Fluctuations in turbidity in response to rainfall and land use associated with river basins experiencing elevated flood levels

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Abstract: *Five river basins (Gin, Kalu, Kelani, Kala Oya, Mundeni Aru) were selected to study the contribution of rainfall, land use and flood occurrence to turbidity fluctuations in coastal waters associated with river basins in Sri Lanka. Shallow reefs and seagrass extent up to 10m depth were mapped. Monthly turbidity products from January 2019 to December 2021 were derived using the shallow water turbidity estimation algorithm from Allen Coral Atlas and the Google Earth Engine. Satellite based precipitation data, the occurrence of flood and land use data were used in describing the landscape and seascape interactions. Only Gin (5.071Km^2) and Mundeni Aru (0.086Km^2) had shallow reefs directly facing the river basins. When adjacent basins were considered, the shallow reef extent expanded in Gin (9.202Km^2), Kalu (5.435Km^2), and Kala Oya (0.215Km^2). The average turbidity level was 3.0FNU during the study period. The turbidity level of Gin river (2.0FNU) was significantly lower, while Mundeni river had the highest turbidity level (4.2FNU). Mundeni Aru had the highest cover of natural vegetation (54.92%) and the least was in Kelani (18.91%). The land above 500m was considered as hilly terrain, and in Mundeni Aru, 83.78% was natural vegetation, 16.02% rocky terrain and 0.11% was paddy fields. In Kelani, 51.30% was natural vegetation followed by tea 32.85%. Monthly rainfall, flood occurrence and quarterly mean turbidity had no significant relationship. Ground truthing, trend analysis and incorporation of data related to coastal sediment fluxes from the ocean over the long term are recommended in interpreting the interactions.*

Keywords: Allen Coral Atlas, River water discharge, River mouth, Turbidity

1. Introduction

Water turbidity is used to measure the degree of scattered light due to suspended particulate matters and sediment matter (SPM) in water (Flores et al., 2012). Turbidity can be measured using measures such as concentrations of total suspended solids (TSS, in milligrams per litre), Suspended-sediment concentration (SSC, in milligrams per litre), Nephelometric turbidity units (NTU) Secchi disc readings (in centimetres) and attenuation coefficient (Kd) (Garg et al., 2020). Both organic or inorganic suspended particulate matters and sediment matters contribute to high turbid water (Fabricius, 2005; Flores et al., 2012). Turbidity is one of the critical water quality index which directly affects sensitive coastal aquatic ecosystems such as coral reefs and seagrass (Bessell-Browne et al., 2017; Borum et al., 2004). Effects of turbidity on corals greatly vary depending on the growth form or coral species, environmental conditions and also on the sediment type, amount, intensity, duration and frequency of exposure to increased turbidity conditions (Fabricius, 2005). Moreover, high turbidity conditions obstruct light transmission and hinder photosynthesis in seagrass. Fine sediment particles settle on the leaves and block light absorption and oxygen production (Rigdon, 2006). The amount of light that reaches any underwater habitat is highly variable depending on the factors such as the orientation of the sun, the weather, shading, reflection, and refraction (Erftemeijer et al., 2012). Understanding the major contributing factors for the occurrence of coastal turbidity is essential to determine the alterations in these ecosystems (Soto-mardones et al., 2020).

1.1 Major contributing factors in creating turbidity conditions around coral reefs in Sri Lanka.

1.1.1 Rainfall and Flood events.

River water discharges have been identified as a significant contributing factor for near shore coastal water turbidity. These river water runoffs can cause large plumes of turbidity around its river mouth areas, especially at the times of high rainfall and occurrence of flood events (Kotsovinos et al., 2009; Pereira et al., 2020). Larger sediment particles deposit within a few kilometres of the river mouth, while fine-grain sediment particles create plumes of turbidity transporting over longer distances (Fabricius, 2005). Data says that at least 25% of corals worldwide are affected by river water runoff and flooding (Butler et al., 2013). Flood water brings high turbid water with loads of sediments and suspended particulate matter which can cause large plumes of turbidity around the river mouth area (Orpin and Ridd, 2012).

Turbidity associated with the river discharges varies with many factors like rainfall, the extent of the river basin and land use, ready and constant supply of mud, energetic water motions, trade winds, anthropogenic activities, wind events, waves suspensions and duration of the flood and rainfall (Orpin & Ridd, 2012). High sedimentation and turbidity due to flooding can cause physiological stress, reduced photosynthesis, physical damage and many more impacts on coastal communities. Studies have revealed that the turbidity levels associated with Flood rivers are long term persistent and the elevated turbidity levels in river mouth areas are always correlated with the periods of high river discharges and high rainfall irrespective of the wave height, wave period and tidal range. The turbid plumes created by flood deposits may disappear over sedimentation but turbidity conditions rise again with the resuspension due to mild waves and mild currents even in dry periods. This will create a long-term impact on coastal ecosystems (Fabricius, De, et al., 2013).

Climate change scenarios project an increase in extreme weather events such as frequent flooding, high intensity for extreme rainfall, and sea-level rise. The predictions have stated by 2070 1 m sea-level rise will destroy the sand bars found in the river inlets like Kalu and Gin rivers in Sri Lanka. And also, the sea level rise has impacted to increase the flood level and risk of floods in coastal areas (Nianthi & Shaw, 2015). The climate models have predicted that almost all the Asian countries are expected to experience an increase in the frequency of extreme river flows which will lead to extreme flood events (WB and ADB, 2020). According to the 2019 INFORM risk index, Sri Lanka occupies the 56th rank out of 191 countries resembling moderate exposure to flooding, including riverine and flash flooding (WB and ADB, 2020).

1.1.2 Anthropogenic activities/ Land usage

Land-use activities and dredging are the anthropogenic sources of turbidity in the coastal zone (Zweifler et al., 2021). The heavy concentration of industries, increasing population, coastal erosion, land usage-based water pollution and other anthropogenic activities lead to the collection of higher sediment matters in the coastal zone. Especially human-altered lands in higher elevations with steep slopes accelerate soil erosion adding loads of sediment inputs to water. The flow across elevated lands and steep slopes is at high speed with great power. If there is low vegetation cover, it causes a high quantity of soil particles to wash off with water (Siswanto & Sule, 2019).

