“IMPACT OF URBANIZATION ON GEOMORPHIC ENVIRONMENT OF PUNE AND SURROUNDING”

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JULY 2016

DECLARATION

I hereby declare that the thesis entitled **"IMPACT OF URBANIZATION ON GEOMORPHIC ENVIRONMENT OF PUNE AND SURROUNDING"** completed and written by me has not previously been formed as the basis for the award of any degree or other similar title upon me of this or any other Vidyapeeth or examining body.

(GABALE SHRIKANT MANGAL)
Research Student
Place: Pune
Date: July 2016

CERTIFICATE

This is to certify that the thesis entitled **"IMPACT OF URBANIZATION ON GEOMORPHIC ENVIRONMENT OF PUNE AND SURROUNDING".** Which is being submitted herewith for the award of the Degree of Vidyavachaspati (Ph.D.) in Earth Science (Geography) of Tilak Maharashtra Vidyapeeth, Pune is the result of original research work completed by **Mr. Gabale Shrikant Mangal** under my supervision and guidance. To the best of my knowledge and believe that the work incorporated in this thesis has not formed the basis for the award of any degree or similar title of this or any other university or examining body upon him.

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Date: July 2016 Mr. GABALE SHRIKANT MANGAL
Place: Pune

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ABBREVIATION

AMSL	:	Average Mean Sea Level
BRT	:	Bus Rapid Transport
CD	:	Change Detection
CR	:	Central Railway
CRESS	:	Centre for Renewable Energy Sources and Saving
CWPRS	:	Central Water and Power Research Station
DEM	:	Digital Elevation Model
DRDO	:	Defence Research and Development Organization
ESR	:	Elevated Service Reservoir
ESR	:	Environment Status Report
GIS	:	Geographical Information System
GSI	:	Geological Survey of India
IC	:	Information Communication
IMD	:	Indian Metrological Department
IRS	:	Indian Remote Sensing
IT	:	Information Technology
LULC	:	Land Use and Land Cover
MSL	:	Mean Sea Level
NEERI	:	National Environmental Engineering Research Institute
PCMC	:	Pimpri Chinchwad Municipal Corporation
PMC	:	Pune Municipal Corporation
PMR	:	Pune Metropolitan Region
PMRDA	:	Pune Metropolitan Regional Development Authority
SOI	:	Survey of India
WCED	:	World Commission on Environment and Development

ABSTRACT

About Pune City

Geographically, Pune is situated on the Deccan plateau and lies on the leeward side of the Western Ghats with an average altitude of 560 m from the mean sea level. It is located at the confluence of the Mula and Mutha rivers and lies between latitudes 18°25' N and 18°37' N and longitudes 73°44' E and 73°57' E. River Mutha passes through the city and has an asymmetrical valley. Pavna and Indrayani traverse the North-Western outskirts of the urban area. The highest point in the city is Vetal Hill (800m above mean sea level-(MSL)) whereas the highest point just outside the urban area is the Sinhagad Fort (1300 m above MSL). The general drainage pattern formed in this area is of dendritic type.

In 1987, the urban area of Pune was 138.36 sq.km. With an addition of 23 villages in 2001, the area has increased to 243.84 sq.km. and it is predicted to increase in future by addition of 34 more villages till 2016, covering a total area of 541.45 sq.km. The population of Pune city as per Census 2011 is 33,04,888 which has grown by more than six times in the last 60 years. Pune has been urbanizing at phenomenal pace. The reason for such rapid development is develoment of the IT sector in the city pushing the boundary of the municipal limit.

Urbanization and Pune City

Urbanization is evolving on the peripheries of upcoming developing cities, and simultaneously the connection between urban and rural areas is changing rapidly in India. Population growth, migration and settlement forms are hastily changing new systems of urban, suburban and exurban development, mounting competition for city expansion and peri-urban land located adjacent to towns and cities. Increasing rate of peri-urbanization is caused by increasing demand for residential, commercial and recreational land uses at the expense of agricultural, barren and forest land uses causing negative implications on geomorphic environment in the city and surroundings.

In Pune city, the rate of vertical and horizontal growth has been increasing very rapidly. Pune's growth and its geographic conditions are ideal for the

development and expansion which has caused conversion of agricultural lands along streams and transportation routes as various types of services are easily available along it. Vertical growth of city is more in central part of the city and horizontal growth is towards its periphery. As extent of development increased, settlement started creeping on slope at foot hills causing cutting and filling disturbing natural flow of streams and blocking it due to dumping of construction debris/waste. This debris dumping has caused cementing of stream/river base avoiding infiltration of water in ground and also caused breaking of stream links triggering water logging on sites and also experience flash floods in the rainy season.

Due to rapid and heavy urbanization, streams connecting to Mula and Mutha River in central part of Pune are getting blocked or chocked causing hazardous conditions in many areas disturbing Pune's water table and ecology around it causing streams to diappear over the period of time. Increase in impermeable surfaces is one of the many human fabrications that disorder hydrological processes. Impervious surfaces are materials that stop the penetration of water into the soil. The result of this barrier is increased runoff, higher stream channel velocities and greater flooding.

Vegetation Cover

Cities are biodiversity hot spots due to the variety of habitats available in public and private open space. Analysis of urban vegetation cover is generally limited to inventories of tree structure and composition on urban lands. Due to increase in Built-up areas, vegetation cover is rapidly getting converted into residential and other uses.

The present study, while using a qualitative research approach, aims to map the vegetation cover of Pune and its surrounding areas between the year 1991 and 2015, and analyze the adverse effects of urbanization, land use changes and its impact on vegetation cover using remote sensing and GIS techniques. The obtained information also assisted in detailed analysis and effectively monitoring spatiotemporal distribution of the vegetation cover, Landsat satellite image were used to classify land use and land cover of study area for the assessment of the linear, areal and relief aspects of change detection. Most of the results acquired through ground truthing with reference to Toposheets and Google images.

Drainage Basin and Urban Change

The Study area is influenced by two major river basins, Mula river basin and Mutha river basin. These river basins can be further divided into sub basins up to 5th order stream. There are six major Sub-basins 1) Nandoshi, 2) Ram Nadi, 3)Wagholi, 4) Ambil Odha, 5) Bhairoba Nala and 6) Wadki nala are considered as sub-study areas for watershed analysis. These representative sub-basins cover around 35 % of total study area. It is observed that rapid urbanization is taking place in these watershed areas (Sub-Basins) since year 1991 to 2015.

To understand the spatial and temporal changes in the study area, morphometric analysis of these major sub basins were carried out. Changes in the stream network over the period of 25 years (1991 to 2015) were studied and maps are prepared. By using SOI Toposheets (1:25,000 scales) and satellite images (Ladsat 5 and Landsat 8) were used. On the basis of these maps digital elevation model of these basins were generated to understand history of basin development. Supervised classification of individual sub basins for the period of 1991 to 2015 was carried out for change detection in the study area. Change in the stream numbers, stream length, and stream area due to urbanization is threatening the physical and urban setup of the study area.

Morphometric Analysis

Morphometric analysis of a watershed is one of the important aspects for comprehending the landform characteristics and the processes operating in a particular region. In this study, an attempt has been made to study the morphometric characteristics of major six watersheds which are the part of Mutha river basin in Pune. For the detailed analysis of the watersheds, Digital Elevation Model of the area and Geographical Information System was used for the assessment of the linear, areal and relief aspects of morphometric parameters. The aim of the study is to find out the critical factors which have caused impact over period of years on geomorphic environment of the study area.

Slope Analysis

Understanding the topological pattern of human settlements and their geographical associations are important for understanding the drivers of land use and land cover change and the relationship between stream flow and slope on one hand and settlement pattern on the other. Each watershed is alienated by number of cross sections and longitudinal sections (profiles) for studying slope variation along fifth order stream. Heights (AMSL) of converging points of these cross and longitudinal profiles were calculated to achieve an exact slope difference which helps to analyze the growth / spread of settlement in a particular area. This study demonstrated a new approach to analyzing the urban growth patterns of human settlements from a wide geographical perspective.

Methodology

In the present study, an attempt has been made to assess the adverse effects of urbanization, land use change and its impact on Pune city and Peri-Urban by using a qualitative research approach. The impetus of urban growth has overtaken the traditional techniques of surveying and mapping. Remote Sensing techniques and GIS tools have become important in management of urban environment. In the present study, an attempt has been made in assessing stream degradation impact selected watersheds which are the part of Mutha river basin in Pune. Since last two decades selected watershed has been in spot light due illegal construction activity by local people along the channel and dumping of construction debris to urban enrichment. For the detailed analysis of the watersheds, Landsat satellite image were used to classify land use and land cover of study area for the assessment of the linear, areal and relief aspects of change detection. Non existing streams were identified on the basis of LU and LC analysis and spot survey.

The land use and land cover patterns for 1991, 2000, 2010 and 2015 were mapped using Landsat-5 and Landsat 8 satellite imagery. A supervised classification was conducted using ERDAS IMAGINE software (Version 13) and the accuracy of the classification was verified by limited field check. Landsat 5 and Landsat 8 satellite images were used for identification of sub-watershed areas.

The current study conducted in Pune and its surrounding areas indicates that multi-temporal remote sensing images i.e. Landsat images are very useful to detect the changes in land cover quickly and precisely. The study reveals that the major land cover categories in the study area in which changes over the years were observed are, water bodies, vegetation and settlement area.

Different types of residual plots can be used to check the validity of these assumptions and provide information on how to improve the model. For example, the scatter plot of the residuals will be disordered if the regression is good. A trend would indicate that the residuals were not independent. On the other hand, a histogram plot of the residuals should exhibit a symmetric bell-shaped distribution, indicating that the normality assumption is likely to be true.

The statistical analysis of data was carried out Multivariate as well as Bivariate Regression analysis results were plotted. Residual plotting's of different variable were compared and the patterns of distribution with maps were prepared for change detection as well as to understand future trends of urbanization.

CHAPTER - 1 : INTRODUCTION

1.1 Introduction

Geomorphology is a scientific discipline of geography which is concerned with the study of landscapes. A detailed study of morphology of any area can provide a reliable base for its future development. In the present period, the anthropogenic activities are transforming the natural landscape which consequently alters the nature of geomorphology.

"Urban geomorphology", a recent but more useful branch of applied geomorphology, studies the related process, materials and hazards, and the ways that are beneficial for planning, development and management of urbanized areas or areas where urban growth is expected (Cooke1982). It primarily deals with lithology, geomorphic processes, hydrological conditions and topological characteristics of a specific area. Such factors are not only significant in determining the rate of urbanization, but also have a direct influence on the size of population and stability of ground surface of urbanized localities. In urban areas, the study of geography is primarily concerned with interpreting the patterns and interrelationships of the concerned parameters that exists within it. It is important to note that each city has its unique morphology from the geographical perspective, but the contemporary growth patterns result in the transition of its morphology.

In the developing countries, not much attention is paid towards understanding the geomorphological conditions in urban areas. Consequently, it results in uncontrolled growth of the settlement giving rise to shanty towns, which are observed in many deprived countries. This not only creates social problems but is also responsible for environmental problems (Cooke 1982). The transitions in the environment landscapes are inevitable if urbanization is considered to be a positive indicator of development.

The World Commission on Environment and Development in its report 'Our Common Future' stated that the environment and development are not separate challenges; they are linked. Development cannot subsist on a deteriorating resource base; the environment cannot be protected when growth leaves out of account the costs of environmental destruction (WECD 1987).

1.2 Geomorphology

Geomorphology can be defined as a science which studies the genesis and the causes of evolution of land surfaces and their rate of change in relation to nature and human. Geomorphologic studies aim at describing the present nature of the topography and interpreting the causes of its formation. Much work in geomorphology is of great potential value to man in his use of the physical environment (Cook and Doornkamp 1974). In recent years, the application of geomorphological knowledge has increased in harmony with growing public and political awareness of environmental problems. Geomorphologist have emphasized on the practical application of the subject by establishing dynamic relationships between landforms, materials and contemporary processes. Now-a-days, geomorphology is influenced by one of the most advanced structure of human settlements in the form of cities, and its correlation with natural and environmental factors. Thus, the role of this discipline in establishment, site selection and physical development of cities especially arid and semi-arid cities is undeniable (Cooke 1982).

1.3 Geomorphic Processes and the Human Landscape

Over a period of few centuries, human activities have affected geomorphic processes on a scale that transcends natural impacts with an effect likened to a major global climate change (Knighton 1998). Deforestation reduces the rate of evapo-transpiration and infiltration and increases runoff and sediment supply to water-courses. Farming involves tile drainage and water-course re-direction through ditches, which reduces stream length and alters the flow. It curtails the habitat potentiality of the area. Urban development typically results in the extensive compression and paving of land surfaces, which significantly reduces infiltration and dramatically increases runoff to watercourses unless extensive mitigation is applied. When changes in flow regime and sediment supply from land clearing and urbanization exceed the thresholds for self-regulation in affected water-courses, the dynamic equilibrium will be upset, causing the channel to become unstable. In such circumstances the water-course adjusts with physical changes that occur more rapidly than the controlled adjustments of the natural dynamic equilibrium.

These changes are rapid, extensive and often catastrophic and may include severe bank erosion, a lowering of the bed level of the stream, or major changes to the path of the channel itself. Such changes can result in destruction of aquatic and riparian habitat, damage to infrastructure and property, and risks to public safety.

Research into the effects of urbanization on watercourses has indicated that the critical threshold, at which channel destabilization begins, typically corresponds to a total drainage basin imperviousness of three to five percent (Hammer 1972; Booth 1990). Significant enlargement of the channel cross-section begins once the drainage basin reaches five to ten percent imperviousness. It is estimated that the channel will continue to enlarge, in response to urbanization, for a period of 35 to 65 years after the end of development in the watershed.

Once adjustment of the channel to urbanization is complete, the cross-sectional area may be up to 6 times greater than that of the channel prior to disturbance (Hammer 1972). This enlargement can occur by erosion of the channel banks and incision of the channel bed, the degree of each being determined by their relative resistance to erosion. In addition to cross-section enlargement, urban water-courses also experience adjustment of their plan form as the channel attempts to evolve a new meander pattern that is compatible with the new hydrologic and sediment regime. This adjustment process is thought to take an order of magnitude longer than cross-section change, resulting in a total period of instability as a result of urbanization that may be measured in centuries. It is theorized that urban watercourses will eventually achieve a new form of dynamic equilibrium through these adjustments. Even if this should occur, experience suggests that the ultimate form of an urban water-course will bear little resemblance to a natural river or stream and will not possess the stability or structure required to support diverse aquatic ecosystems (Booth and Jackson 1997; Fuerstenberg 1997).

1.4 Urban Area

An urban area is characterized by high population density and vast human features in comparison to areas surrounding it. Urban areas may be cities, towns or conurbations, but the term is not commonly extended to rural settlements such as villages and hamlets. Urban areas are created and further developed by the process of urbanization. Measuring the extent of an urban area helps in analyzing population density and urban and rural population (Cubillas 2007).

Urbanization is the movement of population from rural to urban areas and the resulting increased proportion of a population that resides in urban rather than rural places. It is derived from the Latin word "Úrbs'a" used by the Romans to denote a city. Urbanization is two way process because not only does it involve movement from village to cities and change from agricultural occupation to business, trade, service, and profession but it also involves changes in the migrant attitude, belief, values and behavior patterns.

The criteria provided by the "Census of India" for identifying urbanization in a particular area are as follows:

- Population should be more than 5000
- The density should be over 400 persons per sq. km.
- 75 % of the male population should be engaged in non-agricultural occupation.
- Cities are urban areas with population more than one lakh.
- Metropolises are cities with population of more than one million.

1.5 Urban Geomorphology

In the urban environment, man is considered to be the creator of the landscape or "cityscape". Thus, urban geomorphology is concerned with the study of man as a physical process of change whereby he metamorphoses a more natural terrain to an anthropogenic cityscape. In such a context, urban geomorphology is the surface component of urban geology which is one of the important subfields of environmental geology (Coates, 1976).

Anthropogenic activities play an important role in the transformation of the Earth surface. Maximum distortion occurs, however, in urban areas where he has chosen to congregate and congest. The emphasis of urban geomorphology is on this unique geographic setting where man has thoroughly intruded some of the natural physical systems. The study of these aberrations, some of which are deliberate while others are by-products, constitutes one of the subfields of geomorphology (Coates, 1976).

The urban geomorphologist can use his expertise to predict the kind of destruction that will ensue from the anthropogenic activities when the type, degree, and magnitude of the environmental upsets are understood. It is not sufficient for the scientist to "merely know" what will happen, but he should become involved in decision-making matters. It is necessary to provide advice for those plans that seek alternate paths whereby man's activities can be consummated in a manner that will minimize environmental degradation (Coates, 1976).

Local and regional landforms have played a central role throughout history in the choice of sites for settlements and their further development has often been influenced by the regional geomorphology.

The erosion processes increase in urban areas where the building activities remove the soil cover and causes extensive wash denudation. The streams become overloaded with sediment as a result and their cross-sections change (Wolman 1967, Wolman and Schick 1967). As urban areas expand, impervious surfaces like buildings, streets, parking areas, industrial and commercial areas are built up. Such construction leads to the surface runoff flows into the sewage system. As a result of this Groundwater supplies are reduced causing increase in flood frequency and the peak flood height. (Leopold 1968, Graf 1975, Sala and lnbar 1992).

Human activities have increased the runoff maxima in many river basins, and this has been compensated by building of reservoirs which store the excess runoff and release it gradually. Reservoirs act as sediment traps for all the bed-load and part of the suspended load. Immediately below the dam, the stream is practically free of solid load so that it picks up new load and erodes its channel bed downstream from the reservoir. The bed-load is smaller than before because the high-water peaks are lower than before the dam was completed (Gregory and Park 1974, Gregory 1979).

Applied urban geomorphology is the study of landforms and their related processes, material and hazards, in ways that are beneficial to planning, development, and management of urbanized areas or areas where urban growth is expected. To prevent urban growth destroying or sterilizing valuable resources, especially aggregates; to identify and evaluate land and material resources required for development; to limit undesirable impact of urban development on geomorphological conditions; to predict the potential resources of ground surfaces to urban development; and to assess the potential impact of geomorphological hazards on the urban community (Cooke, 1982).

Along with the aerial photographs or other remote sensing imageries, the geomorphological mapping of the concerned area can assist in understanding, classifying and describing the terrain features. Analysis of process dynamics and landform change may be accomplished through historical records such as climate and hydrologic data, and the evidence of topographical maps, aerial photographs and satellite imagery. Less secure and less common, is to describe one, poorly known situation by analogy with another similar but better – documented situation elsewhere (Leopold, 1962).

Urban geomorphology combines the ambient geology, landforms, and geomorphological processes with the evaluation of impacts brought by urbanization. The practitioners of urban geomorphology tend to concentrate on alteration, using the physical environment as a baseline. A number of case studies from different parts of the world (dealing with topics such as slope instability, seismic hazards, increased flood problems, and land subsidence) have demonstrated the utility of urban geomorphology to engineers, city managers, and urban planners (Gupta and Ahmad 1999).

1.6 Effect on Urban Morphology

Various negative effects in terms of loss of agricultural land, surface and groundwater depletion, changes in geomorphic features, flooding, landslides, etc are experienced by the people of cityscapes and the surrounding areas. With the increase in population, it has become inevitable to adopt proper urban planning to attain sustainable environmental stability of an area.

Towns and cities have mostly expanded in accordance to the relief of the terrain and the relief changes as per the planning and needs of construction (Ahnert1996). The other factors that have influenced the geomorphological process in the urban environment are the weathering of the building stones due to air pollution (Viles 1993). Ahnert (1996) was of the opinion that settlement geography is incomplete without taking into consideration the morphology and hydrology of an area. There is a need to understand the dynamic interaction between the different aspects of urban expansion as expansion of built-up area, construction activities over natural features which cause diversion and destruction of aquifers, and the specific geomorphic features of the urban area. (Wolman1967).

The groundwater supply of the urbanized area also gets reduced and as a result drainage frequencies increase (Leopold 1968, Graf 1975, Inbar 1992). The local geomorphic features have played a crucial role by establishing and developing the kind of settlements in the history of civilization. The expansion of a city over the years and the construction activities gradually alter the topography of the area. These changes ultimately affect the rate of geomorphic process such as weathering and erosion (Viles 1993).

1.7 Urbanization and Watershed

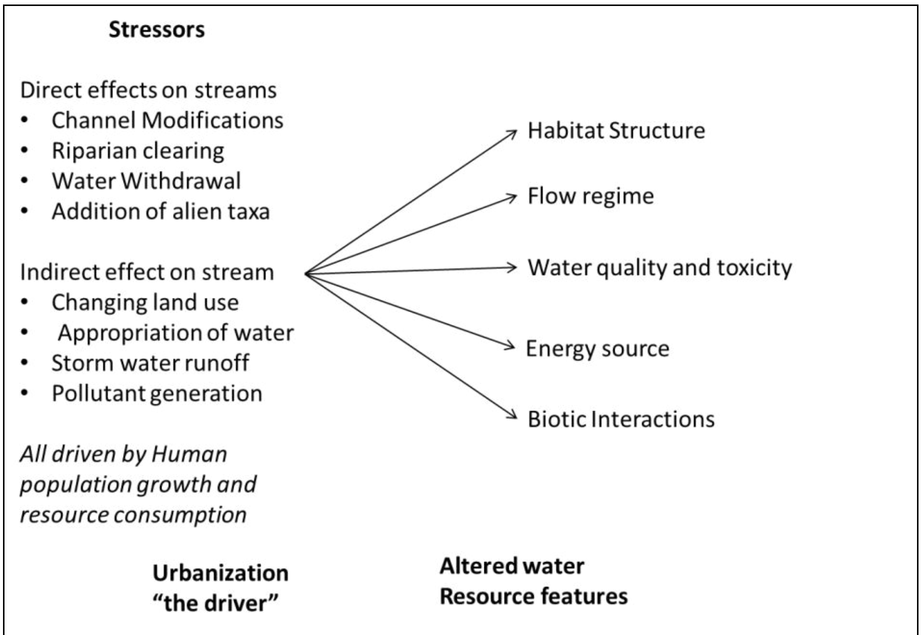
Urbanization alters river ecology in and downstream of cities, harming aquatic systems thus prompting efforts to protect, rehabilitate, and even fully restore urban streams. Yet these efforts seldom succeed because of narrowly prescriptive solutions that do not take advantage of interdisciplinary knowledge in the physical, biological, and social sciences or because they do not treat the full range of urban change in streams (Karr and Rossano, 2001).

Several studies have shown that land clearing, poor agricultural practices and urbanization can change watershed hydrology and disrupt the physical behavior of channel systems (Graf 1975). This study sets up a conceptual framework for assessing stream degradation and uses it to recommend realistic improvements. Few urban streams can be entirely restored – that is, returned to a state that supports the full range of living things and ecological processes. Many urban streams can, however, be rehabilitated with their biological conditions. The framework used here explicitly links the human actions collectively termed “urbanization” with biological conditions, the primary endpoint of concern. Urbanization does not itself cause biological decline; instead, it alters the landscape, inflicting stresses on stream biota. Successful stream rehabilitation requires understanding of stressors and their interactions, which link human actions to biotic changes (Grimm et al., 2000). This complexity demonstrates the futility of one-size-fits-all urban restoration.

1.8 Human Impact on Channels

Human-induced landuse changes can have a significant effect on streams morphology. Deforestation, urbanization, agricultural practices and wetland conversion can all contribute to stream channel degradation (Hammer 1972; Knox 1977; Hooke 1994). Impervious surfaces are one of the many human fabrications that disrupt the hydrological processes. Impervious surfaces are simply substances that halt the penetration of water into the soil. The result of this barrier is increased runoff, higher stream channel velocities and greater flooding (Chester L. Arnold and C. James Gibbons 1996; Wolman 1967).

Urbanization can also have a significant effect on channel characteristics within a watershed. The hydrology is vastly altered when vegetation is replaced with impervious surfaces like pavement and rooftops (Hammer’s, 1972).



Conceptual Model of the varied stressors resulting from human actions (modified from Karr and Yoder, 2004)

Stream degradation caused by urbanization is not a single problem with a single solution, or even a well-defined set of problems with well-defined solutions. Rather, it results from a collection of individual decisions and actions that lead to specific urban landscapes and, in turn, to altered stream condition. “Urbanization” itself is multidimensional and has been defined in many different ways (McIntyre et al., 2000). It may constitute industrial, retail, or housing development; it may proceed quickly or gradually. It can be halted at an early stage by zoning or hastened by incentives that encourage development. An urbanized watershed may contain polluting or nonpolluting industries, dense road networks or only a few roads. The topography, soils, vegetation, and channel networks in an urban basin may be altered. Thus no single change defines urbanization; instead, the cumulative effect of the variety of human activities in urban basins profoundly influence urban streams (Booth et al., 2004)

Most of the key reasons for flooding of the Mithi River in Mumbai, Maharashtra, apart from tidal variations, flat gradients downstream and mud flats (in the eastern catchments, which cause excessive siltation), are the inappropriate levels of manmade outfalls, poor placement of drainage channels, loss of holding ponds due to land development over the years, increase in runoff coefficient due to widespread development and paving of open areas, dilapidated drains encroachments on drains, enhanced silting and choking of drains due to sewage inflows and garbage dumping in drains, obstruction due to crossing utility lines, poor structural conditions (NEERI 2011).

The recharge structures like lakes, tanks, ponds and other wetlands in the city have been ignored. All the wetlands of Chennai, Tamilnadu, became sites of waste disposal, housing, commercial and industrial purposes. Wetlands act as a sponge, soaking up rain water, playing vital role in floods. According to a report of leading daily, over 5,550 hectares of wetlands in that area have been developed into commercial real estate and only 10 percent of the original wetlands remain. Hence, rain water runoff has nowhere to go and settles instead onto roads, causing flooding. From past four decades the open and green areas are converted into urban area almost twenty times. The unplanned urbanization not only makes a city prone to urban flooding but also decreases its groundwater recharge. Chennai recorded 374 millimeters rainfall in 24 hours, which were highest record set after 190 millimeters. Because of this incidence almost 250 people have died (2015).

1.9 Man-made Environment

An environment made by humans results on the consumption of excessive amount of material and energy demanding core, supervision, management and often interferes with the natural environment. Industries, cities, town, crop fields, artificial lakes and dams are the major man-made environment. Environmental degradation might be caused by many factors such as intensification of agriculture, population growth, indiscriminate industrialization, rising energy use and transportation etc.

1.10 Literature Review

Fracassi C. (2013) Focus on several aspects like São Pedro, Brazil for urban sprawl with master plan zoning, bed rock soil map, environmental protection area, Area Steepness map, Urban Sprawl chart. The municipality of São Pedro presents a considerable potential of areas suitable for urban expansion intercalated with areas of intermediate and restricted potential. These limiting areas comprise a set of physical factors (geological and geomorphologic) with a high probability for the occurrence of erosion and mass movements, characterizing them as areas of environmental risk. Therefore, even in areas classified as suitable, urban expansion should be considered carefully, and it is essential that the guidelines for expansion take into account the natural conditioning factors. Hence, it is crucial for land use planning to be based on the quality and characteristics of the land in order to satisfy certain priorities and/or occupy any terrestrial space.

Siddhartha K. and Mukherjee S. (2012) emphasize on the social and physical system of urbanization and the interaction between them in term of spatial attributes, including dimensions, densities, scale relationships, associations and patterns. In their book, they have studied the layout, demographic characteristics and functions for structure of the Indian city. In the view of rural-urban fringe area they have explained important characteristics like changing pattern and land occupation, crop production, residential expansion, services & other public utility and speculative building.

Sarmah et al (2012) carried out a morphometric analysis of a highland micro-watershed WahUmbah area by using remote sensing and GIS techniques. Drainage map of the area was prepared from the high resolution satellite image and SOI topo-sheet. This map was updated using IRS-1D PAN sharpened LISS-III analog data. The relationship between geological setup and drainage pattern was analyzed. This study concludes that WahUmbah river micro-watershed is in the process of evolution as the basin is in the process of tilting. Their study well defends the rationale of remote sensing and GIS techniques to understand extent of geological controls on the morphology of watershed.

Kuldeep P. and Sanjay P. (2012) studied the geomorphological aspects for urban planning, which gives an idea about the variations in landscape and indirectly facilitates in evaluating the resources of an area. They studied the urban expansion from 1972 to 2011 for Sagar Town. For the study of urban mapping and urban expansion databases integrated, multi-scale, and multi-resolution catalogue, these deliver the baseline information for the planner and decision-makers to observer/monitor and predict the patterns and future trends of urbanization. Geomorphological and progressive urban maps have instant applications in monitoring of urban sprawl/urban expansion and predictive modeling techniques to better forecast future areas of urban growth.

Bhaskar (2012) studied the urbanization, development and changing green space in Pune city from 1857 to 1997.Land use planning describes the ongoing destruction and degradation in Pune city due to rapid and hazardous urbanization in development and making them more vulnerable to environmental change impacts. Hence, land use, land cover and green cover change monitoring becomes very crucial in decision making and conserving green spaces in Pune city.

Punithavathi J., Tamilenthi S. and Baskaran R. (2011) analyzed geomorphology and land use pattern of Thanjavur agriculture and urban area using IRS P6 data. The geomorphic units under structural landforms such as lineament, fault, and Pedi-plains; in fluvial landforms such as alluvial plain, flood plain, channel bar, and natural levee; in coastal landforms include beach ridge, brackish water, and mud flat, salt flat, upland and coastal plain area. Various categories of land (residential planned, and unplanned, agricultural land, waste land and others) were studied under the Land use pattern.

Kam Wing Chan and Man Wang (2008*)* stressed on the urban geographical views in *Urban Geography*. Urban development in China from their origins to infrastructure and policies development shows systematic growth because of geographical view for city development. Transportation planning based on geographical landscape of particular area. On the other hand western development program design varies in Delta region in China on the basis of land characteristics.

Duraiswami R. A., Dumale V and Shetty U (2009) With the help of Remote Sensing and Geographic Information System, study suitable for rooftop rainwater harvesting by integrating traditional hydrogeological survey data is done. Development of SLUGGER-DQL program identified potential sites for rooftop rainwater harvesting and artificial recharge. Traditional hydrogeological surveys combined with modern techniques used for solving problems related to urban hydrogeology and town planning.

Duraiswami R. A., Dumale V. and Shetty U. (2009) Describing study of Geospatial Mapping of Potential Recharge Zones in Parts of Pune City while identifying areas suitable for rooftop rainwater harvesting by integrating traditional hydrogeological survey data with the help of Remote Sensing and Geographic Information System. Potential sites for rainwater harvesting and artificial recharge have been identified in the Pune University-Shivajinagar-Kothrud area by SLUGGER-DQL program. This study demonstrates the utility of traditional hydrogeological surveys combined with modern techniques in solving problems related to urban hydrogeology and town planning.

Steve Kardinal Jusuf (2007) Also used the remote sensing data and GIS to investigate and identify the impact of land use types on ambient temperature in Singapore. The study shows that there were different temperature orders within different urban land cover between daytime and night times. The above mentioned descriptive research established the parameters of study, but these urban/rural comparisons are at best only an approximation of the urban modification.

Cristiano P. and Henrique M. G. (2007) This paper on the greatest problems in Brazilian urban watersheds are concerned to the amount of solid residues, domestic sewerage and sediments that are disposed in the rivers and streams that drain those areas. The results suggest the occurrence of a high enrichment of the fluvial sediment by these metals. The concentrations of (Zn, Pb and Cr) elements vary temporally during storms due to the input of impervious area runoff containing high concentration of elements associated to vehicular traffic and other anthropogenic activities. The contamination of the urban watershed is reflected in the results obtained in the fluvial suspended sediments.

According to **Chattopadhyay B. C. (2005),** Metropolitan growth of India shows physical characteristics towards development, pattern of growth spreading horizontally as well as vertically.

Voogt J. (2002) mentions that anthropogenic heat contributes to atmospheric heat islands and refers to heat produced by human activities. It can come from a variety of sources and is estimated by totaling all the energy used for heating and cooling, running appliances, transportation, and industrial processes. Anthropogenic heat varies by urban activity and infrastructure, with more energy-intensive buildings and transportation producing more heat.

Mandal R. B. (2000) urban geography deals with urban land use, urban population, urban transport, industrial development etc. concept and theory framing regarding cities distribution, size, function and rate of growth. Urban geography gives the clue of cities in terms of their morphology besides origin, growth and function. Location and siting of town in an area shows latitudinal and longitudinal position and its significance and important. Location shows the importance of town and highlights the surrounding environment.

Dixit and Ahmed (1998) focused on the complexities related to flood control in the Himalayan watersheds, they considered that even partial flood control is an exercise that many be geopolitically, financially, and technically problematic at present. They are of the opinion that the hydrology of the Himalayan watershed is scantily studied, little understood and its potential for damage is often underestimated.

Oke, T. R. (1997) Many urban and suburban areas experience elevated temperatures compared to their outlying rural surroundings. This difference in temperature is what constitutes an urban heat island. The annual mean air temperature of a city with one million or more people can be 1.8 to 5.4°F (1 to 3°C) warmer than its surroundings.

Chengtai Diao (1995) Focused on geomorphic substance with various shapes and materials is an underlying surface for a city and an important factor to control the layout, regional structure and development of a city. Many

Huda Manirul (1990) Rate of growth of urbanization and its contributing factors such as demographic dynamics, growth and distribution of income, pattern of consumption, structure of industries as well as the cultural and educational aspects of the growing urbanization in Sibsagar town were studied. By arranging this data in a suitable manner and by the application of appropriate statistical technique, he has tried to deduce the significant trends in the urban economy of Sibsagar and their concomitant problems.

Harvey (1989) The place of urban politics in the geography of uneven capitalist development includes space, technology, structured coherence, physical and social infrastructures. The urban region shows Geopolitical unit in the uneven geographical development of capitalism. Urbanization modes Space of representation accessibility, political responses, knowing physical landscape of extraordinary complexity, etc. describing through example of America city of emphasis flexible accumulation through urbanization.

Zavoianu (1985) has authored a book on morphometry of drainage basins. His comprehensive work deals with historical developments in the field of measurement of forms i.e. morphometry. Besides, he has also elaborated on issues like stream classification, basin area, perimeter of drainage basins, basin shape, river length etc and various other principles and techniques related to drainage basins in a lucid manner. He has also devoted one chapter on relationships between morphometrical and hydrological features in the present series.

Diddee Jaymala (1984) explained the significance of central place theory that deals with temporal pattern of evolution, the spatial distribution and the functional organization of central places. Some methods deal with measuring centrality, the determination of a hierarchical arrangement of central places service area relationship. Functional and locational factors growth characteristics of particular area.

Cooke R. U., Brunsden D., Doornkamp J. and Joines D. (1982) focus their attention on methods recording, analysis and presenting geomorphological information. Geomorphological mapping, morphological mapping and land system surveys have been used with success in many resource surveys prior to urban development. They specifically focus on geomorphological problems related to urban development in dry-land. Review of the nature of the problems posed by the presence of surface salt and saline wares in many areas of dry-land urban growth. One set of approaches to evaluating environmental data relevant to urban development in dry-land. The geomorphological perspective advocated in no way precludes equally valid approaches to the study of environmental problems in urban areas of dry-land adopted by geologists, ecologists, penologists, hydrologists and hydrologists.

Kumar and Pandey (1981) have studied the morphometry of some drainage basins of the Hazari-bagh plateau region. They indicated that "The present landscape is the combined output of the denudation processes operating since its earliest geological period". They analyzed the morphometry of four catchment areas in terms of linear, areal and relief properties. The linear properties have studied using Strahler and Horton's law of stream numbers. The study indicates the regional variations in the morphometric properties of four sample basins.

Singh and Singh (1979) have conducted a comparative study on morphometric evaluation of Himalaya and the peninsular uplands. The study is based on topographical maps, aerial photographs, and field observations in the region. They employed four principal methods i.e. relative relief, dissection index, drainage texture, and slope to identify morphological units. It is noted that these four principal morphometric attributes are significant enough in understanding the morphological character of both the terrain types.

Jackson (1972) describes urbanization as a process of growth and change, the expansion of government intervention in the affairs of the environment, the emerging consideration of interrelations between land use and transportation at the regional level of appreciation, and the minerals, atmospheric pollution, steep slope, height, tree less environment, noise zone, etc are important for urban study towards morphological approach.

1.11 Background of the Study Area

1.11.1 Introduction: Pune

Pune is the seventh largest metropolis in India, the second largest in the state of Maharashtra after Mumbai and the largest city in the Western Ghats. Pune is the cultural capital of Maharashtra. Pune has many popular nicknames such as 'Queen of Deccan', 'Pensioners Paradise', 'Cultural Capital of Maharashtra', Cyber City', etc. City is known for various cultural activities like music, spirituality, theatre, sports and literature and job opportunities attract migrants and students from all over India and abroad, which makes for a city of many communities and cultures. Pune's culture reflects a blend of traditions with modernity This City has more than a hundred educational institutes and nine universities. This results in a large student population, and a large number of quality academic and research institutes and has witnessed maximum floating population. As one of the largest cities in India and as a result of its many colleges and universities, Pune has emerged as a prominent location for IT and manufacturing companies to expand. It epitomizes the Marathi culture, which lays emphasis on education, arts and crafts, music and theatre. In recent times, Pune has emerged as a centre of modern architecture in India.

Pune's is urbanizing at a phenomenal pace. The reason for such rapid development is the introduction of the IT sector in the city. The city is working on the three major sectors the educational sector at the core, the Industrial sector of Pimpri Chinchwad at one end and the IT sector of Hinjewadi and Aundh at the other. The improvisation in the transport connectivity by the introduction of BRT route and the upcoming metro within and in the periphery of the city is pushing the boundary of the municipal limit.

1.11.2 History of Pune

'Punnaka' a tiny agricultural settlement in the 8th century, has grown into a megalopolis called Pune covering more than 700 sq. km. area and supporting a population of about 4 million. During the Mughal reign in the 11th century, this settlement of the 8th century developed into a small town 'Kasbe' Pune. During the mid-16th century, this settlement became the transitory residence of King Chatrapati

Shivaji Maharaj. From 1630 to 1647, King Shivaji Maharaj was crowned Chhatrapati (King) in 1649, he masterminded the further developments in Pune, including the planning and construction of the Guruwar, Somwar and Mangalwar Peths. Before the rise of the Peshwe, five other peths were built i.e. Shukrawar, Raviwar, Shaniwar, Bhavani, and Ghorpade Peth. During the 27-year-long conflict between the Marathas and the Mughals, the town was occupied by Aurangzeb from 1703 to 1705; during this time, the name of the town was changed to "Muhiyabad".Two years later, the Marathas recaptured Sinhagad fort and later Pune city from the Mughals.

The city rose to distinction when the Peshwas established the rule of Maratha's empire here (1749 A.D.) During the Peshwa rule, the city expanded considerably. The 1761 defeat at Panipat by Abdali, affected the fate of the Maratha Empire and consequently that of the city. In 1818, the dynasty changed in trifling transition from Mughals to Marathas. The Maratha rule came to an end at Khadki near Pune, in 1871 when the British defeated them and the city and the surroundings came under the British rule. Pune became the 'Monsoon Capital' of the then Bombay Presidency, under the British rule. On the city's outskirts the British established few army bases, which later transformed into the cantonments of Pune and Khadki.

In the 1850s Pune Municipality was established and Pune was connected to Mumbai by the railway in 1858. Pune became the home of many reputed educational institutes like: the Deccan College (one of the oldest in western India), Engineering College (second oldest in the Indian Subcontinent), Fergusson College (amongst ten most reputed in India), Agricultural College (one of the earliest in the country) to name a few. Pune is also the Headquarters of the Army Southern Command and has many other defense establishments.

Confined towards the north by the Mula-Mutha river, areas such as Deccan Gymkhana, Erandwane and Shivajinagar in the west; Camp, Bund Garden and Koregaon Park in the east; Swargate, Parvati Hill, Sahakarnagar, Mukund Nagar, Maharshi Nagar, Gultekdi and Salisbury Park to the south; were developed after post-independence era. Due to establishment of various educational institutes across Pune, areas such as Ganeshkhind, Kothrud, Sahakarnagar, Bibwewadi, Yerawada, Wadgaon Sheri (Kalyani Nagar, Viman Nagar and Shastri Nagar) Kharadi flourished.

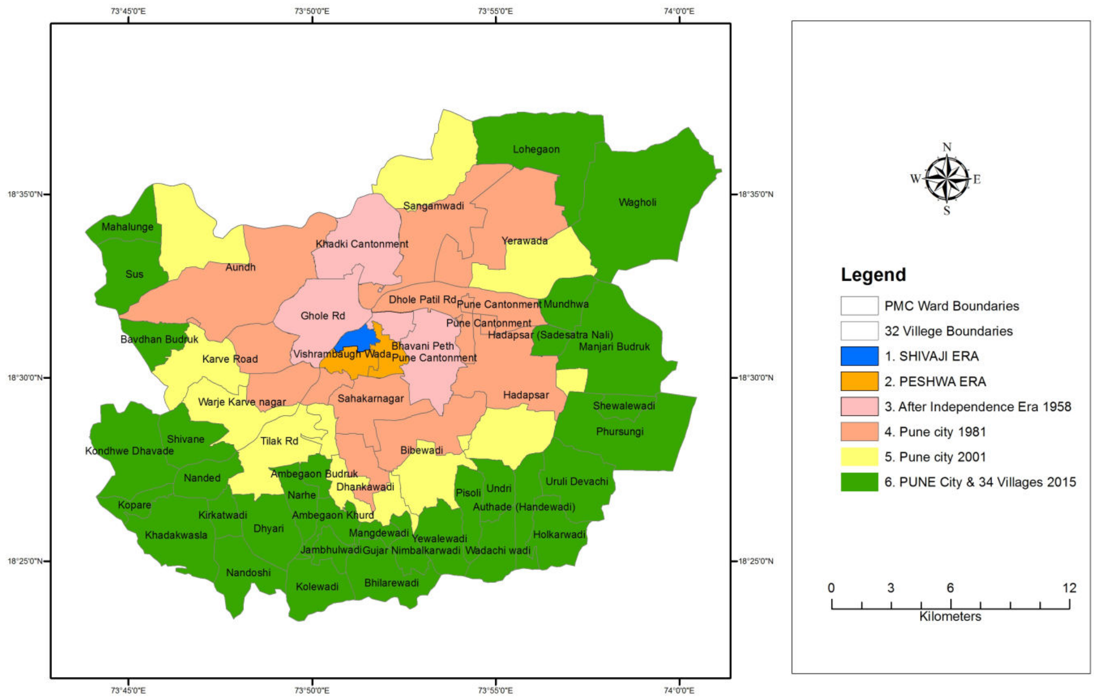


Figure 1 : Historical Development of Pune City

The important events in the city's history, culture, its growth and development include the Peshwa era, progression of Peth areas, the development of Deccan Gymkhana and other colonies across the river in 1920's, the establishment of Pune Municipal Corporation in 1950, the establishment of an industrial estate in Pimpri-Chinchwad (1960), Panshet floods (1961). Development of educational and IT industries, and connection of Mumbai by expressway gave a unexpected boost to the growth of Pune.

1.12 Significance of Study

Local landforms or geomorphic features have played a crucial role in the establishment and development of settlements in the history of the civilization of Pune. The expansion of Pune city over the years and rising construction activities has gradually altered the topography of the entire area. These changes ultimately affect the rate of geomorphic processes such as weathering and erosion. Pune had the natural advantage of local topography and the hydrological conditions to flourish. Various negative effects in terms of physical environment such as loss of agricultural land, surface and groundwater depletion, changes in geomorphic features, flooding and landslides, etc have increased due to changes in the city's environment.

The early geomorphological studies and design with respect to urban stream management have been mainly through classification schemes, which were based on the historical geomorphology developed by Davis in the first half of the twentieth century. This theory specifies evaluation of waterways, latitude and longitude profiles if the city is located in the vicinity of the flood river, one can calculate the channels present stability, past conditions and probable trend if left undisturbed. It is observed that many streams are overloaded due to ongoing construction activities and dumping of garbage causing their disappearance from Pune and its surroundings.

Pune has geographically ideal physiography for growth of human settlement. Massive unplanned urbanization happened post the 1961 floods in Pune city. Urban sprawl of Pune is spread in circular form due to the Sinhgad-Bhuleshwar range (towards south) and Mutha river (towards north) guiding development to grow in horizontal direction. Growth of settlement and change in land use is spreading towards southern and southern east area. Physical landforms such as hills and watershed streams have changed due to the enormously growing housing projects around Pune city. With the increase in population, it has become inevitable to adopt proper urban planning standards to attain a sustainable environmental stability of an area. It is necessary to understand the dynamic interaction between the different aspects of urban expansion like built-up area, construction activities over natural features which cause diversion, destruction and change in geomorphology of Pune and surrounding area.

The reason behind selecting Pune and its surrounding areas as study area is its dynamic growth and topology. This study intends to learn slope, geomorphology, drainage and watershed analysis of Pune city. In this study, Remote Sensing data was extremely useful to understand change detection. It is important to study the change in slope in relation to sustainability of land and the role of dominant processes of degradation.

The morphometric characteristics of a watershed reveal information regarding its formation and development. It represents simple approach to describe the drainage basin geo-hydrological processes. This study is an attempt to comprehend geomorphic analysis with respect to the nature of the watershed and slope analysis to use it as an important tool for further planning. The study is limited to Pune city and 34 villages' (Administrative boundaries) surrounding it topographically.

CHAPTER – 2: STUDY AREA AND METHODOLOGY

2.1 Physical Setting of Pune and its Surrounding Areas

Geographically Pune is situated on the Deccan plateau and lies on leeward side of the Western Ghats with an average altitude of 560 m from the mean sea level. It is located at the confluence of the Mula and Mutha rivers and lies between latitudes 18°25’ N and 18°37’ N and longitudes 73°44’ E and 73°57’ E. River Mutha passes through the city and possesses an asymmetrical valley. Pavna and Indrayani traverse the northwestern outskirts of the urban area. The highest point in the city is Vetal Hill (800m above mean sea level-(MSL)) whereas the highest point just outside the urban area is the Sinhagad Fort (1300 m above MSL).

According to the Environmental Status Report Pune comes under the top green cities of the country, currently with 23 lakh trees. The major-forested areas of the city include Katraj and Sinhagad valley. The other few areas under tree cover include institutions like Pune University, National Defense Academy, Pune Cantonment and gardens like the Empress Garden, Sambhaji Baug, Saras Baug etc. Some of the hills in the city covered green areas. Vetal Hill (ARAI Hill) covered Fergusson College Hill and Chaturshringi Hill, Parvati Hill, Baner Hill, Taljai Hill, Law College Hill, Bhamburda Tekdi, Pachgaon Tekdi, VarjeTekdi, Ghorpadi, Wanwadi, Vadgaon Sheri, Kondwa Bk., Kondwa Khurd, Mohamadwadi, Kharadi, Warje (ESR, 2010-2011) are small hills in the city. It is hard to identify the terrain due to dense construction and infrastructure. These hills are an off-shoot of the Western Ghats, a global Hot Spot of endemism and rich bio-diversity. Most of the hills have undergone extensive afforestation by the Forest Department.

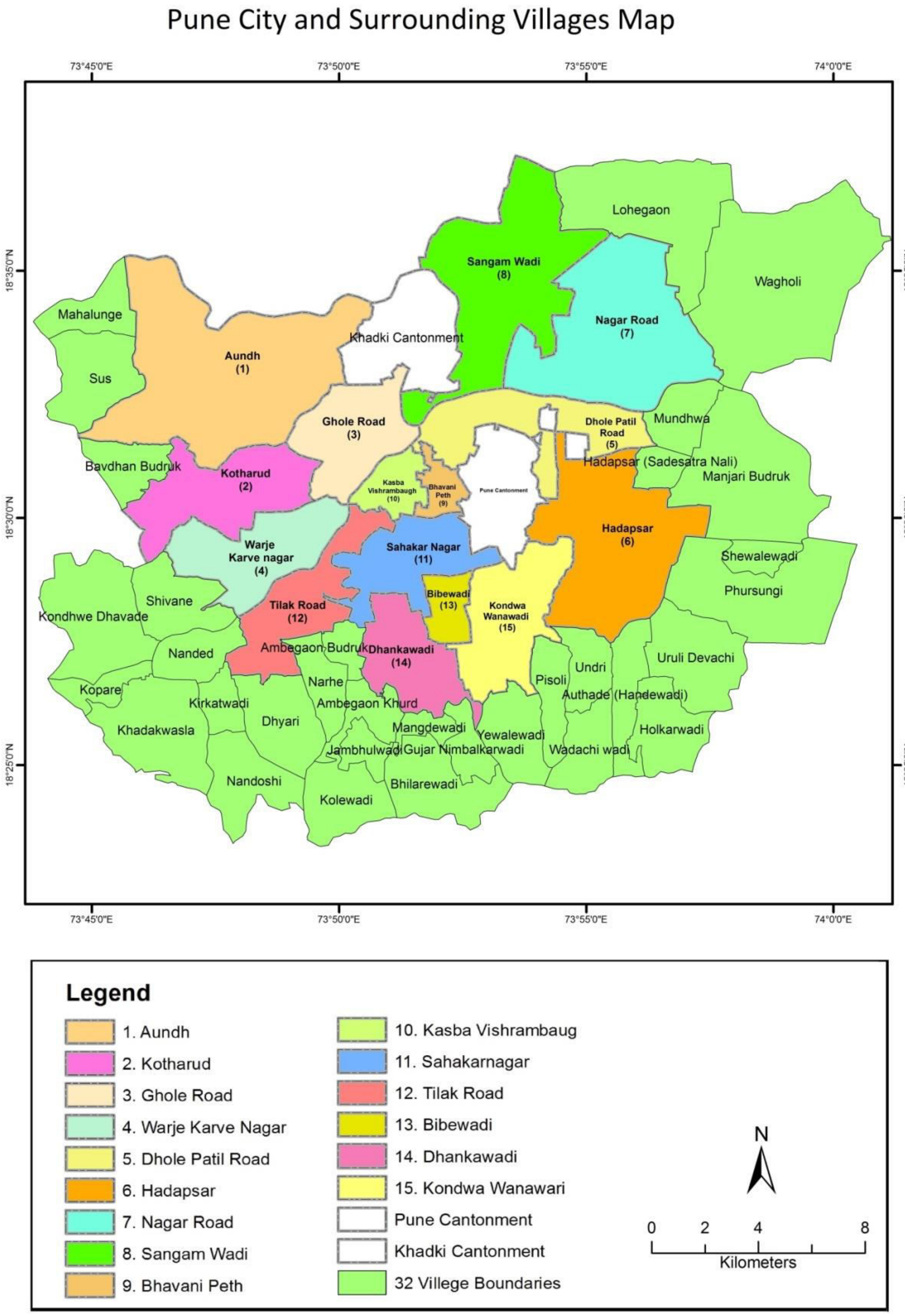


Figure 2: Pune and surrounding area

The Urban expanse of the city has been extending day by day since 1997 to 2013, 23 villages with an area of 97.64 sq. km were included Pune's Corporation limit. .

