ABSTRACT

Urban sprawl is considered a potential menace to sustainable development. Concurrent with the significant rise in population, urban expansion, driven by the need for housing, industry, and commerce, is extending into the outskirts of cities, resulting in the encroachment upon natural vegetation, agricultural lands, and barren lands. The regulated/unregulated and spontaneous expansion is known as sprawl. Changes in land use/land cover (LULC) are emphasized in the present study for monitoring the temporal changes and analyse its impact on runoff.

In the present work, Vadodara city is selected as study area, as the city is frequently observing the problems of flooding/waterlogging in the recent years. The daily rainfall data is collected from the State Water Data Center, Gandhinagar for the period of 1961 – 2018. The daily rainfall data collected is used for analysing the rainfall variability and trend analysis has also been carried out. The current study presents the change detection of land use/land cover for Vadodara City using approaches of remote sensing and geographic information systems. The landsat satellite images of the years 1977, 1988, 1998, 2008 and 2018 are collected from the USGS website and are used for assessing the changes in LULC. Using the LULC maps, rainfall data, the runoff is computed using Soil Conservation Services -Curve Number (SCS – CN) method.

To classify the landsat images, a combined classification comprising of unsupervised and supervised classification was utilised in the pre-processing of the landsat images. Using image categorization based on satellite images and Google Maps, five distinct LULC classes namely waterbodies, urban settlement, natural vegetation, agricultural land, and barren land —have been identified. Urban settlement has not only expanded in terms of land holding, but it has also led to the phenomenon of sprawl in the area. Several sprawl indices were computed to confirm the occurrence of urban sprawl in the city of Vadodara. A total of nine sprawl indices are computed, specifically Land Consumption Ratio (LCR), Population Density, Urbanness, Urban Expansion Index (UEI), Landscape expansion Index (LEI), Average Annual Urban Expansion Rate (AUER), Urban Growth Coefficient (UGC), Urban Expansion Intensity Index (UEII), Urban Expansion Differentiation Index (UEDI).

The urban sprawl affects the LULC in the area, which in turn affects the runoff in the area. So it is necessary to analyse the impact of LULC on Runoff. The SCS – CN method is used in the present study to compute the runoff, incorporating the LULC classes identified. The calculation of runoff involved considering factors such as soil type and land use/land cover classifications. This is done using a dimensionless quantity called the curve number. Subsequently, the curve numbers are corrected for the antecedent moisture conditions and employed in conjunction with runoff formulae to determine the amount of runoff. The curve numbers are derived from the soil type and land use/land cover categories.

The IDF curves are used to describe rainfall intensity as a function of duration for a given return period which are important for the design of storm water drainage systems and hydraulic structures. In this study, IDF curves are generated for rainfall and runoff data. The daily rainfall data, for different rainfall durations are computed using Indian Meteorological Department (IMD) empirical reduction formula to estimate the short duration rainfall intensity i.e. 1, 2, 6, 12 & 24 hours, with return periods of 2, 5, 10, 25, 50, 100 years, to determine rainfall intensity and runoff intensity using Gumbel's Extreme Value Distribution. The various empirical formulas given by Tablot, Bernard, Kimijima and Sherman are used to estimate the rainfall intensity. Amongst these empirical equations, Sherman's equation is considered as the best approximation of rainfall intensity for return periods of 2, 5, 10,15, 20, 25, 30, 50, 75 and 100 years. The results show a good match as the correlation coefficient is observed greater than 0.999. This indicated that the empirical formula given by Sherman can be used to estimate rainfall intensity in the study area for short durations.

To predict the probable LULC changes in the study area, various statistical models namely linear, logarithmic, polynomial, exponential and power models have been used. The equations developed using these models are used to estimate the LULC classes for the years 2028, 2038 and 2048.

