Spatio-temporal assessment of waterbodies for sustainable sub-urban planning and development – A geo-informatics approach

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Abstract

Due to the rapid urban and peri-urban growth, most of the industries and industrial colonies are developed in the lake catchment and polluting the lake water and its environment. Hence, it is an urgent need to assess the lake catchment using Geo-spatial tools for their sustainability. The Kolavai Lake of the Chennai City Sub-urban has been taken as a study area, where the water deterioration and encroachments are existence. Multi-dated satellite data has been used to study the Level-II land use/land cover classification of the catchment. About 7 water samples location has been chosen and samples were collected and analysed. The Water Quality Index (WQI) has been calculated and it is observed that the Kolavai Lake water is unsuitable for drinking because of WQI values exceeds 100. It is recommended that the catchment area to be taken in to a comprehensive ecological auditing and continuous monitoring of land use/land cover practices.

Key Words: Catchment assessment, Sub-urban, Water Quality Index, Sustainable Water usage, land use/land cover, Water pollution

Introduction

Water is essential and vital for human survival especially for domestic and agricultural purposes in the production of food and animals rearing, it is a resource that needs to be harnessed in a sustainable manner for the benefit of present and future generations. Over the year's water quality is deteriorating and the factors responsible are attributed to anthropogenic activities due to increase in population, subsequent urbanization and industrialization which put pressure on water by excessive usage, water bodies encroachment and conversion in to built-up lands, dumping of industrial wastes, domestic sewage and unrestrained siltation. These activities result in the obliteration of water and the entire catchment area.

Lakes are water bodies that are completely surrounded by land with no access to ocean or sea. Urban and periurban lakes are excellent reservoir of excessive runoff generated from paved urban areas which serves as source of water in the time of its dare need. The most wide-spread problems facing lakes in the urban and peri-urban areas are sewage from domestic sector, effluents from industrial sector (point sources), and agricultural nonpoint runoff of silt and associated nutrients and pesticides. This has led to the eutrophication, due to excessive inputs of nutrients and organic matter. Hydrologic and physical changes and siltation from catchment activities have resulted in special decline. Lakes are sinks for incoming contaminants that recycle and maintain the impaired conditions. Due to inadequate infrastructure facilities for waste disposal in the urban areas the urban lakes get polluted due to the natural topography and as collection points for the waste from the haphazard urban settlements. As a result of this and a number of other compounding factors most of the urban lakes are getting degraded beyond the point of recovery. Encroachments, accumulation of silt, weed infestation, discharge of domestic sewage, industrial effluents are the main causes for degradations of these lakes. Declining water quality, nuisance algae blooms, excessive weed growth, deteriorating fisheries, sediment infilling, eutrophication, contamination, bund erosion, water-use conflicts, impaired scenic qualities and upward appreciation of property values around the lake due to rapid urbanization are common problems being experienced by lake overseers as a result of human activities. The above factors hassled to either loss of the lake in its entirety or reduction in the area of the water body or the lake being deprived of aquatic life and choked with aquatic weeds leading to depletion of dissolved oxygen and release of obnoxious gases due to anaerobic reaction in the lake water. Mosquitoes breeding leads to various vector diseases on the surrounding areas of the lake.

Many studies have been carried out to understand the causes behind the lakes's alarming rate of eutrophication. However, analysis for understanding this phenomenon through the establishment of a statistical relationship between changing LULC and WQ is missing. Therefore, the present study was aimed to understand the degrading condition of the lake using long-term relationships between the changing LULC and WQ so that policymakers through informed decision-making could devise strategies aimed at reversing the changes that have resulted in its degradation.

Study Area

The study area Kolavai Lake (Figure-1) is a lake adjoining the town of Chengalpattu in Tamil Nadu, India. The lake is located about 60 kilometres from Chennai. The Kolavai Lake is one of the largest lakes situated at about 200 metres on the northeast of Chengalpattu and close to Pulipakkam village and it is located between longitude 79°58'40.235''E and 80°0'690''E and latitude 12°41'18.003''N and 12°43'25.749''N. The Kolavai Lake also receives water from rain drain canals (27 Km in length) during rainy season. It spread over 894 hectares and presently 12 villages are benefitted by this lake. This Lake has an annual storage capacity of 476.69 Mcft and with a depth of 4.59 metres. The total discharging capacity is about 5131 cusecs through by 5 sluices. The surplus water flows into Palar, Neenjal and Madura rivers. Earlier days, during the acute water shortage in summer, this lake serves as an additional source of water for the city of Chennai. The lake hosts migratory birds such as the whiskered tern, Indian spot-billed ducks, moorhens, coots, and small waders. Around 200 Kilogram of fish has been harvested per day in the lake. At present, this lake is getting polluted by the agricultural wastes, domestic sewage, hospital wastes and industrial effluents. As per the Water Resources Department (WRD), Government of Tamil Nadu, the Mahindra World City Industrial Park drew five million gallons of water from this lake daily. According to the Census of Indian 2011, the population of Chengalpattu town is 64,136. The local population also dump their garbage in most of the stations nearby the lake and an average of 1,450 litres of municipal waste water enters into the lake per day. As per the official record, the Town Panchayat collects 48 tonnes of garbage per day. During the rainy season most of the garbage is washed into the lake and it also causes pollution.