2.1.1 Climate

The proper evaluation of the climate of the area is of importance as the climatic factors rainfall, evaporation, transpiration etc. play a vital role in the case of geomorphological study. The climate of the Pune city is mainly dry and warm. Pune has a low-latitude semi-arid hot climate (Köppen-Geiger classification: BSh). Pune experiences three distinct seasons: summer, monsoon and winter. Typical summer months are from March to May, with maximum temperatures ranging from 30°C to 35°C (86°F to 95°F). The city receives an annual rainfall of 722 mm, mainly between June and September as a result of the southwest monsoon.

Table 1: Climate in Pune and surrounding area

2014	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Temp (Degree)	30	31	35	38	38	34	29	29	30	32	31	29
Min. Temp (Degree)	13	13	17	20	23	24	22	22	21	19	16	12
Average Temp (Degree)	21	22	26	29	30	29	26	25	25	26	24	20
Precipitation (mm)	0	0	3	18	9	15	277	297	120	38	26	53
Relative Humidity (%)	55	46	36	36	48	70	79	82	78	64	28	4

Source: IMD 2014, Pune

The effective temperatures for comfort are generally taken between 21°C and 24°C. These limits however, can probably be exceeded by another 2°C to 3°C on either side, without any serious discomfort being experienced. Values of effective temperature beyond these limits indicate condition too hot or too cold for thermal comfort.

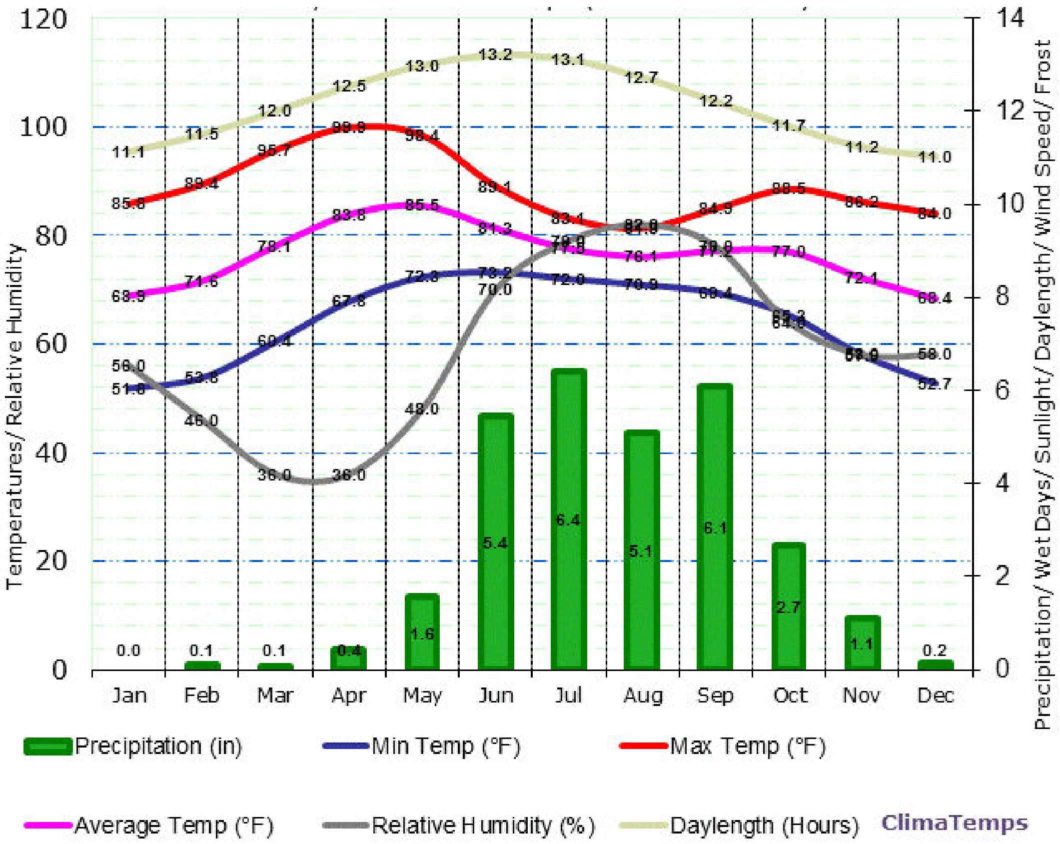


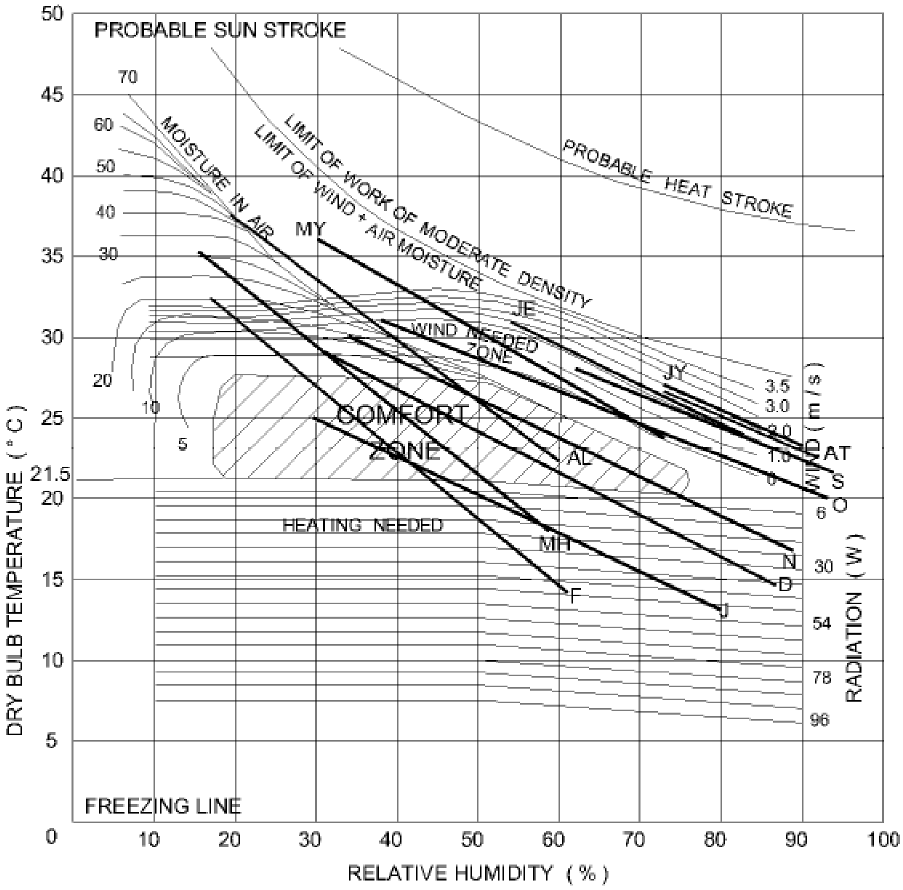
Figure 3: Humidity and Rainfall of Pune and its surroundings

Source: ***Handbook on Energy Conscious Buildings, by J.K. Nayak (2002)***

The winds are generally light to moderate with an increase in the force during the monsoon season. During November and December the winds are generally calm or blow mainly from the east or southeast. During remaining part of the year the winds blow mainly between southwest and northwest. The westerly's and south-westerly's are more common during the late summer and monsoon seasons.

A bioclimatic chart is a preliminary analysis tool used during the early planning stages of a building project. In the process known as bioclimatic architecture, an architect uses the bioclimatic chart to design buildings that include the most efficient passive cooling and heating strategies based on the climate and location of a building site, according to the Center for Renewable Energy Sources and Saving (CRESS).

The climatic conditions in Pune are mostly warm (Fig. 3). The day temperatures are relatively high during March, April and May; the corresponding night temperatures are within comfort level. April is the hottest month with the monthly average daily maximum temperature of 38 °C and a corresponding relative humidity of 19%. Evaporative cooling is indicated in these months during daytime. Ventilation can be adopted to achieve comfort at night, as the conditions are relatively cooler. In monsoon months (June to October), ventilation is required to provide comfort throughout the day. Winter months (January, February, November and December) are generally comfortable during the day and cool at night (Fig. 4).



J=January, F=February, MH=March, AL=April, My=May, JE=June, JY=July, AT=August, S=September, O=October, N=November, D=December

Figure 4: Bioclimatic chart of Pune

Source: *Nayak J.K. and Prajapati J.A. (2002)*

2.1.2 Geology of the Pune city and surroundings

The entire study area of Pune city and surrounding is underlain by Deccan Volcanic Basalts of Upper Cretaceous to Eocene age. The area comprises of various lava flows, which can be classified in the field into two types as simple and compound flows. The compound flows occur at lower elevations whereas the simple flows are confined to the elevation above 680 m. The compound flows although vesicular and amygdaloidal in nature, hard and compact in their middle sections. They are fractured and jointed, and show moderate degree of weathering at places. The middle section of the flow comprises of dark grey to black dense basalt. Since the top portion is of vesicular basalt it is more susceptible to weathering. The individual flows are separated from each other by red bole, which varies in thickness from a few centimeters to more than a meter. These are essentially ferruginous clayey horizons and are useful as marker horizons for flow separation. These red bole horizons are observed near the Chaturshringi hills at an elevation of 595 m in the Pune city, in the southern part of the area along Pune-Saswad road in the Diveghat and along Satara road in Katraj Ghat section. The total thickness of these flows, as observed in and around the city of Pune is of the order of 130 meters. In the riverbed of the Mula-Mutha River near Manjri (18 31': 74 00'), the 'aa' flows occur amidst the pahoehoe flows. In the eastern part of the area on the Pune-Ahmednagar Road and Pune Sholapur Road only pahoehoe flows are seen. The pahoehoe flows are traced up to 724 m amsl south of Pune city. At higher levels the aa flows are dominant. On the Sinhgad hills in the southwest part of the area (18 22': 73 45') from 749 m to 1310 meters above mean sea level (mamsl) 20 flows of 'aa' type varying in thickness from 7 to 42 m are seen. These lava flows at places are intruded by dykes, which are trending NNE-SSW, North-South and NNW-SSE. (G.S.I.,1996)

Basalts

The fresh basalts in the area are grey to dark grayish black in colour. The texture of basalts varies from fine-grained non-porphyritic to coarse grained porphyritic. The basaltic flows from the study area are divisible in to Indrayani, Karla, Diveghat and Purandargad formations as per G.S.I map 47 F and B. These formations are separated by Megacryst basaltic flows.

Dykes

The dykes act as barrier or pathways for the movement of groundwater flow depending on intensity of fracturing in the dyke rock. Whether the dykes act as water conduits or as barriers, their structure, location and orientation with respect to the groundwater flow are very important. (Dikshit K. R. 1986). The basalts are intruded by dykes and are found commonly in pahoehoe flows in the area. The dykes vary in thickness from one or two meters to as much as 10 meters and extend for long distances. They are found in the area south of Katraj ghat the dykes have NNE- SSW strike. The dykes display the joints parallel to the walls, at right angle to the walls besides horizontal ones, with chilled margins.

Alluvial Deposits

The Quaternary alluvial deposits are restricted as narrow belts along the banks of major river courses like Krishna, Godavari, Bhima and their tributaries. The tributaries of Bhima draining through the study area include Mula and Mutha (Dikshit K. R. 1986). The alluvium occurs in patches in paleo depressions, such as in the area south of Chatursbringi hills. These shallow alluvium deposits comprise of loose or semi-consolidated medium to coarse grained sands, gravels, fine silt with admixture of clays resting directly on the massive, weathered or amygdaloidal zones of the basaltic lava flows.

The stratigraphic sequence of the geological formations occurring in the area as given by G.S.I.(2001) is given in Table no. 2.

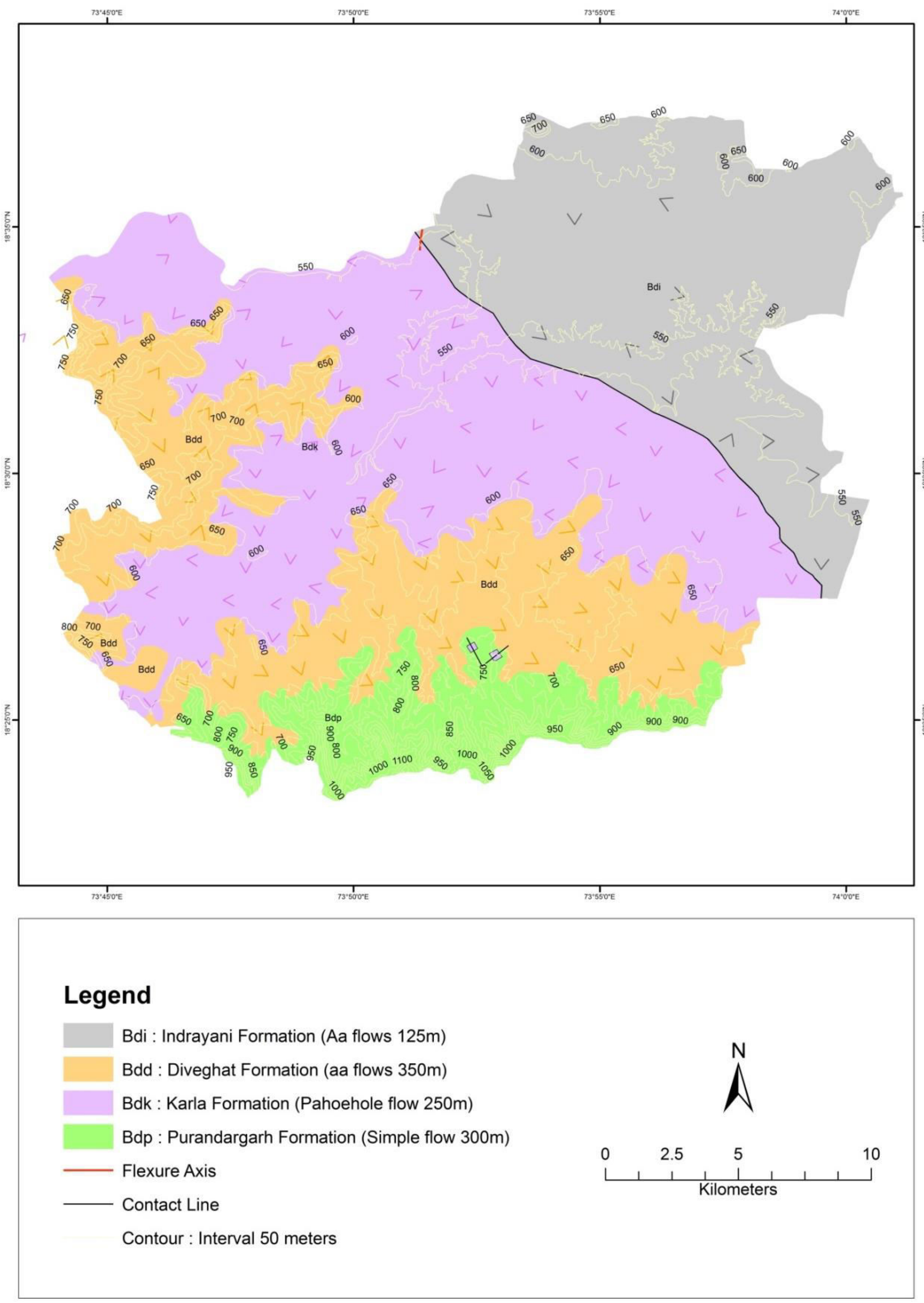


Figure 5: Geological Quadrangle Map

(Based on G.S.I, 1997)

Table 2: Stratigraphic succession of region

		Group	Sub-groups	Formation	Thickness in meters	Lithology
Upper Cretaceous to Eocene	DECCAN TRAP	NORTH SAHYADRI	Diveghat	Purandargad	300	Simple flows, aphyric to plagioclase microphyric
				Diveghat	350	Simple/ Aa flows, aphyric.
			Lonavala	Karla	250	Fine grained, aphyric, pahoehoe flows
				Indrayani	125	Aphyric to sparsely phyric flows

Source: G.S.I, 1997

2.1.2.1 Purandargad Formation

This is the youngest formation in the study area and is exposed in the southern part covering Sinhgad Fort and Katraj hills. It overlies the Diveghat Formation and occurs above 800 m amsl. The formation is characterized by the presence of aphyric to plagioclase microphyric basalt with the phenocrysts embedded in a fine-grained groundmass. Based on chemostratigraphy the formation is correlated with Ambenali Formation.

2.1.2.2 Diveghat Formation

This flow overlying the Karla Formation is exposed in the western and southwest covering parts of the study area. The outcrops of this formation are observed on the hills and along the hill slopes above 700 m from msl. It comprises mainly of simple flows of ‘aa’ type that are aphyric. The lava flows of this formation are characterized by presence of vesicular, plagioclase basalt with medium-grained groundmass.

2.1.2.3 Karla Formation

In the study area, this formation is present in the three directions of the Pune city towards central to North-West, South-East and South-western part covering adjoining areas and overlies the Indrayani formation. This formation essentially comprises of compound lava flows exhibiting the pahoehoe characters. Based on geochemical characters this formation has been classified as Bushe Formation. It is comprised of aphyric or sparsely plagioclase phyric compound flows. The flows are characterized by the presence coarse grained, altered, amygdaloidal basalt and near absence of plagioclase.

2.1.2.4 Indrayani Formation

The Formation Indrayani is exposed in the North – East part of study area. It has covers about 30% of the study area. The formation comprises of simple flows. In the field, formation is characterized by the presence of compact, massive, porphyritic basalt. The phenocrysts are embedded in fine-grained groundmass. This formation is classified as Khandala Formation of Lonavala sub group based on geochemical consideration.

2.1.3 Soil

Soil constitutes the physical origin of urban and agricultural practices. The capacity of the soil to retain and transmit moisture depends upon the structure and the texture of the soil. This in turn has effect on its infiltration potential, waste management capacity and geotechnical suitability. In the rural agricultural areas nutrient status of the soils accounts for its fertility. Therefore, soils have multiple implications in urban and rural planning.

The soils of the area are the product of weathering of basalts controlled by climate. In general they are clayey loam in texture and fairly high in calcium carbonate, high porosity but moderate to low permeability. In view of this, the soils from study area can be classified from low to moderate infiltration capacity. Based on physical characteristics the soils of the area have been classified into three major groups. They are as follows:

- Medium black soil.

- Red Sandy soils
- Shallow black soils

Different types of soils in the study area are shown in Fig 6**.** The Red Sandy soils are developed in western and central part of study area and covers major part of the study area. The shallow black soils have developed in the eastern part of the area, whereas medium black soils are developed along the minor drainage courses in the south and south-eastern parts of the area.

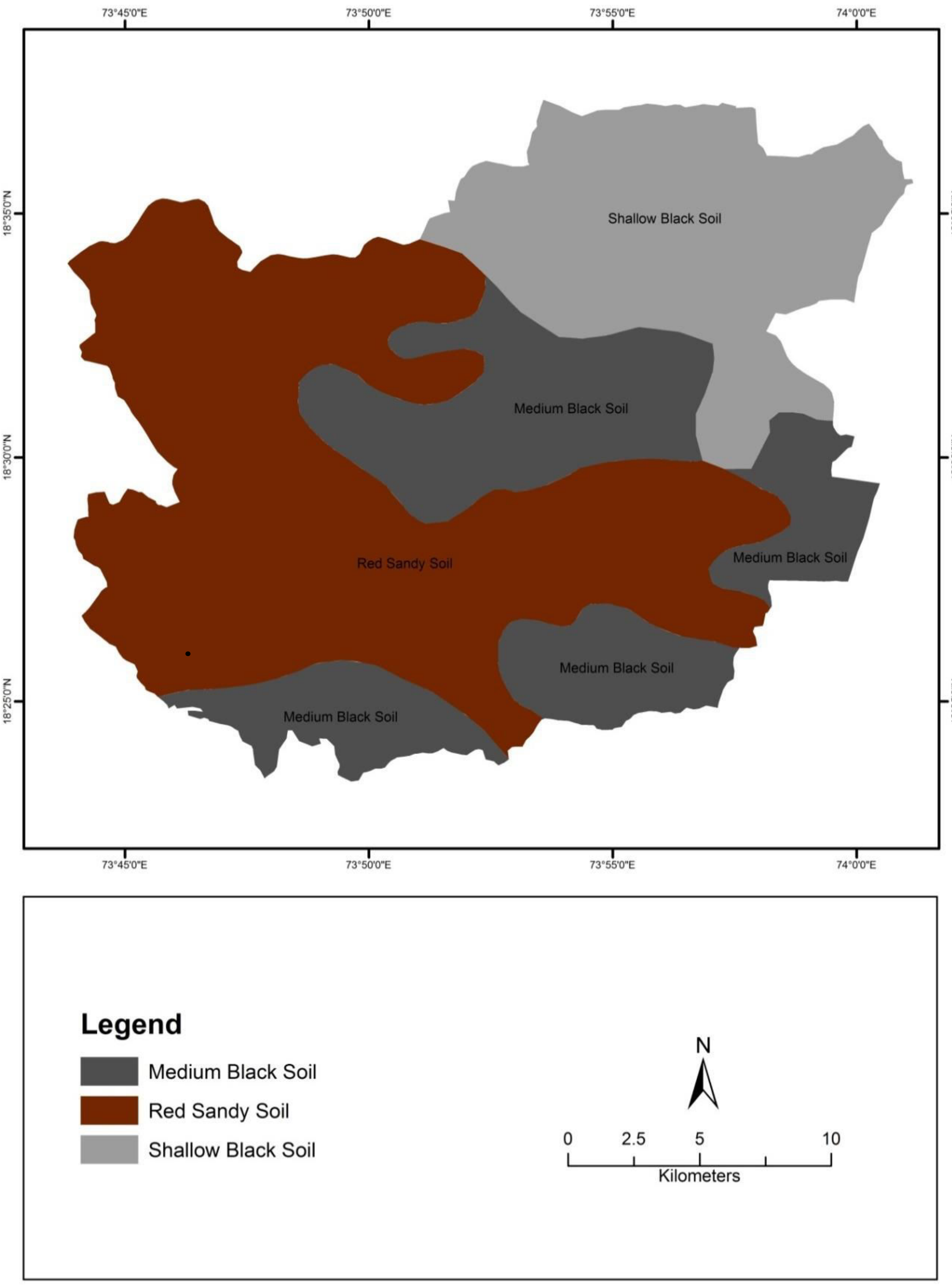


Figure 6: Soil Regions in Pune and Surroundings

(Based on (NATMO 1981): Western India Plate 200)

2.1.4 Drainage Type

Two major rivers pass through the study area. The Mutha River flows in the northeast and joins the easterly flowing Mula River near Sangam Bridge in Pune city. The Mutha arises in the Western Ghats and flows eastward until it merges with the Mula River in the city of Pune. Pune lies in the watershed of Mula-Mutha Rivers, with numerous small streams and rivulets. The city of Pune draws water from the Khadakwasla Dam, Panshet Dam, Warasgaon Dam and Temghar Dam as surface source of drinking water. The total live storage of all the 4 dams is around 30 tmc. the total water supplied to the city is around 14.5 tmc (1250 mld) and around 70 % of the total requirement of the city is fulfilled through closed conduit of 3000 mm dia, 30% of the total requirement of the city is fulfilled through open canal (PMC, Water supply dept.).

The drainage pattern formed in this area is dendritic type. All the major streams are perennial and they flow to full capacity during monsoon but in other season streams are converted into sewage lines due to pollution.

2.1.5 Earthquakes

Bombay, Latur, Beed, Parbhani, Nanded, Nagpur, Nashik, Satara, Pune, Sangli and Ratnagiri have been identified as districts of maximum earthquake risk in the state as per the Maharashtra Disaster Management Plan. As per top ten earthquake prone cities in India, Pune stand at 6th place where the probability of an Earthquake occurring is more. Pune city falls under seismic zone III (Moderate damage risk zone) and thus an earthquake of 7 Richter scale is possible causing destruction to buildings. (Dasgupta S., 2000) From 18th century to till date, around four times Pune has faced severe earthquake shocks.

Table 3: Earthquake shocks in Pune and surroundings

Sr.No.	Year	Location	Intensity
1	February 1812	18.50 N, 73.90 E	3
2	28 August 1993	Koyna area. 17.240 N, 73.730 E, D=005.0 kms, OT=04:26:24 UTC	4.8
3	17 May 2004	Katraj-Dive Ghats, Pune 18.365 N, 73.936 E, D=08.3 kms, OT=22:14:41 UTC	3.2
4	6 June 2007	Katraj-Khadakwasla region, Pune OT=07:48 UTC	2.6

Source: ***Earthquakes of Peninsular India--A seism tectonic study 2007***

As per above information (Table no. 3) A mild earthquake was felt in the Pune metropolitan area in Maharashtra, on 17 May 2004 at 03:44 AM local time. The earthquake had a magnitude of ML=3.2 and was centered in the Dive-Katraj range between the Dive and Katraj Ghats to the south of the Pune urban area. Second mild earthquake was felt in the Pune metropolitan, on 6 June 2007 at 13:18PM local time. The earthquake had a magnitude of M=2.6 and was felt in parts of the Pune metropolitan area.

2.1.6 Demography

Pune is one of the most renowned places in Maharashtra for various educational institutions, tourist places, presence of a number of industries and offices of virtually every array of economic activity which have made it a prosperous city. In 1987 the urban area of Pune was 138.36 sq.km. With an addition of 23 villages in 2001, the area has increased to 243.84 sq.km. and it is predicted to increase in future by addition of 34 more villages till 2016, covering a total area of 541.45 sq.km. The demographic scenario is one of the important parameters indicating development and growth of a city. Population is the term used to define the number of the inhabitants of particular species of particular place. In this chapter the demographic scenario of the Pune is explained.

2.1.6.1 Importance of demographic study

Demography is a very general science; it can analyse any kind of dynamic living population, i.e., one that changes over time or space. It covers the study of the size, structure and distribution of these populations, and spatial/temporal changes in them in response to time, birth, migration and death. It helps to calculate and derive governing policies for required infrastructure & basic services accordingly. It also helps in accessing impact of population growth on geographical features, resources consumption, waste generation & local ecosystem.

2.1.6.2 Demographic profile

As per 2001 census of India, population of Pune was 25,40,069 as compared to 72,32,555 of the Pune District (about 35% of the district). The population of Pune city as per Census 2011 is 33,04,888 which has grown by more than six times in the last 60 years. Migration has increased from 3.7 Lakhs in 2001 to 6.6 Lakhs in 2011.

Table 4: Population details for Pune (2011)

Sr. No	Census year	No. of House-holds	Total population (including institutional and houseless)			Population in the Age-group 0-6		
			Persons	Males	Females	Persons	Males	Females
1	2001	586439	2695911	1405965	1289946	320018	167606	152412
2	2011	781507	3304888	1700867	1604021	355703	186372	169331

Source: Census 2001 & 2011

A fall in 0-6 age group sex ratio in last decade which is a negative indicator for social development has been observed.

Table 5: Gender ratio in Pune city

Sr. No	Census Year	Gender Ratio No. of females per 1000 persons
1	2001	917
2	2011	943

Source: Census data 2001 and 2011

2.1.6.3 Population Density

The population density has increased from 10,405.28 persons per sq.km.in 2001 to 12,770.25 persons per sq.km. in 2011. Population density especially in the core areas is very high. Figure 7 shows distribution of density of all wards in Pune and its surrounding areas. It is observed that areas such as Lohiya Nagar (Ward No. 56), Doke Talim (Ward No. 77) & Ghorpade Udyan (Ward No. 84) are the most densely populated areas in Pune having 1713.63, 1252.24 & 1074.23 PPH respectively. Pune's rapid socio-economic development has had a significant impact on the urbanization in the city. Future growth is governed to a large extent by the development patterns in the city and Pune Metropolitan Region (PMR).

Table 6: Pune city area and density

Year	Area (Ha.)	Population	Population Density
1961	13894	6,06,777	43.67
1971	13979	8,56,105	61.24
1981	14766	12,03,351	81.49
1991	16611	15,66,651	94.31
2001	22768	25,40,069	111.56
2011	24631	33,04,888	134.18

Source: Census data

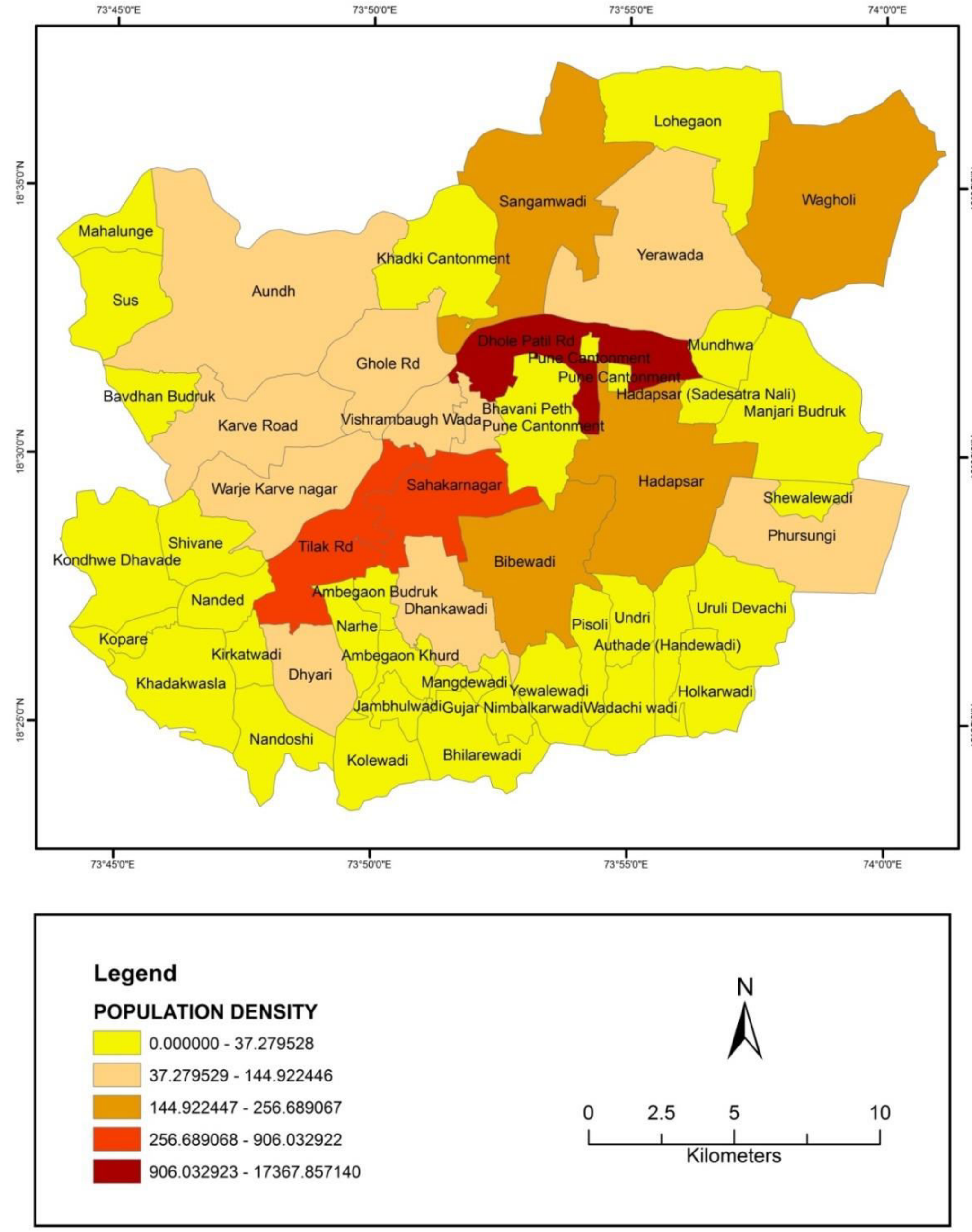


Figure 7: Population Density in Pune City and Surrounding area

(Based on Census 2011)

2.1.6.4 Trend of population growth

As per the latest data available from census 2011, the population of Pune is approximately 33, 04,888. The growth trend of Pune shows that there was a sudden decrease in the population in year 2001. From year 1981 a low growth is observed of an average 22.5 % per decade. The growth trend of Pune shows that growth rate is decreased from 1991 to 2011 but a sudden positive growth is observed from 1991 to 2001.

Table 7: Decadal growth rate of Pune from 1921 to 2011

Sr. No.	Year	Total Population of Pune	Growth Rate
1	1921	1,33,227	0.0
2	1931	1,62,001	21.6
3	1941	2,57,554	59.0
4	1951	4,88,419	89.6
5	1961	6,06,777	24.2
6	1971	8,56,105	41.1
7	1981	12,03,351	40.6
8	1991	15,66,651	30.2
9	2001	25,40,069	62.1
10	2011	33,04,888	30.1

***Source**: Census 2001 and 2011*

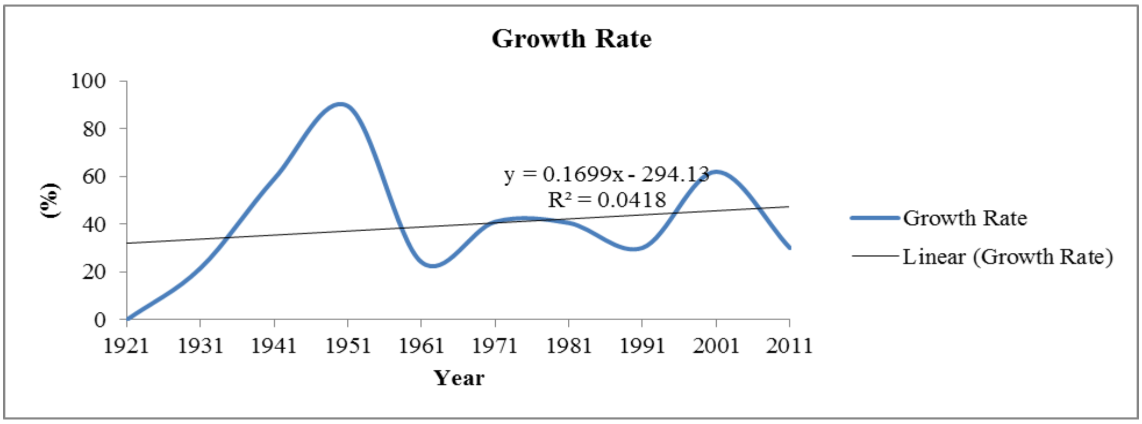


Figure 8: Decadal population growth trend in Pune

2.1.6.5 Population Projection

Government policymakers, geographers and planners around the world use population projections to measure future demand for food, water, energy, services and changes in land use and to forecast future demographic characteristics. Population projections help geographers to visualize the impact of population density on land use and physical setting of a city. Population projections also show major trends that may affect economic development and help policymakers craft policies that can be adapted for various projection scenarios.

As Pune showed low growth pattern from 1921 to 2011, among all the four methods, the population calculated by the compound average growth rate method is considered as forecasted population, which is around 51,14,251 people in the year 2045, considering the datum population 33,04,888 in the year 2011.

Methods adopted to calculate population projection

- **Calculating Percent (Straight-Line) Growth Rates**

The percent change from one period to another is calculated from the formula:

$$PR = \left(\frac{(V\ Present - V\ Past)}{V\ Past}\right) * 100$$

Where, PR = Percent Rate, V Present = Present or Future Value & V Past = Past or Present Value

- **Arithmetical Increase Method**

This method is based on the assumption that the population is increasing at a constant rate. The rate of change of population with time is constant. This method is suitable for large and old city with considerable development. Average increase in population is calculated from past decades' census &then added in current population to get population forecast.

$$Pn = P + nD$$

Where, Pn = future population after 'n' decades (D), P = present population.

- **Geometrical Increase Method**

This method is based on the assumption that the percentage increase in population from decade to decade remains constant. In this method, the average percentage growth of last few decades is determined. The population forecasting done on the basis of this percentage increase per decade will be the same.This method is suitable for a new industrial town at earlier stages of development for few decades. Geometric mean increase is used to find out the future increment in population.

$$Pn = P(1 + \frac{r}{100})\hat{}n$$

Where, Pn = Future population after the period of 'n' decades. P = Present population, r = average percentage increase in population.

- **Incremental Increase Method**

This method is an improvement over the above two methods. The average increase in the population is determined by arithmetical method and to this is added the average of the net incremental increase once for each future decade. This method is suitable for an average size town with increasing growth rate. The incremental increase is determined for each decade from the past population and the average value is added to the present population along with the average rate of increase.

$$\mathrm{Pn} = P + nd + \frac{n(n+1)}{2} * t$$

Where, P = Present population, d = Average increase per decade, t= Average incremental increase, n = number of decades.

- **Compound Annual Growth Rate**

The compound annual growth rate (CAGR) is a useful measure of growth over multiple time periods. It can be thought of as the growth rate that takes you from the initial population (value) to the ending population (value) if it is assumed that the population has been compounding over the time period. The formula to calculate future population given current population and a growth rate is

$$\mathrm{CAGR} = \left(\frac{Pp}{Ppa}\right)^{\left(\frac{1}{n} - n1\right) - 1} * 100$$

Where, Pp = Present Population, Ppa = Past Population, n = Present year, n1 = Past year.

Table 8: Forecasted population of Pune by various methods

Sr. No.	Population Forecasting Method	Population for 2015	Population for 2020	Population for 2030	Population for 2045
1	Arithmatical Increase	3,257,402	3,423,581	3,755,940	4,254,479
2	Geometrical Increase	3,609,995	4,324,356	6,205,133	10,665,855
3	Incremental Increase	3,275,583	3,479,098	3,934,828	4,740,171
4	Compound Average Growth Rate (1921-2011)	3,594,775	4,283,442	6,081,846	10,289,616
5	Compound Average Growth Rate (1991-2011)	3,587,031	4,262,710	6,019,868	10,102,732
	Average of all methods	**3,464,957**	**3,954,637**	**5,199,523**	**8,010,570**

Based on Census 1921 to 2011, Computed by Author

The Workforce Participation Rate of Pune is approximately 38% and the non-workers (Toddlers, students, housewives & retired people) contribute 62% indicating the dependency rate. The city has emerged as one of the major education/business centres in Maharashtra. It is one of the main investment hubs of the state and comes under the DMIC Project Influence area.

Over the years, the growth of the city has been like a ring and radial pattern, with reliance on road based transport. The high rate of in-migration and lack of formal access to appropriate housing has led to the genesis of unauthorized colonies in Pune. Unplanned settlements in the form of slums and squatters are spreading on the hillsides and along the water bodies, threatening the breathing lungs of the city. The slum population is gradually increasing and is now approximately 40% of the population.

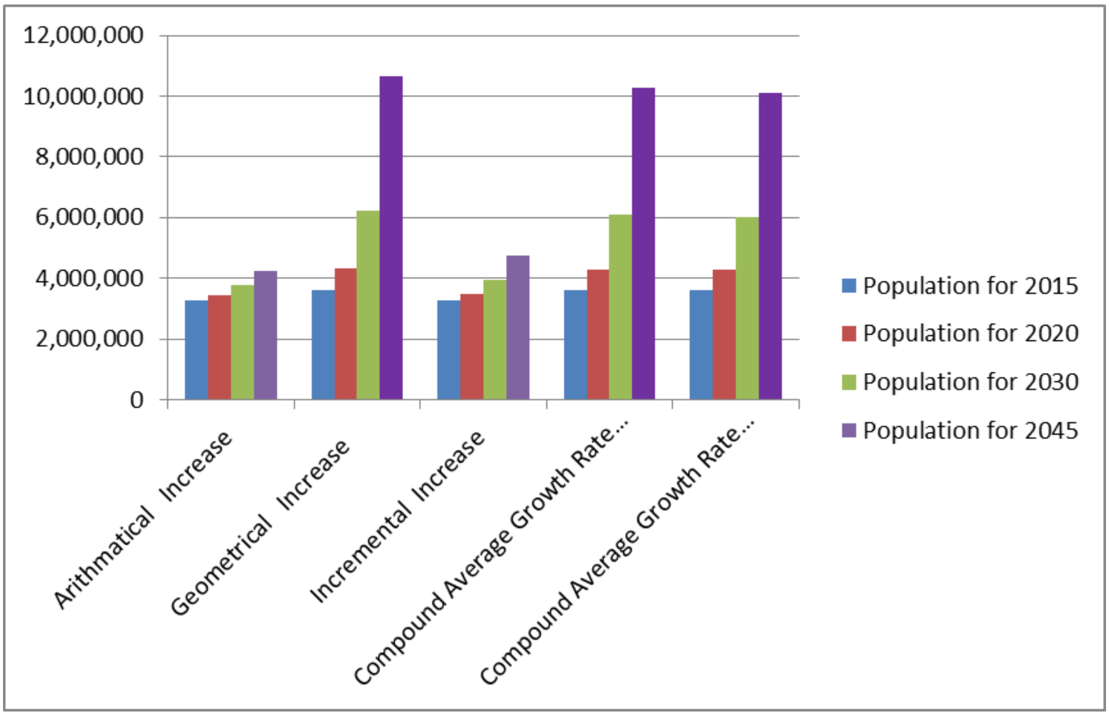


Figure 9: Forecasted population of Pune by various methods

2.1.7 Communication Network

The road network consists of National Highways, State Highways, Major District roads and other secondary roads. The rail network consists of both broad gauge (electrified and non-electrified) double track as well as single track lines. The city is well connected with the state capital and surrounding districts and states through road and rail network. Pune has both private and public inter-city transport available for the travellers.

As far as the National Highways are concerned Pune is connected with NH 4 for Mumbai-Kolhapur-Bangalore, NH 9 for Hyderabad and NH 50 for Nashik. Pune's urban growth specially increased due to these three National Highways. IT parks are located near to Mumbai-Pune National Highway. Pune has two intra-city highways. One of the National Highway-50 connected with Nashik-Pune-Mumbai, it's popularly known as golden triangle. Second is National Highway 4, Katraj-Dehu Road Bypass and old Pune-Mumbai Highway is important highway as per the development is concerned.

Pune has three main State Highways, SH 27 is Pune–Shirur–Ahmednagar, SH 64 is Pune–Saswad –Jejuri and SH 114 is Pune to Satara. In rainy season, various location on SH 114 tend to become disaster prone. Pune city historically known as the 'Cycle City of India', Pune has now become a city of two-wheelers. Pedestrian movements also suffer due to the lack of adequate facilities in city. City bus services have been inadequate and of poor quality, their performance further reduced as passengers have turned to intermediate and personal modes to meet their mobility needs (PMC 2006). Since the 1960's, while the city's population grew four times, vehicle population increased 87 times (PMC 2006). As per the Regional Transport Office, Pune showed that in 2011, the total number of registered vehicles were 2.3 million (nearly double from the 1.2 million in 2005) Although Pune is growing rapidly, the poor public transport system has not been able to keep up pace with Pune's growth rate.

From geographical point of view, Pune city is divided by Mula - Mutha Rivers. As this city is divided by railway lines of Central and South Central Railways, there are several Railway crossings (MSRDC). Pune Suburban Railway, also known as Pune Suburban Service or Pune Local Railway, is a suburban rail system connecting Pune to its suburbs and neighboring places in Pune. It is operated by Central Railway (CR). Pune's suburban railway operates on two routes, i.e. from Pune Junction to Lonavla and from Pune Junction to Talegaon.

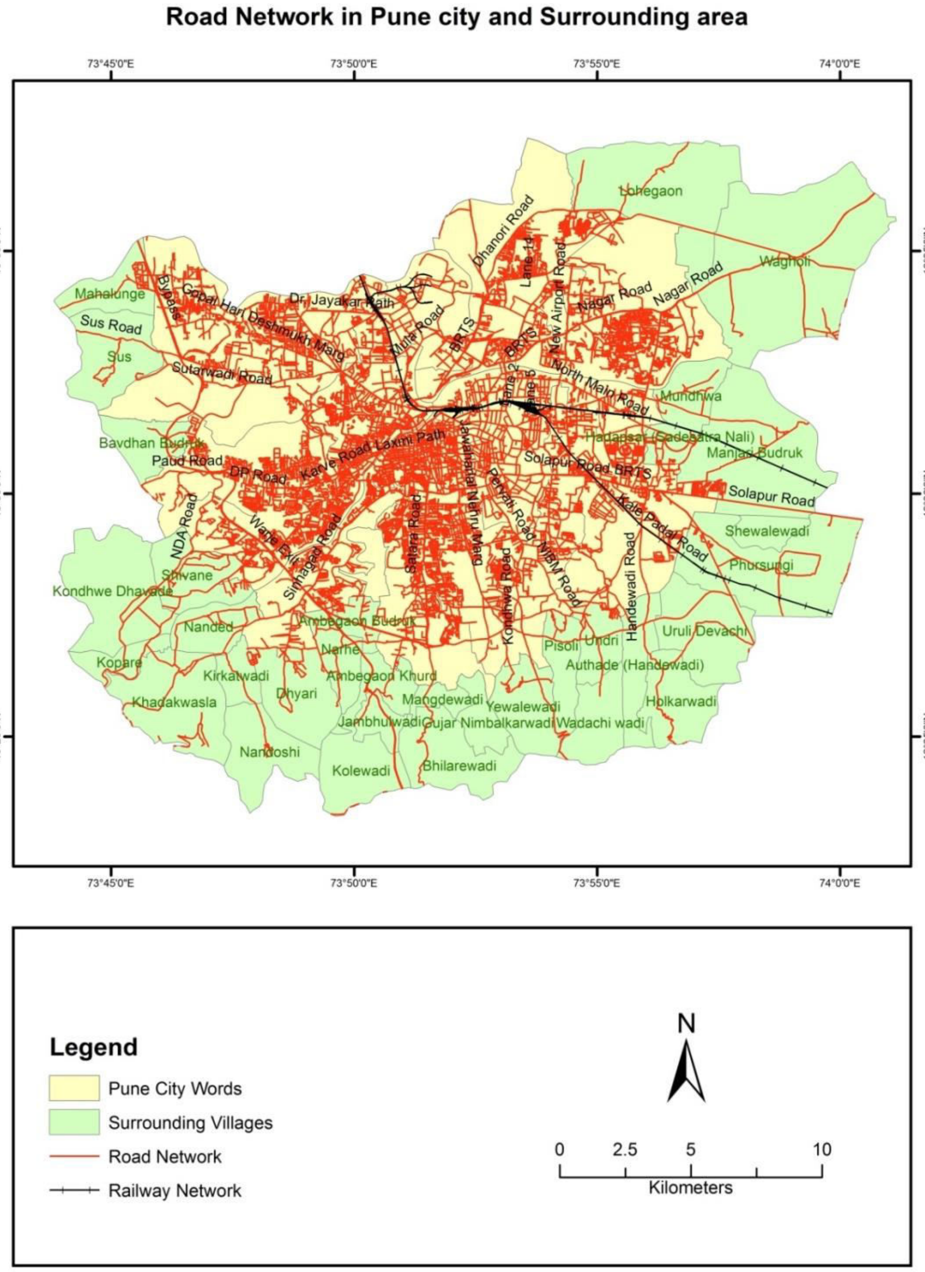


Figure 10: Road Network in City and Surrounding area

2.2 Methodology

2.2.1 Introduction

This part of the chapter discusses in detail the research methodology that has been adapted to study the Impact of urbanization on geomorphic environment of Pune and its Surroundings. As the area of study is a urban area, where extreme urbanization and rapid growth of urban sprawl is observed. While studying these drastic geomorphic changes over last 25 years, Toposheets, Landsat 5 satellite image and field survey were very much helpful to arrive at the findings that will explore the impact of urbanization on geomorphic environment. The key area of the research is the impact of urban sprawl on natural environment in today's rapid growth of Pune City and its surroundings. Remote sensing data is very useful for change detection. The literature reviews have assisted to focus on the type of research method that is most suitable for this area of study.

2.2.2 Research Problem

Changes in the environment are inevitable in the process of development. The expansion of Pune city over the years and rising construction activities has gradually altered the topography and geomorphic environment of the entire study area. Various negative effects in terms of physical environment such as loss of agricultural land, surface and groundwater depletion, changes in geomorphic features, flooding, and landslides etc. have increased due to changes in city's environment. It has been observed that many streams are overloaded due to ongoing construction activities and dumping of garbage causing their disappearance from Pune and its surrounding areas. Massive unplanned urbanization happened post 1962 floods in Pune city. Physical landforms such as hills and watershed streams have changed due to enormously growing housing projects around Pune city. However, not much research has been carried out to know the impact of urbanization on natural streams and changes in land-cover.

Therefore, such research study entitled: "***Impact of urbanization on Geomorphic Environment of Pune and Surroundings***" was initiated. Accordingly, study area is divided into small watersheds in the Mula-Mutha drainage basin. The morphometric analysis of these watersheds are carried out to study parameters of Linear, Arial and Relief aspects.

