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Wetland spatial dynamics and mitigation study: an integrated remote sensing and GIS approach

R. Sivakumar[1] · Snehasish Ghosh[1]

Abstract Wetland is a valuable and most important natural resource in the environment. The present research aimed to study the wetland spatial dynamics by analysing the multidated satellite images and to develop a wetland mitigation plan through integrated geoinformatics techniques. The four stages of methodology include data acquisition, thematic database generation, wetland spatial dynamic study and mitigation plan. The satellite data, toposheets and other relevant data were collected from different sources and analysed in the GIS platform to study the spatial dynamics of wetland. The various thematic databases were prepared to better understand the physical environmental features of the study area. The analytical result shows that the total wetland area has reduced from 140.01 to 31.64 km^2 during 1977–2011. Many wetland areas are reduced due to increasing rate of siltation and eutrophication process. Mankind has also stressed wetlands by dumping garbage and industrial waste over the wetland. It further contaminates groundwater and affects human health. Also, the impact of natural factors leads to the depletion of groundwater level, which makes further vulnerable condition to the wetland ecosystems. The thematic databases were integrated with field data to develop wetland mitigation plan for the conservation of existing wetland and the restoration of lost wetland.

Keywords GIS · Wetland spatial dynamics · Rank and weightage · Wetland mitigation plan

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1 Introduction

A wetland is a land area which is saturated with water and either permanently or seasonally receives water from the catchment area. It is one of the most important sources of water resource and has many functional services such as the regulation of climate and purification of the environment and maintains hydrological cycle (Barducci et al. 2009; Beeton 2002). It helps to keep water levels normal and purify the surface water which prevents flooding by holding water. It also helps to counterbalance the surrounding ecosystems and is crucial for preserving the biodiversity of flora and funna species in their own environments. Wetland plays a significant role in the conversion process to control the overall functioning of ecosystem by recycling the nutrients. This conversion process helps to maintain sustainable condition in the wetland environment.

The rapid morphological changes were observed in many wetlands throughout the world due to either natural or anthropogenic activities (Du et al. 2011; Gong et al. 2010; Trolle et al. 2011). The impact of climate change was studied and identified that the water level declined due to increase in evaporation and decrease in precipitation, which further distressed the life of flora and fauna in the aquatic ecosystem (Huang et al. 2010; Maeda et al. 2011; McMenamin et al. 2008; Chase et al. 1999; Fragoso et al. 2011). Global climate change was recognized as a threat to species survival in the wetland region. This system was vulnerable to changes in quantity and quality of their water supply and also noticed that climate change had a higher impact on wetland alterations in hydrological regimes (Erwin 2009). Groundwater was also impacted, as aquifer levels and recharge rates were reduced due to climate dynamics (Malmaues 2004; Trolle et al. 2011; Qi et al. 2009). The transparency declined due to several natural factors such as an increase in external nutrient loading by low precipitation in winter and bacterial activity as a consequence of high temperature (Du et al. 2011; Song et al. 2012; Wang et al. 2009; Fragoso et al. 2011).

Further mankind had also stressed the wetland after dumping the solid and liquid waste materials in the lakes (Zhao et al. 2000; Brazner 1997). Also, the rapid growth of population and urbanization increased the exchange of nitrogen and phosphorous between lands and surface water. This process further increased the amount of nutrients in aquatic environments and accelerated the eutrophication process. Despite, inland wetlands were highly influenced by urban stress, such as industry, residences etc. (Brazner 1997). Song et al. (2012) studied the wetland dynamics and found that the expansion of population, socioeconomic development and agricultural land expansion were the main driving force for wetland fragmentation. Mushtaq and Pandey (2014) investigated the impacts of temporal changes in land use and land cover to evaluate the current status of Wular Lake environment using multisensor, multitemporal satellite and field observation data. Guidoum et al. (2014) developed model of water erosion in north-eastern Algeria using a seasonal multicriteria approach and explained the anthropogenic impact of erosion on aquatic environment. The impact of human activities such as dumping materials and supply of industrial waste material in wetland had been considered to be the most important factors in wetland dynamics (Friese et al. 2010).

Determination of the causes and consequences of the changes of wetland is thus the precondition of solutions for wetland conservation and restoration which is one of the main challenges in the present research. Wetland restoration is defined as the re-establishment of a degraded wetland which means restoring a lost wetland back to its best condition (Klemas 2011; Newcomer et al. 2013). Wetland management and mitigation strategies were proposed on the basis of specific familiar objectives, such as improving water quality,

strengthening biodiversity and providing flood control. A stepwise approach was designed to study wetland spatial dynamics and restoration plan for mitigation in Monegros region of NE Spain (Moreno and Comin 2010; Kershner 1997). An effort had been taken to conserve existing wetlands and to restore lost wetlands by the simulation model in the Otter Tail River watershed (Wang et al. 2010). The stream compensatory mitigation and ecosystem restoration plan were adopted for North Carolina wetland (Kaza and BenDor 2013). The wetland was restored by transplanting the wetland soil and increasing the number of wetland plant species in wetland restoration sites, Northern New York, USA (Stephen et al. 1997). A cumulative impact assessment was studied and identified the profile of types, numbers, relative abundances and spatial distribution of wetland in the USA and southern Canada. These profiles of the wetland landscape had been used to make decisions regarding the type and location of restorations. It was suggested that the regional wetland diversity can be restored if individual restoration decisions about wetland type and location are made in terms of the ecological diversity (Bedford 1999). A conceptual model was developed towards prioritization of wetland restoration for sediment yield reduction in US EPA Region (Vellidis et al. 2003). A sustainable re-establishment plan was prepared for a Karla Lake, Greece, using Ramsar restoration guidelines (Zalidis et al. 2005). Wetland condition was monitored, and potential restoration plan was developed at the watershed level in Spring Creek, Pennsylvania, USA (Brooks et al. 2006). Further, soil and water assessment tool was developed to examine the effects of various wetland restoration scenarios on stream flow and sediment in Broughton's Creek watershed, south-western Manitoba, Canada (Yang et al. 2010). Similarly, the conservation and mitigation plan was suggested to improved watershed functions by retention of sediment and nutrients in the wetland (Gassman et al. 2007; Yang et al. 2010). An attempt had been taken to understand the causes for the wetland environmental changes in Southern Iraq on the basis of palynological study and proposed a mitigation plan prior to the drying of the wetland (Khazal and Jassim 2011). Martinez et al. (2014) developed a model to study the hydrological significance for wetland restoration. The spatio-temporal changes in Hokersar wetland were monitored and developed strategies for the conservation and restoration of these ecologically important ecosystems (Romshoo and Rashid 2014). The restoration plan was also adopted for Canadian Prairie wetland, and it provided dual benefits for both industry and the environment. The industry was created for wastewater treatment to improve water quality in nearby wetlands. It was more environmentally significant to conserve the wetland (Donia 2013). Even the decision-making framework was developed to preserve and restore the wetland (Wyant et al. 1995; Tripp and Herz 1988; Jordan et al. 1988; Hyman and Leibowitz 2000). Wetland restoration process can improve water quality by reducing suspended sediment, total phosphorus and nitrate in the lake. Restoration process is one of the lowland best-management practices in basin region and was applied to the Minnesota River Basin region for the improvement of water quality (Almendinger 1999).

