Table of Contents

Executive Summary

For any country, managing its water supplies has always been a big challenge. The development of water resources necessitates resolving the crucial challenges of storage, conservation, and ultimately utilisation of water. In order to develop a comprehensive management strategy for the efficient conservation and use of water resources, space technology plays a crucial role in managing country's available water resources. To achieve the best planning and operation of water resources projects, systematic procedures incorporating the thoughtful blending of traditional ground measurements with remote sensing techniques are necessary. To track the development and effects of the aforementioned projects, the satellites' synoptic and repeated coverage can be a useful addition to the traditional data. In order to plan and track several water resources management initiatives, remote sensing imagery from polar orbiting satellites is a viable tool.

The Earth's surface has undergone significant change as a result of urbanisation, agriculture, timber harvesting, mineral extraction, and other land uses. Ecological, environmental, and hydrologic systems and processes are significantly impacted by changes in land use and the resulting shift in land cover. For effective management, it is essential to have a grasp of past and current land-cover change as well as an analysis of anticipated future change; this necessitates the use of models. The different purposes of hydrologic models are hydrologic prediction and hydrologic process comprehension. In order to evaluate the effects of various land use/ land cover scenarios, hydrologic models now use technology-based tools like GIS. Future land use/ land cover can be projected using hydrologic models integrated with GIS to increase the clarity, probability, or likelihood of prospective effects on ecosystem services including biodiversity, water quality, and climate.

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.

OBJECTIVES OF THE PRESENT STUDY

1. To study the changes in Land Use/ Land Cover (LULC)/Urban Sprawl over a period, that influences the runoff characteristics of the study area.
2. To study and analyse the Rainfall over a number of decades in the study area.

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).
4. To analyse the impact of Land Use/ Land Cover changes on Runoff in the study area.
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.
6. To predict probable Land Use/ Land Cover changes in the study area.

Suggestive measures/ recommendations will be drawn out from the present study, to store/discharge the rainfall excess/runoff water so as to safely reduce the probable occurrences of flood peaks.

The Literature review briefly shows the research papers studied for the current objectives of the study. The literature review carried out under the study is categorised as follows:

- Literature related to Rainfall Analysis
- Literature related to Land Use/ Land Cover Analysis
- Literature related to Urban Sprawl
- Literature related to Runoff Computations
- Literature related to Rainfall Analysis

This is followed by the methodology, adopted for the individual objective. The chapters are divided into six sections, each section contains the specific methodology for the specific objective.

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.
In principle, land cover mapping from satellite data consists of following steps: data acquisition, pre-processing, analysis/classification, product generation and documentation.

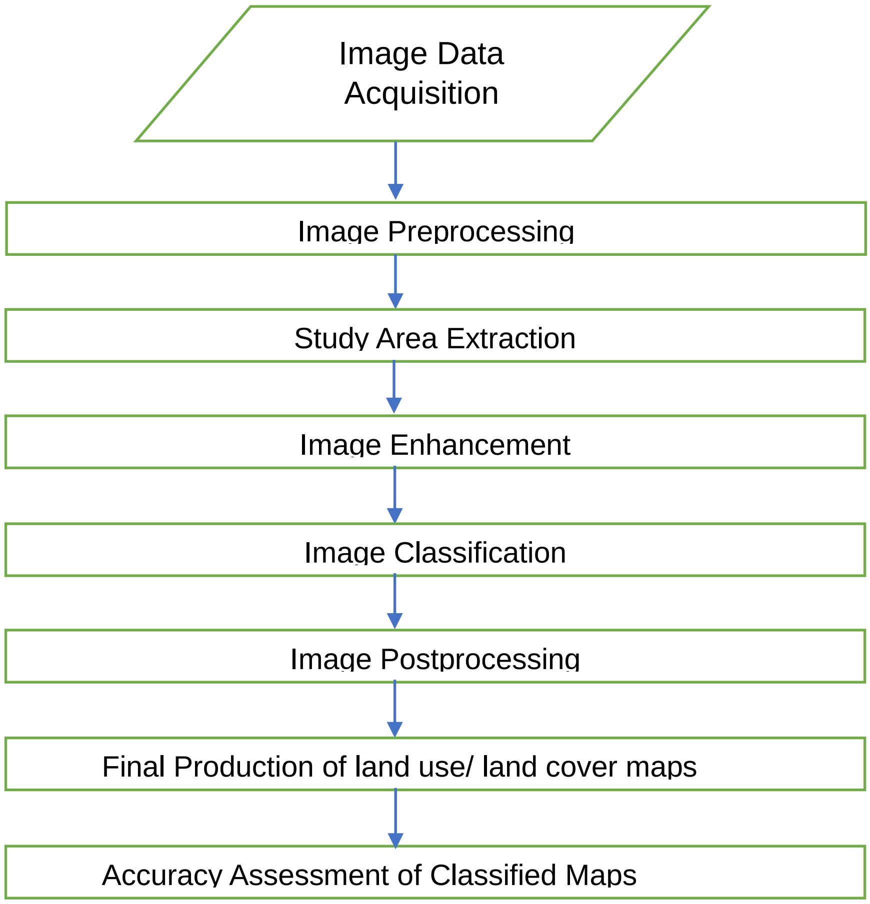


Figure 4.2: Flowchart for LULC detection

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).

Rainfall analysis has been carried out using the rainfall variability studies and trend analysis test namely the mann kendall test.

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.

To analyse the impact of land use/ land cover changes on runoff three scenarios have been considered, where in for each of the years of 1977, 1988, 1998, 2008 and 2018, five maximum daily rainfall events of each year have been considered, to compute and analyse the runoff. The purpose of considering these five values of maximum rainfall is that those values are most likely to affect the runoff in the area.

Scenario 1 – Considering 1977 as a base year and superimposing the LULC maps of 1988, 1998, 2008 and 2018 on the base map and considering the extent of area to be same as that of 1977, the changes in runoff values are analysed. The changes in runoff will definitely occur due to the changes in LULC for different years.

Scenario 2 – Considering 1988 as a base year and superimposing the LULC maps of 1998, 2008 and 2018 on the base map, the changes and considering the extent of area to be same as that of 1988, the changes in runoff values are analysed. The change in runoff will definitely occur due to the changes in LULC for different years.

Scenario 3 – Considering 1998 as a base year and superimposing the LULC maps of 2008 and 2018 on the base map, the changes and considering the extent of area to be same as that of 1998, the changes in runoff values are analysed. The change in runoff will definitely occur due to the changes in for different years.

Alternative Approach

Scenario 4: Considering 1977 as a base year, daily maximum rainfall of base year, the runoff of base year is compared to the runoff of the years 1988, 1998, 2008 and 2018 respectively by swapping their LULC maps.

Scenario 5: Considering 1988 as a base year, taking top 5 daily rainfall values from this year, daily maximum rainfall of base year, the runoff of base year is compared to the runoff of the years 1977, 1998, 2008 and 2018 respectively by swapping their LULC maps.

Scenario 6: Considering 1998 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LULC of study years 1977, 1988, 2008 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 1998.

Scenario 7: Considering 2008 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LULC of study years 1977, 1988, 1998 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 2008.

Scenario 8: Considering 2018 as a base year, taking top 5 daily rainfall values from this year, runoff is computed considering the LULC of study years 1977, 1988, 1998 and 2008 and then, comparing these values of runoff with values of base year runoff i.e., 2018.

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%.

A decadal analysis of the LULC maps obtained, is carried out from 1977 to 2018, for four decades namely 1977 – 1988, 1988 – 1998, 1998 – 2008, 2008 to 2018, respectively. The areas and percentages of land use/land cover by each of the LULC class of Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land for the years 1977, 1988, 1998, 2008 and 2018 respectively, are shown in Table 5.9.

