CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL

This chapter briefly shows the conclusions obtained for the individual objective. Based on the conclusions, recommendations have been drawn, which are described below.

6.2 CONCLUSIONS

Objective 1: To study the changes in Land Use/Land Cover (LULC) over a period, that influences the runoff characteristics of the study area.

The LULC classification carried out for the years 1977, 1988, 1998, 2008 and 2018 shows that in the year 1977 the total area was 88.10 Sq. Km. with a holding of 2% waterbodies, 13% urban settlement, 46% natural vegetation, 4% agricultural land, 34% barren land. From 1977 – 1988, the total area was increased by 23%, expanding from 88.10 Sq. Km. to 108.18 Sq. Km., with a maximum increase of agricultural land by 27% and an increase in urban settlement 9%, i.e. from 13% in 1977, increased up to 22% in 1988.

From 1988 – 1998, the total area expanded from 108.18 Sq. Km to 149.96 Sq. Km., in which the urban settlement increased from 22% to 32%, i.e. a raise of 10%, natural vegetation and agricultural land increased about 5%, barren land decreased at about 12%, waterbodies showed a slight decrease of about 0.35%.

From 1998 – 2008, the total area increased from 149.96 Sq. Km. to 168.75 Sq. Km. In this decade, maximum growth of 16% i.e. from 32% in 1998 to 48% in 2008, was seen in urban settlement, barren land was observed to be reduced by 14% and, 7% increase in natural vegetation was also observed.

From 2008 – 2018, the total area increased from 168.75 Sq. Km. to 214.63 Sq. Km. The barren land had drastically reduced by 18% against 9% i.e. from 48% to 57%, increase in urban settlement and 4% increase in each natural vegetation and agricultural land.

Amongst all these changes, that took place, in the year 1977, natural vegetation had the maximum holding of 33% of area. In 1988, the agricultural land was maximum with a holding of 31% of area. In 1998, urban settlement overtook 32.07% of maximum holding area and it continued to increase by 47.85% in 2008 and increased around 56.85% in 2018.

The total area of the study, for the year 1977, 1988, 1998, 2008 and 2018 have increased in every decade. As the total area is increasing, agricultural land, natural vegetation and barren land are included in these areas. Later on, these areas are gradually shifted into urban settlement. Urban settlement is the only LULC class which is continuously increasing in every decade and others are increasing/decreasing in varied proportions. So, it can be said that, in future also urban settlement will go on increasing and the other classes may also shift towards urban settlement.

The LULC classification for mid years in the decades of 1988 – 1998 – 2008 – 2018, was done for the years 1993, 2003 and 2013. For the decade of 1988 – 1998, the urban settlement was increased by 9% in which it was increased by only 1% in 1988 – 1993 and from 1993 – 1998, it was raised by 8%. Similarly in 1998 – 2008, the urban settlement was raised to 16%, in which only 1% rise was observed in 1998 – 2003, whereas 15% increased from 2003 – 2008. The rate of change of urban settlement in last five years of decade is found to be high.

The results show that the urban settlement increased by 1% in 1988 – 1993 and 8% from 1993 – 2003, for 9% increase in 1988 – 1998, Similarly for the decade of 1998 – 2008, the total increase in urban settlement is 16%, which is 1% from 1998 – 2003 and 15% from 2003 – 2008. For the decade of 2008 – 2018, there is a total of 9% increase, which is 15% increase from 2008 – 2013.

The various sprawl indices calculated, ensured the sprawl taking place in the Vadodara city.

Nine sprawl indices are calculated namely 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 LCR has been increasing steadily over the years, with a maximum increase of 12.77 in 2008-2018. The population density is also increasing, with a maximum of 112.32 in 2008. Urbanness is also increasing, with a maximum of 0.160 in 1998-2008. The UEI and LEI shows growth patterns as edge expansion. Amongst these nine indices calculated, four of them are qualitative results and others are showing quantitative results. two qualitative indices namely UEI and LEI ensure that the type of growth in all four decade is type of edge expansion growth. Other two qualitative indices namely UEII shows that the area is observing a high-speed expansion in the first decade and a very high-speed expansion in the other three decades and UEDI shows type of area is fast growing in all the four decades. Other quantitative indices like LCR shows a high land consumption rate in every year with maximum in the year 2018 with a value of 66.52. Population density shows the lowest value in 2018 which shows that maximum amount of sprawl has taken place in the year 2018. Urbanness values show an increasing trend from 1977 to 2018. AUER yields maximum growth in the last decade with a value of 45.06 and lastly UGC showing growth coefficient in the increasing trend with a maximum of 10.80 in the year 2018.

All the results of urban sprawl indices ensure a high degree of sprawl being observed, in the city of Vadodara, which can directly affect and impact runoff due to urbanisation.

Objective 2: To study and analyse the Rainfall over a number of decades in the study area.

The rainfall analysis is carried out from 1961 to 2018, for a period of 58 years. Results shows that, in the six decades i.e.1961 – 1970, 1971 – 1980, 1981 – 1990, 1991 – 2000, 2001 – 2010 and 2011 – 2018. The number of zero/no rainy days are decreasing in all the decades except 1991 – 2000. The number of rainy days with heavy rainfall (31 mm – 50 mm) is maximum, i.e. 49 days, during 2001 – 2010. Similarly, very high rainfall (> 50 mm) is 53 days during 2001 – 2010. This indicates a shift in the rainfall pattern and this together with change in LULC highly impacts runoff. The trend in increased rainy days with heavy rainfall can be used to inform future climate predictions. Also, from the results of annual rainfall analysis it was observed that there was a major shift in rainfall pattern after 2001 years as seasonal rainfall during the southwest monsoon was increasing while increasing in post-monsoon season.

