Identification and Classification of Wetlands to Prioritise Considering the Importance for Flood Mitigation - Western Province, Sri Lanka

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Abstract:

Wetlands, acting as natural sponges, play a critical role in capturing rain, surface water, and floodwaters. Their services extend to both human and wildlife. In Sri Lanka, wetlands serve as vital buffers against extreme climatic events, yet urbanisation and exploitation threaten their ecosystems. Proper management remains challenging due to data limitation. This study was focused on the Western Province of Sri Lanka to map and prepare an Online Spatial Wetland Inventory, to classify the wetlands based on the Ramsar Wetland Classification and to prioritise the wetlands considering the hydrological importance on flood mitigation for conservation. The study employed QGIS and Google Earth satellite images to map wetlands. Wetland classification was based on field observations, Ramsar Classification and secondary data. A multi-criteria approach identified crucial wetlands for flood mitigation. Three main criteria were considered: flood event frequency, surface volume (storm water flow direction), and water volume (storage capacity of wetlands). Flood event data from 1989, 1992, 2006, 2010, and 2016 were analysed. Calculation of water storage capacity was done based on LiDAR point cloud data using Surface Volume Tool, available under 3D Analyst Tool in ArcGIS 10.6.1 software. The results revealed distinct wetland types within the Western Province and a comprehensive map was prepared to visualise the wetland classification. Wetlands were mainly categorised as coastal, inland, and man-made wetlands. To prioritise wetlands for flood mitigation, a map was created, highlighting three classes: highly important, moderately important and less important wetlands based on hydrological importance. The Online Spatial Wetland Inventory for the Western Province of Sri Lanka is a remarkable achievement that addresses the scarcity of spatial data. By identifying and safeguarding wetlands, thus promoting sustainable development and enhance resilience in the face of climate-related challenges.

Keywords: classification, flood, surface volume, wetland

Introduction

A wetland is a distinct ecosystem that is characterized by the presence of water, either permanently or seasonally, at or near the surface of the soil. Wetlands play important role on the landscape of tropical countries functioning as natural sponges that trap rain, surface, ground and flood waters slowly while providing numerous beneficial services for wellbeing of human and wildlife. Wetlands can be found in various forms, including marshes, swamps, bogs, and fens. They play a crucial role in the environment by providing habitat for a diverse range of plant and animal species, improving water quality through filtration, storing floodwaters, climate regulation, coastal protection and acting as carbon sinks and also wetlands are significant for biodiversity and are often considered vital for ecological health.

Figure 1: Muthurajawela wetland in Sri Lanka

Sri Lanka, with its rich biodiversity and unique ecosystems, is home to several types of wetlands. There are some of the main types of wetlands found in Sri Lanka include marshes, swamps, floodplains, coastal wetlands, mangrove, lagoons, tanks and peat lands. These wetlands are vital for maintaining ecological balance and supporting various forms of life, from aquatic species to migratory birds and plant communities.

Wetlands around the world, including those in Sri Lanka, face a variety of threats that impact their ecological health and biodiversity. There are some of the main threats to wetlands are included urbanization and development, agricultural expansion, pollution, water diversion, climate change, invasive species, overexploitation, land reclamation, tourism and recreation and soil erosion.

Addressing these threats requires a combination of conservation efforts, effective management practices, and sustainable development policies. Protecting and restoring wetlands is essential for maintaining their ecological functions and the services they provide to both nature and human communities.

Ensuring of protection and management of the wetlands have been an important part of the development process that led to achieve the sustainable development. Global inland and coastal wetlands have been highly vulnerable to anthropogenic and development pressures. Actual rate of wetland loss could not be seen due to lack of data in global level. Global Wetland Outlook 2018 of RAMSAR shows long-term decline of natural inland and marine/coastal wetlands in around the world, between 1970 and 2015, by approximately 35%, where data are available.

Effective wetland management requires a collaborative approach that involves various stakeholders, including government agencies, non-governmental organizations, local communities, and researchers, to ensure the long-term health and sustainability of these critical ecosystems.

Literature Review

Sri Lanka, an island nation with a tropical climate, is home to diverse wetland types including marshes, swamps, and floodplains. The WP, encompassing areas like Colombo and Gampaha, is particularly important due to its high population density and economic activities (Ramsar Convention, 2013). Wetlands in this region are crucial for flood mitigation, especially given the increasing frequency of extreme weather events associated with climate change (Siriwardena et al., 2019).

Wetlands are crucial ecological systems that provide a multitude of services including biodiversity support, water purification, climate regulation, and flood mitigation (Mitsch & Gosselink, 2015). In tropical regions like Sri Lanka, wetlands function as natural sponges, trapping and slowly releasing water to mitigate flood impacts and support groundwater recharge (Barbier et al., 2011). Despite their significance, wetlands face substantial threats from anthropogenic activities, such as urbanization and industrialization, which lead to habitat loss and degradation (Dugan, 1990). Studies have shown that wetland restoration and conservation can significantly diminish flood impacts in urban and rural settings (Lehner et al., 2011).

The identification of wetlands typically involves field surveys and remote sensing techniques. Field surveys provide detailed ecological data, while remote sensing using satellite imagery offers broad-scale information (Turner et al., 2015). Remote sensing methods, including Landsat and MODIS imagery, can classify wetland areas based on vegetation patterns, water extent, and land cover (Jensen, 2015).

Accurate mapping of wetlands is fundamental for effective management and conservation. Traditional mapping methods, including surveys and manual digitization, are increasingly supplemented by remote sensing technologies and GIS (Geographic Information Systems). In this study, QGIS software was utilized for digitizing wetlands, leveraging updated Google Earth imagery to create baseline data layers (Open-Source Geospatial Foundation, 2024). The integration of Lidar high-resolution imagery is planned to enhance the accuracy of wetland data (Friedrich et al., 2018).

Wetlands are classified using several systems, such as the Ramsar Classification System and the Cowardin Classification System. The Ramsar Wetland Classification provides a framework for categorising wetlands based on their origin and ecological functions. The classification includes natural inland wetlands. In WP, wetlands were classified into these categories, with 518.41 sq km representing human-made wetlands, 75.39 sq km as natural inland wetlands, and 34.91 sqkm as marine/coastal wetlands. This classification supports targeted conservation efforts by highlighting the diverse roles wetlands play in the landscape (Junk et al., 2014). The Cowardin System divides wetlands into classes based on their hydrology, vegetation, and substrate (Cowardin et al., 1979).

In Sri Lanka, wetlands like the Muthurajawela Marsh and the Bolgoda Lake have demonstrated their effectiveness in flood regulation. Muthurajawela, for example, acts as a buffer zone, absorbing floodwaters and protecting the Colombo metropolitan area (Siriwardena et al., 2019). The Bolgoda Lake has been crucial in managing flood risks in the surrounding areas, particularly during heavy monsoons (Ramsar Convention, 2013).

Sri Lanka's wetlands, integral to its ecological balance, are increasingly under threat from rapid urbanization and developmental pressures. The CEA recent findings indicate a staggering 44% loss of wetlands in the Colombo Flood Detention Area over the past six decades, primarily driven by urban expansion (CEA, 2023). The WP, being the most urbanized region, exemplifies these challenges with extensive wetland degradation impacting flood management and ecological integrity (Seneviratne et al., 2021).