The change detection of LULC classes has been carried out for the four decades of 1977 – 1988, 1988 – 1998, 1998 – 2008 and 2008 – 2018. Amongst all these changes, that took place, in the year 1977, natural vegetation had the maximum holding of 33% of area. In the year 1988, the agricultural land was maximum with a holding of 31% of area. In 1998, urban settlement overtook 32.07% of maximum area and it continued to increase by 47.85% in 2008 and also increased to 56.85% in 2018. The results of LULC change detection also showed that, for these four decades, the urban settlement is gradually increased in the first two decades by 9% & 10% respectively, i.e. from 13% to 22% in 1977 – 1988 and 22% to 32% and in the third decade there is 16% of rise observed i.e. from 32% to 48% and again the last decade, it is raised by 9% i.e. from 48% to 57%. For the same decades, the natural vegetation is found to be decreased by 31%, barren land decreased by 33%, agricultural land increased by 21% and water bodies are stable up to 1%.

Out of the nine urban sprawl indices calculated, four of them give qualitative outcomes while the rest demonstrate quantitative findings. The two qualitative indexes, UEI and LEI, confirm that the increases observed in all the four decades is characterized by edge expansion growth. Two further qualitative indices, namely UEII and UEDI, indicate that the area is experiencing rapid increase in the first decade and even faster expansion in the subsequent three decades. Furthermore, UEDI suggests that the area is consistently developing at a fast pace during all four decades. The LCR exhibits consistently high values each year, peaking in 2018 at 66.52. The population density reached its lowest point in 2018, indicating a significant increase in urban sprawl during that year. Urbanness values exhibit a steady upward trend from 1977 to 2018. AUER has experienced the highest level of growth in the past ten years, reaching a value of 45.06. Additionally, UGC has shown an increasing tendency in its growth coefficient, reaching a maximum of 10.80 in 2018. The results indicate a significant level of urban expansion in the city of Vadodara, which can have direct impacts on the runoff. The rapid expansion of urban areas has a significant impact on the runoff.

The curve numbers for the study area obtained for the years 1977, 1988, 1998, 2008, and 2018 are 74.80, 82.81, 81.19, 85.54, and 84.92, respectively. The curve numbers accurately depict the land use and land cover regions. As the area becomes more impermeable, the CN value is observed to be increased. During the study period, a consistent increase in the CN values is noticed, indicating a significant alteration in the land use and land cover for every decade.

The runoffs are obtained against the Annual One Day Maximum Rainfall (AODMR) for the years from 1977 – 2018. The maximum runoff obtained in the decades of 1977 – 1987, 1988 – 1997, 1998 – 2007, 2008 – 2018, has been analysed. From the analysis it can be said that the maximum amount of rainfall/ maximum AODMR during the first decade considered, is 224 mm and minimum of AODMR is 77 mm and the corresponding runoff comes out to be 138 mm and 42 mm, which is 62% and 55%. Similar analysis when carried out for 1988 – 1997, the percentage of runoff corresponding to maximum of AODMR and minimum of AODMR comes out to be 87% (for AODMR 256 mm – 228 mm runoff) and 63% (for AODMR 66 mm – 43 mm runoff). For 1998 – 2007, and 2008 – 2018, the runoff corresponding to maximum & minimum AODMR values comes out to be 90% (for AODMR 315 mm – 284 mm runoff) & 70% (for AODMR 93 mm – 66 mm runoff) and 91% (for AODMR 232 mm – 209 mm runoff) & 80% (for AODMR 103 mm – 82 mm runoff) respectively. It is clearly evident that around 30% of additional runoff can be observed when compared with the year 1977 and 2018, which may be directly attributed to the changes in LULC and Urban Sprawl.

The three different scenarios are considered to analyse the impact of LULC changes on runoff. In Scenario 1, superimposing the maps of 1988, 1998, 2008 and 2018 on the map of 1977, by considering the area same as that of 1977, the changes in runoff observed are varying from 60% to 84%, which is found to be increasing in every decade. Similarly, In Scenario 2, superimposing the maps of 1998, 2008 and 2018 on the map of 1988, by considering the area same as that of 1988, the changes in runoff observed are varying from 60% to 87%, which is found to be increasing in every decade and In Scenario 3, superimposing the maps of 1998, 2008 and 2018 on the map of 1998, by considering the area same as that of 1998, the changes in runoff observed are varying from 65% to 85%, which is found to be increasing in every decade. These increasing runoffs clearly depict the rise is due to the impact of LULC changes. By considering an alternative approach, in which five scenarios are considered to analyse the impact of LULC change on runoff by keeping the rainfall constant for the base year and swapping the other years with the base year, the results obtained shows that the runoff values are increasing with time, which is in decades.