Areas of vegetation clearing, fertilizer application, and large land cultivation near the river areas are highly erosive which collect loads of sediments with inorganic and organic nutrients and other chemical contaminants during rainy periods. This way sediment coming from expanded agricultural land areas lead to excessive sedimentation and turbidity around coastal communities with a minimum potential for recovery (Carlson et al., 2019)**.** Forested land covers benefit the coastal zone due to the absorption of rainfall water, stabilizing soils and preventing the collection of sediment loads with terrestrial runoff, absorption and fixing of soil nutrients and mineralizing heavy metals in soils without washing off. Factors such as plant species, type of plants, plant density, the direction of plants, spacing, and height of the plants determine how far the vegetation cover can prevent soil erosion (Siswanto & Sule, 2019). Moreover, mangrove areas which are associated with the coastal ecosystems act as sediment filters and protect them from harmful impacts of sedimentation and turbidity (Carlson et al., 2019).

1.1.3 Ocean currents and weather conditions

Sediments that reached the beach area are continuously moved by waves. The movement of the sediment matters depends on the strength of the current and the degree of agitation of the bottom sediments. Tides, wind and wave actions generate the nearshore currents contributing to the agitation of bottom sediments and turbidity conditions (Dayananda, 1992).

Sri Lanka experiences two monsoon seasons the northeast monsoon and the southwest monsoon. The southwest monsoon season usually occurs from June to October and the northeast monsoon season occurs from December to April (De Vos et al., 2014). When considering the coastal Zone of Sri Lanka, the west coast line is covered by the Indian peninsula while the rest is uncovered and directly open and connect to the Ocean. Hence, the coastline around Sri Lanka has a direct chance of getting disturbed by the ocean Currents. The most importantly the strong monsoon climate and sea level fluctuations directly results in bringing sediments to the coastal zone allowing the process of coastal sedimentation. Moreover, the East Indian coastal currents and the circulations generated in the Bay of Bengal directly impact the sediment load around the coastal belt in Sri Lanka (Adikaram et al., 2018). Coastline erosion is also a significant contributing factor in creating turbidity conditions in coastal waters. The coastline erosion of the southwestern coastline of Sri Lanka can be observed during the southwestern monsoon period and it gets recovered during the northeastern monsoon period (Lakmali et al., 2017). This way the wind, wave and rainfall patterns depending on the monsoon season are responsible for fluctuations of turbidity in coastal waters.

1.1.4 Other major Contributing factors

Long term climate events similar to El Nino Southern Oscillation influence in keeping turbidity conditions in coastal waters up to months (Seers & Shears, 2015). Erodibility, rainfall erosivity of soil and slope of the catchment area which brings runoff water to the coastal waters also matters in causing high sediment concentration to coastal waters (Wickramasinghe & Premalal, 2015). Moreover, the presence of high organic matter content and higher riverine nutrient load lead to the triggering of high phytoplankton biomass causing turbidity in coastal waters (Seers & Shears, 2015).

1.2 Remote sensing in evaluating water turbidity

In situ measurements of water quality parameters like turbidity, chlorophyll content, temperature and salinity over a large scale are labour intensive, time-consuming and expensive. Therefore, remote sensing is more applicable in identifying and monitoring water quality parameters on large scale. Spatial and temporal variations of the water quality parameters can be investigated effectively and efficiently using remote sensing. Remote sensing data is easy to access over a large geographical area at a low cost for efficient analysis of water quality (Gholizadeh et al., 2016).

Suspended sediment matters create turbidity conditions in the water. These sediment matters which obstruct the optical properties of water are known as colour-producing agents. The presence of these colour producing agents can be clearly identified using aerial and spatial satellite images. Moreover, the spectral response of the suspended sediment matters and water are different making them easy to differentiate and detect using remote sensing. Visible regions of the spectrum, red and NIR regions are more sensitive to detecting turbidity in water (Lillesand et al., 2015). There are instances where field measurements or in situ measurements of turbidity are not very much accurate because of the placement of the turbidity sensor below the scattering materials or there may be several other materials such as phytoplankton, algae blooms and dissolved organic molecules where its scattering properties are not sufficient to detect by the turbidity sensors. Therefore, satellite images are more suitable for detecting and measuring water turbidity (Orpin & Ridd, 2012). The silt and sediment loads from river discharges can spread to many kilometres away from the river mouths with the wave actions and longshore currents creating plumes of turbidity. These large plumes of turbidity created around the river mouth areas can be easily monitored using remote sensing data (Fabricius, De, et al., 2013). Turbidity concentration of water temporally differs with the variations in weather, climate patterns, and human activities along the river banks. Based on these factors, there may be high turbidity periods even if there are no experiencing flood events near river mouth areas. This temporal variation of turbid conditions can be detected easily using remote sensing data (Orpin & Ridd, 2012).

The signatures left by extreme flood events to shallow water ecosystems can be used to predict how such ecosystems may fare in future. At the same time, relating land use and land cover in related basin landscapes to seascape may provide indicators that can be used for future monitoring. Hence, this study is focused on identifying the contribution of extreme rainfall events, flood events and land use activities in the elevated catchment areas for the fluctuating turbidity levels around the selected river mouth areas where there are sensitive coastal ecosystems of coral reefs and seagrass. The objective of the study therefore was to test the efficacy of remote sensing driven data in explaining the variability of turbidity in selected coastal areas with varying levels of forest cover and rainfall in respective river basins.

2. Methodology

Gin River Basin, Kala Oya Basin, Kelani River Basin, Kalu River Basin and Mundeni Aru Basin were selected as the study area (Figure 1).

Frequency of flood events from the year 2014 to 2021 in the river basins were considered using the data available on the official site of DesInventar (DesConsultar - Charts / Query Module). The benthic habitat maps in Allen Coral Atlas (ACA) were used for the observation of shallow reef areas and seagrass beds in the coastal zone of Sri Lanka. The extracted data from ACA were used in analyzing the extent of shallow reef area and the seagrass beds in the study region. The area of shallow reefs within the 2 km buffer zone and the area of seagrass within buffer zone of 8km associated to river basins were taken into consideration in order to include all the observed areas in the satellite imagery. Moreover, National Spatial Data Infrastructure Sri Lanka (SL NSDI) Geoportal and the maps developed by the irrigation department were used to identify the river basins and in building assumptions for the study area selection (Table 1) (NSDI Geo Portal).

