# Impact of Urban Sprawl and Land Use/Land Cover Changes on Runoff: A Case Study of Vadodara City

A Synopsis Submitted to
The Maharaja Sayajirao University of Baroda
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DOCTOR OF PHILOSOPHY
in
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# CERTIFICATE

This is to certify that the synopsis entitled "Impact of Urban Sprawl and Land Use/Land Cover Changes on Runoff: A Case Study of Vadodara City" which is being submitted to The Maharaja Sayajirao University of Baroda in fulfilment of the requirements for the award of degree of Doctor of Philosophy in Civil Engineering by Ms. Sumitra Dineshbhai Sonaliya written by her under my supervision and guidance. This is an original work carried out by her independently. The matter presented in this synopsis has not been submitted for the award of any other degree.

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# 1. Introduction

## 1.1 General

This chapter describes the objectives of the present study and also gives brief introduction of land use/ land cover, remote sensing and geographic information system, rainfall, runoff, use of RS & GIS in Land use/ Land Cover Mapping and Urban sprawl.

## 1.2 Introduction

Managing water resources is a major challenge for the country. Water resources development calls for addressing the key issues of storage, conservation and subsequently utilization. Towards evolving comprehensive management plan in suitable conservation and utilization of water resources. Space technology plays a crucial role in managing country's available water resources. Systematic approaches involving judicious combination of conventional ground measurements and remote sensing techniques pave way for achieving optimum planning and operational of water resources projects. The synoptic and repetitive coverage provided by the satellites can effectively complement the conventional data to monitor the progress and impact of the above projects. Thus, remote sensing imagery from the polar orbiting satellites is a potential tool for mapping and monitoring of many water resources management projects.

Human activities have modified the environment over the years. Urbanization, agriculture lumbering, mining and other land uses have substantially altered the Earth's surface. Land use and the resultant change in land cover have significant effects on ecological, environmental and hydrologic systems and processes. An understanding of past and present land-cover change, together with an analysis of potential future change, is necessary for proper management; thus, the need for models. Hydrologic models are primarily used for hydrologic prediction and for understanding hydrologic processes. With recent technological advances, technological based tools such as GIS are incorporated into hydrologic models for assessing the impacts of various land use land cover. Hydrologic models incorporated with GIS can be used to project future land uses/ land cover to provide an increased clarity, probability or likelihood of potential consequences on ecosystem services such as biodiversity, water quality and climate.

Although the terms land cover and land use are often used interchangeably, their actual meanings are quite distinct.

**Land Use**

Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the land use changes from year to year.

**Land Cover**

Land cover refers to the surface cover on the ground - vegetation, urban infrastructure, water, bare soil etc. Identification, delineation and mapping land cover is important for monitoring studies, resource management, and planning activities.

Identification of land cover establishes the baseline from which monitoring activities can be performed.

Water resources, which are substantially affected by land use land cover (LU/LC) and climate changes, are a key limiting factor for ecosystems in arid and semi-arid regions exhibiting high vulnerability. It is crucial to assess the impact of LU/LC and climate changes on water resources in these areas. It is hypothesized that under climatic warming and drying conditions, LU/LC change, which is primarily caused by intensive human activities, such as the conversion of cropland to forest and grassland will alter runoff. The main factor responsible for runoff is rainfall along with varying land uses.

Rain is liquid water in the form of droplets that have condensed from atmospheric water vapour and then precipitated that is, becomes heavy enough to fall under gravity. Rain is a major component of the water cycle and is responsible for depositing most of the fresh water on the Earth. It provides suitable conditions for many types of ecosystems, as well as water for hydroelectric power plants and crop irrigation. Increasing temperatures tend to increase evaporation which can lead to more precipitation. Globally there has been no statistically significant overall trend in precipitation over the past century, although trends have varied widely by region and over time. Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Most precipitation falls as rain.

Rainfall is the important element of Indian economy. Although the monsoons affect most part of India, the amount of rainfall varies from heavy to scanty on different parts. There is great regional and temporal variation in the distribution of rainfall. Over 80% of the annual rainfall is received in the four rainy months of June to September.

When rain or snow falls onto the earth, it just doesn't sit there, it starts moving according to the laws of gravity. A portion of the precipitation seeps into the ground to replenish Earth's groundwater. Most of it flows downhill as runoff. Runoff is extremely important in that not only does it keep rivers and lakes full of water, but it also changes the landscape by the action of erosion. Flowing water has tremendous power—it can move boulders and carve out canyons.

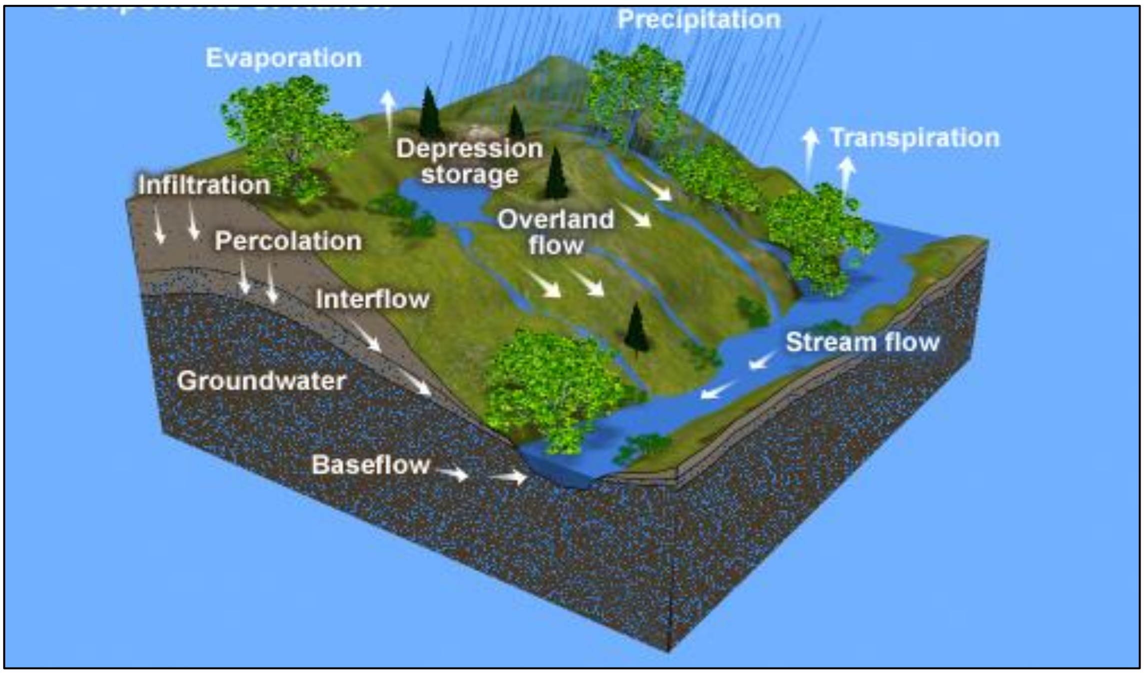


Figure 1: Components of Runoff

Figure 1 shows the components of hydrologic cycle and specifically the all the after precipitation following runoff.

**Factors affecting Runoff**

Apart from rainfall characteristics such as intensity, duration and distribution, there are a number of site (or catchment) specific factors which have a direct bearing on the occurrence and volume of runoff.

i. Soil type

The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have considerable smaller infiltration capacities.

ii. Vegetation

The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. Values of interception are between 1 and 4 mm. A cereal crop, for example, has a smaller storage capacity than a dense grass cover. More significant is the effect the vegetation has on the infiltration capacity of the soil. A dense vegetation cover shields the soil from the raindrop impact and reduces the crusting effect. In addition, the root system as well as organic matter in the soil increases the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving the water more time to infiltrate and to evaporate. In conclusion, an area densely covered with vegetation, yields less runoff than bare ground.

iii. Slope and catchment size

Investigations on experimental runoff plots have shown that steep slope plots yield more runoff than those with gentle slopes. In addition, it has been observed that the quantity of runoff decreased with increasing slope length. This is mainly due to lower flow velocities and subsequently a longer time of concentration (defined as the time needed for a drop of water to reach the outlet of a catchment from the most remote location in the catchment). This means that the water is exposed for a longer duration to infiltration and evaporation before it reaches the measuring point. The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e., the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency.

## 1.3 SCS – CN Method for computation of Runoff

The runoff curve number (CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service, which was formerly called the Soil Conservation Service or SCS — the number is still popularly known as a "SCS runoff curve number" in the literature. The runoff curve number was developed from an empirical analysis of runoff from small catchments and hillslope plots monitored by the USDA. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. It is important to note that the curve number methodology is an event-based calculation and should not be used for a single annual rainfall value, as this will incorrectly miss the effects of antecedent moisture and the necessity of an initial abstraction threshold.

## 1.4 Remote Sensing and Geographic Information System

**Remote sensing** is the acquisition of information about an object or phenomenon without being in physical contact with the object and thus in contrast to on site observation.

A **Geographic Information System** or Geographical Information System (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data.
Remote sensing in combination with the Global positioning system (GPS) and Geographical Information System (GIS) produces the terrain maps at the location accurately and containing detailed information of the variables under study. In India, satellite remote sensing technology is being used effectively in the areas of irrigation performance evaluation, snowmelt-runoff forecasts, reservoir sedimentation, watershed treatment, drought monitoring, flood mapping and management.

## 1.5 USE of RS AND GIS in Land Use Land Cover Mapping

Land use land cover plays an essential role for understanding the physical characteristics of earth surface, captured in the distribution of vegetation, water, soil and other physical features of the land, including those created solely by human activities. Information on the land use land cover in the form of maps and data is very important for planning, conservation, management and utilization of land for agriculture, forestry, urban, industrial, environmental studies and economic development. Assessing and monitoring the earth's surface is a key requirement for global change research. With the impending threat to environment, vegetation type/land use mapping is now given the highest priority. Classifying and mapping of vegetation is an important technical task for managing natural resources as vegetation provides a baseline for all living beings and plays an essential role in affecting global climate change e.g., influencing terrestrial $CO_2$.

Mapping is a key tool in studying vegetation types, especially its spatial inventory, dynamics, and biodiversity characterisation at landscape level. Now days, vegetation types/land use map can be successfully prepared and effectively updated using remote sensing and Geographic Information System (GIS) technology. The mapping of vegetation type/land use is an important activity for managing the natural resources. Remote sensing and geographic information system have a major role in timely assessment and monitoring of land resources.

Urban Sprawl or growth/expansion is one form of land use and land cover change in which rural areas are transformed into urban area and has been used to describe the urban environment since the mid-20th Century. The integration of Remote sensing (RS) and Geographical Information System (GIS) technique is an effective tool for detecting urban sprawl and modeling.

GIS provides diverse methods to create spatial planning scenario for decision making. Application of Remote Sensing technology have been identified and used as an important tool to monitor land use and surface changes. Satellite remote sensing collects multispectral, multiresolution, multitemporal data providing valuable information for understanding and monitoring the process of urban land cover changes. As it is in the digital format, it can be brought into GIS, to provide a suitable platform for data analysis, update and retrieval. Land use can be captured both in terms of geographic location and absolute area. The growth profile obtained helps in formulation of development policies. LAND SAT, TM, ETM can be used for detecting the characteristics of land use change.

ERDAS imagine, digital image processing software can be used for supervised classification. Further, ARC info can be used to prepare thematic maps and data base.

Moreover, our water supply is finite. From areas of abundance to places struck with drought, ensuring access to a clean, reliable source of water is critical. We can protect water supplies and their integrity by understanding how human behaviours impact the natural system. We can document water sources and quantify their capacity based on current and historic data, then share the story of the water system through engaging maps so everyone can see how today's actions affect tomorrow's water system.

Modern life as we know it depends on our ability to match the supply and demand of water of appropriate quality to specific communities and users at specific times or rates. Our cities, farms, parks, and recreation areas all require water and their success (i.e., sustainability) relies on natural and human water delivery systems. Large amounts of time and effort are invested in learning more about the spatial and temporal patterns and characteristics of individual hydrologic processes so we can anticipate, manage, and modify system behaviour to sustain modern lifestyles and prevent shortages (droughts), surpluses (floods), and resource impairment (pollution).

## 1.6 Objectives of the Present Study

The objectives of the present study are:

- To study the changes in Land Use/ Land Cover (LU/LC) over a period, that influences the runoff characteristics of the study area.
- To study and analyse the Rainfall over a number of decades in the study area.
- 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).
- To analyse the impact of Land Use/ Land Cover changes on Runoff in the study area.
- 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.
- To predict probable Land Use/ Land Cover changes in the study area.
- To provide suggestive measures to store/discharge the rainfall excess/runoff water so as to safely reduce the probable occurrences of flood peaks.

# 2. Literature Review

## 2.1 General

This chapter briefly shows the research papers studied for the objectives mentioned in previous chapter.

## 2.2 Literature Review

**Kothiyari and Garde (1992)** showed that, a rainfall intensity-duration-frequency relationship is needed for planning and design of water resources projects. Data from 80 rain-gage stations in India were analysed. Making use of the assumption that general properties of the convective cells that are associated with short-period (i.e., less than 24 hr) rainfalls are similar in different hydrologic regions, a general relationship for rainfall intensity, duration, and frequency was developed. The correctness of form of the developed relationship was ascertained through its comparison with existing equations and the use of data from different hydrological regions. The relationship proposed herein is found to produce more realistic results for Indian conditions than the ones in vogue. The applicability of this relationship to the data from other countries was checked with the limited data available. The proposed relationship may be used in India for design practices.

**Srivastava and Gupta (2003)** presented that rapid growth in population coupled with expansion of urban fringe and encroachment in the prime land is a matter of great concern for the authorities associated with the urban planning. The expansion of sub-urban territory in Allahabad city of Uttar Pradesh State was a matter of concern for Planning Departments. Keeping this in view, it is planned to develop a remote sensing-based methodology for the preparation of land use/ land cover map using digital image processing techniques for Allahabad city and to monitor the changes in various classes. Changes in area under major land use/ land cover types have been determined through the comparison of their spatial extent in 1994 and 2000. It is observed that there has been an increase of nearly 8.0 km2 in built up area, coupled with decrease of about 20 $km^2$ and 2.5 $km^2$ in agriculture and scrub respectively in 6 years.

**Tang et al. (2005)** analysed that one of the goals of smart growth was water resources protection, in particular minimizing the runoff impact of urbanization. To investigate the magnitude of the potential benefits of land use planning for water resources protection, possible runoff impacts of historical and projected urbanization were estimated for two watersheds in Indiana and Michigan using a long-term hydrological impact analysis model. An optimization component allowed selection of land use change placements that minimize runoff increase. Optimizing land use change placement would have reduced runoff increase by as much as 4.9 percent from 1973 to 1997 in the Indiana study watershed. The results of this study had significant implications for urban planning.

**Angel, Parent & Civco (2007)** defined and presented a comprehensive set of metrics for five dynamic attributes of urban spatial structure commonly associated with ‘sprawl’: (a) the extension of the area of cities beyond the walkable range and the emergence of ‘endless’ cities; (b) the persistent decline in urban densities and the increasing consumption of land resources by urban dwellers; (c) ongoing suburbanization and the decreasing share of the population living and working in metropolitan centers; (d) the diminished contiguity of the built-up areas of cities and the increased fragmentation of open space in and around them; and (e) the increased compactness of cities as the areas between their finger like extensions are filled in. They also introduce several metrics for key manifestations of sprawl. They present these metrics as well as actual calculations of these metrics for two cities: Bangkok and Minneapolis.

**Abbas *et al.* (2010)** in their study of the urbanization in Katsina, Nigeria, indicated that urban sprawl and its concomitant effects of soil and land degradation resulting from increasing built environments, continues to characterize the peri-urban landscape. **Sreenivasulu and Bhaskar (2010)** have once again supported this assertion by explaining that changes in land use can be due to urban expansion and the loss of agriculture land, changes in river regimes, and the effects of shifting cultivation.

Due to the instrumental limitation, short duration rainfall data are not available in Sylhet. **Rashid, Faruque and Alam (2012)** developed an IDF empirical formula to estimate the rainfall intensity for any duration and any return period with minimum effort.

**Mallupattu and Reddy (2013)** studied land use/land cover (LU/LC) changes in an urban area, Tirupati, from 1976 to 2003 by using Geographical Information Systems (GISs) and remote sensing technology. The study area was classified into eight categories on the basis of field study, geographical conditions, and remote sensing data. The comparison of LU/LC in 1976 and 2003 derived from toposheet and satellite imagery interpretation indicates that there is a significant increase in built-up area, open forest, plantation, and other lands. It is also noted that substantial amount of agriculture land, water spread area, and dense forest area vanished during the period of study which may be due to rapid urbanization of the study area. **Aghil and Rajashekhar (2013)** analysed that the Loss of wetland and vegetation due to urbanization is the reason behind frequent floods during heavy rainfall in Bengaluru. Recalling the recent disaster occurred in Bengaluru, the South –West monsoon was supposed to wind up by the end of September, but it extended to few more days causing overflowed lakes situation and many parts of the city were inundated. Their work focused on estimating direct runoff using Soil Conservation Service Curve Number (SCS-CN) method, one of the popular and widely used method to estimate the direct runoff from a watershed. SCS–CN method based on all the three antecedent moisture conditions (AMC I, AMC II and AMC III) were used for their study. Rainfall data for 17 years (2000-2017) was collected from the meteorological department. In addition, Land use and Land cover maps were used. This study is useful for watershed development and planning of water resources effectively. The results revealed that SCS – CN method is a promising potential and reliable method to estimate the runoff of the Yelahanka watershed area.

Urban sprawl is mainly driven by unorganized growth, increased immigration, rapidly increasing population was stated by **Sankhala and Singh (2014).** Urban expansion and pattern could be depicted by spatial and temporal remote sensing satellite data. In this study, an attempt had been made to investigate the effect of Urban Sprawl on Land use / Land cover change of the year 1995, 2000, 2006 and 2010 for Jaipur city, one of the planned cities in India. The pattern of urban sprawl was identified using Remote Sensing technique. The investigation resembles noteworthy change in the spatio-temporal urban sprawl pattern, direction, magnitude and effects on Land use/ Land cover.

**Mohan and Kandya (2015)** investigated the effect of urbanization on the land surface temperature (LST) based DTR. This study presented spatial and temporal variations of satellite-based estimates of annually averaged DTR over megacity Delhi, the capital of India, which are shown for a period of 11 years during 2001–2011 and analyzed this about its land-use/land-cover (LU/LC) changes and population growth. **Appiah et al. (2015)** using Satellite Remote Sensing and Geographic Information System, analysed the land use and land cover change dynamics in the Bosomtwe District of Ghana, for 1986, 2010 thematic mapper and enhanced thematic Mapper+ (TM/ETM+) images, and 2014 Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIS) image. Their findings showed some of the important changes in the land use and land cover patterns in the district.

**Yangchen et al. (2015)** attempted to analyse land use land cover (LULC) changes in Bhutan over a period of thirteen years from 2000 to 2013. The images of Landsat 5, 7 and 8 were used for LULC classification and change detection. There was a significant increase in the built-up area which accounted for 6% in 2006 and 14% in 2013. Also, the snow cover increased from 4% in 2000 to 6% in 2006 and 9% in 2013. The overall accuracy of about 66% for 2000 and 2006 was fairly good. A low accuracy of 52% for 2013 may be partially because the spectral quality of the images was not good enough and partially due to the fact that the wavelengths of the bands of Landsat 8 satellite are little different than the corresponding bands of Landsat 5 and 7 satellites.