Geoinformatics, mainly remote sensing and GIS, is playing a significant role in monitoring and restoring of wetland (Gong et al. 2010; Yu et al. 1993; Rebelo et al. 2009; Jensen et al. 1995). The dynamics of lake in Egypt were studied using multitemporal satellite remote sensing imagery, digital image processing techniques and GIS overlay analysis of different environmental as well as in situ hydrological parameters (Chipman and Lillesand 2007; Donia 2013; Hereher 2015) and also suggested suitable mitigation plan such as wastewater treatment, improvement of groundwater quality and long-term monitoring of water storage changes for restoration. Similarly, the impact of land use/land cover dynamics and hydrometeorological variability was analysed, and action plan was developed for its conservation in India using geospatial techniques (Garg 2015; Mushtaq

and Pandey 2014). The main aims of the study are to understand the wetland spatial dynamics and to develop a mitigation plan to save the wetland through integrated geoinformatics techniques.
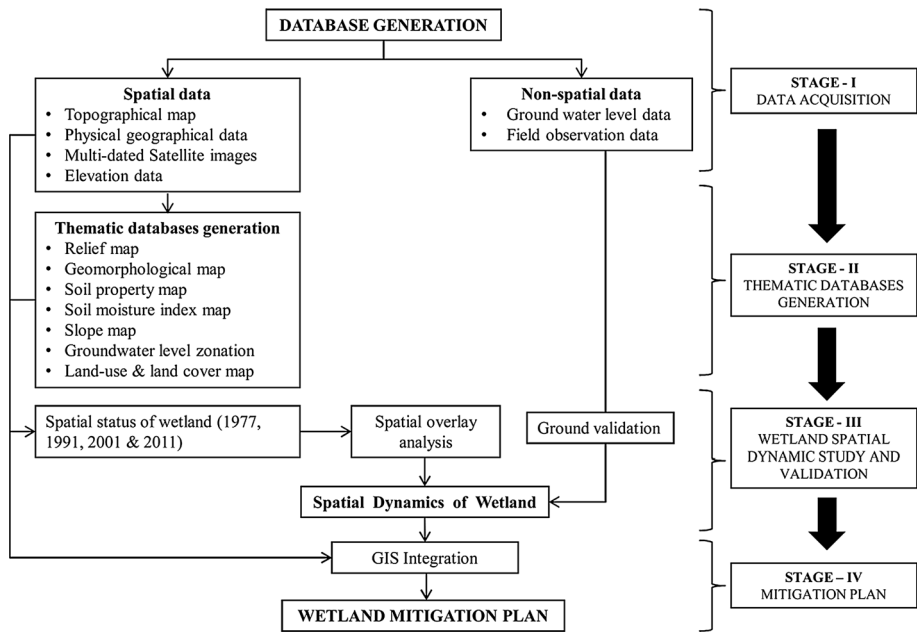
2 Study area

The study area Kattankulathur Block is located between 12°37′24″N–12°54′11″N in latitude and 79°52′42″E–80°10′17″E in longitude. It is the part of Kancheepuram District, a lake district in Tamil Nadu, India (Fig. 1). The total geographical area is approximately 353.062 km^2. The wetland is mainly comprised of lakes, waterlogged area, swamp area, tank/ponds and salt pan. It is well connected by streams/channel and distributed over the low alluvial plain and lacustrine plain which is formed by the streams and lake sediments. It receives water either directly from rain or from the surrounding catchment area where the water level varies seasonally based on the monsoon. The average annual precipitation is about 1083 mm, of which 48 % is by north-east monsoon and 32 % through the south-west monsoon. The water storage capacity has decreased dramatically, in the last few decades. Also the shrinkage of wetland extent has influenced the social and economic development of the study area.

3 Methodology

The study was conducted in various stages as shown in the flow chart (Fig. 2). At first, the spatial and non-spatial data were collected from different sources to develop the thematic database. In the second stage, GIS-based thematic databases were generated to study the
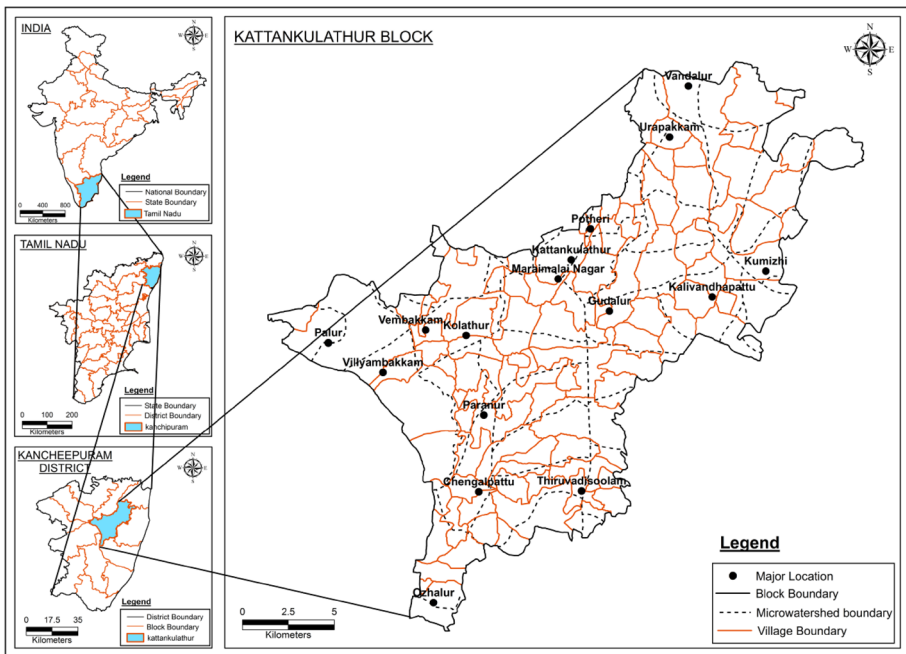
Fig. 1 Location map of study area

Fig. 2 Flow chart of methodology

physical environmental characteristics of the study area. In the third stage, spatial wetland dynamics were studied using a topographical map and multidated satellite data. Similarly, the spatial overlaying techniques were used to study the spatial shrinkage of lakes, and it was validated by field observation data. Finally, the wetland mitigation plan was proposed by integrating GIS-based thematic database with field observation data and using rank and weightage spatial overlay analysis method for the conservation of existing wetland and the restoration of lost wetland.