Materials & Methods

The Survey of India 1:50,000 topographical maps have been used to trace the Kolavai Lake area (Figure.2). The SRTM DEM satellite data with limited Ground Control Point of GNSS, the slope aspect has been created. Further, the SRTM DEM has been used to derive the network of drainage, flow direction, flow accumulation and catchment boundary of the Kolavai Lake through Arc hydro tool. The morphometric analyses were carried out for the entire catchment to determine the linear, areal and relief aspects of the Kolavai Lake catchment. The Remote sensing data (Landsat) were used for mapping the land use and land cover of the study area for threetime period (2000, 2010 and 2020). The level-II classification of NRSC has been adopted to prepare the land use/land cover for the three-time period. The area of the respective categories has been calculated and the land use/land cover change detection is made. Various indices like Normalised Difference Vegetation Index (NDVI), Normalised Difference Built-up Index (NDBI) and Normalised Difference Turbidity Index (NDTI) have been derived from the remote sensing data to support the catchment analysis. About seven water sample locations have been chosen in the lake by considering various land use practices and stream morphometry. The water sample have been collected in the seven locations and tested the laboratory as per the Central Pollution Control Board norms. Thirteen physicochemical parameters, namely pH, TDS, Nitrate, Calcium, Magnesium, Total hardness, Chloride, Fluoride, sulphate, DO, COD and BOD were used to calculate the Water Quality Index (WQI). The WQI have correlate with the land use/land cover and stream morphometry to justify the level of pollution in the lake.

Results and Discussion

Landuse/Landcover Analysis of Kolavai Lake Catchment

Land use (LU) refers to the human employment of land and is the planned hiring and management strategy laced on the land defined by humans (Pradhan 2010). On the contrary, land cover (LC) is the natural cover on the land defined by natural processes. It includes the distribution of vegetation, water, desert and ice, and the immediate subsurface, including biota, soil, topography, surface, and groundwater (Meraj et al. 2012). LULC change is a dynamic process driven by natural phenomena and anthropogenic activities that, in turn, compel deviations impacting natural ecosystems (Skilodimou et al. 2003). Changes in LULC have a significant influence on earth system processes such as hydrology, climate, biogeochemical cycles resulting in adverse environmental issues if promulgated unfettered (Bhat et al.2016). Many urban landuse studies have used satellite images to generate accurate urban landuse maps and also detected changes in urban land use/land cover (Javed et al. 2009). The short- and long-term monitoring of LULC change is vital in establishing links between policy decision-making, regulatory actions, and subsequent land use planning activities for the management of natural resources.

Landsat multi-resolution/multi-temporal satellite data were used for the LULC analysis, comprising of Landsat ETM (19 September 2000, 14.25 m), ETM+ (24 October, 2010, 30 m), and OLI (27 September 2020, 30 m). The National Natural Resource Management Scheme (NNRMS) standards for land use/land cover mapping were followed in the entire LULC classification The supervised classification has been used to prepare the LULC classification for the year 2000, 2010 and 2020. The reliability of the LULC is adjudged by the accuracy assessment technique designated by the Kappa coefficient. The Kappa coefficient of 0.91 for LULC 2019 revealed significant accuracy of the LULC products generated and was calculated. The area of the LULC categories have been calculated for the individual years and the change detection also arrived between the years.

The results of the LULC of the Kolavai Lake catchment along with the change analysis are presented in Table-1. The LULC analysis of the study area (Figure-3) for the year 2000 revealed that out of six LULC classes, Agriculture and forest are the dominant categories in the study area with 23% and 20% of the total geographical area respectively. Land with scrub and land without scrub covered 19% and 16% of the total geographical area. The water bodies occupy about 14% and Built-up area occupied a minimum of 8% to the total geographical area. During the year 2010, there had been some changes in the LULC class (Figura.4). The Land with scrub and Land without scrub dominant category and constitute about 21% and 19% of the total geographical area of the catchment, followed by Agricultural land (18%), Built-up area (15%), Forest (15%) and waterbodies (12%) respectively. In the year 2020 (Figura.5), Built-up area was the dominant category in the study area that constituted about 27% of the total geographical area of the catchment, followed by Land without scrub (20%), Land with scrub (19%), Agricultural land (13%), Water bodies (11%) and Forest (10%) respectively.

Decadal LULC change analysis of the Kolavai Lake catchment

There has been a considerable change in all of the six landuse/landcover categories identified and mapped since

2000. The area under agriculture, forests, and water bodies has been decreasing unceasingly between 2000 and 2010. On the contrary, the area under Land with scrub, Land without scrub and Built-up area has been witnessing increase, consistently between 2000 and 2010. The results, as indicated in Table-1 reveal that area under forests has decreased from 20% in 1980 to 15%in 2010, showing a negative growth rate of -5 %. Agriculture has also witnessed a decreasing trend in the area since 2000. The area under agriculture decreased from 23% in 2000 to 18% in 2010, recording a negative growth rate of -5%. Water bodies has also observed a decreasing trend in the area since 2000. The area under water bodies decreased from 14% in 2000 to 12% in 2010, recording a negative growth rate of -2%. The area under Built-up area has increased from 08% in 2000 to 15% in 2010, recording a positive growth rate of +7% followed by Land with scrub increased from 19% in 2000 to 21% in 2010, positive growth of +2% and Land without scrub increased from 16% in 2000 to 19% in 2010, shows positive growth rate of +3%.