**Bajracharya et al. (2015)** analysed that in urban and suburban areas, much of the land surface is covered by buildings and pavements, which do not allow precipitation and snowmelt to soak into the ground. Hard surfaces such as streets, parking lots and built-up areas are impervious surfaces through which, water cannot pass through. As more and more landscapes are covered with hard impervious surfaces, the amount of water that infiltrates, decreases and the amount that runs off, increases. This research is focused on studying run-off conditions in context of urban areas. The study area was Kathmandu Metropolitan City (KMC). The city was in the stage of rapid urbanization and with it, a rapid increase in built-up spaces. Parameters for determining run-off coefficients were mainly land cover and land use data, soil type and slope of surface. Results showed that runoff was alarmingly high, indicated by the difference between the run-off values of pre- development and post-development scenarios. Urban development pattern had caused a major impact, in the prevailing run-off and it is very crucial that these issues were addressed in urban planning to promote effective solutions for maintaining water cycle and water resources in urban areas.

The study by **Mridha et al. (2016)** depicted the Land use and Land cover change analysis of Ramganjmandi tehsil of Kota district in Rajasthan, for a period of 30 years, 1990 to 2020. Supervised classification in ERDAS imagine software, opting maximum likelihood classifier is used for the classification of the region into 7 classes. LANDSAT 1-5, 7, 8 Level 1 collection were used for the years 1990, 2000, 2011, 2018 and 2020. The region showed a rapid change in the classes of Mining, Agriculture, Vegetation, and waterbody. The vegetation cover of the region has also declined from the year 1990 to 2020.

The change in rainfall pattern and intensity is becoming a great concern for hydrologic engineers and planners. Many parts of the world are experiencing extreme rainfall events such as experienced on 26th July 2005 in Mumbai, India. For the appropriate design and planning of urban drainage system in an area, Intensity Duration Frequency (IDF) curves for given rainfall conditions are required was discovered by **Zope, Eldho and Jothiprakash, (2016).** The aim of the study was to derive the IDF curves for the rainfall in the Mumbai city, Maharashtra, India. Observed rainfall data from 1901 pertaining to Colaba and from 1951 of the Santacruz rain gauge stations in Mumbai were used in the study to derive the IDF curves. Initially, the proposed IDF curves are derived using an empirical equation (Kothyari and Garde), by using probability distribution for annual maximum rainfall and then IDF curves are derived by modifying the equation. IDF curves developed by the modified equation gave good results in the changing hydrologic conditions and were compatible even with the extreme rainfall of 26th July 2005 in Mumbai.

**Bhat et al. (2017)** observed that the fast rate of increase in urban population is mainly due to large scale migration of people from rural and smaller towns to bigger cities in search of better employment opportunities and better quality of life. Urban sprawl resulted in loss of productive agricultural lands, open green spaces and loss of surface water bodies. In their study, an attempt had been made to monitor land use/land cover of part of Dehradun city over two periods of time i.e., from 2004 to 2014 for change detection analysis and to assess urban sprawl using IRS P-6 data and topographic sheets, in GIS environment for better decision making and sustainable urban growth.

**Ara and Zakwan (2018)** showed that the use of remote sensing and GIS technology can be useful to overcome the problem in conventional methods for estimating runoff. In this paper, modified Soil Conservation System (SCS) CN method is used for runoff estimation that considers parameter like slope, vegetation cover, area of watershed. The land cover map developed for the study region were used in analysing the runoff generated over the command area. Rainfall data and soil map for the region was acquired to calculate the antecedent moisture condition (AMC) and hydrological soil group (HSG) map respectively. SCS curve number model was employed to determine the runoff. The computation was carried out on a GIS platform to accommodate the spatial variability. Total runoff generated over the study region during the year 2007 was computed as 17.98 mm.

**Muthusi et al. (2020)** stated that Mavoko Municipality which borders Nairobi city in Kenya had experienced widespread land use \ land cover change which has altered the hydrological patterns of this watershed leading to occurrence of widespread flooding after rainfall events. This study used the Soil Conservation Service Curve Number (SCS-CN) method integrated with remote sensing and Geographic Information Systems (GIS) techniques to estimate urban runoff and to study the impact of the land use\land cover changes on surface runoff rates between 1989 and 2018. Built-up areas that were largely impervious increased from 24.6% in 1989 to 37.0% in 2018 while the more pervious land under grasslands, open spaces and barren land decreased from 65.5% in 1989 to 44.5% in 2018. 69% of the annual precipitation in 1989 was converted into runoff while in 2018 76% of the annual precipitation was converted in runoff. The result was consistent with the land use/land cover changes and modelling results which showed that 68% of the area experienced increased runoff, 23% no change and 9% a decrease in runoff. Correlation between potential maximum storage and the runoff volumes increased from 0.56 in 1989 to 0.59 in 2004 and 0.77 in 2018. The observed correlation between potential maximum storage and the runoff volumes indicates that the SCS-CN Method, Remote Sensing and Geographic Information Systems Approach can be a useful tool for runoff estimation.

Blantyre City had experienced a wide range of changes in land use and land cover (LULC) was observed by **Gondwe, Lin and Munthalim (2021)** in their study and used Remote Sensing (RS) to detect and quantify LULC changes that occurred in the city throughout a twenty-year study period, using Landsat 7 Enhanced Thematic Mapper (ETM+) images from 1999 and 2010 and Landsat 8 Operational Land Imager (OLI) images from 2019. A supervised classification method using an Artificial Neural Network (ANN) was used to classify and map LULC types.

Land use land cover (LULC) changes act as global environmental drivers, and therefore, LULC change analysis has become the primary concern for the monitoring agencies. The study by **Ande et al**. **(2022)** aimed to project the land use and land cover (LULC) by analysing the change rate in the past, forecasting the near, middle, and far future scenarios of Cochin, a highly urbanised coastal city of Kerala, India. Their model simulated LULC was validated by comparing the observed LULC 2020 with the simulated one. The model demonstrated acceptable LULC dynamics with an overall accuracy of 87.5%. The simulated future LULC scenarios illustrate a sweeping increase in the built-up lands and shrinkage of natural land covers such as agricultural lands, forests, fallow lands, and water bodies.

**Abebe et al. (2022)** analysed the status of LULC changes and key drivers of change for 30 years through a combination of remote sensing and GIS with the surveying of the local community understanding of LULC patterns and drivers in the Gubalafto district, North-eastern Ethiopia. Five major LULC types (cultivated and settlement, forest cover, grazing land, bush land and bare land) from Landsat images of 1986, 2000, and 2016 were mapped.

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# 3. STUDY AREA AND DATA COLLECTION

## 3.1 General

In the present work, the area selected for the study is Vadodara City. Vadodara has suffered due to floods in the years 1974,1976, 1994, 1996 and 2005, not only due to heavy rainfall but also due to changes in land use/ land cover changes.

## 3.2 Study Area

The study area selected is Vadodara city of Gujarat state in India. Vadodara is located at 22.30°N 73.19°E in western India at an elevation of 34 metres, with an area of 149 square kilometers. The city sits on the banks of the Vishwamitri River, in central Gujarat. The Vishwamitri frequently dries up in the summer, leaving only a small stream of water.

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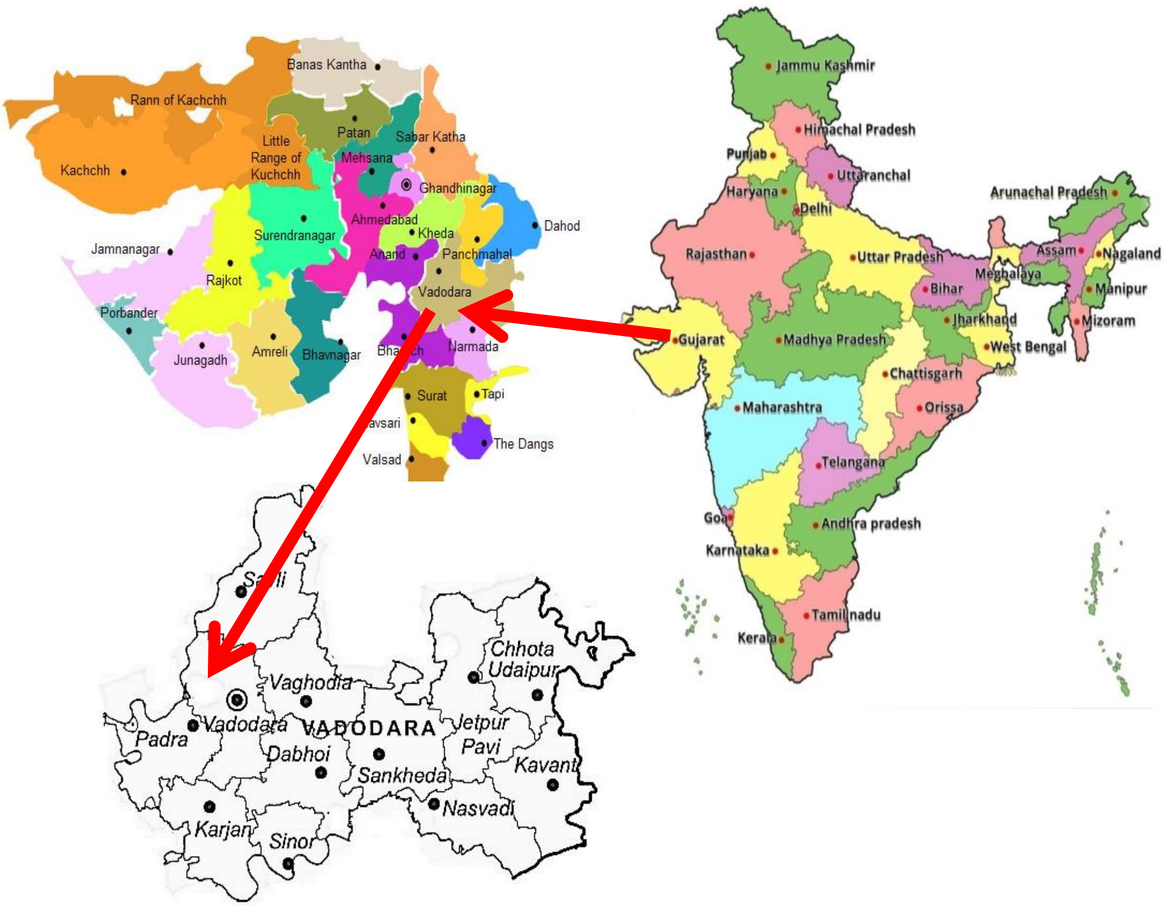


Figure 2: Location map of Vadodara City

The city is located on the fertile plain between the Mahi and Narmada rivers. According to the Bureau of Indian Standards, the cosmopolis falls under seismic zone-III, in a scale of I to V (in order of increasing proneness to earthquakes).

## 3.3 Data Collection

The city of Vadodara has witnessed a rapid urban development during past two decades resulting into enhanced land use change, parallel to the increase in population and economic growth. The city has expanded horizontally in all directions, resulting in large-scale changes in the land use. One of the major concerns is the increase in the number of slums, especially along the banks of river Vishwamitri and its adjoining low-lying areas, which are severely flooded during monsoons, leading to widespread economic loss and impacts on health and environment.

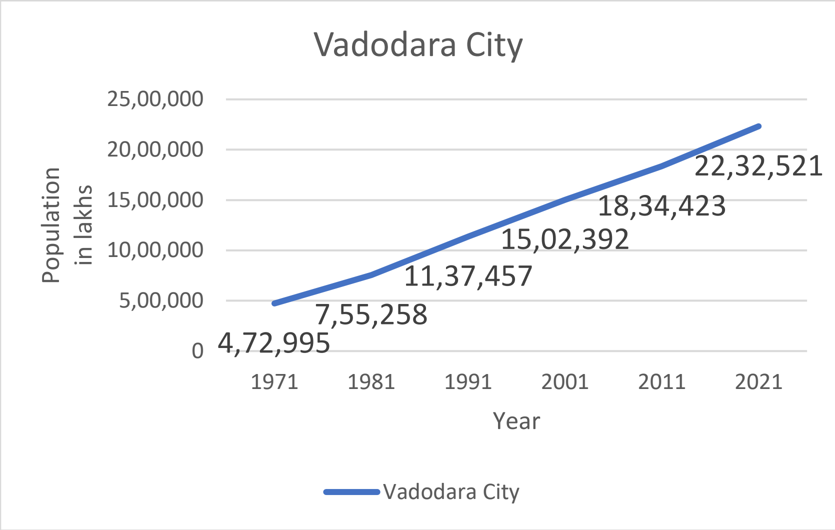


Figure 3: Population Growth in study area for the years 1971, 1981, 1991, 2001, 2011 and 2021

Figure 3 shows the population data for the years 1971, 1981, 1991, 2001, 2011 and 2021. It shows a decadal increase in the range of 60% to 20%. A minimum of 21% increase from 2001 to 2011 and a maximum 59% increase from 1971 to 1981.

Rapid population growth would definitely increase the pressure on land use, but if the implementation of proper planning is executed, its impacts can be mitigated. Remote Sensing and GIS aids in both preparing accurate land use maps and monitoring changes at regular intervals of time. The potential of remote sensing to detect the growth of urban land use changes and determination of statistics has already been proved. This has become a need for Vadodara city as it is facing the grave problem of both urbanization and industrialization.

A GIS is a computer application program that stores Spatial and Non-Spatial information in a digital form. Spatial information for an area is what is traditionally represented in maps which for a region, may broadly be classified as given in the following table. The corresponding source of such data for our country is also indicated.

Table 1:Data Collection

| | Spatial features of a region | Obtained from |
|---|---|---|
| 1 | Rainfall data | State Water Data Centre |
| 2 | Soil map | National Bureau of Soil Survey and Land Use Planning |
| 3 | Latest information on land-use and land cover, like Vegetation, Water body, Built-up and Barren land | Satellite Imageries from USGS website |

**LU/LC Data**

Landsat 8 Operational Land Imager (OLI) image of 2018, Landsat 7 Enhanced Thematic Mapper (ETM+) image of 2008 & 2003, Landsat 5 Thematic Mapper (TM) image of 1998, 1993 & 1988 and Landsat 1 Terrain Precision (TP) image of 1977 with a resolution of 30 m, were utilized in this study to evaluate changes in LU/LC in the study region during a 41-year period from 1977 to 2018.

| | |
|---|---|
| Landsat 8 Operational Land Imager (OLI) | 2018 |
| Landsat 7 Enhanced Thematic Mapper (ETM+) | 2013, 2008 and 2003 |
| Landsat 5 Thematic Mapper (TM) | 1998, 1993 and 1988 |
| Landsat 1 Terrain Precision (TP) | 1977 |

Almost, cloud-free Landsat satellite scenes for Path/Row 148/45 from two types of sensors covering the study area were downloaded freely from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov/). For easy visibility, the cloud-free imagery used in this study was captured during the month of March. The detailed characteristics of the Landsat images used in this study are presented in Table 2.

Table 2:Satellite Imagery.

| Satellite Imagery used | | | | | |
|---|---|---|---|---|---|
| Satellite sensor | Path/row | Acquisition date | Number of bands | Spatial resolution (m) | Cloud Cover |
| L1_TP | 159/45 | March 10 1977 | 4 | 60 | 0.00 |
| L5_TM | 148/45 | March 19 1988 | 7 | 30 | 0.00 |
| L5_TM | 148/45 | March 17 1993 | 7 | 30 | 0.00 |
| L5_TM | 148/45 | March 15 1998 | 7 | 30 | 0.00 |
| L7 ETM+ | 148/45 | March 05 2003 | 9 | 30 | 1.00 |
| L7 ETM+ | 148/45 | March 18 2008 | 8 | 30 | 0.00 |
| L7 ETM+ | 148/45 | March 16 2013 | 8 | 30 | 0.00 |
| L8 OLI | 148/45 | March 22 2018 | 11 | 30 | 0.00 |

Data source: US Geological Survey.

## 3.4 Data Preparation

- The maps of the project are processed and analysed using GIS mapping software (ArcMap of ArcGIS and Erdas Imagine, etc.); different layers that have the same coordinates and projection systems.

- The statistical parameters of meteorological data considered are calculated using in Excel using Excel stats and curve expert is used.

# 4. Methodology

## 4.1 General

This chapter briefly shows the methodology adopted for the individual objective. The chapter is divided into six sections, each section contains the specific methodology for the specific objective.

## 4.2 Methodology

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

Land use land cover (LU/LC) change detection based on remote sensing data is an important source of information for various decision support systems.
Information derived from land use and land cover change detection is important to land conservation, sustainable development, and management of water resources.
Landsat Imagery data was collected for the years 1977, 1988, 1993, 1998,2003, 2008, 2013 and 2018.

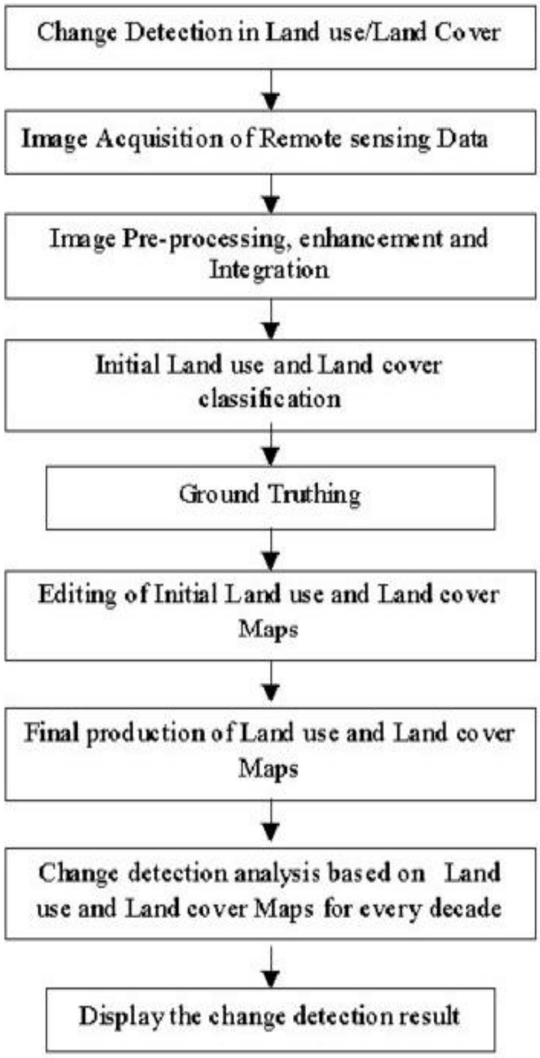


Figure 4: Flowchart for LU/LC detection

**Methodology of Land Use / Land Cover Analysis**

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

**Image Pre-processing**

In principle, it entails geometric and radiometric corrections.

In remote sensing data for georeferencing refers to the process of assigning to image data from some map coordinate. Geometrical distortion is an error on an image between actual image acquisition (sensor) coordinate data and ideal image coordinate data.

Here for few images georeferencing is done using ArcMap software.

Vadodara lies in the following UTM Zone: WGS_1984_UTM_Zone_43N.

Details on radiometric corrections is presented in the subsequent paragraphs.