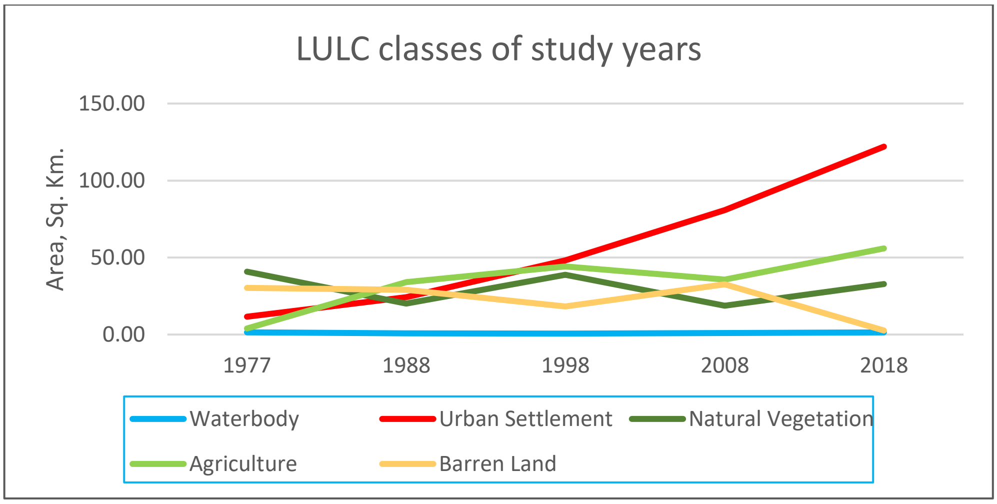


Figure 5.16: Comparison of LULC Classes in study years

From Fig. 5.16, it can be observed that the waterbodies remain stable for almost all the years of 1977, 1988, 1998, 2008 and 2018. The urban settlement is seen to be continuously increased in all the study years, specifically from 1977 to 1998, it is seen gradually increasing, and there is a significant spike observed from 1998 - 2018. Barren land is observed to gradually decrease from 1977 - 1998, but later from 1998 to 2008 there is surge, up to the year 2008 and then after 2008 - 2018, there is a sudden fall. During this period, mainly from 1998 to 2008, where surge is observed in barren land, the natural vegetation and agricultural land are seen to be declining, which puts forth the point that during this decade (1998 – 2008) a lot of construction activities were going on, which led the urban settlement to rise by 18%, highest amongst rise among all the years. During the next decade (2008 – 2018), a constant increase in urban settlement is observed. Although natural vegetation and agricultural land are also observed to be gradually increasing but in a lesser proportion than that of urban settlement.

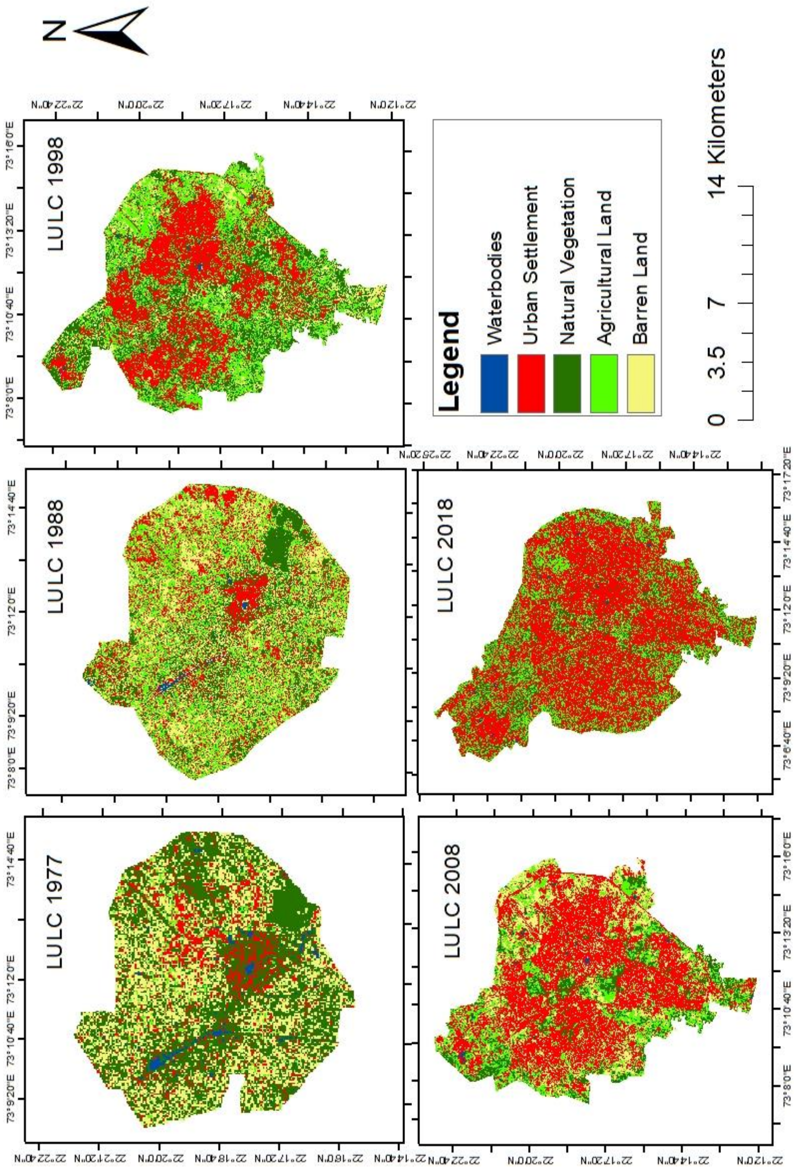


Fig: LULC Classified Maps

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 days with no rainfall, means that there is no measurable precipitation, and the atmosphere remains dry. This can occur due to stable weather conditions, high-pressure systems, or a lack of significant moisture in the air. The range of 0 to 10 mm of rainfall is considered a very low amount of precipitation. This typically results from a steady rain or drizzle over the course of the day. The range more than 50 mm shows that moderate to heavy rainfall and it can have positive effects on soil moisture levels and water reservoirs. However, it may also pose challenges such as flooding in low-lying areas, increased runoff, and potential transportation disruptions. Adequate preparedness and infrastructure are important to manage the impacts of this level of rainfall.

Mann-Kendall Test and Sen’s Slope Estimation

Mann-Kendall Test and Sen’s Slope Estimation are two non-parametric test used to detect the presence of a significant trend (upward or downward) in a time series dataset. The results of Mann Kendall (MK) test and Sen’s slope test for rainfall data considered from 1961-2018, are analysed for the months of June, July, August, September, analysed for Annual rainfall and for southwest monsoon. The results of the same are shown in below Table 5.21

In the Mann-Kendall trend test, the value of Z is a test statistic that measures the strength and direction of a trend in a time series dataset. The sign (positive or negative) and magnitude of the Z statistic provide information about the nature of the trend.

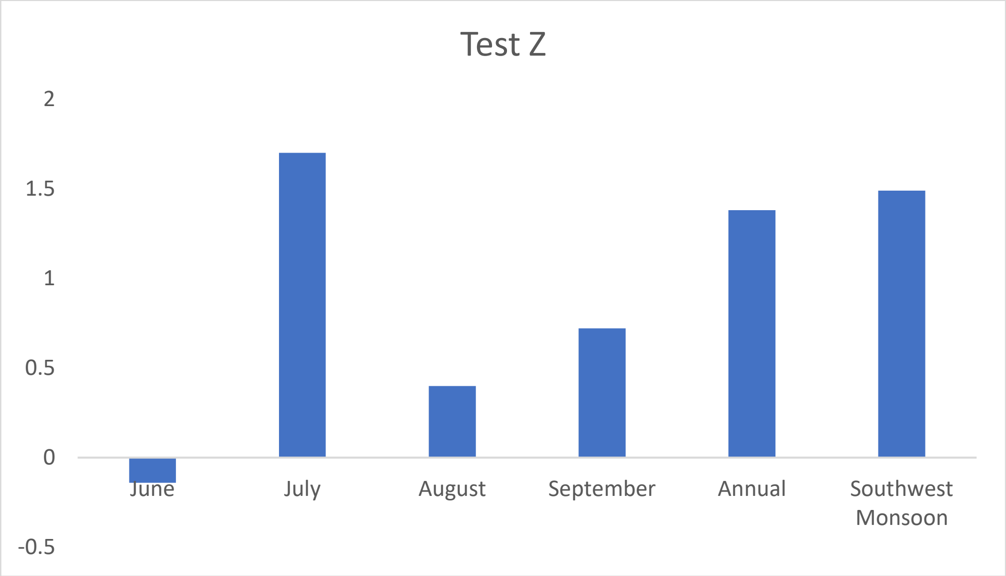


Figure 5.22: Test Z value

Analysis of Monthly Rainfall data

The analysis of monthly rainfall data is carried out for the monsoon months which are June, July, August and September for the period of 1961 – 2018, The monthly rainfall data analysis shows that month of June contributes 15%, July contributes 38%, August 31 % and September 16% of the average annual rainfall, The contribution of rainfall of these months is represented in percentage in below Fig. 5.23