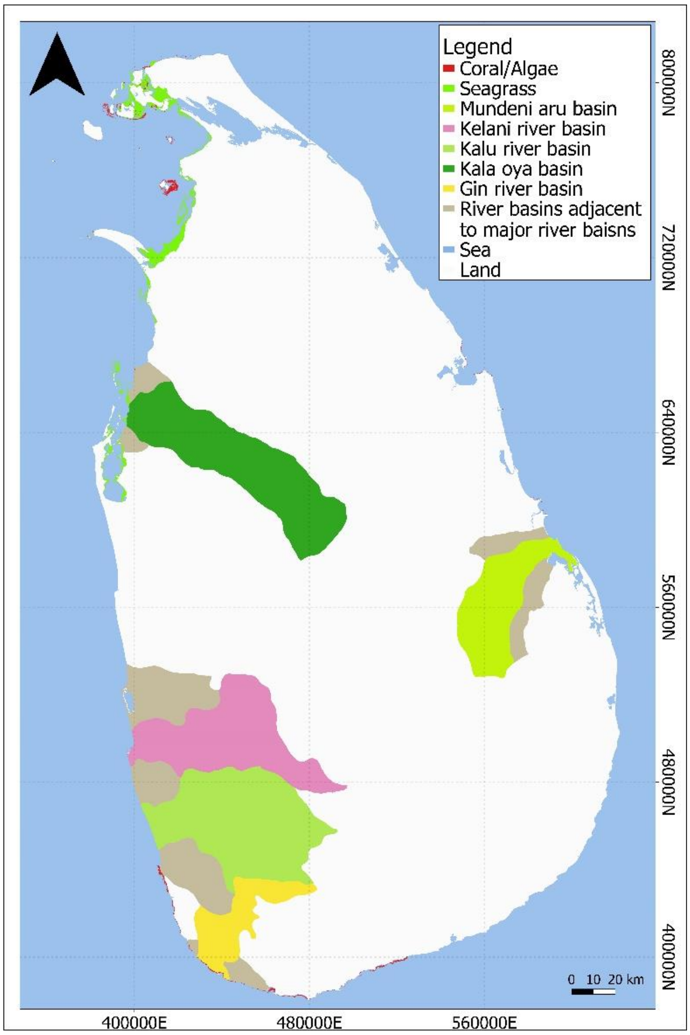


Figure 1: Selected river basins around Sri Lanka

Table 1: Selection of river basins as the study area based on assumptions/hypothesis

Selection of river basins			
Frequently flooded districts	**River Basin Name**	**Presence of shallow reef areas nearby (According Satellite imagery data)**	**Assumptions/Hypothesis**
Galle	Gin river	Yes	There is a higher chance of creating turbidity conditions around shallow reef areas at the river mouth and the adjacent reef areas.
Puttalam & Kurunegala	Kala Oya	No	The river basin can bring a considerable quantity of river water discharges to the coastal zone as most parts of the river basin have experienced frequent flood events. Therefore there is a greater potential for creating large plumes of turbidity. The effects of longshore currents in monsoon seasons can spread the plumes impacting shallow reefs located far away.
Kaluthara	Kalu river	No	The extent of the river basin is large. The vast array of anthropogenic activities in the river basin can create higher sediment loads with river water runoff. Although the river mouth does not open to a shallow reef area, there is a greater chance of creating large plumes of turbidity extending even to the shallow reef areas located far away from longshore currents.
Colombo	Kelani river	No	
Batticaloa	Mundani Aru	Yes	The river basin includes the districts that experience frequent flood events. Therefore the river discharges have the potential in creating impacts with high turbidity conditions.

Land use data that had been updated in the year 2018 using image classification and field verification were collected from the Land Use Policy Planning Department (Land Use Policy Planning Department, 2018). The land use data were extracted as categories based on different land usage activities for respective river basins. The area of several categories of land usage was calculated using QGIS to check and see the contribution of land usage to turbidity levels in respective river basins. The land usage in elevated lands was evaluated based on the assumption that the land at higher elevation levels has a greater potential to create increased turbidity levels. Each of the river basins was categorized into three classes based on the elevation of the land, an area with low elevation (100m – 300m), middle elevation (300m -500m) and high elevation (Above 500m). Digital elevation model (DEM) data were downloaded from USGS Earth Explorer to classify the River basin area based on elevation. First, the Digital Elevation Model (DEM) files of 30m resolution covering Sri Lanka were downloaded. Then DEM files for selected river basins were extracted by 'clipping raster by mask layer' in QGIS. DEM files of the river basins were reclassified to derive elevation classes using the 'r.reclass' processing tool in QGIS with GRASS. The reclassified DEM files were converted from raster to vector layers using the raster conversion tool in QGIS. Then the elevation classes were extracted separately. Extracted vector layers were clipped with land use shapefiles of the respective river basins. The percentage of land usage in elevated land was evaluated to check the contribution of sediment inputs with river water runoff.