Coarse resolution data:

In the past, some classification projects employing coarse resolution data were carried out with single-date, relatively cloud-free images. However, this approach is fundamentally limited because the probability of cloud-free scenes decreases as the area covered by one scene increases. It is thus very difficult to obtain useful images for land cover mapping, especially if the eligible time interval is short. Furthermore, such images contain systematic errors due to atmospheric effects (as a function of the path length) as well as monotonically changing spatial resolution for most coarse resolution sensors. For these reasons, research in recent years has emphasised the use of image composites. In a compositing process, the image product is prepared so as to contain, as far as possible, information about the land surface itself. Since a large fraction of the pixels typically contain clouds, the main objective of the procedure is to select the most cloud-free measurement from those available for a given pixel of the composite image.

Fine resolution data:

In the past, most land cover studies employing high resolution data were carried out with single images (hereafter called ‘scenes’), parts of scenes or an assembly of such scenes from different areas. In these cases, radiometric consistency was not an issue because the classification could be optimized individually for each scene. When classifying a scene composite (i.e., a mosaic of scenes), the situation is more complicated.

In principle, two options are possible. First (case I), one can classify each scene separately and subsequently reconcile the classes across the mosaic. Another approach (case II) is to assemble a mosaic of scenes for the entire area, establish radiometric uniformity across the mosaic, and then classify it as one entity. In case I, each scene is treated as a separate data set to be classified, using ancillary data that are appropriate for the classification procedure employed.

Because of the infrequent satellite revisits, the compositing of fine resolution data over large areas (case II) employs entire scenes, as opposed to individual pixels in the coarse resolution data.

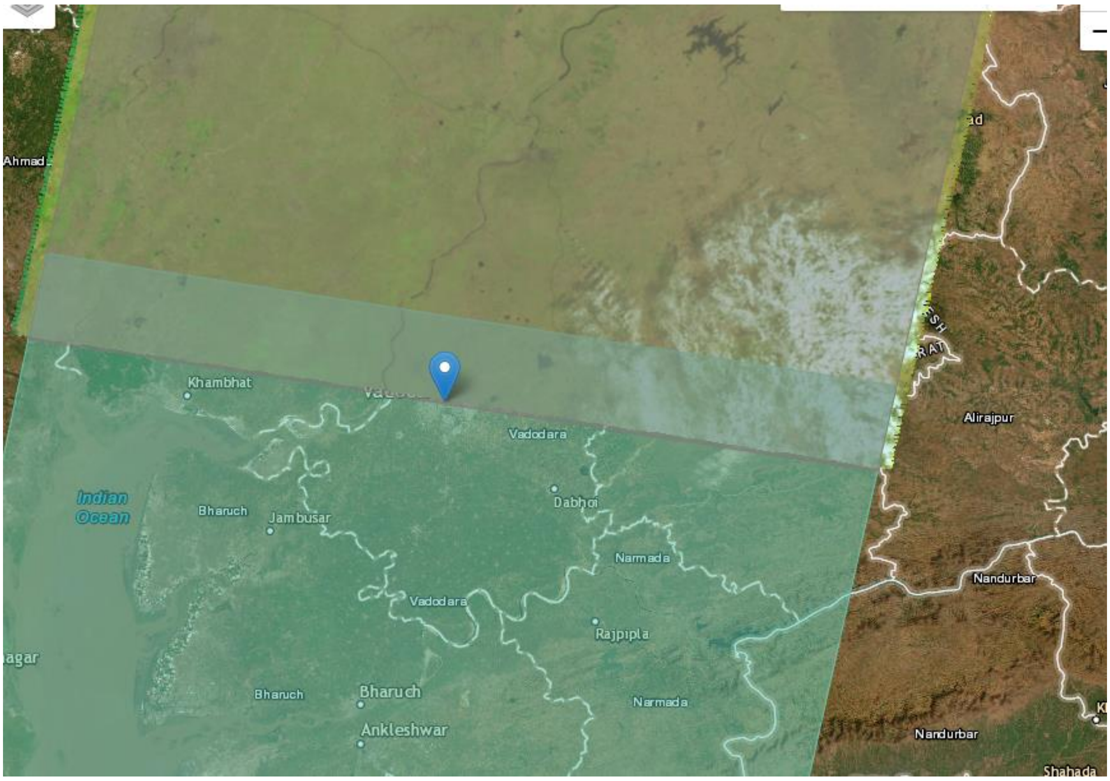


Figure 5: Satellite Imagery of Vadodara in two tiles

**Image Enhancement**

Image enhancement is **the process of making an image more interpretable for a particular application**. Enhancement makes important features of raw, remotely sensed data more interpretable to the human eye.

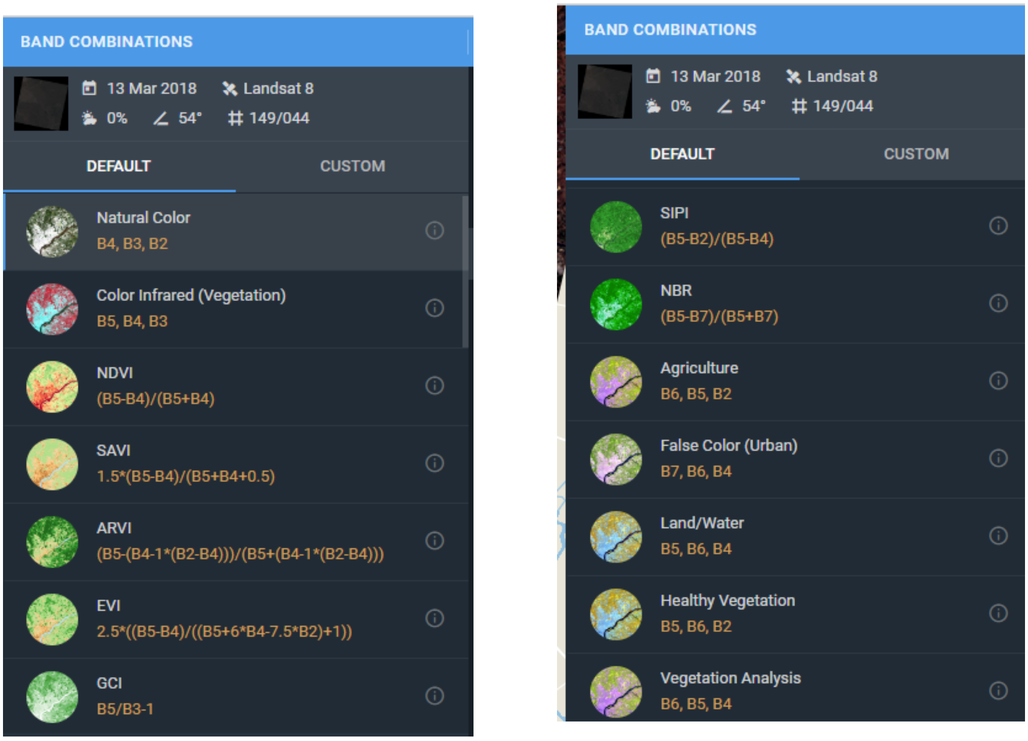


Figure 6: Band combinations for False Colour Composite (FCC)

**Colour Composites**

A multispectral image data has six bands (nominally 30m per pixel) where the sensor on the satellite measures the intensity of reflected light in six distinct bandwidths filters ranging from blue light to near infrared and short-wave infrared.

A colour composite is an image created using combinations of these image band data displayed in red, green and blue display channels. We have to create true and false colour composites for general image enhancement

False colour composites (FCC) can be generated using different combinations of the Landsat bands displayed in red, green, blue (RGB) image display channels.

**Image Classification**

The classification of unsupervised data through ERDAS Imagine helped in identifying the terrestrial objects in the Study Image. The spectral pattern present within the data for each pixel was used as the numerical basis for categorization.

The first analysis of the Image involved the use of generalized Unsupervised Classification with 4 categories (Water body, Vegetation, Built-up and Barren land). The result of the Unsupervised Image was used to create another image by using Supervised classification.

Image clipping was conducted to create a fully classified image, Computer-guided (Unsupervised) and User-guided (Supervised) Procedures were used on image clipping to view each classification one at a time and stack them into a complete Classified Image. Land cover information that can be gleaned from satellite images is the spectral and spatial attributes of individual cover types.

**Urban Sprawl**

“Urban sprawl” is known as a “form of spatial development, characterized by low density, scattered and discontinuous leapfrog expansion, and a segregation of land use”. It consists of prominent characteristics such as single use development, fragmentation, shape irregularity, inequality/low concentration and linear development. Hence, it has contributed significantly to convert rural land use topologies into urban land use and depleted the number of rural lands In term of sprawl is the opposite to be compact urban development as well as it more concern about unplanned and uncontrolled growth of a city.

Urban Sprawl Index (USI)

Urban Sprawl Index (U.S.I.), a measure of the built environment in a city.

It is calculated from the following formula:

U.S.I. = Urban expansion / Population increase

= A2- A1 / P2 – P1

Where, A1 and A2 are the areal extents for the early and later years and

P1 and P2 are population for the early and later years, respectively.

Land Consumption Rate (L.C.R.) is an estimate of the rate at which the land is consumed by the developing area.

It was calculated from the following formula:

L.C.R = Areal extent of the city / Population

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

An intensity-duration-frequency curve (IDF curve) is a mathematical function that relates the rainfall intensity with its duration and frequency of occurrence. These curves are commonly used in hydrology for flood forecasting and civil engineering for urban drainage design. Development of rainfall Intensity-Duration-Frequency (IDF) relationship is a primary basic input for the design of the storm water drainage system for cities. The rainfall depths derived from the intensity duration frequency relationship is being used by water resource managers for planning, designing and operation of water resource related projects. To ascertain the hydrologic risks, assessment of extreme precipitation and establishment of IDF curves is important. IDF is a statistical relationship between the rainfall intensity (I), the duration (D), and the return period (T). The statistical analysis of daily as well as hourly rainfall data was carried out using Gumbel distribution. In this study, annual maximum daily method is used in the IDF development.

The step-by-step procedure used is given below.

- Find out year wise annual maximum daily rainfall series.
- Rank (m) the rainfall totals.
- Find out return periods (T).
  T = (N +1) / m
  where N is the number of years data.
- Plot the graph of rainfall depth v/s return period on semi log paper.
- Find out the equation of regression line to find out precipitation depth.
  $$R_{24}^2 = P_{(mm)} = a\ln(T) + (b)$$
  where, P = maximum daily precipitation.
- Finding out rainfall intensity for different return periods and different durations by using formulas as described as below.

The following procedure is followed for preparation of IDF curves.

**Step 1:** Collection of annual daily rainfall data.
Daily rainfall data from the years 1961 to 2016 is used to obtain recent trends in the rainfall intensity.

**Step 2:** Preparation of short duration rainfall data using IMD formula as in equation 1.
Shorter duration rainfall series is generated from Daily Rainfall data and shown in Table 1.

$$P_t = P_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}} \qquad \text{---- 1}$$

Where
$P_t$ = Rainfall in mm for t hours duration,
$P_{24}$ = Daily Rainfall data in mm and
t = Shorter duration in hours

**Step 3:** Probability Distribution
In this study, Gumbel's Extreme Value distribution method is used for probability distribution for each selected duration data series. Chow (1951) has shown that hydrological studies can be expressed by the following equation of the hydrologic

frequency analysis: The rainfall ($P_T$) corresponding of a given return period (T) using the Gumbel's Distribution is given by:

$P_T = \sigma + K.S$ --- 2

Where σ = Average Annual Daily Maximum Rainfall
S = Standard Deviation of Annual Daily Maximum Rainfall
K = Frequency Factor given by:

$K = -\frac{\sqrt{6}}{\pi}[0.57720 + \ln[\ln(\frac{T}{T-1})]]$ --- 3

Table 3: Sample data showing Shorter Duration Rainfalls

| **Year** | **1 hr** | **2 hr** | **6 hr** | **12 hr** | **24 hr** |
|---|---|---|---|---|---|
| **1981** | 32.10 | 20.22 | 9.72 | 6.12 | 3.86 |
| **1982** | 60.67 | 38.22 | 18.37 | 11.57 | 7.29 |
| **1983** | 44.20 | 27.85 | 13.39 | 8.43 | 5.31 |
| **1984** | 39.35 | 24.79 | 11.92 | 7.51 | 4.73 |
| **1985** | 63.86 | 40.23 | 19.34 | 12.18 | 7.67 |
| **1986** | 31.89 | 20.09 | 9.66 | 6.09 | 3.83 |
| **1987** | 36.82 | 23.19 | 11.15 | 7.02 | 4.42 |
| **1988** | 31.20 | 19.66 | 9.45 | 5.95 | 3.75 |
| **1989** | 36.40 | 22.93 | 11.02 | 6.94 | 4.38 |
| **1990** | 54.29 | 34.20 | 16.44 | 10.36 | 6.53 |
| **1991** | 28.95 | 18.24 | 8.77 | 5.52 | 3.48 |

Table 3 shows rainfalls (in mm), Derived from Maximum Daily Rainfall using IMD 1/3rd rule

Using equation 3, Frequency Factors for the return periods of 2, 5, 10, 15, 20, 25,30, 50, 75 and 100 years are calculated, and those values are 0.16, 0.72, 1.30, 1.63, 1.87, 2.04, 2.19, 2.59, 2.91 and 3.14 respectively. The above values of frequency factor are used to obtain $P_T$ corresponding to return periods of 5, 10,15, 20, 25,30, 50, 75 and 100 years for durations of 1 to 24 Hours. Then, the intensity of rainfall ($I_T$) is obtained for the return period T from the below equation: $\mathbf{I_T = \frac{P_t}{T_d}}$ --- 4

Where $T_d$ is duration in hours.

The frequency of the rainfall is usually defined by reference to the annual maximum series, which consists of the largest values observed in each year.

Step 4: Preparation of IDF Curves by using these data, Intensity Duration Frequency curves are plotted for various return periods.

**IDF Curves by Empirical Equations**

The IDF formulas are the empirical equations representing a relationship among maximum rainfall intensity (as dependant variable) and other parameters of interest such as rainfall duration and frequency (as independent variables). There are several commonly used functions found in the literature of hydrology applications (Chow et al., 1988), four basic forms of equations used to describe the rainfall intensity duration relationship are summarized as follows:

Talbot equation:

$$i = \frac{a}{d + b}$$

Bernard equation: ---(5)

$$i = \frac{a}{d^e}$$

Kimijima equation: ---(6)

$$i = \frac{a}{d^e + b}$$

Sherman equation: ---(7)

$$\frac{a}{(d + b)^e}$$

---(8)

where i is the rainfall intensity (mm/hour); d is the duration (minutes); a, b and e are the constant parameters related to the metrological conditions.

**3. Objective: 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 soil conservation service curve number (SCS-CN) method was developed in 1954 and is documented in section 4 of the National Engineering Handbook (NEH-4) published by the Soil Conservation Service (now called as Natural Resources Conservation Service) of the United States Department of Agriculture (USDA) in 1956. It is one of the most popular methods for computing the volume of surface runoff for a given rainfall event from small agricultural, forest and urban watersheds. The primary reasons for its wide applicability and acceptability lies in the fact that it accounts for most runoff producing are characteristics: soil type, land use/treatment, surface condition and antecedent moisture condition.

The amount of direct surface runoff (Q) to the total rainfall (P) (or maximum potential surface runoff) to the ratio of the amount of actual infiltration (F) to the amount of the potential maximum retention (S). The second hypothesis relates the initial abstraction (Ia) to the potential maximum retention; thus the SCS-CN method consists of:

(a) Water Balance Equation:

$P = I_a + F + Q$ (9)

(b) Proportional Equality Hypothesis:

$Q/P-I_a = F/S$ (10)

(c) Ia -S hypothesis

$I_a= \lambda S$ (11)

Where P= total rainfall; $I_a$ =initial abstraction; F= cumulative infiltration excluding $I_a$; Q= direct runoff; and S= potential maximum retention or infiltration.

Combining equations 9 and 10, it becomes

$Q = (P - I_a)2/(P - I_a + S)$ (12)

Equation is valid for $P \geq I_a$. For $\lambda = 0.2$, the equation can be written as:

$Q = (P - 0.2 S)2/(P + 0.8 S)$ (13)

Thus, the existing SCS-CN method is a one parameter model for computing surface runoff from daily storm rainfall, for the method was originally developed using daily rainfall-runoff data of annual extreme flows. S is a constant and is the maximum difference of (P-Q) that can occur for the given storm and watershed condition. S is limited by either the rate of infiltration at the soil surface or the amount of water storage available in the soil profile, whichever gives the smaller S value. Since parameter S can vary in the range of $0 \leq S \leq \infty$, it is mapped into a dimensionless curve number (CN), varying in a more workable range $0 \leq CN \leq 100$, as follows: (Actually, to make Eq. 12.6 mathematically workable, the CN limit should be $0 < CN \leq 100$)

$S = (1000/CN) -10$ (14)

The underlying difference between S and CN is that the former is a dimensional quantity (L) whereas the latter is a non-dimensionless quantity. The CN theoretically varies from 0 to 100.

The **Curve Number** is a dimensionless parameter indicating the runoff response characteristic of a drainage basin. In the Curve Number Method, the CN is related to land use, land treatment, hydrological soil group, and antecedent soil moisture condition in the drainage basin.

Factors Affecting SCS Curve Number

(a) Land Use or Cover
Land use represents the surface conditions in a drainage basin and is related to the degree of cover. In the present study land use classes are distinguished as water body. Vegetation, built-up and uncultivated land.

(b) Practice in relation to Hydrological Condition
Land treatment applies mainly to agricultural land uses. It includes mechanical practices such as contouring or terracing, and management practices such as rotation of crops, grazing control, or burning.
For grazing control and burning (pasture range and forest), the hydrological condition is classified as poor, fair, or good. Pasture range is classified as poor when heavily grazed and less than half the area is covered; as fair when not heavily grazed and between one-half to three-quarters of the area is covered; and as good when lightly grazed and more than three-quarters of the area is covered. Woodlands are classified as poor when heavily grazed or regularly burned; as fair when grazed but not burned; and as good when protected from grazing.

(c) Hydrological Soil Group

Soil properties greatly influence the amount of runoff. In the SCS method, these properties are represented by a hydrological parameter: the minimum rate of infiltration obtained for a bare soil after prolonged wetting. The influence of both the soil's surface condition (infiltration rate) and its horizon (transmission rate) are thereby included. This parameter, which indicates a soil's runoff potential, is the qualitative basis of the classification of all soils into four groups. The Hydrological Soil Groups, as defined in the SCS-CN method, are:

Table 4: Land Use Categories and Associated Curve Numbers)

| **Description** | **Average % Impervious** | **Curve Number by Hydrologic Soil Group** | | | | **Typical Land Uses** |
|---|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** | |
| Residential (High Density) | 65 | 77 | 85 | 90 | 92 | Multi-family Apartments, Trailer Parks |
| Residential (Med. Density) | 30 | 57 | 72 | 81 | 86 | Single-Family, Plot Size 0.1 to 0.4 ha |
| Residential (Low Density) | 15 | 48 | 66 | 78 | 83 | Single-Family, Plot Size 0.4 ha and Greater |
| Commercial | 85 | 89 | 92 | 94 | 95 | Strip Commercial, Shopping Centers, Convenience Stores |
| Industrial | 72 | 81 | 88 | 91 | 93 | Light Industrial, Schools, Prisons, Treatment Plants |
| Disturbed/Transitional | 5 | 76 | 85 | 89 | 91 | Gravel Parking, Quarries, Land Under Development |
| Agricultural | 5 | 67 | 77 | 83 | 87 | Cultivated Land, Row crops, Broadcast Legumes |
| Open Land | 5 | 39 | 61 | 74 | 80 | Parks, Golf Courses, Greenways, Grazed Pasture |
| Impervious | 95 | 98 | 98 | 98 | 98 | Paved Parking, shopping malls, Major Roadways |
| Water | 100 | 100 | 100 | 100 | 100 | Water Bodies, Lakes, Ponds, Wetlands |

Group A: Soils having high infiltration rates even when thoroughly wetted and a high rate of water transmission. Examples are deep, well to excessively drained sands or gravels.