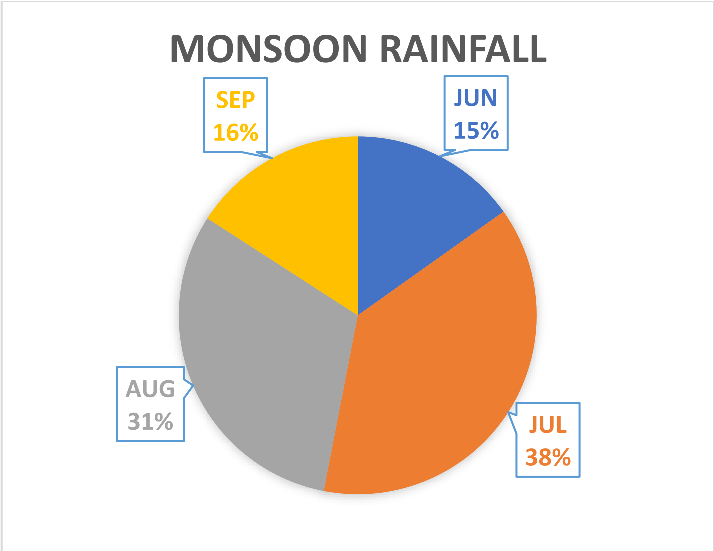


Figure 5.23: Percentage of Annual Rainfall in Monsoon Season

The monthly precipitation of June, July, August, and September can also be regarded as reliable. Nevertheless, the rainfall patterns throughout the monsoon season in the study area exhibit significant regional and temporal disparities, resulting in both floods and droughts across different regions and cities. However, when the rainfall data is aggregated for the entire season or month, it demonstrates a consistent pattern.

Rainfall Variability

To analyse the rainfall variability the months of June, July, August and September which are the monsoon months are considered in the present study. The basic statistical attributes such as mean, standard deviation (SD), coefficient of variation (CV) of seasonal and annual rainfall series for the period of 58 years (1961-2018) are analysed. The results are shown in Fig. 5.25

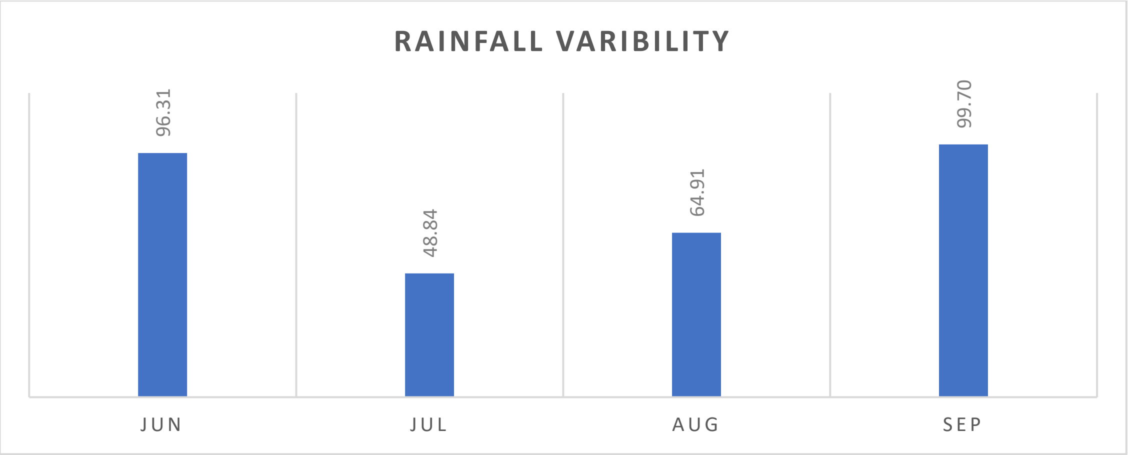


Figure 5.25: Rainfall Variability over the years 1961-2018

The rainfall variability for the month of June, July, August and September as 96.33%, 48.84%, 64.91% and 99.70% respectively, which shows that there is low variability in rainfall during month of July.

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 annual one day daily maximum runoff against the annual one-day maximum rainfall (AODMR) is used for the purpose of analysis. The maximum rainfall & runoff will determine more accurately the runoff properties. So, the annual one-day maximum value is considered for analysis. The annual one day daily maximum runoff values are plotted against the annual one-day maximum rainfall, shown in below Fig.5.27

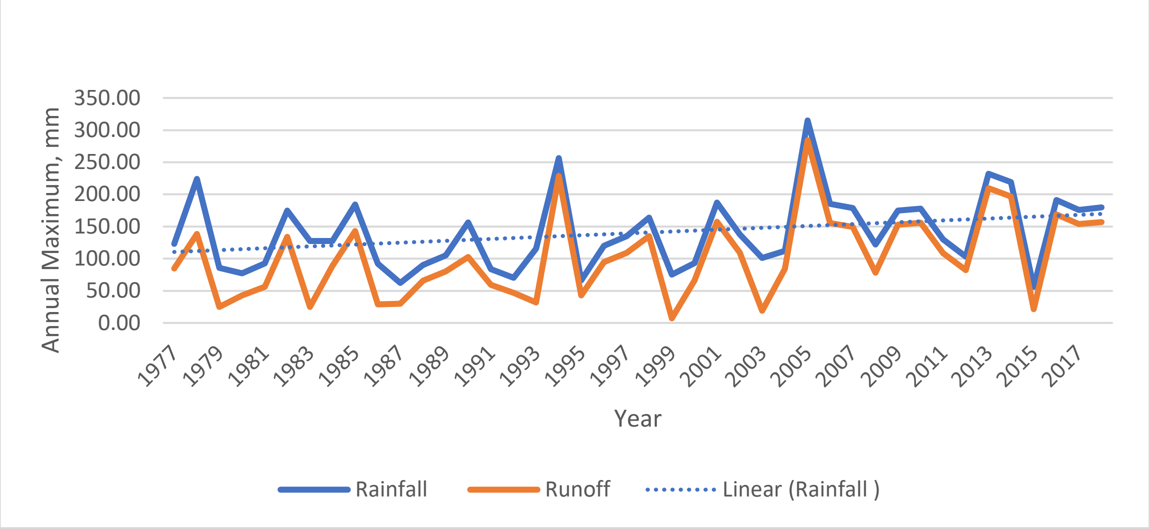


Figure 5.27: Annual One Day Maximum Rainfall – Runoff [1977 – 2018]

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 7 mm and the corresponding runoff comes out to be 138 mm and 42 mm, which is 61% and 54%. 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 87% and 63%. 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.

Decadal analysis of Runoff against maximum AODMR

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.

Scenario 1 – Considering 1977 as a base year and superimposing the LULC maps of 1988, 1998, 2008 and 2018 on the base map and considering the extent of area to be same as that of 1977, the changes in runoff values are analysed. The changes in runoffs will definitely occur due to the changes in LULC for different years.