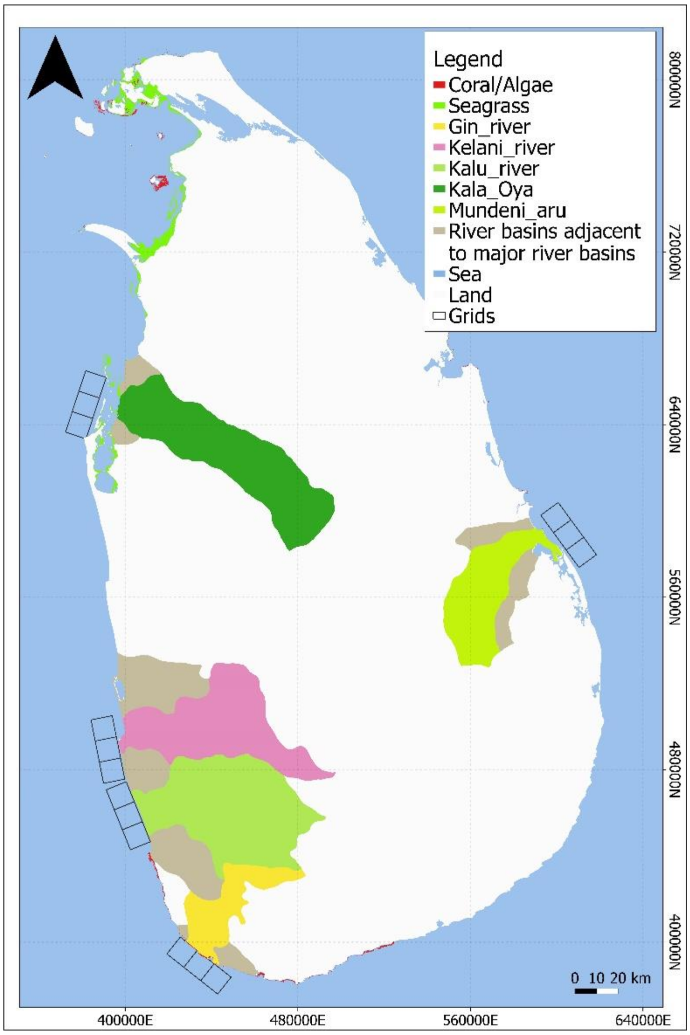


Figure 2: Grids created to calculate mean turbidity associated with river basins

Rainfall data were collected from available satellite precipitation data from the PERSIANN_Cloud classification System in Center for Hydrometeorology and Remote Sensing (CHRS) from 2014 to 2021 (CHRS, 2017). Monthly rainfall data for the river basins were downloaded as raster data from the CHRS data portal. The mean monthly rainfall in the river basin was calculated using the Zonal Statistics tool in QGIS.

Mean rainfall erosivity data for river basins which has derived based on previously collected reference dataset (Wickramasinghe & Premalal, 2015) were used.

Mean monthly turbidity base maps were extracted from the Google Earth Engine. Satellite images of Sentinel-2: MultiSpectral (MSI) Level 1 – C data were used for processing. The Shallow Water Turbidity algorithm (SWaT) used by ACA team was modified and used here to extract the monthly turbidity data (Allen Coral Atlas / Science and Methods). Three grids of size 10m x 10m were created covering the coastal zone associated with the river basins (Figure

2) (Li et al., 2022). Mean turbidity values covering the grid area (300 m^2) were calculated using the Zonal Statistics tool in QGIS.

3. Results and Discussion

Only two river basins of the selected five river basins had shallow reefs within a 2km buffer zone. Gin river and Mundeni Aru had shallow reefs of 5.071 km^2 and 0.086 km^2 respectively (Table 2). Kalu river and the Kala Oya basin had shallow reefs with the incorporation of adjacent river basins. Bentota river basin adjacent to Kalu river and Wilpattu basin adjacent to Kala oya basin had shallow reefs of 5.435 km^2 and 0.215 km^2 respectively. The influence zone of the Gin river basin extends to an area of 9.202 km^2 with the presence of shallow reefs in Koggala (3.178 km^2) and Rathgama basins (0.953 km^2) (Table 2). Only the Kala Oya basin and its two adjacent river basins had seagrass beds. The total area of seagrass beds within the buffer zone of the Kala Oya basin extends 43.998 km^2 with the incorporation of adjacent two river basins. Kala Oya had seagrass beds of 5.194 km^2 (Table 3). Seagrass beds of 21.748 km^2 and 17.056 km^2 were in the vicinity of Wilpattu and Moongil Oya basins respectively (Table 3). The map layout shows the shallow reefs and seagrass beds associated with the river basins (Figure 3 and Figure 4).

Table 2: Presence and the area of shallow reefs within 2km buffer zone of the selected river basins.

River Basin name	**Area (km^2) of shallow reefs within 2km buffer zone**	**Adjacent river Basins**	**Area (km^2) of shallow reefs within 2km buffer zone**	**Total Area of Shallow reefs (km^2)**
Gin	5.071	Rathgama lake	0.953	9.202
		Koggala lake	3.178	
Kalu	0	Bolgoda lake	0	5.435
		Bentota river	5.435	
Kala	0	Wilpattu	0.215	0.215
		Moongil Oya	0	
Kelani	0	Attanagalu oya	0	0
		Bolgoda lake	0	
Mundeni	0.086	Miyangolla Ela	0	0.086
		Magalavatavan aru	0	