2.2.3 Research Objectives

- To study the geomorphic changes occurred due to rapid urbanization of the Pune city and the surrounding areas.
- To investigate city's spatio-temporal changes in land cover and Land Use.
- To find out impact of urbanization on drainage network of different watersheds in study area.
- To anaylze Linear, Aerial and Relief morphometric parameters in the study area.

2.2.4 Research Methodology

This research is mainly based on the secondary data collected from different sources like Toposheets, Satellite images, Records of the Central, State, Local govt. and other records available with concerned departments. To understand the current situation and to compare it with past, primary data was collected from the field accordingly.

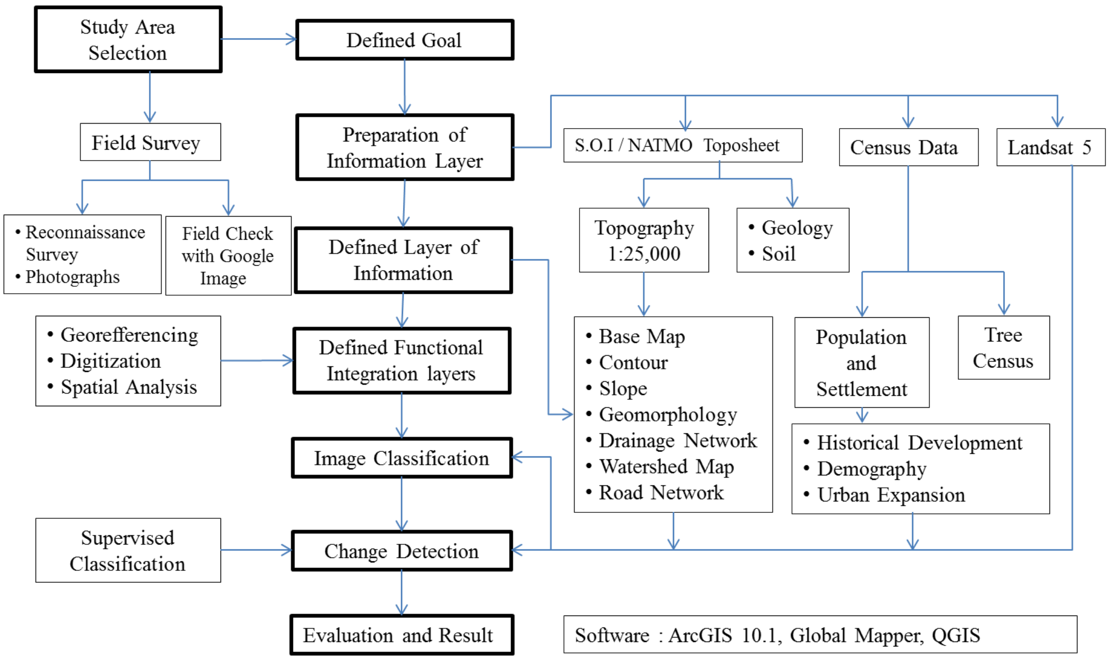


Figure 11: Methodological framework of the study area.

2.2.4.1 Literature Study:

- Books, Journals and Reports
- Related Case studies
- Environment impact assessment report of PMC

2.2.4.2 Primary Survey

- Observations
- Reconnaissance Survey
- Visual and Photographic survey

2.2.4.3 Secondary Data Collection

- **Wards and Villages Base Map:** Presently there are fifteen wards in Pune city. List of wards and related administrative data was acquired from Pune Municipal Corporation. According to the State government's notification, the 34 villages that would be included within the PMC limit were included in study area.

- **Physiographic**: The measurement of linear, aerial and relief aspects of the watershed and sub-basin is studied in the morphometric analysis. The Contour, DEM, Valley cross section and longitudinal profile, Slope, Drainage and Geomorphic maps were prepared on the basis of Survey of India Toposheet no. 47/F/14/2, 47/F/14/3, 47/F/14/5, 47/F/14/6, 47/F/15/SE, 47/F/15NW, 47/F/15/NE, 47/J/3/NW and 47/J/2/SW on the scale of 1:25000. The topographical map was geo-referenced in the GIS environment and the streams were digitized using the ArcGIS software (version 10.1). The stream orders, stream length and watershed area were calculated by using the same software.

Table 9: Data Layer and its sources

Sr. No	Data Layer / Maps	Source
1 2 3	Topographical Map Contour Geomorphic zone	Topographical map, Survey of India (1:25,000) 47F/14/2, 47F/14/3, 47F/14/5, 47F/14/6, 47F/15/SE, 47F/15NW,

	Map	47F/15/NE, 47J/3/NW and 47J/2/SW
4	Slope	
5	Drainage Map	
6	Watershed Map	
7	Geological Map	Pune district Geological Map collected from Geological Survey of India 47 F & B, Scale 1:250,000
8	Soil Map	Survey of India, National Atlas and Thematic Mapping Organization (NATMO): Western India Plate 200. Scale 1:2,000,000.
9	Climate Data	Climate data i.e. Rainfall, Temperature, Relative Humidity has been collected from India Methodological Dept.(IMD)
10	Demographical Data	Census of India, 2011.
11	LU and LC	Landsat 5 : USDS
12	Tree Census	Tree Census Data of Pune city by Garden Department, Pune Municipal Corporation (PMC)

- **Demography Data**

Information on the size, distribution and characteristics of a country's population is essential for describing and assessing its economic, social and demographic circumstances and for developing sound policies and programmes aimed at fostering the welfare of a country and its population (United Nations, 1998).

Demographic data used for population data collection and production of information in the country. Acquisition of demographic information used for calculating population estimates. Production of information which serves various elements in the fields of planning, environment analysis with respect to research. Population data used from Census of Indian Publications

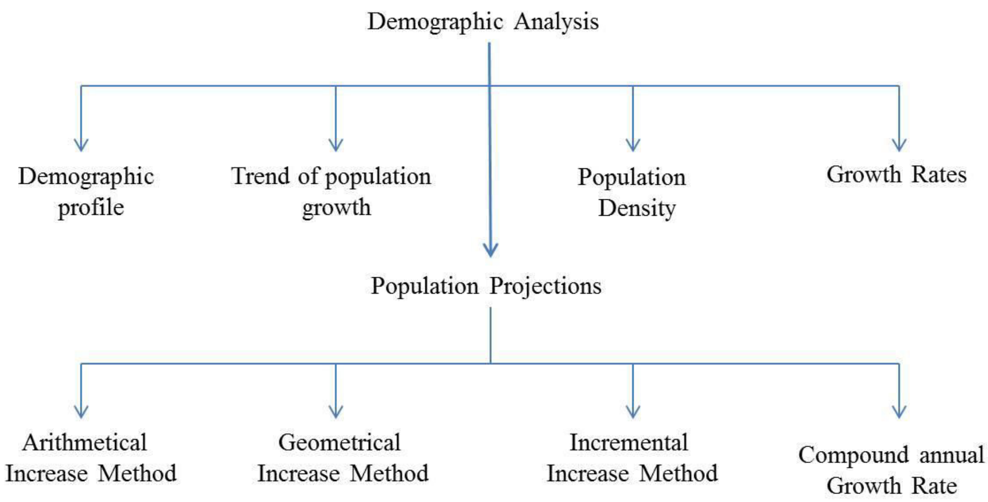


Figure 12: Demographic analysis

- **Tree Census**

Trees are major urban infrastructure assets in urban area. Analysis of urban tree demographics is generally limited to inventories of tree structure and composition on urban lands. This approach provided valuable information for resource management. However, it does not account for related tree cover information within an urban landscape, thus providing insufficient information on ecological patterns. The relationship between ward size, tree and human demographics and their respective densities were graphically analyzed. For this work, data was collected from various sources. Population census data and Household data were used from Census of India 2011. Tree census data surveyed by Garden department of Pune Municipal Corporation (PMC). Study mainly focuses on 144 electoral wards. This data was analyzed in ArcGIS 10.1 software for map creation and for statistical analysis PAST software were used in work.

- **Climate Data**

Climate data is important for understanding the climate system and its drivers. Understanding of climate impacts and vulnerability also identified by climate data. Human-environment systems analyzing with climate-related human behaviors. Climate data collected from India Methodological Dept. (IMD) for the study of climatic scenario in Pune city and surrounding areas.

- **Land cover assessment** – Landsat 5 satellite image used to classify land use and land cover of study area. Landsat 5 image have an excellent price-quality ratio, good spectral (seven bands from visible to the infrared specters) and spatial features (30 m resolution). Landsat 5 (02/02/1991), Landsat 5 (05/02/2010) and Landsat 8 (Feb. 2015) multispectral images have been applied.

  The land use and land cover patterns for 1991, 2000, 2010 and 2015 were mapped using Landsat-5 and Landsat 8 satellite imagery. A supervised classification was conducted using ERDAS IMAGINE software (Version 13) and the accuracy of the classification was verified by limited field check. Landsat 5 and Landsat 8 satellite images were used for identification of sub-watershed areas.

- **Morphometric analysis** - The morphometric analysis of the watershed was carried out. The topographical map (1:25,000) was geo-referenced and the streams were digitized using the ArcGIS software (version 10.1). Different morphometric parameters of the watershed were generated in the GIS environment.

CHAPTER – 3: GEOMORPHIC CHARACTERISTICS AND URBAN GROWTH

3.1. Physiography

The study of spatial and temporal characteristics and relationship of all the phenomena within the earth's structure (lithosphere, atmosphere, hydrosphere and biosphere) is the main concern of Physical Geography. Geomorphology is a significant branch of physical geography that is defined as the scientific study of surface involving interpretative description of landforms, their origin and development, nature and mechanism of geomorphological processes, and that the landforms thus developed may evolve with time through a sequence of forms dependent in part, on the relative time a particular process has been operating (Easterrook 1969). Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them (W. D. Thornbury 1954). The main task in physiographic studies is describing the landform characteristics either subjectively or objectively on the basis of detailed information available, classifying the landforms either genetically or quantitatively, and finally explaining the evolutionary processes of the concerned landforms.

Pune city and its surrounding areas ideally have perfect geomorphic scenario. Hill ranges, rivers, plateau, etc. are well spread over the area. The total area under study is 541.45 sq.km. Water divide of river Mula and Mutha basin is considered as boundary of the study area. The administrative boundary of Pune Municipal Corporation is also taken into consideration while demarcating study area. Towards southern side, the Pune Corporation area is surrounded by villages like Nandoshi, Kolewadi and Bhilarewadi. Towards northern side wards (Administrative divisions) such as Sangamwadi, Aundh and Khadki are located. Eastern side is surrounded by Kondhwe Dhawade and Bavdhan and to the west the extent of the area under study is till Phursungi and Manjari. To the south hilly terrain of Katraj region having maximum height of 1100 meter. The western boundary of the study area is also hilly terrain of Khadakwasla and Mulshi area. These areas mainly have vegetation and barren rocks covered on the slopes of the hills.

3.1.1 Physiography of the study area

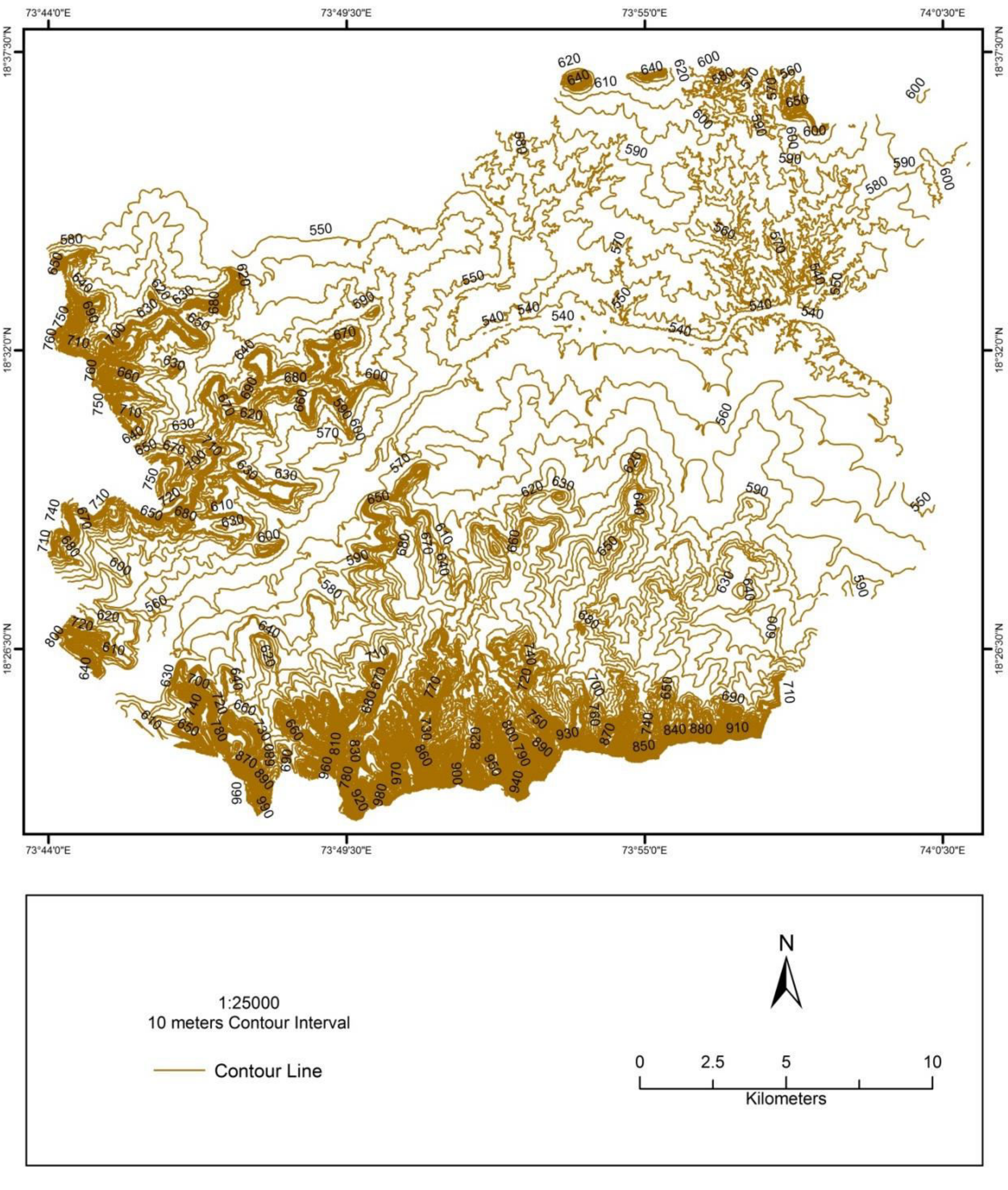


Figure 13: Contour map of study area (1970-80)

3.1.2 Digital Elevation Model (DEM)

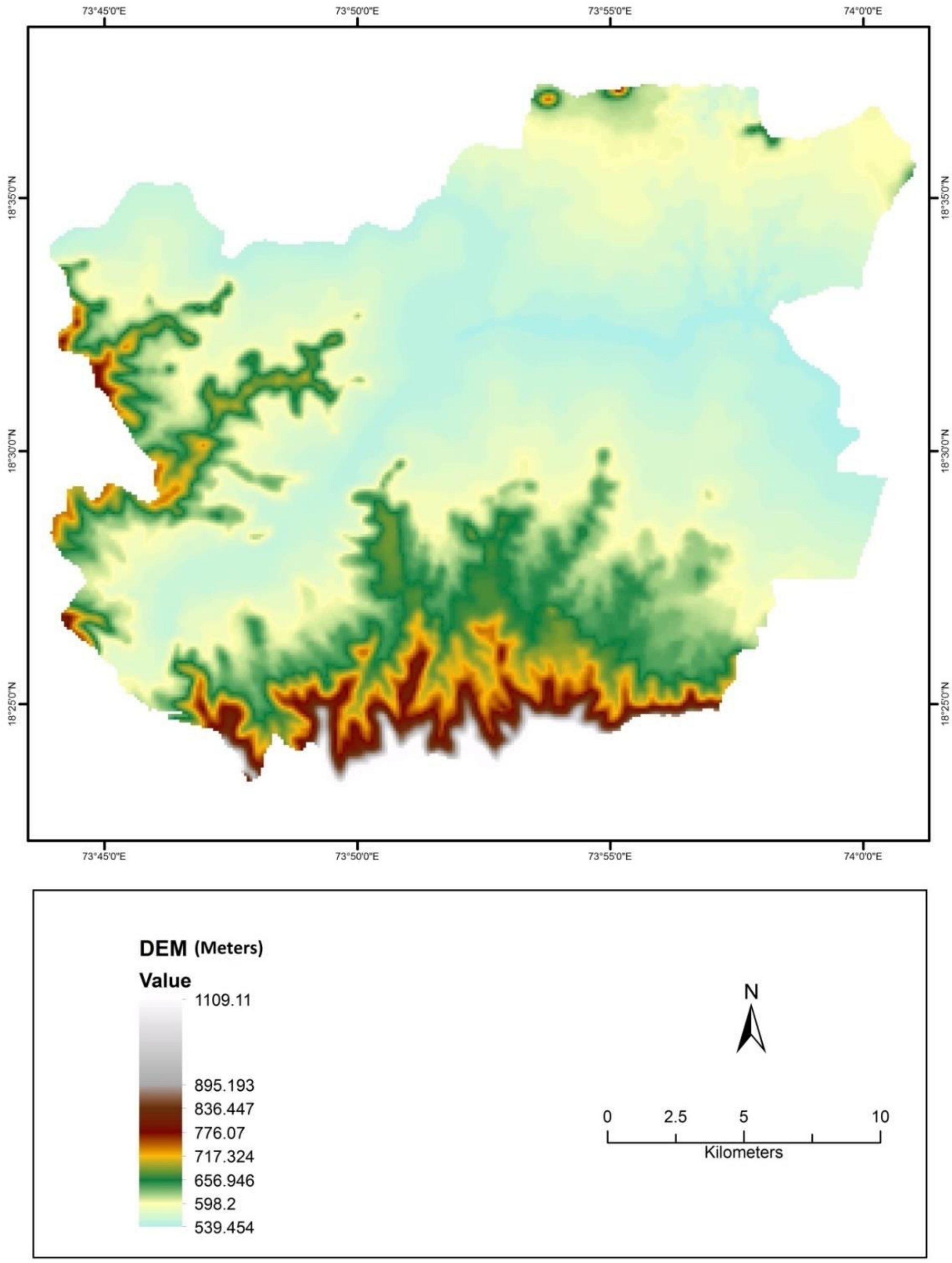


Figure 14: Digital Elevation Model

Above Fig.14 shows that, the average altitude of study area is 900 meters above the sea level and maximum height of this region is 1109 meters from Mean Sea Level. The hills of extreme south region of the study area are the tallest in the region. Southern parts of Kolewadi, Bhilarewadi and Yewalewadi have the height over 900 Meters. South-western part of Nandoshi also has level over 900 meters from MSL.

This mountain range is an offshoot range of the main Sahyadris, which is called as "Bhuleshwar Range".

The extreme western part of Bavdhan and Kopare, southern parts of Holkarwadi and Handewadi and central parts of Yewalewadi, Bhilarewadi and Kolewadi are having the altitude between 770-1100 meters. These areas cover highest elevation in the region shown in Brown Color. (Fig. 14 and Table 10)

The south-central part of the study area has an elevation between 710 to 770 meters. Western side of the study area also having same altitude. South Central parts like Mangadewadi, Yewalewadi, Wadachiwadi, Jambhulwadi, Nimbalkarwadi, Nandoshi and some parts of AmbegaonKhurd are regions in this area. Ward areas like Sus, Bavdhan, Kondhwe, Aundh, Karve Rd. and Warje also have some area under this altitude category shown in Yellow Color (Fig. 14 and Table 10)

The widely spreadfoothill ranges or small hilly region lies between 590-710 meters from MSL are indicated by green color. Some parts of the western region like Nandoshi, Khadakwasla, Sus and Kopare, northern region like Undri, Pisoli, Bibwewadi, Dhanakawadi, Ambegaon Budruk and Kh. Dhayari, Kirkatwadi and southern part of the study area occupied with same height. Handewadi, Holkarwadi, Wadachiwadi. Kondhwe, Warje, Shivane, Bavdhan, Aundh and Karve road and Eastern regions like Sahakar Nagar, Hadapsar and Uruli Devachi are located along same iso-lines.

The lowest altitude region lies between 590-540 meters. This region is demarcated by plane plateau region considering Mula and Mutha river basin. Hence, it is shown by light yellow and light blue color respectively. Both rivers flow through the central part of the study area. Most of the wards of the central city lie under this category. Tilak Road, Sahakar Nagar, Vishrambaug Wada, Pune Cantonment, Ghole Road, Dhole Patil Road, Bhavani Peth, Warje, Karve Nagar are under this category. Western wards and Villages like Karve Road, Mhalunge, Aundh, Khadakwasla and Nanded have same. The east and north side Hadapsar, Manjari, Shewalewadi, Mundhwa, Yerwada, Sangamwadi, Khadki Cant., Wagholi, Lohegaon are situated between the altitude range of 540-590 meters, which is highly favorable for settlements and its growth.

In this study area, the lowest point is 540 meters and the highest point is 1109.11 meters from MSL. The lowest altitude is in the central part and highest altitude in the extreme southern part of the study area with gradual decrease from southern part to northern part and west to east.

Table 10: DEM details

Sr.	Elevation Class (Mtr.)	Color	Wards (Administrative Division)	Villages
1	900-1109		-	Kolewadi, Yewalewadi, Bhilarewadi,
2	770-900		-	Holkarwadi, Yewalewadi, Bhilarewadi, Kolewadi, Handewadi, Kopare, Bavdhan
3	710-770		Kondhwe, Kopare, Aundh, Karve Rd	Handewadi, Holkarwadi, Wadachiwadi UruliDevachi, Bavdhan Mangadewadi, Yewalewadi Nandoshi, Sus
4	590-710		Bibwewadi, Dhanakawadi,Ambegaon Bk. and Kh. Dhayari, Kirkatwadi, Kondhwe, Warje, Shivane, Bavdhan, Aundh, Karve Rd, Sahakar Nagar, Hadapsar	Handewadi, Holkarwadi, Wadachiwadi, Undri, Pisoli UruliDevachi
5	539-590		Tilak Road,Sahakar Nagar,Vishrambaug Wada,Pune Cantonment, Ghole Road, Dhole Patil Road, BhavaniPeth, WarjeKarve Nagar, Karve Rd.,Mhalunge,Aundh, Mundhwa, Yerwada, Sangamwadi, Khadki Cant, wagholi, Lohegaon	Khadakwasla, Nanded, UruliDevachi

3.1.3 Slope of the Study Area

The slope map of the study area is prepared on the basis of contour map (1970-80) with GIS software (Fig. 15). A slope is a measure of change in elevation. It is a crucial parameter in well-known predictive models used for different geographic purposes. The slope can be expressed in two types: percentage and degree. Percent slope is calculated by the difference between the elevations of two points by the distance between them. Degree slope is expressed as a slope angle or degree of slope.

The southern and western part of the study area has a hilly terrain and the central and eastern part is plain area. So the hilly areas have more variation in the degrees of slope than flat areas.

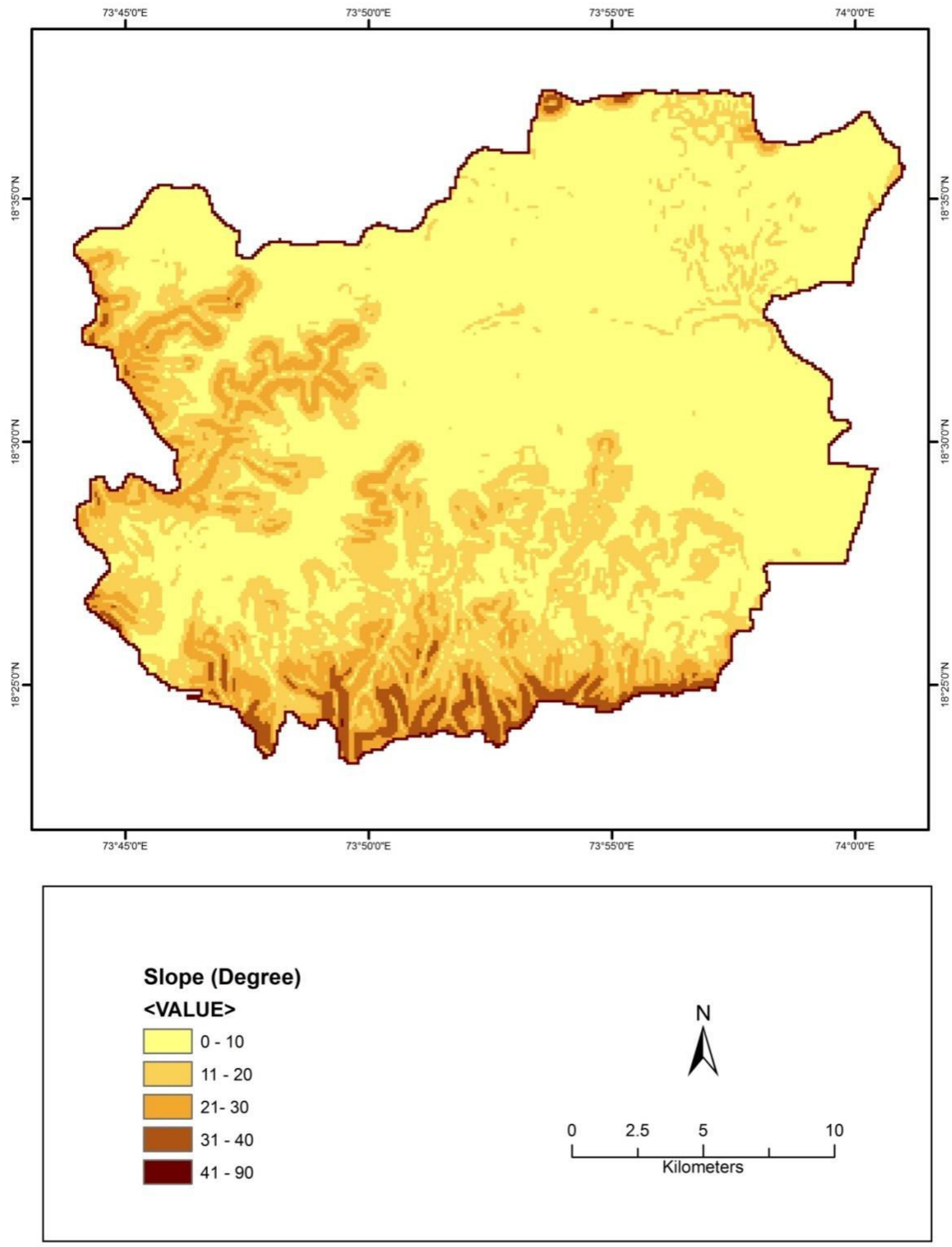


Figure 15: Slope map of study area

On the basis of slope, the study area is divided in to four slope categories i.e. Steep slope, moderate slope, gentle slope and plain slope. The southern part of the study area is characterized by hilly terrain and show variation in slope. Steep to gentle slopes can be identified in this area. (Fig. 15). The highest slope i.e. 20^0 is found in that part of the study area which is occupied by Bhilarewadi, Kolewadi and Yewalewadi. Some areas of Holkarwadi, Wadachiwadi, Bavdhan also show high slope. It resembles to a Hillocks and flat top hills.

The area between 700 m to 800 m elevation shows the slopes ranging from 15^0 to 20^0. These moderate slopes are seen in Holkarwadi, WadachiWadi, Bavdhan, Jambhulwadi, Nandoshi, Dhayari, Ambegaon Khurd and Sus. Small hills in the central city like Parvati, VetalTekdishows moderate slopes.

The next range of slope is 10^0-15^0. These slopes are seen near small hills are present. The foothill area of Sinhagad-Bhuleshwar Range. Dhayari, Khadakwasla, Narhe, Ambegaon, Dhankawadi, Bibwewadi, Pisoli, Undri, UruliDevachi, KondhweDhawade, Warje, Karve Nagar, Bavdhan, Sus and Aundhis having uniform slope ranging from 10^0-15^0.

The central parts of study area consist of river basin or valley of Mula and Mutha River. It is comparatively flat or plain region having slope 1^0-10^0. This region consist of wards viz. Vishrambag Wada, Sahakar Nagar, Tilak Road, Ghole Road, Nanded, Dhole Patil Road, Yerwada, Hadapsar, Pune Cantonment, Khadki Cantonment, Sangamwadi, Lohegaon, Phursungi, Mundhwa etc. with high population and settlement density.

3.1.4 Drainage Network

Water is essential for life. Nearly all organisms require constant access to water or at least water–rich environments for survival, humans are no exception. We need a constant supply of fresh water from precipitation over the lands. Some of the water store in soil, regolith, pores in bedrock and a small amount of water flows as fresh water in streams and rivers (Strahler 2011). The origin and subsequent evolution of any drainage system in a region are determined and controlled by two main factors viz. nature of initial surface and slope, geological structure (Savindra Singh 1998). Dendritic or tree shaped drainage pattern is observed in Pune and surrounding area. The network of tributaries of various orders and magnitudes of the trunk or master stream resembles the branches and roots and rootlets of a tree.

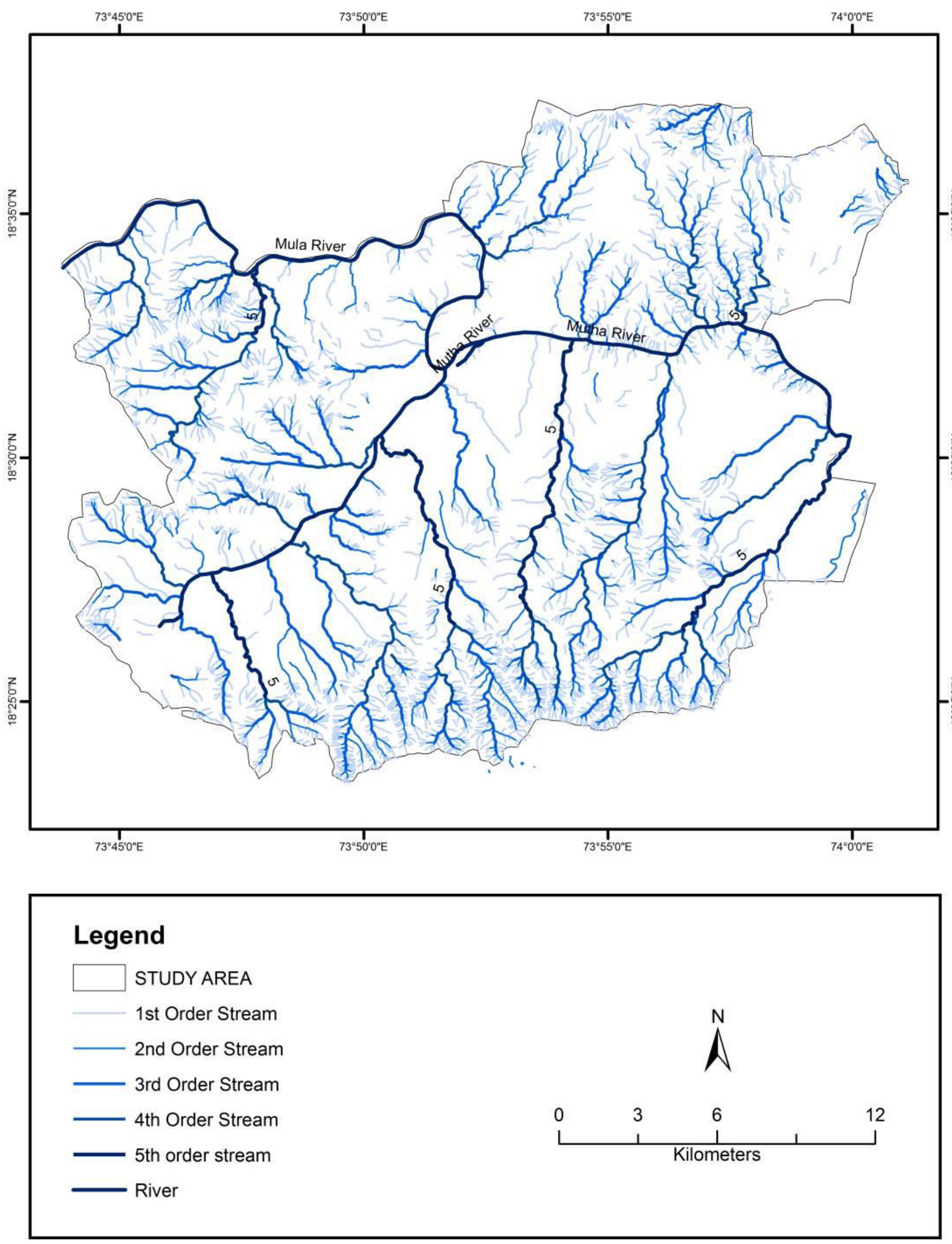


Figure 16: Stream Network of study area

At city level, a common problem is observed that the management of a single, natural unit, such as a drainage basin, is divided between several administrative divisions, resulting duplication or dispersion of efforts, and perhaps conflict.

Two major drainage basins are developed in this area: the Mula and Mutha river basins. A detailed morphometric analysis of Mula and Mutha river basins were carried out by dividing them in major and minor sub basins. The toposheets no. 47F/14/2, 47F/14/3, 47F/14/5, 47F/14/6, 47F/15/SE, 47F/15NW, 47F/15/NE, 47J/3/NW and 47J/2/SW year 1990 to 1980 were used. The Mula and Mutha basins are having 2246 first order, 483 second order, 128 third order, 28 fourth order and 6 fifth order streams. These two major basins are divided in to sub basins like Nandoshi, Ramnadi, AmbilOdha, BhairobaNala, WadkiNala and Wagholi (Fig. 16). The detailed analysis of drainage basin and urban change is discussed in chapter four.

The development of Pune city can be observed within these sub basin areas. As per the topographical characteristics of study area, concentration of first order streams in southern area is more than other area. Around four major watersheds are occupied in southern zone. Nandoshi, AmbilOdha, BhairobaNala and WadkiNala are major watersheds with fifth order streams.

The North-West area is covered with hilly terrain having major hill-locks presently situated in ths area. Vetal hill range from Kothrud is the water divide for Mula and Mutha rivers. Streams flowing from Aundh, Baner, Sus and Mahalunge area are the part of Mula river system. Ram Nadi plays important role in this area, which covers major part of the area.

The northern area, especially Dhayari, Viashrantwadi, Lohgaon and Wagholi follow dendritic pattern of stream network. Concentrations of first order streams are highest in this area because of change in geological flow. This area is located in Dighi hill range having uneven topography i.e. flat and small hill locks. Most of the streams in this region are non-perennial.

The central part of the study area is relatively flat and can be identify as river valley of Mutha and Mula rivers. This area is occupied by 4^{th} and 5^{th} order streams.

3.1.5 Geomorphic Zones of Pune city and its surrounding Areas

On the basis of geological setup of this study and geomorphology of the region, the study area shows two major geomorphic units:

1. Upper Diagonal region (River plainArea)
2. Lower Diagonal region (Upland Area)

These geomorphic units, identified SOI Toposheets No. 47/F/10/SE, 47/F/11/NE, 47/F/14/2, 47/F/14/3, 47/F/14/5, 47/F/14/6, 47 F/15/NE, 47 F/15/SW, 47/J/03/NE, 47/J/03/NW (scale 1:25,000) were digitized and digital elevation model (DEM) is prepared (Fig. 14)

The Upper Diagonal region shows river plane province of Mula-Mutha River. The Dighi hills act as a water divide between Mutha and Indrayani River, which lies to North of Dighi Hills. Confluence of Mula and Mutha River is in the central part of the study area, which flow from West and South-West direction respectively.

The Lower Diagonal region is the upland area. The western part of study area is covered with eastern foot hills of Sahyadri, while southern zone shows the offshoot range of Sahyadri which emerges from Sinhgad fort to the west and ends at Bhuleshwar hill to the east. This region shows the concave valley of Mutha river. Valley slope gradually increases towards the upland from Mutha river banks.
Four Geomorphic zones are classified in accordance to the morphology of the study area.

1. Scarp zone
2. Spur zone
3. Pediment zone
4. River zone

Scarp Zone: These geomorphic zones ultimately follow the pure geological flows present in the study area. Scarp zone covers area towards extreme south of Pune city, occupieng part of Purandar Formation flow. Scarp zones are present at southern part of the study area, which shows Sinhgad Bhuleshwar range. Ram hill, ARAI hill, Law college hill, Baner hills etc. are the western Escarpment areas. Escarpment zone covers 73.22 sq. km. of study area. Highest elevation of 1150 meters is observed in Bhilarewadi village area.

Spur Zone: Spur Zone covers 135.87 sq. km. area. Spurs runs along the northern side of the study area. The central area represents more elongated spurs than the eastern and western parts. Taljai and Parvati hills are located on central elongated spurs. Now-a-days these areas have encroached spaces around these hills. ARAI, Malwadi, Ferguson, Vetal, Ram, Baner, Chatushrungi, Law College Hills indicate the western side spurs with low elevation as far as elevation of southern spurs are concern.

The undulating topography exists in this zone. This spur zone denotes the mid- transportation zone, which follows the erosional zone of escarpment area. The difference between average maximum elevation and average minimum elevation among spur zone is 70 meters.

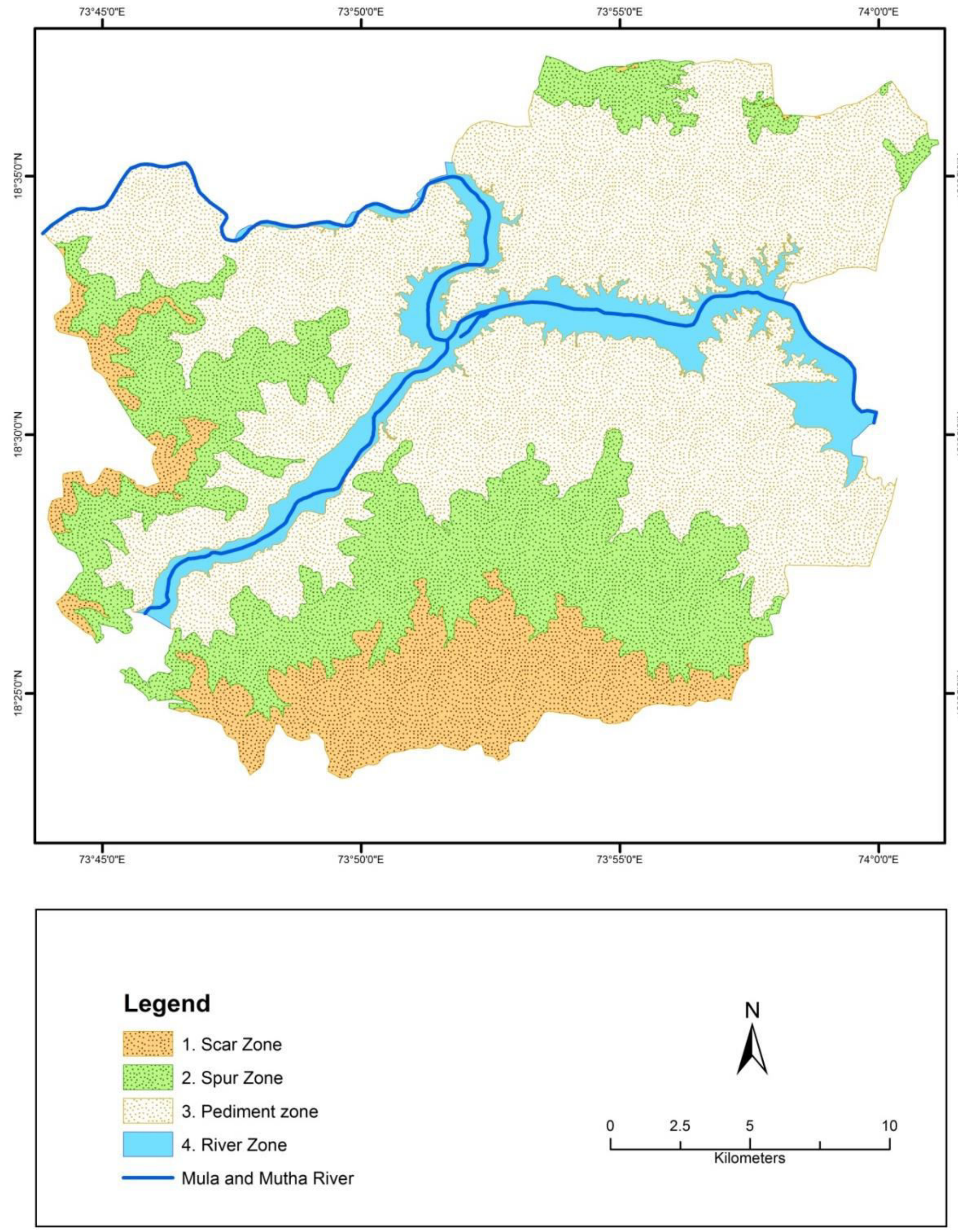


Figure 17: Geomorphic zones of study area

Pediment zone: The spur zone is followed by the pediment zone which covers the largest portion in the study area, which is 279.25 sq. km. This pediment zone is nothing but a river depositional zone and also represents the valley. This is dominated by Mutha River drainage basin area to the eastern side. Pediment zone of Mula River lies to its right bank and the North Western side. The pediment area widens towards east as both the rivers reach their pre-mature stage. Their early mature stage denotes minimum pediment area. The dense population is settled on this pediment zone of Mutha river.

River Bank: An area which comes under a maximum discharge of river to its normal position afterwards is considered as a river bank. This is the flood plain region of the river. In the study area river zone covers 46.76sq. km. As both rivers are flowing in their matured stage, this region is mainly dominated by river's depositional activity. The rivers deposits alluvial materials near confluence, increasing their channel widths of both river channels. Near the confluence, a depositional island 'Naik bait' is formed due to heavy sediment depositions over the period. This natural island is also occupied by human settlement.

3.2. Vegetation Cover

3.2.1. Introduction

Urban areas across the world are experiencing rapid population growth, increased impervious surfaces and an overall decrease in population demography. Trees in cities contribute significantly to human health and environmental quality. Urbanization transforms the range and type of vegetation on a landscape through losses from deforestation and fragmentation and advantages from reforestation and afforestation. With deforestation and fragmentation there are reductions of native flora, fauna & increases in non-native species, increase in stream sedimentation and water pollution (Douglas, 1990) and changes in air temperature, evapotranspiration (Jager and Barry 1990). Despite these impacts, ecologists know relatively little about ecological processes of urban systems (Stearns and Montag 1974, McDonnell).

Pune ranks in one of the top five greenest cities in India. Currently it has more than 23 lakh trees (PMC Tree Census 2011). The major-forested areas of the city include Katraj and Sinhagad valleys. The other areas under tree cover include institutions like Pune University, National Defense Academy, Pune Cantonment and gardens like the Empress Garden. Some of the hills in the city, such as the Vetal hill range and the Parvati hill have undergone extensive afforestation by the Forest Department. According to the Environmental Status Report 2013 of the Pune Municipal Corporation, the city has more trees today than a few years ago.

Specifically the role of trees in urban area is reducing wind speed, providing shade and decreasing the heat island effect. Due to climate change, it is alarming situation that open spaces are disappearing because of urban renewal and development that puts at risk long term sustainability. The lack of tree covers in urban area automatically raises questions about the economic viability of such developments, as well as their long term environmental sustainability. New approach in studying urban tree demography in Pune city is considered. Ward area density, ward wise population identification and evaluation of trees in concerned areas with ward-patch area analysis is done.

Available Demographic population data and Tree census data of Pune city (Part of whole study area) were studied to provide a direction for future studies of urban vegetation.

For the present study, the tree census data was collected by using modern GIS tools to create a more effective, portable and comfortable database of tree cover was considered. The tree census data is important for scientific, technical, and educational analysis. Tree census information can be used for planning, management and mitigation. From the urban planning perspective, tree census is used to analyse changes and their impact or prediction for further study. Composition, condition and distribution of trees is used for management purpose in urban area. Number, diversity and density of trees help in developing appropriate mitigation measures.

3.2.2. Tree Census Map

It was observed that many ward areas such as Junabazar, City Post, Harkanagar, Doketalim, Ghorpade Udyan etc. are less in area but have excellent tree population. On the contrary, ward areas such as Vidyanagar Lohegaon, Baner, Balewadi, Popular nagar Warje, Kaleborate Nagar, Vadgaon Budruk are large in areas but have very few trees providing a broad scenario of Pune city.

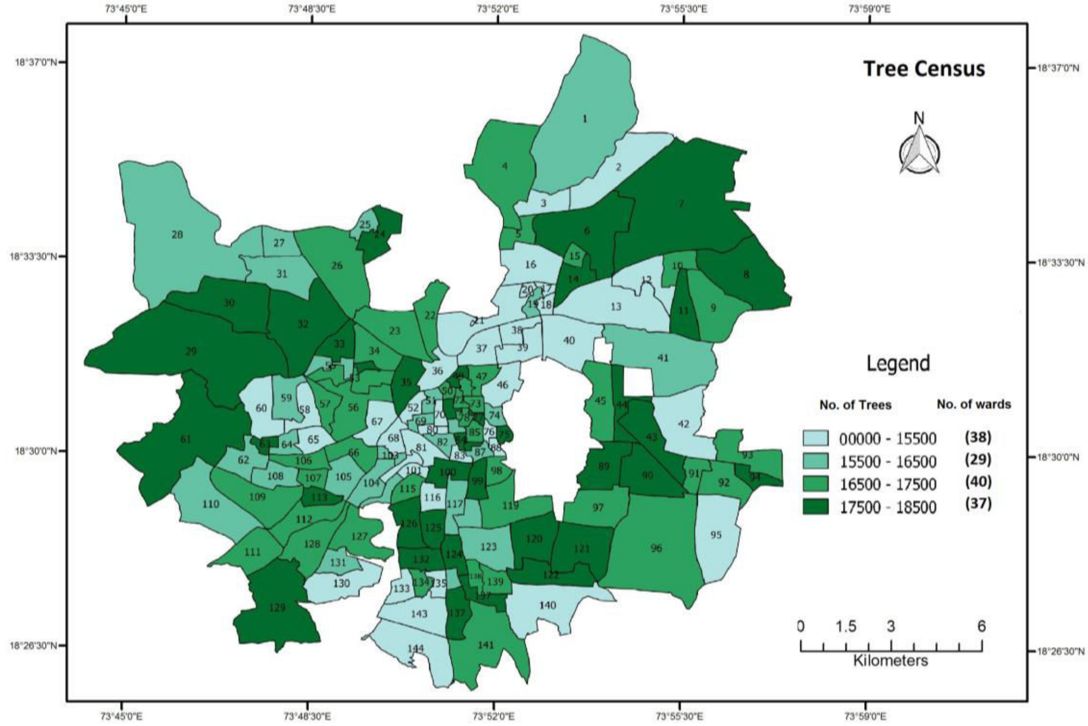


Figure 18 : Tree Census Map of Pune city

3.2.3. Tree Density

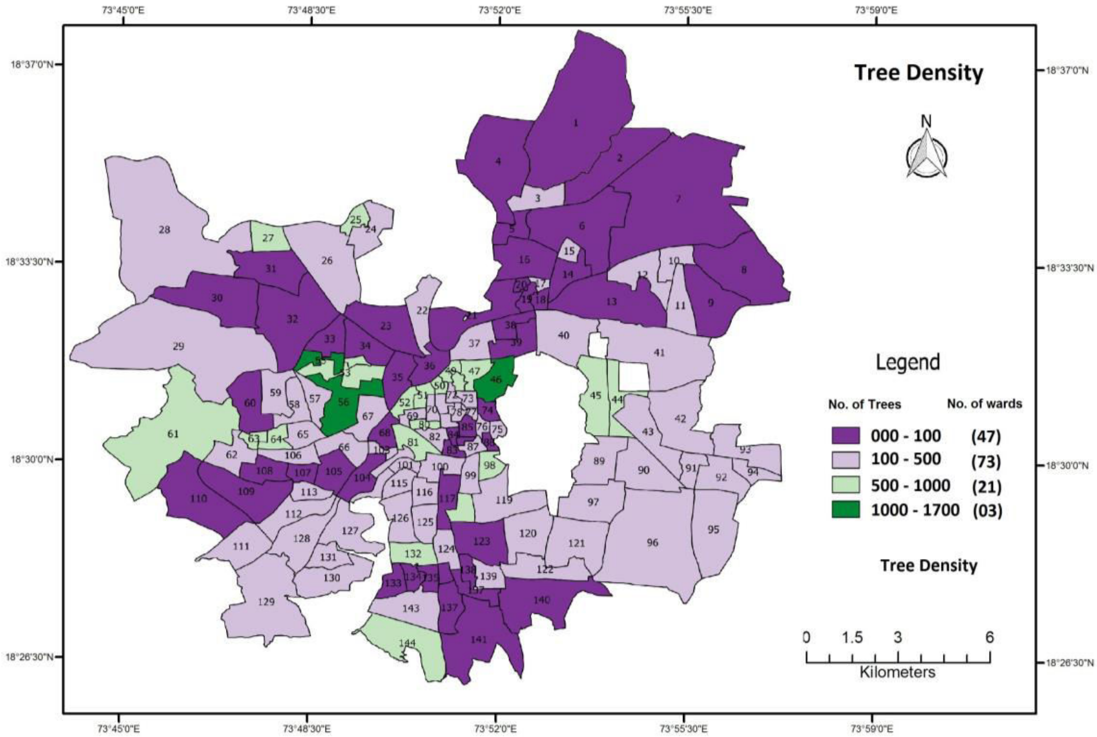


Figure 19 : Tree Density

As seen in Fig. 19, tree density across Pune city is unevenly distributed. Areas of all 144 wards (Hectare) and tree population were superimposed on the map of Pune City and the tree density was assessed by ranking on a scale of 1 to 1700. It was observed that many wards have large areas but number of trees/ha are very low in areas like Dhanori, Vidyanagar Lohogaon, Lohogaon Airport, Kharadi Gaon, Rajiv Gandhi Prani Sangrahalaya etc. There are a few wards that have very less area, but good tree density like Gokhalenagar, Dr. Babasahab Ambedkar Udyan and Law College.