Group B: Soils having moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. Examples are moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils having low infiltration rates when thoroughly wetted and a low rate of water transmission. Examples are soils with a layer that impedes the downward movement of water or soils of moderately fine to fine texture.

Group D: Soils having very low infiltration rates when thoroughly wetted and a very low rate of water transmission. Examples are clayey soils with a high swelling potential, soils with a permanently high-water table, soils with a clay pan or clay layer at or near the surface, or shallow soils over nearly impervious material. Table 12.1 shows Land use categories and associated curves number, according to soil group; commercial land has different curve number.

(d) Antecedent Moisture Condition

The soil moisture condition in the drainage basin before runoff occurs is another important factor influencing the final CN value. In the Curve Number Method, the soil moisture condition is classified in to three Antecedent Moisture Condition (AMC) Classes:

AMC I: The soils in the drainage basin are practically dry (i.e., the soil moisture content is at wilting point).

AMC II: Average condition.

AMC III: The soils in the drainage basins are practically saturated from antecedent rainfalls (i.e., the soil moisture content is at field capacity).

These classes are based on the 5-day antecedent rainfall (i.e. the accumulated total rainfall preceding the runoff under consideration), as illustrated in Table 5. In the original SCS method, a distinction was made between the dormant and the growing season to allow for differences in evapotranspiration.

Table 5: Seasonal rainfall limits for AMC classes

| Antecedent Moisture Condition | 5 Day Antecedent rainfall (mm) | | |
|---|---|---|---|
| Class | Dormant Season | Growing Season | Average |
| I | < 13 | < 36 | < 23 |
| II | 13-28 | 36 – 53 | 23 – 40 |
| III | > 28 | > 53 | > 40 |

After obtaining CN – II values. Weighted curve number (WCN) is computed using the following formula:

WCN = ∑(Area of individual land use * CN of that land use)

(e) Agricultural Management Practices

Agricultural management system involves different types of tillage, vegetation, and surface cover. Moldboard Plough increases soil porosity from 10-20%, depending on the soil texture and, in turn, increases infiltration rates as compared to those for the non-tilled soils. Also, an increase in the organic matter content in the soil lowers the bulk density or increases porosity, and hence increases infiltration and in turn, decreases the runoff potential.

(f) Initial Abstraction and Climate
The initial abstraction consists of interception, surface detention, evaporation, and infiltration. The water held by interception, surface detention, and the infiltration at the beginning of a storm finally goes back to atmosphere through evaporation. The effect of the climatic condition of watershed is accounted for by the existing SCS-CN method in terms of the initial abstraction. It is the amount of initial abstraction for a given rainfall amount in watershed. Thus, the initial abstraction reduces the runoff potential of the watershed and the curve number.

(g) Rainfall Intensity and Duration and Turbidity
A high intensity rainfall or raindrop breaks down the soil structure to make soil fines move into the soil surface or near-surface pores, leading to the formation of crust that impedes infiltration. The crust formation actually decreases the effective soil depth responsible for infiltration and also the soil porosity, decreases S or increases CN. It is for this reason that a fallow land exposed to rain, produce a higher runoff for a given rainfall amount than does the unexposed or covered land. The term turbidity refers to impurities of water that affect infiltration by the process of clogging of soil pores and consequently, affecting the soil conductivity or ease with which water is transmitted into the soil. The contaminated water with dissolved minerals, such as salts, affects the soil structure and consequently, infiltration.

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

To analyse the impact of land use/ land cover changes on runoff the following scenarios are taken into consideration:

Scenario 1: Considering 1977 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely 1988, 1998, 2008 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 1977.

Scenario 2: Considering 1988 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely 1977, 1998, 2008 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 1988.

Scenario 3: Considering 1998 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely1977, 1988, 2008 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 1998.

Scenario 4: Considering 2008 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely 1977, 1988, 1998 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 2008.

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

5. **Objective: 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.**

Using equation 3, Frequency Factors for the return periods of 2, 5, 10, 15, 20, 25,30, 50, 75 and 100 years are calculated, and those values are 0.16, 0.72, 1.30, 1.63, 1.87, 2.04, 2.19, 2.59, 2.91 and 3.14 respectively. The above values of frequency factor are used to obtain $P_T$ corresponding to return periods of 5, 10,15, 20, 25,30, 50, 75 and 100 years for durations of 1 to 24 Hours. Then, the intensity of rainfall ($I_T$) is obtained for the return period T from the below equation: $\mathbf{I_T = \frac{P_t}{T_d}}$ **--- 4**
Where $T_d$ is duration in hours.

Similarly, to compute Runoff Intensity in mm/hr. at various durations and return periods, rainfall – runoff models are prepared. Namely linear, logarithmic, polynomial and power. Out of these models developed, the non-linear model with polynomial degree 5 was best suited for the computation of runoff based on training and test of data.
Using the rainfall and runoff data, a non-linear, polynomial model was developed for the dataset of 70 – 30 (Training – Validation).

The non-linear model equation is
$Y = a + bx + cx^2 + dx^3 + ex^4 + fx^5$, where Y = Runoff and x = Rainfall
where a, b, c, d, e and f are constants whose values are obtained using excel.

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

The land use/ landcover changes in the study are predicted by developing various models like linear model, logarithmic model, polynomial mode with order 2 and power model. These various models are developed with the help of Microsoft excel.

# 5. RESULTS AND ANALYSIS

## 5.1 General

This chapter briefly shows the results obtained for the individual objective. The chapter is divided into six sections, each section contains the results obtained for the specific objective.

## 5.2 Results and Analysis

1. **Objective: To study the changes in Land Use/Land Cover (LU/LC) over a period, that influences the runoff characteristics of the study area.**
   After carrying out the image classification, the following results are obtained.

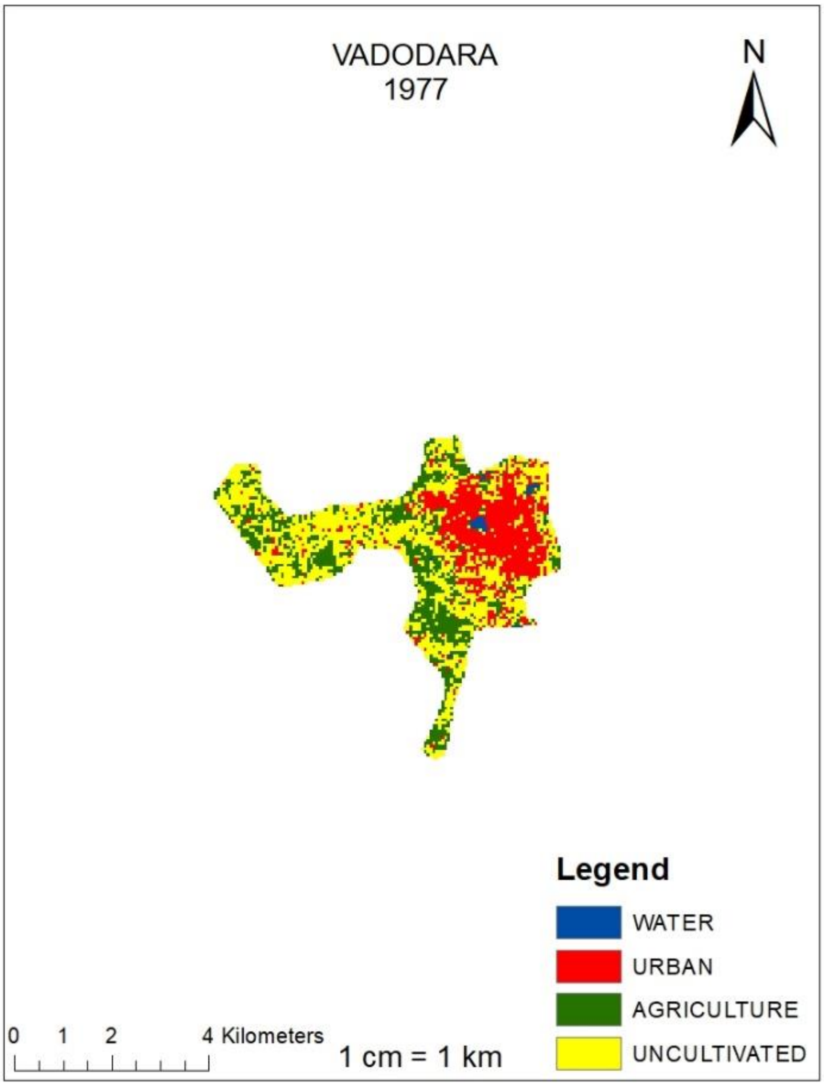


Figure 7: LU/LC for Vadodara City in 1977

Figure 7 shows the land use classification of Vadodara city for the year 1977

The values of areas of four classes namely Waterbody, Built-up represented by Urban, Vegetation represented by Agriculture and Uncultivated land are given in Table 6

Table 6: Area of land uses in Sq. Km. for the year 1977

| Year | 1977<br>Area, Sq. Km |
|---|---|
| Waterbody | 0.176 |
| Built-up | 4.205 |
| Vegetation | 4.291 |
| Uncultivated | 7.754 |
| Total Area | 16.427 |

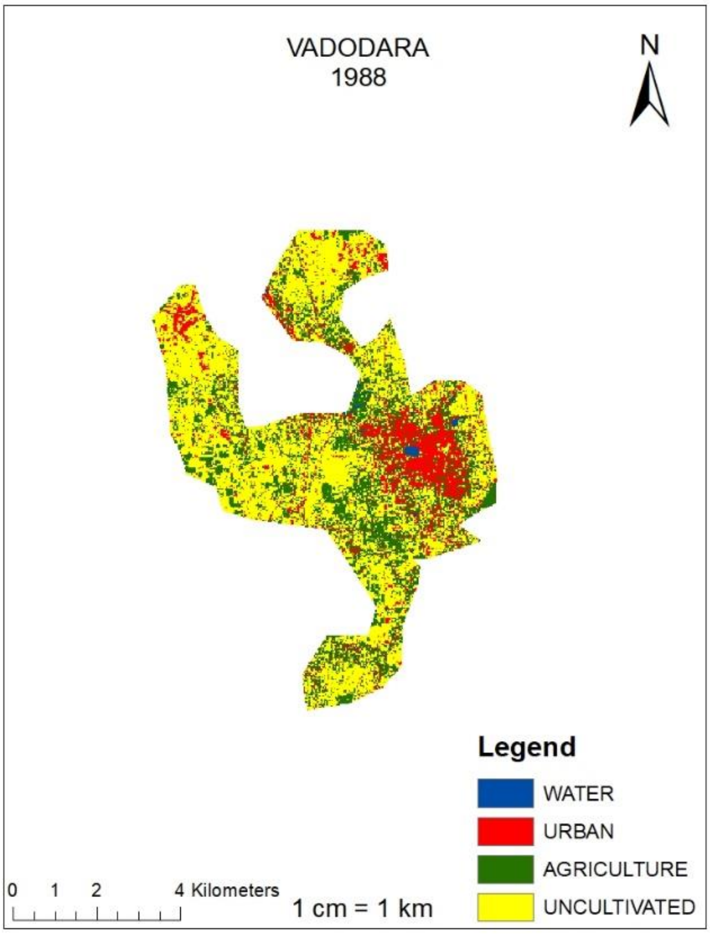


Figure 8: LU/LC for Vadodara City in 1988

Figure 8 shows the land use classification of Vadodara city for the year 1988

Table 7: Area of land uses in Sq. Km. for the year 1988

| Year | 1988<br>Area, Sq. Km |
|---|---|
| Waterbody | 0.393 |
| Built-up | 5.857 |
| Vegetation | 11.072 |
| Uncultivated | 22.141 |
| Total Area | 39.463 |

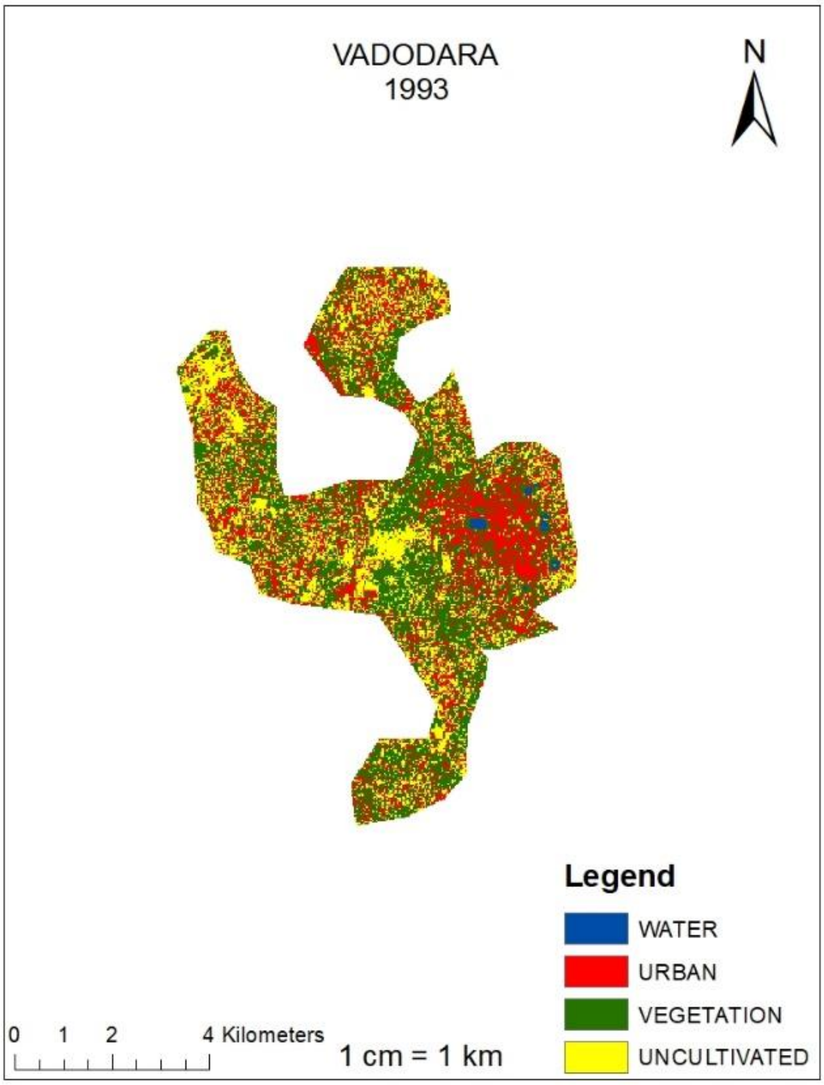


Figure 9: LU/LC for Vadodara City in 1993

Figure 9 shows the land use classification of Vadodara city for the year 1993 and the values of areas of four classes namely Waterbody, Built-up represented by Urban, Vegetation represented by Agriculture and Uncultivated land are given in Table 8

Table 8: Area of land uses in Sq. Km. for the year 1993

| Year | 1993<br>Area, Sq. Km |
|---|---|
| Waterbody | 0.256 |
| Built-up | 11.274 |
| Vegetation | 17.063 |
| Uncultivated | 10.870 |
| Total Area | 39.463 |

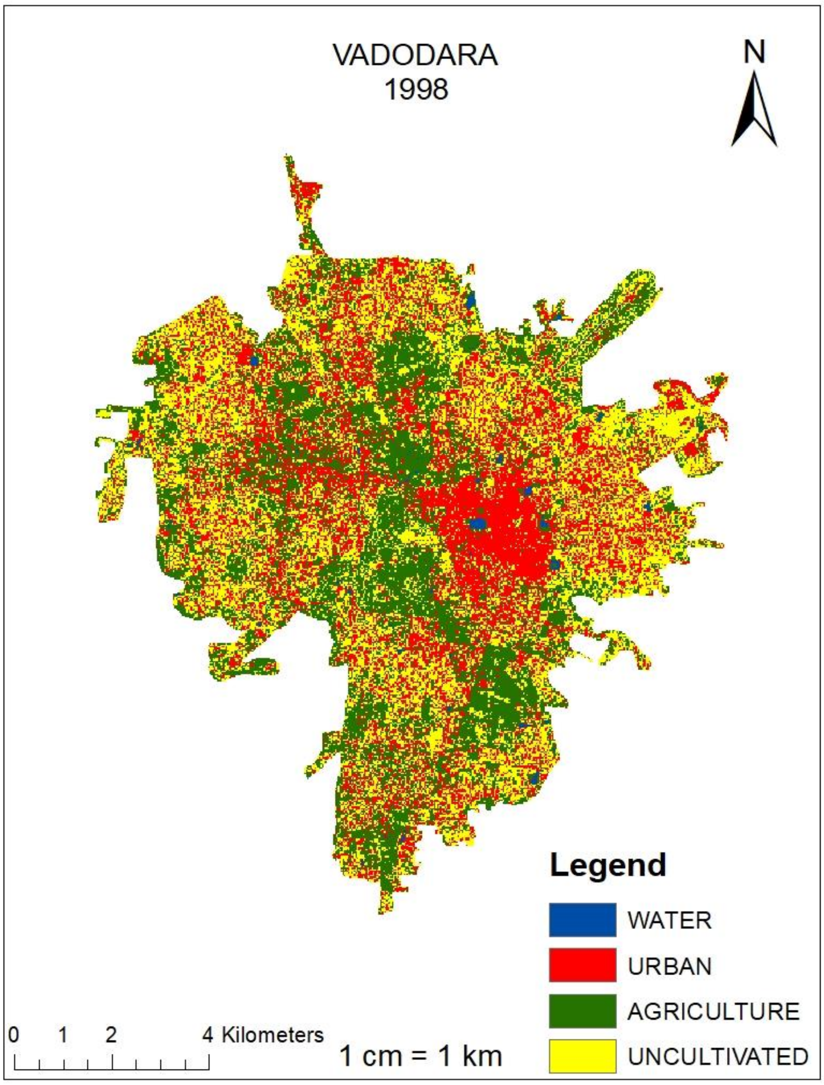


Figure 10: LU/LC for Vadodara City in 1998

Figure 10 shows the land use classification of Vadodara city for the year 1998 and the values of areas of four classes namely Waterbody, Built-up represented by Urban, Vegetation represented by Agriculture and Uncultivated land are given in Table 9

Table 9: Area of land uses in Sq. Km. for the year 1998

| Year | 1998<br>Area, Sq. Km |
|---|---|
| Waterbody | 0.578 |
| Built-up | 28.136 |
| Vegetation | 30.996 |
| Uncultivated | 34.569 |
| Total Area | 94.279 |