The monthly rainfall analysis from 1961 – 2018, shows that June month contributes 15%, July contributes 38%, August 31 % and September 16% of the average annual rainfall. The decadal analysis of rainfall shows that during 2011-2018 there is maximum amount of rainfall in the month of July which is 438.75 mm and minimum amount of rainfall in the month of June which is 117.50 mm during 1961 – 2018.

When the rainfall variability is analysed for the six decades of 1961 – 1970, 1971 – 1980, 1981 – 1990, 1991 – 2000, 2001 – 2010, 2011 -2018, the results indicate that during the first four decades the rainfall variability is high which is more that 40% and for 2001-2010 and 2011-2018 the rainfall variability is less than 40%. Similarly, when rainfall variability is analysed from 1961 – 2018, for months of June, July, August and September, the results shows that the percentage variabilities are 96.33%, 48.84%, 64.91% and 99.70% respectively.

From the analysis of Mann Kendall trend test and Sen's slope estimator, from 1961 – 2018, it is observed that in the month of July, the test Z value is 1.7 which is maximum and for month of June the test Z value is -0.14. Which depicts that the rainfall in the month of June is following a decreasing trend and the rainfall in July month is following an increasing trend. Similarly, August is following decreasing trend and September is following an increasing trend.

Objective 3: To determine and analyse the runoff in the study area using quantitative techniques like Soil Conservation Services-Curve Number (SCS-CN) method using Remote Sensing and Geographic Information System (GIS).

The SCS-CN method was originally devised by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) and is used in the present study to calculate runoff.

The curve numbers obtained based on the type of soil, land use/ land cover and corrected for AMC, for the study years of 1977, 1988, 1998, 2008 and 2018. The curve numbers truly represent the land use/land cover areas. The more the area is impervious higher is the CN value.

Annual One Day Maximum Rainfall (AODMR) values are used to calculate the runoff for the decades of 1977 – 1988, 1988 – 1998, 1998 – 2008, 2008 -2018 respectively. The one-day maximum runoff of the decade is used for analysis. From the results, it is observed 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 – 1998, the percentage of runoff corresponding to maximum of AODMR and minimum of AODMR comes out to be 89% and 65%. For 1998 – 2008, and 2008 – 2018, the runoff corresponding to maximum & minimum AODMR values comes out to be 90% & 70% and 91% & 80% 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.

Also, considering the total rainfall and total runoff values for every decade, an increasing trend in the runoff has been observed, with reference to the same magnitude of rainfall. When the total rainfall and total runoff, are compared and analysed, the results of the percentage of runoff during every decade, i.e. 1977 – 1988, 1988 – 1998, 1998 – 2008 and 2008 - 2018 is increasing which is around 34%, 47%, 52 and 57% for every decade respectively. This again can be seen increasing, which may be due to changes in LULC/ urban sprawl changes.

Objective 4: To analyse the impact of Land Use/ Land Cover (LULC) changes on Runoff in the study area.

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 increased 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 are varying from 55% to 85% from 1977 - 2018, with an increasing trend showing the impact of LULC on runoff.

Objective 5: To determine rainfall and runoff for various recurrence intervals i.e., for 2, 5, 10, 15, 20, 25, 50, 75 and 100 years return period.

The rainfall and runoff intensities for various durations of 1 hour (H), 2H, 6H, 12H and 24H and for various return periods different are obtained using IDF curves.

The Gumbel distribution is used for generation of IDF curves, and the results shows 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.

Furthermore, various empirical formulas were used viz., Tablot, Bernard, Kimijima and Sherman to calculate the rainfall intensities for the various durations and various return periods. 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.

Objective 6: To predict probable Land Use/ Land Cover changes in the study area.

To predict 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 total areas in 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 in urban settlement.

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.

6.3 RECOMMENDATIONS

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.

6.4 RECOMMENDATIONS FOR FURTHER STUDY

ResourceSat series developed by the Indian Space Research Organisation (ISRO) that can be used for LULC mapping with a high spatial resolution of up to 5.8 meters with revisit time of 5 days. The data of ResourceSat with 5.8 m resolution is available from the year 2014. Sentinel-2 is a satellite mission developed by the European Space Agency (ESA) which is available at different spatial resolutions of 10 m, 20 m, 60 m., with a revisit time of 5 days to 2 days. The high temporal and spatial resolution of Sentinel-2 imagery makes it valuable for monitoring dynamic processes and changes on Earth's surface over time. The data availability of Sentinel images started in the year 2014.

LULC changes other than runoff, that can influence local and regional climate patterns through alterations in surface albedo, evapotranspiration rates, and heat absorption. Urbanization, deforestation, and agricultural expansion can contribute to the urban heat island effect, increased temperatures, and changes in precipitation patterns. Therefore, the impact of LULC on these changes may be studied and analysed.

LULC can also impact ecological systems. Alteration of land use and land cover can disrupt ecosystems, leading to habitat loss, fragmentation, and degradation. Changes in land cover affect biodiversity by modifying habitats and reducing the availability of resources for wildlife. Conversion of natural landscapes into urban or agricultural areas can result in the loss of ecosystem services such as carbon sequestration, water filtration, and soil conservation. Therefore, the impact of LULC on the above said changes may be studied and analysed leading to a multidisciplinary approach.

6.5 LIMITATIONS OF THE PRESENT STUDY

- The present study does not deal with the quality aspect of the runoff.
- Urban sprawl is a complex phenomenon influenced by various factors including population growth, economic development, transportation infrastructure, land use policies, and social preferences. The present study deals with forecasting of the area of urban expansion, but however the direction/ concentration of urban sprawl is not considered.