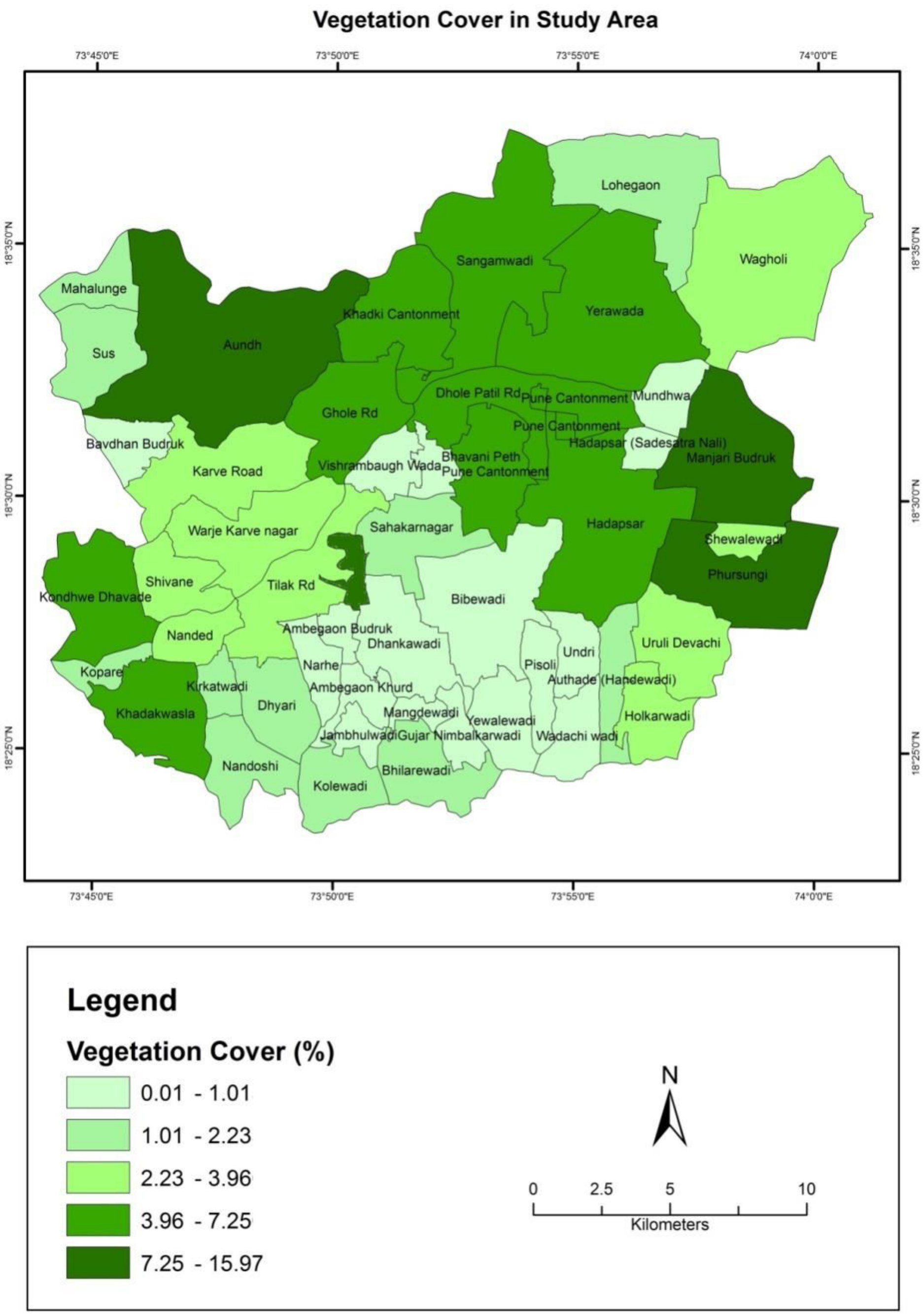


Figure 20: Vegetation Cover in Study area

Within Pune, the most crowded areas like City Post, Shukrawar Peth including Mahatma Phule Mandai , Ganesh Peth, Kasaba Peth, Vishrambaug wada and Shaniwarwada show balanced tree population. But areas such as Kondhwa, Dhankawadi, Yerawada, Katraj, Vithalwadi and Hadapasar have alarmingly less number of trees compared to other areas in the city.

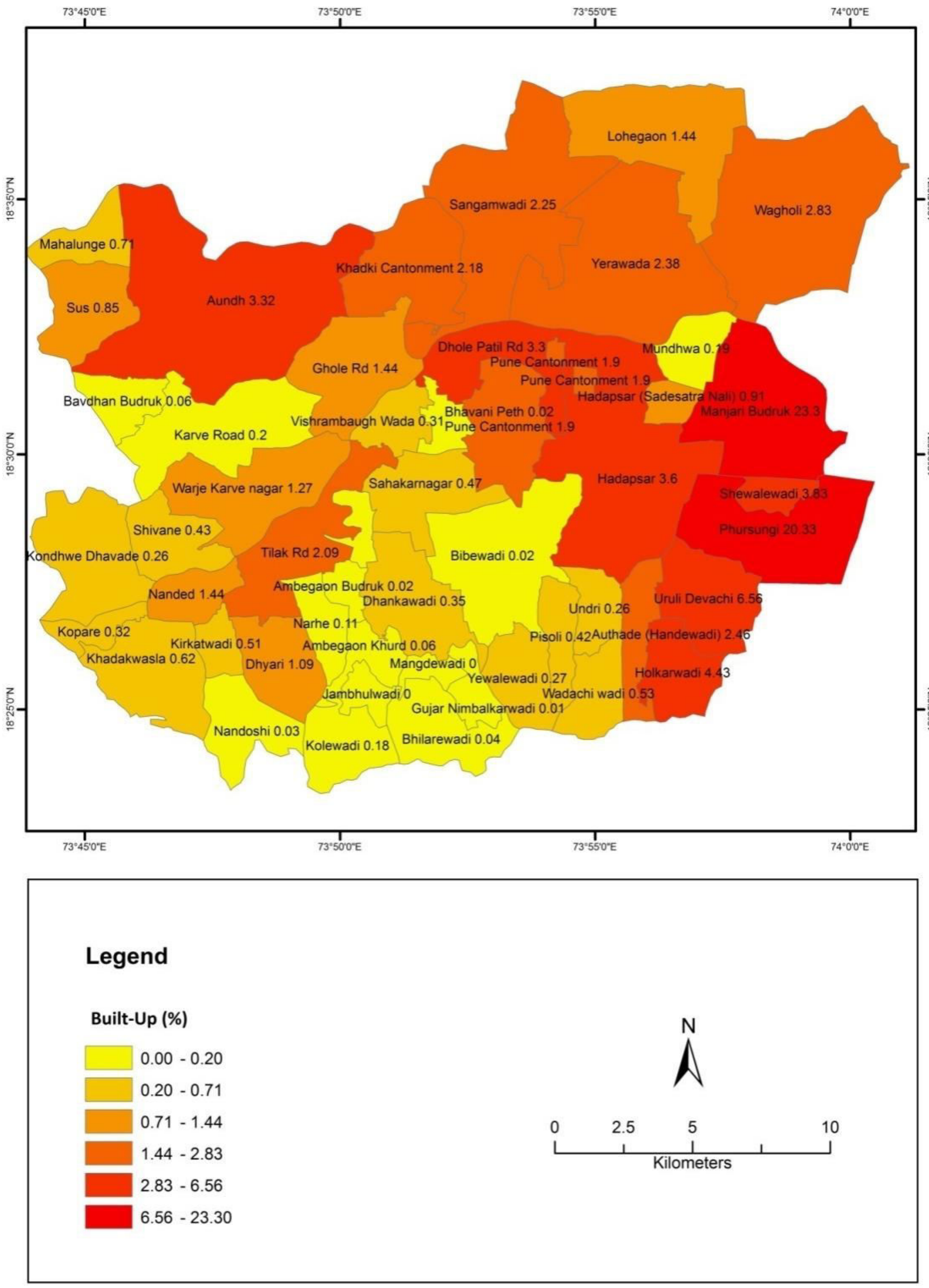


Figure 21: Built-Up in study area

3.3. Urban Growth

Pune city Administrative wards

Presently there are 15 wards in Pune city which consist of Aundh, Kothrud, Ghole Road, WarjeKarvenagar, Dhole Patil Road, Hadpsar, Nagar Road, Sangamwadi, BhavaniPeth, KasbaVishrambaug, Sahakarnagar, Tilak Road, Bibvewadi, Dhankawadi, Pune city.

Surrounding Villages

According to the State government's notification, the 34 villages that will be included within the PMC limit are mentioned below:

Table 11: Villages included in PMC limit as per 2014

Sr. No.	Name of the Revenue Village	Area of the villages to be included in area of the city of Pune
1.	Mahalunge,	Entire area
2.	Sus,	Entire area
3.	BavdhanBudruk,	Entire area
4.	Kirkatwadi,	Entire area
5.	Pisoli,	Entire area
6.	Lohegaon (Remaining),	Entire area with already included area in Municipal Corporation
7.	KondhweDhavade,	Entire area
8.	Kopare,	Entire area
9.	Nanded,	Entire area
10.	Khadakwasla,	Entire area
11.	Shivane (Entire Uttamnagar),	Entire area
12.	Hadapsar (Entire Sadesatranali),	Entire area
13.	Mundhwa (Remaining Keshavnagar),	Entire area with already included area in Municipal Corporation
14.	ManjariBudruk	Entire area of revenue village
15.	Narhe,	Entire area of revenue village
16.	Shivane,	Entire area with already included area in Municipal Corporation
17.	AmbegaonKhurd,	Entire area with already included area in Municipal Corporation
18.	Undri,	Entire area with already included area in Municipal Corporation
19.	Dhyri,	Entire area with already included area in Municipal Corporation
20.	AmbegaonBudruk,	Entire area with already included area in Municipal Corporation
21.	UruliDevachi,	Entire area
22.	Mantarwadi,	Entire area
23.	Holkarwadi,	Entire area
24.	Authade (Handewadi),	Entire area
25.	WadachiWadi,	Entire area
26.	Shewalewadi,	Entire area
27.	Fursungi	Entire area
28.	Nandoshi,	Entire area
29.	Mangdewadi,	Entire area
30.	Bhilarewadi,	Entire area
31.	GujarNimbalkarwadi,	Entire area

32.	Jambhulwadi	Entire area
33.	Kolewadi	Entire area
34.	Wagholi	Entire area

Pune Urban expanse can be divided into five major zones namely Central, North, West, South and East Pune. Zone wise division of wards and villages are shown in table below.

Table 12: Pune Urban expanse zone

Zone	Pune –Wards	Pune – Surrounding Villages
East zone	Nagar Road, Dhole Patil Road, Hadapsar, Pune cantonment board	Revenue boundary of Wagholi, Mundwa, ManjriBudruk, Shewalewadi and Phursungi village
West zone	Aundh, Kotharud, Ghole Road, WarjeKarve Nagar	Revenue boundary of Mhalunge, Sus, BawdhanBudruk, Shivne, Kondhawe-Dhawade village
North zone	Dhanori, Vishrantwadi, Lohgaon, Aundh and Khadki cantonment board	Lohagaon (remaining) Entire area of revenue village is already included in area of Municipal Corporation
South zone	Tilak Road, Sahakarnagar, Dhankawadi, Bibvewadi, Kondhwawanawadi, Ambegaon and Katraj	Revenue boundary of UruliDevachi, Holkarwadi, Handewadi, Wadachiwadi, Yewalewadi, Gujar-Nimbalkarwadi, Bhilarewadi, Mangdewadi, Kolewadi, Jambhulwadi, AmbegaonKhurd, AmbegaonBudruk, Narhe, Dhayari, Nandoshi, Kirkatwadi, Khadakwasla, Kopre, Villages.
Central zone	Kasba – Vishrambaug, BhavaniPeth	

East zone: Boat club, Hadapsar, Kalyani Nagar, Kharadi, Koregaon Park, Wagholi etc. the other end of the city expansion is the east zone. Hadapsar and Kharadi have come up as a preferred location for the IT / ITES sector. East Pune consists of various townships such as Magarpatta City, Amanora Park Town.

West zone: Aundh, Balewadi, Baner, Bavdhan, Kothrud, Pashan etc. Kothrud area is the most rapidly developing area in Pune, as the core of city gets congested the population preferred to shift towards the fringe and the area was under pioneer town planning schemes introduced in the city. The Aundh ward was well developed as a Residential zone for IT professionals, and its connectivity with city made it favorable.

The National Sindh Society was once a refugee colony but today is the most elite area of the city.

North zone: Dhanori, Vishrantwadi, Lohgaon, Aundh and Khadki cantonment board are under this zone. Since few years, the area has developed as one of the suburbs of the city.

South zone: Tilak Road, Sahakarnagar, Dhankawadi, Bibvewadi, Kondhwa Wanawadi, Ambegaon and Katraj are under this zone. South Pune is facing lot of urban pressure due to which many new residential projects are proposed in this area. As the cost of upcoming development lot of deforestation hastaken place for last few years in this area.

Central zone: Kasba – Vishrambaug, Bhavani Peth, Apte Road, Bhosle Nagar, Deccan, Model Coloy, Prabhat Road and Shivajinagar come under this zone. This area majorly consists of commercial spaces and educational institutes. Being a core and old part of the city this area is congested and provides favorable conditions for small-scale commercial development.

3.4. Change Detection Analysis and Image Classification

3.4.1. Land Use and Land Cover Map

Landsat satellite image has been used to classify land use and land cover of study area. Landsat 5 image have an excellent price-quality ratio, good spectral (seven bands from visible to the infrared specters) and spatial features (30 m resolution). Landsat 5 (02/02/1991) and (05/02/2010) multispectral images have been applied. Below are a few specifications of LANDSAT 5 and 8 Satellite Sensor mentioned below in table no. 13.

Table 13: LANDSAT 5 Satellite Sensor Specifications

	LANDSAT 5	LANDSAT 8
Launch Date	March 1, 1984 – January 2013, Vandenberg Air Force Base, California	February 11, 2013, Vandenberg SLC-3E
Spatial Resolution	30 meters	OLI panchromatic band 8: 15-meters
Orbit	Circular, sun-synchronous, near-polar orbit at an altitude of 705 km (438 mi)	Circular, sun-synchronous,
Orbit Inclination	98.2 degrees	98.110 degrees
Orbit Period	98.9 minutes	98.83 minutes
Grounding Track Repeat Cycle	16 days	16 days

Source: USGS

Landsat 5 Thematic Mapper (TM) images consist of seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7. Spatial resolution for Band 6 (thermal infrared) is 120 meters, but is resampled to 30-meter pixels. Approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi). Below table shows thematic mapper of study area of various bands having varied wave lengths.

Table 14: Landsat 5 Thematic Mapper (TM)

Landsat5	Wavelength(micrometers)	Resolution(meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.76-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	30
Band 7	2.08-2.35	30

Source: USGS

Landsat 8 Thematic Mapper (TM)

Table 15: Landsat 8 Thematic Mapper (TM)

Spectral Band	Wavelength	Resolution
Band 1 - Coastal / Aerosol	0.433 - 0.453 µm	30 m
Band 2 – Blue	0.450 - 0.515 µm	30 m
Band 3 – Green	0.525 - 0.600 µm	30 m
Band 4 – Red	0.630 - 0.680 µm	30 m
Band 5 - Near Infrared	0.845 - 0.885 µm	30 m
Band 6 - Short Wavelength Infrared	1.560 - 1.660 µm	30 m
Band 7 - Short Wavelength Infrared	2.100 - 2.300 µm	30 m
Band 8 – Panchromatic	0.500 - 0.680 µm	15 m
Band 9 – Cirrus	1.360 - 1.390 µm	30 m

Source: USGS

Landsat Image is classified on the basis of supervised and unsupervised classification methods. Both methods are most commonly used classification methods of satellite images. With supervised classification the operator determines the areas, where a distinct particular type of land cover is present and then the computer computes the spectral signatures. On the other hand, in the unsupervised classification the computer creates the spectral signatures using mathematical data clustering in the multidimensional feature space (Žiga Kokalj and Krištof Oštir, 2007).

3.4.2. Image Classification (IC)

For Image Classification, supervised classification technique is used. The first and most important step in supervised classification is the selection of training samples. The researcher digitizes the areas with known land cover on the screen. The image processing software then computes the spectral signatures of the land cover types. The process runs interactively, as the quality of the training samples has to be constantly evaluated and usually some have to be improved or even discarded (Žiga Kokalj and Krištof Oštir, 2007).

There are a number of classification algorithms to perform supervised classification. Maximum Likelihood and Minimum Distance are the most commonly used ones. Others are Parallel piped Classifier, fuzzy maximum likelihood etc. The objective of IC is to identify and portray, as a unique grey level (or colour), the features occurring in an image in terms of the object or type of land cover, as these features are actually represented on the ground.

There are majorly two Image Classification techniques broadly used to classify satellite images: Supervised Classification can be very accurate and effective. The user can apply and look up to each pixel in this method. The user, who has the knowledge of the selected area, can define the spectral signature for each class and then according to the algorithm other pixels of same reflectance get classified in the respective classes. The outcome is that of a classified image showing resemblance to the actual ground reality.

3.4.3. Change Detection (CD):

Change detection can be defined as the process of identifying differences in the state of an object or phenomenon by observing it at different times. This process is usually applied to Earth surface changes at two or more times. CD involves the application of multi-temporal datasets to quantitatively analyze the temporal effects. It gives the understanding of relationships and interactions to better manage and use the resources. There are several methods available for CD according to the input types and desired results. These methods are majorly categorized into pixel-based, object-based and spatial data mining. The pixel-based approach is most commonly used, because it involves techniques like image differencing, regression analysis, principal component analysis, post-classification comparison, multi-date direct comparison, decision tree, etc.

For this work, the pixel-based post-classification comparison method has been used to detect changes in all the feature classes of the classified images of over 2 decades. Post classification method is widely used and easy to understand. Two images acquired at different times are independently classified and then compared. Ideally, similar thematic classes are produced for each classification. Changes between the two dates can be visualized using a change matrix indicating, for both dates, the number of pixels in each class. This matrix allows one to interpret what changes occurred for a specific class. The main advantage of this method is the minimal impacts of radiometric and geometric differences between multi-date images.

However, the accuracy of the final result is the product of accuracies of the two independent classifications (e.g., 64% final accuracy for two 80% independent classification accuracies).CD especially for the urban class in all the 3 images was calculated manually by comparing their pixel count; and also by adding the area column in the attribute table, and comparing areas of each class in each of the images.

In the classified Map each class is represented by different colour. Water is represented by blue, Agriculture in Yellow, Vegetation in Green, and Settlements in red and Barren/Open land in tan colour.

3.4.4. Overview of Land Use and Land Cover change Detection

The current study conducted in Pune and its surrounding areas indicates that multi-temporal remote sensing images i.e. Landsat images are useful to detect the changes in land cover quickly and accurately. The study reveals that the major land cover categories in the study area in which changes over the years were observed are water bodies, vegetation and settlement area.

Table 16: Overview of changes in Land Cover over the years from 1991 to 2015.

Sr. No.	Class / Land Cover Type	Year 1991		Year 2000		Year 2010		Year 2015	
		(%)	(Ha.)	(%)	(Ha.)	(%)	(Ha.)	(%)	(Ha.)
1	Water bodies	1.70	92047	1.46	79052	1.32	71471	0.92	49813
2	Agricultural Land	4.65	251774	3.92	212248	1.96	106124	1.08	58477
3	Vegetation	25.76	1394775	22.29	1206892	16.08	870652	14.22	769942
4	Settlement area	29.07	1573995	35.81	1938932	45.16	2445188	49.30	2669349
5	Open / Barren Land	38.82	2101909	36.52	1977375	35.48	1921065	34.48	1866920
Total		**100**	**5414500**	**100**	**5414500**	**100**	**5414500**	**100**	**5414500**

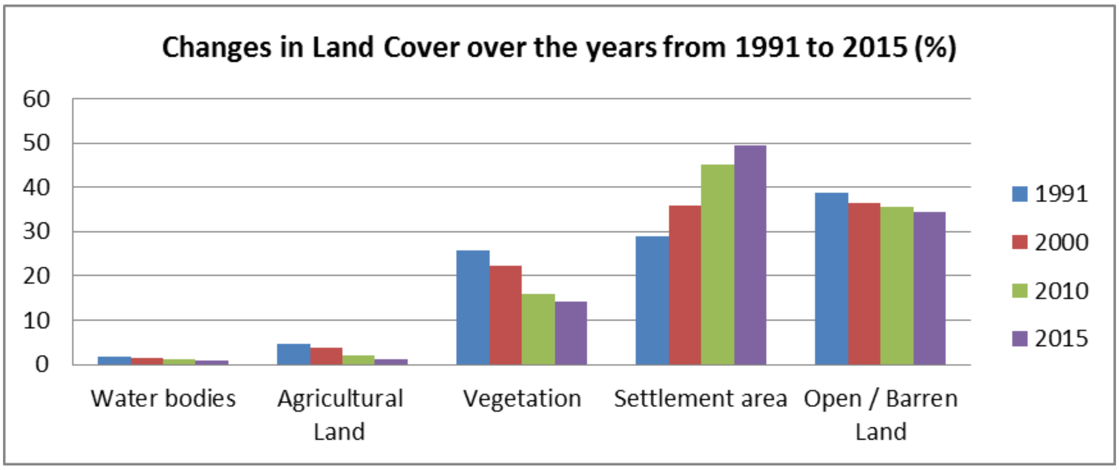


Figure 22: Changes in Land Cover over the years from 1991 to 2015 (%)

Pune 1991: The results of classification suggest that area under Water bodies accounts 1.70%, area under Agriculture is 4.65%, Vegetation is 25.76 %, Settlements is 29.07 % and Open/Barren Land is 38.82 % of the total area and thus this total area is divided in above five components or areas. The fig. 23 shows natural, physical and human intervention in the study area. Vegetation, Open/Barren Land and Water bodies together occupy 66.28% of the total area. Human settlements and agriculture land occupy 33.72% area. These percentages suggest that the impact of human activities or human interference on nature or physical features were comparatively less during these years.

Pune 2000: Area under Water bodies accounts 1.46%, Agriculture 3.92%, Vegetation 22.29%, Settlements 35.81% and Open/Barren land occupies 38.82%.The natural features like Vegetation, Open/Barren Land and water bodies occupy 62.57% of the total area and human settlements and agricultural land occupy 39.81 % of the total area. During this period development was on a rise because of which growth of settlements can be observed in west, and north east direction as well as it got denser (population density wise) in the central part of the study area along rivers (fig. 24).

Pune 2010: Area under water bodies accounts 1.32%, Agriculture 1.96%, Vegetation 16.08%, Settlements 45.16% and Open/Barren land occupies 35.48 %. The natural features like Vegetation, Open/Barren Land and water bodies occupy 52.88% of the total area and human settlements and agricultural land occupy 47.12 % of the total area. Settlements were flourishing around water bodies and streams.

Development seems to be spreading towards western and southern side of the study area. According to statistical data and observations, vegetation and barren lands were rapidly being converted due to human interference with nature (fig. 25).

Pune 2015: Area under water bodies accounts 0.92%, Agriculture 1.08%, Vegetation 14.22%, Settlements 49.30% and Open/Barren land occupies 34.48 %. The natural features like Vegetation, Open/Barren Land and water bodies occupy 49.62% of the total area and human settlements and agricultural land occupy 50.38 % of the total area. Comparing it to fig.26 in which physical aspects of the study area in year 2015 were analyzed, an unambiguous difference is observed in area under water bodies (422.33 Ha.) indicating heavy development along them, and a swift increase in area under settlement (10957.87 Ha.) is observed endangering vegetation cover and conversion of Open/Barren land in and around the city. Hence, heavy urbanization is reason for depletion of good fertile land in Peri-Urban area, heavy development along water bodies and vanishing of non-existing streams.

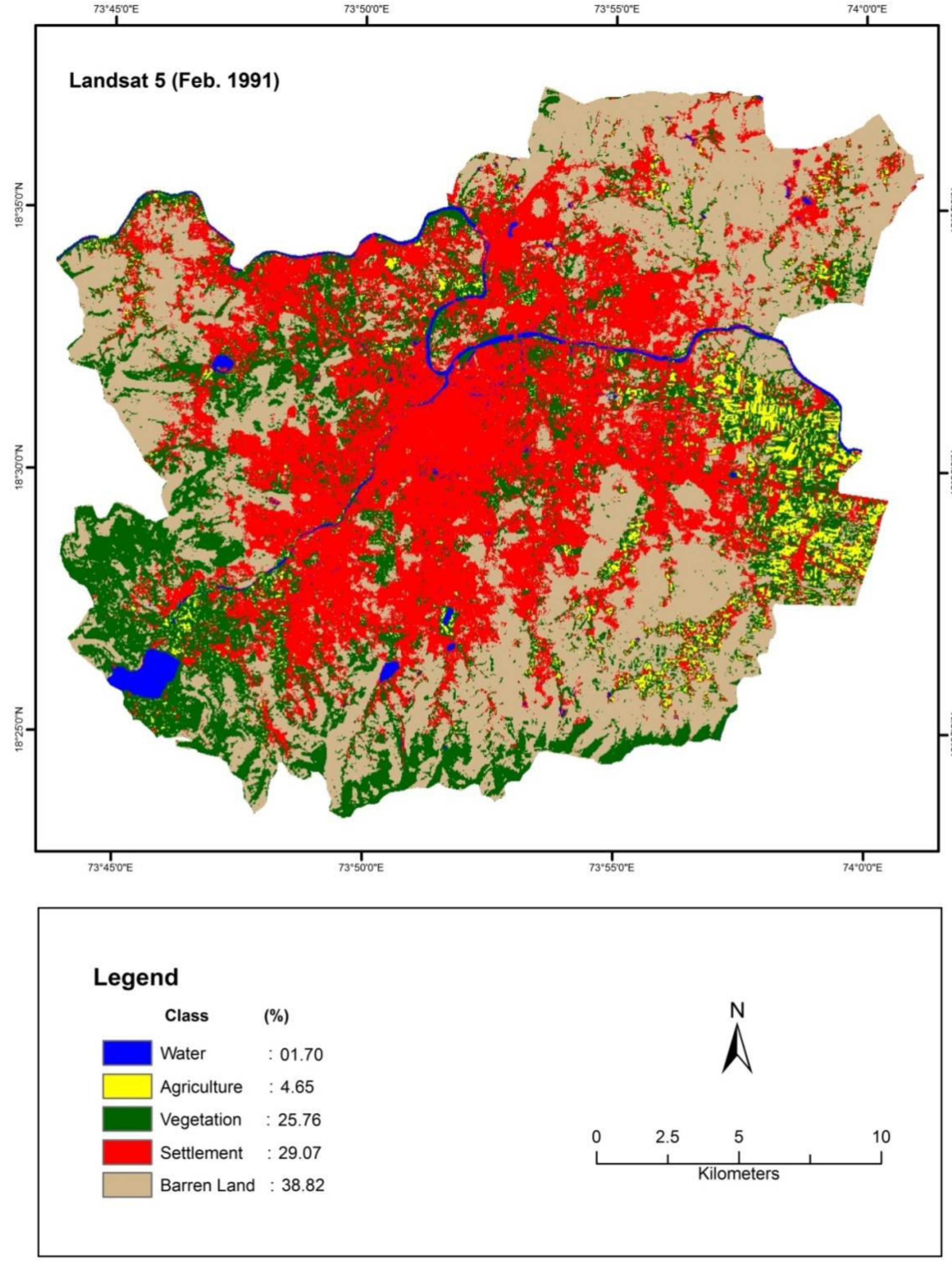


Figure 23: LUand LC in 1991 (Landsat 5)

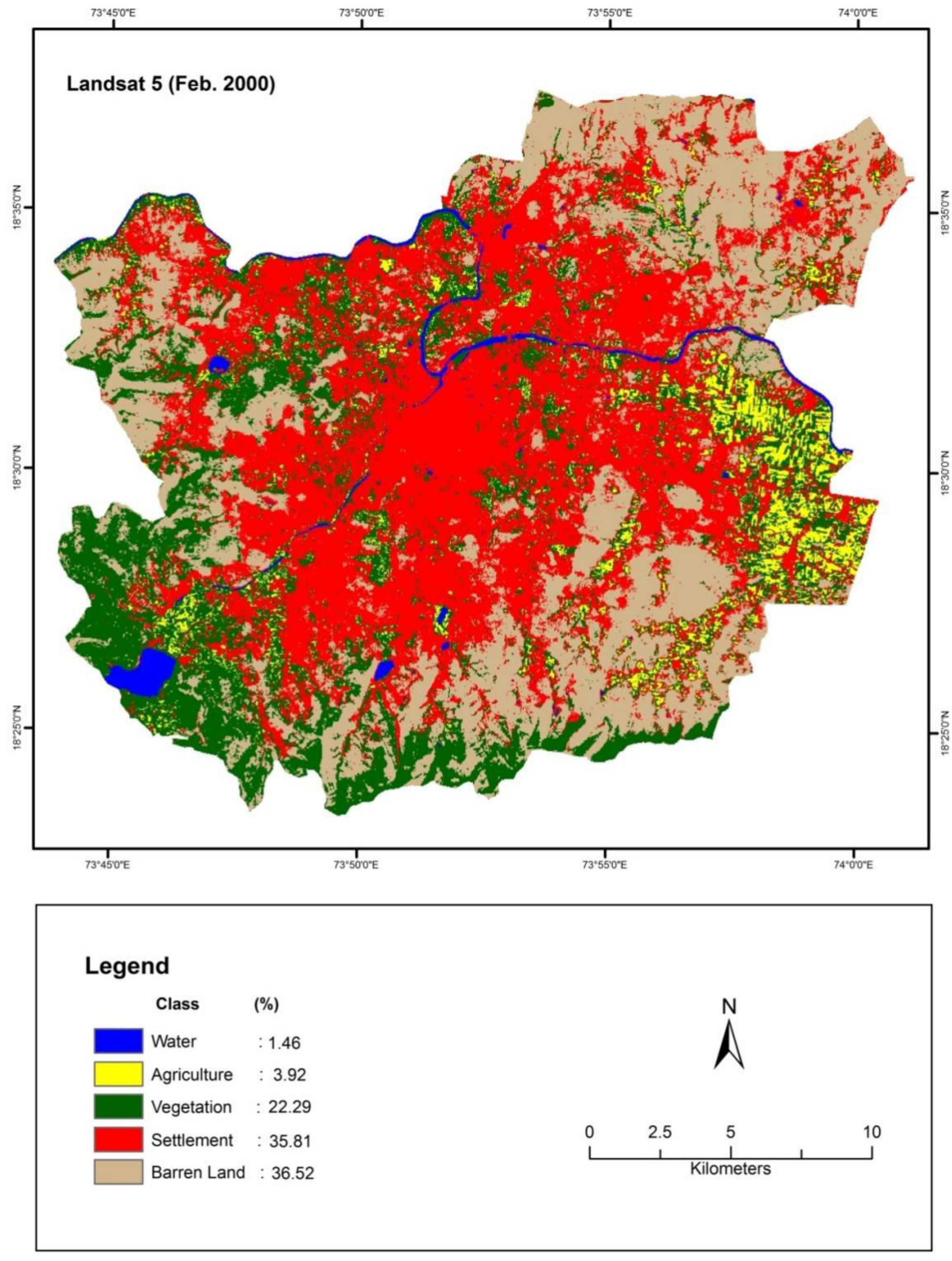


Figure 24: LUand LC in 2000 (Landsat 5)

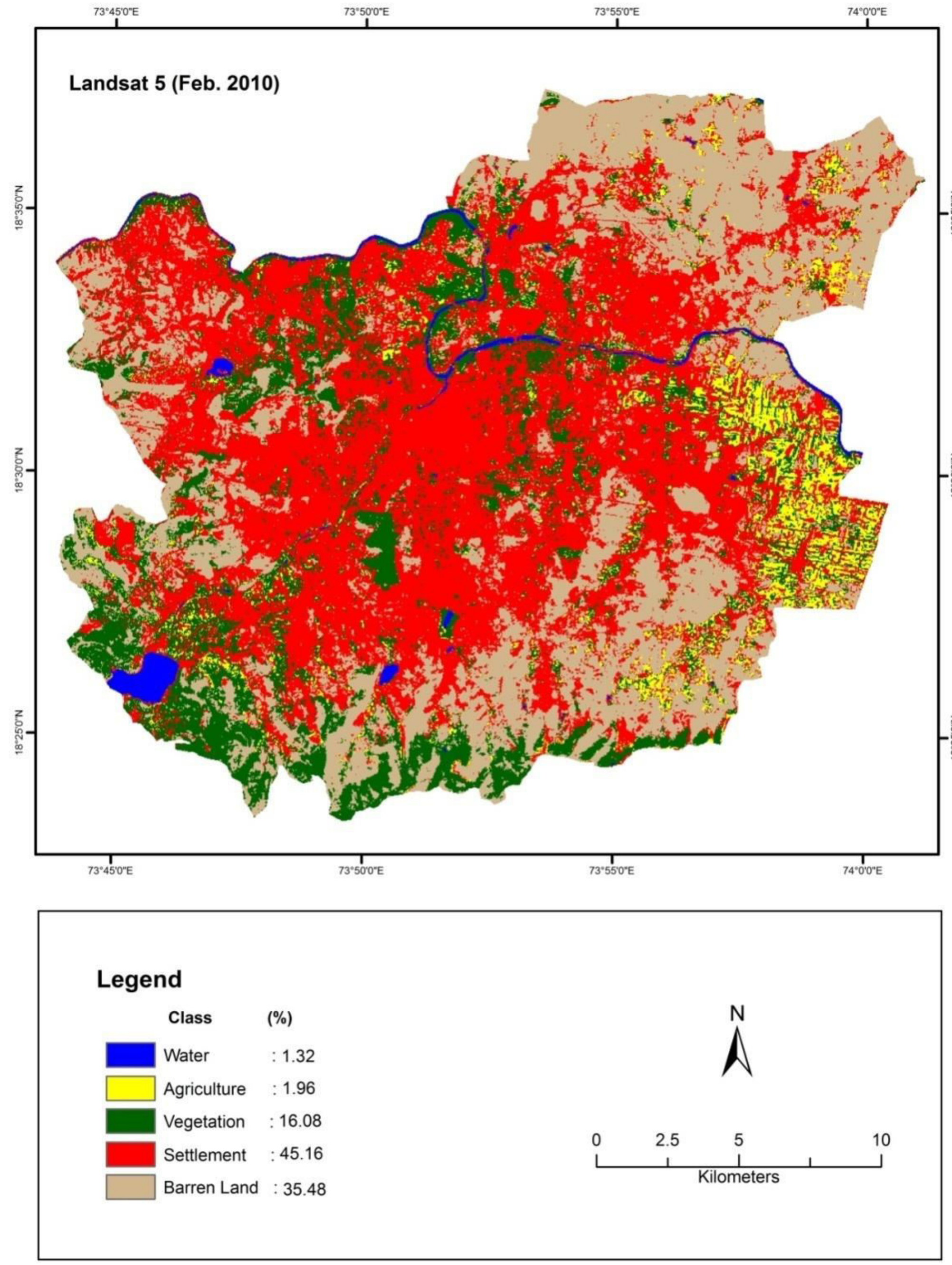


Figure 25: LUand LC in 2010 (Landsat 5)

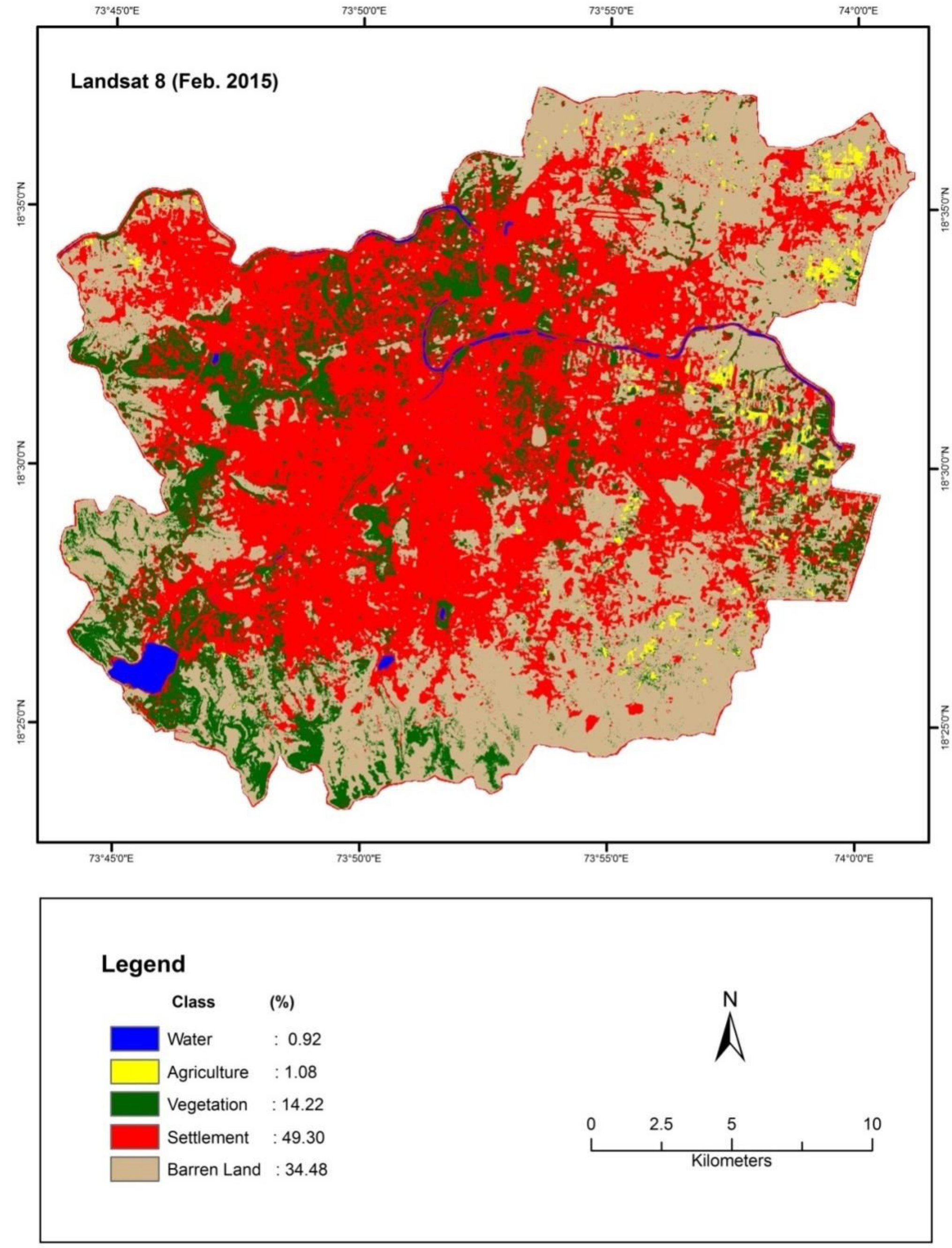


Figure 26: LUand LC in 2011 (Landsat 8)

3.4.5. Comparative Analysis of Study Area Between Years 1991 to 2015

During the last two and half decades (1991 to 2015) the area under vegetation has decreased by approximately 11.54% (62.48 sq.km) probably due to development in core and peri-urban areas of city. During the stipulated period, the area under settlement area has increased by 20.23% (109.54 sq.km) due to conversion of vegetation and Open/Barren land due to human interventions.

The results show that during the last two and half decades, open/barren land has been decreased by 4.34% (23.50 sq.km) due to urbanization while agricultural land and area under water bodies has been decreased by considerable amount i.e. 3.57% (19.33 sq.km) and 0.78% (4.22 sq.km) respectively causing depletion of good fertile land, heavy development along water bodies. Thus, the current study exemplifies that remote sensing and GIS are important technologies for temporal analysis and quantification of spatial phenomena, which is otherwise not possible to attempt through conventional mapping techniques. Change detection is made possible by these technologies in less time, at low cost and with better accuracy.

The area like Bhilarewadi show changes in water bodies, vegetation cover and barren land, these areas are converted into settlements during last 25 years. Thus this area lies in spur zone as geomorphic unit.

Table 17: Difference from year 1991 to 2015

Sr. No.	Class / Land Cover Type	1991	2015	Difference from year 1991 to 2015		
		(%)	(%)	(%)	(Ha.)	(Sq.km.)
1	Water bodies	1.70	0.92	0.78	422.33	4.22
2	Agricultural Land	4.65	1.08	3.57	1932.97	19.32
3	Vegetation Cover	25.76	14.22	11.54	6248.33	62.48
4	Settlement area	29.07	49.30	20.23	10953.53	109.53
5	Open / Barren Land	38.82	34.48	4.34	2349.89	23.49

3.4.5.1. Settelment Area

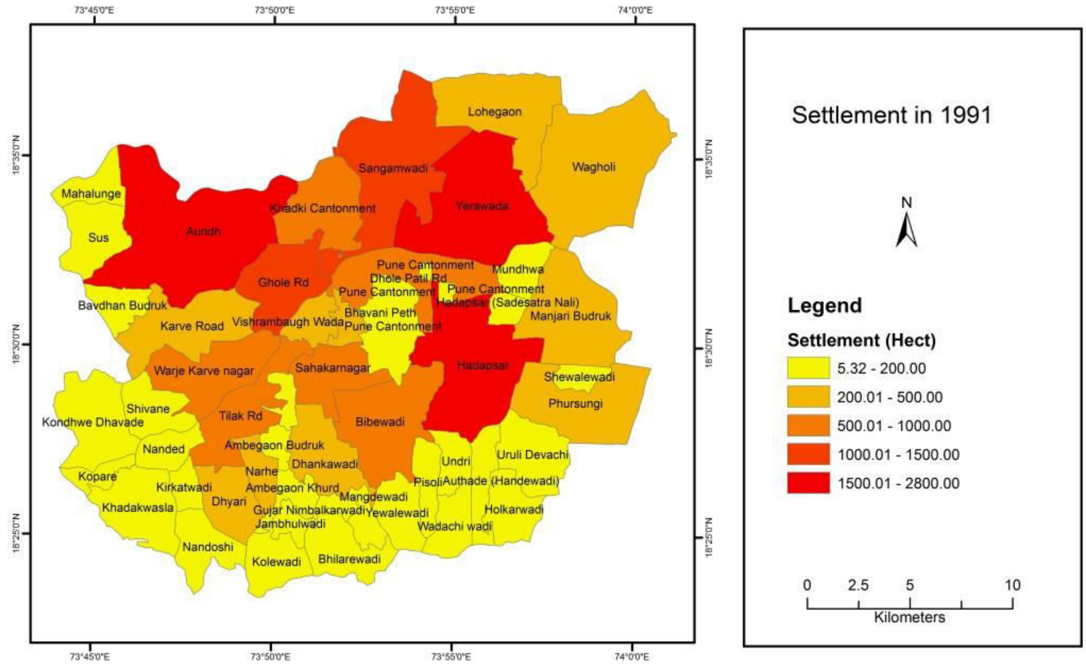


Figure 27: Area under settlement (1991)

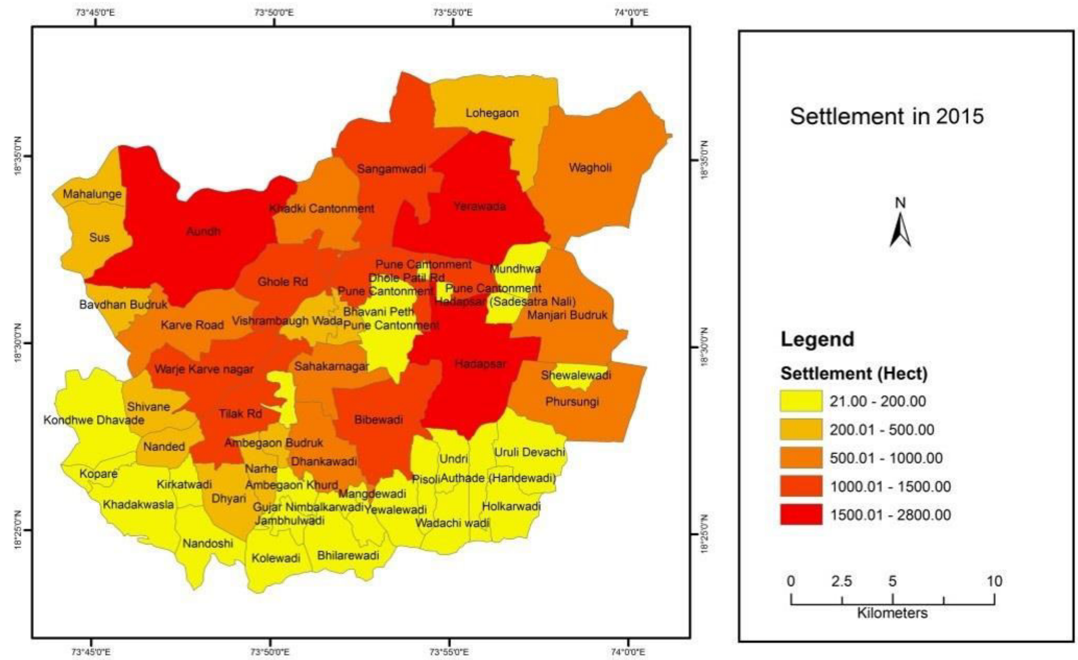


Figure 28: Area under settlement (2015)

The comparison of satellite image of year 1991 (fig. 27) to 2015 (fig. 28) shows increase in settlement area within the wards inside Pune city like Hadapsar, Ghole Road, Aundh, Yerawada and Sangamwadi and also villages like Lohegaon, Wagholi, Manjri, Phursungi and Dhayri are rapidly increasing in settlement area.

Urban settlement or built-up area has been increased by 2 times in a span of 25 years and most of the built-up area is spread in Peri-urban areas. During this selected study period of 1991-2015 Administrative Wards such as Bibewadi, Aundh, Yerawada, Sangamwadi, Ghole Road, Tilak Road and Karve Nagar & villages such as Wagholi, Nanded, Ambegaon Budruk, Warje, Manjri, Phursngi, Dhayari, Sus, Bavdhan, Mhalunge, Shivne and Narhe have indicated increase in settlement area due to development pressure asserted by the city.

3.4.5.2. Open / Barren Land

The supervised classification for Satellite image of year 1991 show that wards (administrative area) within city and 34 villages around Pune city reflect sufficient open/barren land, plenty area towards South-eastern part of the city. Average area of around 200 Hectares is covered under open/barren land, which indicate availability of good extent of barren land.

The comparison of satellite image of year 1991 (fig. 29) to 2015 (fig. 30) shows that the conversion of Open/Barren Lands within the wards inside Pune city has increased but in areas like Lohegaon, Wagholi, Sangamwadi, Yerawada, Manjari Budruk and Hadapsar is comparatively less. Sahakar Nagar, Ghole Road, Pune Cantonment, Tilak Road wards are shrinking in Open/Barren land immensely.

During this selected study period of 1991-2015 Administrative Wards such as Bibewadi, Aundh, Yerawada, Sangamwadi. Lohegaon & Wagholi, Nanded, Kirkatwadi, Ambegaon Budruk, Warje, Gujar Nimalkar wadi and Shewalewadi villages have indicated decrease of around 35% of its Open/Barren Land due to the urban expansion. Depletion of barren lands is more observed in core areas due to increase in population density. Thus increase in Built-up area has forced conversion of land and simultaneously decrease in Open/Barren Land.