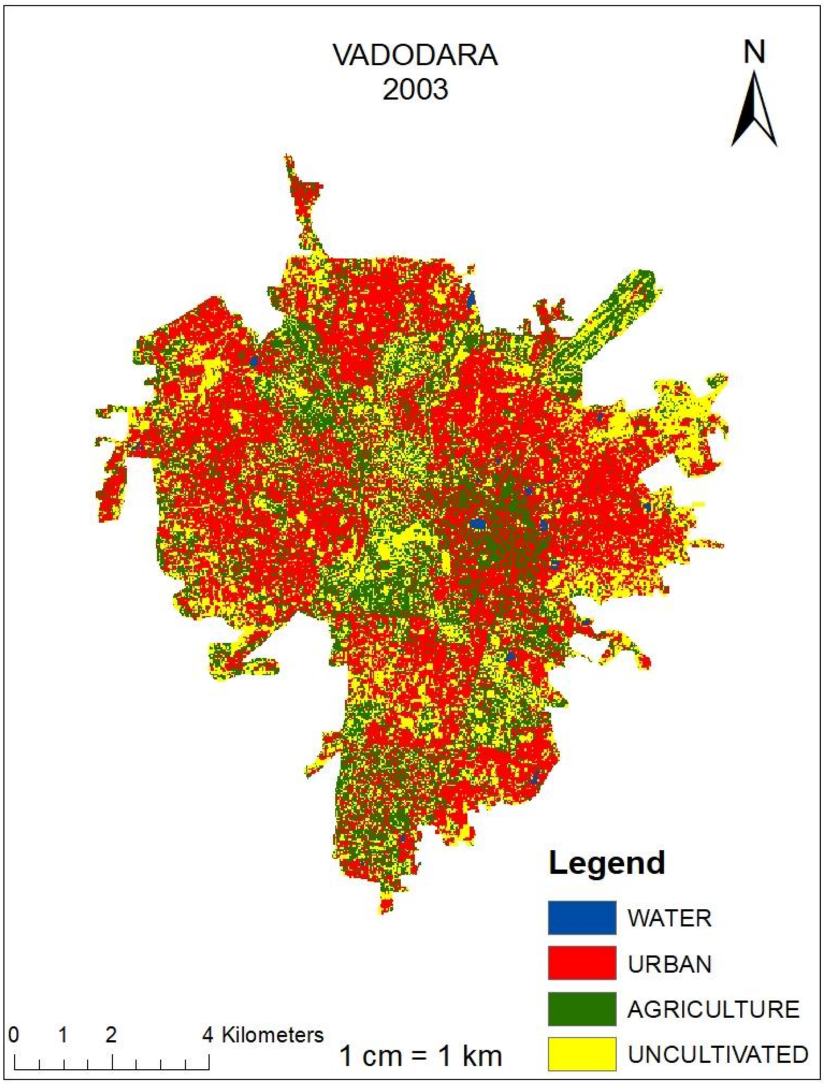


Figure 11: LU/LC for Vadodara City in 2003

Figure 11 shows the land use classification of Vadodara city for the year 2003 and the values of areas of four classes namely Waterbody, Built-up represented by Urban, Vegetation represented by Agriculture and Uncultivated land are given in Table 10

Table 10: Area of land uses in Sq. Km. for the year 2003

| Year | 2003<br>Area, Sq. Km |
|---|---|
| Waterbody | 0.414 |
| Built-up | 44.0523 |
| Vegetation | 25.3413 |
| Uncultivated | 24.471 |
| Total Area | 94.279 |

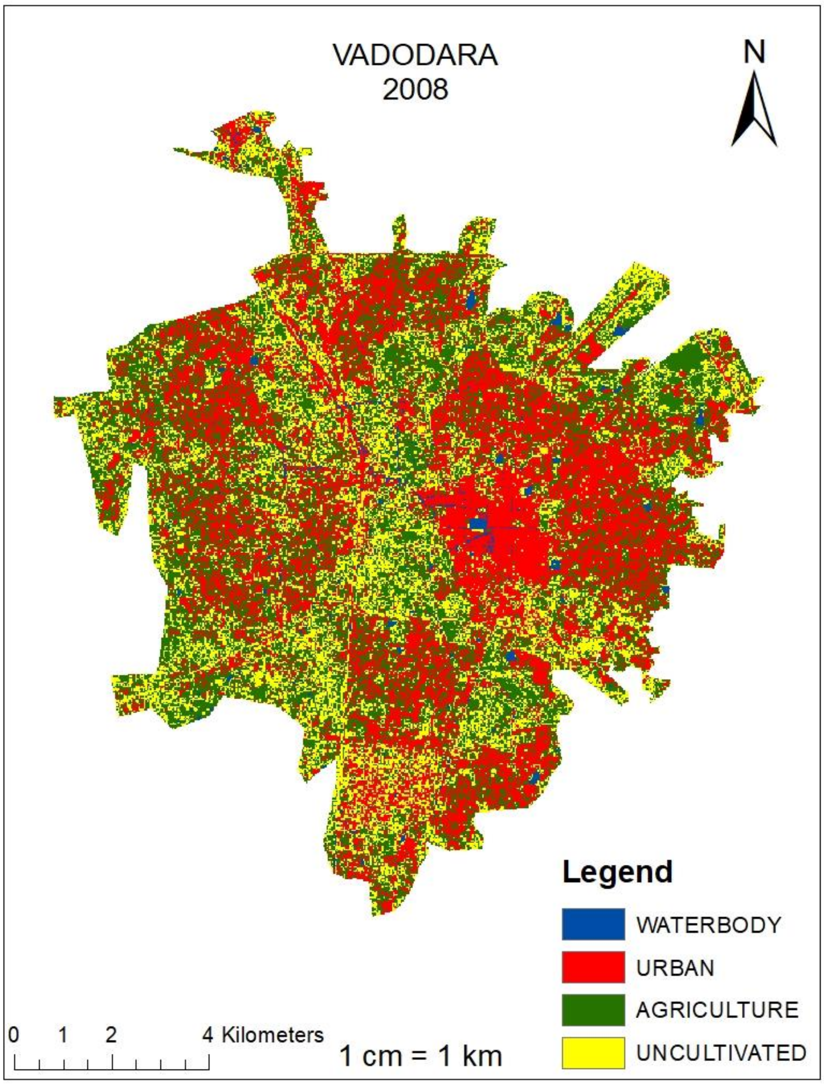


Figure 12: LU/LC for Vadodara City in 2008

Figure 12 shows the land use classification of Vadodara city for the year 2008 and the values of areas of four classes namely Waterbody, Built-up represented by Urban, Vegetation represented by Agriculture and Uncultivated land are given in Table 11

Table 11: Area of land uses in Sq. Km. for the year 2008

| Year | 2008<br>Area, Sq. Km |
|---|---|
| Waterbody | 2.203 |
| Built-up | 41.882 |
| Vegetation | 46.514 |
| Uncultivated | 28.710 |
| Total Area | 119.309 |

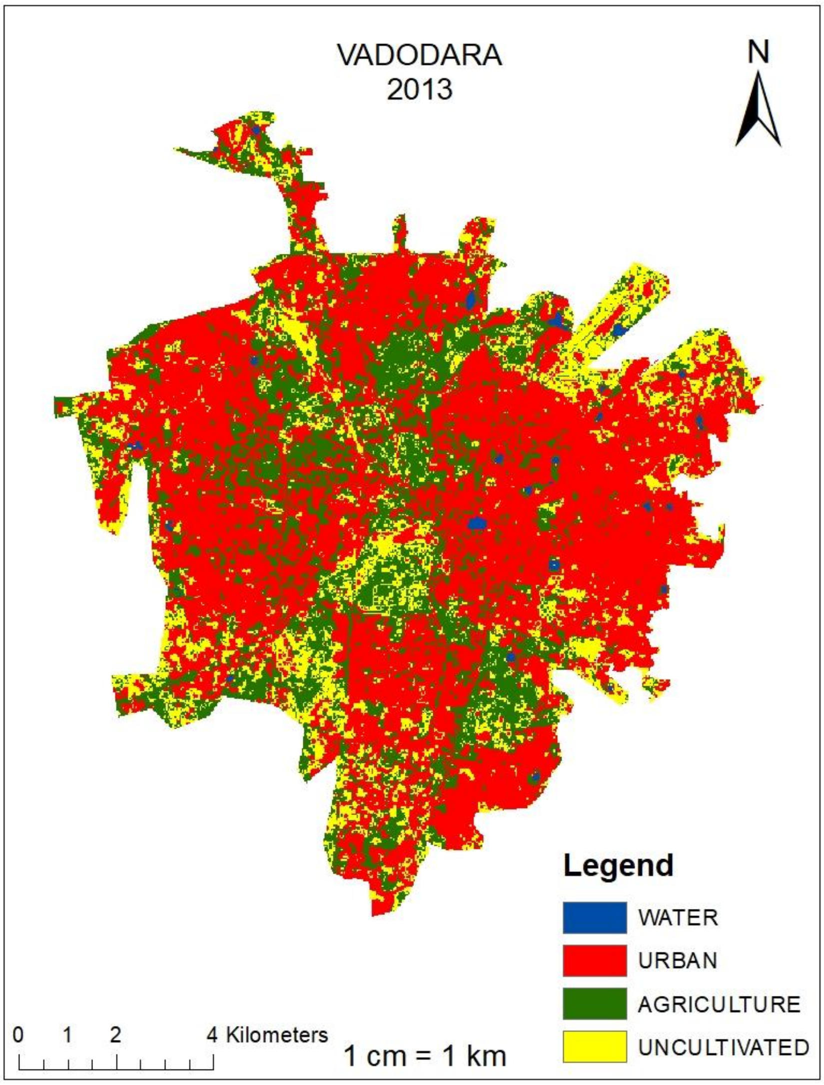


Figure 13: LU/LC for Vadodara City in 2013

Figure 13 shows the land use classification of Vadodara city for the year 2013 and the values of areas of four classes namely Waterbody, Built-up represented by Urban, Vegetation represented by Agriculture and Uncultivated land are given in Table 12

Table 12: Area of land uses in Sq. Km. for the year 2013

| Year | 2013<br>Area, Sq. Km |
|---|---|
| Waterbody | 0.6939 |
| Built-up | 69.1191 |
| Vegetation | 30.7206 |
| Uncultivated | 18.7758 |
| Total Area | 119.309 |

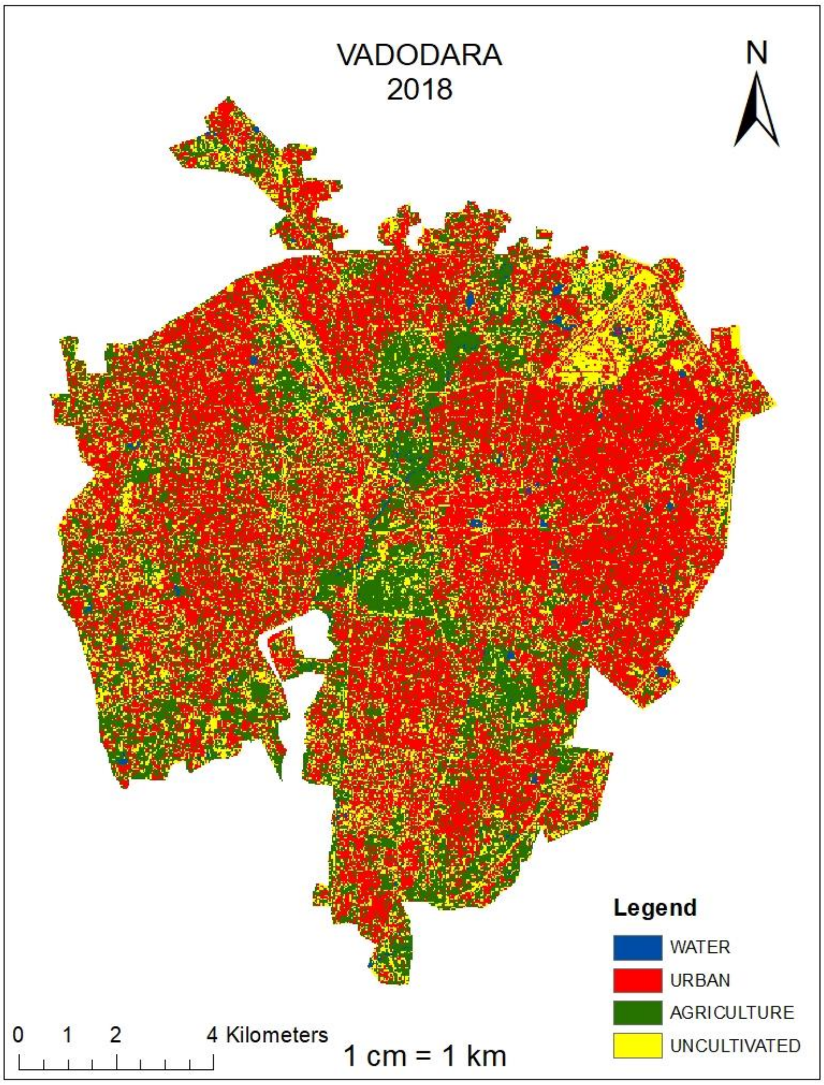


Figure 14: LU/LC for Vadodara City in 2018

Figure 14 shows the land use classification of Vadodara city for the year 2018 and the values of areas of four classes namely Waterbody, Built-up represented by Urban, Vegetation represented by Agriculture and Uncultivated land are given in Table 13

Table 13: Area of land uses in Sq. Km. for the year 2018

| Year | 2018<br>Area, Sq. Km |
|---|---|
| Waterbody | 2.011 |
| Built-up | 74.795 |
| Vegetation | 41.270 |
| Uncultivated | 31.108 |
| Total Area | 149.184 |

0

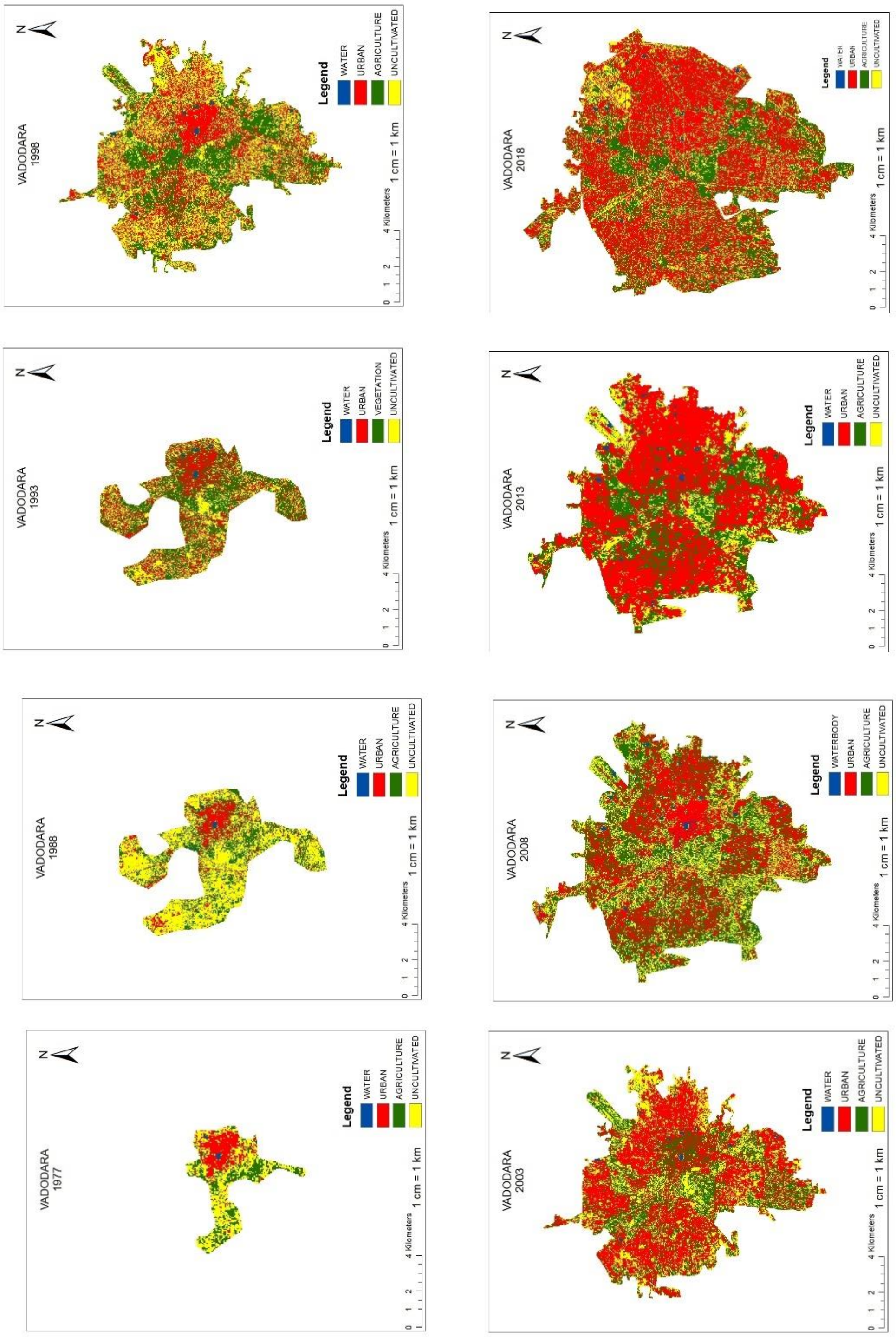


Figure 15: LU/LC for Vadodara City in 1977, 1988, 1993, 1998, 2003, 2008, 2013 and 2018

Figure 15 shows the comparisons of the various land use classes for the study years. It is a visual interpretation of urban sprawl from 1977 to 2018.

**Urban Sprawl**

The results for Urban Sprawl Index (USI) and Land Consumption Rate (L.C.R.) are as follows:

Table 14: Urban Sprawl Index (U.S.I.)

| **Year** | **Urban Expansion (Sq. Km.)** | **Population Growth (lakhs)** | **USI** |
|---|---|---|---|
| 1977 – 1988 | 23.04 | 3.82 | **6.03** |
| 1988 – 1998 | 54.82 | 3.76 | 14.58 |
| 1998 – 2008 | 25.03 | 3.43 | 7.30 |
| 2008 – 2018 | 29.87 | 3.82 | 7.82 |

Table 14 represents the values of USI, in which the lower values represent higher sprawl.