There has been a drastic change in all of the six landuse/landcover categories identified and mapped since2000. The area under agriculture, forests, and water bodies has been decreasing unceasingly between 2000 and 2020. On the contrary, the area under Land without scrub and Built-up area has been witnessing increase, consistently between 2000 and 2020. The results, as indicated in Table-1 reveal that area under forests has decreased from 20% in 2000 to 10% in 2010, showing a negative growth rate of -10 %. Agriculture has also witnessed a decreasing trend in the area since 2000. The area under agriculture decreased from 23% in 2000 to 13% in 2020, recording a negative growth rate of -10%. Water bodies has also observed a decreasing trend in the area since 2000. The area under water bodies decreased from 14% in 2000 to 11% in 2010, recording a negative growth rate of -3%. The area under Built-up area has increased from 08% in 2000 to 27% in 2020, recording a positive growth rate of +19% followed by Land without scrub increased from 16% in 2000 to 20% in 2020, shows positive growth rate of +4%. There is no change in Land with scrub from 19% in 2000 to 19% in 2020.

The change detection analysis shows that the built-up area has increased drastically 19% compared the period from 2000-2020. It is a clear evident that most of the agricultural, forest and water bodies categories of LULC has converted in to industrialisation and urbanisation process. Due to the water and soil stress the land without scrub increased 4% when compared to 2000-2020.

Water quality Analysis of Kolavai Lake Catchment

The physico-chemical parameter results clearly show (Table-2) the level of lake water degraded due to the mismanagement of the surface water body. The pH values observed higher in the sample location 4 and less observed in 6 and 7 sample locations. It shows that the concentration of pH is less in the deeper area of the lake. The Dissolved Oxygen (*DO*) is one of the important parameters in water quality assessments (Solanki et al, 2006). Decrease allochthonous in the dissolved oxygen level in sample location 3, 4, 6 in this study might be the result of utilization of dissolved oxygen for the decay of autochthonous and materials that get dumped (Radhika et al., 2004). A low value of dissolved oxygen was also due to the increased microbial activity in the water. The dissolved oxygen depiction could also be attributed to the phytoplankton respiration and sediment oxygen demand (Wani et al, 2002). The values of Biological Oxygen Demand (*BOD*) directly show the extent of pollution in water samples. Biological oxygen demand values of the sample location 1, 4, 5, 2 and 6 in the present analysis were above the permissible level as suggested by CPCB for drinking, bathing and swimming. Higher value of Biological oxygen demand might be due to higher rate of organic decomposition (Bhatt et al, 1999). Low Chemical Oxygen Demand (*COD*) values recorded in sample location 2 and 7 in the present study might be the result of sedimentation of organic materials to the bottom.

Calcium was a very important element influencing the flora of ecosystem which played a potential role in metabolism and growth and in the present study calcium level in sample location 5, 6 and 7 were below the permissible limit of CPCB (1995). Very low concentration of nitrate in sample location 1 and 7 in this study might be due to the utilization of nitrate for the luxuriant growth of macrophytes. The presence of fluoride concentration in a water source was used as an indicator of organic pollution by domestic sewage (Chandrashekar et al 2003). There was a direct relation between fluoride concentration and pollution level. Low concentration of fluoride in the sample location 2, 3, 6 and 7 indicated the low amount of organic waste of animal origin and the high concentration of fluoride gives and undesirable taste of water (sample location 1, 4 and 5). The Water hardness observed higher in all the samples except sample location 2.

The analysis of physico-chemical characteristics from seven locations of water samples of Kolavai Lake shows the *DO*, *BOD*, and fluoride values were observed higher than the permissible limits for drinking water standards prescribed by CPCB (1995) indicated high level of pollution in the lake. Since the sample location 4 is the entry point of industrial and domestic waste, it highly polluted than the other six sample locations.

Conclusions

The land use/land cover changes over a period of time has been modified the Kolavai Lake catchment landscape in a larger way. The network of natural streams has been blocked and small ponds were disappeared by the urbanisation and industrialization process. Due to the blockages of the surface water flow, during the rainy period the lake catchment is getting flooded. The sewage drains and some of the storm water drains carrying sewage water and let it in to the Kolavai Lake. The WQI indices proved that the upstream anthropological activities, garbage, municipal wastes, hospital wastes, make the changes in the water quality of the lake. The turbidity Indices also proved that the Lake is getting more sediments and sludge from its catchment and it is reducing the carrying capacity of the lake. Hence, it is an urgent need to conserve physical, chemical and biological status of the lake with community participation. The present study demonstrated the usefulness of remote sensing data and techniques to analyse the catchment area of the lake for bringing the sustainability for the future generation.

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