3.1 Data acquisition

Topographical map of 1977 was used to extract the basic geographical information of the study area. Soil properties data, geological data, Shuttle Radar Topography Mission (SRTM) elevation data and existing groundwater level data were acquired from various authenticated sources and analysed in the GIS platform to prepare thematic databases. Multidated satellite images were also collected from different sources and integrated in GIS platform. Landsat Multispectral Scanner (MSS) image of 1977, Thematic Mapper (TM) image of 1991 and Enhanced Thematic Mapper (ETM$^+$) image of 2001 and 2011 were used to study the wetland dynamics during the study period. High-resolution QuickBird image and Resourcesat-1 LISS-III image of 2011 were also referred. The above satellite data were digitally processed by adopting pre- and post-image processing techniques in ERDAS IMAGINE for further preparation of GIS-based thematic database. Field observation was done to check and compare with the findings of image interpretation and GIS data analysis as a ground truth. The sources of data and its details are given in Table 1.

3.2 Thematic database generation

A thematic database mainly focuses on to prepare maps based on specific theme or structure of the distribution for a particular geographical area (Robinson et al. 1995). It is derived either from spatial reference or by analysing the non-spatial database. It displays the spatial distribution of univariate data with base information such as major location, transportation network and boundaries. A base map was prepared for the study area using the Survey of India topographical map (Fig. 3a) and used further to prepare thematic databases. The different GIS-based thematic maps were prepared on relief, geology, geomorphology, soil, Soil Moisture Index, groundwater level zones, slope, land use and land cover using ArcGIS 9.3 software to understand the physical environmental condition of the study area and further used as a suitable parameters to make restoration plan.

3.2.1 Relief characteristics

Shuttle Radar Topography Mission (SRTM) data were used to extract elevation contour to prepare relief map (Fig. 3b). The topographical map was also referred to compare with analysed information. The five major relief zones have been identified for the study area, namely very high, high, medium, low and very low region. The very high and high relief regions are the part of hilly terrain which covers at about 20 % of total study area. The elevation of very high elevated relief region is greater than 170 m. The region consists of intermittent residual hills in Kumizhi, Paranur, Thiruvadisoolam and western part of Chengalpattu region. The highly elevated region is observed around Kolathur, Thiru-vadisoolam, western part of Paranur and Kumizhi regions, and the elevation differs from 120 to 170 m. The medium relief zone is the part of dissected plateau which is segmented into different landforms covering maximum part almost 50 % of total study area. The medium relief zone covers Chengalpattu and eastern part of Kalivandhapattu region where

Table 1 Used data and sources

Data used	Year/month	Scale/resolution in metre/pixel (m/p)	Source of data
Topographical map	1972	1:50,000	Survey of India
Soil properties data	1994	1:500,000	National Bureau of Soil Survey and Land Use Planning, Nagpur
Geological data	2001	1:250,000	Geological Survey of India
Landsat 2—MSS image	1977, November	80 m/p	USGS Earth explorer
Landsat 5—TM image	1991, August	30 m/p	Global Land Cover Facility (GLCF)
Landsat 7—ETM$^+$ image	2001, October	30 m/p	Global Land Cover Facility (GLCF)
Landsat 7—ETM$^+$ image	2011, September	30 m/p	USGS Earth explorer
Resourcesat-1—LISS-III	2011, November	23 m/p	NRSC, India
QuickBird image	2011, September	8 m/p (available data)	Google Earth satellite image
SRTM elevation data	2005	30 m/p	USGS Earth explorer
Groundwater level data	2011	–	Groundwater information system, Central groundwater board, NIC
Field observation data	2011	–	Field visit and data collection
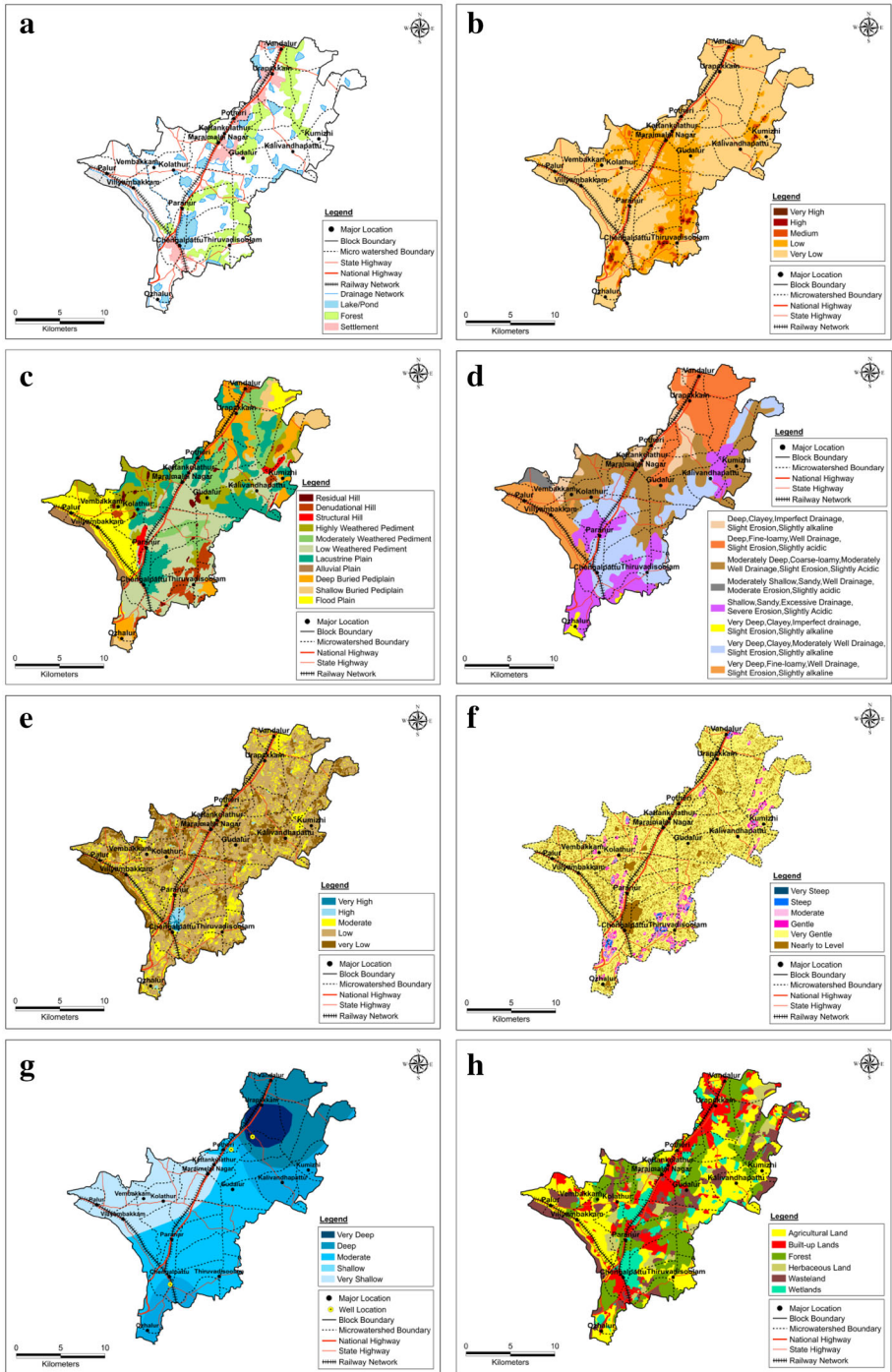
Fig. 3 **a** Base map, **b** relief map, **c** geomorphology map, **d** soil properties, **e** Soil Moisture Index, **f** slope map, **g** groundwater level map and **h** land use and land cover map (2011)