Wetlands in the WP face significant threats from urbanization, pollution, and land reclamation. These pressures lead to the loss of wetland functions and exacerbate flood risks (Bishop et al., 2017). Effective management requires balancing development with conservation to ensure wetlands continue to provide their critical ecosystem services.

Climate change is altering rainfall patterns and increasing the frequency of extreme weather events. This shift impacts wetland hydrology and effectiveness in flood mitigation. Adapting wetland management strategies to account for these changes is essential for maintaining their flood-regulating functions (IPCC, 2021).

Despite the ecological significance of wetlands, their conservation in Sri Lanka has faced numerous challenges. Amarasinghe et al. (2013) points out that a lack of comprehensive wetland policies and insufficient enforcement of existing regulations have hindered effective management. The CEA (2023) highlights conflicting land-use priorities, such as the demand for agricultural and urban land, as major obstacles to wetland conservation. Additionally, inadequate data on wetland ecosystems and the absence of integrated management frameworks further complicate efforts to protect these habitats (Gunawardena et al., 2017). Addressing these challenges requires comprehensive data collection and stakeholder engagement. The study involved contributions from multiple agencies, including the Department of Wildlife Conservation and the Department of Irrigation, to ensure a holistic approach to wetland management (Department of Wildlife Conservation, 2024). Collaboration between government agencies, local communities, and NGOs is seen as essential for sustainable wetland management and restoration.

Sri Lankan policies, such as the National Wetland Conservation Policy, aim to protect and manage wetlands effectively. Integrating flood mitigation into these policies can enhance the resilience of wetland ecosystems and the communities that depend on them (Ministry of Environment, Sri Lanka, 2018).

Further research is needed to refine wetland classification systems specific to the WP's unique context. Integrating advanced remote sensing technologies with ground-truthing can enhance wetland mapping and monitoring (Gibson et al., 2016). Additionally, assessing the long-term impacts of climate change on wetland functions will help in developing adaptive management strategies (Zedler & Kercher, 2005).

Problem Statement

Recent study done by the Central Environmental Authority (CEA) shows a loss of wetlands by 44% in Colombo Flood Detention Area during past 06 decades. Further urbanization process has been identified as the major driver of degrading wetlands in this area. Centralized Urbanization process can be seen in Sri Lanka that spread from the Colombo city (Main Commercial city) of the Western Province (WP).

Thus, lots of areas of WP gradually converting into urban areas while creating a threat on vacant lands. WP Mega-Police Project is a major development project that has been established to build a well-planned urban setting instance of the unplanned urban development of the province. Therefore, many development activities have been planned to establish using occupied and unoccupied lands of the province.

The research on "Identification and Classification of Wetlands to Prioritise Considering the Importance for Flood Mitigation - WP, Sri Lanka" was initiated by CEA with the collaboration of International Water Management Institute considering the increasing threat on wetlands due to development projects and the urbanization process. Lack of detailed database including spatial information has been a major barrier for managing and protecting the wetlands to the relevant authorities.

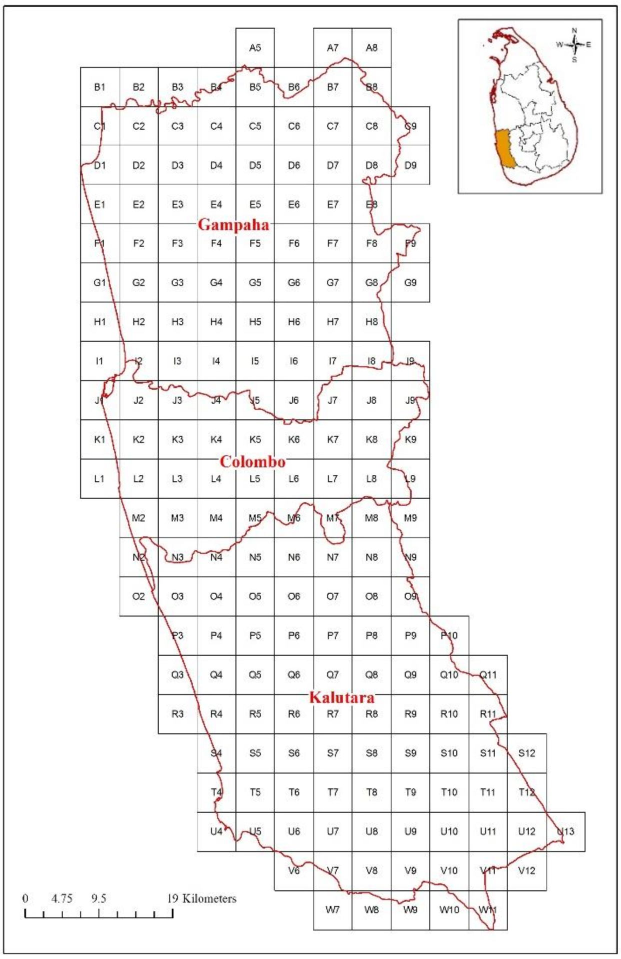
The most frequent natural hazard that effect on WP is flood. Wetlands have a key role to mitigate flood, providing a considerable storage capacity of storm water. As well as Urbanization process form the majority of land surfaces impermeable and it reduces the capability of infiltration into ground. Thus, run off is increasing while reducing the space of water retention due to Wetland degradation. This has caused to raise the frequency of flooding due to reduction of storage capacity of storm water. Thus, it is very important to identify and prioritize the hydrological importance of the wetlands to develop a better mechanism to manage them.

Objectives

- To map wetlands located in WP
- To classify the wetlands based on the Ramsar wetland classification
- To prioritize the wetlands considering the hydrological importance on flood mitigation for conservation
- To prepare an inventory for wetlands in WP

Methodology

a. Study Area



The WP (06°50′N 80°05′E) is one of the nine Provinces in Sri Lanka and the first level administrative division of the country. WP is located in the Southwest of Sri Lanka. The province is surrounded by the Indian ocean to the West, North Western Province to the North, Sabaragamuwa Province to the East and the Southern Province to the South. The WP is divided into three administrative districts, 40 Divisional Secretary's Divisions (DS Divisions) and 2,505 Grama Niladhari Divisions (GN Divisions). The study area is comprising densely urban, peri-urban and rural environments and total extent of the province is 3742sqkm. The WP is vulnerable to recurrent flooding as a result of an increase in average rainfall coupled with heavier rainfall events, with knock-on impacts on the infrastructure, utility supply, and the economy of the province.

b. Secondary data used

Before commencing the research, the secondary data was collected from different government organizations for preparation of baseline data for wetlands in the study area. Topographic maps and 1:10,000 digital data layers were collected from the Survey Department of Sri Lanka. Geo-referenced one-inch topographic maps used to verify the historical background of some wetland areas. Flood data in the years of 1989, 1992, 2006, 2010 and 2016 was obtained from Disaster Management Centre of Sri Lanka and is also collected in Grama Niladhari Divisions level that important to use in Hydrological analysis. Lidar point cloud data of the WP also obtained from the Survey Department.