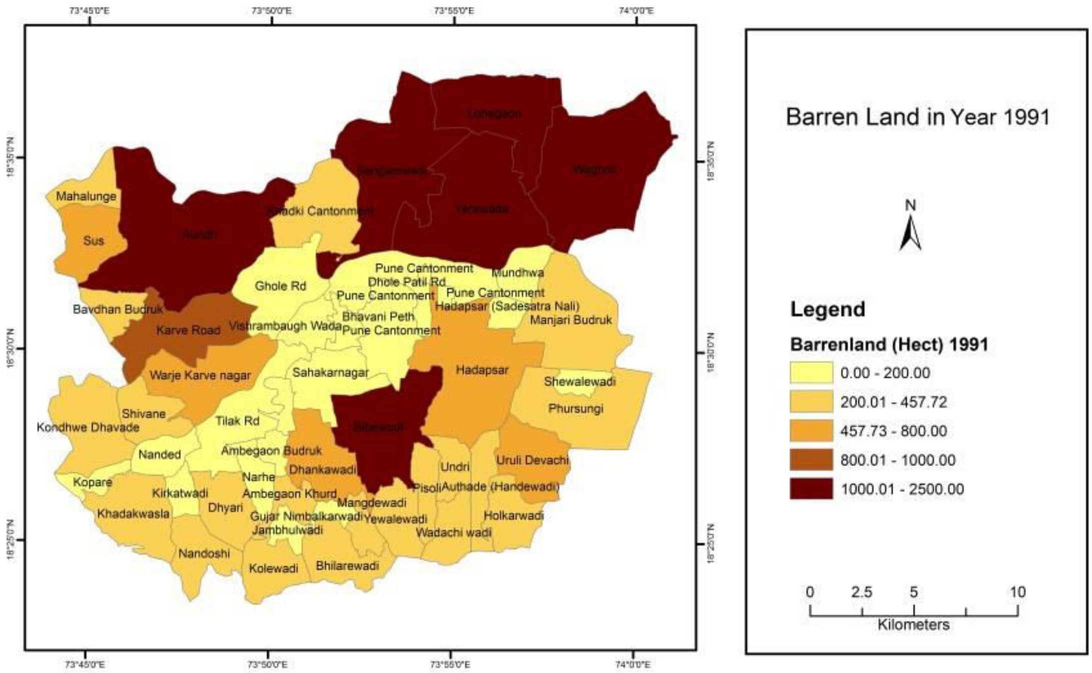


Figure 29: Open/Barren Land in study area (1991)

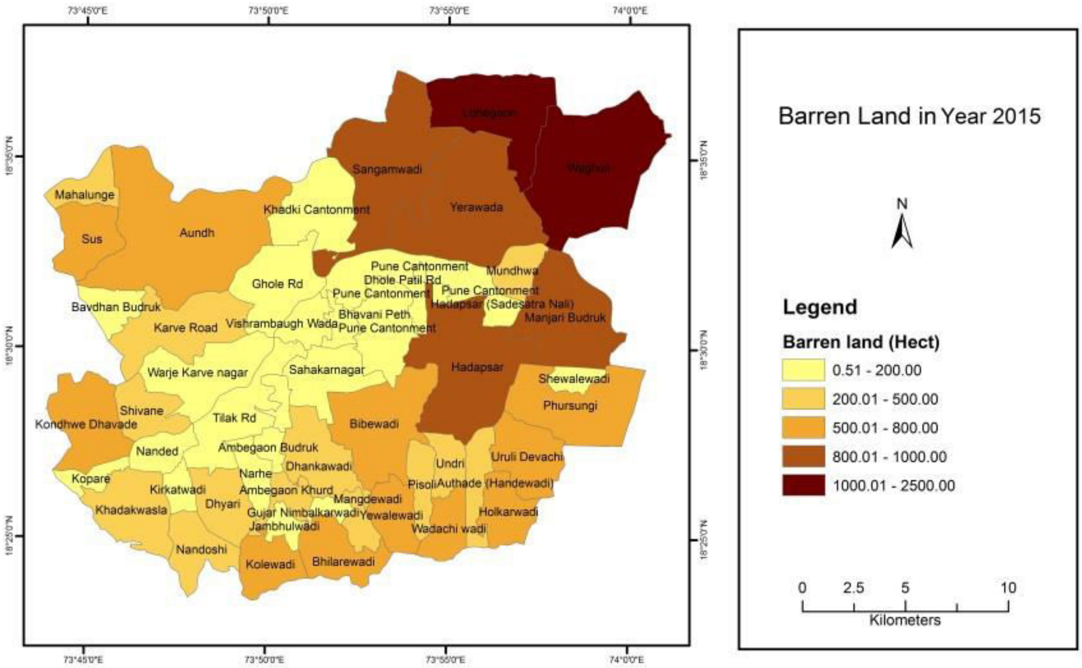


Figure 30: Open/Barren Land in study area (2015)

3.4.5.3. Vegetation Cover

The supervised classification for Satellite image of year 1991 show that wards (administrative area) within city and 34 villages around Pune city reflect very scattered vegetation cover, dense towards west and scattered towards south-east part of the city. Average area of around 200 Hectares is covered in mentioned wards and villages which is relatively less.

The comparison of satellite image of year 1991 (fig. 31) to 2015 (fig. 32) shows that the vegetation cover within the wards inside Pune city has increased but in surrounding villages specially Undri, Uruli Devachi, Autadewadi, Hanadewadi, Ambegaon, Mangadewadi, Gujara Nimbalkarwadi it has comparatively decreased. Warje karve nagar, Pune Cantonment, Tilak Road wards are shrinking in vegetation cover massively.

During this selected study period of 1991-2015, Handewadi, Shivne, Kolewadi, Nanded, Holkarwadi, Wagholi, Kopre villages have lost 50% of its vegetation cover and area is converted into concrete jungle. Karve road, Ghole road, Sangamwadi, Yarwada wards and Dhayari, Kolewadi, Nandoshi, Sus villages are covering upto an average area of 200 to 400 hectares area of vegetation cover. Till date, Aundh, Khadki Cantonment wards and villages such as Manjari Budruk, Kondave Dhavade, Khadakwasala are still having substantial vegetation cover, covering upto average area of around 600 to 1000 Hectares.

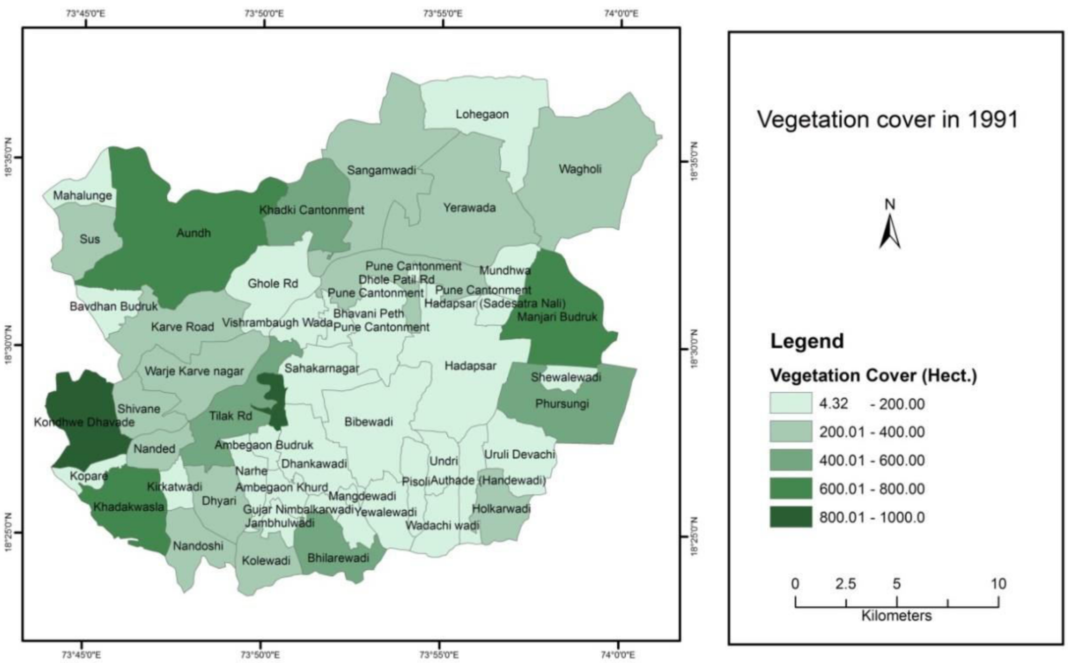


Figure 31: Vegetation cover in study area (1991)

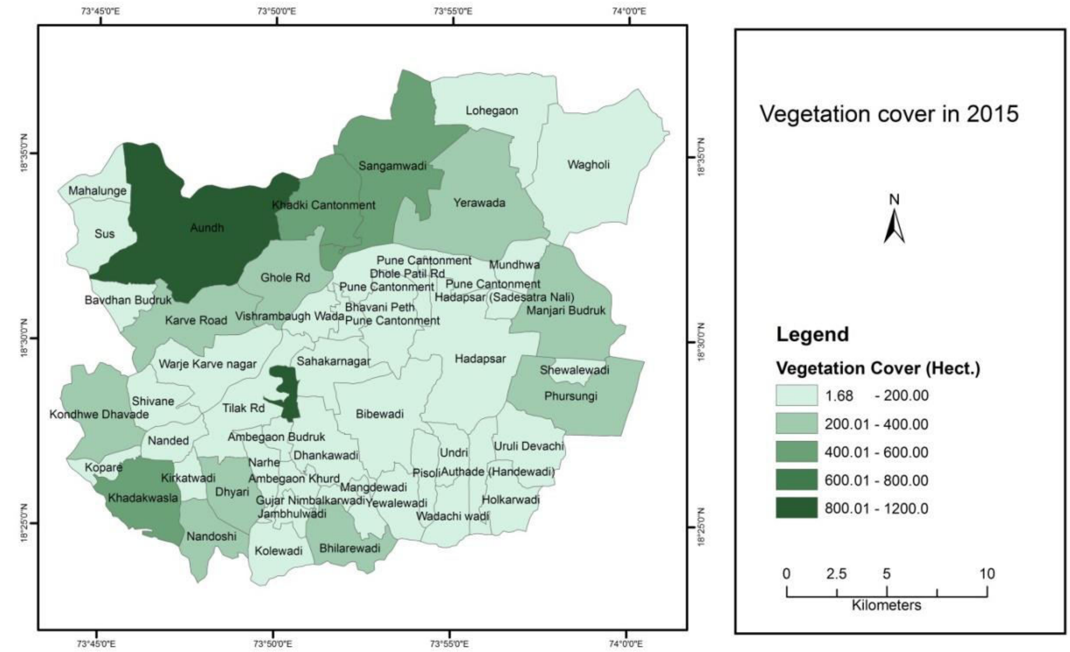


Figure 32: Vegetation cover in study area (2015)

CHAPTER – 4: DRAINAGE BASIN AND URBAN CHANGE

4.1 Watershed and Urban Change

Healthy urban streams have been recognized as a fundamental prerequisite to achieve sustainable management of our cities and fulfilling our imperative to maintain healthy aquatic ecosystems for future generations (United Nations General Assembly 1987). There are a number of excellent summaries on the effects of urbanization on stream health (Walsh *et al.* 2005). Urbanization alters river ecology in and downstream of cities, harming aquatic systems and prompting efforts to protect, rehabilitate, and even fully restore urban streams. Yet these efforts seldom succeed, mostly because of narrowly prescriptive solutions that do not take advantage of interdisciplinary knowledge in the physical, biological, and social sciences or because they do not treat the full range of urban change in streams (Karr and Rossano 2001).

Stream degradation caused by urbanization is not a single problem with a single solution, or even a well-defined set of problems with well-defined solutions. Rather, stream degradation results from a collection of individual decisions and actions that leads to specific urban landscapes and, in turn, to altered stream condition. “Urbanization” itself is multi-dimensional and has been defined in many different ways (McIntyreet al. 2000). The deleterious influences of urbanization on the hydrology and geomorphology of small streams have been extensively explored and documented (Hammer 1972).

4.2 Quantitative Morphometric Analysis

4.2.1. Introduction

Morphometry in simple term means the measurement of a shape or geometry (Strahler 1975). Morphometry is not only related to the measurement but also to the mathematical analysis of the earth’s surface configuration and dimensions of landforms (Hajam et.al. 2013). Horton (1945) initiated the use of quantitative approaches in fluvial geomorphology to study the stream system of the drainage basin. The entire area that collects the rainwater and contributes it to a particular channel is known as the drainage basin or catchment area (Kale and Gupta 2001).

River basins have special relevance to drainage pattern and geomorphology and consist of distinct morphologic regions (Gundekar et.al. 2011). Morphometric parameters comprise the form and structure characteristics of drainage basin and their associated drainage networks (Goudie 2004). The morphometric characteristics of a watershed may reveal information regarding its formation and development because the hydrologic and geomorphic processes take place within the watershed (Pareta and Pareta 2011).

There are several morphometric parameters which are useful in understanding the processes shaping the morphology of the watershed. The most important factor is the basin shape, which exerts a control over the geometry of the stream network. Circularity ratio, elongation ratio, form factor ratio and compactness coefficient are used to determine the shape of the basin (Eze and Efiong 2010). GIS is a significant tool, which has the potential to give rapid and accurate analysis of the spatial information and is used to determine the characteristics of the watershed. Morphometric factors represent relatively simple approaches to describe the drainage basin processes and to compare the drainage basin characteristics (Gundekar et.al. 2011).

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Table 18: Morphometric parameters of Major Watersheds

Sr. No.	Parameters	Abbreviation	Formula	Ram Nadi	Nandoshi	Ambil Odha	Bhairoba Nala	Wadki Nala	Wagholi
A	**DRAINAGE NETWORK**								
1	Stream Order			1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5
2	Stream Number	Nu	Nu=N1+N2+...Nn	311	155	237	153	262	61
3	Stream Length	Lu		136.73	63.77	95.71	70.38	128.26	23.28
4	Bifurcation Ratio	Rb				2 - 6.67			
5	Length of main channel	Cl		19.20	10.17	15.96	17.01	17.24	9.03
6	Rho coefficient	ρ	ρ=Lur/Rb			0.44			
B	**BASIN GEOMETRY**								
7	Length of the basin	Lb	Lb=1.312*A^0.568	10.70	7.63	9.06	9.65	9.65	7.63
8	Basin Area	A		40.23	22.18	30.02	33.52	33.52	22.18
9	Basin Perimeter	P		50.95	15.93	33.56	27.78	38.96	15.93
10	Lemniscate	k	k=Lb^2/A	2.85	2.62	2.73	2.78	2.78	2.62
11	Form Factor Ratio	Ff	Ff=A/Lb^2	0.35	0.38	0.37	0.36	0.36	0.38
12	Elongation Ratio	Re	Re=(2/Lb)*(A/π)^0.5	0.67	0.70	0.68	0.68	0.68	0.70
13	Texture Ratio	Rt	Rt=N1/P	8.16	10.11	7	7.13	8.06	6.15
14	Circularity Ratio	Rc	Rc=12.57*(A/P^2)	0.19	1.10	0.34	0.55	0.28	1.10
15	Drainage Texture	Dt	Dt=Nu/P	6.10	9.73	7.06	5.51	6.73	3.83
16	Compactness Coefficient	Cc	Cc=0.2841*P/A^0.5	2.28	0.96	1.74	1.36	1.91	0.96
17	Fitness Ratio	Rf	Rf=Cl/P	0.31	1.00	0.48	0.57	0.41	1.00
18	Wandering Ratio	Rw	Rw=Cl/Lb	1.49	2.09	1.76	1.65	1.65	2.09
C	**DRAINAGE TEXTURE ANALYSIS**								
19	Stream Frequency	Fs	Fs=Nu/A	7.73	6.99	7.89	4.56	7.82	2.75
20	Drainage Density	Dd	Dd=Lu/A	3.40	2.88	3.19	2.10	3.83	1.05
22	Drainage Intensity	Di	Di=Fs/Dd	2.27	2.43	2.48	2.17	2.04	2.62
D	**RELIEF CHARACTERISTICS**								
25	Total basin relief	H	H=Z-z	410.00	560.00	550	460.00	450.00	140.00
26	Relief Ratio	Rh	Rh=H/Lb	38.32	73.41	60.71	47.69	46.66	18.35
27	Absolute Relief	Ra		960.00	1120.00	1100	1000.00	990.00	680.00
28	Dissection Index	Dis	Dis=H/Ra	0.43	0.50	0.50	0.46	0.45	0.21

4.2.2. Results of Morphometric Analysis

Based on the Survey of India toposheet (1970-80), the morphometric analysis results were prepared. The morphometric parameters are classified into Drainage network, Basin Geometry, Drainage texture analysis, and Relief characteristics. In the present study, morphometric attributes like the stream order, stream length, bifurcation ratio, rho coefficient, circularity ratio, wandering ratio, elongation ratio, lemniscate, form factor ratio, drainage texture, drainage density, absolute relief, relative relief were calculated using the formulae given in Table no. 18.

4.2.2.1. Drainage Network

Stream Order

The most significant step to carry out the quantitative morphometric analysis of a watershed is stream ordering. Horton (1945) was the first one to advocate the stream ordering system. His system of stream ordering was later modified by Strahler (Pareta and Pareta 2011). Stream ordering is the method of assigning a numeric order to links in a stream network (Das et.al. 2012). The stream ordering of the study area was based on the Strahler's method and exhibited 5th order drainage basins.

Stream Number

It is the number of stream segments for each order. The comparison of the stream numbers of 1970 with the present numbers reveal that the stream numbers have decreased for each sub-watersheds. During the decade of 1970's the total number of streams in the study area were 1471 in number. In the present condition, the stream number has decreased to1164. This shows that there is significant change in the number of streams of the present study area.

Stream length

Stream length is measured from the mouth to the drainage divide. Horton's law of stream length suggests a geometric relationship between the number of stream segments in successive stream orders and landforms (Horton 1945). In the present study, the stream length has been calculated by using the Survey of India (SoI) toposheets. The total length of streams of the present watershed has decreased as compared to the stream length of 1970. During the decade of 1970s, the total length of streams in the study area was 635.46 km. In the present condition the stream length has decreased to 518.13 km. This shows there is significant change in the length of streams of the present study area.

Bifurcation Ratio

It is the ratio of the number of stream segments of given order to the number of streams in the next higher order (Goudie 2004). The bifurcation ratio varies with the irregularities in the geological development of the drainage basin. It shows the degree of integration prevailing between the streams of various orders in a drainage basin (Selvan et.al. 2011). According to Kale and Gupta (2001), the bifurcation ratios ranging between 3 and 5 indicate the natural drainage system within a homogenous rock. The lower value of bifurcation ratio are characteristics of the watershed which have flat or rolling watersheds while the higher values of bifurcation ratio indicate strong structural control on the drainage pattern and have well-dissected drainage basins (Horton 1945; Fryirs and Brierley 2013). The higher bifurcation ratio leads to less chances of risk of flooding (Eze and Efiong 2010).

Length of main channel

This is the length along the upper limit of the watershed boundary to the outflow point. Comparing all watersheds, it was observed that the Ram Nadi watershed has highest main channel length of 19.2 km while Wagholi watershed area has lowest main channel length of 9.03 km.

Rho coefficient

This is a parameter which can be identified from the relation of the drainage density with the physiographic development of the concerned watershed. Combined influences of climatic, geologic, geomorphic, biologic and anthropogenic factors determine the change in this parameter (Pareta and Pareta 2011). Rho value of the study area ranges between 2.23-2.93, which indicates excess flow of water during floods without any storage.

4.2.2.2. Basin Geometry

Length of the basin

Pareta and Pareta (2011) defined the basin length as the longest dimension of the basin parallel to the principal drainage line. The length of basin varied for each watershed as follows: Ram Nadi (10.70 km), Nandoshi (7.63 km), Ambil Odha (9.06 km), Bhairoba Nala (9.65 km), Wadki Nala (9.65 km) and Wagholi (7.63 km). In the study area it is observed that Ram Nadi is having the largest basin length as compared to other watersheds.

Area of the basin

The area of the basin was considered between the divide and the mouth of the basin. The total area occupied by the six sub watersheds is181.65 km^2.

Basin perimeter:

In general, it can be defined as the total length of the outer boundary of basin. Basin perimeter is measured along the divides between the watersheds and is one of the important factors that determine the shape and size of the watershed basin. The total basin perimeter of the study area is 183.11 sq.km.

Lemniscate

The slope of the watershed basin can be determined by the Lemniscate values (Pareta and Pareta 2011). In the formula $k = Lb^2/4 * A$, Lb is the basin length and A is the area of the basin. The lemniscate value for the study area ranges from 2.62-2.85. The lemniscate value indicates that maximum area is occupied in its region of inception with large number of streams of higher order.

Form Factor ratio

Form factor may be defined as the ratio of basin area to the square of the basin length. The form factor provides a measure of relationship between catchment area and catchment length and effects on hydrology (Fryirs and Brierley 2013). The value of form factor for a perfectly circular watershed is 0.754 (Pareta and Pareta 2011). The elongated nature of the sub-watershed in the study area can be determined by the value of form factor ratio which ranges from 0.35 to 0.38. The elongated watershed basins have small value of form factor while the higher value indicates a basin which is nearly circular. In the elongated basin, the flow of water is distributed over a longer period of time as compared with the circular basin (Eze and Efiong 2010).

Elongation ratio

According to Pareta and Pareta(2011), elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length and have classified the watershed with the help of the index of elongation ratio, i.e., circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5). Catchments with elongation ratio around 0.6 are relatively elongated (Fryirs and Brierley 2013). The elongation ratio of all the sub-watersheds in the study area ranges between 0.67 and 0.70. Hence, it is clear that the sub-watershed basins are elongated.

Texture ratio

Texture ratio is an important factor in the drainage morphometric analysis which is dependent on the underlying lithology, infiltration capacity and relief aspect of the terrain (Pareta and Pareta2011). There is a significant change in the texture ratio values of 1970 and the present. During 1970, the texture ratio values ranged from 6.15 to 10.11 while in the present conditions, the texture ratio value ranges between 3.83 and 9.73.In the present study, the texture ratio of the sub-watersheds can be categorized as moderate to high in nature.

Circularity ratio

Circularity ratio is defined as the ratio of watershed area to the area of a circle having the same perimeter as the watershed and it is pretentious by the lithological character of the watershed (Pareta and Pareta 2011). Catchments with low circularity ratios are elongated in shape and controlled primarily by the geologic structure (Fryirs and Brierley 2013). The circularity ratio of the study area ranges from 0.19 to 1.10, which indicates that the basin is not circular.

Drainage texture

Drainage texture is the total number of stream segments of all orders per perimeter of that area (Das et.al. 2012). Pareta and Pareta (2011) have classified drainage texture into five different textures namely, very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The areas having low drainage density have coarse texture while high drainage density leads to fine drainage texture. The drainage texture of the sub-watersheds decreases from 1970 to present conditions. In 1970, the drainage texture ranged from 6.15 to 10.11. The present condition of drainage texture in the sub-watersheds is between 3.83 and 9.73. The value of drainage texture in study area indicates that the texture varies from course to very fine. The area of Nandoshi is dominated by hill terrain hence the drainage in such region is high i.e. it displaced the value of 9.73, which suggest that the drainage texture is very fine. In constrast with Nandoshi watershed area watershed of Wagholi is relatively flat with low drainage density. This characteristic gives the value of 3.83 indicating very course drainage very course drainage texture.

Compactness coefficient

Compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed (Pareta and Pareta 2011). The compactness coefficient of sub-watersheds in the study area ranges between 0.96 and 2.28.

Fitness ratio

The ratio of main channel length to the length of the watershed perimeter is fitness ratio, which is a measure of topographic fitness (Pareta and Pareta 2011; Hajam et.al. 2013). For all the sub-watersheds in the study area, the fitness ratio ranges from 0.31 to 1.00.

Wandering ratio

Wandering ratio is defined as the ratio of the mainstream length to the valley length (Pareta and Pareta 2011; Hajam et.al. 2013). Valley length is the straight-line distance between outlet of the basin and the farthest point on the ridge. In the present study, the wandering ratio of the sub-watersheds ranges between 1.49 and 2.09.

4.2.2.3. Drainage Texture Analysis

Stream Frequency

The total number of stream segments of all orders per unit area is known as stream frequency (Selvan et.al. 2011; Das et.al. 2012). It provides additional information concerning the response of drainage basin to runoff process (Selvan et.al. 2011). It mainly depends on the lithology of the basin. The stream frequency for the sub-watersheds in the study area is varies from 1970 to present circumstances. The range for the year 1970 was 4.42 to 10.34 and the range for present conditions is 2.75 to 7.89. The Stream Frequency for Ambil Odha is high with a value of 7.89 and for Wagholi, the Stream Frequency is low having a value of 2.75.

Drainage density

The degree of dissection of the terrain can be quantitatively characterised by the drainage density (Dingman 2009). Drainage density is the stream length per unit area in region of watershed (Horton 1945; Goudie 2004; Selvan et.al. 2011) is another element of drainage analysis. Drainage density determines the spacing of channel, length of hillslope and reflects the processes governing landscape dissection (Goudie 2004). High drainage density reflects highly dissected drainage basin and rapid hydrological response to the rainfall events while low drainage density means slow hydrological response (Selvan 2011; Hajam et.al. 2013). The low value of drainage density is one of the characteristics of the humid region (Dingman 2009). During 1970, the sub-watersheds exhibited a range from 1.81/km to 4.57/km. During the contemporary conditions, the range varies between for Wagholi watershed 1.05/km and Wadki Nala watershed 3.83/km. The study area has low to moderate drainage density. Thus the value clearly indicates that Wagholi is having low drainage density and Wadki Nala having Moderate drainage density.

Drainage intensity

Drainage intensity is the ratio of the stream frequency to the drainage density. The high value of drainage intensity indicates that together the drainage density and stream frequency have more effect on the surface denudation. The drainage intensity for the sub-watersheds of the study area varies between 2.11 and 2.78. The study shows a moderate drainage intensity of for the sub-watershed basins.

4.2.2.4. Relief Characteristics

Relief ratio

The relative relief of a basin is the difference in the elevation between the highest point and the lowest point on the valley floor. The relief ratio is a dimensionless number which provides a measure of the average drop in elevation per unit length of river (Fryirs and Brierley 2013). If the relative relief is more, the degree of dissection is maximum. In the study area, the value of relief ratio ranges from 18.35 for Wagholi to 73.41for Nandoshi. The relief ratio values range from low to high indicating undulating relief and slope. Wagholi doesn't show undulating relief with gentle slope. Nandoshi shows undulating relief with moderate slope

Absolute relief

It is the highest elevation of a given location in a river basin. According to Selvan et.al. (2011) absolute relief gives the elevation of any area above the sea level in exact figure. The absolute relief of the area is 1100m.

Dissection index

Dissection index is the ratio of maximum relative relief to maximum absolute relief (Selvan et.al. 2011). It is an important morphometric indicator which explains the nature and magnitude of the dissection in a terrain. On average, the values of dissection index vary between'0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and'1' (it may be at vertical escarpment of hill slope or at seashore) (Pareta and Pareta 2011). The dissection index of the study area varies between 0.13 and 0.51. The dissection index of the study area shows that the sub-watersheds are low to moderately dissect.

Various stream properties can be evaluated with the help of morphometric studies. The morphometric analysis of drainage basin play an important role in understanding the geo-hydrological behavior of drainage basin (Hajam et.al. 2013). The assessment of present condition of water resource in an area can be investigated with the study of drainage basin.

The sub-watersheds of the study area are fifth order drainage basins. The mean bifurcation ratio indicates that the area has homogenous rock type and a structural control on the drainage pattern. The drainage density, stream frequency and the drainage intensity are correlated with the degree of dissection in the area. Hence it is clear that intensity of dissection varies from low to moderate in the study area and this can also be determined by the low to moderate dissection index value. Drainage density indicates that the study area is in humid region.

The elongated basins have low to moderate drainage density, low stream frequency and high value of drainage texture (Hajam et.al. 2013). From the Form Factor ratio, Circularity ratio and Elongation ratio it is clear that the sub-watershed basins are elongated in shape. This fact emphasizes that there is low and delayed discharge of runoff. From the present study, it is clear that the area is not susceptible to flooding. The study area has coarse to very fine drainage texture which is an indication of fine grained rocks with lesser permeability. The drainage density and stream frequency have a low to moderate effect on the surface denudation in the present area.

Vegetation cover and land use influence drainage density. Sparse vegetation cover leaves the landscape exposed to intense rainfall that induces high rate of erosion and landscape dissection increasing drainage density (Fryirs and Brierley 2013). In future, this will consequently lead to the high rate of erosion in the form of hillslope instability and increase in the sediment discharge.

Impervious surface tends to affect the infiltration capacity of the land and increases the flow transmission in the streams. Thus, direct human impact in the area will modify the character and behaviour of the streams. It may either expand or suppress the capacity of the river to adjust.

In order to study the transformation of the stream, it is necessary to study the human disturbances in the context of past and present. Further assessment of the channel geometry and hydraulic characteristics will reveal the overall transformation made by human.

The drainage basin is a primary landscape unit for hydrological, water supply and land management activities (Goudie 2004). From the study, it is clear that GIS is an important tool for the geomorphometric analysis of a drainage basin. Such studies can be used for the future planning and management of drainage basin.

4.3 Major Sub-Watersheds in the study area

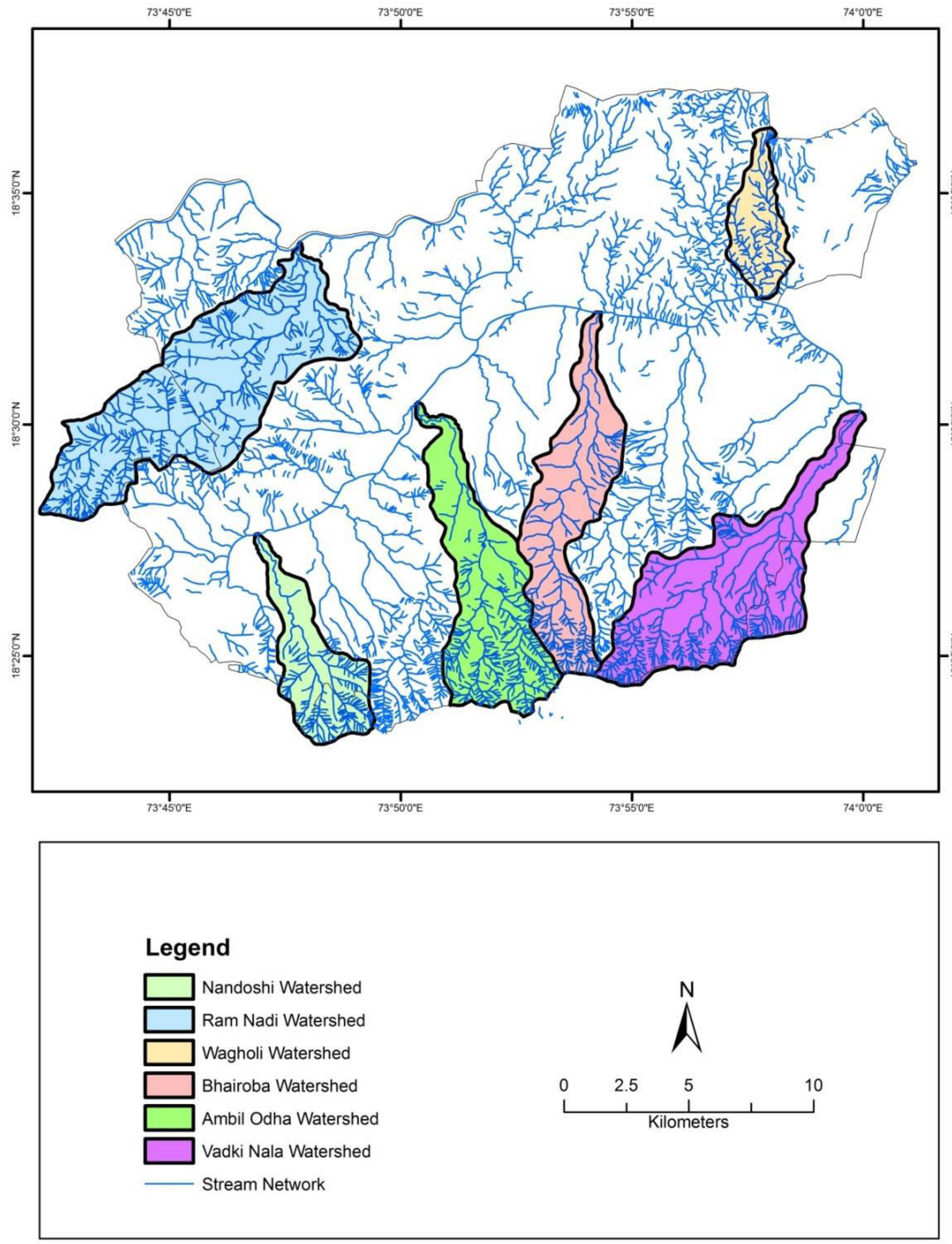


Figure 33: Major Sub-Watersheds in study area

Study area is occupied by two major river basins, the Mula river basin and the Mutha river basin. These river basins can be further divided into sub basins up to fifth order streams. There are six major sub basins Nandoshi, Ram Nadi, Wagholi, Ambil Odha, Bhairoba Nala and Wadki nala are considered for watershed analysis (fig. 33). These sub-watershed basins cover about 35% of total study area. These watershed areas are having rapid urbanization since year 1980 to 2015. Methodology use for change detection in the watershed area is explained in chapter number 2.

To understand the spatial and temporal changes in the study area, morphometric analysis of these major sub basins were carried out. Changes in the stream network over the period of 25 years (1991 to 2015) were studied and maps are prepared. SOI Toposheets (1:25,000 scales) and satellite images (Ladsat 5 and Landsat 8) digital elevation model of these basins were used to understand the basin development. Supervised classification of individual sub basins for the period of 1991 to 2015 was carried out for change detection in the study area. Change in the stream numbers, stream length, and stream area due to urbanization is threatening to physical and urban setup of the study area.

4.3.1. Ram Nadi Watershed Area

The Ram Nadi (rivulet) drains a catchment of 50.95 Sq.Km. It is located to the north-west of Pune City between 18°27’55’’N to 18°33’55’’N Latitudes and 73°42’10’’E to 73°49’06’’E Longitudes. The rivulet originates at an elevation of 955 m above mean sea level (AMSL) in Sahyadri range near Kathpewadi and flows towards north-west direction to join the Mula river. This watershed area consist of Aundh, Baner and Pashan in Pune city and Khatpewadi, Bavdhan, Bhukum, Bhugaon, Someshvarwadi and Pirangut villages in the western part of watershed area. Ram Nadi watershed area largely consists of moderate to gently sloping plane, with massive rock basalt combination. Comparatively runoff is high of Ram Nadi due to hard and massive rock terrain; the majority of river bed is relatively shallow, rocky and wide. In 2011 Ram Nadi’s monsoon flooding affected the low lying areas of Bavdhan, Pashan, Aundh and Baner and exposed its encroachment for the first time. After that, a survey was undertaken jointly by the PMC and District Administration to list out encroachments along the river bank and channel.

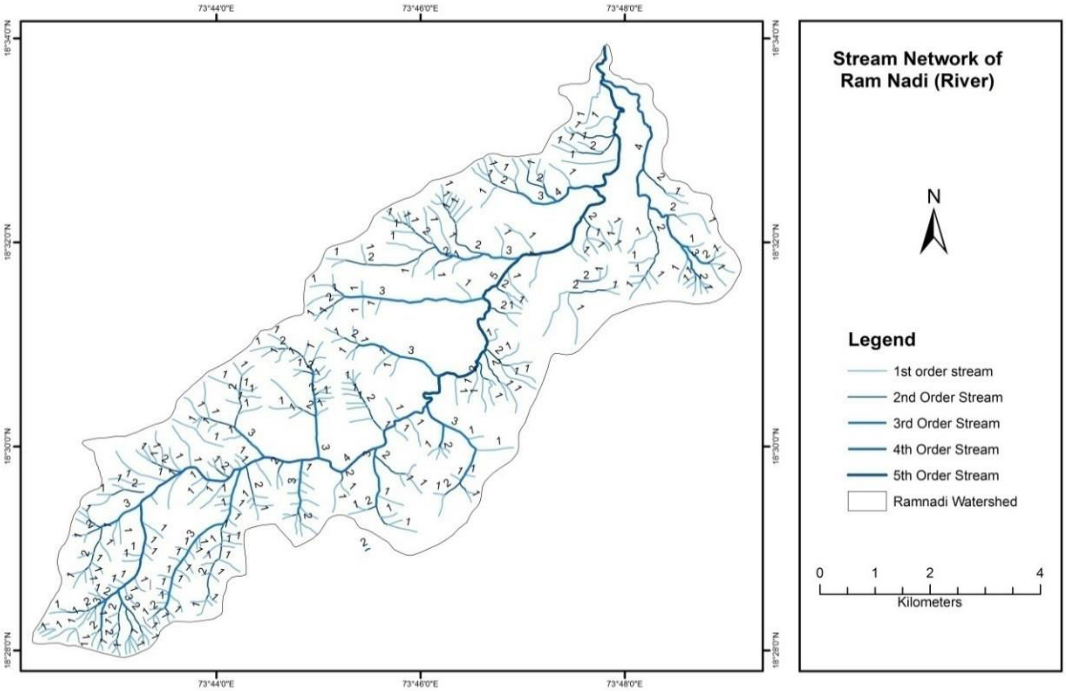


Figure 34 : Stream Network of Ram Nadi Watershed

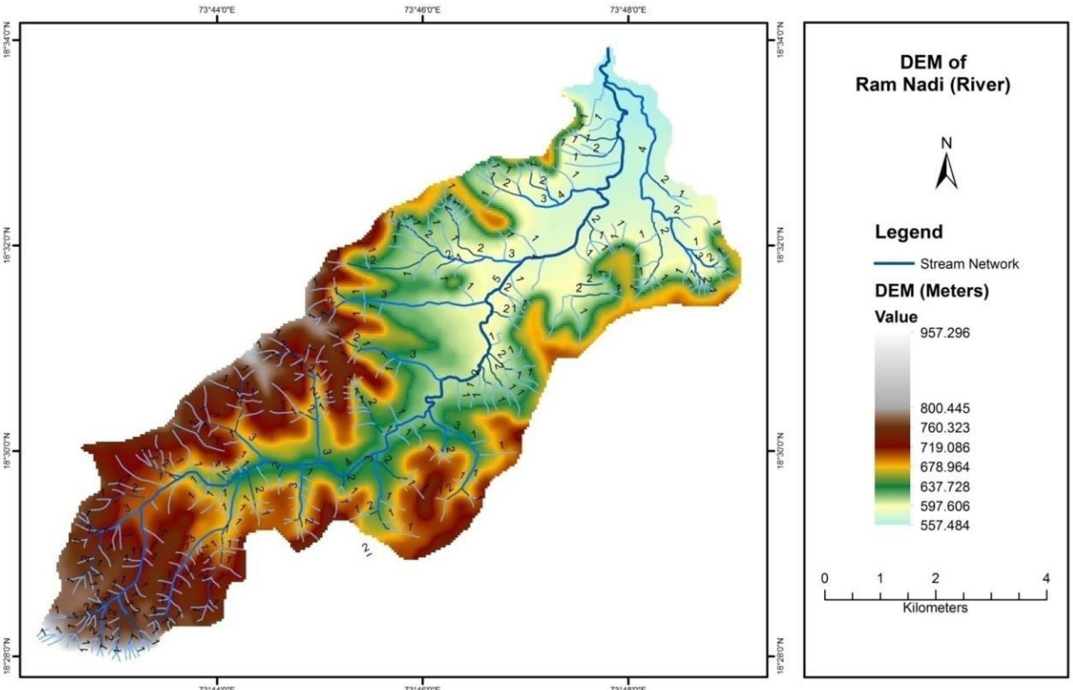


Figure 35: DEM of Ram Nadi Watershed

4.3.2.1. Supervised Classification (LANDSAT 5) and Change Detection

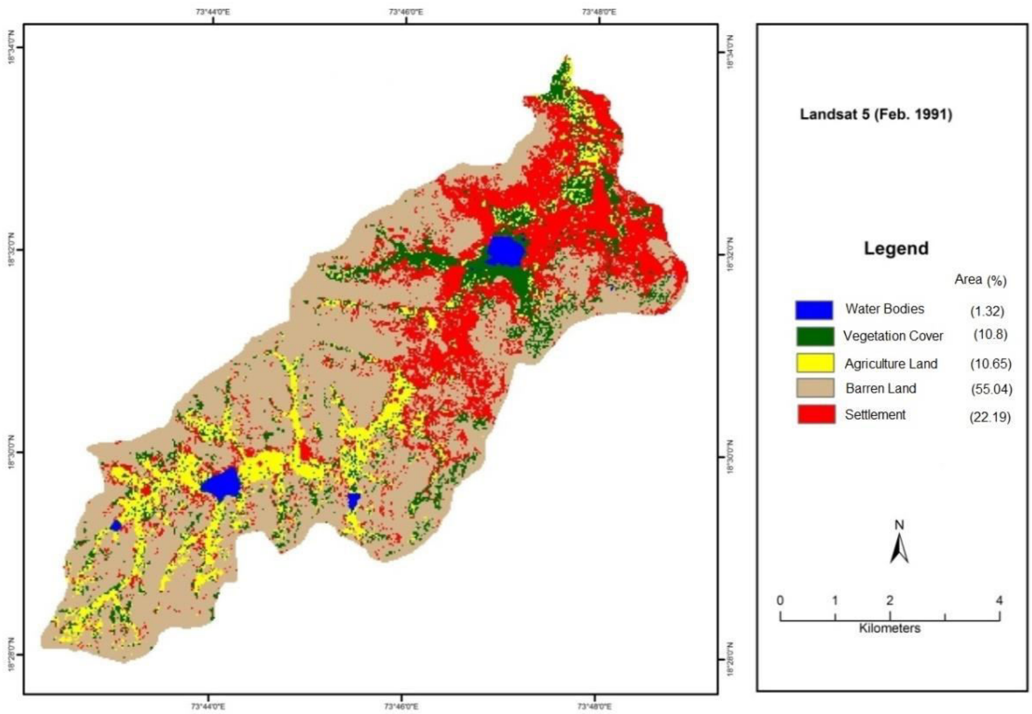


Figure 36: Change Detection of Ram Nadi Watershed (1991)

As per Land Use and Land Cover analysis in the year 1991 shows that classes were spread as Water bodies 1.32%, Vegetation cover 10.8%, Agriculture land 10.65%, Settlements 22.19% and Barren land 55.04%. The physical features were present on 67.16% and human activities were present on 32.84% land. Settlement area is denser on the northern part and distributed dispersedly on the south and central part of the study area. Agriculture is still practiced in the central and southern part. Water bodies like lakes, reservoir and main stream are present in this part of the study area. Barren land is also seen on the west and south western part.

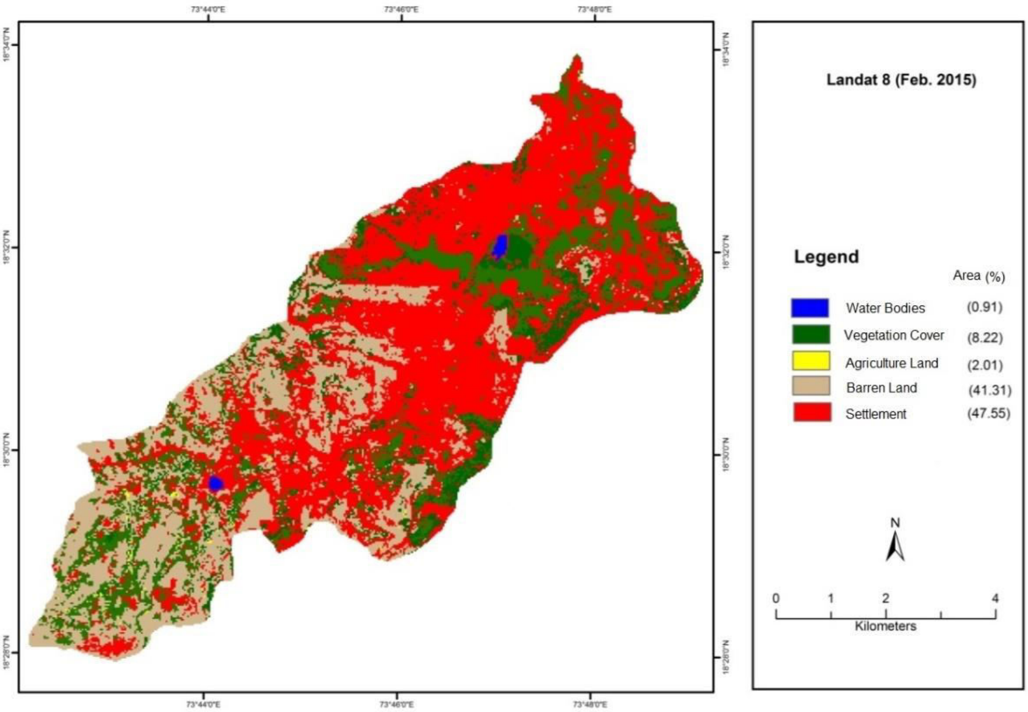


Figure 37: Change Detection of Ram Nadi Watershed (2015)

The LULC analysis of 2015 shows significant changes as compared to LULC in 1991. Area covering Water bodies 0.91%, Vegetation 8.22%, Agriculture 2.01%, Settlements 47.55%, and Barren land on 41.31% in 2015. Physical features accounted 50.44% of the total area and human activities on 49.56% of the total area. The settlements developed rapidly in south and south-eastern part of this part of the study area. Settlements of central part have become denser. Agricultural activities, vegetation has decreased and most of the barren land is converted into the human settlements.

4.3.1.1 Spatio-temporal variation in Land use and Land cover

Table 19: Comparative LULC of Ram Nadi Watershed (1991 and 2015)

Sr. no	LU LC	Area 1991 (%)	Area 2015 (%)	1991 (Hectare)	2015 (Hectare)
1	Water Bodies	1.32	0.91	67.77	46.72
2	Vegetation	10.8	8.22	552.87	420.80
3	Agriculture	10.65	2.01	545.94	103.04
4	Barren Land	55.04	41.31	2820.69	2117.05
5	Settlements	22.19	47.55	1137.42	2437.33

In 1991 the northern side of the study area was developed largely, particularly in Aundh and Pashan. Bavdhan, one of the developing areas, is situated in the central part of the study area. Villages like Pirangut and Sutarwadi are situated in Sahyadri ranges. Agricultural activities are mainly found in these outskirt villages. There are two major water bodies in this study area, one is Pashan Lake and another is Manas Lake in the western side near Bhugaon.

In 2015 Pashan, Bhugaon and Bavdhan areas grew rapidly to the far west. Bavdhan experienced very high percentage of urbanization. The map shows that this growth of settlement is growing towards the west side. Hills near Bavdhan and Pashan were mercilessly sliced by builders and developers for constructing colonies and towers causing depletion of vegetation and barren land. As per the map, this growth will further grow towards west.

The State Highway 93 connects Konkan region to Pune via Tamhini Ghat. This road is primary connecting road to the villages like Pirangut and Sutarwadi. As Human interference in this region is moderate but, still there are Barren lands available for future growth.

4.3.1.2 Non Existing Streams in Ram Nadi Watershed

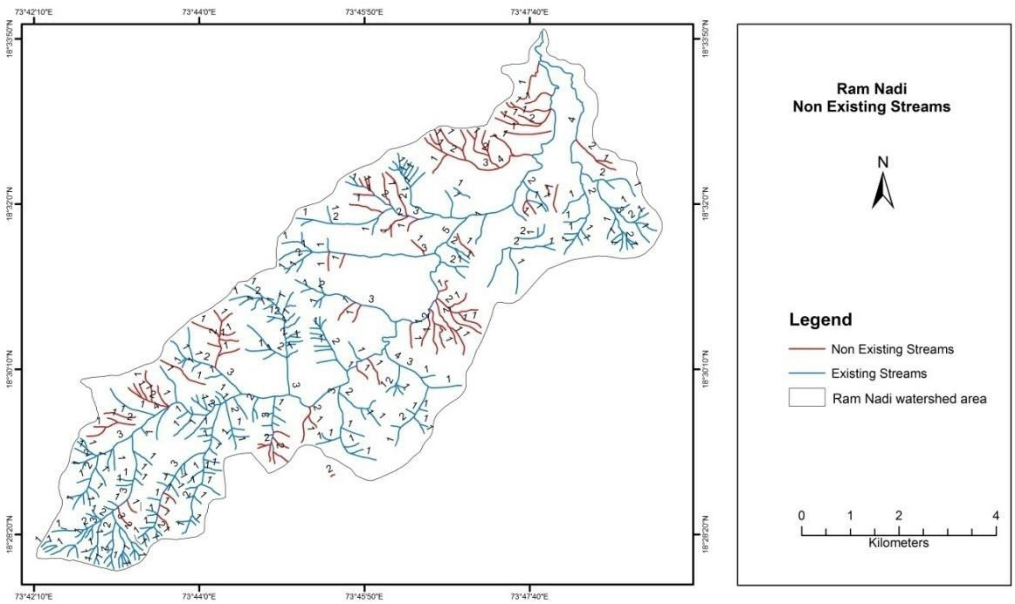


Figure 38 - Non Existing Streams in Ram Nadi Watershed

The drainage network analysis of Ramnadi from the toposheet no.47F/14/2, 47F/14/3, 47F/15/SE, (year 1970-80) shows the stream order and numbers in table no. 38. The results indicate reduction in stream number. This watershed region is having the highest number of streams i.e. about 323 first order streams; 86 of them have now become non-existing. Similarly not only 16 streams out of 67 second order streams have become non-existing but also 3 stream out of 21 third order stream and one stream out of 4 fourth order stream have also become non-existent. There were no changes recorded in the fifth order stream. There are around 416 streams in total and out of them 106 streams dose not exist. Most of the streams were destroyed due to continuous construction activities in this watershed. From 1970-80 to 2015 only 74.52 % streams are intact in the concerned area. This shows that around 25.48% streams non-exist in watershed area.

Photo 1: Retaining wall in Ram Nadi channel (Front View)

Photo 2: Retaining wall in Ram Nadi channel (Back View)

Since two decades, Ram Nadi has been in spotlight due to urban encroachment. Areas such as Bhukum to Baner, having new constructions, are facing flash floods. In spite of that, plotting and construction activities at the source of Ram Nadi are increasing day by day. Half of Bhukum has hilly terrain, which lies offshoot of Sahyadri range. From Manas Lake to Bhugaon Village, this river flows like a minor stream, with sewage and construction debris being deposited in the stream along its way. In the last 5 to 6 years, construction activities have increased near Paud-Pirangut area, so its impact is seen on total landscape of concerned area. It is observed that, flash flooding is activated mainly in rainy season because of dumping construction debris and sewage deposition, ultimately blocking the natural flow of stream.

Photo 3: Dumping in Channel

Photo 4: Construction and Dumping near Channel

The second part of Ram Nadi flows from Bavdhan to Pashan area. Due to unplanned construction activities, 20% of total streams of this watershed have non-exist. At both sides of Bavdhan road, near Chandani Chowk, around 7 first order and 3 second order streams have vanished. Sagar Cooperative Society, Vinyan nagar society and Shinde nagar area are located on streams, which have disappeared. The eastern sides of Bavdhan, foot hills are excavated (30^0 slope) and totally occupied by commercial and residential buildings. Pashan Lake, having historical importance has been destroyed due to dumping of sewage and construction debris.

Photo 5: Construction on Hill Slope (Bavdhan Area)

Photo 6: Construction on Stream (Banner - Pashan Road)

Pashan - Sus road is constructed in east- west direction on north- south Pashan hill cutting the hill against slope and residential development from State Bank Nagar to Pashan Lake which covers half the hills are the main cause of obstructing the natural flow of water.