Table 15: Land Consumption Rate (L.C.R.)

| **Year** | **Area (A), Sq. Km.** | **Population (P), lakhs** | **L.C.R. (A/P)** |
|---|---|---|---|
| 1977 | 1642.68 | 6.27 | 2.62 |
| 1988 | 3946.32 | 10.09 | 3.91 |
| 1998 | 9427.86 | 13.85 | 6.81 |
| 2008 | 11930.9 | 17.28 | 6.90 |
| 2018 | 14918.4 | 21.10 | 7.07 |

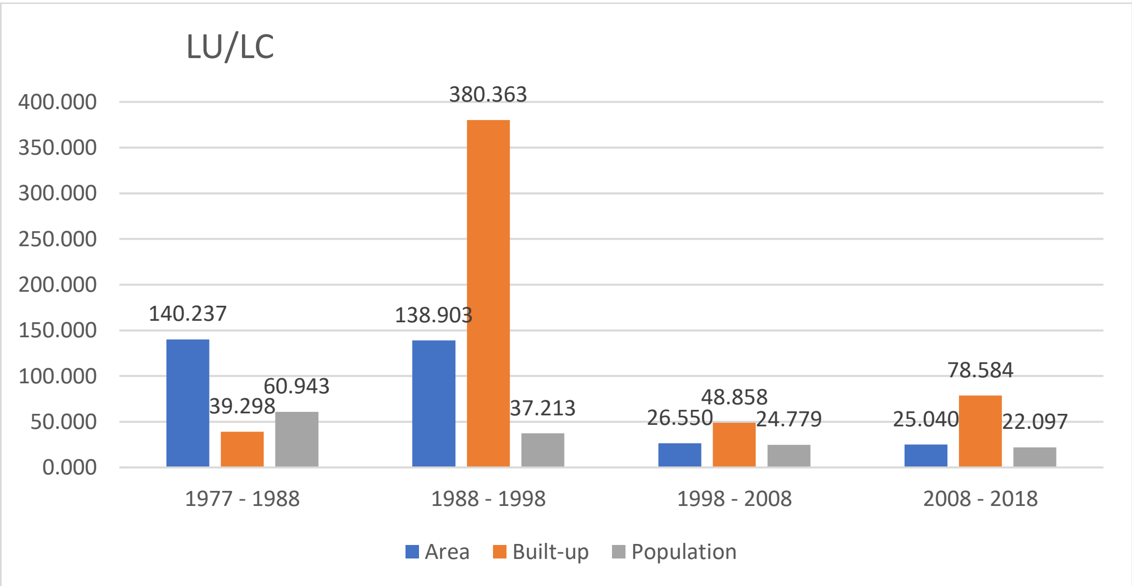


Figure 16: Overall Change in Percentage of Total LU/LC area, Built-up area and Population

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

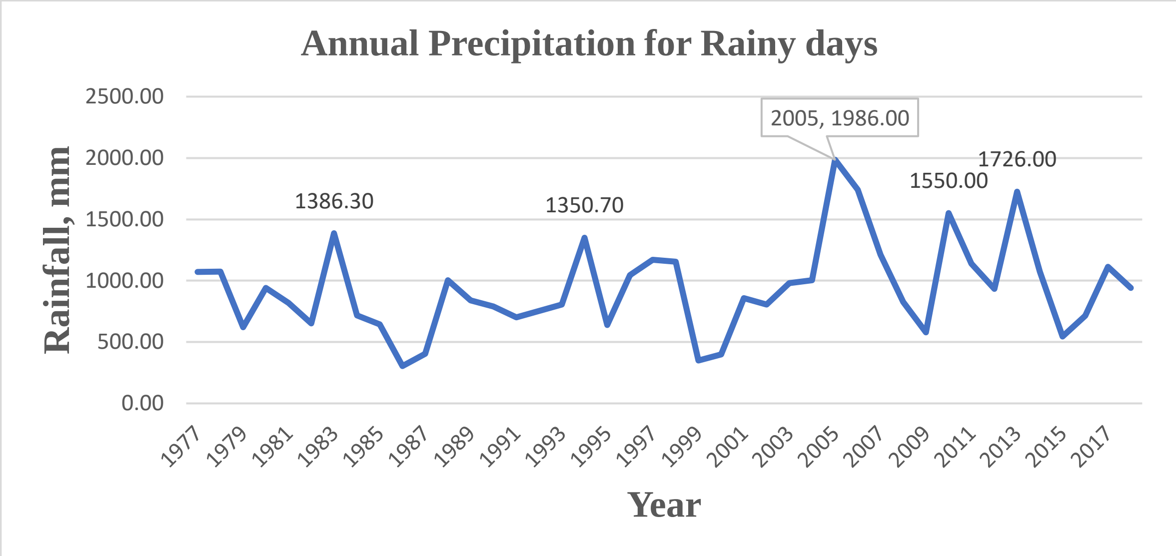


Figure 17: Annual Maximum Precipitation from 1977 to 2018

The annual rainfall of the area varies from a minimum annual of 304.10 mm in 1986 to a maximum of 1986.0 mm in 2005, in the period of 41 years.
The average annual rainfall for the years 1977 - 2018 was found to be 941 mm. The years 1983,1994, 1997, 2005, 2006, 2007, 2010, 2011 and 2013, received more than 1200 mm of annual rainfall. However, the city experienced floods in the years 1994, 1996, 2005 and 2014

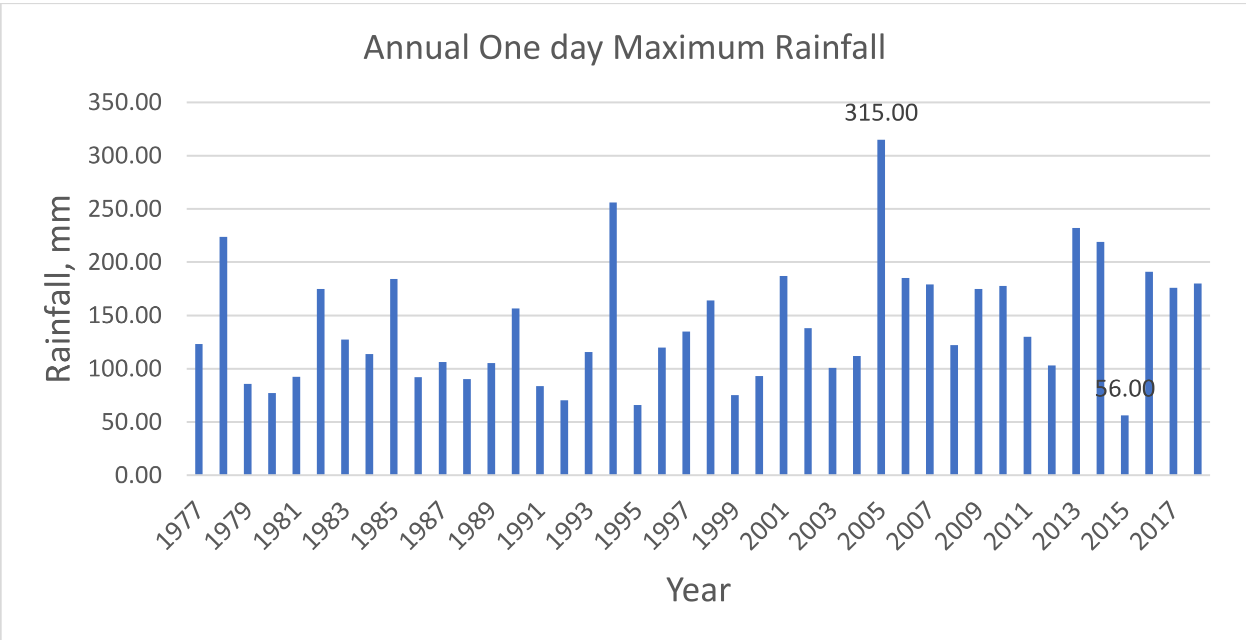


Figure 18: Annual One day Maximum Precipitation from 1977 to 2018

Figure 18 shows that while the average daily rainfall of the area is 140.73 mm, the actual annual maximum daily rainfall received ranges from a minimum of 56.00 mm in July 2015 to a maximum of 315.00 mm in July 2005, in the period of 41 years.

3. **Objective: 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).**

After analysing the soil map obtained, it was found that Vadodara city lies in Group C type soil. Based on Land cover and hydrologic soil group and hydrologic condition we have select the curve number for various land use classes for different year

Table 16: CN values for LU/LC Classes (CN – II) Values

| CN Values | Waterbody | Built-up | Vegetation | Uncultivated |
|---|---|---|---|---|
| 1977 | 97 | 80 | 74 | 79 |
| 1988 | 97 | 77 | 74 | 79 |
| 1998 | 97 | 81 | 74 | 79 |
| 2008 | 100 | 82 | 74 | 79 |
| 2018 | 100 | 88 | 73 | 79 |

Table 16 shows the values of curve numbers obtained based on land use/land cover, obtained for study year, hydrologic soil group C, and average hydrologic condition.

Table 17: Calculated Weighted CN for Study Years.

| | A | B | C | D | E | F | G | H | J | L |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | CN II * Area | WEIGHTED CN |
| 2 | Sr. No. | Change Detection | CN II | 1977 | 1988 | 1998 | 2008 | 2018 | | |
| 3 | 1977 | Water | 97 | 0.176 | 0.393 | 0.578 | 2.203 | 2.011 | 17.11 | **78.14** |
| 4 | | Built-up | 80 | 4.205 | 5.857 | 28.136 | 41.882 | 74.795 | 336.38 | |
| 5 | | Vegetation | 74 | 4.291 | 11.072 | 30.996 | 46.514 | 41.270 | 317.55 | |
| 6 | | Uncultivated Land | 79 | 7.754 | 22.141 | 34.569 | 28.710 | 31.108 | 612.60 | |
| 7 | | | | 16.43 | 39.46 | 94.28 | 119.31 | 149.18 | | |
| 8 | | | | | | | | | | |
| 9 | Sr. No. | Change Detection | CN II | 1977 | 1988 | 1998 | 2008 | 2018 | | |
| 10 | 1988 | Water | 97 | 0.176 | 0.393 | 0.578 | 2.203 | 2.011 | 38.15 | **77.48** |
| 11 | | Built-up | 77 | 4.205 | 5.857 | 28.136 | 41.882 | 74.795 | 451.00 | |
| 12 | | Vegetation | 74 | 4.291 | 11.072 | 30.996 | 46.514 | 41.270 | 819.31 | |
| 13 | | Uncultivated Land | 79 | 7.754 | 22.141 | 34.569 | 28.710 | 31.108 | 1749.13 | |
| 14 | | | | 16.43 | 39.46 | 94.28 | 119.31 | 149.18 | | |
| 15 | | | | | | | | | | |
| 16 | Sr. No. | Change Detection | CN II | 1977 | 1988 | 1998 | 2008 | 2018 | | |
| 17 | 1998 | Water | 97 | 0.176 | 0.393 | 0.578 | 2.203 | 2.011 | 56.05 | **78.06** |
| 18 | | Built-up | 81 | 4.205 | 5.857 | 28.136 | 41.882 | 74.795 | 2279.00 | |
| 19 | | Vegetation | 74 | 4.291 | 11.072 | 30.996 | 46.514 | 41.270 | 2293.70 | |
| 20 | | Uncultivated Land | 79 | 7.754 | 22.141 | 34.569 | 28.710 | 31.108 | 2730.95 | |
| 22 | | | | | | | | | | |
| 23 | Sr. No. | Change Detection | CN II | 1977 | 1988 | 1998 | 2008 | 2018 | | |
| 24 | 2008 | Water | 98 | 0.176 | 0.393 | 0.578 | 2.203 | 2.011 | 215.91 | **78.45** |
| 25 | | Built-up | 82 | 4.205 | 5.857 | 28.136 | 41.882 | 74.795 | 3434.36 | |
| 26 | | Vegetation | 74 | 4.291 | 11.072 | 30.996 | 46.514 | 41.270 | 3442.02 | |
| 27 | | Uncultivated Land | 79 | 7.754 | 22.141 | 34.569 | 28.710 | 31.108 | 2268.09 | |
| 28 | | | | 16.43 | 39.46 | 94.28 | 119.31 | 149.18 | | |
| 29 | | | | | | | | | | |
| 30 | Sr. No. | Change Detection | CN II | 1977 | 1988 | 1998 | 2008 | 2018 | | |
| 31 | 2018 | Water | 99 | 0.176 | 0.393 | 0.578 | 2.203 | 2.011 | 199.05 | **82.12** |
| 32 | | Built-up | 88 | 4.205 | 5.857 | 28.136 | 41.882 | 74.795 | 6582.00 | |
| 33 | | Vegetation | 73 | 4.291 | 11.072 | 30.996 | 46.514 | 41.270 | 3012.74 | |
| 34 | | Uncultivated Land | 79 | 7.754 | 22.141 | 34.569 | 28.710 | 31.108 | 2457.50 | |
| 35 | | | | 16.43 | 39.46 | 94.28 | 119.31 | 149.18 | | |

F

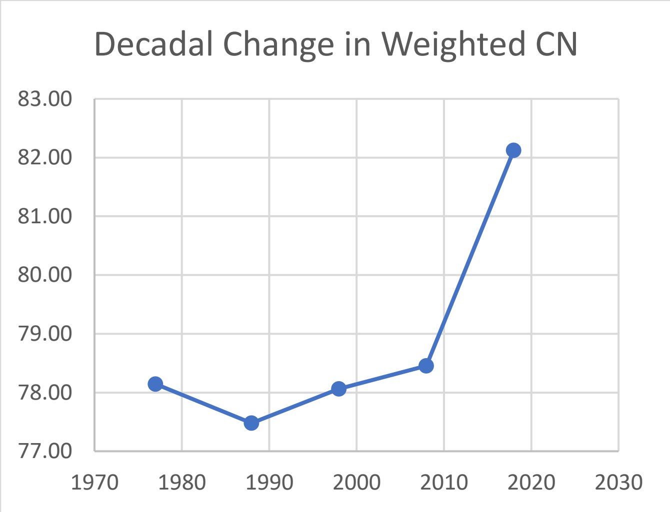


Figure 19:Decadal change in Weighted Curve Number

From Table 17 and Figure 19, it is very clearly seen that the weighted curve number was 78.14 in 1977 and increased to 82.12 in 2018, which directly/indirectly represents land being impervious from pervious.

After that actual curve number, S and runoff are calculated using SCS-CN method and the results of sample data are shown in Table 18.

Table 18: Sample Data showing calculation of Actual CN, S and Runoff

| 1 | Station Code | Year | Month | Day | Rain | AMC | AMC (Dormant) | Weighted CN | Calculated CN | S | RUNOFF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 562 | VADODARA | 2017 | 7 | 22 | 52.00 | 21.00 | II | 78.45 | 78.45 | 69.77 | 9.57 |
| 563 | VADODARA | 2017 | 8 | 27 | 48.00 | 6.00 | I | 78.45 | 61.48 | 159.15 | 0.00 |
| 564 | VADODARA | 2017 | 7 | 27 | 46.00 | 213.00 | III | 78.45 | 89.50 | 29.79 | 20.55 |
| 565 | VADODARA | 2017 | 7 | 5 | 40.00 | 279.00 | III | 78.45 | 89.50 | 29.79 | 15.85 |
| 566 | VADODARA | 2017 | 7 | 26 | 40.00 | 173.00 | III | 78.45 | 89.50 | 29.79 | 15.85 |
| 567 | VADODARA | 2017 | 6 | 13 | 38.00 | 12.00 | I | 78.45 | 61.48 | 159.15 | 0.64 |
| 568 | VADODARA | 2017 | 8 | 30 | 37.00 | 72.00 | III | 78.45 | 89.50 | 29.79 | 13.61 |
| 569 | VADODARA | 2017 | 7 | 15 | 31.00 | 39.00 | III | 78.45 | 89.50 | 29.79 | 9.39 |
| 570 | VADODARA | 2017 | 7 | 2 | 28.00 | 12.00 | I | 78.45 | 61.48 | 159.15 | 2.80 |
| 571 | VADODARA | 2017 | 7 | 13 | 28.00 | 16.00 | II | 78.45 | 78.45 | 69.77 | 0.65 |
| 572 | VADODARA | 2017 | 7 | 28 | 23.00 | 207.00 | III | 78.45 | 89.50 | 29.79 | 4.51 |
| 573 | VADODARA | 2018 | 6 | 26 | 180.00 | 31.00 | III | 82.12 | 91.49 | 23.61 | 152.14 |
| 574 | VADODARA | 2018 | 7 | 20 | 97.00 | 126.00 | III | 82.12 | 91.49 | 23.61 | 71.21 |
| 575 | VADODARA | 2018 | 7 | 11 | 75.00 | 2.00 | I | 82.12 | 66.82 | 126.15 | 8.45 |
| 576 | VADODARA | 2018 | 7 | 12 | 62.00 | 75.00 | III | 82.12 | 91.49 | 23.61 | 38.40 |
| 577 | VADODARA | 2018 | 8 | 18 | 56.00 | 47.00 | III | 82.12 | 91.49 | 23.61 | 32.99 |
| 578 | VADODARA | 2018 | 7 | 17 | 53.00 | 164.00 | III | 82.12 | 91.49 | 23.61 | 30.32 |
| 579 | VADODARA | 2018 | 8 | 17 | 46.00 | 1.00 | I | 82.12 | 66.82 | 126.15 | 0.50 |
| 580 | VADODARA | 2018 | 7 | 15 | 45.00 | 186.00 | III | 82.12 | 91.49 | 23.61 | 23.36 |
| 581 | VADODARA | 2018 | 7 | 4 | 41.00 | 2.00 | I | 82.12 | 66.82 | 126.15 | 0.08 |
| 582 | VADODARA | 2018 | 8 | 22 | 29.00 | 107.00 | III | 82.12 | 91.49 | 23.61 | 10.55 |

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

**Scenario 1**: Considering 1977 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely 1988, 1998, 2008 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 1977. Scenario 1 is represented in Table 19:

Table 19: Top 5 rainfall values & LU/LC of 1977 and Runoff against various LU/LC of Study Years.

| Year | Rainfall | Runoff_1977, mm | Runoff_1988, mm | Runoff_1998, mm | Runoff_2008, mm | Runoff_2018, mm |
|---|---|---|---|---|---|---|
| 1977 | 123.10 | 90.03 | 88.97 | 89.90 | 90.53 | 96.39 |
| | 122.80 | 89.75 | 88.68 | 89.62 | 90.25 | 96.10 |
| | 63.00 | 1.17 | 0.86 | 1.13 | 1.33 | 4.18 |
| | 60.00 | 31.89 | 31.13 | 31.80 | 32.25 | 36.59 |
| | 52.20 | 25.29 | 24.60 | 25.21 | 25.62 | 29.61 |

From Table 19 it can be observed that a minimum of 0.16mm to a maximum of **6.36mm** of water per day flows as direct runoff

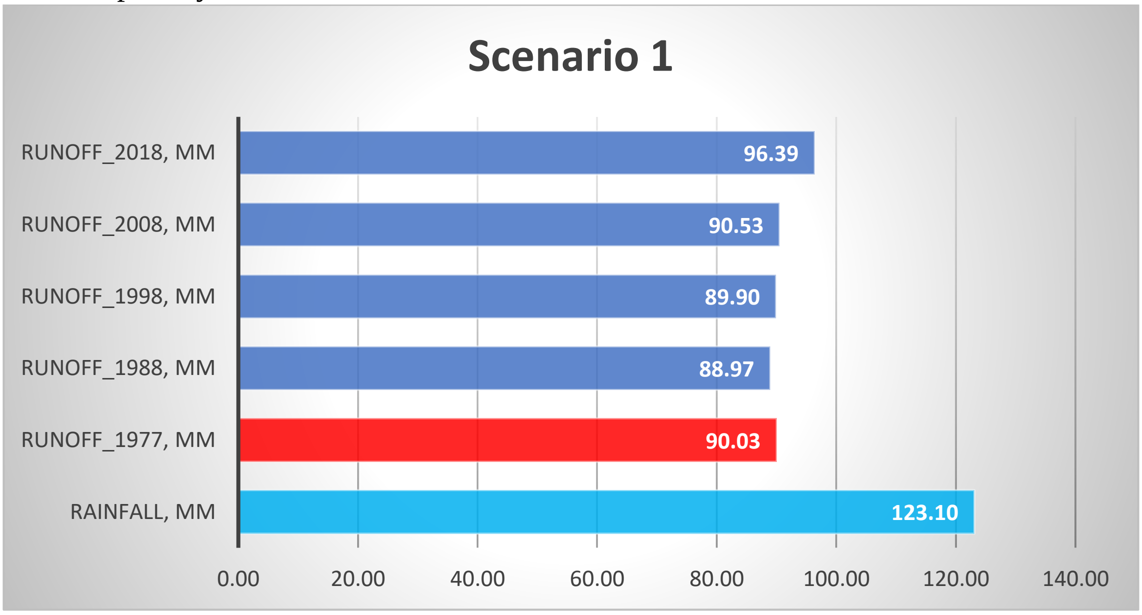


Figure 20: Scenario 1 - Daily Runoff values for Study Years, Base Year 1977

Figure 20 shows that for a rainfall of 123.10mm, runoff according to LU/LC of 1977 is 90.03mm and that of 2018is 96.3, which clearly shows 6.36mm of runoff being increased.