First objective of the research was to map wetlands located in the WP. The QGIS software was used to mapping wetlands due to capability of obtaining current updated Google Earth satellite images as the base map. Updated Google Earth satellite images in QGIS were very useful to identify the existing boundaries of the wetlands. Spatial distribution of wetlands was extracted from 1:10,000 land use data and the extracted layer is used as a base line data layer to identify the wetland distribution and remaining wetlands were digitized using QGIS. To increase efficiency and accuracy of the digitization process study area was divided into equal size of grids using ArcGIS software. Geo-referenced one-inch topographic maps also used to verify the historical background of some wetland areas. Digitized wetlands layer was verified by field observations and collected data were used for the classification of wetlands. Field data were collected through Survey123 App, developed by using Arc GIS Online.

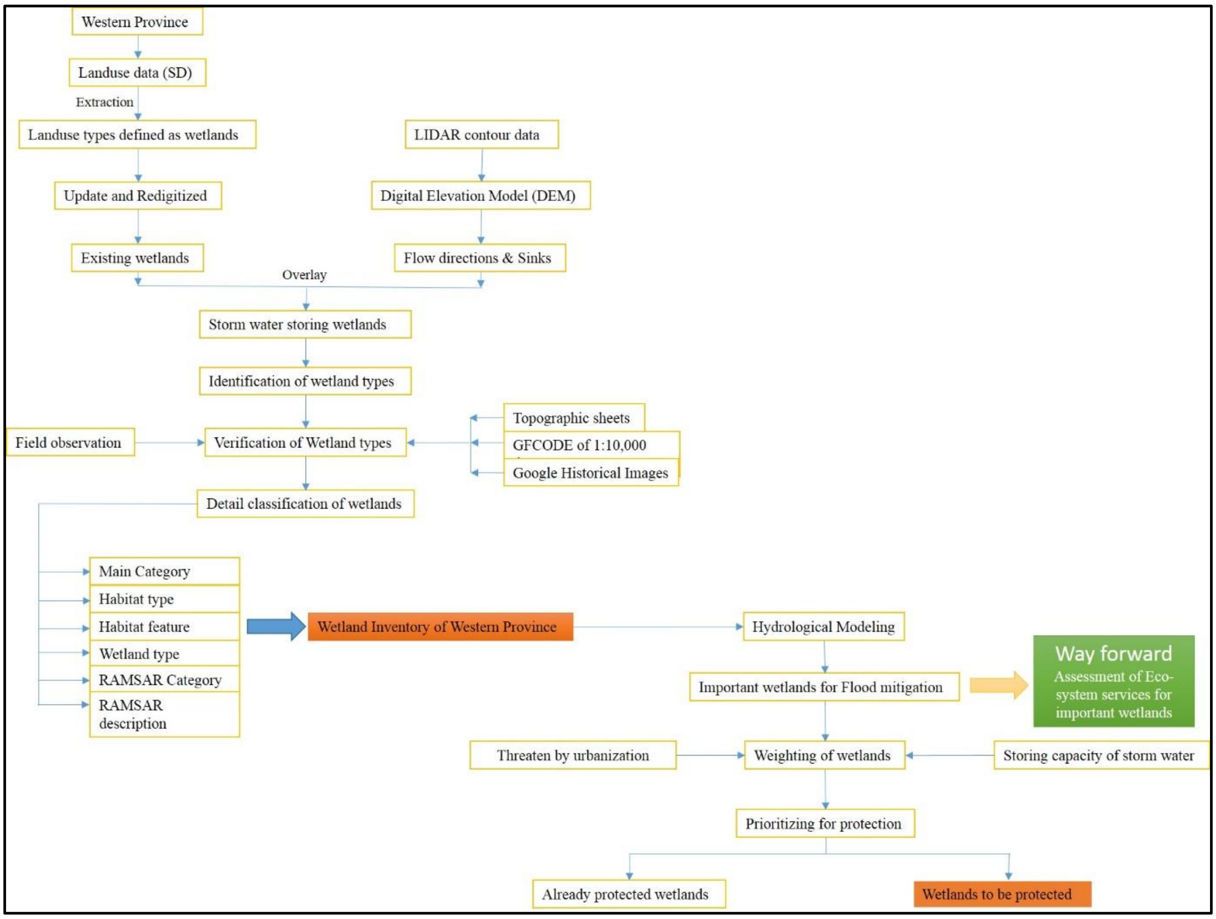


Figure 3: Flow chart of the methodology

The expert committee was appointed from the relevant stakeholder agencies to classify wetlands based on the Ramsar wetland classification system. The expert committee was composed of Department of Irrigation, Department of Agrarian Development, Coast Conservation Department, Sri Lanka Land Reclamation and Development Corporation, Urban Development Authority and Ministry of Mahaweli & Environment. The mapped wetlands were classified using QGIS software together with information extracted by image interpretation and habitat characteristics which were identified by field observations.

Prioritizing of wetlands was done using three criteria which important to identify the hydrological importance for flood mitigation. Number of flood events had been appeared in the area, flow direction of storm water and surface water volume that shows the water storage capacity of wetlands.

The Grama Niladhari Divisions that had affected due to flood events in the years of 1989, 1992, 2006, 2010 and 2016 have been identified from Disaster Management Centre of Sri Lanka and those flood data was fed in to Grama Niladhari Divisions layer of WP. Spatial join tool of Arc GIS software was used to join the flood information with digitized wetland layer. According to that flood affected wetlands were identified and it was used as a major criterion to identify the hydro logically important wetlands for flood mitigation.

Water storage areas in WP was identified using LiDAR point cloud data. Arc GIS 10.6.1 software used for this analysis and Digital Elevation Model was created using LiDAR data to analyze the flow direction of the study area. Flow accumulation tool in Arc GIS software were used to get final water storage areas where illustrate the storage areas of storm water.

Final criteria for prioritizing wetlands were calculate surface water volume. It was needed to calculate the submerged water volume for each wetland polygons mapped. In order to calculate this, Surface Volume tool available under 3D Analyst tool in ArcGIS 10.6.1 software was used. It calculated the area and volume of the region between a surface and a reference plane.

In order to run surface volume tool, it is needed to introduce reference plane for each of the wetland polygons, surface layer and specify whether area/volume needed to be calculated above or below the reference plane. Surface layer was the clipped digital elevation model and to get the highest elevated point of each polygon, performed zonal statistics tool. Since there are more than 10,000 wetland polygons therefore, ArcGIS model was created to iteratively run through each polygon. Finally output tabular tables were merged using the Excel and its attribute joined with the original wetland shape file. Hydrology analytical tools were applied for this activity and it was done by the International Water Management Institute (IWMI).

As it discussed earlier, three main criteria were used to identify the hydrological importance of the wetlands on flood mitigation and prioritize them for future management. Multi criteria analysis was used for the prioritizing of mapped wetlands with above mentioned criteria. In the first step two criteria (wetlands in flood affecting Grama Niladhari Divisions and wetlands in water storage areas) were applied with weighted overlay analytical tool and identified the important wetlands for flood mitigation. This was helped to identify the wetlands in flood vulnerable areas and their role on storing storm water. Secondly, third criterion (storage capacity /surface volume) was applied to prioritize the important wetlands that identified in first step. Finally, weighted overlay tool of Arc GIS 10.6.1 software was used for this analysis.