Ram Nadi has no proper flood line demarcation done till today. Reason behind the flash floods, according to local residents, is the careless attitude of local government (PMC) towards encroachment into the flood lines of City Rivers / natural streams of Ram Nadi.

The width of the river channel has decreased by illegal construction activity dumping of construction debris near the confluence of Ram Nadi and Mula River. Due to reduction in width of Ram Nadi its channel is burdened by fluctuating volume of water causing harmful conditions for surroundings. Construction of retaining wall along the channel banks by PMC may create problem of flood in monsoon due to reclamation of land in flood zone by builders or societies. Also, the construction of retaining wall has reduced its width which covers almost 15% of the channel area creating problems like, overflow of sewage which gets mixed with river stream spreading all over causing water logs and back wash.

Photo 7: Sewage dumping in channel (Pashan *Gaothan*)

Photo 8: Silt deposition near Pashan Lake

Photo 9: Construction on stream near Chandani chowk – Bawdhan

Photo 10: Sewage dumping and unwanted vegetation in channel (Bhugaon)

4.3.2. Nandoshi Watershed Area

The rivulet in Nandoshi drains a catchment of 15.93 sq.km. It is located to the south of Pune City between 18°23’5’’N to 18°27’37’’N Latitudes and 73°47’21’’E to 73°49’19’’E Longitudes. The rivulet originates at an elevation of 1020 m above mean sea level (AMSL) near the Sinhagad- Bhuleshwar range, in the Western Ghats and flows toward north-west direction to join the Mutha river. This watershed area consists of Nanded, Kirkatwadi and Nandoshi villages. The physiography in the upper catchment area is hilly and of undulating nature. A dendritic type of drainage pattern is observed as the rivulet flows through the basalt. In summer season this rivulet is dried up at watershed source to Nandoshi village. Due to less urbanization in this area, water in this rivulet is comparatively of good quality. Central Water & Power Research Station tested water in this rivulet in Nanded area. This rivulet also passes undisturbed through Nanded City township area.

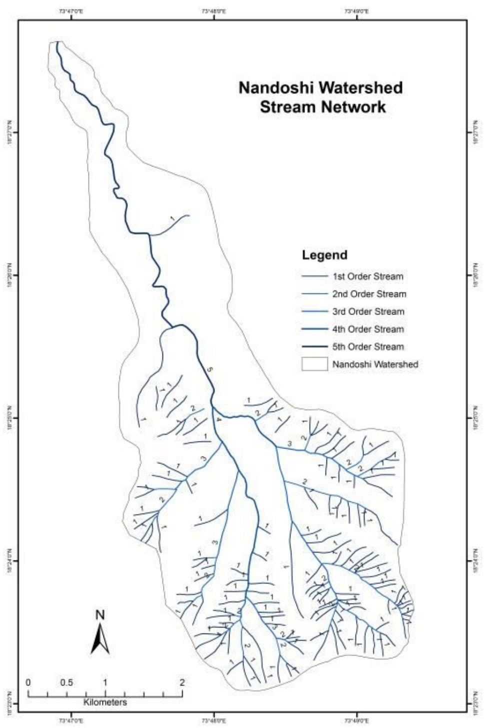


Figure 8: Stream Network of Nandoshi Watershed

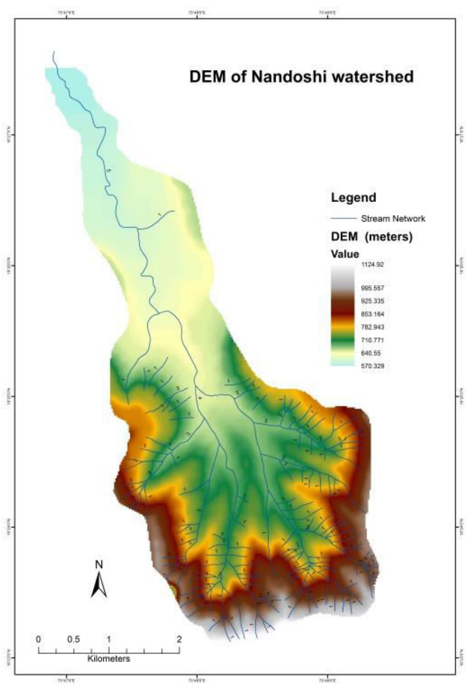


Figure 39: DEM of Nandoshi Watershed

4.3.2.2. Supervised Classification (LANDSAT 5) and Change Detection

The result of classification shows that area under Water bodies 0.81%, Vegetation 36.74%, Agriculture 8.39%, Settlements 3.26% and Barren land 50.8%. Results suggest that physical features like Water, Vegetation and Barren Land accounts for nearly 88.35 % of the total area. It shows that in 1991 the human interference with the nature was almost negligible. Agricultural activities are found towards northern side near the water body while the settlement has saturated in the middle part and vegetation is on the hill slope on southern side.

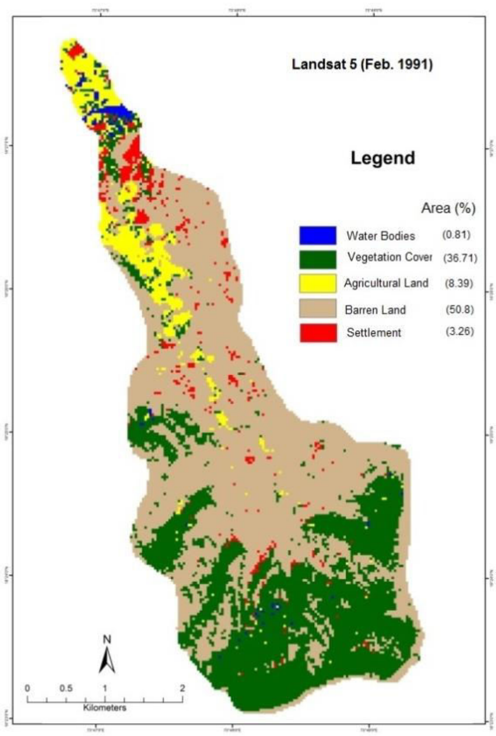


Figure 9: Change Detection of Nandoshi Watershed (1991)

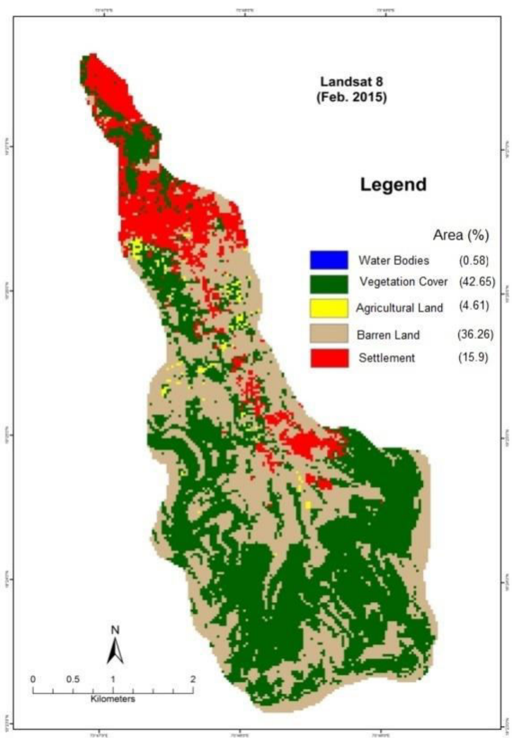


Figure 10: Change Detection of Nandoshi Watershed (2015)

The situation change in 2015 Land use pattern changed considerably. Water bodies is 0.58%, Vegetation 42.65%, Agriculture 4.61%, Settlements 15.90% and Barren Land: 36.26%. Physical features account for nearly 79.49% of the total area. Human settlements and Agricultural activities are covering over 20.51 % of the area. Present development is spreading towards north direction and has increased in central area too. It is also obsereved that vegetation cover particularly in the southern part of the study area has increased.

4.3.2.3. Spatio-temporal variation in Land use and Land cover

Table 20: Comparative LULC of Nandoshi Watershed (1991 and 2015)

Sr. no	LU LC	Area 1991 (%)	Area 2015 (%)	1991 (Hectare)	2015 (Hectare)
1.	Water Bodies	0.81	0.58	13.05	9.34
2.	Vegetation	36.7	42.65	526.05	611.34
3.	Agriculture	8.39	4.61	106.55	58.55
4.	Barren Land	50.8	36.26	918	655.25
5.	Settlements	3.26	15.9	52.11	254.16

Nandoshi is an area surrounded by hills at south. These hills have good amount of vegetation cover. In 1991 area covered by Water was 0.81% which is lowered to 0.58% in 2015. Barren Land has decreased by nearly 4% and Agriculture lowered by 2%. The only two classes are vegetation and settlements with an increase of nearly 7% and 12% in these two decades respectively. Barren land and agriculture land predominantly are converted into 18% in to settlement and 18% vegetation respectively.

Human activities are increasing in this area. However, even in 2015, physical aspect accounts for nearly 79.49% in this area. In 1991 this number was 88%. It means that, this area is still vulnerable. Agricultural practices are still present in the area but comparatively decreased. Compared to 1991, the rate of urbanization is increasing in this area. The settlements have increased in the northern part and indicate that the direction of development is towards north.

4.3.2.4. Non Existing Streams in Nandoshi Watershed

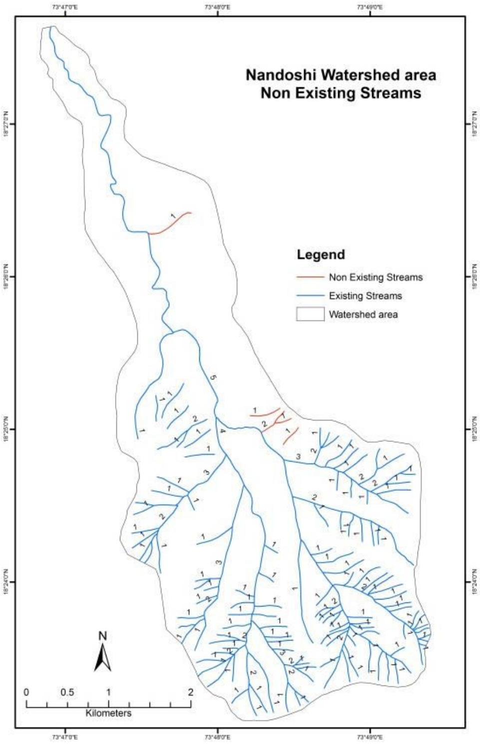


Figure 43 - Non Existing Streams in Nandoshi Watershed area

The drainage network from toposheet no. 47 F/15 NE (year 1979-80) as shown in table no 43, basin is fifth order. The results indicate reduction in stream numbers. Most of the northern part is covered with development and the remaining part is still covered with vegetation. This area is away from the main city. Due to its physiography, Nandoshi watershed area has comparatively low number of streams. In 2015, the satellite image analysis and field survey indicates that during the last 25 years, there is a drastic change in drainage network. Out of 130 first order streams, 5 of them are now become non-existing. One second order streams reduced out of 22 streams. There is no change in the number of third, fourth and fifth order streams.

The southern part of the watershed region is of highly terrain and there is no sign of urbanization as a result only 3.73 % streams are reduced during last 25 years. Vegetation cover is maintained and in some areas, it has been increased due to forest land. The northern part of the watershed is recently added in PMC and result in rapid urbanization.

Photo 11: Sewage in Channel

Photo 12: Garbage Dumping in Channel near Kirkitwadi

4.3.3. Ambil Odha (Rivulet)

The Ambil Odha (rivulet) drains a catchment of 30.02 sq.km. It is located to the south of Pune City between 18°23’40’’N to 18°30’33’’N Latitudes and 73°50’20’’E to 73°53’30’’E Longitudes. The rivulet originates at an elevation of 1100 m above mean sea level (AMSL) near the offshoot Western Ghats and flow towards north north-west direction to join the Mutha river. This watershed area consists of Katraj area, Dhankawadi, Sahakar Nagar, Navi peth area of Pune city and three villages at southern part of watershed i.e. Bhilarewadi, Gujar Nimbalkarwadi and Mangdewadi. The physiography in the upper catchment area is hilly and of undulating nature. A dendritic type of drainage pattern is observed as the rivulet flows through the basalt. The water from the upper catchment areas gets accumulated in a reservoir known as Katraj Lake from where the rivulet flows. (Joglekar et.al. (2006-07)) have reported the presence of a tributary stream (Ambil Odha) which drained during the Holocene period at an elevation of around 549m AMSL. The documentary evidence reveals that the rivulet was diverted during the Peshwa era in 17th century. The need for such construction was to meet the water demand of the areas near Pune city. The overall altitude in the study area ranges between 1100 m and 550 m above MSL.

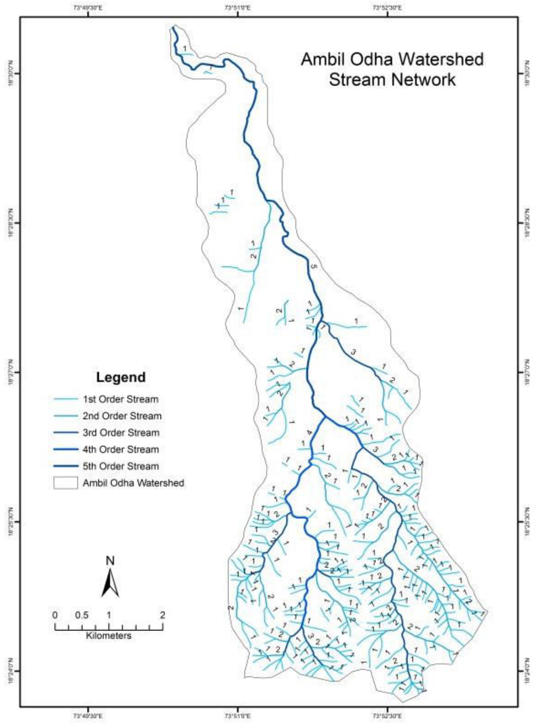


Figure 44 - Stream Networking of Ambil Odha (Rivulet)

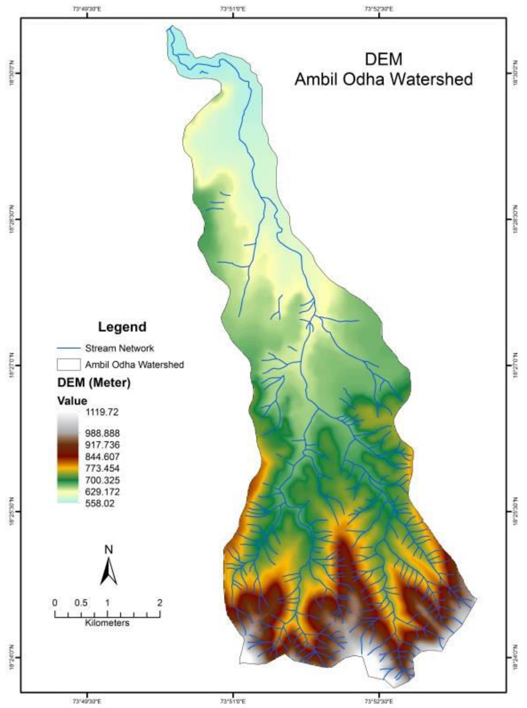


Figure 45 - DEM of Ambil Odha (Rivulet)

4.3.3.1. Supervised Classification (LANDSAT 5) and Change Detection

In 1991, this watershed area was occupied by water bodies 0.75%, Vegetation 21.29%, Agriculture 0.79%, Settlements 37.91% and barren land was 39.26% of the total area. Vegetation, Water Bodies, Agriculture and Barren Land together account nearly 62.1% area whereas remaining is occupied by human settlement, 37.9% area. In 1991, watershed area occupied by settlements like Sahakarnagar, Parvati, Navi peth and Dhankawadi. During last 25 years a rapid growth of urbanization has been observed towards source region. Expect Katraj Lake, no significant water reservoir is present in the area. Agricultural activities are limited. There is barren land in southern Katraj, Magalewadi, Bhilarewadi and Gujar Nimbalkarwadi available in 2015 landuse pattern was changed in different parts of plenty of barren land available.

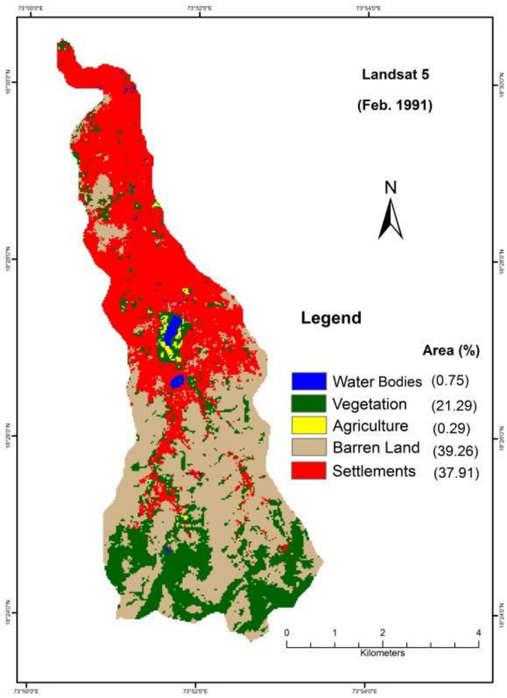


Figure 14: Change Detection of Ambil Odha (Rivulet) (1991)

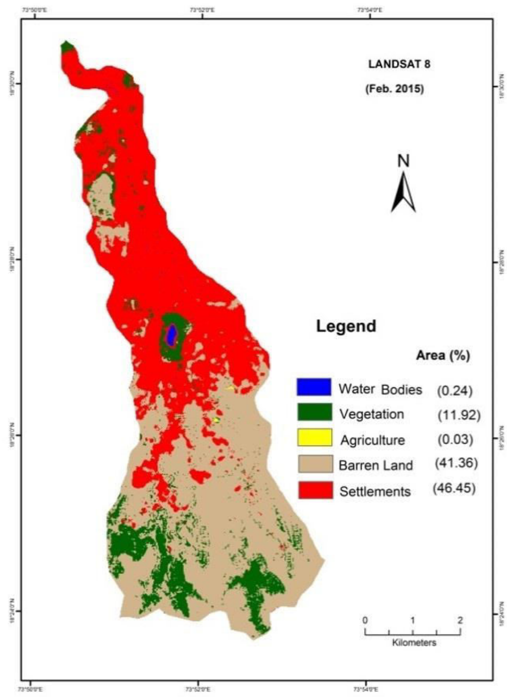


Figure 15: Change Detection of Ambil Odha (Rivulet) (2015)

Water Bodies 0.24%, Vegetation 11.92%, Agriculture on 0.03%, Settlements 46.45%, and Barren land 41.36% are observed in Ambil odha watershed area. The physical features occupied nearly 53.52% and human activities were present on 46.48% of the total land. Around 2015 settlement area has increased by 8.94%, i.e. as compared to the area 1991. It is observed that the southern and eastern part area newly developed residential area.

4.3.3.2. Spatio-temporal variation in Land use and Land cover

Table 21- Comparative LULC of Ambil Odha Watershed (1991 and 2015)

Sr. no	LU LC	Area 1991 (%)	Area 2015 (%)	1991 (Hectare)	2015 (Hectare)
1	Water Bodies	0.75	0.24	22.05	7.06
2	Vegetation	21.29	11.92	644	360.57
3	Agriculture	0.79	0.03	23.94	0.91
4	Barren Land	39.26	41.36	1188.36	1251.92
5	Settlements	37.91	46.45	1147.41	1405.89

Navi peth lies in the eastern core area of the city; hence it is densely populated in both the maps. The concentration of settlement is mainly at Vishrambaug Vada, Sahkar Nagar and Dhankawdi area. These areas are saturated because of urbanization. Differences can be observed in the southern parts like Bhilarewadi and Mangadewadi. Human settlements are increasing in this area because of availability of land.

In 1991 southern villages like Mangadewadi, Bhilarewadi and Gujar Nimbalkar wadi had low amount of settlements and this area was occupied with vegetation and barren land. During last 25 years growth of settlements reached up to the lower hills of Bhilarewadi. This encroachment of the hills has resulted into the loss of vegetation and causing hill slop alteration. National Highway number 4, passes through this area, which is also an important reason for the growth of settlement in the area. It is an important connecting road which triggered growth of settlement alongside this road. Upper hilly area is still free from the human interference but lower hills area having fewer gradients is slowly populating. These growing settlements are heading towards the southern part of the watershed area and few hilly areas because of the saturation and unavailability of land in the northern side.

4.3.3.3. Non Existing Streams in Ambil Odha (Rivulet)

The drainage network analysis of Ambil odha from the toposheet no. 47/F/14/3, 47/F/14/6, 47/F/15/NW, 47/F/15/NE (year 1970-80) show the stream order and numbers in table no. 48. For the change detection in stream order and stream number during last 25 years a morphometric analysis of Ambil odha for the year 2015 based on satellite image and field survey was carried out. The result indicates reduction in stream number. Rapid growth of urbanization is responsible for loss of 48 first order streams out of 235 during this period. 11 second order and 1 third order streams are now not in existence due to construction as well as slope alteration and mining activity. From 1970-80 to 2014 only 78.87 % streams are safe in concern area. This shows that around 21.13% streams are non-existing streams.

The old Katraj tunnel towards southern Bhilarewadi village boundary area is well covered with vegetation. Old Katraj tunnel road area is a hilly area and some hills in this area with 30^0 to 40^0slope were cut massively and excessively altered for construction activities. Increased demand for land, the agricultural land and vegetation covered land was purchased by builders and plotting and construction of internal roads change the land use pattern of the area. The hill slope and upper spur area now converted into residential and commercial activity centres.

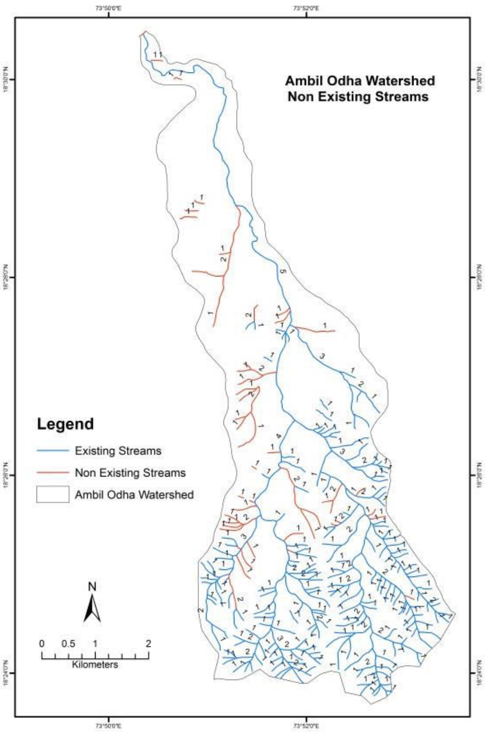


Figure 48 - Non Existing Streams of Ambil Odha (Rivulet) Watershed area

Katraj gaothan having dense population density and compact settlement has become prone to environmental problems. Due to unplanned and illegal development sprawl 4 first order streams and 2 second order streams have been disappeared. Bhilarewadi lake - new Katraj Lake - Rajiv Gandhi Udyan Katraj lake are connected/Linked with one major stream, these lakes are stored upto its capacity and remaining water is discharged into the next water reservoir. Newly constructed manmade Katraj Lake has only one source of water collection, which comes from this main channel. It has no other source of streams for water collection. Presently first order streams have totally disappeared due to lack of negligence about environment. Dhankawadi area is totally set up upon eight first order streams and two second order streams which do not exist today. Now this area does not have stream footprint for stream detection. Near Katraj Lake total three first order streams have disappeared due to construction of multistoried buildings. Massive construction activity with unplanned development has hampered the whole stream network.

Photo 13: Ambil Odha from Katraj Lake

Photo 14: Condition of Channel at Bibvewadi

Photo 15: Construction in Channel at Mangadewadi

Photo 16: Slope cutting near Bhilarewadi Lake

Due to covering of natural land with concrete and tar road water percolation decreased and surface runoff increased. Ambil Odha flowing from Katraj Lake to Mutha River has not been connected by any natural streams. City's sewage line is connected with Ambil odha, so water contamination with sewage water is become major issue in this area. In most of the areas concrete channels were constructed with 8 feet width 10 to 14 feet high retaining wall has been constructed along the channel.

Two minor first order streams near Navi peth area have disappeared due to total negligence due to human activities and encrochment. Depositions of sewage waste on both sides of this rivulet near confluence of Mutha River were observed polluting its microenvironment.

Photo 17: New Katraj Lake

Photo 18: Dumping in Channel at Katraj

Photo 19: Sewage line from Katraj Lake

Photo 20: Hill cutting at Mangadewadi, Bhilarewadi

Photo 21: Massive dumping near Gangadham Society

4.3.4. Bhairoba Nala

The Bhairoba nala (rivulet) drains a catchment of 27.78 sq.km. It is located to the south of Pune City between 18°24’42’’N to 18°32’24’’N Latitudes and 73°52’30’’E to 73°54’22’’E Longitudes. The rivulet originates at an elevation of 1000 m above mean sea level (AMSL) near the offshoot Western Ghats and flows towards north north-west direction to join the Mutha river. This watershed area consists of Kondhwa area, Pune Cantonment, Bibewadi, Fatima Nagar in Pune city and a village Yewalewadi. The physiography in the upper catchment area is hilly and of undulating nature. A dendritic type of drainage pattern is observed as the rivulet flows through the basalt.

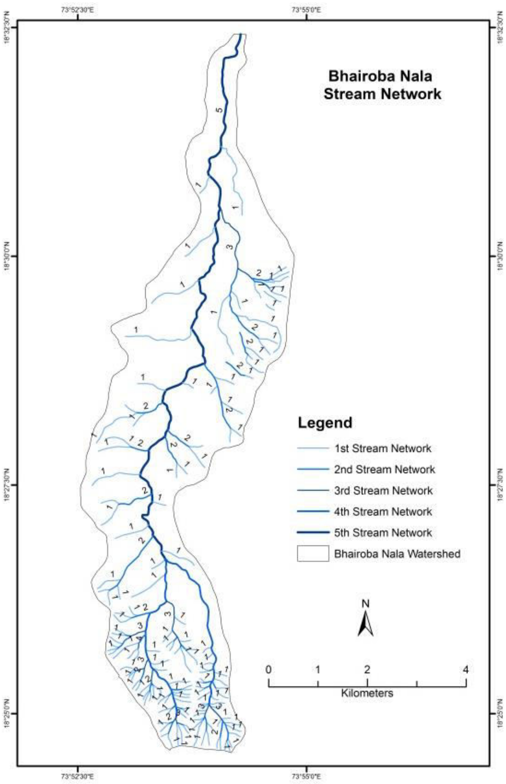


Figure 49 - Stream Network of Bhairoba Nala

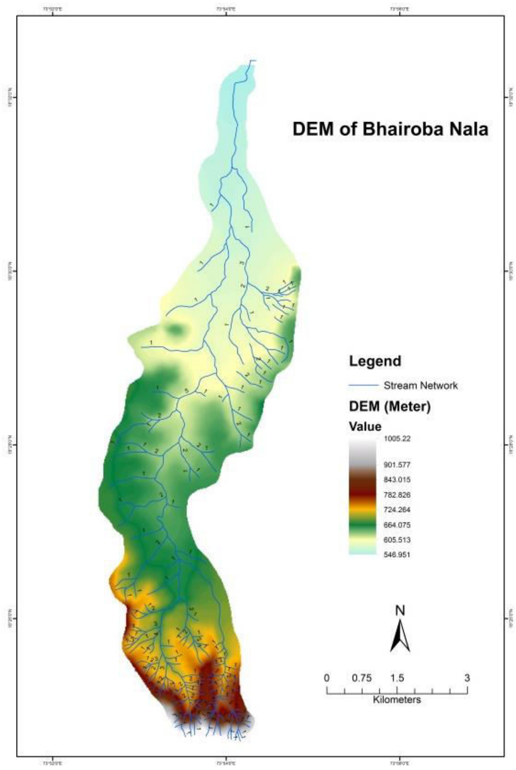


Figure 50 - DEM of Bhairoba Nala

4.3.4.1. Supervised Classification (LANDSAT 5) and Change Detection

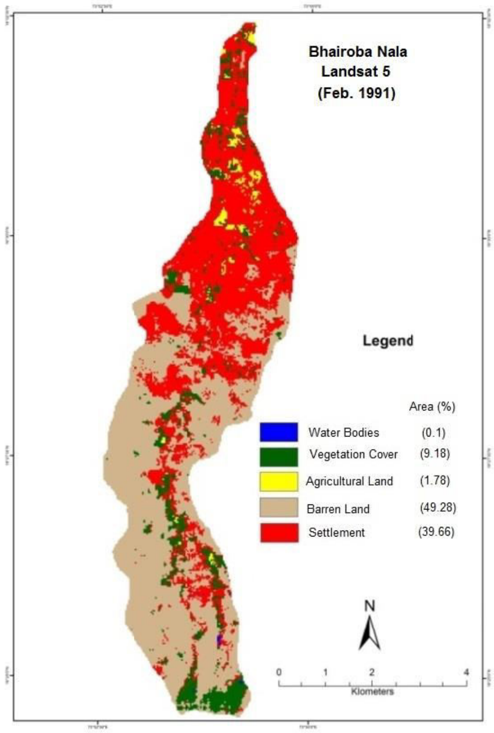


Figure 20: Change Detection of Bhairoba Nala Watershed (1991)

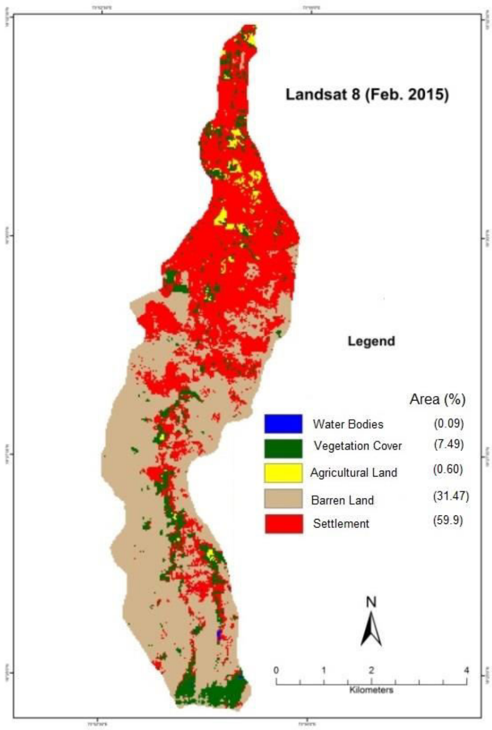


Figure 19: Change Detection of Bhairoba Nala Watershed (2015)

The result of classification in 1991 shows that area under Water Bodies 0.1%, Vegetation 9.18%, Agriculture 1.78%, Settlements 39.66% and Barren Land 49.28%. The physical features account nearly 58.56% of the total area and Human interference was on 41.44%. Human settlements are densely spread out on northern side of the study area. Some part of agriculture land is also observed on the northern side, vegetation lies mainly on the southern side and barren land is in the central part of the study area.

The situation in the 2015 Land use pattern changed considerably Water Bodies 0.09%, Vegetation 7.94%, Agriculture 0.6%, Settlements 59.09% and Barren Land on 37.47%. Physical features have occupied 39.5% and Human activities are presently on 60.5% of the total area. In 2015 settlements on the northern part became denser and also spread to southern and south-eastern part of the study area. The analysis shows that the percentage of barren land has dropped drastically and further occupied by settlements.

4.3.4.2. Spatio-temporal variation in Land use and Land cover

Table 22- Comparative LULC of Bhairoba Nala Watershed (1991 and 2015)

Sr. no	LU LC	Area 1991 (%)	Area 2015 (%)	1991 (Hectare)	2015 (Hectare)
1	Water Bodies	0.1	0.09	2.61	2.35
2	Vegetation	9.18	7.94	257.76	222.94
3	Agriculture	1.78	0.6	50.13	16.90
4	Barren Land	49.28	31.47	1382.94	883.14
5	Settlements	39.66	59.9	1112.94	1680.92

This study area had quite dense settlements in the year 1991. Pune Cantonment is at the northern part of Bhairoba nala watershed area. Due to settlements along border of cantonment area are restricted in spread, the density of settlements is increasing towards to Pune station area. But other areas like Bibvewadi near to the central part and Yewalewadi in the south were covered by Barren land and Vegetation. Due to availability of open barren land the development of residential area increased rapidly. After 2000, the area of east Kondhwa is still Barren land.

After year 2000 Katraj, Dhankawadi area has saturated, no open space is available for construction. This leads to eastward development of settlements in Bibvewadi, Sukhsagar nagar, Kondhwa and Undri in 2015. In 2015, development in Bibvewadi became denser. Southern part of the Yewalewadi was also experiencing development. Kondhwa area (NIBM road) is presently occupied by townships and multistoried buildings. Slum areas of Kondhwa have extend Katraj-Kondhwa road. Part of ring road of Pune city is also responsible for development of educational institutes with their campus along this road. This road connects the villages in the southern part of the Pune city that has lead to rapid development of residential and commercial activity in this area.

4.3.4.3. Non Existing Streams in Bhairoba Nala Watershed

The drainage network analysis of Bhairoba nala from the toposheet no. 47 F/14 6 and 47 F/15 NE, (year 1962-63 and 1979-80) shows the stream order and numbers in table no.53. To assess the change in stream order and stream number during last 25 years a morphometric analysis of Bhairoba nala for the year 2015 based on satellite image and field survey was carried out. The result indicates reduction in stream number. First order streams from central southern region have dominant role in concerned watershed area. Rapid growth of urbanization is responsible for loss of 39 first order streams out of 145 during this period. 6 second order streams out of 40 are now not in existence due to construction as well as slope alteration. No change is observed in 3rd, 4th and 5th order streams. A total of 198 streams are present in the area but 45 of them have presently vanished which is almost 22.73% of the total streams. These streams have vanished specifically in Yewalewadi and Kondhwa part due to enormous construction activities in concern area.

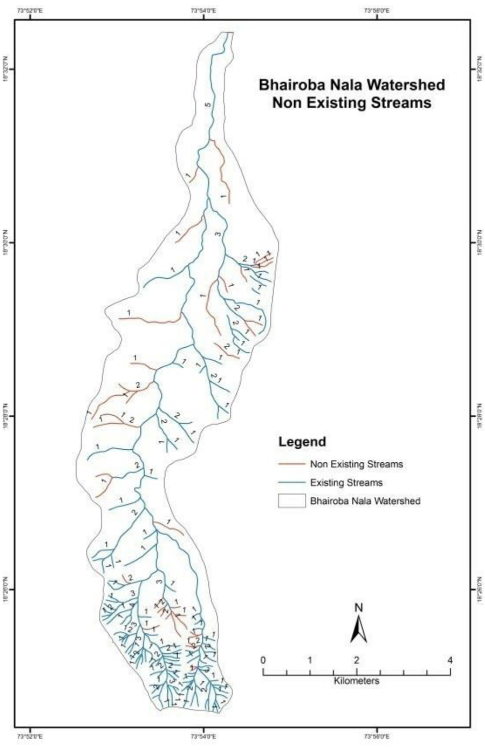


Figure 53 - Non Existing Streams in Bhairoba Nala Watershed area

Bhairoba nala originates from Bapdev ghat range in the south of Pune. Increasing quarry activities at foothills of this hill range are responsible for slope alteration, stream diversion or stream non-existence and air and noise pollution. In last two years tremendous construction activity in this area has changed the land use and land cover pattern of this area.

Upper Bhuleshwar – Sinhgad hill range slope cutting has disturbed the micro ecosystems in this watershed area. Presently, 20^0 to 30^0slope cutting and construction activities were observed in this area. As a result, around 14 to 16 first order and 3 second order streams are become none existing in southern part of watershed area.

Photo 22: Quarrying activity at Yevalewadi

Photo 23: Construction material along the road (Kondhwa)

In the middle of the watershed, starting from Kondhwa Budruk to V R Shinde road area is covered with very dense uncontrolled and unplanned development. Ambedkar nagar, a settlement along the eastern sides of the watershed, lost 2 first order streams because of unplanned construction activity. At Rupnagar, near SRPF, 2 first order streams are blocked due to dumping of construction debris and garbage. The central part of Kondhwa is particularly occupied by many un-authorized densely populated slums. 6 first order streams and 2 second order streams are lost in this area. The roads in this area are characterized by debris of construction material on both sides. During rainy season due to blockage of natural flow of streams, flash flooding is observed in this area.

Photo 24: Hill Cutting at Kondhwa road

Photo 25: Dumping in channel at Kondhwa

Due to increasing construction activity during last 7 to 8 years on hill slopes at a hill behind Ruby Hall Hospital, 3 first order streams are now not in existence.

Photo 26: Construction material along the channel

Photo 27: Construction on the stream near hill slope

4.3.5. Wadki Nala Watershed Area (Bapdev Ghat)

The Wadki Nala (rivulet) drains a catchment of 38.95 sq.km. It is located to the south east of Pune City between 18°24’22’’N to 18°30’11’’N Latitudes and 73°54’5’’E to 74°00’00’’E Longitudes. The rivulet originates at an elevation of 990 m above mean sea level (AMSL) near the eastern side of Sinhagad-Bhuleshwar range to join the Mutha river. This watershed area consists of surrounding villages of Pune city viz. Wadachiwadi, Holkarwade, Autadi Handewadi, Urali Dewachi, Phursungi, South-east part of Undri and eastern part of Shewalewadi. The physiography in the upper catchment area is hilly and of undulating nature towards south-east which directs flow of Wadki Nala towards Mutha river. A dendritic type of drainage pattern is observed. Comparatively it has scattered settlement and no interference of human activities instead it has plenty of agriculture land.

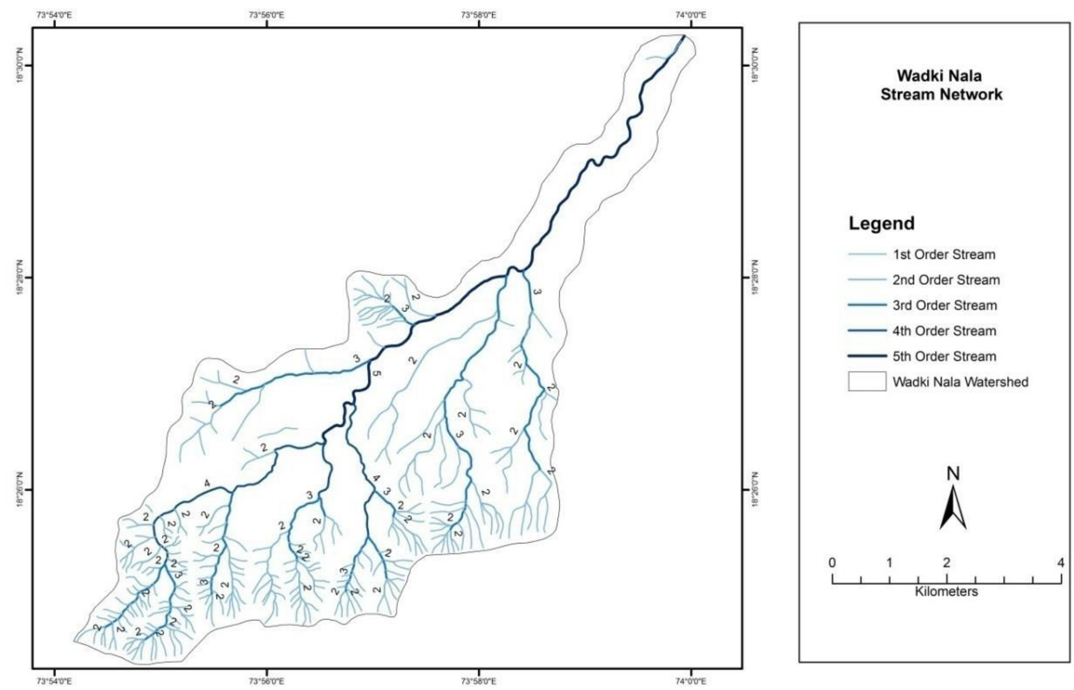


Figure 54 - Stream Network of Wadki Nala

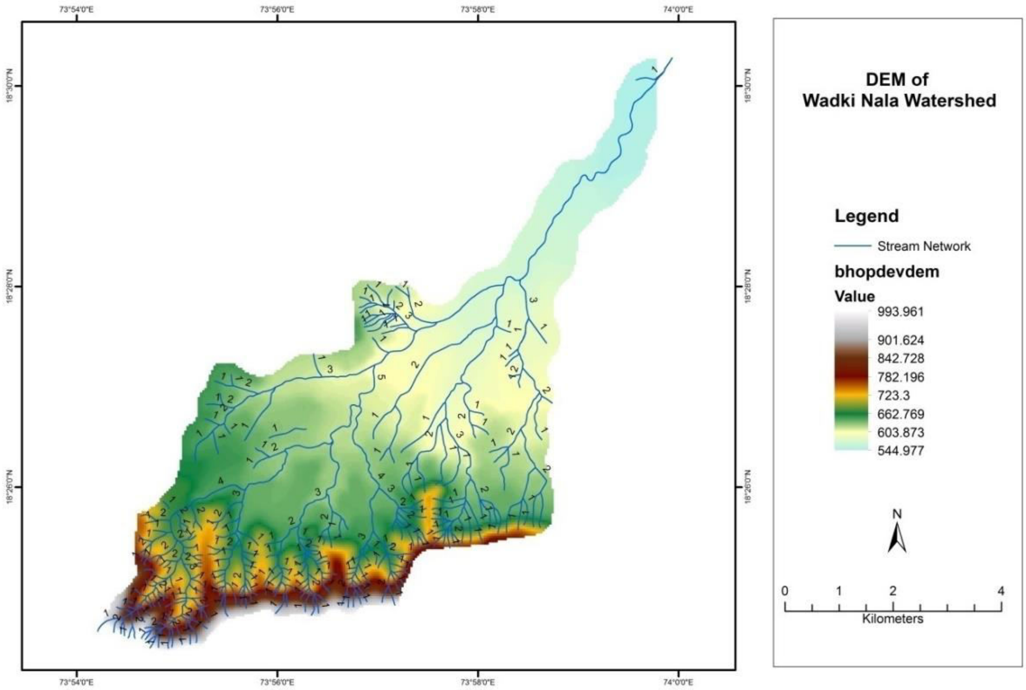


Figure 55 - DEM of Wadki Nala

4.3.5.1. Supervised Classification (LANDSAT 5) and Change Detection

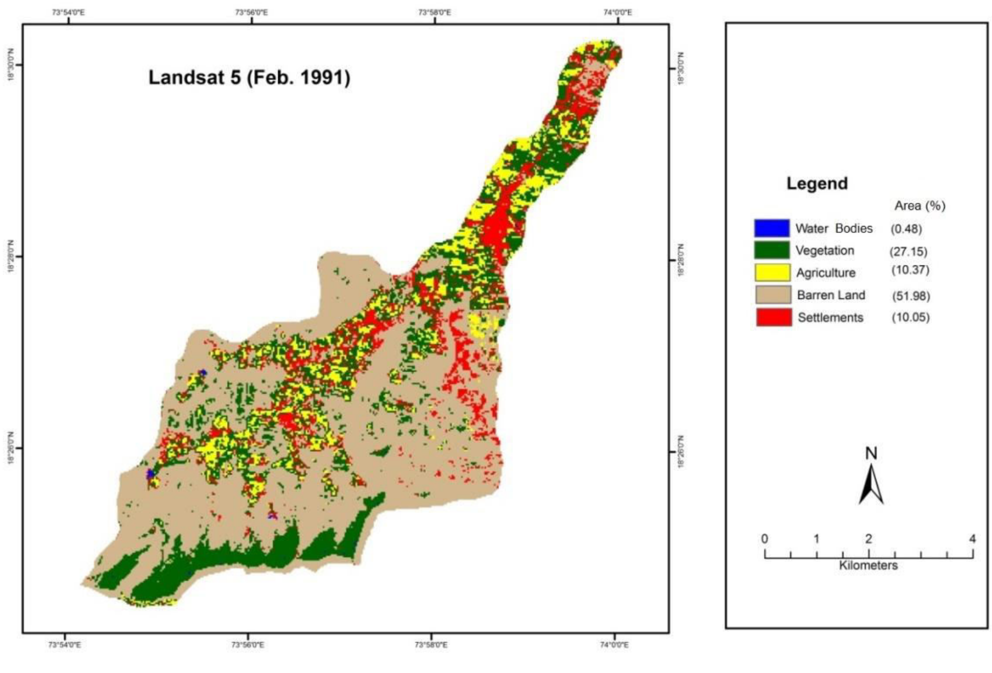


Figure 56 - Change Detection of Wadki Nala Watershed (1991)

The result of classification in 1991 shows the area under Water Bodies 0.48%, Vegetation 27.15%, Settlement 10.05%, Barren Land 51.98%, and Agriculture 10.34%. The physical aspects like water, vegetation and Barren land occupy 79.61%

and human settlement and agriculture occupy 20.39% of the total area. The numbers suggest that the human interference in physical feature is really low. Human settlements and agricultural activities are mainly found in north side of the area. Vegetation can be seen on the south side on the slopes of hills.

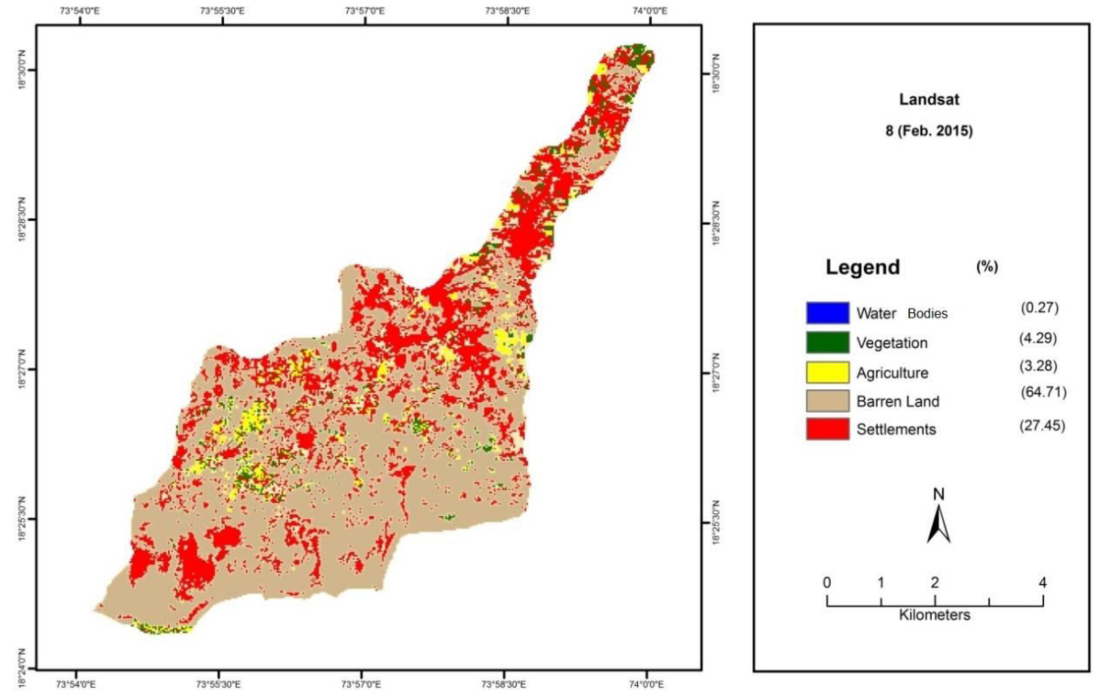


Figure 57 - Change Detection of Wadki Nala Watershed (2015)

The situation in 2015 Land use pattern has changed considerably Water Bodies 0.27%, Vegetation 4.29%, Settlement 27.45%, Barren Land 64.71%, and Agriculture 3.28%. The physical aspects occupy 69.27% of the total area and human activities occupy 30.73% of the total area. This suggests that in 2015 settlements have grown in southern part of the study area. The human interference has increased by nearly 17%.The analysis shows that the percentage of barren land has dropped drastically and further occupied by settlements.

4.3.5.2. Spatio-temporal variation in Land use and Land cover

Table 23 - Comparative LULC of Wadki Nala Watershed (1991 and 2015)

Sr. no	LU LC	Area 1991 (%)	Area 2015 (%)	1991 (Hectare)	2015 (Hectare)
1	Water Bodies	0.48	0.27	4.50	2.53
2	Vegetation	27.15	4.29	873.90	138.09
3	Agriculture	10.34	3.28	846.43	268.50
4	Barren Land	51.98	64.71	4135.55	5148.35
5	Settlements	10.05	27.45	799.95	2184.94

Wadki Nala watershed area is dominated by many natural/ physical features. It is observed that agriculture and vegetation areas are wide spread in these parts. In the centre part of study area lies Uruli Devachi village and on northern side Phursungi which had good agricultural land converted in to settlement area during this period. Holkarwadi and Wadachi wadi are situated in the southern part of study area which has offshoot hill ranges of Sahyadri. These hilly areas have dense vegetation around. Most of the lands in Handewadi were barren land. It has been observed that in 2015 most of the hilly areas in southern part are still free from human interference. There is no major water body present in this area and plenty of barren land is also available. Presently agriculture is still practiced in patches of this area. Bopdev ghat area has few settlements at its foothills and Pune-Saswad road has some residential and commercial development along the road in patches.