elevation varies between 70 and 120 m which is represented as pediment zone. It covers the central part of the region around Gudalur, Maraimalai Nagar, which is recognized as a major watershed divider of Palar River Basin. The remaining parts are plain land which consists of low relief and very low relief zones. The low relief zone is found in both sides of watershed divider around Vandalur, Kattankulathur, Palur and Vembakkam regions which is represented as a pediplain zone. The observed elevation alters from 20 to 70 m in this zone. The very low relief zone consists of alluvial plain land with less than 20-m elevation around Vijayambakkam, Urapakkam and Potheri regions.

3.2.2 Landforms

The geomorphic landforms map was prepared using satellite image as well as elevation data and also verified with the field observation data (Fig. 3c). The study area shows 11 geomorphic units, namely residual hill, denudational hill, structural hill, highly weathered pediment, moderately weathered pediment, low weathered pediment, lacustrine plain, alluvial plain, deep buried pediplain, shallow-buried pediplain and flood plain.

Residual hill is the isolated, steep-sided, rounded-topped mount with the elevation of 60 m. It is scatterly distributed throughout the study area. The weathering is more active agent to develop flat-topped plateau hills which are collectively known as denudational hill. The residual and denudational hills are more prone for high soil erosion and less forest cover zone. Structural hill is the folded structure with an elongated ridge which is found in the hard rock terrain. Weathered pediment is represented as a rock cut surface in the part of dissected plateau. On the basis of rock weathering, it is divided into three categories—high, moderate and low weathered pediments. Pediplains are low elevated plain surface. It is extended in Urapakkam and Ozhalur regions as buried and shallow-buried landform. The flood plain and alluvial plain have been originated by fluvial action of rivers. It is well traced in the left bank of the Palar River. Lacustrine Plains are the sedimentary landform inside the lake. It is developed due to continuous sedimentation process which leads drastic deterioration in wetland area as well as depth.

3.2.3 Soil characteristics

Soil map was prepared using soil survey data which was published by National Bureau of Soil Survey & Land Use Planning, Nagpur, in 1994. The study area has been classified as eight major soil types on the basis of soil texture, drainage, erosion potential, chemical properties and depth. The very deep and clay soil is characterized by imperfect drainage, slight erosion and slightly alkaline. It is found in the south-western part of the region covering 3 % of the total study. Similarly, the very deep and clay soil is characterized by moderately drained and slight erosion with slightly alkaline, which has been originated in the Chengalpattu and Thiruvadisoolam areas covering almost 20 % of the study area. The very deep fine-loamy soil is extended over Palur region and covers 10 % of the study area. It is well drained with a slight erosion and slightly alkaline soil. The moderately deep and coarse-loamy soil is characterized by moderately well drained, slight erosion, and slightly acidic, which covers 30 % of the study area. It covers throughout Potheri and Maraimalai Nagar. The shallow and sandy soil is formed in the Paranur region. It is characterized by excessive drainage, severe erosion and slightly acidic. The deep and clay soil is characterized by imperfect drainage, slight erosion and slightly alkaline. It is found in the Kattankulathur region. The deep and fine-loamy soil is well drained, slight erosion, slightly acidic. It is distributed over Urapakkam and Vembakkam region. The moderately shallow

and sandy soil is extended through north-eastern side. It is well drained, moderate erosion and slightly acidic soil (Fig. 3d).

Soil Moisture Index (SMI) map was derived from the recent satellite image using the following equation

$$SMI = [Band\ 4 - Band\ 5]/[Band\ 4 + Band\ 5] \tag{1}$$

In the above equation band, 4 is near-infrared (NIR) and band 5 is middle-infrared (MIR). Moisture index has been classified into five zones, namely very high, high, medium, low and very low saturated zone (Fig. 3e). The index value is very high in the wetland region consisting of lacustrine plan, flood plain and alluvial plain. It is gradually decreasing in the dry region consisting of hard rocks and elevated terrain.

3.2.4 Slope

Slope map was derived from digital elevation data and classified into six categories, namely very steep, steep, moderate, gentle, very gentle and near to level slope (Fig. 3f). Very steep slope is observed in the hilly region near Kumizhi, Paranur and Thiruvadisoolam where slope is greater than 31°. Steep slope is recognized in the Kolathur, Thiruvadisoolam, western part of Paranur and Kumizhi regions, and slope ranges between 23° and 31°. Moderate slope is found in the foothill region of Gudalur, Maraimalai Nagar, Chengalpattu and eastern part of Kalivandhapattu region where slope alters from 15° to 23°. The gentle slope varies from 8° to 15° which is observed around Vandalur, Kattankulathur, Palur and Vembakkam regions. The maximum part of the study area includes very gentle slope covering the area of Kattankulathur, Potheri, Vembakkam, Kolathur, Urapakkam and Ozhalur where slope ranges between 1° and 8°. The near to level slope is less than 1° which is recognized near the lacustrine plain region around the lakes.