Results and Discussion

According to the results, total land extent of wetlands in WP is 63330.10 ha. The wetland types found within the WP can be broadly categorised in to three major types based on the Ramsar wetland classification such as coastal, inland and man-made wetlands. Mangrove and lagoon have been considered as the coastal wetlands under this study. River, stream, marshy land and freshwater swamp forest are the main categories found under inland wetlands.The large number of man-made wetlands are found in the WP such as aquaculture ponds, ponds, irrigated lands, water storage areas, excavation pits, wastewater treatment areas, drainage channels, irrigation canals and fishery harbor etc. (Figure 4).

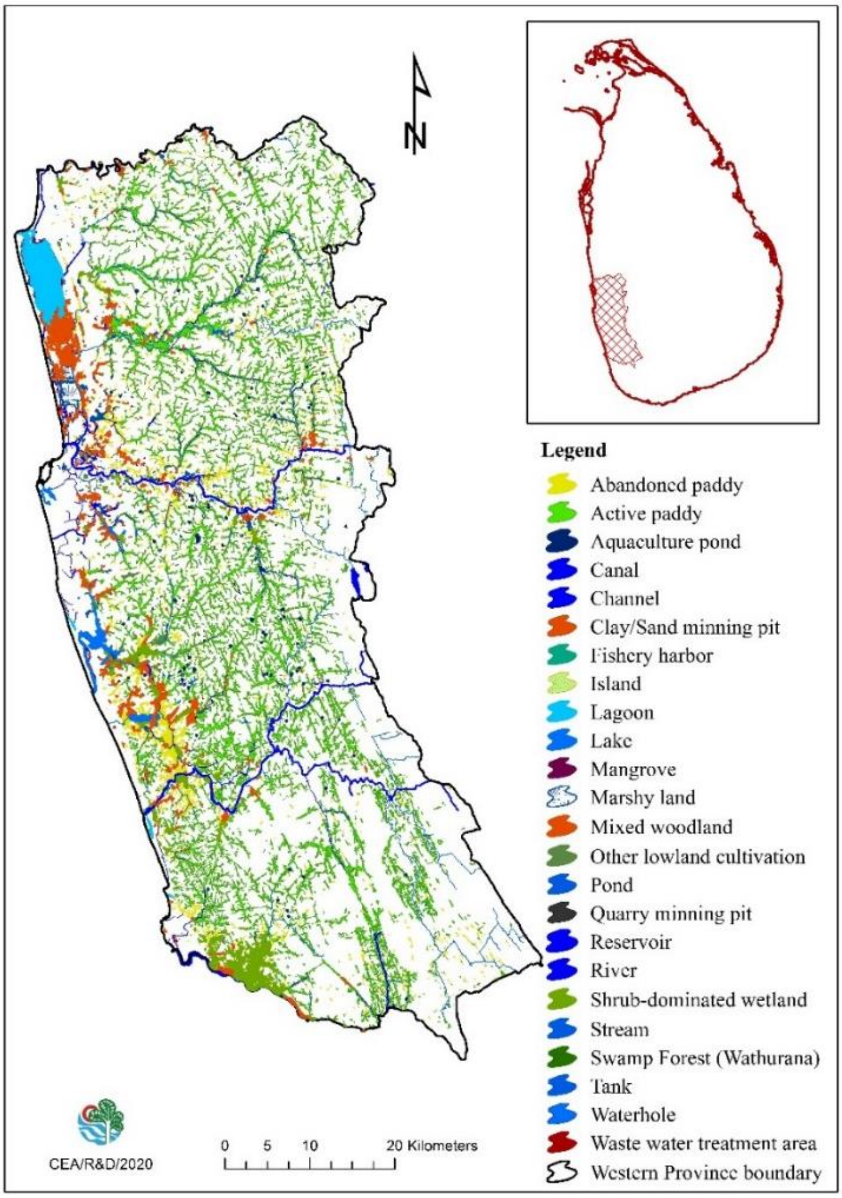


Figure 4: Distribution of wetlands in WP of Sri Lanka

Digitized wetland layer was verified by field observations and collected data were very useful for the classification of wetlands according to the Ramsar wetland classification. Totally 789 locations were randomly selected (Figure 5) from identified wetlands for field verification, and GPS location data and relevant information were collected. As an easy and efficient way of data collection during field observation, a Survey123 App was developed using Arc GIS Online.

This app was very useful for collecting geo tag photographs relevant to observed wetlands. Wetland type, habitat type, habitat feature, invasive plants and photographs are the main information that collected by field observations.