By superimposing the maps of 1988, 1998, 2008 and 2018 on the map of 1977, the results obtained are shown in Fig. 5.34

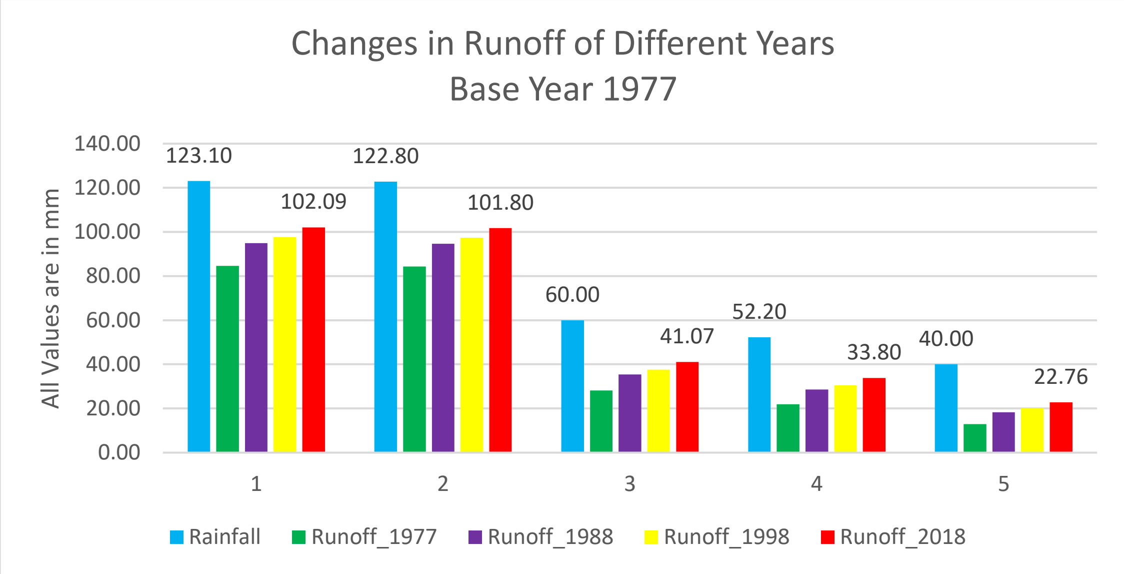


Figure 5.34: Changes in Runoff of different years with Base year 1977

From Fig. 34, it is observed that for 123.10mm of rainfall, the runoff percentages are 68%, 77%, 79%, 84% and 83% respectively for the years 1977, 1988, 1998, 2008 and 2018. These values show that the runoff is varying from 60% to 84%, with an increasing trend, which shows that the runoff values are increasing due to the change in LULC.

Similarly all the eight scenarios have been computed. 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.

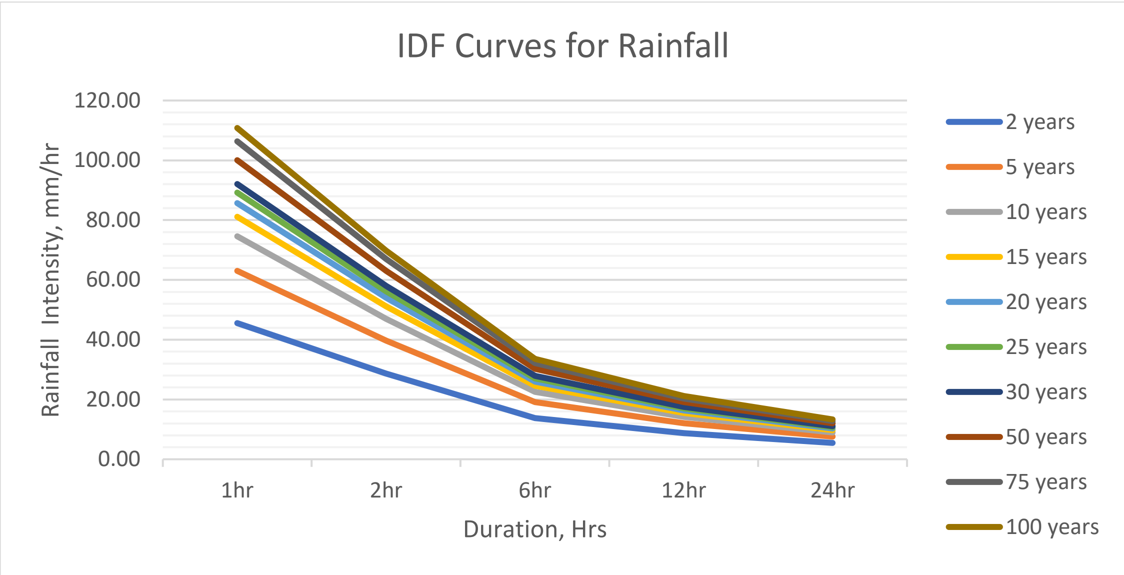
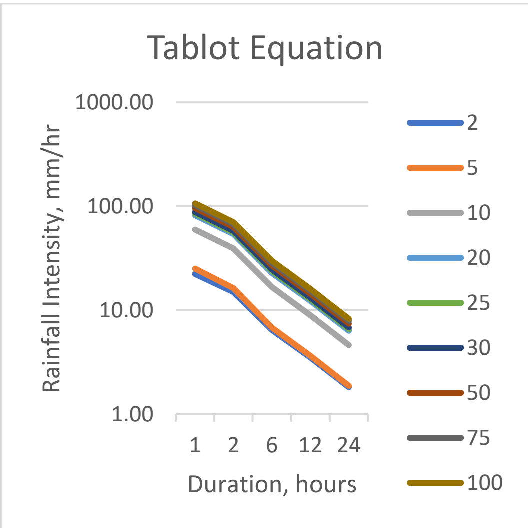
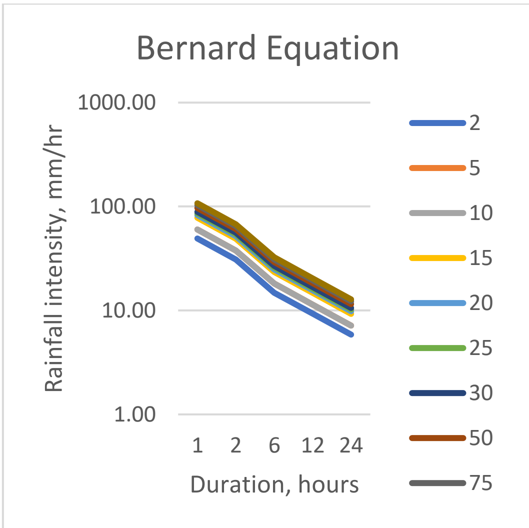
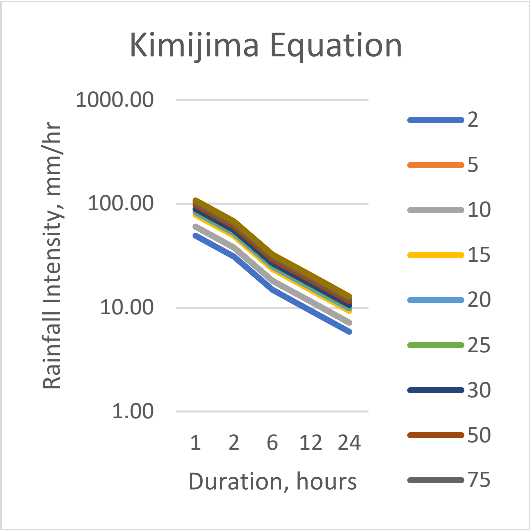


Figure 5.42: Intensity Duration Frequency Curve by GEV Distribution







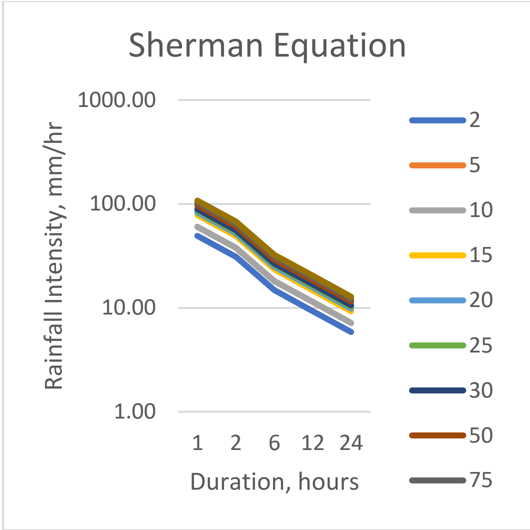


Figure 5.43: Rainfall Intensity Duration Frequency (IDF) curves using empirical equations.