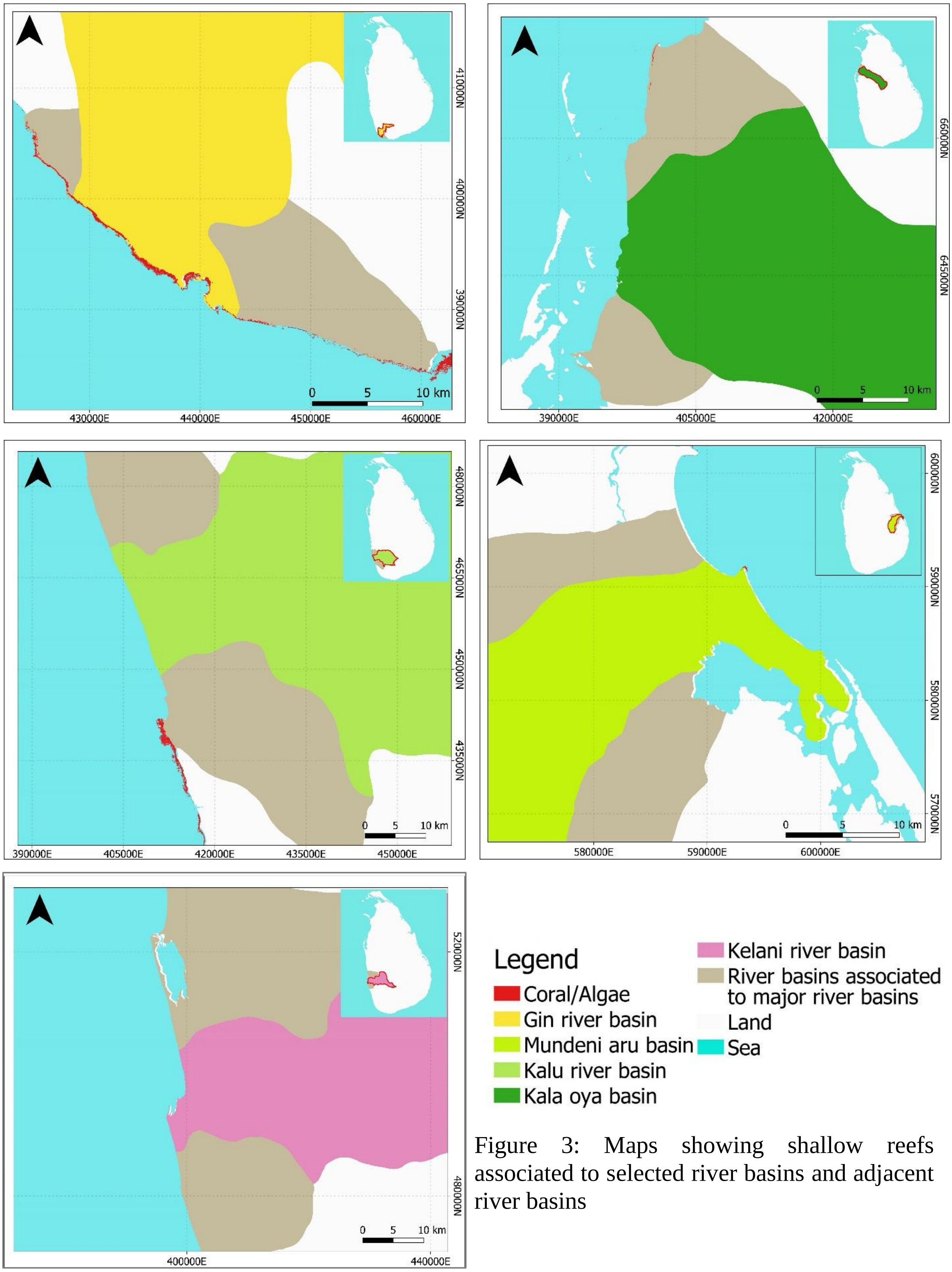


Figure 3: Maps showing shallow reefs associated to selected river basins and adjacent river basins

Table 3: Presence and the area of seagrass associated to the selected river basins.

River Basin name	Area (km^2) of Sea Grass at the vicinity of river mouth	Adjacent River basins	Area (km^2) of Sea Grass at the vicinity of adjacent river mouth	Total Area (km^2)
Gin	0	Rathgama lake	0	0
		Koggala Lake	0	
Kalu	0	Bolgoda lake	0	0
		Bentota river	0	
Kala	5.194	Wilpattu	21.748	43.998
		Moongil Oya	17.056	
Kelani	0	Attanagalu oya	0	0
		Bolgoda lake	0	
Mundeni	0	Miyangolla Ela	0	0
		Magalavatavan aru	0	

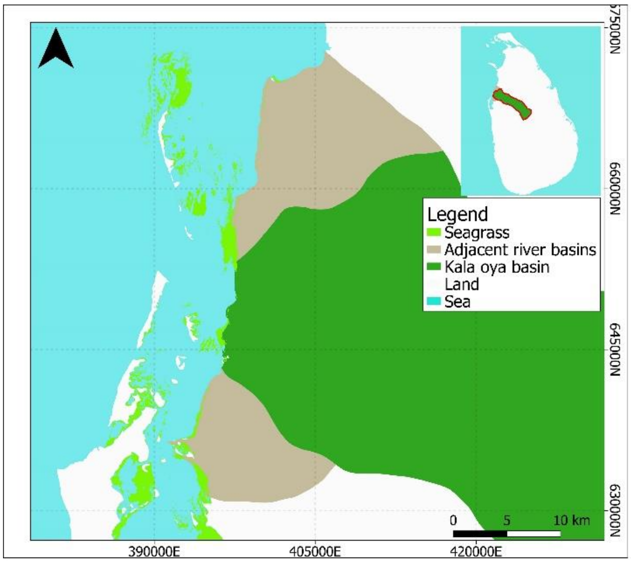


Figure 4: Map showing seagrass associated to kala oya basin and adjacent basins

The extent of seagrass and shallow reefs in the study area has been observed using remote sensing data. The remote sensing observations may not measure the actual cover of seagrass and shallow reefs in the study area. However, the remote sensing observations for the presence of shallow reefs and seagrass to a certain extent in the vicinity of river basins ensure that these ecosystems may be threatened due to turbidity fluctuations and river plumes of turbidity as also observed (El Mahrad et al., 2020; Lewis et al., 2020). Therefore, all the selected five river basins have the capacity to influence the survival of shallow reefs and seagrass beds in terms of turbidity.

Mundeni Aru basin had the highest proportion of natural vegetation (57%) and the Kelani river basin had the lowest proportion of natural vegetation (18.91%) of the selected five river basins. Agricultural land use proportions were taken into consideration by summing up the land use categories of tea, rubber, coconut, paddy, and other agricultural lands. In terms of agricultural land use, the Gin river basin had the highest proportion (49.75%) and the Mundeni Aru basin had the lowest proportion (26.72%) (Table 6).

Land usage in elevated land in the river basins impacts the accumulation of sediments (Joab et al., 2016). Therefore, land usage above 500m elevation is considered as the hilly terrain of the river basins. When considering the hilly terrain of the river basins, Mundeni Aru had the highest natural vegetation (83.78%) and the Kelani river had the highest Agricultural land use proportion (34.75%). Mundeni Aru had the lowest agricultural land use proportion (0.18%) and the Kelani river basin had the lowest natural vegetation proportion (51.30%) in the hilly terrain of the selected five river basins (Figure 5).

The highest frequency of flood occurrence could be observed in the Kelani river basin and the lowest frequency of flood occurrence has occurred in the Kala Oya basin (Figure 7).

According to the satellite precipitation data, the average monthly rainfall value in river basins shows that the Gin, Kalu and Kelani river basins have received a considerably higher average rainfall amount, while the Kala Oya basin and Mundeni Aru basin have received the lowest average rainfall amount (Figure 7).

According to the rainstorm erosivity map derived (Wickramasinghe & Premalal, 2015), Kala Oya basin has the lowest mean erosivity while Kelani river basin has the highest mean erosivity value (Table 4).