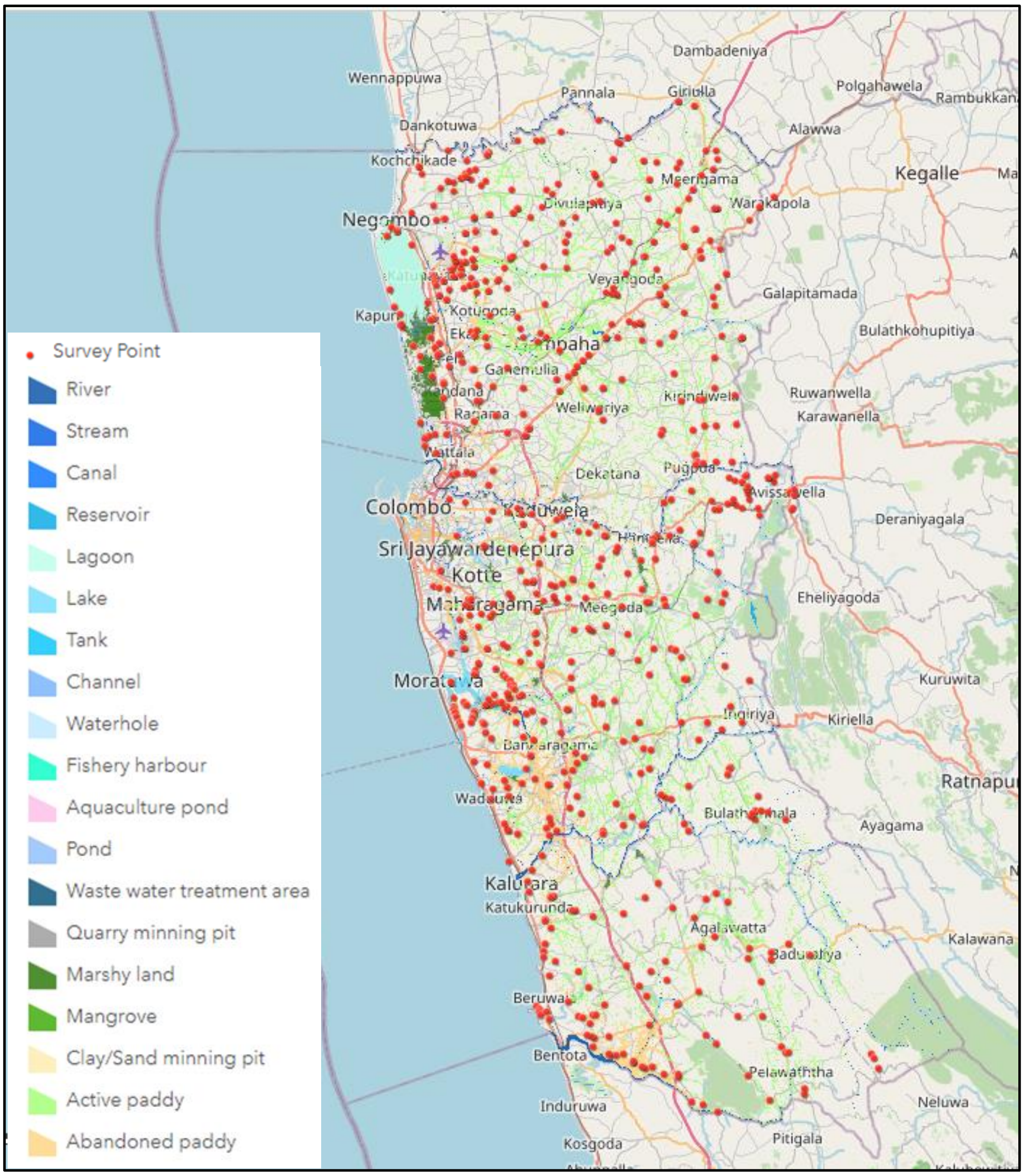


Figure 5: Locations of GPS points visited for field verification

In addition to the Ramsar categorizations the tree dominated, and herb dominated wetlands can be further categorized based on the vegetation structure and composition. Therefore, all together six main vegetation types were identified within and in association with the wetlands in the WP.

These vegetation types are included,

1. Herb dominated low herbs vegetation

2. Herb dominated tall herbs vegetation
3. Mixed woodland
4. Shrub land
5. Mangrove woodland
6. Freshwater swamp forest

The open water habitat was further sub-divided into standing open water bodies, such as lakes, ponds (farm ponds, aquaculture ponds), tanks, reservoirs and wastewater treatment areas, and flowing open water bodies, such as rivers, streams, canals (drainage, irrigated) and channels. The standing water bodies are found scattered throughout the study area. They vary in size from large lakes (such as the Beira Lake, Bolgoda Lake and Talangama tank) to small ponds less than 8 ha in extent. Flowing open water bodies are the 9 main rivers and 40 main streams and interconnected tributaries which made hydrological network of the study area. Following are the main wetland types consider in this study.

Basically, three major categories were considered based on the origin and location of the wetlands as natural inland wetlands, human-made wetlands and marine/coastal wetlands. The extent of 518.41sqkm of total wetland representing human-made wetlands while 75.39sqkm extent representing natural inland wetland. According to the analysis marine/coastal wetland extent is 34.91sqkm in WP. According to Ramsar wetland classification system this paper will discuss types of wetlands found during the research.

I. Marine/Coastal Wetlands

1. Mangrove

In this study several mangrove ecosystems found mainly in Muthurajawela, Negambo lagoon, Kerawalapitiya, Bolgoda Lake, Bolgoda Ganga and the river mouth of the Bentota Ganga areas. The Muthurajawela and Negombo lagoon wetland complex is a diverse mangrove ecosystem located in rapidly developing urban area near Economic capital of Sri Lanka. This wetland complex is an important habitat for mangroves in Sri Lanka where 16 mangrove species were recorded belongs to nine families including three Nationally Endangered mangrove species (*Bruguiera cylindrica, Sonneratia alba (Kirala), Xylocarpus granatum (Mal Kadol*)). This mangrove ecosystem can be utilized in a sustainable manner for providing the economic and ecological benefits to the nation. However, at present this is extremely vulnerable ecosystem and need rapid and strong interventions for the conservation and sustainable use. As such the CEA has declared Muthurajawela and Bolgoda Lake as an Environmental Protection Area (EPA) under the provision of the NEA in year 2006 and 2009 respectively.

2. Lagoon

A lagoon is a shallow body of water protected from a larger body of water (usually the ocean) by sandbars, barrier islands, or coral reefs. Lagoons are often called estuaries, sounds, bays, or even lakes.

The size and depth of coastal lagoons often depend on sea level. When the sea level is low, coastal lagoons are swampy wetlands. When the sea level is high, they can look like coastal lakes or bays. Within the study area 4 lagoons were identified such as Negambo, Lunawa, Kalutara and Maggona. Out of these four lagoons Negambo lagoon and Lunawa lagoon were identified as two major lagoons which located rapidly developing urban areas and highly threaten for the ecosystem.

II. Inland Wetlands

1. Freshwater swamp forest

Swamp forests are the forest type that seasonally inundated with river water. It is the rarest wetland type named "Wathurana" in Sri Lanka and good examples are the Walauwawatta, Irriyangala and Ulpath wathurana swamp forest located in the Kalu river basin within the study area. These swamps are late successional stages of freshwater marsh ecosystem. The natural vegetation consists of a freshwater swamp community and patches of lowland rainforest (Mainly secondary vegetation). The swamp vegetation includes tall trees dominated by *Stemonoporus moonii* ('Hora Wal*')* and *Mesua stylosa* (Suwanda) and herbaceous species (*Cryptocoryne spp*. and *Lagenandra spp*.). The area is subjected to seasonal inundation, especially during the southwest monsoon period. The CEA has declared Walauwatta wathurana (6.2 ha) swamp forest as an Environmental Protection Area (EPA) under the provision of the NEA in year 2009.

2. River

A river is a flowing stream of water that leads to the sea, a lake or another river. The water is usually fresh, and rivers tend to begin as small streams that get larger the further, they flow. Six major rivers were identified and they are Maha Oya, and Bentota Ganga which is bounded the northern and southern part of the study area respectively and Attanagalu Oya, Kelani Ganga, Bolgoda Ganga and Kalu Ganga flow across the study area. In addition, large number of minor streams and tributaries are connected to those rivers creating a network of hydrological system which is very important for agriculture and other development and social sectors.

3. Stream

A stream is continuing body of surface water flowing within the bed and banks of a channel. Within the WP it is observed forty (40) main streams and all those being fed by tributary waterways creating a network finally inter connected with main river system.

4. Marshy land (Shrub-dominated and Mixed woodland)

A marsh is a wetland dominated by herbaceous plants such as grasses, rushes, or sedges. Small shrubs often grow along the perimeter as a transition to drier land. Marshes usually form along the shallow edges of lakes and rivers. Unless there's a drought, swamps and bogs and wetlands are always marshy, and water-loving plants grow happily in these areas. Vegetation types and their varieties in marshy lands discuss later in this paper.

III. Man-made wetlands

1. Aquaculture pond

Aquaculture pond means an artificial water body set up on the surface of land, in its trench, pit or a river bed, containing embankments, fish harvesting pits. In the study area most of the aquaculture ponds are found in the Negambo area for prawn farming other than that some of the abandoned irrigated lands were converted to aquaculture ponds specially for recreational fishing or for ornamental purposes.

Some of the fresh water fish species are guppy (*Poecilia reticulata*) which contributes 60 % of the total exports. Other species are Platy (*Xiphophoru.c maculates*). Swordtails (*Xiphophorus helleri* and *X variatus*), Molly (*Poecilia sphenops*). Angels (*Pierophylum scalare*) fighters (*Belta splendens*). Gouramis, and Catfishes.

