29 rivers directly empty into the ocean, forming distinct estuary types. Understanding these distinctions is crucial for water resource management, conservation efforts, and sustainable development planning. Future research should focus on monitoring the long-term impacts of human interventions on river systems, assessing the effectiveness of conservation measures, and exploring innovative water management solutions. Policies should prioritize the balance of developmental needs with environmental sustainability, ensuring that Sri Lanka’s river systems continue to support both natural ecosystems and human societies for generations to come.

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