4.3.5.3. Non Existing Streams in Wadki Nala Watershed

The drainage network analysis of Wadki Nala from the toposheet no 47 F/14 6 and 47 F/15 NE, (year 1962-63 and 1979-80) was carried out. For the change detection the stream order and numbers in table no. 58. During last 25 years due to rapid growth of urbanization the morphometric analysis of Wadki Nala for the year 2015 based on satellite image and field survey. The results indicate reduction in stream numbers. Rapid growth of urbanization is responsible for loss of 42 first order streams out of 241 during this period. 10 streams out of 57 second order a streams are now not in existence due to construction as well as slope alteration and mining activity. All third, fourth and fifth order streams are safe in near past. There are around 364 streams in total and out of them 52 streams have become non-existent As per the calculation of stream loss in percentage, from 1970-80 to 2015 in Wadki nala watershed region only 83.44 % streams are safe in the concerned area. This shows that around 16.56% streams are non-existing streams. Most of the streams passed through borders of agriculture land holding in past but presently paddy agricultural fields were observed on these streams.

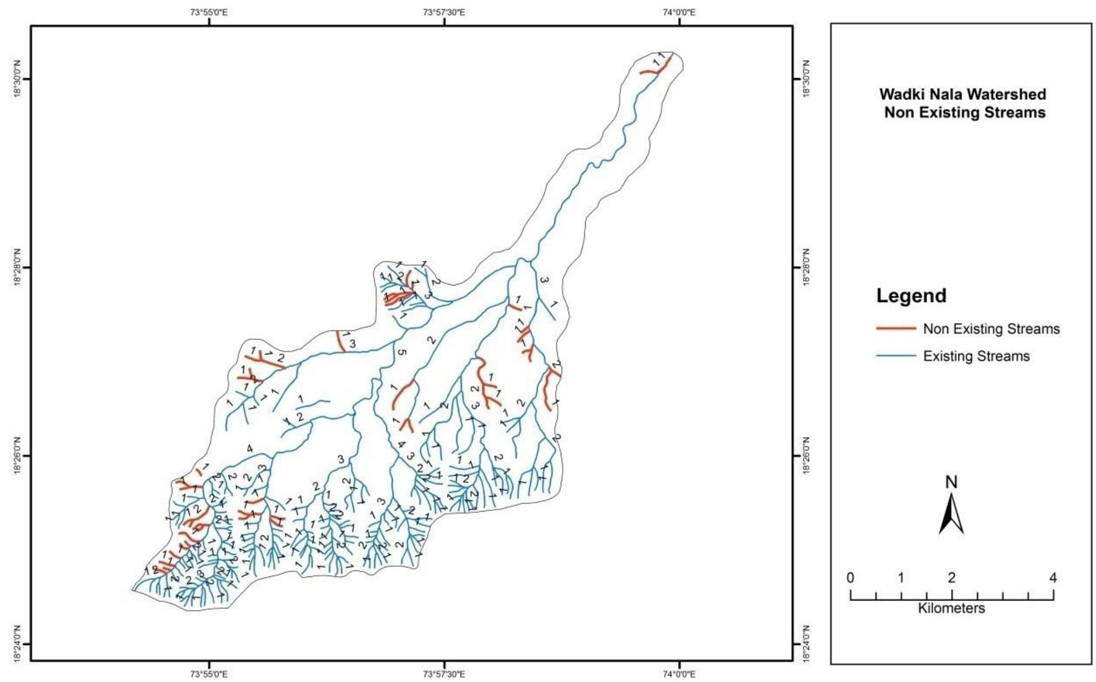


Figure 58 - Non Existing Streams in Wadki Nala

Wadki Nala flows from South to North–West direction of study area. Most of the streams in southern part i.e. hilly area have been flowing in this direction. Majority of streams have played a significant role for Wadki Nala. Intensive quarrying activities near Bapdev ghat results in air pollution, increase in barren land and destruction of streams. 15 first order and 3 second order streams are now nowhere due to these activities in upper Wadki Nala area.

Undri, Pisoli areas have upcoming residential destinations in Pune city as most of the agricultural land of this area converted into residential land. Bapdev Lake was constructed at Bapdev ghat area for agriculture and drinking purpose but water is continuously extracted for construction purpose. Hills slope of 20^0 of this area were sliced vertically for construction purpose to obtain flat horizontal base.

In Autadewadi, Autadewadi Lake had been constructed on 2 first order streams. However, due to construction of residential buildings near this lake, now both streams are blocked and causing Autadewadi Lake to run dry. Construction debris was dumped on both side of Autadewadi Lake. Autadewadi Lake filled with water in monsoon period for few days, but within a 15 to 20 days' time span after monsoon, lake dries up. Many upcoming residential developments are observed in Handewadi area.

Photo 28: Hill cutting at upper catchment area

Photo 29: Construction at hill slope

Near Kondhwa – Undri – Saswad road around 45 % of agricultural land has been converted into residential zone. Major upcoming residential projects are announced by builders in this area. Streams in the vicinity of this road have been occupied by sewage and plastic garbage. Due to this central part of this watershed area have been facing flash flood-like situation in monsoon.

Photo 30: Quarrying activity near Bapdev ghat

Photo 31: Construction and dumping along the stream

Solid waste dumping ground at Uruli Devachi area created many environmental and health related problems in this area. During monsoon run off passing through this dumping ground gets contaminated with hazardous elements which cause ground water as well as surface water pollution. Villagers are facing the health issues, continuous malodorous air and many social problems. Most of the open land surrounding this dumping ground is covered with plastic bags and garbage. Wadki Nala flowing From Phursungi to Bhapkar mala near Mutha River has comparatively less water, but still in good condition than other streams.

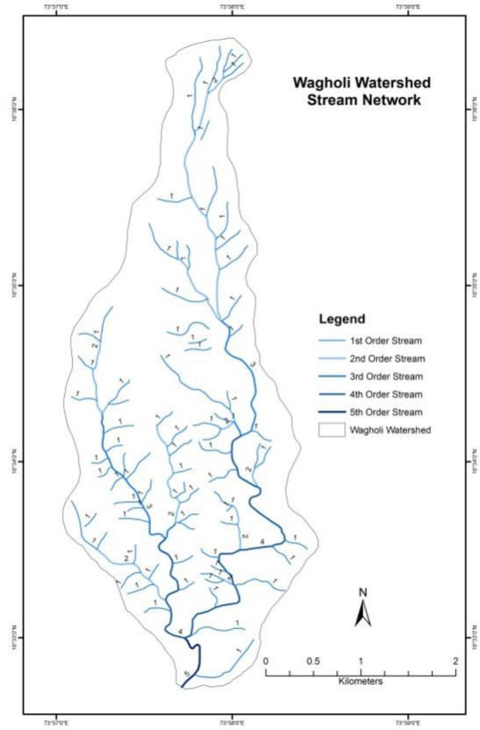
Photo 32: Dumping in stream

Photo 33: Condition of Autadewadi Lake

Photo 34: Hill cutting and plotting at Undri

4.3.6. Wagholi Watershed Area

The rivulet in Wagholi drains a catchment of 9.93 sq.km. It is located to the north-east of Pune City between 18°32'40''N to 18°36'24''N Latitudes and 73°57'2''E to 73°58'28''E Longitudes. The rivulet originates at an elevation of 680 m above mean sea level (AMSL) from Dighi hill range and flows towards south direction to join the Mutha river. This watershed area mainly consists of Wagholi area, and eastern part of Yerawada. The physiography in the upper catchment area is moderate hilly and of plateau nature. An elongated dendritic type of drainage pattern is observed as the rivulet flows through the basalt. Wagholi, is located on the Pune-Nagar Highway close to the Kharadi IT hub, has been enjoying rapid development in terms of real estate, social infrastructure and education sectors. Infrastructure development and proximity to IT hubs are the other influencing factors which are causing development in Wagholi. This region is comparatively dry than the other watershed regions. There are more than 15 stone quarries which are given on lease by the government and covers around 10 to 12 Km's area in and around this watershed area.



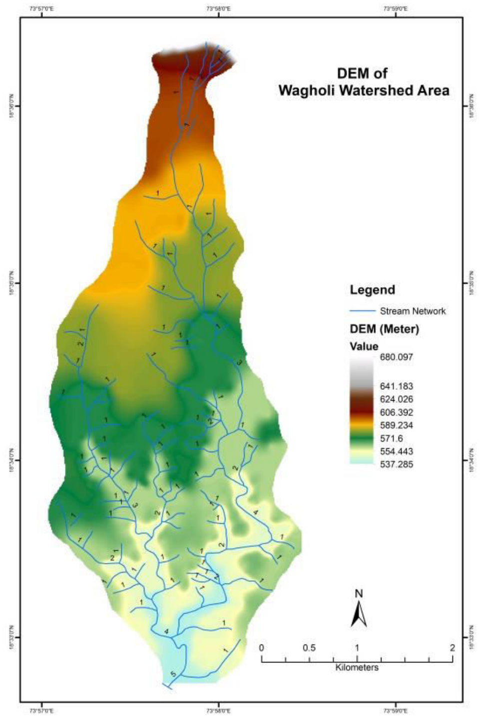


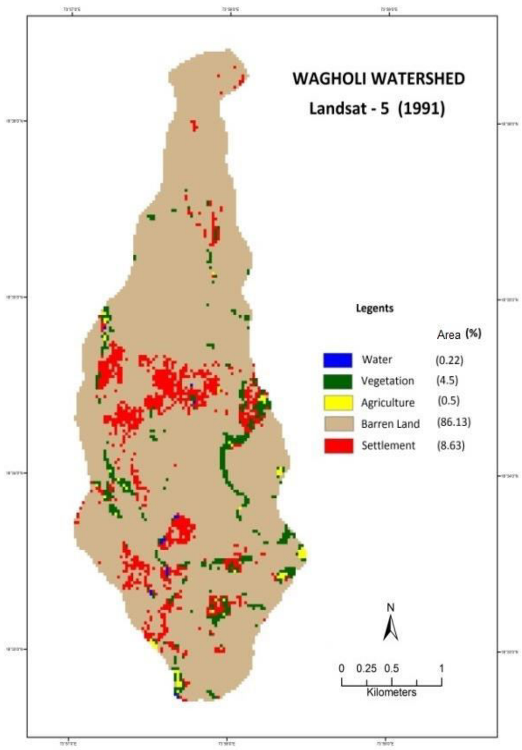
Figure 59 - Stream Network of Wagholi Watershed

Figure 60 - DEM of Wagholi Watershed

4.3.6.1. Supervised Classification (LANDSAT 5) and Change Detection

Water Bodies account for 0.22%, Vegetation 4.5%, Agriculture 0.5%, Settlement 8.63% and Barren land accounts for 86.15% of the total area. Physical Features occupy nearly 90.87% of the total area and human activities occupy 9.13% of total area. There were not much human activities carried out in this area. Barren land is the biggest class with 86.15% of the total area. There is absence of any large water body and vegetation is also very less which makes this area quite dry.

According to the 2015 map, Water Bodies covered 0.005% of the area, Vegetation on 2.42, Agriculture 0.05%, Settlements on 23.33%, and Barren land on 74.19%. In 2015 physical features were on 76.61% and human activities were present on 23.38% of the total area. In 2015 the settlement in central part grow denser. The growth of settlements can be observed in the southern part too. Vegetation and Barren land areas are lowered to quite an extent in 2010.



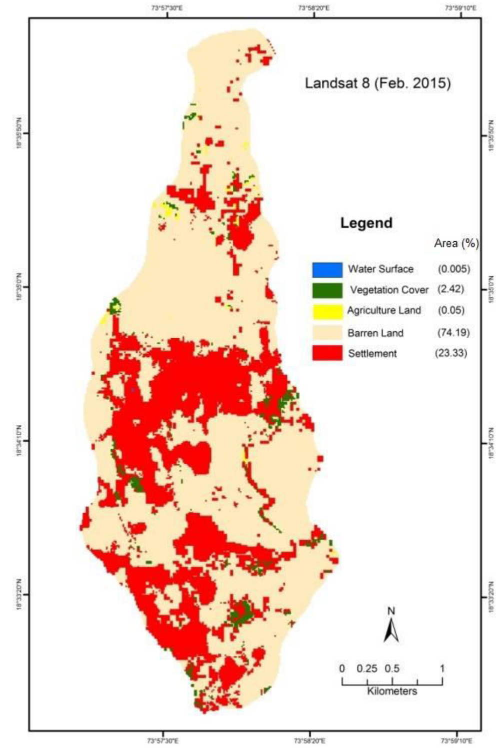


Figure 61: Change Detection of Wagholi Watershed (1991)

Figure 62 - Change Detection of Wagholi Watershed (2015)

4.3.6.2. Spatio-temporal variation in Land use and Land cover

Table 24 - Comparative LULC of Wagholi Watershed (1991 and 2015)

Sr. no	LU LC	Area 1991 (%)	Area 2015 (%)	1991 (Hectare)	2015 (Hectare)
1	Water Bodies	0.22	0.005	1.35	0.03
2	Vegetation	4.5	2.42	45.54	24.49
3	Agriculture	0.5	0.05	6.12	0.61
4	Barren Land	86.15	74.19	870.57	749.71
5	Settlements	8.63	23.33	87.21	235.76

Wagholi is located on the eastern side of Pune. In 1991 this area did not have much development. The whole area was covered by barren lands and very few dispersed settlements were present. In 2010 this settlement grew denser in the central parts and southern parts but still large area is occupied by barren land. State Highway number 27 goes through this study area triggering development along it. In future this area will experience urbanization due to availability of land.

4.3.6.3. Non Existing Streams in Wagholi Watershed

The drainage network from toposheet no.47 F/14 5 and 47 F/14 6, (year 1962-63) shows the basin is fifth order (table no. 63). During last 25 years due to rapid growth of urbanization the morphometric analysis of Wagholi done for the year 2015 based on satellite image and field survey strongly indicate reduction in stream numbers. This watershed region is having 77 first order streams; 31 of them are now become non-existing. Similarly, not only 5 second order streams are reduced out of 12 streams, but also 3 streams out of 6 third order stream are now non-existent . There were no changes recorded in fourth and fifth order streams. There are around 98 streams in total and out of them 38 streams are become non-existing. Most of the streams vanished due to construction activities in this watershed. From 1970-90 to 2014 only 61.22 % streams are safe in concern area. This shows that around 38.78 % streams are become non-existing.

Wagholi watershed area divided into two parts: one is Wagholi village and other is Kharadi which are separated by Pune – Nagar Highway. Catchment area starts from Lohgaon and Wagholi boundary, where upper part is covered with hillocks and plain area. Lohgaon airport is located near Wagholi watershed area. Due to this, high-rise building construction is restricted in its surrounding areas. At upper catchment area construction activities are comparatively less than other area. Suyog Sundarji Wisdom School and two major housing societies are constructed on first order stream, and 3 first order streams are non-existed in upper catchment area.

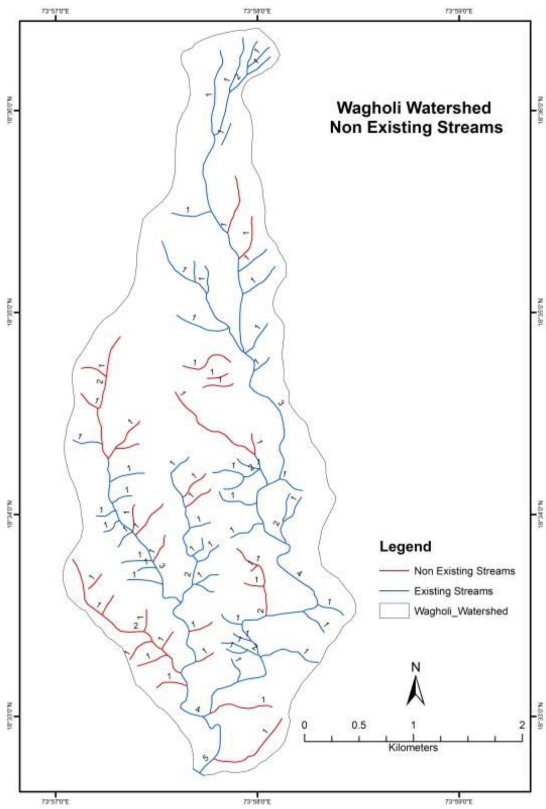


Figure 63 - Non Existing Streams in Wagholi Watershed

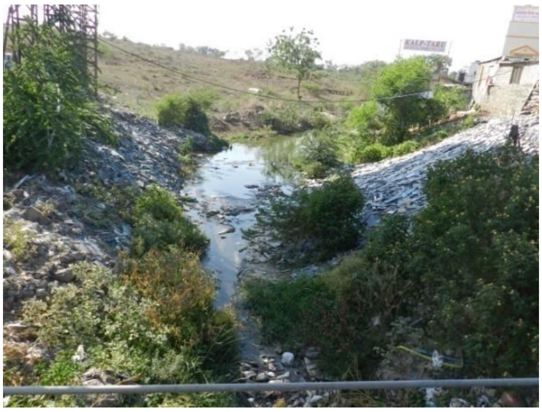


Photo 35: Construction material in the channel at Nagar road highway

Photo 36: Sewage dumping in the stream

Three third order streams crossing Pune – Nagar Highway are filled with sewage and construction debris reducing its channel width. Most of the streams have turned into dumping ground area. Kharadi area is a plateau area with North- South slope. The plateau area is diminishing fast due to large scale development activities, resulting in non-existence or divergence of many streams. Residential complexes and commercial buildings were constructed by diverting the existing stream channel in Kharadi area. Construction on water bodies, including streams, their tributaries and natural rivulets is a major concern as its results in water logging.

Photo 37: Road on stream

Photo 38: Construction of school on stream (Stream blocking)

Constructions of residential and commercial towers have increased over the years at the confluence of Wagholi stream and Mutha River. Some streams of Wagholi – Kharadi were blocked by retaining walls and some streams were diverted. The channel width of Mutha River has reduced due to dumping of construction material along the banks of river.

Photo 39: Stream blocking by construction in Kharadi

Photo 40: Construction on Stream

4.4 Existing Scenario of Streams in Watershed Areas

Table 25: Existing Scenario of Streams in Watershed Areas

Watersheds	Stream Order	Total Streams	No. of Vanished Streams	No. of Present Streams	Vanished Streams (%)	Present Streams (%)
Ram Nadi	1	323	86	237	26.63	73.37
	2	67	16	51	23.88	76.12
	3	21	3	18	14.29	85.71
	4	4	1	3	25.00	75.00
	5	1	0	1	0.00	100.00
		416	**106**	**310**	**25.48**	**74.52**
Nandoshi	1	130	5	125	3.85	96.15
	2	22	1	21	4.55	95.45
	3	6	0	6	0.00	100.00
	4	2	0	2	0.00	100.00
	5	1	0	1	0.00	100.00
		161	**6**	**155**	**3.73**	**96.27**
Ambil Odha (Rivulet)	1	235	48	187	20.43	79.57
	2	40	11	29	27.50	72.50
	3	6	1	5	16.67	83.33
	4	2	0	2	0.00	100.00
	5	1	0	1	0.00	100.00
		284	**60**	**224**	**21.13**	**78.87**
Bhairoba Nala	1	145	39	106	26.90	73.10
	2	40	6	34	15.00	85.00
	3	10	0	10	0.00	100.00
	4	2	0	2	0.00	100.00
	5	1	0	1	0.00	100.00
		198	**45**	**153**	**22.73**	**77.27**
Wadki Nala	1	241	42	199	17.43	82.57
	2	57	10	47	17.54	82.46
	3	12	0	12	0.00	100.00
	4	3	0	3	0.00	100.00
	5	1	0	1	0.00	100.00
		314	**52**	**262**	**16.56**	**83.44**
Wagholi	1	77	31	46	40.26	59.74
	2	12	5	7	41.67	58.33
	3	6	2	4	33.33	66.67
	4	2	0	2	0.00	100.00
	5	1	0	1	0.00	100.00
		98	**38**	**60**	**38.78**	**61.22**

Table 26: Existing Status of Streams in Pune City

Over all	Stream Order	Total Streams	No. of None Existing Streams	No. of Existing Streams	None Existing Streams (%)	Existing Streams (%)
Pune City	1	1151	251	900	21.81	78.19
	2	238	49	189	20.59	79.41
	3	61	6	55	9.84	90.16
	4	15	1	14	6.67	93.33
	5	6	0	6	0.00	100.00
		1471	**307**	**1164**	**20.87**	**79.13**

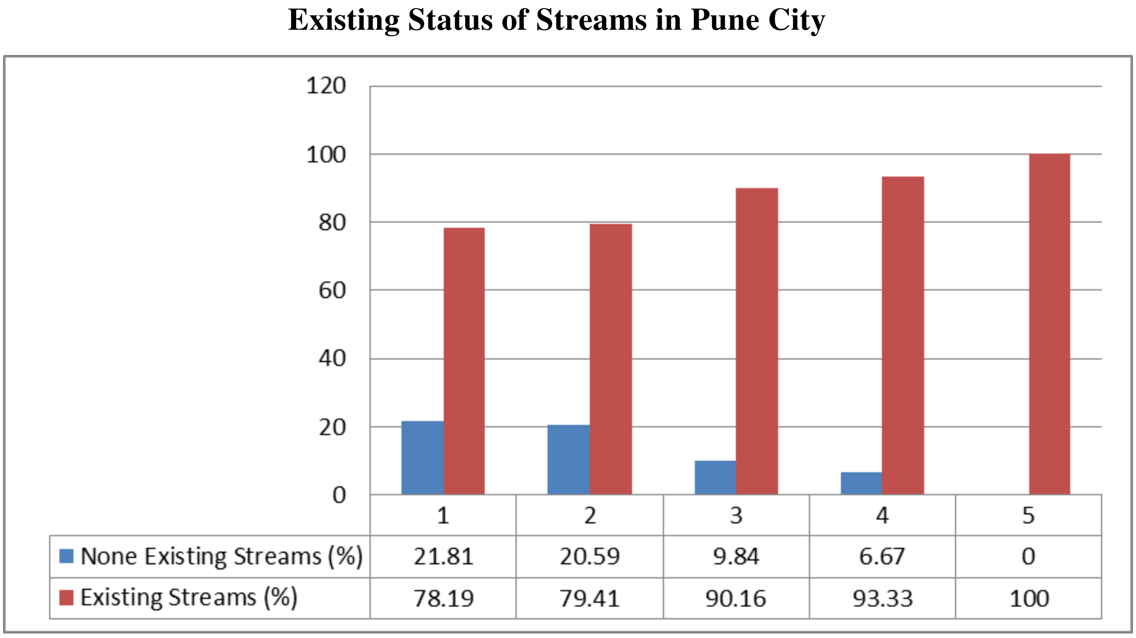


Figure 64: Existing Status of Streams in Pune City

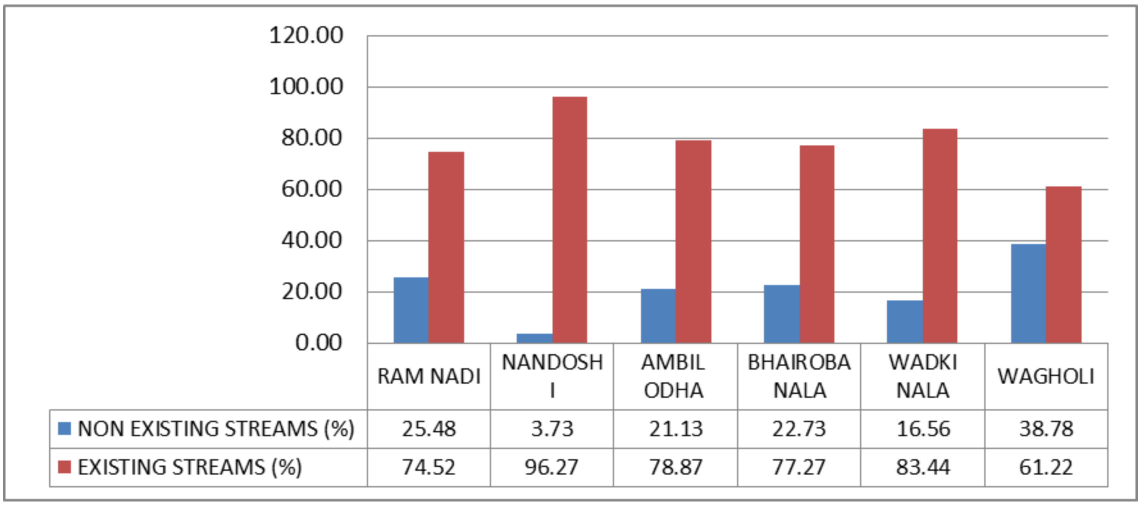


Figure 65: Existing Status of Streams in Pune City (Major Watershed Area)

Wards and Village wise physiographical details:

Table 27: Wards and Village wise physiographical details

		Contour (m)		Slope (Degree)		Streams					Watershed Area	Geology	Geomorphic Zone
WARDS		Lowest	Highest	Low	High	1st	2nd	3rd	4th	5th		Flows	
1	Aundh	550	790	0.05	15.75	152	40	13	4	1	Ram Nadi	BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
2	Kotharud (Karve Road)	570	750	0.03	13.29	80	19	8	1		Ram Nadi	BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT
3	Ghole Road	550	710	0.04	14.41	29	9	2	1			BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
4	Warje Karve nagar	550	720	0.02	12.15	60	12	10	2			BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
5	Dhole Patil Road	540	570	0.01	2.62	33	8	2	2	1	Bhairoba Nala	BDI,BDK	PEDIMENT,RIVER BANK
6	Hadpsar	560	660	0.02	8.72	103	24	12	1	1	Bhairoba Nala	BDD,BDK	SPUR,PEDIMENT
7	Nagar Road	540	590	0.02	19.35	84	19	5	1			BDI	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
8	Sangam Wadi	540	750	0.01	3.58	161	28	6	3	1		BDI	PEDIMENT,RIVER BANK
9	Bhavani Peth	550	570	0.03	1.92	1		1				BDK	PEDIMENT,RIVER BANK
10	Kasba Vishrambaug	550	570	0.04	2.1	1		1	1	1	Ambil Odha	BDK	PEDIMENT,RIVER BANK
11	Sahakarnagar	570	680	0.03	11.62	14	4	1		1	Ambil Odha	BDD,BDK	SPUR,PEDIMENT
12	Tilak Road	550	660	0.02	12.58	29	5	6	3	1		BDD,BDK	SPUR,PEDIMENT,RIVER BANK
13	Bibewadi	600	680	0.14	10.04	20	3	1		1	Ambil Odha	BDD,BDK	SPUR,PEDIMENT
14	Khadki Cantonment	550	580	0.04	4.38	28	6	3				BDK	PEDIMENT,RIVER BANK
15	Dhankawadi	600	780	0.02	13.02	53	11	3	3	1	Ambil Odha	BDD	SPUR,ESCARPEMENT

16	Pune Cantonment	550	640	0.01	6.91	8	2	1		1	Bhairoba Nala	BDK	SPUR,PEDIMENT,RIVER BANK
17	Kondhwa Wanawari	590	740	0.06	9.93	62	14	3	3	1	Bhairoba Nala	BDD	SPUR,ESCARPEMENT,PEDIMENT
VILLAGES													
1	Mahalunge,	560	660	0.05	13.03	10	2		1			BDD,BDK	PEDIMENT
2	Sus,	580	800	0.7	16.8	58	11	4	1			BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT
3	Bavdhan Budruk,	600	790	0.35	15.47	20	4	2	1		Ram Nadi	BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT
4	Kirkatwadi,	580	650	0.19	8.58	1				1	Nandoshi	BDD,BDK	SPUR,PEDIMENT
5	Pisoli,	620	880	0.5	18.64	48	9	4	1			BDD	SPUR,ESCARPEMENT
6	Lohegaon (Remaining),	560	970	0.02	20.75	125	31	4	1			BDI	SPUR,ESCARPEMENT,PEDIMENT
7	Kondhwe Dhavade,	560	800	0.02	16.58	48	10	3	1			BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
8	Kopare,	560	810	0.07	18.71	25	2	2				BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
9	Nanded,	560	600	0.4	3.9	5	1	1	1	1	Nandoshi	BDD,BDK	PEDIMENT,RIVER BANK
10	Khadakwasla,	560	850	0.06	18.32	42	8	4				BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
11	Shivane (Entire Uttamnagar),												
12	Hadapsar (Entire Sadesatranali),	550	560	0.68	2.09	1		1	1			BDI,BDK	PEDIMENT,RIVER BANK
13	Mundhwa (Remaining Keshavnagar),	540	560	0.26	3.25	24	5	1	2			BDI	PEDIMENT,RIVER BANK
14	Manjari Budruk	540	570	0.07	3.33	42	10	4	1	1		BDI	PEDIMENT,RIVER BANK
15	Narhe,	580	760	0.17	15.98	13	5	1	1			BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT
16	Shivane,	560	740	0.09	14.53	34	7	1				BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
17	Ambegaon Khurd,	630	810	0.1	15.97	36	5	2	2			BDP,BDD	SPUR,ESCARPEMENT

18	Undri,	610	690	0.36	5.71	24	6	5	1		Bopdev Ghat	BDD	SPUR,ESCARPEMENT
19	Dhyri,	590	950	0.89	19.63	33	8	2				BDD,BDK	SPUR,ESCARPEMENT,PEDIMENT
20	Ambegaon Budruk,	580	670	0.58	7.149	6	1		1			BDD,BDK	SPUR,PEDIMENT
21	Uruli Devachi,	580	650	0.06	5.93	45	9	3	1	1	Bopdev Ghat	BDD,BDK	SPUR,PEDIMENT
22	Mantarwadi,												
23	Holkarwadi,	620	920	0.2	21.45	65	15	5	3	1	Bopdev Ghat	BDP,BDD	SPUR,ESCARPEMENT
24	Authade (Handewadi),	600	920	0.5	23.07	46	10	3	1		Bopdev Ghat	BDP,BDD	SPUR,ESCARPEMENT
25	Wadachi Wadi,	650	990	0.12	21.3	101	25	4	1		Bopdev Ghat	BDP,BDD	SPUR,ESCARPEMENT
26	Shewalewadi,	550	560	0.43	1.1				1		Bopdev Ghat	BDI,BDK	PEDIMENT
27	Fursungi	550	620	0.35	6.32	40	13	7	1	1	Bopdev Ghat	BDI,BDK	PEDIMENT,RIVER BANK, SPUR
28	Nandoshi,	620	990	0.15	24.06	62	12	4	2	1	Nandoshi	BDP,BDD	SPUR,ESCARPEMENT
29	Mangdewadi,	670	810	0.43	17.7	20	2	1	1		Ambil Odha	BDP,BDD	SPUR,ESCARPEMENT
30	Bhilarewadi,	680	1100	1.26	24.15	146	25	5	1		Ambil Odha	BDP,BDD	ESCARPEMENT
31	Gujar Nimbalkarwadi,	680	870	0.61	19.48	55	10	2	1		Ambil Odha	BDP,BDD	ESCARPEMENT
32	Jambhulwadi	650	810	0.77	23.43	42	5	3	1			BDP,BDD	SPUR,ESCARPEMENT
33	Kolewadi	690	1150	0.37	26.46	131	23	3	1			BDP	ESCARPEMENT
34	Wagholi	540	680	0.02	10.94	143	23	7	2	1	Wagholi	BDI	SPUR,ESCARPEMENT,PEDIMENT,RIVER BANK
35	Yewalewadi	660	1000	0.04	22.49	101	28	9	2		Bhairoba Nala	BDP,BDD	SPUR,ESCARPEMENT

Land Use and Land Cover in 1991

Table 28: Land Use and Land Cover in 1991 (Hectors)

NAME	Water	Agriculture	Vegetation	Barren Land	Settlement
WORDS					
Karve Road	0.09	9.45	254.79	910.17	475.65
Ghole Rd	0	82.53	75.33	111.69	1060.65
Khadki Cantonment	70.8	62.05	423.18	241.02	580.92
Sangamwadi	55.08	60.3	351.63	1167.92	1350.72
Yerawada	10.26	23.13	377.28	1116.9	1545.93
Bhavani Peth	0.09	0.45	4.32	0	304.11
Sahakarnagar	3.42	20.52	53.37	121.77	825.66
Bibewadi	0	4.68	109.71	1217.25	629.46
Pune Cantonment	10.38	15.51	272.16	150.08	830.94
Dhole Patil Rd	94.14	188.19	239.58	16.74	979.65
Hadapsar	3.69	274.95	111.51	532.44	1830.24
Vishrambaugh Wada	15.21	18.54	21.78	0.72	430.47
Tilak Rd	30.42	145.62	429.57	152.64	626.76
Warje Karve nagar	2.79	45.27	247.59	561.33	635.85
Aundh	92.97	200.07	741.96	1413.9	1771.11
Dhankawadi	19.17	2.25	86.67	624.24	435.78
VILLAGES					
Kondhwe Dhavade	0.72	11.99	954.33	305.39	85.5
Nanded	11.01	43.02	308.54	22.99	121.76
Mahalunge	18.85	19.75	136.64	238.73	118.24
Sus	0.36	19.57	204.2	609.7	83.07
Bavdhan Budruk	0	1.53	55.01	395.22	50
Shivane	0.72	5.68	367.35	260.92	125.9
Kirkatwadi	0	7.66	140.61	87.12	69.44
Nandoshi	0.27	7.03	342.19	396.03	61.6
Dhyari	0.9	17.85	290	289.78	269.94
Narhe	0.18	1.62	97.22	132.58	237.02
Ambegaon Khurd	30.93	0.81	61.69	220.79	93.34
Jambhulwadi	1.71	1.44	87.21	133.21	41.93
Kolewadi	0.27	0.36	323.15	413.17	15.78
Khadakwasla	252.08	28.59	714.95	214.29	63.67
Bhilarewadi	0.81	3.33	441.67	457.72	32.64
Undri	0.81	11.36	47.26	314.5	81.8
Wadachi wadi	1.62	12.08	165.23	405.86	16.41
Authade (Handewadi)	0.09	45.54	128.52	384.49	30.48
Holkarwadi	1.44	61.33	203.29	419.3	57.63
Uruli Devachi	0	75.31	170.37	704.4	104.98
Phursungi	3.06	351.57	580.38	399.55	486.76
Shewalewadi	0	99.12	138.26	6.85	43.65

Manjari Budruk	56.28	457.99	774.12	346.42	374.65
Hadapsar (Sadesatra Nali)	0.72	14.61	64.75	31.29	141.78
Mundhwa	33.82	63.58	111.92	148.38	149.08
Lohegaon	6.85	17.4	86.4	1592.89	233.41
Yewalewadi	3.87	12.44	143.58	445.46	91.63
Pisoli	0.99	17.22	87.66	345.61	41.75
Ambegaon Budruk	0.27	1.35	19.84	56.28	157.29
Gujar Nimbalkarwadi	0	1.26	56.73	267.87	17.85
Mangdewadi	0.45	0.27	20.02	151.25	27.41
Kopare	0.36	5.59	199.35	105.34	5.32
Wagholi	14.07	89.2	358.51	2433.39	438.06

Land Use and Land Cover in 2015

Table 29: Land Use and Land Cover in 2015 (Hectares)

NAME	Water	Agriculture	Vegetation	Barren Land	Settlement
Words					
Karve Road	0.49	0.09	383.76	262.59	990.85
Ghole Rd	15.23	0	217.73	67.47	1086.6
Khadki Cantonment	31.68	0.51	492.34	56.43	793.35
Sangamwadi	20.27	7.24	461.48	994.01	1485.41
Yerawada	8.12	0.65	203.04	993.66	1847.09
Bhavani Peth	2.47	0	4.14	0.51	321
Sahakarnagar	1.95	0	58.14	106.62	843.63
Bibewadi	0.99	6.23	58.63	648.42	1228.07
Pune Cantonment	1.32	0	297.31	155.36	843
Dhole Patil Rd	58.29	10.17	189.27	195.59	1044.05
Hadapsar	3.42	20.97	123.48	841.5	1865
Vishrambaugh Wada	3.19	0	21.26	9.47	446.26
Tilak Rd	4.16	0.63	112.11	105.97	1137.56
Warje Karve nagar	1.03	0	181.35	164.11	1132.29
Aundh	23.17	8.59	1024.04	520.94	2636.64
Dhankawadi	6.81	0.54	52.22	250.24	845.16
VILLAGES					
Kondhwe Dhavade	0.02	2	385.33	731.37	174.15
Nanded	1.21	0.06	162.58	39.62	296.91
Mahalunge	2.74	16.56	37.73	272.97	202.07
Sus	0	1.05	123.79	561.75	225.56
Bavdhan Budruk	0.09	0	57.84	23.49	210.46
Shivane	0.18	0.38	154.71	350.32	243.69
Kirkatwadi	0	2.58	74.92	117.22	104.24
Nandoshi	0	1.62	362.67	406.82	68

Dhyari	0.02	0.05	223.76	319.63	318.69
Narhe	0.24	0.05	35.88	121.97	302.17
Ambegaon Khurd	17.68	0	16.51	212.24	151.71
Jambhulwadi	0	0	26.88	196.98	48
Kolewadi	0	0.15	176.64	560.9	21
Khadakwasla	254.56	1.5	460.41	370.71	186.32
Bhilarewadi	0	0	238.11	662.6	37.12
Undri	0	4.61	14.55	291.64	136.57
Wadachi wadi	0	9.24	8.25	541.05	37.66
Authade (Handewadi)	0	28.84	26.19	458.7	65.09
Holkarwadi	0	5.15	20.04	703.1	91
Uruli Devachi	0.2	32.13	28.28	795.21	195.88
Phursungi	0.22	24.61	308.63	797.58	690.75
Shewalewadi	0.02	8.34	65.76	127.01	78.3
Manjari Budruk	31.81	119.92	399.44	884.63	574.44
Hadapsar (Sadesatra Nali)	0.38	0	9.06	66.71	173.2
Mundhwa	20.74	32.1	30.17	258.43	159.75
Lohegaon	0.09	45.11	45.87	1621.75	267.1
Yewalewadi	0.24	0.06	12.51	535.83	141.09
Pisoli	0.13	2.25	10.48	353.36	119.61
Ambegaon Budruk	0.06	0	4.63	17.77	206.68
Gujar Nimbalkarwadi	0	0.56	13.38	317.03	27
Mangdewadi	0.06	0	1.68	137.79	55.19
Kopare	0.2	0	166.95	101.67	43.67
Wagholi	1.95	198.04	82.39	2191.25	859.77

CHAPTER – 5: SLOPE ANALYSIS

5.1. Introduction

The word 'slope' in a restricted sense refers to an area of land or a line that makes a definite angle to the horizontal. In geomorphology, a much wider view is sometimes taken, in which a slope includes any facet of the solid land – surface, be it flat or otherwise. Measurement of the slope is an angle at its maximum steepness along a profile line running from the hillcrest to an adjacent stream channel. Here slope forms have been measured with drawn from maps with large contour intervals. Slopes have been at the centre of several broad schemes of landscape evolution proposed by various geomorphologists, which means that some rather doctrinaire attitudes often prevail over slopes.

It is now generally accepted that slopes cover a wide range of adjustment between from and process; that is, some slopes are in intimate equilibrium with present process, whereas others are not. There are two approaches to slope: a historical approach in which slopes are regarded as a reflection of what has happened in the past and a dynamic approach which regards slopes as being in adjustment with reasonably contemporaneous processes. Both approaches are valid and indeed necessary for the proper understanding of slopes (Brunsden 1970).

The amount of available relief, the difference between the highest and lowest points in the landscape and the degree of dissection are bound to affect slope form. Slope angle tends to be greatest in areas of high relief and where dissection is rapid, whereas in stable, low relief areas, slopes are usually less steep and more concavo-convex in profile. The connection lies in the activity of the valley streams. It is impossible to consider slopes and streams as completely separate entities, as they are parts of the same open system, the drainage basin. The channel at the foot of the slope will exert a considerable influence on the hillslope form. On the other hand, the stream will tend to adjust its gradient so it can transport away the amount of debris the slope supplies to it (Brunsden 1970).

Slope gradient is a key factor in influencing the relative stability of a slope. It determines the degree to which gravity acts upon a soil mass. Slopes are often irregular and complex, with gradients varying greatly throughout a given shoreline profile. There are three different ways to indicate the slope of a surface relative to the horizontal plane: degree, gradient, and percentage.

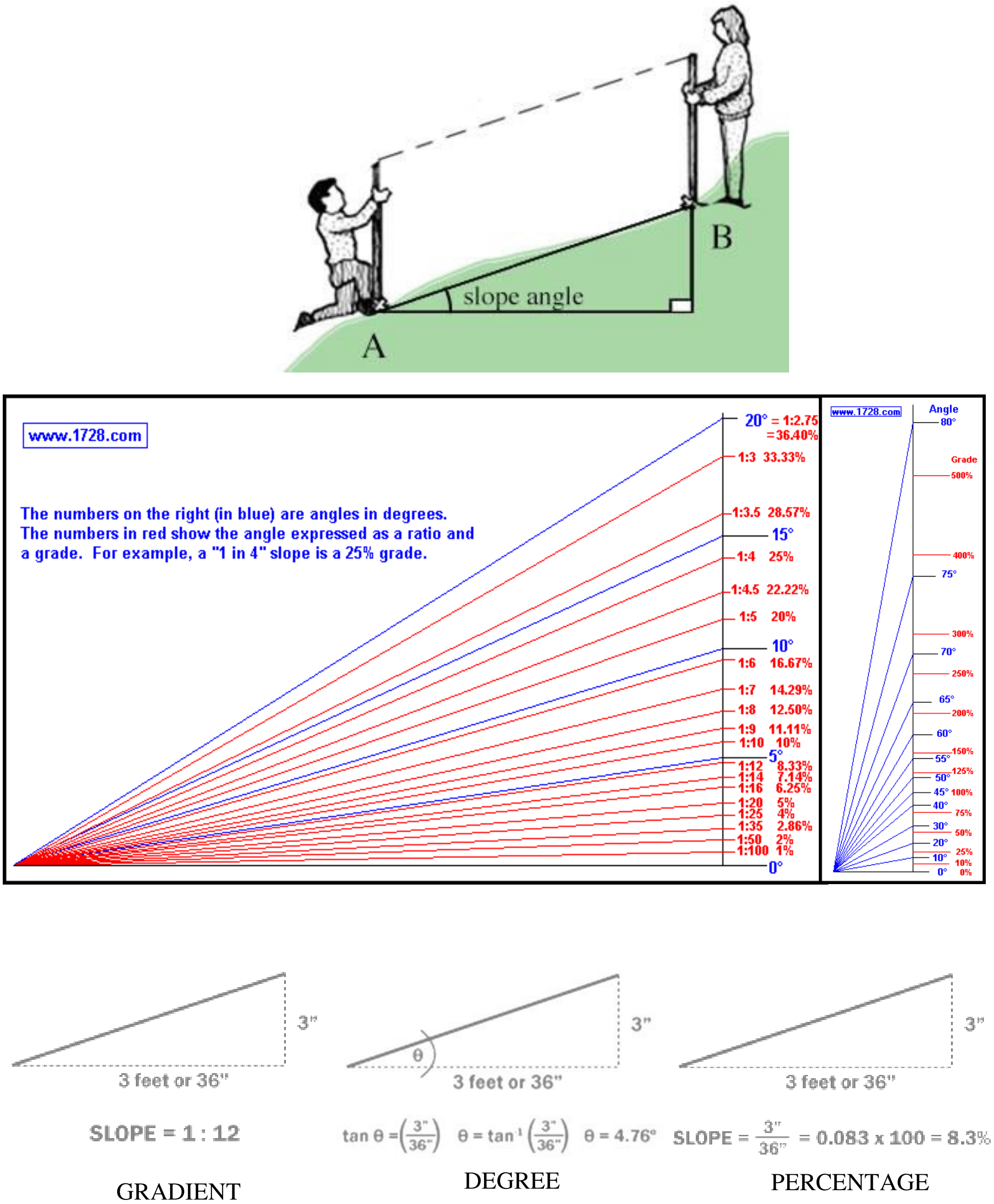


Figure 1: Measurements/Geometry/Slope

5.2. Slope Analysis

Understanding the topological pattern of human settlements and their geographical associations is important for understanding the drivers of land use and land cover change and the relationship between stream flow and slope on one hand and settlement pattern on the other. As each watershed area is unique, having different lengths, sinuous nature of streams, land coverage, etc., the parameters considered for studying each watershed area are different. Each watershed is divided by a number of cross sections and longitudinal sections (profiles) for studying slope variation along fifth order stream. Heights (AMSL) of converging points of these cross and longitudinal profiles were calculated to achieve an exact slope difference which helps to analyze the growth / spread of settlement in a particular area. This study demonstrated a new approach to analyze the urban growth patterns of human settlements from a wide geographical perspective.

The study of the longitudinal profiles allows tracing the presence of urbanization activity. Here construction work must be responsive to the constraints of changes in slope profile. As per the profile, the upper region (source) identified has comparatively less settlement due to topographical factor. An important component of any drainage basin system is provided by its valley – side slopes. These direct surface water towards the river channels, and are a major source for river sediments. A simple but effective functional subdivision of valley – side slopes (Hack and Goodlett 1960) recognizes five types

- **Nose:** The driest area, whose contours are convex outwards from the valley (as on a spur). It receives least moisture from up-slope and provides shedding sites. Runoff is proportional to a function of the radius of curvature of the contours.
- **Side Slope:** This has straight contours, receives water from the nose, and has water sites than those on the nose. Runoff is proportional to a linear function of slope length.
- **Hollow:** The contours are concave outwards and demarcate the central part of the valley. All slopes converge on the stream, and it comprises very moist slopes, increasing in water content towards the stream. Runoff is proportional to a power function of slope length.

- **Foot Slope:** The gentle lower part of a side slope, and may be composed of regolith rather than based on solid rock.
- **Channel way or Valley floor:** The river course plus any adjacent floodplain.

5.2.1. Ram Nadi Watershed Area

The Ram Nadi watershed area is divided by ten cross profiles (north-east to south-west) and one longitudinal profile to understand the relation between urbanization / settlements and valley cross profile topography. The growth of urban settlements increased along both the banks of river Ram Nadi during 1991to 2015.

The river originates at an elevation of 957 m (AMSL) range of Western Ghats and flows in north-west direction to join the Mula river at 550m (AMSL). Villages like Bhukum, Bhugav, Pirangut, Bavdhan and Aundh, Pashan wards and some part of Karve Nagar fall under this watershed. The area between R4 and R10 is under Pune Municipal Corporation, showing rapid growth of urbanization and having high density of settlement, population.

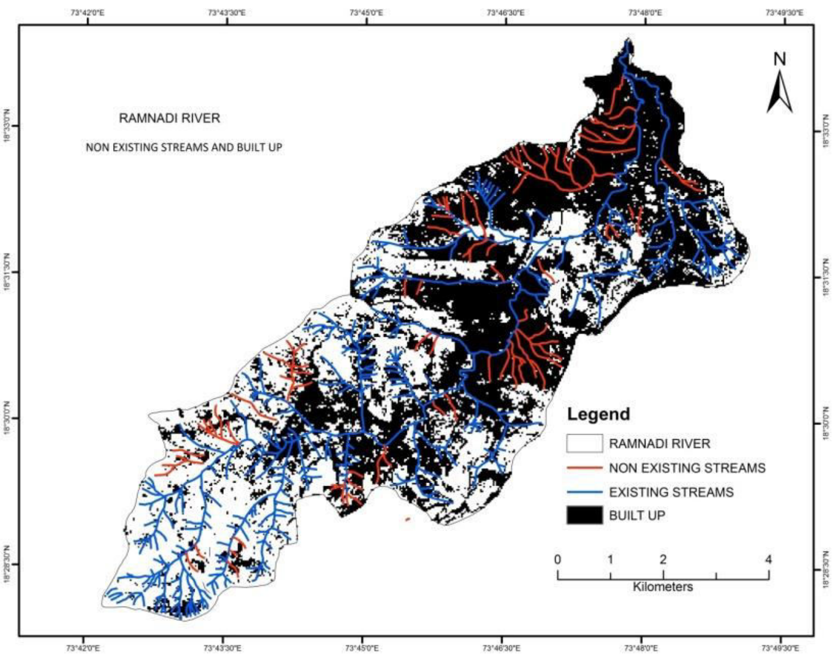


Figure 67 : Built-up area and Non Existing Streams in Ram Nadi Watershed area

5.2.1.1. Latitudinal Slope / Degree / Gradient analysis by Profiles and buffer around Ram Nadi

Table 30: Latitudinal Slope / Degree / Gradient analysis of Ram Nadi

PROFILE	WEST_A (AMSL)	Relative Height (m) (A-R)	GRADIENT (RUN -500m)	SLOPE (DEGREE)	SLOPE %	RIVER (AMSL)	Relative Height (m) (B-R))	GRADIENT (RUN -500m)	SLOPE (DEGREE)	SLOPE %	EAST_B (AMSL)
R1	**762**	16	1:47	1.22	2	**746**	29	1:26	2.21	4	**775**
R2	**761**	59	1:13	4.50	8	**702**	17	1:44	1.30	2	**719**
R3	**736**	76	1:10	5.79	10	**660**	25	1:30	1.91	3	**685**
R4	**688**	51	1:15	3.89	7	**637**	94	1:8	7.14	13	**731**
R5	**707**	78	1:10	5.94	10	**629**	59	1:13	4.50	8	**688**
R6	**764**	148	1:5	11.16	20	**616**	22	1:34	1.68	3	**638**
R7	**609**	9	1:83	0.69	1	**600**	23	1:33	1.76	3	**623**
R8	**601**	11	1:68	0.84	1	**590**	87	1:9	6.62	12	**677**
R9	**610**	21	1:36	1.60	3	**589**	44	1:17	3.36	6	**633**
R10	**594**	24	1:31	1.83	3	**570**	7	1:107	0.53	1	**577**

Areas such as Bavdhan, Bhukum, Pirungut and some part of Karve Nagar fall under this watershed study area. Few areas are within Pune city boundary which covers up to R6 – R10 region. Area between profiles R5 to R7 is more prone to problems as the slope of average 5º -10º (i.e. 1:5) is feasible for construction, and most of the development in recent years has been seen in these parts of study area, causing various environmental problems including flash floods, obstruction to natural flow of streams and also increase in non-existence of many streams. The intensity of development in this area was such that the width of Ram Nadi (River) flowing through the city is literally reduced to 4-5 m i.e. comparitively nothing.