2. Ponds

A pond is a small area of still, fresh water, either natural or artificial. It is different from a river or a stream because it does not have moving water and it differs from a lake because it has a small area and not very deep. It may contain shallow water with marsh and aquatic plants and animals. In this study, farm ponds, stock ponds, small tanks generally below the 8 ha were considered as ponds. Some irrigated areas also converted into pond. 296 ponds are distributed in the entire WP.

3. Irrigated land

If water is supplied artificially to crops or land those lands are considered as irrigated lands. Rice fields and irrigation channels are the main features consider under this category. Rice fields are further categorized in to active paddy and abandoned paddy. Based on the vegetation type of irrigated lands are further categorised as follows;

a. Active paddy- Herb-dominated, low herb

Paddy cultivated lands, classified under this category where the vegetation is dominated by a single species *Oryza sativa* with various weed species such as *Isachne globosa, Fimbristylis miliacea, Panicum repens, Cyperus iria, Echinochloa colonum, Commelina diffusa* and *Ludwigia perennis* occurring either within the paddy cultivated area, bunds in the paddy fields or irrigation canals within the paddy cultivated area. Areas that are under paddy are not cultivated during every possible cultivation season. Some paddy lands are cultivated twice a year, some annually and some areas are cultivated once in several years. Out of the man-made wetland types found in WP active paddy are the most abundance wetland type.

b. Abandoned paddy (open water, shrub land, mixed woodland, other low land cultivation)

Abandoned paddy lands as defined as paddy lands that have not been consecutively cultivated for the last five years. In the abandoned paddy lands vegetation is more diversified compared to a paddy land and land does not undergo marked seasonal change. However, since the land is not managed during the fallow season these areas slowly undergo ecological succession and left undisturbed and converted into herb dominated high vegetation, shrub lands and woodlands as can be seen in some wetlands. At the same time in some areas these lands are managed as aquaculture ponds, or water storage areas for irrigation. Habitat types of these areas are considered as open water, standing water.

c. Herb dominated low herb (low herb dominated area)

In the abandoned paddy lands vegetation is more diversified compared to a paddy land. However, since the land is not managed in a short period slowly undergo ecological succession and will convert into herb dominated low vegetation. This habitat comprises of common semi aquatic herbs such as, *Monochoria vaginalis* (Diya habarala), *Commelina diffusa* (Gira pala), *Lasia spinosa* (Kohila) and *Colocasia esculenta* (Gahala).

d. Herb dominated tall herb (Tall Herbs Dominated Area)

This is a habitat that may arise in some of the abandoned paddy cultivated lands that are left undisturbed for many years allowing ecological succession to take place. This vegetation type was observed mostly in areas where the lands adjacent to the wetlands are occupied by underprivileged communities with poor sanitary facilities. Therefore, these wetlands are subjected to high level of eutrophication resulting from mostly release of raw sewage into wetlands by inhabitants reside there. The landscape will transform the previous type; herb dominated low vegetation to this type, as the short grass is replaced by tall grasses and reeds through successional processes.

e. Shrub lands

Shrub land, scrubland, scrub, brush, or bush is a plant community characterised by vegetation dominated by shrubs, often also including grasses, herbs, and geophytes. Shrub land may either occur naturally or be the result of human activity.

Shrub are woody plants which branch near the ground and do not have a leading shoot in contrast to trees that develop solitary trunks. Main advantage of this life-form is their greater tolerance to mechanical disturbances. In case one shoot is destroyed, there are many others which can replace it.

In Kaluthara District Rata Diyapara (*Dillenia suffruticosa*) which is a large invasive shrub spread all over the active and abandoned paddy lands. However, in the Colombo and Gampaha Districts it is observed that Pond apple (*Annona glabra*), which is perennial exotic plant one of the most noxious invasive weeds spreading all over the abandoned paddy lands.

f. Mixed woodland

These types of habitats were found scattered throughout the WP, but more common in abandoned paddy areas. The vegetation comprises of a mixture of tree species such as, *Annona glabra*, *Hibiscus tiliaceus*, *Pandanus kaida*, *Syzygium caryophyllatum*, *Cerbera odollam*, *Areca concinna and Barringtonia racemosa*. At a given site one of the species may be found more than the others.

As in the case of Annona woodlands, the understory of this habitat comprises of common semi aquatic herbs such as *Acrostichum aureum*, *Monochoria vaginalis* (Diya habarala), *Ludwigia perennis* (Piduruwella), *Ludwigia peruviana*, *Rhynchospora corymbosa*, *Commelina diffusa* (Gira pala), *Lasia spinosa* (Kohila) and *Colocasia esculenta* (Gahala). Further, climbers such as *Mikania cordata* (Wathu palu), *Pothos scandens* (Pota wel) and *Lygodium microphyllum* (Pamba wel) can be seen commonly within this habitat.

g. Other lowland cultivation

In most of the abandoned paddy lands were converted to low land cultivation especially in the urban areas to provide the leafy vegetable in the food chain. It's very important food supply grounds ultimately contributed the leafy vegetable for day today consumption. Some of the species found on these grounds are Gotukola (*Centella asiatica*), Mukunuwanna (*Alternanthera sessilis*), Thampala (*Amaranthus viridis*), Kankun (*Ipomoea aquatica*), Kathurumurunga (*Sesbania grandiflora*), Asamodagam (*Amaranthus viridis*), Sarana (*Trianthema portulacastrum*), Nivithi (*Basella alba*), Casava /Maniyok (*Maniot esculenta*), Kura thampala (*Amaranthus viridis*)

4. Canal

A canal is a man-made waterway that allows boats and ships to pass from one body of water to another. Canals are also used to transport water for irrigation and other human uses. While the advent of more efficient forms of transportation has reduced the need for canals, they still play a vital role as conduits for transportation and fostering national commerce. In the study area some of the canals were developed during the Dutch period for transportation eg. Dutch canal.

5. Channel

A channel is a wide strait or waterway between two landmasses that lie close to each other. A channel can also be the deepest part of a waterway, or a narrow body of water that connects two larger bodies of water.

6. Clay/sand mining pit

In Sri Lanka at present, the mining of clay for the production of bricks and roof tiles is mechanized resulting deep pits left along river basins. These pits get filled with water during the wet season. Some of the clay mining pits found in the study area are now use as floating restaurants and aquaculture ponds.

Sand mining resulting open pits in the river and banks are very common especially in the study area. Because of high environmental damages currently sand mining in Kelani River has been banned. Abandoned clay/sand mining pits have created stagnated water bodies ultimately resulting shrub lands, mixed woodlands and herb dominated wetlands.

7. Lake

A lake is a body of water surrounded by land and they are very greatly in size and depth. There are few lakes were found in the study area. Bolgoda and Beira Lakes are the main lakes found within the WP.

8. Quarry mining pit

A quarry is a place where rocks, sand, or minerals are extracted from the surface of Earth. Many quarries naturally fill with water after abandonment and become tanks or ponds. In the study area some of the abandoned quarry mining pits have been developed as rural water supply schemes in water scarcity areas.

9. Reservoir

A reservoir is an artificial lake where water is stored. Most reservoirs are formed by constructing dams across rivers. Labugama reservoir and part of Kalatuwawa reservoir are the main reservoirs found within the study area. They are the main drinking water sources in the Colombo District.