**Scenario 2**: Considering 1988 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely 1977, 1998, 2008 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 1988. Scenario 2 is represented in Table 20

Table 20: Top 5 rainfall values & LU/LC of 1988 and Runoff against various LU/LC of Study Years

| Year | Rainfall | Runoff_1977, mm | Runoff_1988, mm | Runoff_1998, mm | Runoff_2008, mm | Runoff_2018, mm |
|---|---|---|---|---|---|---|
| 1988 | 90.00 | 58.83 | 57.89 | 58.72 | 59.28 | 64.54 |
| | 62.00 | 33.62 | 32.84 | 33.52 | 33.98 | 38.40 |
| | 62.00 | 14.81 | 13.97 | 14.71 | 15.22 | 20.47 |
| | 55.00 | 27.63 | 26.91 | 27.54 | 27.97 | 32.10 |
| | 55.00 | 27.63 | 26.91 | 27.54 | 27.97 | 32.10 |

From Table 20 it can be observed that a minimum of 0.63mm to a maximum of **6.65mm** of water per day flows as direct runoff.

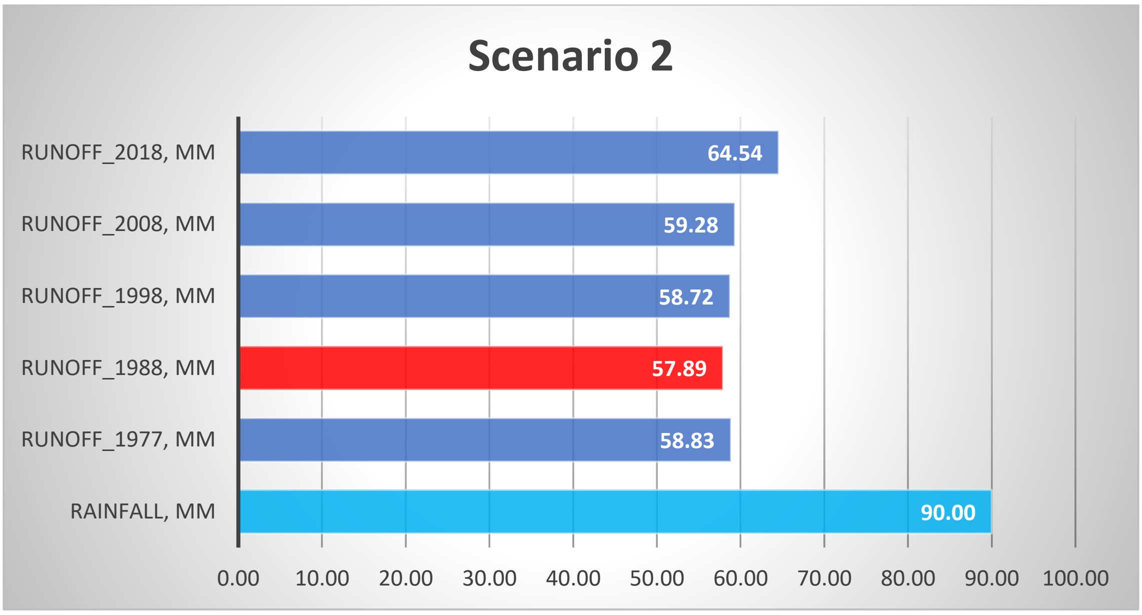


Figure 21: Scenario 2 - Daily Runoff values for Study Years, Base Year 1988

Figure 21 shows that for a rainfall of 90.00mm, runoff according to LU/LC of 1988 is 57.89 and that of 2018is 64.54, which clearly shows 6.65mm of runoff being increased.

Scenario 3: Considering 1998 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely1977, 1988, 2008 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 1998. Scenario 3 is represented in Table 21

Table 21: Top 5 rainfall values and LU/LC of 1998 and Runoff against various LU/LC of study Years

| Year | Rainfall | Runoff_1977, mm | Runoff_1988, mm | Runoff_1998, mm | Runoff_2008, mm | Runoff_2018, mm |
|---|---|---|---|---|---|---|
| 1998 | 164.00 | 129.53 | 128.36 | 129.38 | 130.07 | 136.39 |
| | 158.00 | 123.69 | 122.54 | 123.55 | 124.23 | 130.50 |
| | 75.00 | 45.12 | 44.26 | 45.02 | 45.53 | 50.39 |
| | 73.00 | 21.76 | 20.74 | 21.64 | 22.25 | 28.48 |
| | 49.00 | 22.66 | 22.00 | 22.58 | 22.98 | 26.81 |

From Table 21 it can be observed that a minimum of 0.08mm to a maximum of **7.01mm** of water per day flows as direct runoff.

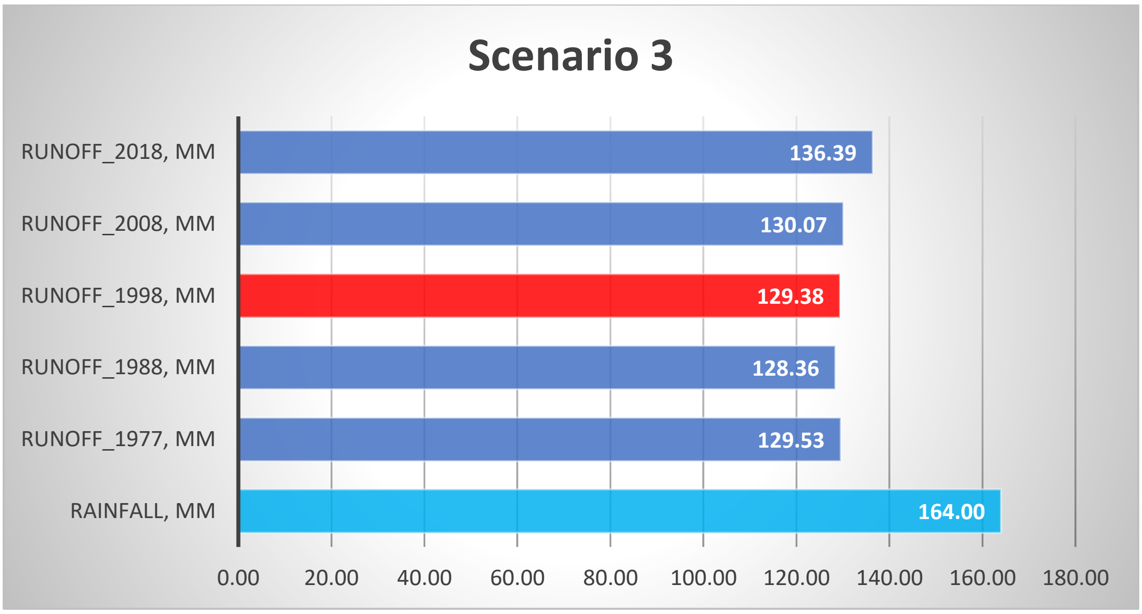


Figure 22: Scenario 3 - Daily Runoff values for Study Years, Base Year 1998

Figure 22 shows that for a rainfall of 164.00mm, runoff according to LU/LC of 1988 is 128.36 mm and that of 2018 is 136.39 mm, which clearly shows 7.01 mm of runoff being increased.

Scenario 4: Considering 2008 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely 1977, 1988, 1998 and 2018 and then, comparing these values of runoff with values of base year runoff i.e., 2008. Scenario 4 is represented in Table 22

Table 22: Top 5 rainfall values and LU/LC of 2008 and Runoff against various LU/LC of study Years.

| Year | Rainfall | Runoff_1977, mm | Runoff_1988, mm | Runoff_1998, mm | Runoff_2008, mm | Runoff_2018, mm |
|---|---|---|---|---|---|---|
| 2008 | 122.00 | 59.03 | 57.41 | 58.83 | 59.79 | 69.14 |
| | 116.00 | 83.27 | 82.22 | 83.14 | 83.75 | 89.51 |
| | 81.00 | 5.39 | 4.67 | 5.30 | 5.75 | 11.00 |
| | 63.00 | 34.49 | 33.70 | 34.39 | 34.85 | 39.31 |
| | 44.00 | 0.14 | 0.26 | 0.15 | 0.09 | 0.29 |

From Table 22 it can be observed that a minimum of 0.05mm to a maximum of **9.35mm** of water per day flows as direct runoff.

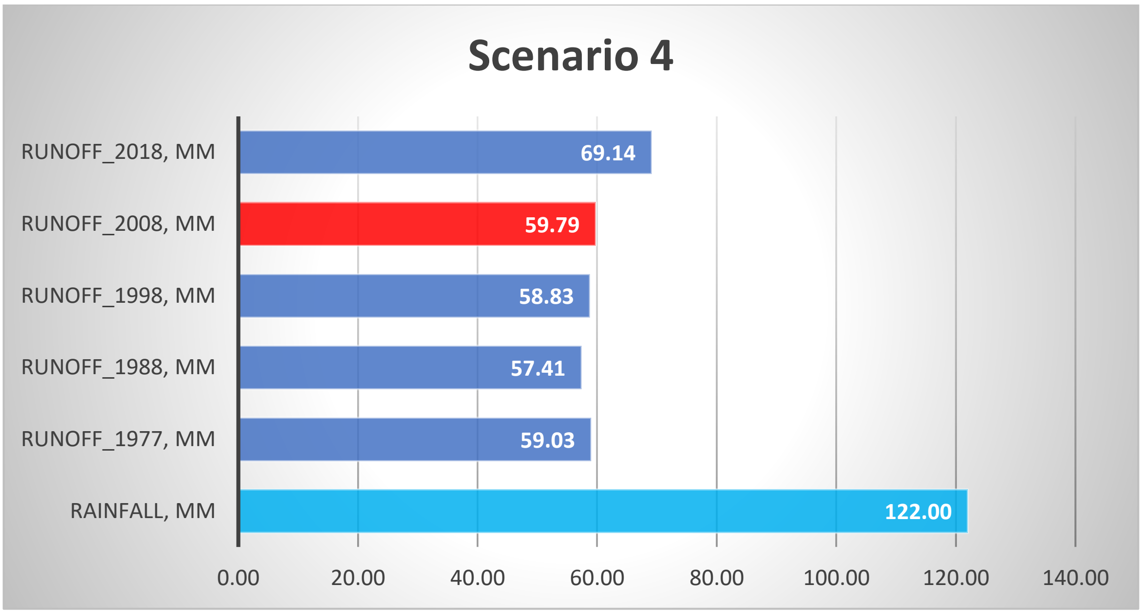


Figure 23: Scenario 4 - Daily Runoff values for Study Years, Base Year 2008

Figure 23 shows that for a rainfall of 122.00mm, runoff according to LU/LC of 1988 is 57.41mm and that of 2018 is 69.14mm, which clearly shows 9.35mm of runoff being increased.

Scenario 5: Considering 2018 as a base year, taking top 5 daily rainfall values from this year, runoff will be computed considering the LU/LC of different study years namely 1977, 1988, 1998 and 2008 and then, comparing these values of runoff with values of base year runoff i.e., 2018. Scenario 5 is represented in Table 23

Table 23: Top 5 rainfall values and LU/LC of 2018 and Runoff against various LU/LC of study Years

| Year | Rainfall | Runoff_1977, mm | Runoff_1988, mm | Runoff_1998, mm | Runoff_2008, mm | Runoff_2018, mm |
|---|---|---|---|---|---|---|
| 2018 | 180.00 | 145.13 | 143.94 | 144.99 | 145.69 | 152.14 |
| | 97.00 | 65.34 | 64.37 | 65.22 | 65.80 | 71.21 |
| | 75.00 | 3.69 | 3.11 | 3.61 | 3.99 | 8.45 |
| | 62.00 | 33.62 | 32.84 | 33.52 | 33.98 | 38.40 |
| | 56.00 | 28.48 | 27.75 | 28.39 | 28.82 | 32.99 |

From Table 23 it can be observed that a minimum of 4.17mm to a maximum of **8.20mm** of water per day flows as direct runoff.

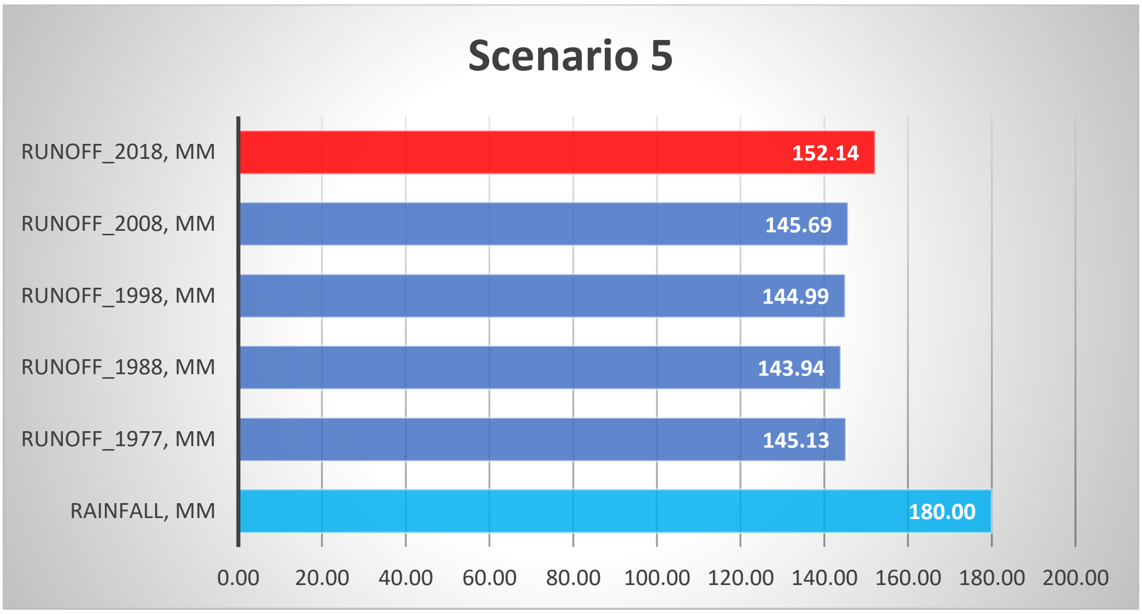


Figure 24: Scenario 5 - Daily Runoff values for Study Years, Base Year 2018

Figure 24 shows that for a rainfall of 180mm, runoff according to LU/LC of 1988 is 143.94mm and that of 2018 is 152.14 mm, which clearly shows 8.20mm of runoff being increased.

5. Objective: **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 IDF curves developed by using the Gumbel distribution method gives the following results:

Table 24: Rainfall Intensity in mm/hr. at various rainfall durations and return periods for Vadodara station by Gumbel's Extreme Value Distribution

| Duration (hours) | Return Period T (Years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ↓ | 2 | 5 | 10 | 15 | 20 | 25 | 30 | 50 | 75 | 100 |
| 1H | 49.26 | 60.13 | 71.51 | 77.97 | 82.67 | 85.99 | 88.93 | 96.76 | 103.03 | 107.53 |
| 2H | 31.03 | 37.88 | 45.05 | 49.12 | 52.08 | 54.17 | 56.02 | 60.96 | 64.90 | 67.74 |
| 6H | 14.92 | 18.21 | 21.66 | 23.61 | 25.04 | 26.04 | 26.93 | 29.30 | 31.20 | 32.57 |
| 12H | 9.40 | 11.47 | 13.64 | 14.87 | 15.77 | 16.41 | 16.97 | 18.46 | 19.66 | 20.52 |
| 24H | 5.92 | 7.23 | 8.59 | 9.37 | 9.94 | 10.34 | 10.69 | 11.63 | 12.38 | 12.92 |

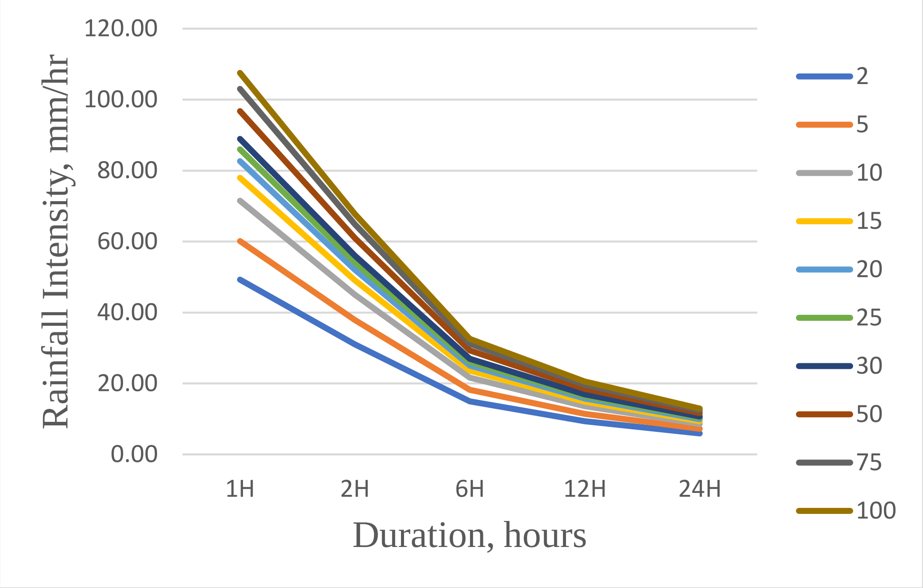

Figure 25: Intensity Duration Frequency curve (semi-log curve) of Vadodara Station

**IDF Curves by Empirical Equations**
To get IDF by empirical equations by Tablot, Bernard, Kimijima and Sherman, among which parameters of Sherman equation are given in Table 25.

Table 25: Parameters of Sherman equation

| Return Period T, years | a | b | e |
|---|---|---|---|
| **2** | 49.23 | 0.00 | 0.67 |
| **5** | 60.14 | 0.00 | 0.67 |
| **10** | 60.14 | 0.00 | 0.67 |
| **15** | 78.01 | 0.00 | 0.67 |
| **20** | 82.66 | 0.00 | 0.67 |
| **25** | 86.00 | 0.00 | 0.67 |
| **30** | 88.93 | 0.00 | 0.67 |
| **50** | 96.83 | 0.00 | 0.67 |
| **75** | 103.00 | 0.00 | 0.67 |
| **100** | 107.50 | 0.00 | 0.67 |

Also, the constant parameters of Tablot, Bernard and Kimijima are found and using a 100 year return these values are compared with the value of Gumbel extreme value distribution. Comparison of the results for the four empirical methods shows that the Sherman equation may fit well at the Vadodara station that has Root mean squared error (RMSE) only 0.159 and its relative coefficient R is approximated 0.99. as in Table 26.