Comparison of the results for the four empirical methods shows that Sherman equations may fit well at the Vadodara station that has Root mean square error (RMSE) only 0.159 mm/hour and its relative coefficient R is approximated 0.99. The results show that the Sherman equations are an acceptable fit to the IDF relationship in Vadodara. This indicated that the empirical formula given by Kimijima and Sherman obtained to estimate intensity in the study area is good for short durations. These IDF Curves and Empirical Equations will help for calculation of peak discharge into Minor Irrigation Tanks and also useful for planning and designing of any water resource management project.

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. Fig. 5.44 shows the runoff intensities in mm/hr.

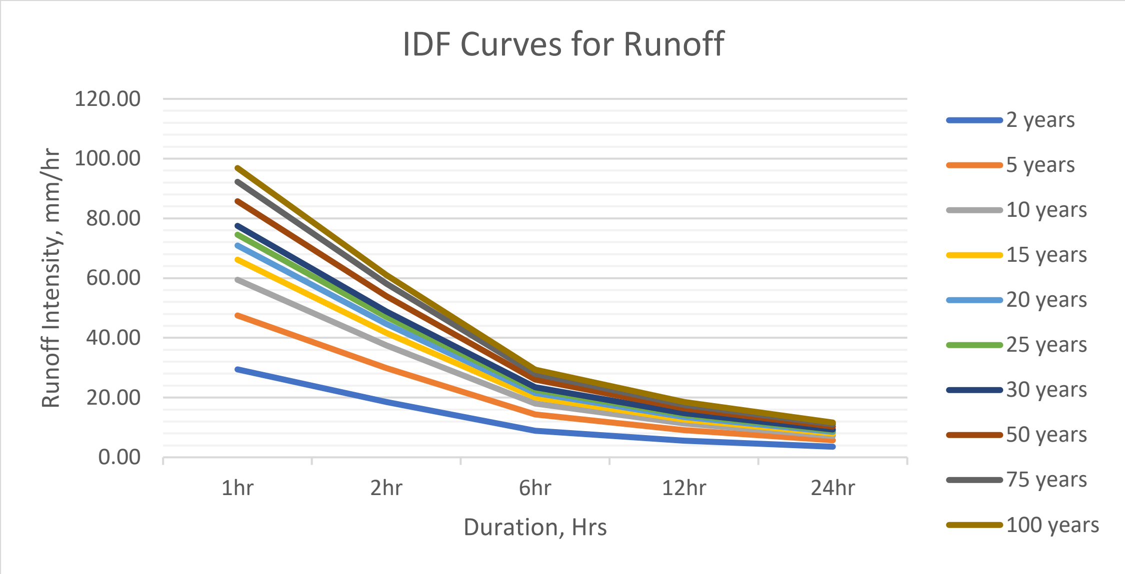
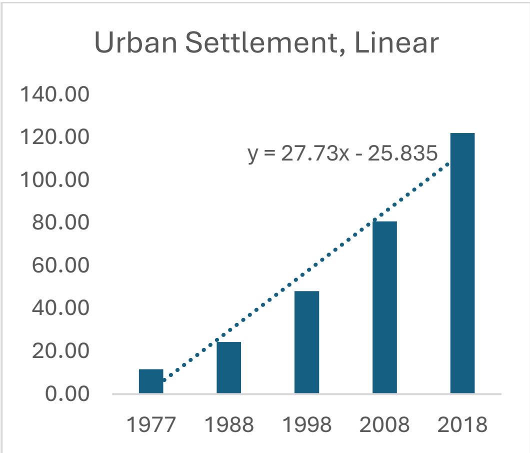


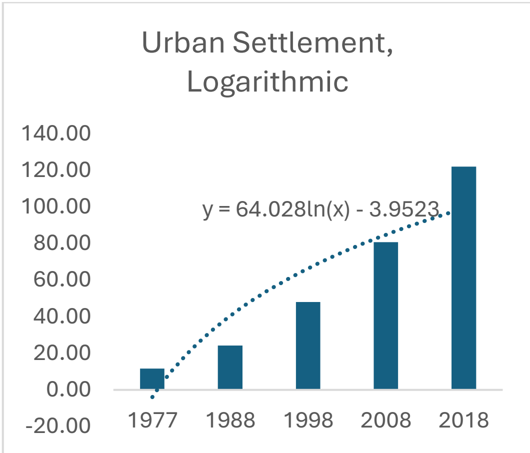
Figure 5.44: Intensity Duration Frequency Curve for Runoff

Models for Urban Settlement Estimation

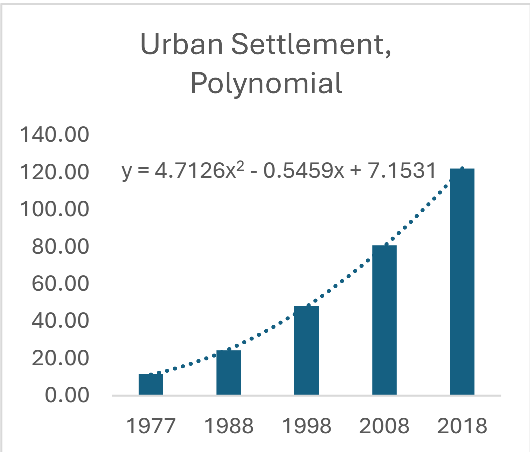
Results Obtained for Urban Settlement Estimation Models



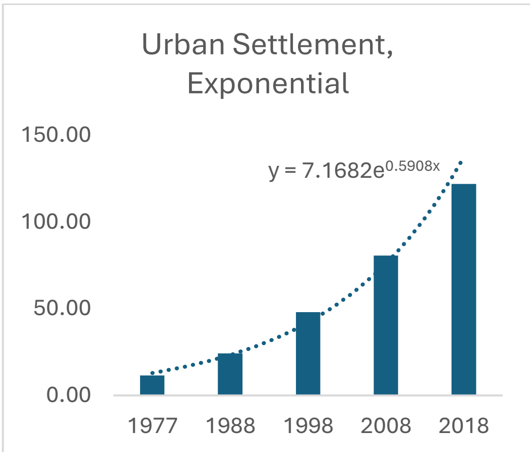
(a) Linear



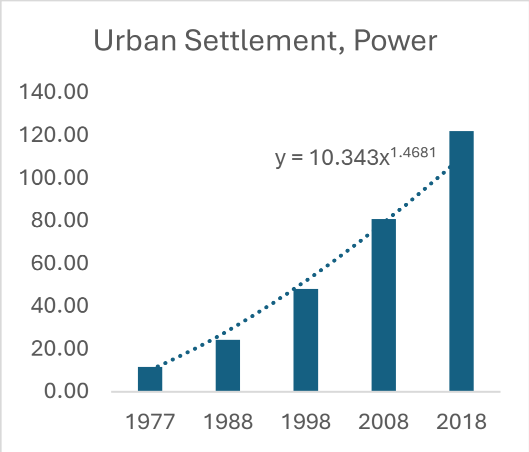
(b) Logarithmic



(c) Polynomial



(d) Exponential



(e) Power

Figure 5.51: Different models obtained for estimation of Urban Settlement

However, the estimation of Urban Settlement has been carried out for all the models and is represented in Table 5.60 The graph of which is shown in Fig. 5.52
Table 5.60 shows the predicted Urban Settlement class.

Analysing the Table 5.60, 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 41%, 91% and 149% increase in urban settlement. This increase will have the direct impact on the increase in runoff.