10. Tank

A tank is an area filled with water artificially, that is smaller than a reservoir. It is totally man-made structures. In this study area, areas over the 8ha were considered as tanks. Tanks, along with other reservoirs created an irrigation paradise in the country during the past. However, 37 tanks were observed in the study area.

11. Wastewater treatment area

Waste water areas are where wastewater stored and used to remove contaminants from wastewater or sewage and convert it into an effluent that can be returned to the water cycle with minimum impact on the environment, or directly reused. The treatment process takes place in a wastewater treatment plant (WWTP), often referred to as a Water Resource Recovery Facility (WRRF) or a Sewage Treatment Plant (STP).

Pollutants in municipal wastewater (households and small industries) are removed or broken down. In the study area number of wastewater treatment plants have been developed as it is the main industrial waste water generating areas.

12. Waterhole

Waterhole is a depression in which water collects and it can be a source of drinking water as a spring or well. It is smaller than a pond. There are 42 waterholes distributed in the study area.

13. Fishery harbor

Fishery harbor is a man-made structure specially found in the coastal areas where fishing boats are tied up. Only one fishery harbor found in the west coast of the study area near Elakanda, Ja- Ela named Dikovita harbor.

Final output of the research was achieved by using multi-criteria analysis with prepared data layers relevant to main criteria. In this step average surface volume of wetland was considered that represent the storage capacity in cubic meters per one hectare. Figure 6 shows the wetlands located in the flood affected Grama Niladhari Divisions and number of flood events had been occured. Number of flood events are categorized from 0 to 5. Wetlands with light blue colour shows zero flood event and wetlands with red colour shows
number of flood events occurred in that welands as 5.

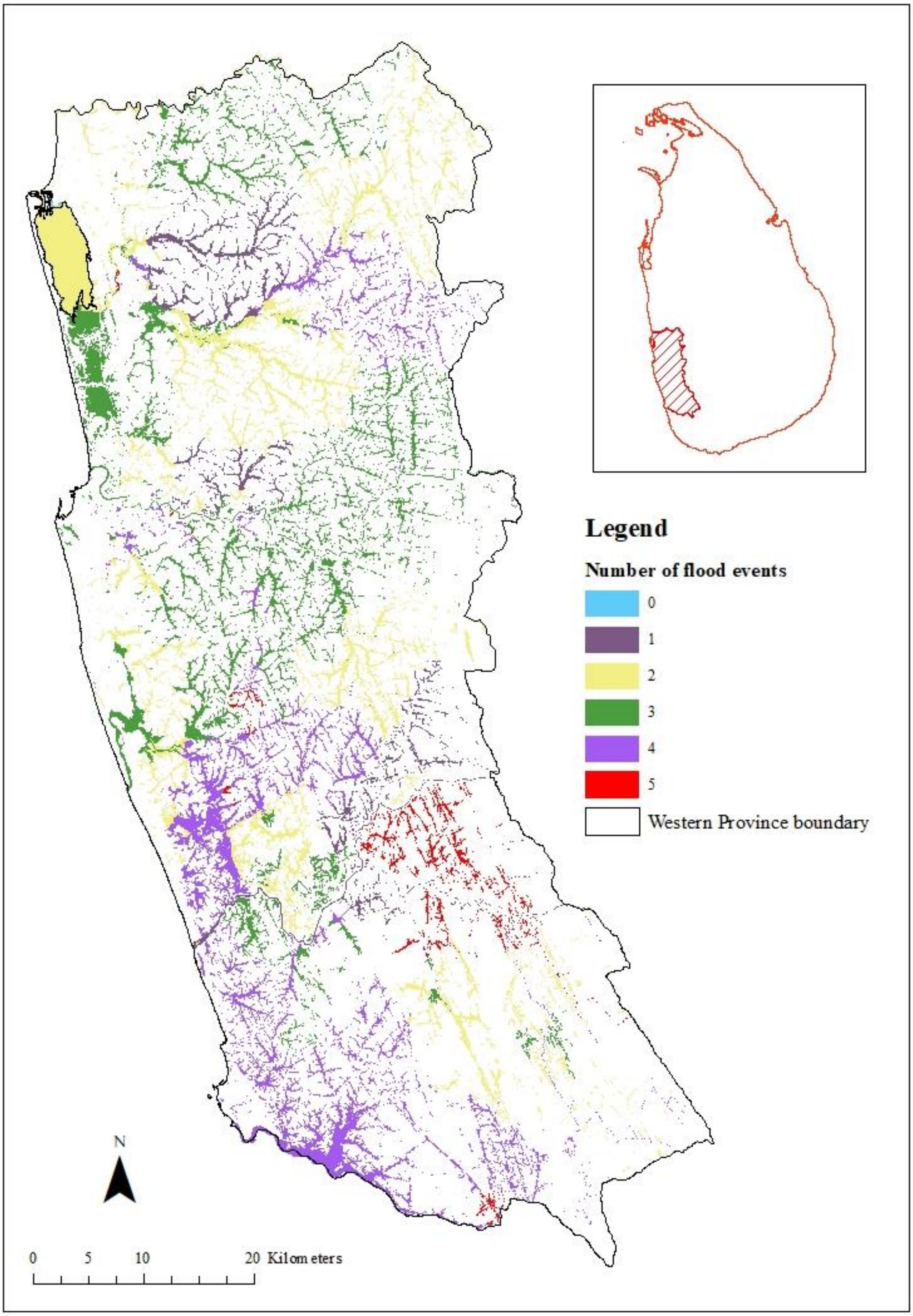


Figure 6: Wetlands located in flood affected Grama Niladhari Divisions and number of flood events had been occured