3.2.5 Groundwater level

Groundwater level zonation map was prepared from groundwater level data and is classified into five zones, namely very shallow, shallow, moderate, deep and very deep (Fig. 3g). The very shallow groundwater level zone is observed less than 1 m in the Vembakkam, Kolathur, Vijayambakkam, Maraimalai Nagar, Kattankulathur and Palur regions. The shallow zone is found around Paranur, Gudalur, Potheri and Thiruvadisoolam regions, and it varies from 1 to 2 m. Moderate water depth is recognized in Ozhalur, Chengalpattu and Kalivandhapattu regions ranging between 2 and 3 m. The deep groundwater level varies from 3 to 4 m in Vandalur and northern part of Urapakkam region. The very deep groundwater level is noticed greater than 4 m in the Urapakkam and Guduvancheri regions.

3.2.6 Land use and land cover map

Land use and land cover map was derived from high-resolution satellite images (Fig. 3h) after using NRSA standard classification technique. The regions have been divided into six major land use and land cover types, namely forests, wetlands, herbaceous land, built-up lands, wastelands and agricultural lands. The forest area consists of deciduous forest, degraded forest and forest plantation and is found in the high elevated region covering an area of Thiruvadisoolam, Vembakkam and Vandalur. The wetland comprises of lakes/

pond, waterlogged area and freshwater swamp where the major lakes are Kolavai Lake, Thirukanchur Lake, Nandivaram Lake, Onnamcherry Lake and Urapakkam Lake. The herbaceous land is well documented in the study region. It is distributed throughout the study region. Agricultural land is extended over flood plain, alluvial plain and lacustrine plain area. Besides, the dry river and lake bed are encroached for agriculture purpose. Built-up land consists of residential area, industrial area and commercial area and is observed in Maraimalai Nagar, Chengalpattu, Kattankulathur, Vandalur, Urapakkam and Guduvancheri regions. The wasteland comprises of sandy area, bare exposed rock, mixed barren land and waste disposal grounds which are recognized besides lake, dry river bed and fallow land region.

### 3.3 Wetland spatial dynamic

ERDAS IMAGINE 9.1 software was used to pre- and post-process the satellite images to study the morphological changes of wetland area. Wetland boundary was extracted from the satellite image on the basis of geometric form, spatial arrangement and relative brightness of the object in the image in ArcGIS platform (Bhatta 2008; Garg and Agarwal 2000). The wetland status map of the study area was generated by digitally processing satellite images followed by visual interpretation in GIS format using the spatial data, mainly topographical map and multidated satellite images of Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper (ETM$^+$) and QuickBird product for the years 1977, 1991, 2001 and 2011, respectively (Fig. 4). The digitization (vectorization) method was used to extract the wetland boundary for multiple years by duly considering the ground control points from the spatial data and field observations.

In the present study, digital spatial overlay techniques were used to study the wetland dynamics for the period from 1977 to 2011. All the above wetland maps were integrated by spatial overlay techniques using ArcGIS analysis tool after superimposing the spatial layers of individual wetland boundary of 1977, 1991, 2001 and 2011 to study the wetland shrinkage and change detection (Fig. 5).

3.4 Wetland mitigation plan

The alarming rate of the wetland shrinkage requires an immediate action plan to restore the wetland for managing the optimum uses of water resources. An attempt had been taken to prepare a mitigation plan for conserving the existing wetland and restoring the lost wetland using geoinformatics-based overlay techniques. It is the method of superimposing the individual vector layer over each other to study the change and construct the overall suitability maps for each land use (Malczewski 2004). The GIS-based approaches of hand drawn overlay techniques were used by American landscape architects in the late nineteenth and early 20th centuries (Steinitz et al. 1976). The GIS-based spatial intersection overlay technique was adopted by integrating vector layer of different variables, namely geomorphology (GM), soil (SO), Soil Moisture Index (SMI), groundwater level (GW), relief (RE), slope (SL) and land use and land cover (LULC) to suggest mitigation plan for wetland restoration.