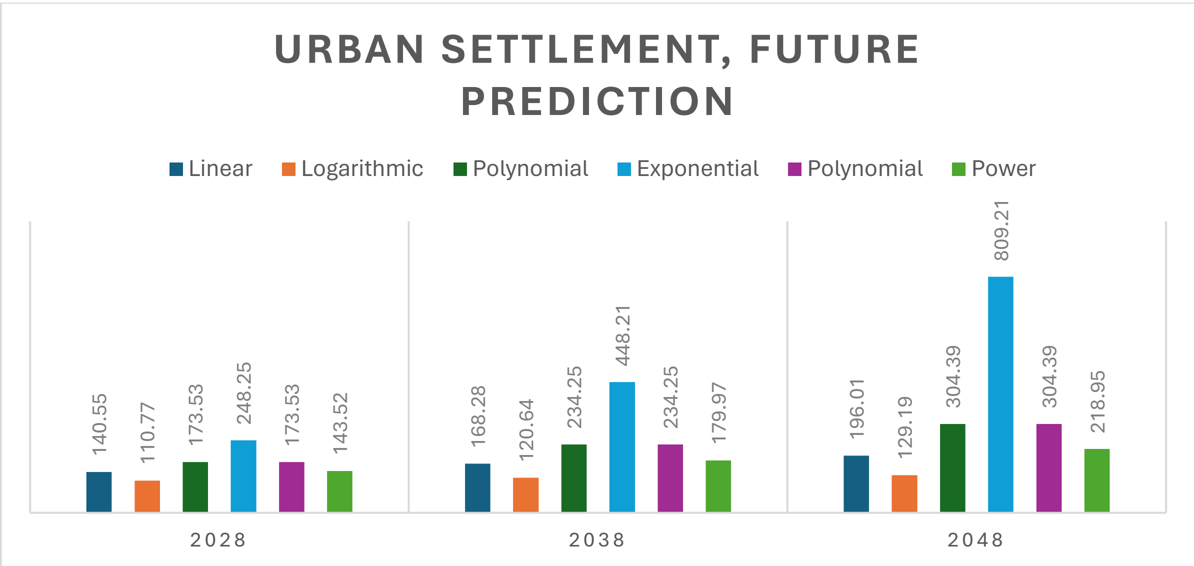


Figure 5.52: Graphs of prediction of Urban Settlement by various models

Analysing the Table 5.60, 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 41%, 91% and 149% increase in urban settlement. This increase will have the direct impact on the increase in runoff.

Models for Total Area Estimation, Waterbodies and Natural Vegetation are carried out in similar manner.

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 that its 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.

REFERENCES

Abdullahi, S., & Pradhan, B. (2017). Urban expansion and change detection. In Spatial Modelling and Assessment of Urban Form. Basel, Switzerland: Springer International Publishing AG.

Abebe, G., Getachew, D., & Ewunetu, A. (2022). Analysing land use/land cover changes and its dynamics using remote sensing and GIS in Gubalafito district, Northeastern Ethiopia. SN Applied Sciences, 4(1), 30.

Acheampong, R. A., Agyemang, F. S., & Abdul, M. (2017). Quantifying the spatio-temporal patterns of settlement growth in a metropolitan region of Ghana. GeoJournal, 82, 823-840.

Ajinkya, D., Dhruvi, P., Drashti, P., Jalpa, J., & Khushali, D. (2015). Change in the land use pattern and water bodies of Vadodara City, India with respect to recurring severe floods. Journal of Environmental Research and Development, 10(1), 175.

Akubia, J. E., & Bruns, A. (2019). Unravelling the frontiers of urban growth: spatio-temporal dynamics of land-use change and urban expansion in greater Accra metropolitan area, Ghana. Land, 8(9), 131.

Alam, I., Nahar, K., & Morshed, M. M. (2023). Measuring urban expansion pattern using spatial matrices in Khulna City, Bangladesh. Heliyon, 9(2).

Angel, S., Parent, J., & Civco, D. (2007, May). Urban sprawl metrics: an analysis of global urban expansion using GIS. In Proceedings of ASPRS 2007 Annual Conference, Tampa, Florida May (Vol. 7, No. 11). Citeseer.

Appiah, D. O., Schröder, D., Forkuo, E. K., & Bugri, J. T. (2015). Application of geo-information techniques in land use and land cover change analysis in a peri-urban district of Ghana. ISPRS International Journal of Geo-Information, 4(3), 1265-1289.

Ara, Z., & Zakwan, M. (2018). Rainfall runoff modelling for eastern canal basin. Water and Energy international, 61(6), 63-67.

Arvind, G., Kumar, P. A., Karthi, S. G., & Suribabu, C. R. (2017). Statistical analysis of 30 years rainfall data: a case study. In IOP Conference Series: Earth and Environmental Science (Vol. 80, No. 1, p. 012067). IOP Publishing., https://doi.org/10.1088/1755-1315/80/1/012067

Asadi S., Hanumantharao C., Prasad L. T., and Reddy A. M. (2010). Evaluation of physical characteristics using geomatics: A Case Study. Indian Journal of Science and Technology, 3(4), pp. 450-454.

Bajracharya, A. R., Rai, R. R., & Rana, S. (2015). Effects of Urbanization on Storm Water Run-off: A Case Study of Kathmandu Metropolitan City, Nepal. Journal of the Institute of Engineering, 11(1).

Bera, S. (2017). Trend analysis of rainfall in Ganga Basin, India during 1901-2000. American Journal of Climate Change, 6(01), 116 – 131

Bhat, P. A., ul Shafiq, M., Mir, A. A., & Ahmed, P. (2017). Urban sprawl and its impact on landuse/land cover dynamics of Dehradun City, India. International Journal of Sustainable Built Environment, 6(2), 513-521.

Bhuvaneswari, E., Ch, A. K. T., Arshad, H., Dhanagopal, R., & Narukullapati, B. K. (2021). Hybrid Enriched Stacked Auto Encoder and FFO-MPARCNN Algorithm for the Multispectral Image LULC Classification.

Bibi T., Nawaz F., Abdul R. A. and Latif A. (2019). Flood Hazard Assessment Using Participatory Approach and Weighted Overlay Methods., International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences

Boakye, E., Odai, S. N., Adjei, K. A., & Annor, F. O. (2008). Landsat images for assessment of the impact of land use and land cover changes on the Barekese catchment in Ghana. European Journal of Scientific Research, 22(2), 269-278.

Brueckner, J. K. (2000). Urban sprawl: Diagnosis and remedies. International regional science review, 23(2), 160-171. https://doi.org/10.2307/1924193

Brueckner, J. K., & Fansler, D. A. (1983). The economics of urban sprawl: Theory and evidence on the spatial sizes of cities. The review of Economics and Statistics, 479-482.

Chaikaew P. (2019). Land Use Change Monitoring and Modelling Using GIS and Remote Sensing Data for Watershed Scale in Thailand. IntechOpen, London, UK.

Chaudhary, B. S., Saroha, G. P., & Yadav, M. (2008). Human induced land use/land cover changes in northern part of Gurgaon district, Haryana, India: natural resources census concept. Journal of Human Ecology, 23(3), 243-252.

Cheruto M. C., Kauti M. K., Kisangau D. P. and Kariuki P. C. (2016). Assessment of land use and land cover change using GIS and remote sensing techniques: a case study of Makueni County, Kenya. Middle East Journal of Applied Science & Technology, Vol.4, Iss.1, Pages 80-93.

Chettry, V. (2022). Geospatial measurement of urban sprawl using multi-temporal datasets from 1991 to 2021: case studies of four Indian medium-sized cities. Environmental Monitoring and Assessment, 194(12), 860.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. Remote sensing of environment, 37(1), 35-46. https://doi.org/10.1016/0034-4257(91)90048-B

Cronshey, R. (1986). Urban hydrology for small watersheds (TR No. 55). US Department of Agriculture, Soil Conservation Service, Conservation Engineering Division.

Downs, A. (1999). Some realities about sprawl and urban decline. Housing policy debate, 10(4), 955-974.

European Environment Agency (2006). Urban Sprawl in Europe. The Ignored Challenge (No. 10). European Commission: Joint Research Center, EEA Report, 6, 23, 24–5. https://doi.org/10.1080/10511482.1999.9521356

Ewing R, Pendall R, Chen D. Measuring Sprawl and its Impact. Washington: Smart Growth America; 2008: 2–31.

Ewing, R. (1997). Is Los Angeles-style sprawl desirable?. Journal of the American planning association, 63(1), 107-126.

Ewing, R., Pendall, R., & Chen, D. (2002). Measuring sprawl and its impact.

Fan, F., Deng, Y., Hu, X., & Weng, Q. (2013). Estimating composite curve number using an improved SCS-CN method with remotely sensed variables in Guangzhou, China. Remote Sensing, 5(3), 1425-1438.

Frame, David E. Urban Meiosis. Carnegie Mellon University Working Paper, 2007.