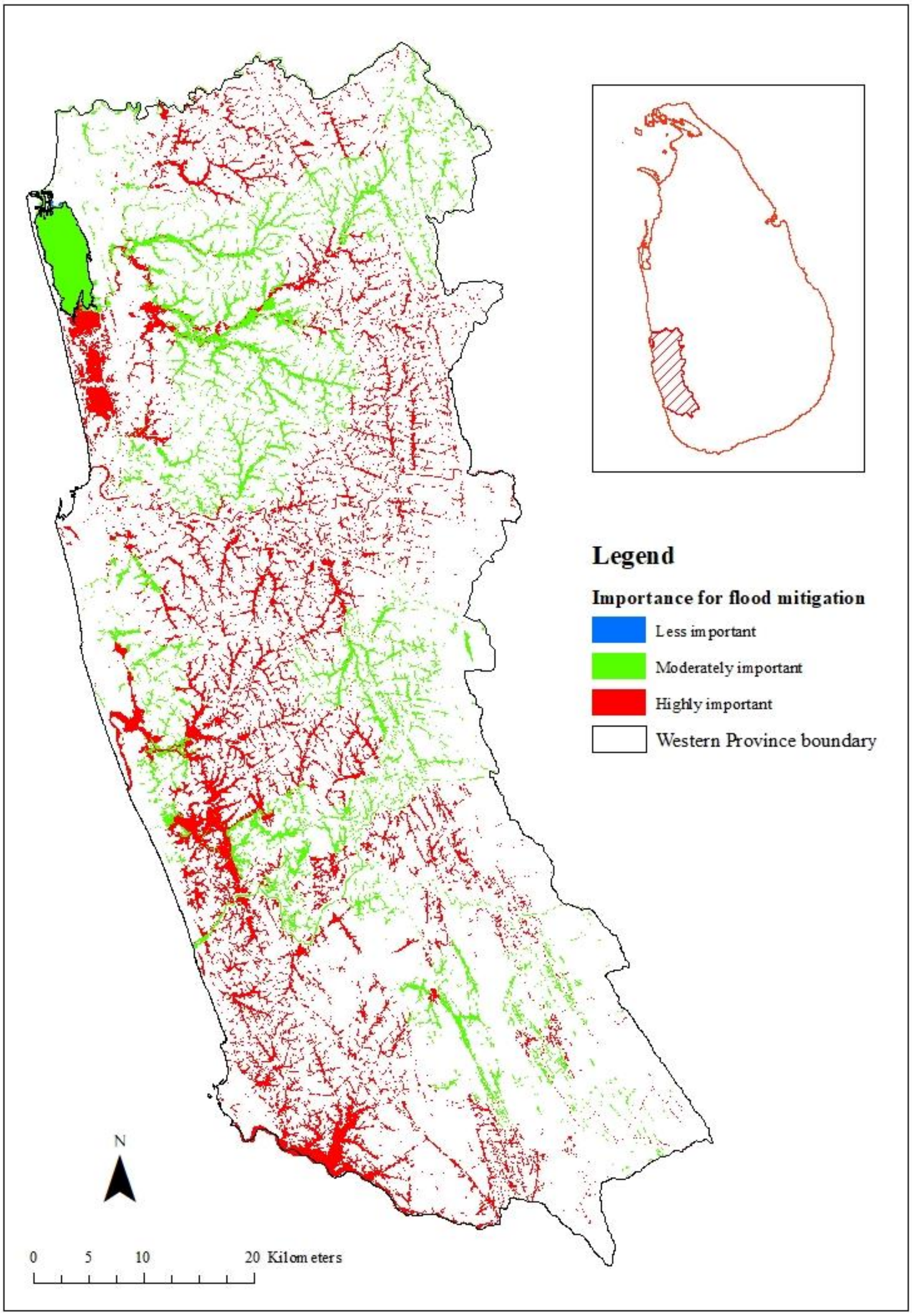


Figure 7: Hydrologically important wetlands in WP

Three classes were used as highly important, moderately important and less important to show the significant levels of the wetlands according to the criteria. Figure 7 shows the significant level of each wetland according to the criteria that had been used for the analysis. The wetlands shows with red colour are the highly important for the prevent from flood events and these wetlands are the wetlands that should be protected or conserved for future flood mitigation.

Finally, online spatial system of wetlands (Figure 8) was developed using ArcGIS online system. Prioritizing order of the wetlands can be observed by accessing in to the 'Online Spatial Wetland Inventory of WP, Sri Lanka' that published on Arc GIS Online Resource Database of CEA. Relevant stakeholders and officers of the CEA can be accessed to this online spatial inventory for their decision making processes.

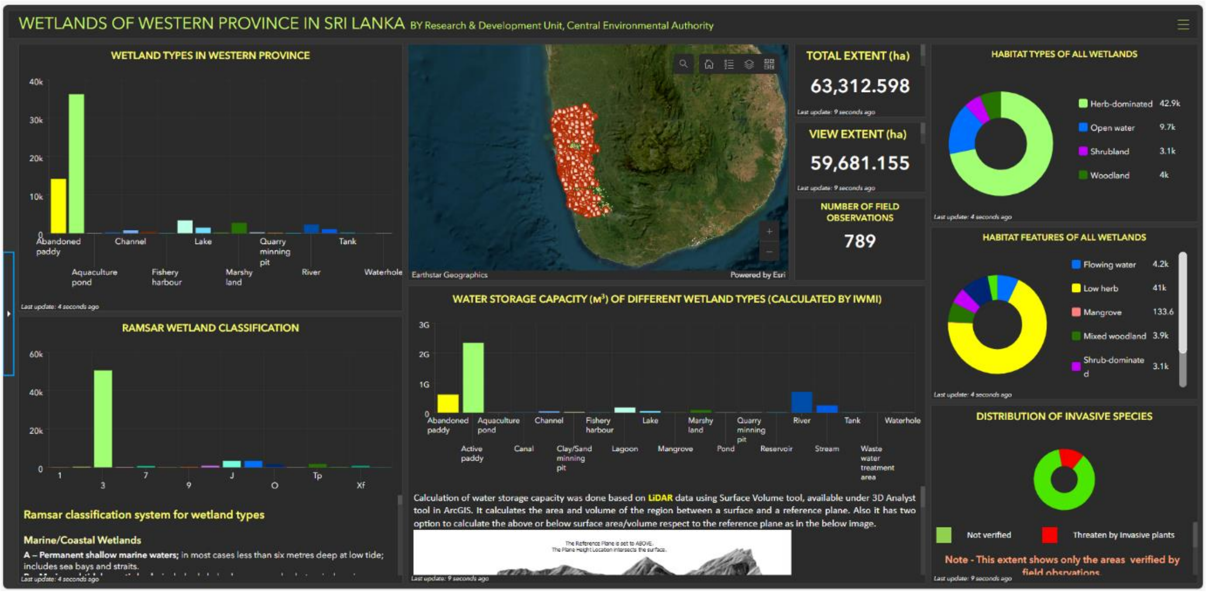


Figure 8: Online Spatial Wetland Inventory of WP, Sri Lanka

Conclusion and Recommendations

The significant output of this research that can be obtained from this study, is the developed Online Spatial Wetland Inventory for WP. Although many researches/studies had been done in minor scale relevant to the wetlands in WP, lack of accurate and complete spatial baseline dataset has been the major barrier to manage and protect wetlands in the study area. Thus, output of this research will be fulfilled this requirement and it will provide the online spatial wetland inventory which will be important for decision making process of stakeholders and better information source for researchers/scientists and general public. Further final results of this research will be used for wetland management activities done by the CEA.

The methodology that had been developed in this study could be replicated for other Provinces of Sri Lanka which are vulnerable for the flood. Then it will be important to identify the wetlands that should be protected and managed for flood mitigation. As well as classification system could be applied for all other Provinces that will help to identify the basic characteristics of the wetlands in those areas. In this research identified and categorised the wetlands in WP according to the RAMSAR wetland classification system and it could be replicated to the other provinces to identify the other non-identified wetland types that should be categorized under RAMSAR wetland classification system.

Time management was the main issue that had to face when completing the digitizing activity and field verification. As such it was realized that it could be better to select one district as the study area other than selecting a province which consisting of three districts considering the project time period.

It is planned to further develop the Online Spatial Wetland Inventory of WP with comprehensive attributes of ecological information and ecosystem services. It was agreed to develop this inventory with the collaboration of all stakeholder agencies according to the requirements of each agency. As an example, Agrarian Services Department agreed to update and include the other information relevant to the active paddy and abandoned paddy. Sri Lanka Land Reclamation and Development Corporation and Irrigation Department were agreed to further develop the hydrological information with the collaboration of the IWMI. Urban Development Authority will be used this database for management and protection of wetlands in urban areas and to develop their existing urban management plans according to the discussion had during the stakeholder committee meeting.

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