On the basis of geoinformatic database and field investigation, rank and weighted spatial overlay method was applied to develop a proper mitigation plan to bring back the wetland to better environment. The weightage was assigned to different major variables by considering their importance for the restoration of the lost wetland area. According to the
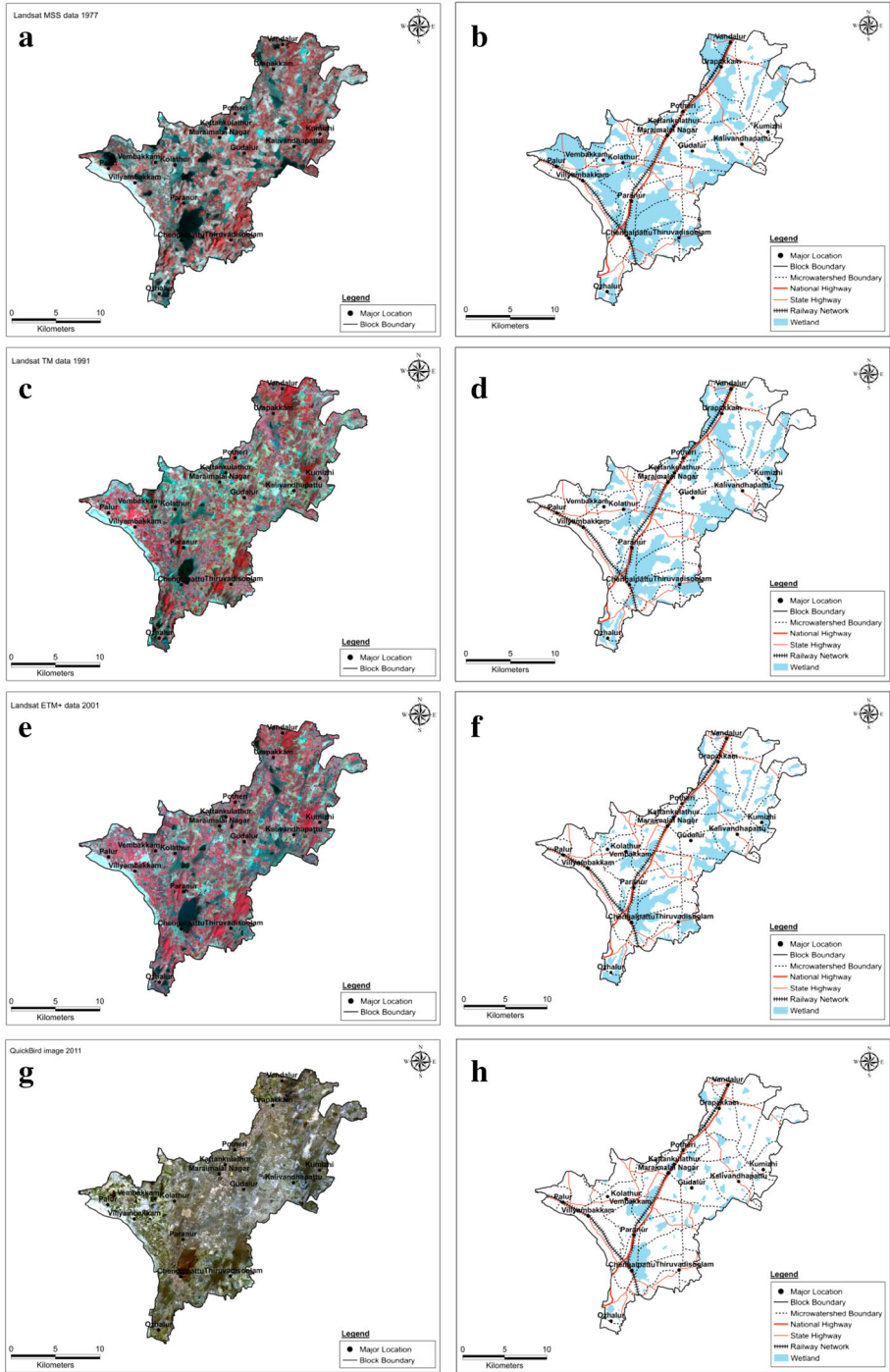
Fig. 4 a Satellite image 1977, **b** status of wetland 1977, **c** satellite image 1991, **d** status of wetland 1991, **e** satellite image 2001, **f** status of wetland 2001, **g** satellite image 2011 and **h** status of wetland 2011
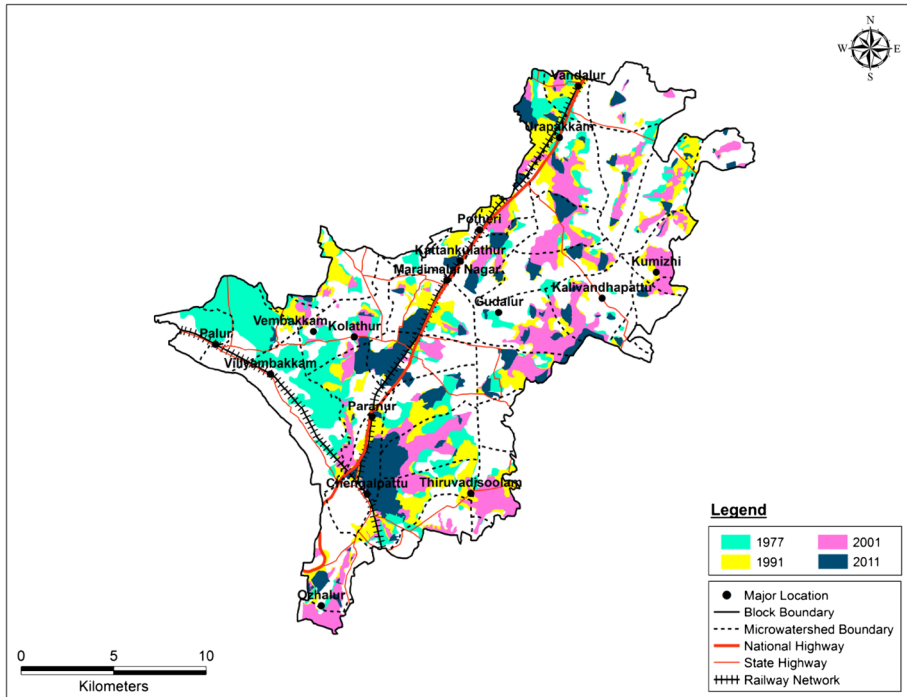
Fig. 5 Shrinkage of wetland area (1977–2011)

significant role and priority, high weightage was assigned to Soil Moisture Index, 7, and low weightage was assigned to relief, 1 (Table 2). Each variable was further split into different sub-classes and had assigned ranks from 1 to 5 based on their suitability for wetland restoration (Table 2). The combined score was calculated using the following equation

$$WMP_{ktr} = (SMI_w \times SMI_r) + (SO_w \times SO_r) + (GW_w \times GW_r) + (SL_w \times SL_r) + (LULC_w \times LULC_r) + (GM_w \times GM_r) + (RE_w \times RE_r)$$

(2)

where 'WMP$_{ktr}$' is wetland mitigation plan of Kattankulathur Block, 'w' is layer weightage, and 'r' is sub-layer rank.

4 Results and discussion

The spatial analysis of the multitemporal satellite image of the study area exhibits the convincing changes occurred in wetland in the study area during 1977–2011. The wetland status maps of the study area were prepared by digital image processing and visual interpretation techniques in GIS format using temporal satellite images for the years 1977, 1991, 2001 and 2011, respectively (Fig. 4). The result shows that the wetland area was reduced and many numbers of wetland patches were disappeared. The GIS spatial overlay techniques were used to understand wetland spatial changes in the study area, and further

Table 2 Rank and weighted parameter for wetland restoration plan

Layer	Sub-parameters/features	Weight	Rank
Soil Moisture Index	Very less saturated (−0.34 to −0.16)	7	1
	Less saturated (−0.16 to 0.01)		2
	Moderately saturated (0.01 to 0.20)		3
	Highly saturated (0.20 to 0.38)		4
	Very highly saturated (0.38 to 0.56)		5
Soil	Very deep, clayey, imperfect drainage, slight erosion, slightly alkaline	6	5
	Very deep, clayey, moderately well drained, slight erosion, slightly alkaline		4
	Very deep, fine loamy, well drained, slight erosion, slightly alkaline		1
	Moderately deep, coarse loamy, moderately well drained, slight erosion, slightly acidic		2
	Shallow, sandy, excessive drainage, severe erosion, slightly acidic		2
	Deep, clayey, imperfect drainage, slight erosion, slightly alkaline		5
	Deep, fine loamy, well drained, slight erosion, slightly acidic		3
	Moderately shallow, sandy, well drained, moderate erosion, slightly acidic		3
Groundwater level (metre)	Very shallow (<1)	5	5
	Shallow (1–2)		4
	Moderate (2–3)		3
	Deep (3–4)		2
	Very deep (>4)		1
Slope (degree)	Nearly to level (<1°)	4	5
	Very gentle (1°–8°)		4
	Gentle (8°–15°)		4
	Steep (15°–23°)		3
	Moderate steep (23°–31°)		2
	Very steep (>31°)		1
Land use and land cover	Wasteland	3	4
	Built-up lands		Restricted
	Wetlands		5
	Herbaceous land		3
	Agricultural land		1
	Forest		2

Table 2 continued

Layer	Sub-parameters/features	Weight	Rank
Geomorphology	Deep buried pediplain	2	3
	Denudational hill		1
	Structural hill		1
	Residual hill		1
	Flood plain		2
	Moderately weathered pediment		2
	Low weathered pediment		2
	Highly weathered pediment		2
	Alluvial plain		4
	Shallow-buried pediplain		3
	Lacustrine plain		5
Relief (m)	Very low (<20)	1	5
	Low (20–70)		4
	Medium (70–120)		3
	High (120–170)		2
	Very high (>170)		1

quantitative databases were also developed. The changes in the wetland area are primarily the consequence of natural and anthropogenic activity due to which total wetland area has decreased from 140.01 to 31.64 km^2 during 1977–2011.