The runoff values vary from 55% to 85% from 1977 - 2018, with an increasing trend showing the impact of LULC on runoff.

The Gumbel's Extreme Value Distribution approach and the empirical equation proposed by Sherman are regarded as the most accurate approximations for rainfall intensity for return periods of 2, 5, 10, 15, 20, 25, 30, 50, 75, and 100 years. The IDF curves are generated for rainfall intensities and runoff intensities by using Gumbel's Extreme Value Distribution. Results of which show that for 1 hour duration, the rainfall intensity comes out to be as 45.54, 63.01, 74.58, 89.20, 100.04 and 110.80 mm/hr. for 2, 5, 10, 25, 50 and 100 years return periods respectively. Simultaneously, for 1 hour duration, the runoff intensity comes out to be 29.43, 47.48, 59.43, 74.53, 85.73 and 96.85 mm/hr. for 2, 5, 10, 25, 50 and 100 year return periods respectively. Similarly, for the durations of 2H, 6H, 12H and 24H, rainfall and runoff intensities are computed, and it is observed that, as time duration increases, the rainfall intensity in mm/hr. is decreased and the amount of rainfall, in mm is increased with increase of return periods from 2, 5, 10, 25, 50 and 100 years.

The total area of Vadodara city for the years 2028, 2038 and 2048 is estimated to be around 483, 625 and 790 Sq. Km. Therefore, the percentage change in future 10 years, 20 years and 30 years with base year as 2018 is estimated as the range of 11%, 26% and 41% increase respectively. From the estimated models, the urban settlement in Vadodara city for the years 2028, 2038 and 2048 is estimated to be around 175, 235 and 305 Sq. Km. Therefore, the percentage change in future 10 years, 20 years and 30 years with base year as 2018 is estimated as 43%, 91% and 150% increase in urban settlement. This increase will have the direct impact on the increase in runoff.

In the present study, the increase in runoff ranges from 30% to 50%, for the city of Vadodara. The water which is flowing as runoff will cause urban flooding/ water logging during the periods of heavy rainfall. Managing of excess rainfall/ runoff is crucial for reducing the peak and minimize the post effects of urban flooding/waterlogging. Improving the current natural areas along riverbanks and in flood plains will help to manage riverine flooding. Vishwamitri river passes from the center of the city, and as it enters the city, it becomes narrower. So widening and deepening the river will help in reducing the flood peaks. Re-establishing plant life in the region near the river will improve the absorption of water, reduce the likelihood of flooding, and limit the severity of destruction caused by river floods. Developing and implementing effective plans and techniques for stormwater management, so the excess water can either be diverted or stored, will help to save the quantity of water which can further be utilised for recharging the groundwater. Construction of retention basins, detention ponds, can be implemented to control and manage the volume of water. The stormwater drainage can be properly positioned to collect water from sources where there is problem of flooding, so that it can be efficiently stored/transported to the nearest site of recharge. In the places where new developments are taking place, efficient rainwater harvesting facilities should be provided. There are several ponds in Vadodara city, so the excess rainfall/ runoff should be diverted to these ponds which will further be useful in groundwater recharge of that area.

In the current study, the decade-wise change in LULC has been identified for the last 40 years. The type of growth that is happening is highly impacting the runoff. So, this study will be useful to the urban planners to observe the changes and control the sprawl taking place in such a way that it's impact on the runoff is either balanced or reduced or improved. The estimations for urban settlement and total area are given for further 30 years, which will help the urban planners to regulate the sprawl, in such a way that it will not impact the further increase of runoff. the This study will be very useful to the water managers, in a way that, this study presents the amount of runoff that is increasing, which is causing flooding situation, so its mitigation is important and, it is also important for the water managers to manage this excess water in a way that it will be useful to society.