Table 4: Average rainstorm erosivity of five river basins (Wickramasinghe & Premalal, 2015)

River Basin Name	Average Erosivity (Jx1000/sq.m/year)
Gin	30.05
Kalu	33.09
Kala	14.21
Kelani	37.72
Mundeni	20.20

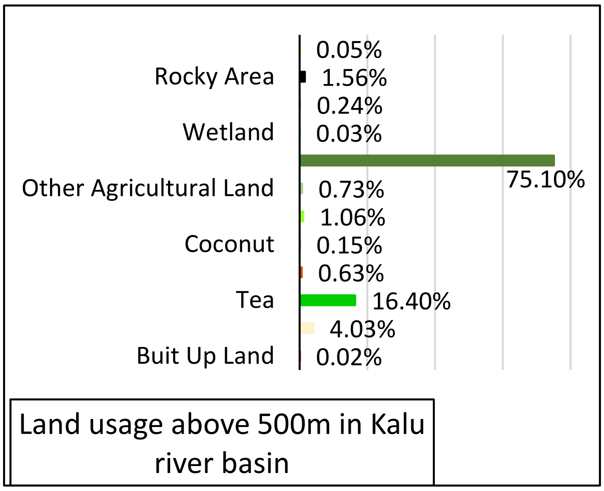
The mean turbidity level during the study period (October 2019 to June 2021) was 3.0 FNU. Gin river had the lowest turbidity level of 2.0 FNU while the Mundeni Aru had the highest turbidity level of 4.2 FNU (Table 5). The result of the ANOVA test for the mean turbidity levels of the river basins showed that the mean turbidity of the Mundeni Aru basin and the Gin river basin were significantly different from the turbidity levels of other river basins (Figure 6).

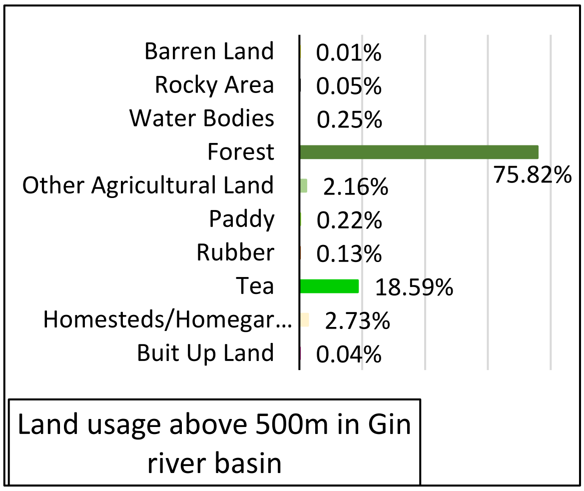
Table 5: Average turbidity levels of five river basins

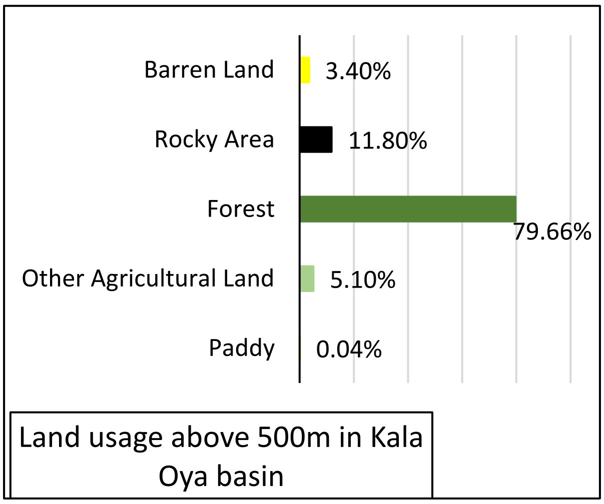
River Basin Name	Average Turbidity (FNU*10)
Gin	19.52
Kalu	26.77
Kala	34.64
Kelani	28.69
Mundeni	41.65
Average Turbidity (FNU)	30.25

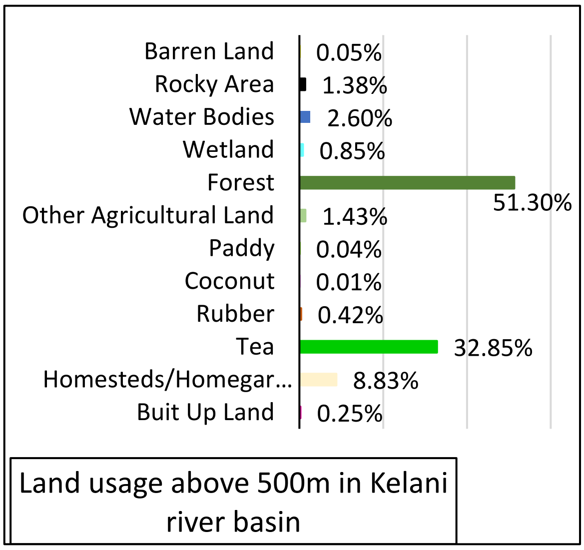
Table 6: Area and percentage of land usage in river basins (🟨 = Most prominent land use type) (🟧 = Second most prominent land use type) (Agricultural land includes subcategories of landuse types of Tea, Rubber, Coconut, Paddy, and other agricultural land)

Category	**Gin river basin**		**Kalu river basin**		**Kala Oya basin**		**Kelani river basin**		**Mundeni Aru basin**	
	Area (Sqkm)	**Percentage**	**Area (Sqkm)**	**Percentage**	**Area (Sqkm)**	**Percentage**	**Area (Sqkm)**	**Percentage**	**Area (Sqkm)**	**Percentage**
Built-Up Land	5.325	0.58%	14.27	0.51%	23.877	0.84%	86.565	3.73%	1.645	0.12%
Homesteads/ Home Garden	172.958	18.74%	599.662	21.59%	516.29	18.13%	680.496	29.31%	90.299	6.64%
Agricultural land	459.109	49.75%	1313.415	47.29%	987.635	34.69%	1014.801	43.71%	363.052	26.72%
Forest	267.433	28.98%	786.872	28.33%	1057.7	37.15%	439.016	18.91%	746.301	54.92%
Wetland	5.756	0.62%	6.025	0.22%	16.227	0.57%	26.909	1.16%	2.058	0.15%
Water Bodies	9.169	0.99%	29.707	1.07%	212.8	7.47%	42.967	1.85%	64.527	4.75%
Rocky Area	0.951	0.10%	19.169	0.69%	24.214	0.85%	19.185	0.83%	79.87	5.88%
Sandy Area	0.249	0.03%	0.162	0.01%	0.044	0.00%	0.037	0.00%	0.026	0.00%
Barren Land	1.934	0.21%	7.98	0.29%	8.264	0.29%	11.558	0.50%	11.149	0.82%
Total	922.884	**100.00%**	2777.26	**100.00%**	2847.1	**100.00%**	2321.534	**100.00%**	1358.93	**100.00%**