The spatial overlay analysis in GIS was adopted to study the wetland dynamics during 1977–2011 (Fig. 5). The result shows that the wetland area has reduced in all over the region. The significant reduction is noticed in Palur, Vembakkam, Kumizhi, Chengalpattu, Urapakkam, Kolathur, Gudalur and Vandalur areas. The major wetland environment such as Kolavai, Kayer, Nandivaram and Thirukanchur Lakes and its adjacent wetland environment are also showing a drastic change, and spatial status is shown in Fig. 5.

The quantitative databases were generated to estimate the spatial changes of wetland area during the study period. The total wetland area has reduced from 140.1 to 105.3 km^2 during 1977–1991 period. Similarly, from 1991 to 2001, the total wetland area has decreased to 72.59 km^2, which is greater than the previous period. Also from 2001 to 2011, the area has drastically declined to 31.64 km^2, which is considerably higher than that in the previous two periods (Table 3).

The field observation was carried out to authenticate the interpretation and analysis of results of wetland dynamics and to identify the proper causes of its reduction in the study area (Fig. 6). The major reduction occurs in wetland area due to the increase in

Table 3 Wetland spatial dynamics and shrinkage in Kattankulathur Block

Year	Total study area—352 km^2	
	Wetland area (km^2)	%
1977	140.1	39.7
1991	105.3	29.8
2001	72.59	20.6
2011	31.64	8.96

Fig. 6 Field observation—**a** soil erosion in the catchment area, **b** siltation in the wetland, **c** rapid eutrophication process in the wetland, **d** aquatic vegetation, **e** solid swamp land with waste disposal, **f** built-up new settlement in wetland environment

eutrophication process, decrease in surface and groundwater level and conversion of wetland area to other land use. The eutrophication process accelerates due to the rapid soil erosion in the catchment area and abundant supply of nutrient into the wetland. Zhao et al. (2000) studied the influence of human activities on environmental change and observed that the increasing rate of exchange of toxic materials between lands and surface water accelerated the eutrophication process. Also, the growth of urbanization increased the supply of nutrients in the wetland (Barducci et al. 2009; Friese et al. 2010).

Soil erosion is caused by deforestation, high rate of run-off volume and velocity. Also, increases soil-carrying capacity and siltation in wetland. The field observation data also show that the depth of lake water is reduced due to increase in siltation and eutrophication

process which further affects flora and fauna in the aquatic ecosystem. Guidoum et al. (2014) explained the causes and anthropogenic impact of soil erosion on aquatic environment. McMenamin et al. (2008) identified the natural factor such as climate change which is the major factor for water level declination. Du et al. (2011) found that the water transparency declined due to several natural factors such as an increase in external nutrient loading by low precipitation in winter and bacterial activity as a consequence of high temperature.

It is observed that the wetlands are highly encroached by the expansion of agricultural land and wasteland and urban stress, such as industry and residences, in the wetland area. The major wetland area is used as a dumping ground which further contaminates lake as well as groundwater. Song et al. (2012) also recognized that the expansion of population, socioeconomic development and agricultural land expansion were the main factors for wetland conversion. Similarly, Mushtaq and Pandey (2014) and Huang et al. (2010) investigated the impacts of temporal changes in land use and land cover to evaluate the current status of wetlands. Friese et al. (2010) showed that the wetland area was used as an industrial waste dumping ground. Malmaues (2004), Trolle et al. (2011) and Qi et al. (2009) identified that the groundwater was also impacted, at aquifer levels, and recharge rates were reduced due to various natural factor.

The spatial overlay analysis techniques and field observation data were combinedly used to prepare wetland mitigation plan. The study area has been divided into five restoration zones by the spatial overlay analysis of different variables (Fig. 7). The specific action plan is suggested for each zone with the help of present field observation data. The
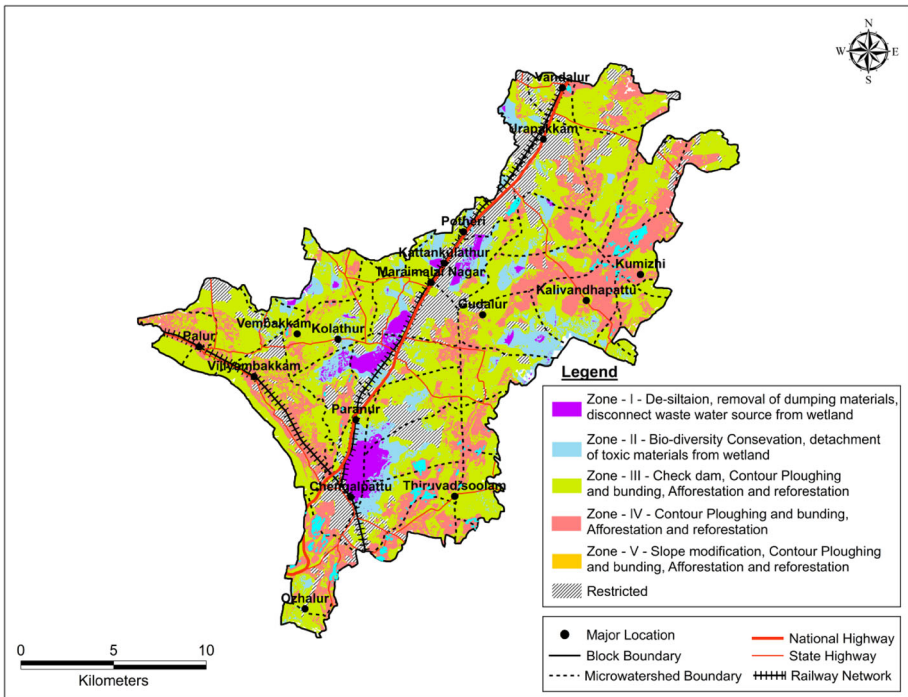