Fulton, W. B., Pendall, R., Nguyễn, M., & Harrison, A. (2001). Who sprawls most?: How growth patterns differ across the US (pp. 1-24). Washington, DC: Brookings Institution, Center on Urban and Metropolitan Policy.

Gadgil, S. (2007). The Indian monsoon: 3. Physics of the monsoon. Resonance, 12, 4-20.

Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S., & Freihage, J. (2001). Wrestling sprawl to the ground: defining and measuring an elusive concept. Housing policy debate, 12(4), 681-717.

Glaeser, E. L., Kahn, M. E., & Chu, C. (2001). Job sprawl: Employment location in US metropolitan areas. Washington, DC: Brookings Institution, Center on Urban and Metropolitan Policy.

Gondwe, J. F., Li, S., & Munthali, R. M. (2021). Analysis of land use and land cover changes in urban areas using remote sensing: Case of Blantyre city. Discrete Dynamics in Nature and Society, 2021, 1-17. https://doi.org/10.1155/2021/8011565

Gordon, P., & Richardson, H. W. (1997). Are compact cities a desirable planning goal?. Journal of the American planning association, 63(1), 95-106.

Gordon, P., & Richardson, H. W. (2000). Critiquing sprawl's critics. Washington, DC: Cato Institute, 365: 1–18.

Gosain, A. K., Rao, S., & Basuray, D. (2006). Climate change impact assessment on hydrology of Indian river basins. Current science, 90, 346-353. https://www.jstor.org/stable/24091868

Guhathakurta, P., & Rajeevan, M. (2008). Trends in the rainfall pattern over India. International Journal of Climatology: A Journal of the Royal Meteorological Society, 28(11), 1453-1469.

Habibi, S., & Asadi, N. (2011). Causes, results and methods of controlling urban sprawl. International Conference on Green Buildings and Sustainable Cities, Procedia Engineering, 21, 133-141. https://doi.org/10.1016/j.proeng.2011.11.1996

Haindongo P. N., Kalumba A. M. and Orimoloye I. R. (2020). Local people's perceptions about Land Use Cover Change (LULCC) for sustainable human wellbeing in Namibia. GeoJournal, 1–15.

IPCC 2007 Climate change (2007). climate change impacts, adaptation and vulnerability. Working Group II Contribution to the Intergovernmental Panel on Climate Change, Fourth Assessment Report, Summary for Policymakers, 23

Jain, S. K., & Kumar, V. (2012). Trend analysis of rainfall and temperature data for India. Current Science, 102(1), 37–49. http://www.jstor.org/stable/24080385

Jain, S. K., & Kumar, V. (2012). Trend analysis of rainfall and temperature data for India. Current Science, 37-49.

Kahn, M. E. (2001). Does sprawl reduce the black/white housing consumption gap?. Housing Policy Debate, 12(1), 77-86.

Kaul, H. A., & Sopan, I. (2012). Land use land cover classification and change detection using high resolution temporal satellite data. Journal of Environment, 1(4), 146-152.

Kothyari, U. C., & Garde, R. J. (1992). Rainfall intensity-duration-frequency formula for India. Journal of Hydraulic Engineering, 118(2), 323-336.

Kumar, V., Jain, S. K., & Singh, Y. (2010). Analysis of long-term rainfall trends in India. Hydrological Sciences Journal–Journal des Sciences Hydrologiques, 55(4), 484-496. https://doi.org/10.1080/02626667.2010.481373

Kumar, V., Singh, P., & Jain, S. K. (2005, April). Rainfall trends over Himachal Pradesh, Western Himalaya, India. In Conference on Development of Hydro Power Projects–A Prospective Challenge, Shimla (Vol. 20, p. 22).

Lal, M. (2000). Climatic change-implications for India's water resources. Journal of Social and Economic Development, 3, 57-87.

Lal, M. (2005). Climatic change–Implications for India's water resources. Clim. Chang. Water Resour. South Asia. AA Balkema Publishers (Taylor & Francis Group), Lieden, The Netherlands, 155-193.

Lillesand T. M. and Kiefer R. W. (2000), Remote Sensing and Image Interpretation, John Wiley & Sons, New York, NY, USA, 4th edition.

Liu, X., Li, X., Chen, Y., Tan, Z., Li, S., & Ai, B. (2010). A new landscape index for quantifying urban expansion using multi-temporal remotely sensed data. Landscape ecology, 25, 671-682.

Lu, S., Guan, X., He, C., & Zhang, J. (2014). Spatio-temporal patterns and policy implications of urban land expansion in metropolitan areas: A case study of Wuhan urban agglomeration, central China. Sustainability, 6(8), 4723-4748.

Lu, S., Guan, X., He, C., & Zhang, J. (2014). Spatio-Temporal Patterns and Policy Implications of Urban Land Expansion. Sustainability, 6, 4723-4748.

Mallupattu P. K. and Reddy S. J. R. (2013). Analysis of land use/land cover changes using remote sensing data and GIS at an urban area, Tirupati, India, Scientific World Journal, vol. 2013, Article ID 268623, 6 pages.

Mas J. F. (1999). Monitoring land-cover changes: a comparison of change detection techniques, International Journal of Remote Sensing, vol. 20, no. 1, pp. 139–152.

Mieszkowski, P., & Mills, E. S. (1993). The causes of metropolitan suburbanization. Journal of Economic perspectives, 7(3), 135-147.

Mishra P. K., Rai A., Rai S. C. (2019). Land use and land cover change detection using geospatial techniques in the Sikkim Himalaya, India. The Egyptian Journal of Remote Sensing and Space Science, Vol. 23, no. 2, 133-143

Mohan, M. (2005). TS24.5 Urban Land Cover/ Land Use Change Detection in National Capital Regional (NCR)Delhi: A Study of Faridabad District. In: Pharaohs to Geoinformatics, FIG Working Week 2005 and GSDI-8, April 16-21, 2005, Cairo, Egypt. TS 24- Planning for Rural and Urban Communities.

Mridha, N., Chakraborty, D., Roy, A., & Kharia, S. K. (2021). Role of Remote Sensing in Land Use and Land Cover Modelling. https://www.researchgate.net/publication/349475872

Muhammed, B. U., Abbas, A. M., & Abdullahi, A. Analysis of the Impacts of Urbanisation on Land Cover Change in Gombe Local Government Area, Gombe State Nigeria

Muthusi, N. N., Dulo, S. O., & Ndiba, P. K. (2020). Runoff estimation for an urban area using SCS-CN method, remote sensing and geographic information systems approach: A Case Study of Mavoko Municipality, Kenya. Int. J. of Eng. Res. & Technol. 9, 4.

Nath, S., Mathew, A., Khandelwal, S., & Shekar, P. R. (2023). Rainfall and temperature dynamics in four Indian states: A comprehensive spatial and temporal trend analysis. Hydro Research, 6, 247-254. https://doi.org/10.1016/j.hydres.2023.09.001

Oyesiji, O. A. (2023). Spatio-Temporal Measurements of Urban Sprawl Dynamics In Oyo Town, Nigeria. African Journal of Land Policy and Geospatial Sciences, 6(1), 94-106.

Panda, A., & Sahu, N. (2019). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. Atmospheric Science Letters, 20(10), e932. https://doi.org/10.1002/asl.93210

Pendall, R. (1999). Do land-use controls cause sprawl? Environment and Planning B: Planning and Design, 26(4), 555-571.

Prasad, R., & Sharma, A. (2018). SPATIAL AND TEMPORAL DISTRIBUTION AND TRENDS IN SEASONAL RAINFALL AND RAINY DAYS ACROSS DIFFERENT STATIONS OF HIMACHAL PRADESH DURING THE PERIOD 1971-2014. MAUSAM, 69(4), 622-630. https://doi.org/10.54302/mausam.v69i4.427

Praveen, B., Talukdar, S., Shahfahad, Mahato, S., Mondal, J., Sharma, P., ... & Rahman, A. (2020). Analyzing trend and forecasting of rainfall changes in India using non-parametrical and machine learning approaches. Scientific reports, 10(1), 10342., https://doi.org/10.1038/s41598-020-67228-7

Priyan, K. (2015). Spatial and temporal variability of rainfall in Anand District of Gujarat State. Aquatic Procedia, 4, 713-720. https://doi.org/10.1016/j.aqpro.2015.02.092

Qiuying, L., Chuanglin, F., Guangdong, L., & Zhoupeng, R. (2015). Quantitative measurement of urban expansion and its driving factors in Qingdao: an empirical analysis based on county unit data. Journal of Resources and Ecology, 6(3), 172-179.