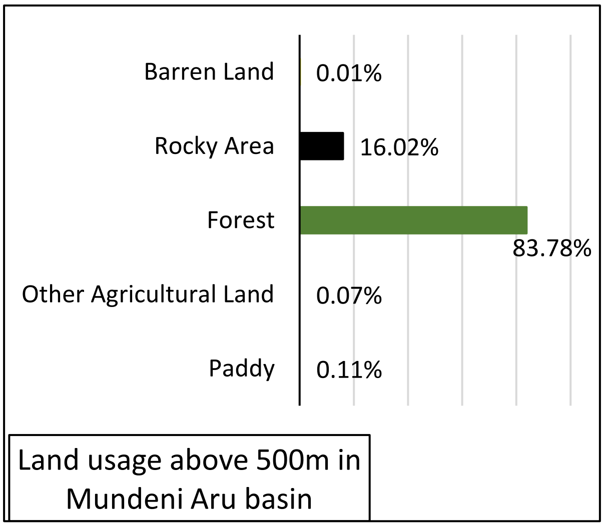


Figure 5: Proportion of land usage in higher elevation class (above 500m) of the selected river basins

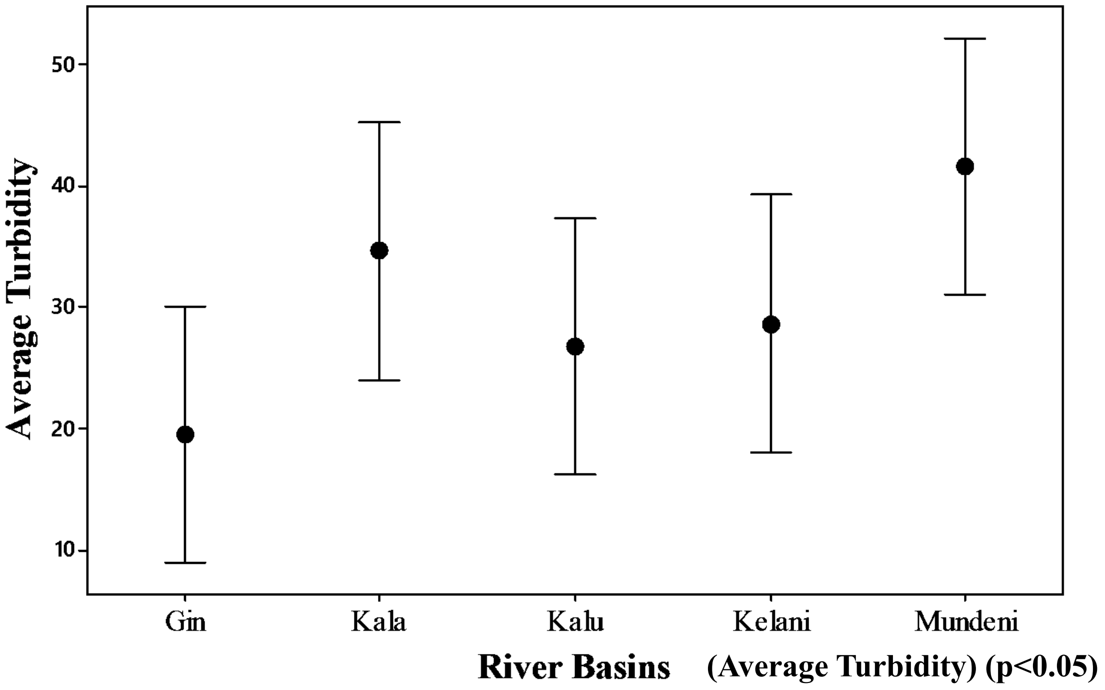
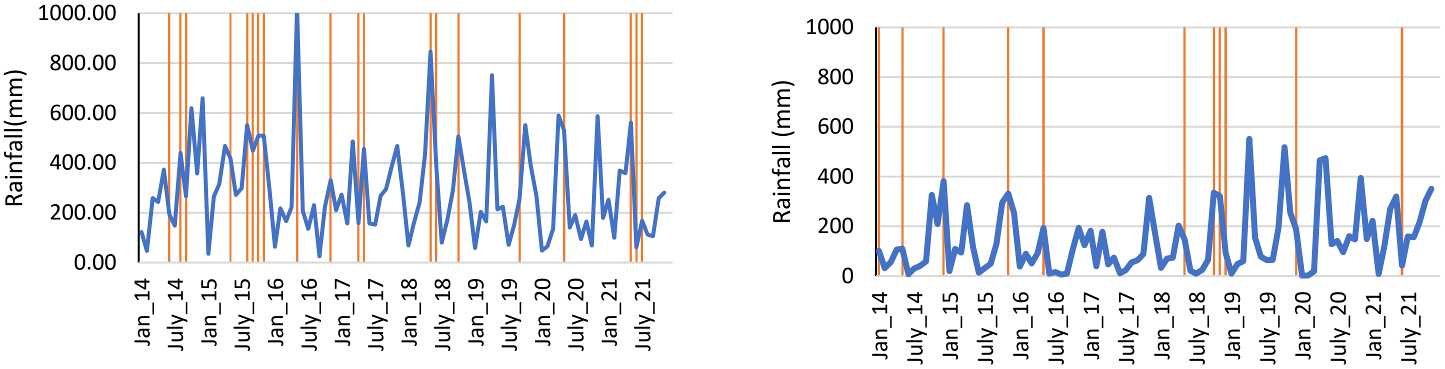


Figure 6: Interval Plot of average turbidity (FNU) levels of the five selected rivers