Fig. 7 Wetland mitigation plan for restoration

Table 4 Wetland mitigation plan

Zones	Area (km^2)	Location	Restoration status
Zone I	11.425	Chengalpattu, Kolathur, Kattankulathur, Potheri, Guduvancheri	De-siltation, removal of dumping materials, disconnect the waste water source from wetland
Zone II	34.401	Chengalpattu, Kolathur, Kattankulathur, Potheri, Gudalur, Guduvancheri	Biodiversity conservation, detachment of toxic materials from wetland
Zone III	167.814	Paranur, Vembakkam, Thiruvadisoolam, Ozhalur	Check dam, contour ploughing and bunding, afforestation and reforestation
Zone IV	87.93	Kumizhi, Kalivandhapattu, Vandalur, Palur, Vijayambakkam	Contour ploughing and bunding, afforestation and reforestation
Zone V	1.57	Thiruvadisoolam, Kumizhi	Slope modification, contour ploughing and bunding, afforestation and reforestation
Restricted	49.92	Maraimalai Nagar, Urapakkam	Built-up land

following mitigation plans were developed in the respective zones to restore and save the wetland (Table 4).

(a) Zone I: This zone is mainly an existing wetland with significant surface water body, namely Kolavai Lake near Chengalpattu, Urapakkam Lake, Thirukanchur Lake, Nandivaram Lake near Guduvancheri, Kayer Lake and Kalayana Lake in the year 2011. It is recognized from geomorphology map that the zone is surrounded by the lacustrine plain area with near to level or very gentle slope which varies <1°. Physiographical observation shows that it is a plain land with low to very low elevated relief zone. It consists of very deep, clayey, imperfect drainage and slight erosion soil with high to very high moisture index. The groundwater level is very shallow ranging between 1 and 2 m in 2011 (Fig. 3b–h).

A major reduction in wetland area as well as depth of water is identified in this zone. In the context of basic needs for restoration of wetland, by studying the overall favourable parameters, it is considered that the region requires de-siltation to bring bank wetland for a better environment. Also, it is suggested for the removal of dumping materials and disconnects the waste water source from wetland (Fig. 7).

(b) Zone II: This zone is a wetland or partially herbaceous and scrub forest land covering the area of Chengalpattu, Kolathur, Kattankulathur, Potheri, Gudalur, Guduvancheri. According to geomorphology, it comprises of lacustrine plain, buried pediplain and low weathered pediment zone. Physiographically, it is a plain land with very gentle slope altering between 1° and 15°. It consists of moderately deep, clayey, moderately well drained, slight erosion soil with high Soil Moisture Index. The groundwater level is shallow to moderate varying from 2 to 3 m which is observed from groundwater level map of 2011 (Fig. 3b–h).

In the context of restoration plan, it is acknowledged that the region is superior for biodiversity conservation to protect flora and fauna in the aquatic ecosystem and detachment of toxic materials from wetland to reduce eutrophication process (Fig. 7).

(c) Zone III: This zone principally constitutes wasteland, scrub forest land and agricultural land covering the area of Paranur, Vembakkam, Thiruvadisoolam,

Ozhalur. Geomorphological observation shows that the region is buried pediplain and alluvial zone with moderate to gentle slope. Physiographically, it is a dissected plateau region with moderate elevation. It comprises of moderate deep coarse loamy, moderate to excessive drainage, slight erosion with moderate to low moisture index. Groundwater level is shallow to moderately shallow (Fig. 3b–h).

In the context of restoration plan for this zone, the region is preferable for the construction of check dam in the catchment area to prevent the soil erosion, which will decrease the sediment deposition into the lakes and increase water level with reduction in siltation. Secondly, contour ploughing and bunding will be superior along the contour line across the slope in catchment region to resist the high run-off during storm and can allow water to timely settle in the soil. Also, afforestation and reforestation can be adopted in the moderate slope region to prevent soil erosion (Fig. 7).

(d) Zone IV: This region is covered by forest land in Kumizhi, Kalivandhapattu, Vandalur, Palur and Vijayambakkam regions. Geomorphologically, it is observed as plateau and weathered pediment zone with moderate to steep slope. It consists of shallow, coarse loamy to sandy, excessive drainage, sever erosion soil, with low to very low moisture index. Physiographically, it is a dissected plateau and partially hilly terrain zone where groundwater level varies from 3 to 4 m (Fig. 3b–h).

In the context of restoration plan, it is recommended that the region is preferable for contour ploughing and bunding in the moderate elevated region. Also, afforestation and reforestation are required in steep slope hilly region to prevent soil erosion (Fig. 7).

(e) Zone V: This zone is mainly a forest cover region with high elevated hilly hard rock terrain covering area of Thiruvadisoolam and Kumizhi. It consists of shallow, sandy, excessive drainage, severe erosion soil with low to very low moisture content where the groundwater level varies from 3 to 5 m (Fig. 3b–h).

In the context of restoration plan, it is suggested that the region is preferable for slope modification by grading, retaining structures, drainage improvements in the unstable slope region to reduce the soil erosion. Secondly, a common method can be applied after constructing earth embankments in which mats of geotextile are placed in horizontal layers and then packed with soil. Such techniques will be best suited for addressing low elevated steep slope region in the study area. Also it is recommended for contour ploughing and bunding and reforestation to control soil erosion (Fig. 7).

5 Conclusion

The multidated satellite image and field observation data were analysed in GIS platform to study the wetland dynamics. The result shows that the wetland area is reduced from 140.01 to 31.64 km^2 during 1977–2011. The fast reduction in wetland area appears to have been largely caused by natural and human activities. This phenomenon leads to the reduction in water resources which will trigger various problems such as increasing vulnerability of aquatic plants and animals in wetland, scarcity of drinking water, increasing frequency on drought condition, alteration of global hydrological cycle and degradation of environmental condition. In the context of basic needs for restoration of wetland, by comparing the overall favourable parameters with field observation data, the wetland mitigation plan is

suggested to bring back good environment and aquatic ecosystem in the wetland area. If the above suggestions are implemented in the respective zones, water can be retained in the wetland, soil moisture concentration can be increased in high and medium slope region, and groundwater level can also be increased after recharging water for near future. This study will be helpful for future management of the wetland area at micro-watershed level by adopting various customized geoinformatics techniques. It will be useful to determine the rate of siltation in wetland through digital image processing techniques. The wetland morphological change can be used to study the conversion rate of wetland to other land use type and practise it for improving potentiality of water resource in future.

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