Rajashekhar, S. L. (2018). Estimation of runoff using SCS-CN method for Yelahanka region. *International Journal of Applied Engineering Research*, *13*(7), 229-233.

Rao, K. N. and Narendra, K. (2006). Mapping and Evaluation of Urban Sprawling in the Mehadrigedda Watershed in Visakhapatnam metropolitan region using Remote Sensing and GIS. Current Science, 91(11), pp. 1552-1557.

Rathod, I. M., & Aruchamy, S. (2010). Spatial analysis of rainfall variation in Coimbatore district Tamil Nadu using GIS. International journal of Geomatics and Geosciences, 1(2), 106-118.

Remi, A., Huang, S., Jiren, L., Herve, Y., and Yvew- LOUIS, D. (2007) Large Scale Land Cover Map Generation based on low and medium resolution, Envisat ASAR Data, Application of Poyang Lake area (JIANG XI, P.R. China). Proc. Envisat

Symposium 2007, April 23-27, 2007, Montreux, Switzerland (ESA SP -636, July 2007).

Rode, P. et al. (2017). Accessibility in Cities: Transport and Urban Form. In: Meyer, G., Shaheen, S. (eds) Disrupting Mobility. Lecture Notes in Mobility. Springer, Cham. https://doi.org/10.1007/978-3-319-51602-8_15

Roy, P. S., Roy, A., Joshi, P. K., Kale, M. P., Srivastava, V. K., Srivastava, S. K., ... & Kushwaha, D. (2015). Development of decadal (1985–1995–2005) land use and land cover database for India. Remote Sensing, 7(3), 2401-2430.

Rudel T. K. (2009). How do people transform landscapes? A sociological perspective on suburban sprawl and tropical deforestation, American Journal of Sociology, 115(1):129 –154

Sankhala, S., & Singh, B. (2014). Evaluation of urban sprawl and land use land cover change using remote sensing and GIS techniques: a case study of Jaipur City, India. International Journal of Emerging Technology and Advanced Engineering, 4(1), 66-72.

Seyam, M. M. H., Haque, M. R., & Rahman, M. M. (2023). Identifying the land use land cover (LULC) changes using remote sensing and GIS approach: A case study at Bhaluka in Mymensingh, Bangladesh. Case Studies in Chemical and Environmental Engineering, 7, 100293. https://doi.org/10.1016/j.cscee.2022.100293

Shukla, A., & Jain, K. (2019). Critical analysis of spatial-temporal morphological characteristic of urban landscape. Arabian Journal of Geosciences, 12, 1-14.

Sierra Club. (1998). The dark side of the American Dream: the costs and consequences of suburban sprawl.

Singh, N. K., & Nathawat, M. S. (2023). Quantifying the characteristics and types of urban growth of Varanasi city using multi-temporal remotely sensed data and geospatial techniques. Transactions, 45(1), 27.

Soil Conservation Service (SCS) (1972), National Engineering Handbook, Section 4, Hydrology, Department of Agriculture, Washington, pp 762.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., ... & Miller, H. L. (2007). Summary for policymakers. Climate change, 1-18.

Sreenivasulu, V., & Bhaskar, P. U. (2010). Change detection in land use and land cover using remote sensing and GIS techniques. International Journal of Engineering Science and Technology, 2(12), 7758-7762.

Srivastava, S. K., & Gupta, R. D. (2003, January). Monitoring of changes in land use/land cover using multi-sensor satellite data. In Map India Conference (pp. 1-7).

Steurer, M., & Bayr, C. (2020). Measuring urban sprawl using land use data. Land Use Policy, 97, 104799. https://doi.org/10.1016/j.landusepol.2020.104799

Tang, Z., Engel, B. A., Lim, K. J., Pijanowski, B. C., & Harbor, J. (2005). Minimizing the Impact of Urbanization on Long Term Runoff 1. JAWRA Journal of the American Water Resources Association, 41(6), 1347-1359.

Thankachan, A., Parvez, B., Inayathulla M., Chalapathi K., Chithaiah E. (2020). Surface Runoff Estimation using SCS- CN Method and GIS Tool for the Palar Watershed, Karnataka, Compliance Engineering Journal, 11(2), 258-266.

Twisa S., Buchroithner M. F. (2019). Land-use and land-cover (LULC) change detection in Wami River Basin, Tanzania. Land 8(9):136

United States Department of Agriculture (1986). Urban hydrology for small watersheds (PDF). Technical Release 55 (TR-55) (Second ed.). Natural Resources Conservation Service, Conservation Engineering Division.

Usman M., Liedl R., Shahid M. A. and Abbas A. (2015). Land use/ land cover classification and its change detection using multitemporal MODIS NDVI data, Journal of Geographical Sciences, vol. 25, no. 12, pp. 1479–1506.

Weerakoon, K. G. P. K. (2017). Analysis of spatio-temporal urban growth using GIS integrated urban gradient analysis, Colombo district, Sri Lanka.

Wu, Y., Li, S., & Yu, S. (2016). Monitoring urban expansion and its effects on land use and land cover changes in Guangzhou city, China. Environmental monitoring and assessment, 188, 1-15.

Xue Q., Liu C., Li L., Sun G. Q. and Wang Z. (2021). Interactions of diffusion and nonlocal delay give rise to vegetation patterns in semi-arid environments, Applied Mathematics and Computation, vol. 399, Article ID 126038.

Yangchen, U., Thinley, U., & Wallentin, G. (2015). Land use land cover changes in Bhutan: 2000-2013. Occasional Publication No.

Yu, H., JOSHI, P.K., Das, K. K., Chauniyal, D. D., Melick D. R., Yang, X., and Xu, J. (2007). Land Use/ Cover Change and Environmental Vulnerability Analysis in Birahi Ganga Sub-Watershed of Garhwal Himalaya. Tropical Ecology, 48(2), pp. 241-250.

Zamani, R., Mirabbasi, R., Nazeri, M., Meshram, S. G., & Ahmadi, F. (2018). Spatio-temporal analysis of daily, seasonal and annual precipitation concentration in Jharkhand state, India. Stochastic environmental research and risk assessment, 32, 1085-1097.

Zope, P. E., Eldho, T. I., & Jothiprakash, V. (2016). Impacts of land use–land cover change and urbanization on flooding: A case study of Oshiwara River Basin in Mumbai, India. *Catena*, *145*, 142-154.

Zubair, A. O. (2006). Change detection in land use and Land cover using remote sensing data and GIS (A case study of Ilorin and its environs in Kwara State). Department of Geography, University of Ibadan, 176.

Books

Subramanya, K. (2008). Engineering hydrology. McGraw-Hill.

Te Chow, V., Maidment, D. R., & Mays, L. W. (1988). Applied hydrology.

Webliography

http://cgwb.gov.in/cgwbpnm/search?type=2&cat_id=7&state_id=&district_id=&year_of_issue=&name_of_author=&keywords=&search=search&page=12

http://edepot.wur.nl/183157

http://kvkvadodara.org

https://dataspace.niua.org/dataset/ward-office/resource/79797beb-7012-463b-89c0-40264045ae5f

https://dolr.gov.in/sites/default/files/Gujarat%20%283%29.pdf

https://www.britannica.com/explore/savingearth/

https://www.dspmuranchi.ac.in/pdf/Blog/CLASSIFICATION%20OF%20ACCURACY%20ASSESSMENT.pdf

https://www.geographynotes.com/hydrology/measurement-of-run-off-functions-precipitation-geography/4297

https://www.geographynotes.com/hydrology/measurement-of-run-off-functions-precipitation-geography/4297

proceedings.esri.com

unstats.un.org https://www.mdpi.com/2072-4292/14/23/6016