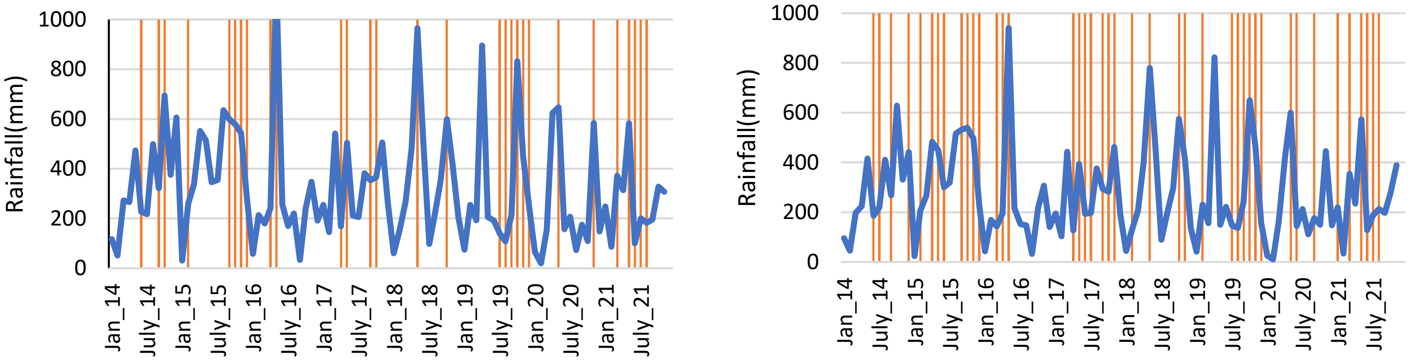
The coastal zone associated with the Mundeni river basin has the highest average turbidity level of 4.2 FNU although it has the highest natural vegetation cover and the lowest agricultural land use proportion. Similarly, the occurrence of flood events, the average rainfall amount and the mean soil erosivity data in the Mundeni Aru basin is recorded as lower values. Hence, beyond the variable measured, other factors may also influence including oceanic variables such as mixing, tidal height and tidal currents, ocean currents, horizontal advection, erodability of the seafloor, waves and wind forcing cyclones (Feng et al., 2020; Torregroza-Espinosa et al., 2020). Moreover, the longshore sediment current patterns and the sea currents generated due to the North East (NE) and South West (SW) monsoons may play a major role in creating turbidity plumes around the coastal zone of Sri Lanka. It can be assumed that the highest turbidity in the coastal area of Mundeni Aru Basin might be the result of sediments coming during NE monsoon season and with the east India coastal current flow. Furthermore, it has been found that there is a greater chance that the cyclonic activities of the Bay of Bengal bring sediments to the NE coastline of Sri Lanka (Adikaram et al., 2018; Chidambaram et al., 2018).

Contrary, Gin river basin has the lowest average turbidity level of 2.0 FNU although it has received a significant average rainfall and the occurrence of flood events are also considerably high. And also, the most prominent land use proportion is agricultural land. Perhaps the fact that the Gin river basin has a shallow continental shelf compared to Mundeni Aru as well as being away from Cauvery basin which is known to bring substantial sediments to the continental shelf of Sri Lanka could be one possible reason (Chidambaram et al., 2018).



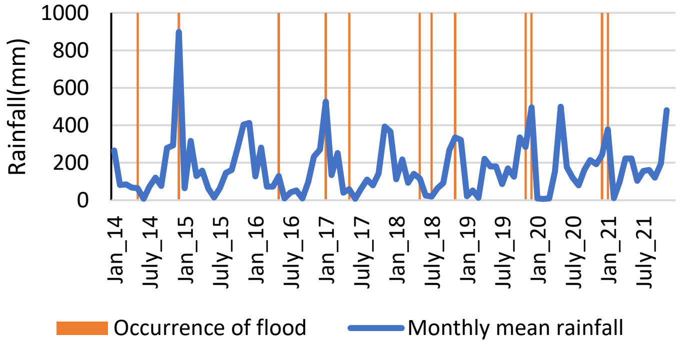
Gin river basin

Kala Oya basin



Kalu river basin

Kelani river basin



Mundeni Aru basin

Figure 7: Time Series analysis graphs showing the mean monthly rainfall and occurrence of flood events

We also found that the Kelani river basin with the highest average erosivity, highest human altered land use cover, highest average rainfall and the maximum occurrence of flood events shows a lower average turbidity value. Hence, overall results indicated that the variables we used which were mostly confined to terrestrial landscape may not properly describe the seascape turbidity fluctuations in shallow areas of Sri Lanka.

Incorporating data such as sedimentation from continental shelf, flow rate, upstream and channel changes and the shape of the river basin may improve the predictability (Dean et al., 2016). For example, Kala Oya basin consists of a connected tank system which serves as silt and sedimentation traps. However, the Kala Oya basin is directly connected to Mahaweli reservoir via Bowatenna diversion which brings sediment and suspended particulate matter from another basin (Vidanage et al., 2005). The time series analysis graphs also show that there is no significant relationship between average monthly rainfall amount, flood occurrence and mean turbidity levels. The usage of satellite precipitation data is also a limitation in finding a relationship between these three variables. PERSIANN cloud classification systems record rainfall amounts by classifying individual patches of clouds based on their characters. Although the PERSIANN cloud classification system has been validated to other regions, there may be outliers when compared with Meteorology data in Sri Lanka. Mean monthly turbidity data for a 2 year time period is also not enough to find a direct relationship among the variables. Extraction of monthly turbidity data for a longer time period (10 years) is ideal to detect a relationship. Moreover, ground truthing of data is much needed.

4. Conclusion and Recommendation

Sedimentation in ecosystems of shallow coastal regions could have detrimental effects on their status, percentage of live cover, extent and also the livelihoods of the communities. Even though the land use and land cover of the studied basins were different and some were heavily altered, those human changes failed to fully explain the turbidity fluctuations. The study recommends incorporating both terrestrial and oceanic variables that may influence turbidity for future studies. The study also highlights the need for more systematic and long term investigations into physical oceanographic variations in shallow coastal areas in the face of expected climatic changes, as they are the host to vital natural capital from the ocean.

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