Table 26:Constant parameters with empirical equations at Vadodara station with 100 years return period

| **Function** | **a** | **b** | **e** | **RMSE** |
|---|---|---|---|---|
| **Tablot** | 206.11 | 0.93 | - | 4.618 |
| **Bernard** | 107.53 | - | 0.67 | 7.119 |
| **Kimijima** | 107.48 | 0.00 | 0.67 | 0.163 |
| **Sherman** | 107.50 | 0.00 | 0.67 | 0.159 |

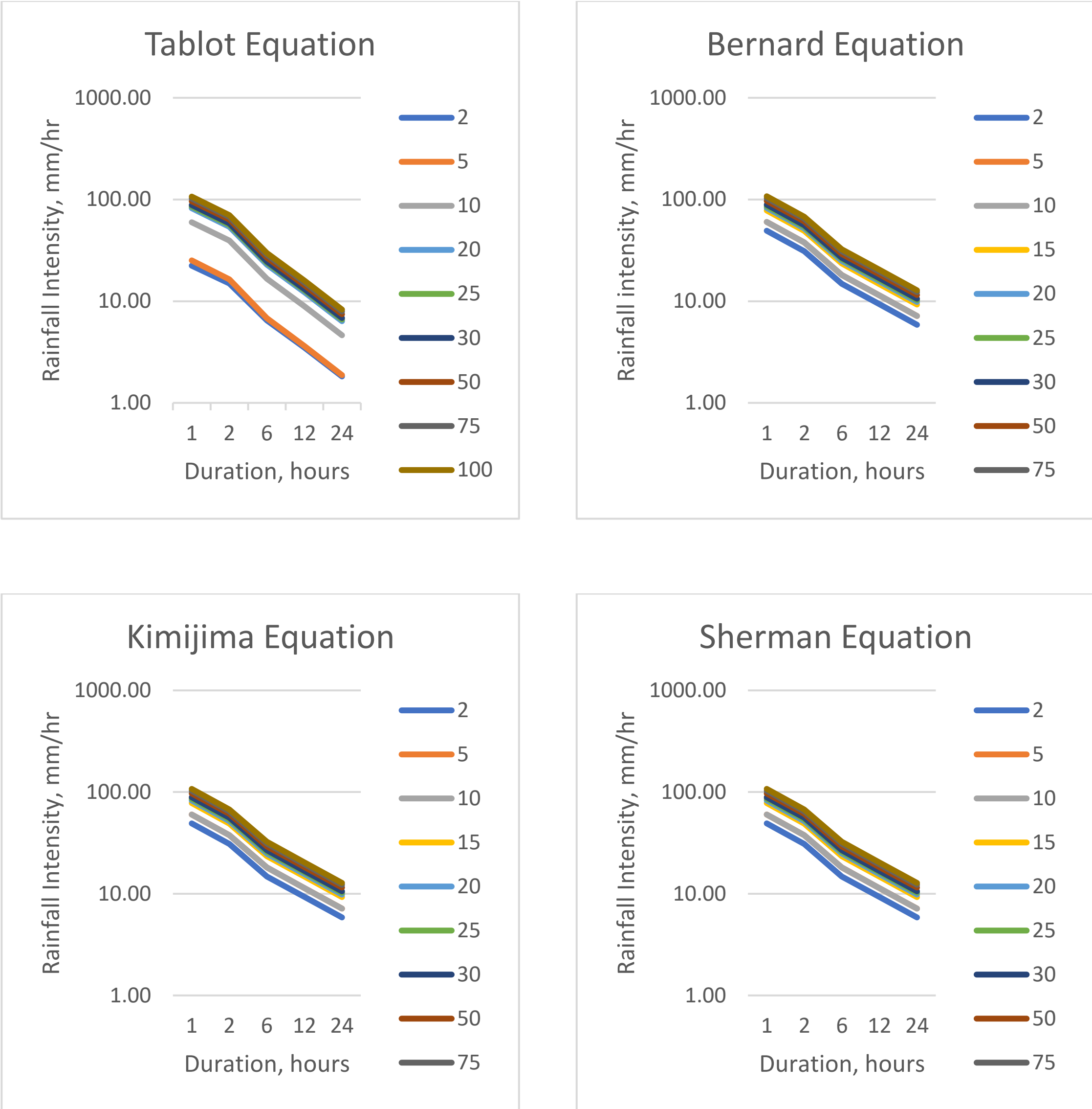

Figure 26: Rainfall Intensity Duration Frequency (IDF) curves using empirical equations

Now, to compute Runoff Intensity in mm/hr. at various durations and return periods, a rainfall runoff model is prepared.

Various models were developed, but the non-linear model with polynomial degree 5 was best suited for this purpose.

The non-linear model equation is:

$$Y = a + bx + cx^2 + dx^3 + ex^4 + fx^5$$, where Y = Runoff and x = Rainfall

where a, b, c, d, e and f are constants whose values are given below:

| | |
|---|---|
| a | -4.8400326 |
| b | 0.3783183 |
| c | -0.0021402 |
| d | $7.3294 * 10^{-05}$ |
| e | $-3.652 * 10^{-07}$ |
| f | $5.4241 * 10^{-10}$ |

To check the accuracy of the polynomial model of order 5, developed, coefficient of correlation is calculated which is, for training and validation, **0.952** and **0.944**, respectively

**Runoff for various recurrence intervals**

Table 27: Runoff Intensity in mm/hr. at various durations and return periods for Vadodara station.

| Duration (hours) | Return Period T (Years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ↓ | 2 | 5 | 10 | 15 | 20 | 25 | 30 | 50 | 75 | 100 |
| 1H | 13.80 | 17.91 | 22.21 | 24.66 | 26.43 | 27.69 | 28.80 | 31.77 | 34.14 | 35.84 |
| 2H | 6.90 | 9.49 | 12.20 | 13.74 | 14.86 | 15.65 | 16.35 | 18.22 | 19.71 | 20.79 |
| 6 | 0.80 | 2.05 | 3.35 | 4.09 | 4.63 | 5.01 | 5.35 | 6.25 | 6.96 | 7.48 |
| 12H | -1.28 | -0.50 | 0.32 | 0.79 | 1.13 | 1.37 | 1.58 | 2.14 | 2.60 | 2.92 |
| 24H | -2.60 | -2.11 | -1.59 | -1.29 | -1.08 | -0.93 | -0.80 | -0.44 | -0.16 | 0.05 |

In Table 27, the negative value represents that, no runoff will take place instead the water will be infiltrated and considered as initial abstraction. So, replacing the negative values with zero, we can get the value of runoff at minimum rainfall event.

Table 28: Modified Runoff Intensity in mm/hr. at various durations and return periods for Vadodara station

| Duration (hours) | Return Period T (Years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ↓ | 2 | 5 | 10 | 15 | 20 | 25 | 30 | 50 | 75 | 100 |
| 1H | 13.80 | 17.91 | 22.21 | 24.66 | 26.43 | 27.69 | 28.80 | 31.77 | 34.14 | 35.84 |
| 2H | 6.90 | 9.49 | 12.20 | 13.74 | 14.86 | 15.65 | 16.35 | 18.22 | 19.71 | 20.79 |
| 6H | 0.80 | 2.05 | 3.35 | 4.09 | 4.63 | 5.01 | 5.35 | 6.25 | 6.96 | 7.48 |
| 12H | 0 | 0 | 0 | 0 | 1.13 | 1.37 | 1.58 | 2.14 | 2.60 | 2.92 |
| 24H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Here, in Table 28, the minimum value of runoff is 1.13mm, against 15.77mm. Also, it can be said that 14.87mm, will be the initial abstraction (this amount of water will be infiltrated in the ground), as up to that negligible runoff is produced.

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

Four models namely Linear, logarithmic, polynomial (order 2) and power models are prepared for predicting the change in total area , which are as follows:

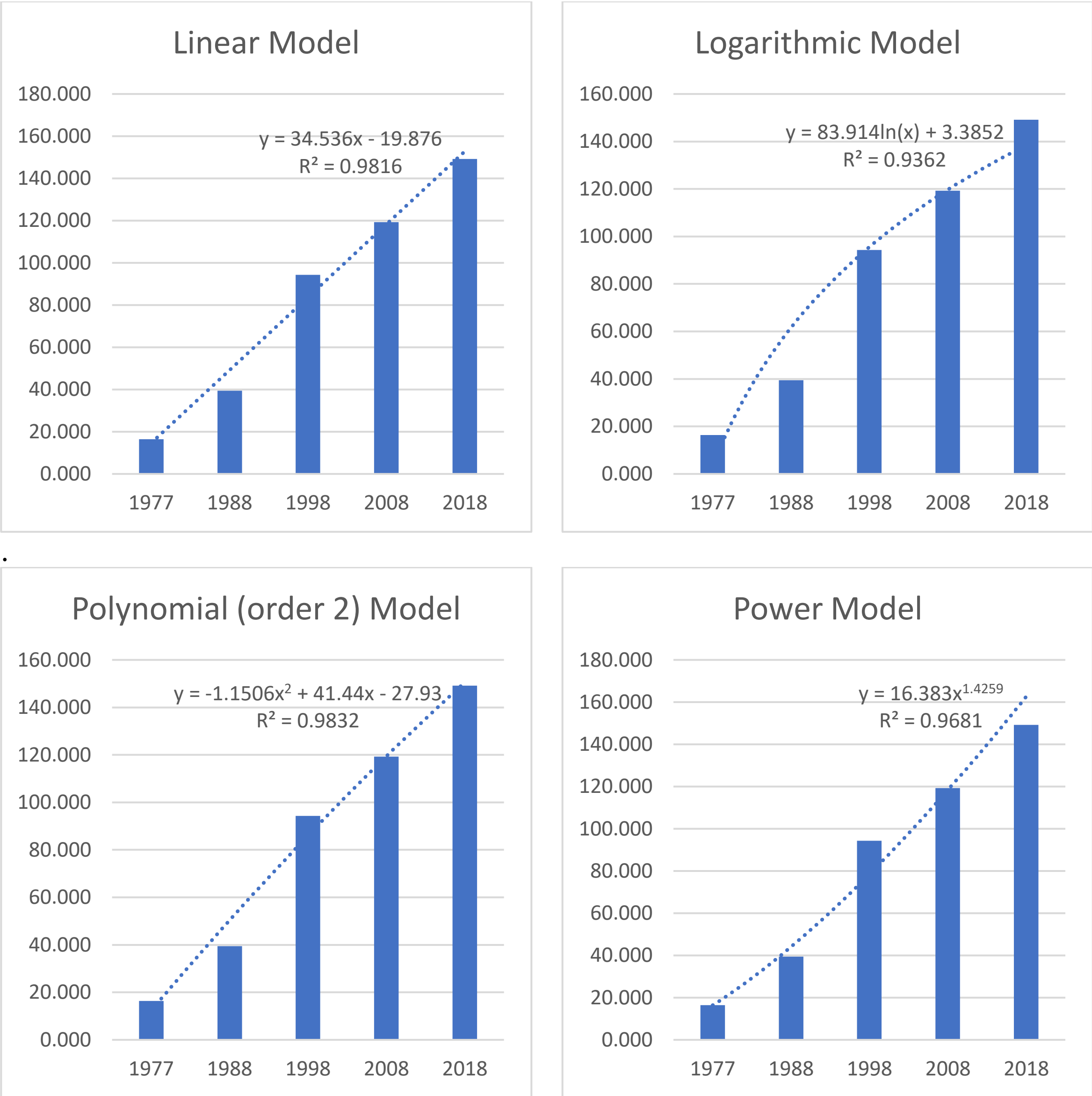


Figure 27: Linear, Logarithmic, Polynomial and Power Models
for predicting total LU/LC

Figure 27 shows various models namely linear, logarithmic, polynomial (order 2) and power model developed for prediction of total LU/LC in that, LU/LC predicted for 2023 using Linear Model, comes out to be 170.04 Sq. Km. LU/LC predicted for 2023 using Logarithmic Model, comes out to be 163.48 Sq. Km. LU/LC predicted for 2023 using Polynomial Model of order 2, comes out to be 165.18 Sq. Km. LU/LC predicted for 2023 using Logarithmic Model, comes out to be 186.24 Sq. Km.

The model developed using polynomial equation of order 2 gives relatable values as compared to current scenario. So, considering this other land use classes namely waterbody, built-up, vegetation and uncultivated land are estimated.

So, with the help of the polynomial model of order 2, overall LU/LC is predicted for the following years followed by the values given in Table: 29

Table 29: Predicted Overall LU/LC Area, Sq. Km.

| Model/ Year | Linear | Logarithmic | Polynomial, order 2 | Power |
|---|---|---|---|---|
| 2023 | 170.04 | 163.48 | **165.18** | 186.24 |
| 2028 | 187.30 | 171.66 | 179.29 | 210.84 |
| 2038 | 221.83 | 186.13 | 205.77 | 262.67 |
| 2048 | 256.36 | 198.67 | 229.95 | 317.77 |

Now, with the polynomial model of order 2, individual land use classes are predicted for the following years followed by the values given in Table: 30

Table 30: Prediction of Area of Waterbody for future years, Sq. Km.

| Model/ Year | Linear | Logarithmic | Polynomial, order 2 | Power |
|---|---|---|---|---|
| 2023 | 2.44 | 2.03 | 2.63 | 2.38 |
| 2028 | 2.72 | 2.14 | 3.03 | 2.74 |
| 2038 | 3.26 | 2.34 | 3.88 | 3.53 |
| 2048 | 3.81 | 2.51 | 4.83 | 4.38 |

Table 31: Prediction of Area of Built-up for future years, Sq. Km.

| Model/ Year | Linear | Logarithmic | Polynomial, order 2 | Power |
|---|---|---|---|---|
| 2023 | 75.28 | 61.10 | 91.67 | 75.61 |
| 2028 | 84.14 | 64.60 | 111.13 | 89.08 |
| 2038 | 101.86 | 70.82 | 155.85 | 119.09 |
| 2048 | 119.58 | 76.20 | 208.28 | 153.15 |

Table 32: Prediction of Area of Vegetation for future years, Sq. Km.

| Model/ Year | Linear | Logarithmic | Polynomial, order 2 | Power |
|---|---|---|---|---|
| 2023 | 54.18 | 47.27 | 54.18 | 62.77 |
| 2028 | 59.65 | 49.65 | 59.65 | 71.92 |
| 2038 | 70.59 | 53.86 | 70.59 | 91.52 |
| 2048 | 81.53 | 57.52 | 81.53 | 112.77 |

Table 33: Prediction of Area of Uncultivated land for future years, Sq. Km.

| Model/Year | Linear | Logarithmic | Polynomial, order 2 | Power |
|---|---|---|---|---|
| 2023 | 38.18 | 36.05 | 25.34 | 42.28 |
| 2028 | 40.84 | 37.35 | 19.71 | 45.60 |
| 2038 | 46.17 | 39.66 | 3.90 | 52.12 |
| 2048 | 51.49 | 41.66 | -17.94 | 58.51 |

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 5.1 General

This chapter briefly shows the conclusions obtained for the individual objective. Based on the conclusion few recommendations have been given.

## 5.2 Conclusions

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

- After carrying out the LU/LC for the study years 1977, 1988, 1998, 2008 and 2018, decadal changes are observed which shows change in area of waterbody varies from 0.2 sq. km to 1.6 sq. km.
- Similarly, the decadal change in built-up area was observed to be varied from 1.65 sq. km to 32.91 sq. km.
- Also, the change in vegetation was seemed to be increasing from 4.29 sq. km to 46.51 sq. km, except a fall of 5.24 sq. km from the year 2008 to 2018.
- The change in uncultivated was randomly varied from increase in range of 2.34 sq. km to 14.39 sq. km and a fall of 5.86 sq. km was found in the decade of 1998 to 2008.
- Also, Sprawl indices namely Urban Sprawl Index (U.S.I.) and Land Consumption Rate (L.C.R.) are computed. The U.S.I. was observed to be 6.03, 14.58, 7.30 and 7.82, respectively in each decade from 1977 – 2018. Here the least value represents maximum sprawl. So, the highest sprawl took place in 1977 – 1988 followed by 1998 – 2008 and 2008 – 2018.
- The L.S.R. was observed to be increasing in every decade i.e., it was 2.62 in 1977 and increased to 7.07 in 2018.

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

- After analysing the daily rainfall data from 1977 to 2018, for 18 years, Intensity – Duration – Frequency (IDF) curves are developed using Gumbel probability distribution method.
- IDF curves using other empirical equations namely, Tablot, Bernard, Kimijima and Sherman were also calculated and the RMSE values for Sherman equation was 0.159, which is minimum of all other equation. So, this equation can be used to find the rainfall intensity for return periods of 2, 5, 10, 15, 20, 30, 50, 75 and 100 years.
- This indicated that the empirical formula given by Sherman obtained to estimate intensity in the study area is good for short durations.

3. **Objective: 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).**

- To determine the runoff using SCS-CN method, the curve numbers for our study were obtained as 78.14, 77.48, 78.06,78.45 and 82.12 respectively for the years 1977, 1988, 1998, 2008 and 2018. These values are seemed to increasing on decadal basis, which directs to the fact that it is directly going to affect the runoff.
- As, the increase in curve number represent increase in impervious surface area, which will directly affect the direct runoff.

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

- For analysing the impact of LU/LC changes on Runoff, various scenarios were considered taking the study years i.e., 1977, 1988, 1998, 2008 and 2018 as a base year for each scenario1, scenario 2, scenario 3, scenario 4 and scenario 5, respectively.
- The results of runoff values as observed, for the year 1977, 1988, 1998, 2008 and 2018 are 6.36 mm, 6.65 mm, 7.01 mm, 9.35mm, 8.20mm respectively.
- The increase in runoff value shows that apart from rainfall, the LU/LC also affects the runoff values.

5. **Objective: 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.**

- Gumbel's Extreme Value Distribution method and empirical equation given by Sherman 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.
- To compute Runoff intensity in mm/hr. at various durations and return periods, a rainfall - runoff model was prepared, and it was observed that a non-linear, polynomial model with order 5, that developed for the dataset of 70 – 30 (Training - Validation) showed accuracy with coefficient of correlation 0.95 and 0.94 respectively for training and validation data set.
- From the runoff intensity obtained for various recurrence intervals, it was observed that, only after 15 mm of hourly rainfall, a significant runoff will take place.

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

- The land use/land cover changes in the study area are predicted using linear model, logarithmic model, polynomial model of order 2 and power model.
- The value obtained using polynomial model of order 2, showed the value of 165.18 sq. km which approximates the area of Vadodara city in current situation according to area obtained from open source on web.
- So, using polynomial model with order 2, the individual land use classes of water body, built-up, vegetation and uncultivated land are predicted.

7. **Objective: To provide suggestive measures to store/discharge the rainfall excess/runoff water so as to safely reduce the probable occurrences of flood peaks.**

- The runoff from the terraces or rooftop can be conveyed to the ground level through a network of pipes and directed to the storage structure which can be an underground masonry tank, or a HDPE (High Density Polyethylene) plastic tank kept above the ground or a tank below ground level.
- One can evaluate the existing landscaping around house and try to reduce any impervious surfaces.
- Planting vegetation or building a rain garden can help absorb stormwater runoff.
- Use of injection wells can be done to dispose off fluid waste.
- By reviving and deepening of existing lakes/ponds in Vadodara city, so that it can accumulate additional excess runoff and probable occurrence of flooding/waterlogging can be minimized.

## 5.3 Recommendations

1. High spatial resolution image data can be used for image classification.
2. The empirical formula given by Sherman can be used to estimate intensity in the study area for short durations, for future studies also.
3. Similarly, in future the rainfall runoff correlation can be used to estimate runoff by polynomial model.
4. The increase predicted land use patterns can be useful in context of planning of future land uses in a judicial manner to the Vadodara Municipal Corporation
5. These results are useful to Vadodara municipal corporation for reviving and deepening of existing lakes/ponds in Vadodara city, so that it can accumulate additional excess runoff and probable occurrence of flooding/waterlogging can be minimized.

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