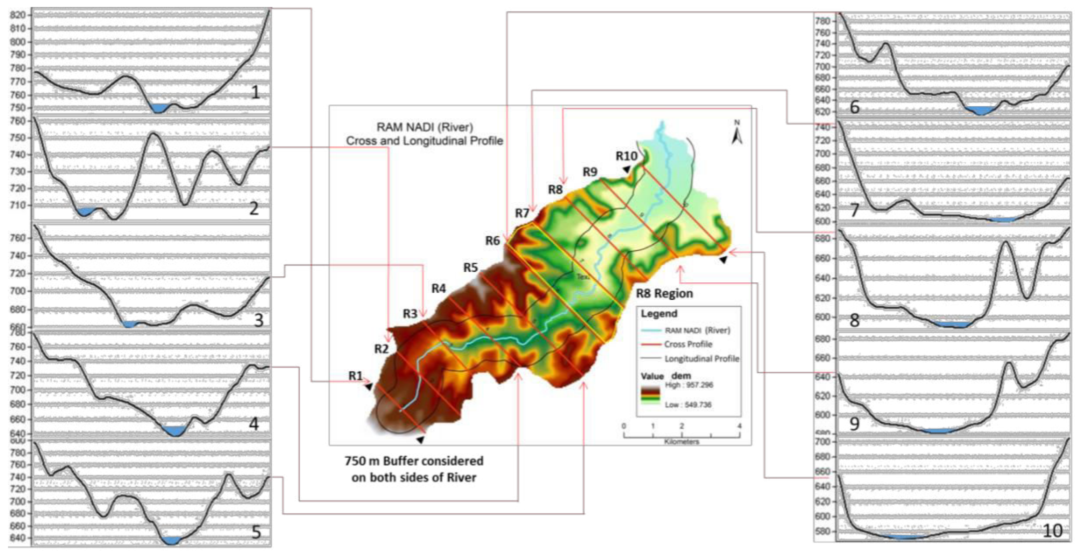


Figure 68: Latitudinal Slope / Degree / Gradient analysis done by Profiles and buffer around Ram Nadi

5.2.1.2. Longitudinal Slope / Degree / Gradient analysis of Ram Nadi

Table 31 : Longitudinal Slope / Degree / Gradient analysis of Ram Nadi

	Altitude (MSL) HEIGHT (M)	SLOPE (DEGREE)	%
Longitudinal Profile	225	17	30

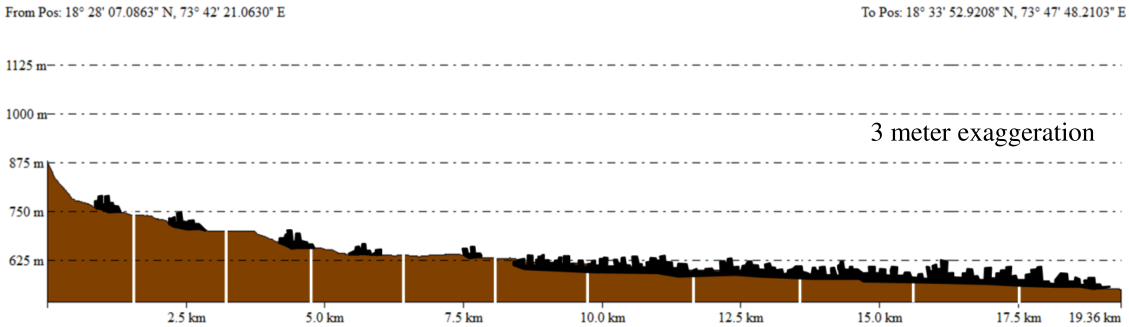


Figure 69: Longitudinal Slope Profile of Ram Nadi

Table 32: Longitudinal Slope of Ram Nadi

PROFILE	HEIGHT (M)	LENGTH (M) FROM SOURCE	SLOPE (%)	SLOPE (DEGREE)
R1	746	1250	59.68	30.83
R2	702	2500	28.08	15.68
R3	660	3750	17.60	9.98
R4	637	5000	12.74	7.26
R5	629	6250	10.06	5.75
R6	616	7500	8.21	4.70
R7	600	8750	6.86	3.92

R8	590	10000	5.90	3.38
R9	589	11250	5.24	3.00
R10	570	12500	4.56	2.61

The longitudinal profile of the river along with the urbanization explains the important relationship with the overall topography of the watershed. It is clearly observed that the source region of the river is having less expansion of the settlements; which is due to the fact that the source of the river is always at a high altitude and slope. Any river or stream can have overland flow when there is sufficient quantity of water and a particular degree of slope. The longitudinal profile of the river explains the status of the river from the source to its mouth. Ram Nadi has a source elevation of around 875 m from the mean sea level. The graded profile of this river explains that it has been altered by the anthropogenic activities.

From the source to the elevation of around 629m (5.75^0), there are few settlements. It can be depicted from the profile that the slope gradient plays a dominant role in the expansion of the settlements in the source region. Below 629m, there is an abrupt change in the landscape. This is indicated by the degree of slope which gently decreases towards the confluence. The gently sloping land has favored the human activities in the form of construction of buildings and infrastructure along with its expansion. There is a high density of settlement and population growth in this section of topography. It also explains that the human intervention is more in this region.

The longitudinal profile of the river clearly explains that anthropogenic activities have altered the landscape according to human needs. Above 629m ($5.75\ ^0$), the terraced profile clearly indicates the change in landscape. Below 629m (R5), the profile is gently sloping favoring expansion of human settlements and infrastructure. The most of the settlements in this basin area lie in between 2.61^0 to 5.75^0slope. Due to saturation and unavailability of plain land there are some settlements which lie in between 9^0 to 30^0 slope region. Allthough these slopes are not favorable for settlements, slopes are altered to form settlements and this type of development is increasing observed in early years from confluence to source of rivers.

5.2.1.3. Built-up area analysis of Ram Nadi watershed area

Table 33: Built-up area analysis of Ram Nadi Watershed area

PROFILE / REGION	REGION AREA (Ha.)	B/U AREA 1991(Ha.)	B/U AREA 2015 (Ha.)	INCREASE IN SETTLEMENT AREA 1991-2015 (Ha.)	% INCREASE FROM 1991 TO 2015
>R1	204	8.29	16	7.71	93.00
R1to R2	346	12.95	64	51.05	394.21
R2 to R3	405	4.14	36.18	32.04	773.91
R3 to R4	398	56.94	80.82	23.88	41.94
R4 to R5	591	46.62	148.36	101.74	218.23
R5 to R6	598	44.14	128.6	84.46	191.35
R6 to R7	604	142.81	286.6	143.79	100.69
R7 to R8	511	178.67	306.26	127.59	71.41
R8 to R9	481	143.63	385.3	241.67	168.26
R9 to R10	498	244.82	487	242.18	98.92
R10 to Next	460	254.41	498.2	243.79	95.83
Total	**5095.2**	1137.42	2437.32	1299.9	

It is observed that during last 25 years settlement has developed rapidly from the regions R1, R1 to R2, R4 to R5 and R5 to R6; while R1, R3 to R4 region are less populated due to influences of relief factors (elevation and slope) as very few settlements are seen across steep slopes. The regions R7 to R8 shows less density of urbanization as this area is occupied by government institutes and DRDO, a defense organization.

Around 500 ha. of vacant land is converted into residential / settlement area from regions R6 to R7 and R8 to R10 which changed the whole scenario of land cover in this area. But region between R4 and R6 shows rapid growth of urbanization within last 10 to 15 years particularly after year 2000.

5.2.2. Nandoshi Watershed Area

The Nandoshi watershed area is divided by ten cross profiles (south to north) and one longitudinal profile to understand the spatio temporal changes in slope due to urbanization. The growth of urban settlements increased along both the banks of stream Nandoshi during 1991to 2015.

The river originates at an elevation of 1020 m (AMSL) near the Sinhgad-Bhuleshwar range of Western Ghats and flows in north-west direction to join the Mutha river at 550m (AMSL). The villages of Nanded, Kirkatwadi, Wanjalewadi, Nandoshi and some part of Dhayari are part of this watershed. The area between N6 to N9 is under Pune Municipal Corporation shows rapid growth of urbanization and having high density of settlement, population. Growth of settlements is rapid in the PMC area than the Grampanchayat area.

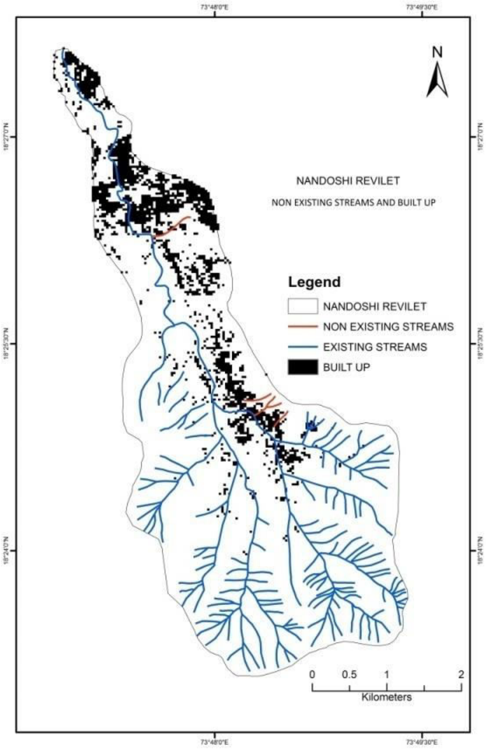


Figure 70 : Built-up area and Non Existing Streams in Nandoshi (Rivulet)

5.2.2.1. Latitudinal Slope/Degree/Gradient analysis by Profiles and buffer around Nandoshi

Table 34: Latitudinal Slope / Degree / Gradient analysis of Nandoshi (Rivulet)

PRO FILE	WEST_A (AMSL)	Relative Height (m) (A-R)	GRADIENT (RUN -500m)	SLOPE (DEGREE)	SLO PE %	RIVER (AMSL)	Relative Height (m) (B-R))	GRADIENT (RUN -500m)	SLOPE (DEGREE)	SLO PE %	EAST_B (AMSL)
N1	**792**	6	1:83	0.46	1	**786**	78	1:16	5.94	10	**864**
N2	**740**	41	1:12	3.13	5	**699**	21	1:24	1.60	3	**720**
N3	**714**	45	1:11	3.43	6	**669**	10	1:50	0.76	1	**679**
N4	**722**	84	1:6	6.39	11	**638**	13	1:38	0.99	2	**651**
N5	**639**	11	1:45	0.84	1	**628**	22	1:23	1.68	3	**650**
N6	**655**	50	1:10	3.81	7	**605**	12	1:42	0.92	2	**617**
N7	**590**	3	1:16	0.23	0	**587**	19	1:26	1.45	3	**606**
N8	**574**	0	-	0.00	0	**574**	5	1:100	0.38	1	**579**
N9	**560**	1	1:50	0.08	0	**559**	1	1:500	0.08	0	**560**

Villages such as Nanded, Kirkatwadi, Wanjalewadi and Nandoshi and some part of Dhayari area fall under this watershed study area. Few areas are inside Pune city boundary, which covers upto N6 – N9 region. Area between profiles N4 to N7 is more prone to problems as the average slope 5º to 10º is feasible for construction. Most of the development in recent years has been seen in this part of study area. Various environmental problems including flash floods, obstruction to natural flow of streams and non-existence (Vanishing) of streams due to anthropogenic activities. Hilly terrain in the southern part at the watershed are restricted the rapid growth of urbanization in the northern part particularly along the bank of river dense growth of settlement is observed. The uncontrolled growth along the backwater of Khadakwasala dam may create environmental problems in future.

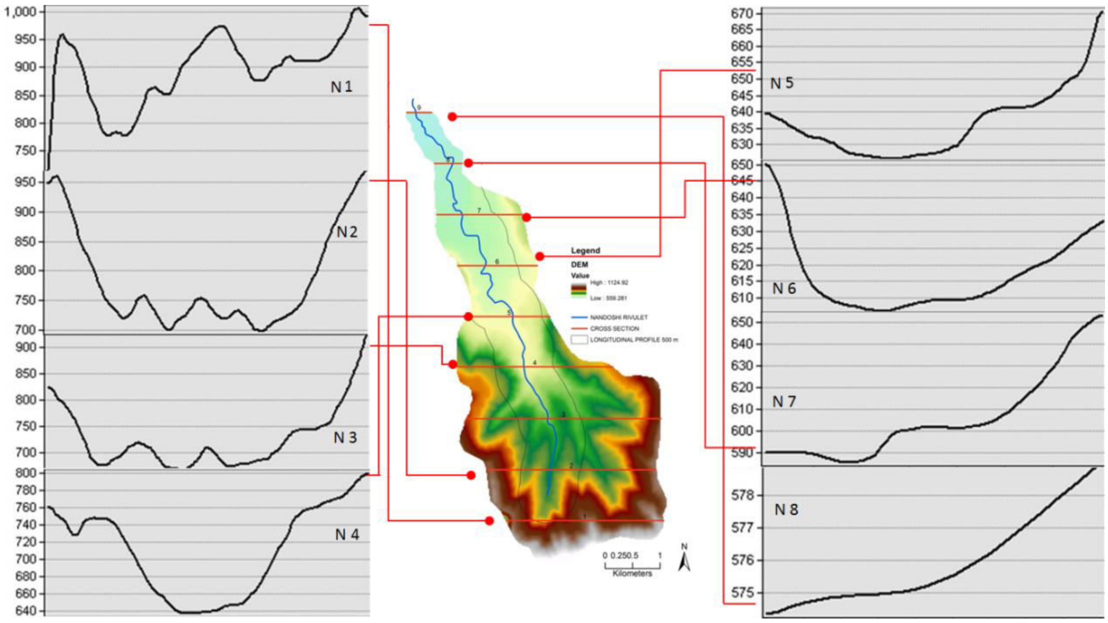


Figure 71: Cross profile of Nandoshi Watershed

5.2.2.2. Longitudinal Slope/Degree/Gradient analysis of Nandoshi

Table 35 : Longitudinal Slope/Degree/Gradient analysis of Nandoshi (Rivulet)

	Height	Slope (Degree)	%
Longitudinal Profile	232	25	46

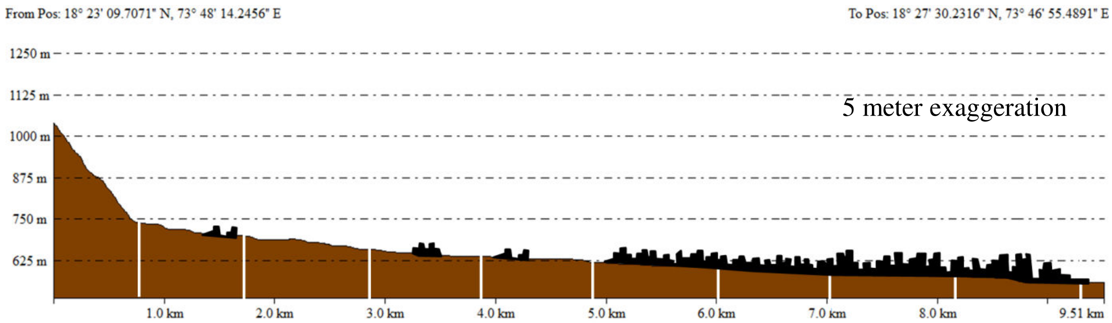


Figure 72: Longitudinal Slope Profile of Nandoshi (Rivulet)

Table 36: Longitudinal Slope Profile of Nandoshi (Rivulet)

PROFILE	HEIGHT (m)	LENGTH (m) (FROM SOURCE)	SLOPE (%)	SLOPE (DEGREE)
N1	786	920	85.43	40.51
N2	699	1840	37.99	20.80
N3	669	2760	24.24	13.63
N4	638	3680	17.34	9.84
N5	628	4600	13.65	7.77
N6	605	5520	10.96	6.25
N7	587	6440	9.11	5.21
N8	574	7360	7.80	4.46
N9	559	8280	6.75	3.86

Nandoshi (Rivulet) has a source elevation of around 1020m from the mean sea level. The graded profile of this rivulet explains that it has been altered by the anthropogenic activities at the confluence.

From the source to the elevation of around 730m, there are few settlements. It can be depicted from the profile that the slope gradient plays a dominant role in the expansion of the settlements in the source region. Below 700m, there is an abrupt change in the land use as the area is densely populated decrease in slope towards the confluence region. The gentle sloping of land surface has favored the human activities in the form of construction of buildings and infrastructure. There is a high density of settlement and population in this part of the watershed. It shows increasing human intervention in this region.

The longitudinal profile of the rivulet clearly explains that the humans have altered the landscape according to their own needs. In Nandoshi rivulet, N5 to N10 region with 3^0 to 7.5^0 slope show terraced profile, which clearly indicates interference of man in this area. Below 628m, the profile is gently sloping favoring expansion of human settlements and infrastructure, up to 5 to 10 km from source region. Most of the settlements in this basin are located in between 3^0 to 7.5^0 slope. There are some settlements which lie between 9^0 to 13^0 slopes. All though these slopes are not favorable for settlements, the slopes are altered and buildings are constructed. The rapid growth of settlements towards source region has been seen in recent years.

5.2.2.3. Built-up area analysis of Nandoshi watershed area

Table 37: Built-up area analysis of Nandoshi (Rivulet) watershed area

PROFILE / REGION	REGION AREA (Ha.)	B/U AREA 1991 (Ha.)	B/U AREA 2015 (Ha.)	INCREASE IN SETTLEMENT AREA 1991-2015 (Ha.)	% INCREASE FROM 1991 TO 2015
N1	129	0	0.01	0.01	1.00
N1 to N2	271	0.23	0.44	0.21	91.30
N2 to N3	307	3.18	9.91	6.73	211.64
N3 to N4	301	2.65	23.31	20.66	779.62
N4 to N5	179	11.8	17.38	5.58	47.29
N5 to N6	116	3.41	18.36	14.95	438.42
N6 to N7	139	7.21	50.69	43.48	603.05
N7 to N8	88	18.03	67.24	49.21	272.93
N8 to N9	54	3.37	47.18	43.81	1300.00
N9 to Next	9	2.23	19.64	17.41	780.72
Total	**1593.83**	**52.11**	**254.16**	**202.05**	

It is observed that during last 25 years settlement has developed slowly between the profiles N1 to N2 and N4 to N5 are less populated due to influences of local relief factors (elevation, slope and aspect) as settlements are less across the steep slopes. Profiles N2 to N3, N3 to N4 and N5 to N6, N6 to N9 settlement has developed rapidly. Almost 120 ha. of open land converted into settlements between profile number N7 and N9. Area between N4 and N5 shows very slow growth of settlement.

5.2.3. Ambil Odha Watershed Area

The Ambil Odha watershed area is divided by ten cross profiles (south to north) and one longitudinal profile to understand spatio temporal changes in slope due to urbanization. The growth of urban settlements increased along both the banks of stream Ambil Odha during 1991 to 2015.

The river originates at an elevation of 1100m (AMSL) near the Sinhgad-Bhuleshwar range of Western Ghats and flow in north-west direction to join the Mutha river at 560m (AMSL). The villages of Bhilarewadi, (manglewadi-check and confirm) Mangadewadi, Gujar Nimbalkarwadi and Wards are Dhanakavadi, Sahakarnagar and some part of Bibwewadi and Vishrambagwada fall under this watershed. The area between profile A5 and A10 is under Pune Municipal Corporation shows rapid growth of urbanization and having high density of settlement and population.

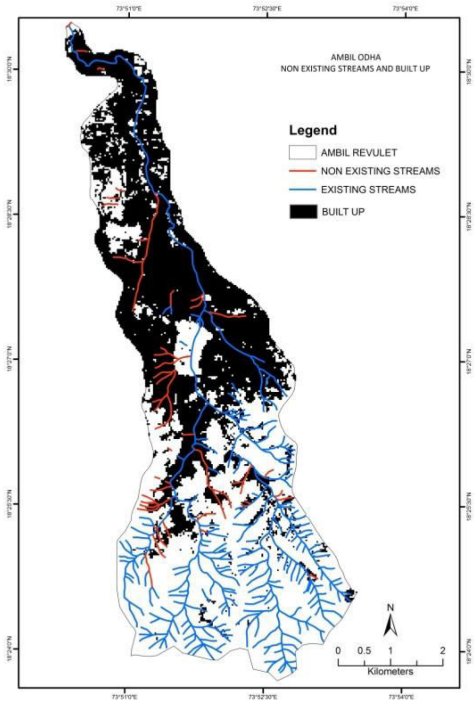


Figure 73 : Built-up area and Non Existing Streams in Ambil Odha (Rivulet)

5.2.3.1. Latitudinal Slope / Degree / Gradient analysis by Profiles and buffer around Ambil Odha (Rivulet)

Table 38: Latitudinal Slope / Degree / Gradient analysis of Ambil odha (Rivulet)

PROFILE	WEST_A (AMSL)	Relative Height (m)	GRADIENT (RUN -750m)	DEGREE	SLOPE %	PROFILE	WEST_A (AMSL)	Relative Height (m)	SLOPE (DEGREE)	SLOPE %	EAST_B (AMSL)
A1	906	158	1:5	11.90	21	748	125	6	9.46	17	873
A2	702	-2	1:-375	-0.15	0	704	81	9	6.16	11	785
A3	820	142	1:5	10.72	19	678	41	18	3.13	5	719
A4	710	53	1:14	4.04	7	657	60	13	4.57	8	717
A5	663	26	1:29	1.99	3	637	24	31	1.83	3	661
A6	653	36	1:21	2.75	5	617	47	16	3.59	6	664
A7	640	44	1:17	3.36	6	596	4	188	0.31	1	600
A8	610	21	1:36	1.60	3	589	2	375	0.15	0	591
A9	623	52	1:14	3.97	7	571	2	375	0.15	0	573
A10	550	1	1:750	0.08	0	549	7	107	0.53	1	556

Areas such as Parvati, Rajendra Nagar, Padmavati, Bhilarewadi, Mangadewadi and major part of Katraj fall under this watershed study area. Few areas are inside Pune city boundary which covers up to A2 – A5 region. Area between profiles A1 to A6 are more prone to problems as the slope of average 8º -17º (i.e. 1:5) is feasible for construction, and most of the development in recent years has been happening in these parts of study area, causing various environmental problems including flash floods, obstruction to natural flow of streams and also has initiated non-existence of many streams. In future problems may arise in regions A1 to A4, consisting Bhilarewadi and Mangadewadi as they are more prone to immediate settlement growth.

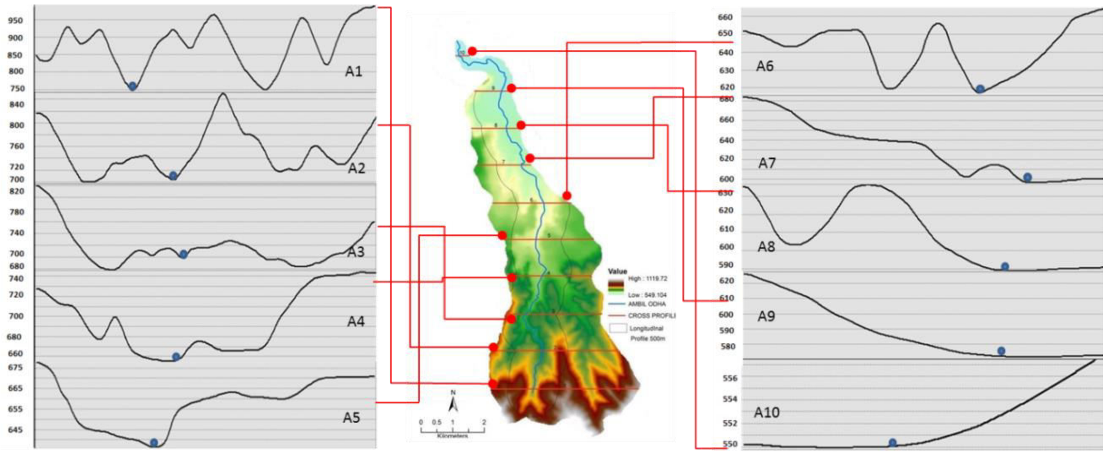


Figure 74 : Latitudinal Slope / Degree / Gradient analysis done by Profiles and buffer around Ambil Odha (Rivulet)

5.2.3.2. Longitudinal Slope / Degree / Gradient analysis of Ambil Odha (Rivulet)

Table 39 : Longitudinal Slope / Degree / Gradient analysis of Ambil Odha (Rivulet)

	HEIGHT	SLOPE (DEGREE)	%
Longitudinal Profile	336	24	45

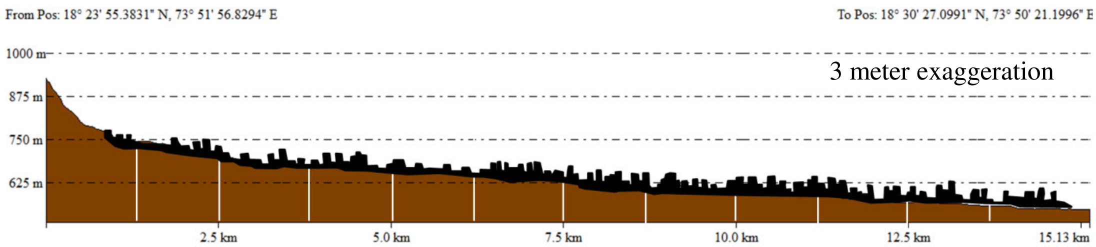


Figure 75: Longitudinal Slope Profile of Ambil Odha (Rivulet)

Table 40: Longitudinal Slope Profile of Ambil Odha (Rivulet)

PROFILE	HEIGHT (m)	LENGTH (m) (FROM SOURCE)	SLOPE (%)	SLOPE (DEGREE)
A1	748	920	81.30	39.11
A2	704	1840	38.26	20.94
A3	678	2760	24.57	13.80
A4	657	3680	17.85	10.12
A5	637	4600	13.85	7.88
A6	617	5520	11.18	6.38
A7	596	6440	9.25	5.29
A8	589	7360	8.00	4.58
A9	571	8280	6.90	3.94
A10	549	9200	5.97	3.42

Ambil Odha (Rivulet) has a source at an elevation of 1100m from the mean sea level. The graded profile of this rivulet indicates the impact of anthropogenic activities in the central part of the study area.

From the source to the elevation of around 704m, high density of settlement is observed. Control of slope on settlement and infrastructural development can be observed in the source region. Foot hill region below 701m is continuously changing due to hill slope cutting, quarrying and unplanned construction activities.

The gently sloping land has favored the human activities in the form of construction of buildings and infrastructure along with its expansion. From source region, 5 km to 15 km area is highly dense settlement and population growth in this section of topography. It also explains that the human intervention is more in this region.

Above 704m, the terraced profile clearly indicates that human activities have changed this sloping area because of massive construction activities from A2 to A5 region. These regions having 7^0 to 19^0 slope. In this particular area, construction activities have been increasing from last 20 years. All though these slopes are not favorable for settlements but slopes are altered to form settlements and these developments increasing in early years from confluence to source.

Below 596m, the profile is gently sloping favoring expansion of human settlements and infrastructure. Most of the settlements in this basin lie in between 3^0 to 6^0 slope.

The area between profile A3 and A5 show high density of population and settlement. The maximum density of settlement and population is observed from A3 to A6. Katraj, Bibvewadi, Sahakarnagar settlements are located in this region. All these settlements are responsible for alteration of scar, spur zone of this region.

5.2.3.3. Built-up area analysis of Ambil Odha (Rivulet) watershed area

Table 41 : Built-up area analysis of Ambil Odha (Rivulet) Watershed area

PROFILE / REGION	REGION AREA (Ha.)	B/U AREA 1991 (Ha.)	B/U AREA 2015 (Ha.)	INCREASE IN SETTLEMENT AREA 1991-2015 (Ha.)	% INCREASE FROM 1991 TO 2015
> A1	432	0.09	1.09	1	1111.11
A1 to A2	515	14.24	15.28	1.04	7.30
A2 to A3	372	53.51	74.33	20.82	38.91
A3 to A4	330	60.82	95.83	35.01	57.56
A4 to A5	321	168.09	232.57	64.48	38.36
A5 to A6	311	244.49	282.31	37.82	15.47
A6 to A7	240	216.18	230.51	14.33	6.63
A7 to A8	175	125.87	155.1	29.23	23.22
A8 to A9	173	159.8	170.2	10.4	6.51
A9 to A10	115	91.37	119.2	27.83	30.46
A10 to Next	15.5	12.95	29.5	16.55	127.80
Total	**2999.5**	**1147.41**	**1405.92**	**258.51**	

It is observed that during last 25 years, settlement has developed rapidly between the profiles A7 to A10, while profile region A3 to A5 are also populated during last 15 years area but construction wise this area is covered with massive development. A1 to A2 profile regions are less populated due to influences of relief factors (elevation, slope and aspect) as settlement locations were less strong across steep slopes. Almost 215.50 ha. of vacant land got converted into settlement area between all over the areas, which changed the whole scenario of land cover in this area.

River plain region of the basin with 3^0 to 6^0 slope is most favorable for the development of settlement and infrastructure. The area below 596m is covered by dense settlements of old Pune city. Recent development of infrastructure and settlements is observed in A1 to A2 region, Hotels and few residential areas are emerging in this region.

5.2.4. Bhairoba Nala Watershed Area

The Bahiroba Nala watershed area is divided by twelve cross profiles (south to north) and one longitudinal profile to understand spatio-temporal changes in slope due to urbanization. The growth of urban settlements increased along both the banks of stream Bahiroba Nala during 1991to 2015.

The stream originates at an elevation of 1000m (AMSL) near the Sinhgad-Bhuleshwar range of Western Ghats and flows in north direction to join the Mutha river at 550m (AMSL) village Yevalewadi and wards Bibwewadi, some part of Hadapsar, Pune Containment are under this watershed. The area between B4 and B9 is under Pune Municipal Corporation and B9 to B12 under Pune Containment area shows rapid growth of urbanization and having high density of settlement and population.

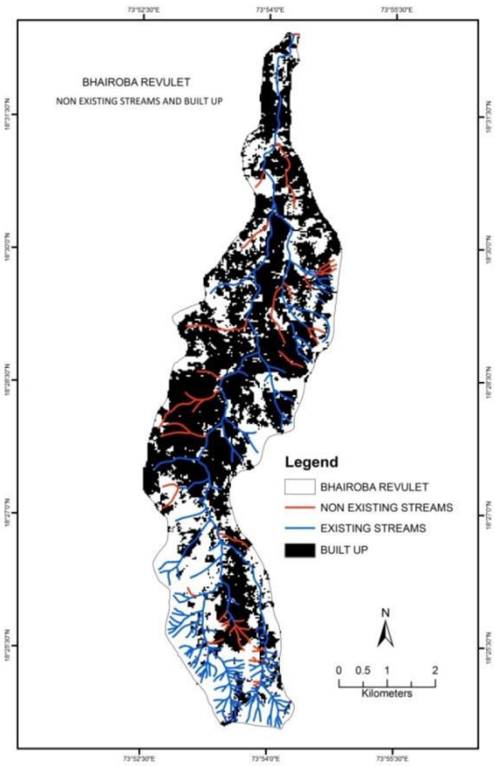


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Figure 76 : Built-up area and Non Existing Streams in Bhairoba Nala (Rivulet)

5.2.4.1. Latitudinal Slope/Degree/Gradient analysis by Profiles and buffer around Bhairoba Nala (Rivulet)

Table 42 : Latitudinal Slope / Degree / Gradient analysis of Bhairoba Nala (Rivulet)

PRO FILE	WEST_A (AMSL)	Relative Height (m)	GRADIENT (RUN -750m)	DEG REE	SLO PE %	PRO FILE	WEST_A (AMSL)	Relative Height (m)	SLOPE (DEGREE)	SLO PE %	East_B (AMSL
B1	**817**	89	1:8	6.77	12	**728**	21	1:36	1.60	3	**749**
B2	**766**	81	1:9	6.16	11	**685**	17	1:44	1.30	2	**702**
B3	**656**	-3	1:-250	-0.23	0	**659**	21	1:36	1.60	3	**680**
B4	**669**	20	1:38	1.53	3	**649**	5	1:150	0.38	1	**654**
B5	**661**	29	1:26	2.21	4	**632**	13	1:58	0.99	2	**645**
B6	**650**	38	1:20	2.90	5	**612**	29	1:26	2.21	4	**641**
B7	**615**	26	1:29	1.99	3	**589**	19	1:39	1.45	3	**608**
B8	**594**	10	1:75	0.76	1	**584**	4	1:188	0.31	1	**588**

B9	**580**	11	1:68	0.84	1	**569**	10	1:75	0.76	1	**579**
B10	**568**	9	1:83	0.69	1	**559**	11	1:68	0.84	1	**570**
B11	**557**	0	-	0.00	0	**557**	2	1:375	0.15	0	**559**
B12	**550**	2	1:375	0.15	0	**548**	1	1:750	0.08	0	**549**

This watershed area consists of Kondhwa area, Pune Containment, Bibewadi, Fatima Nagar in Pune city and village Yewalewadi which is outside Pune city falls under this watershed area. Few areas are inside Pune city boundary which covers up to B5 – B12 region. Area between profiles B4 and B7 are more prone to problems as the slope of average 1º -10º (i.e. 1:3) is favorable for construction, and most of the development in recent years has been happening in these parts of the study area. Various environmental problems including flash floods, obstruction to natural flow of streams and also has initiated the problem of non-existence of many streams.

The channel banks of Bhairoba Nala are reclaimed and retention/retaining walls are constructed to reduce the channel width in many parts of the city.

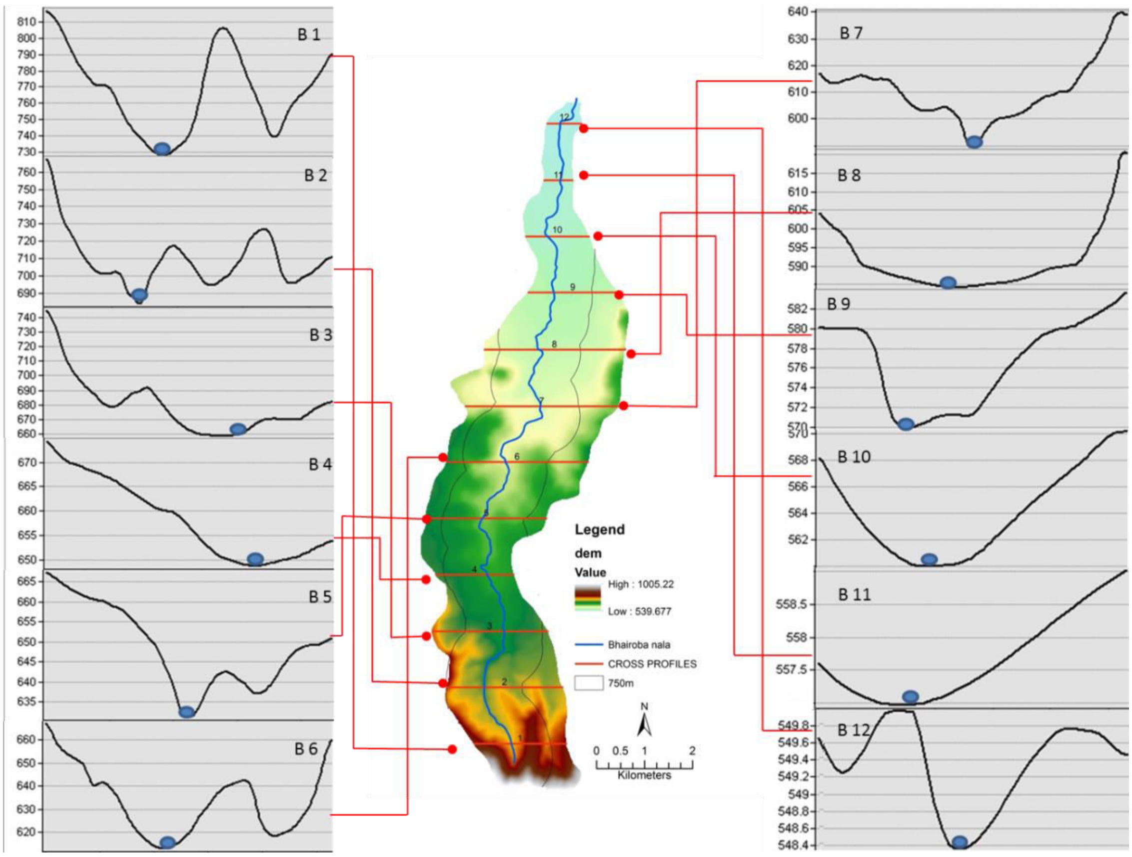


Figure 77 : Longitudinal Slope / Degree / Gradient analysis done by Profiles and buffer around Bhairoba Nala

5.2.4.2. Longitudinal Slope/Degree/Gradient analysis of Bhairoba Nala (Rivulet)

Table 43 : Longitudinal Slope/Degree/Gradient analysis of Bhairoba Nala (Rivulet)

	Height	Slope (Degree)	%
Longitudinal Profile	267	20	36

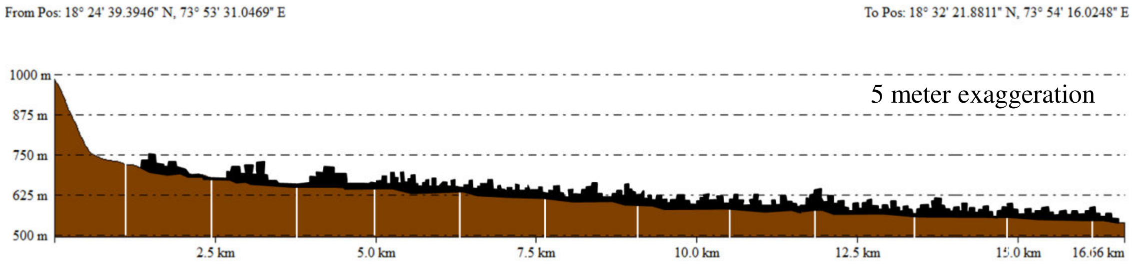


Figure 78: Longitudinal Profile of Bhairoba Nala (Rivulet)

Table 44: Longitudinal Profile of Bhairoba Nala (Rivulet)

PROFILE	HEIGHT (m)	LENGTH (m) (FROM SOURCE)	SLOPE (%)	SLOPE (DEGREE)
B1	728	1180	61.69	31.67
B2	685	2360	29.03	16.19
B3	659	3540	18.62	10.55
B4	649	4720	13.75	7.83
B5	632	5900	10.71	6.11
B6	612	7080	8.64	4.94
B7	589	8260	7.13	4.08
B8	584	9440	6.19	3.54
B9	569	10620	5.36	3.07
B10	559	11800	4.74	2.71
B11	557	12980	4.29	2.46
B12	548	14160	3.87	2.22

Bhairoba Nala (Rivulet) has a source elevation of around 1000m from the mean sea level. The graded/section/stepped/longitudinal profile of this rivulet show changes in slope by anthropogenic activities in stretch of 6 km to 12.5 km area.

From the source to the elevation of 650m, there are few settlements observed. As slope plays a dominant role in expansion/spread of the settlements in the source region. In the near source region, quarring activities have resulted into terraced type slopes causing profile alteration of slope. Below 625m, abrupt change in the slope is observed. This part clearly indicate the slope alteration in this region, the degree of slope gently decreases towards the confluence region. The gently sloping land has favored the human activities in the form of construction of buildings and infrastructural facilities. The stretch of 3km to 6km from source is covered by dense settlements with high population density, which indicates high anthropogenic activities in this region.

Although the area is favorable for the settlement due to Cantonment board rules and regulation, settlements have not developed as they are in Municipal Corporation area. As the area from 12 to 15 km from source is occupied by Containment Board, the settlements are not dense as in PMC area. The rules and regulation at Containment Board restricted the growth of settlements and infrastructural facilities in this area.

Most of the settlements in this basin lie in between 2 to 5 degree slope (B6 to B12). There are some settlements which lie between 7 to 29 degree slope (B2 to B4). All though these slopes are not favorable for settlements but slopes are altered to form settlements and these developments increasing in early years from confluence to source.

5.2.4.3. Built-up area analysis of Bhairoba Nala (Rivulet) Watershed area

Table 45 : Built-up area analysis of Bhairoba Nala (Rivulet) Watershed area

PROFILE / REGION	REGION AREA (Ha.)	B/U AREA 1991 (Ha.)	B/U AREA 2015 (Ha.)	INCREASE IN SETTLEMENT AREA 1991-2015 (Ha.)	% INCREASE FROM 1991 TO 2015
> B1	179	7.36	12.95	5.59	75.95
B1 to B2	267	18.91	46.63	27.72	146.59
B2 to B3	259	49.8	79.87	30.07	60.38
B3 to B4	206	25.9	92.06	66.16	255.44
B4 to B5	229	59.37	155.81	96.44	162.44
B5 to B6	320	81.8	214.71	132.91	162.48
B6 to B7	333	160.58	249.67	89.09	55.48
B7 to B8	334	212.38	234.1	21.72	10.23
B8 to B9	288	248.64	266.61	17.97	7.23
B9 to B10	158	84.5	147.27	62.77	74.28
B10 to B11	111	85.47	90.85	5.38	6.29
B11 to B12	71	59.57	69.93	10.36	17.39
B12 to next	25	18.66	20.46	1.8	9.65
Total	**2778.62**	**1112.94**	**1680.92**	**567.98**	

It is observed that during last 25 years, settlement has developed rapidly between the profile B2 and B6, while profiles B1 are less populated due to influences of relief factors (elevation, slope and aspect) as settlement are sparsely populated along steep slopes. Almost 420 ha. of vacant land has been converted into settlement area between B4 and B7, which changed the pattern of land use land cover in this area. From B8 to B12 although the area are favorable for the settlement due to Cantonment board rules and regulation, settlements are not much developed as they are in Municipal Corporation area.

5.2.5. Wadki -Nala Watershed Area

The Wadki Nala watershed area is divided by thirteen cross profiles (South East to North West) and one longitudinal profile to understand the spatio temporal changes in slope due to urbanization. The growth of urban settlements increased along both the banks of stream Wadki Nala during 1991to 2015.

The stream originates at an elevation of 990 m (AMSL) near the Sinhgad-Bhuleshwar range of Western Ghats and flow in north-west direction to join the Mutha River at 550 m (AMSL) village

Wadachi wadi, Holkarwadi, Uruli Dewachi, Phursungi and some part of Shewalewadi, Undri, Pisoli are under this watershed. The area between W2 and W6 shows rapid growth of urbanization in last 5 to 8 years and W6 and W10 having high density of settlement, population.

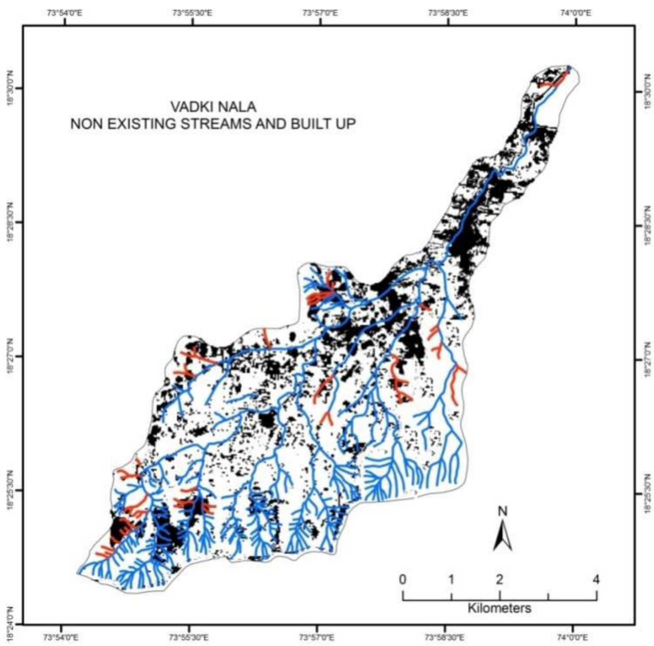


Figure 79 : Built-up area and Non Existing Streams in Wadki Nala (Rivulet)

5.2.5.1. Latitudinal Slope / Degree / Gradient analysis by Profiles and buffer around Wadki -Nala (Rivulet)

Table 46: Latitudinal Slope / Degree / Gradient analysis of Wadki Nala (Rivulet)

PROFILE	SOUTH_A (AMSL)	Relative Height (m) (A-R)	GRADIENT (RUN -500m)	Slope DEGREE	Slope %	RIVER (AMSL)	Relative Height (m) (B-R)	GRADIENT (RUN -500m)	Slope DEGREE	Slope %	NORTH _B (AMSL)
W1	916	916	1:1	50.69	122	-	954	1:1	51.83	127	954
W2	760	56	1:9	4.27	7	704	229	1:2	16.98	31	933
W3	674	6	1:83	0.46	1	668	62	1:8	4.73	8	730
W4	563	-77	1:-6	-5.86	-10	640	2	1:250	0.15	0	642
W5	634	5	1:100	0.38	1	629	12	1:42	0.92	2	641
W6	619	1	1:500	0.08	0	618	11	1:45	0.84	1	629

W7	632	33	1:15	2.52	4	599	5	1:100	0.38	1	604
W8	605	12	1:42	0.92	2	593	3	1:167	0.23	0	596
W9	577	2	1:250	0.15	0	575	3	1:167	0.23	0	578
W10	571	2	1:250	0.15	0	569	11	1:45	0.84	1	580
W11	566	0	-	0.00	0	566	1	1:500	0.08	0	567
W12	557	4	1:125	0.31	1	553	4	1:125	0.31	1	557
W13	546	0	-	0.00	0	546	4	1:125	0.31	1	550

PROFILE	RIVER	NORTH _C (AMSL)	GRADIENT (RUN -1500M)	Slope DEGREE	Slope %
W1	**-**	**954**	-	-	-
W2	**704**	**933**	-	-	-
W3	**668**	**730**	1:27	2.06	4
W4	**640**	**642**	1:26	1.99	3
W5	**629**	**641**	1:5	0.38	1
W6	**618**	**629**	1:14	1.07	2
W7	**599**	**604**	1:-6	-0.46	-1
W8	**593**	**596**	1:1	0.08	0
W9	**575**	**578**	1:13	0.99	2
W10	**569**	**580**	-	-	-
W11	**566**	**567**	-	-	-
W12	**553**	**557**	-	-	-
W13	**546**	**550**	-	-	-

This watershed area consist of surrounding villages of Pune city like Wadachiwadi, Holkarwade, Autadi Handewadi, Urali Devachi, Phursungi, South-east part of Undri and eastern part of Shewalewadi are under this watershed area. The whole watershed area is outside Pune city boundary which covers the area from W1 toW13 region. Area between profiles W5 to W13 are more prone to problems as the average slope 1º to 10º (i.e. 1:3) is favorable for construction.

Recently, the development of infrastructural facilities and settlements in this region is not controlled by local authorities but due to slope alteration. Planation on slopes has been undertaken to construct residential buildings and commercial complexes. This may lead to environmental problems like flash floods, divergence of natural flows and non-existence of streams.

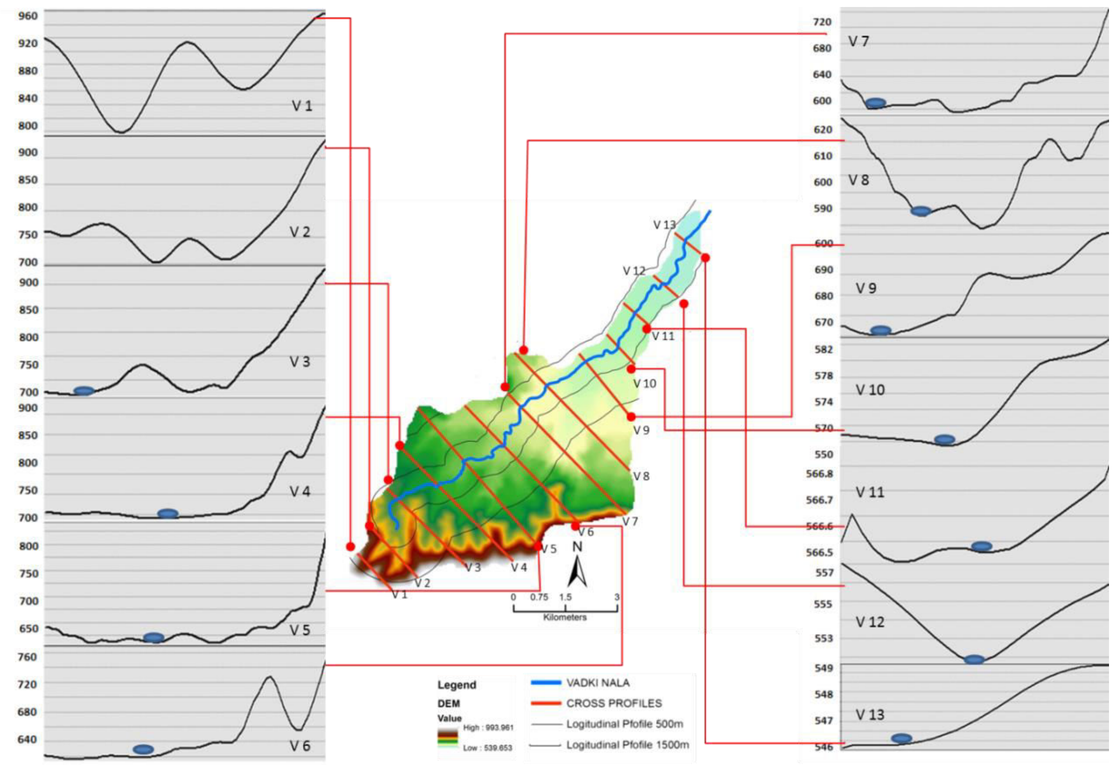


Figure 80 : Latitudinal Slope / Degree / Gradient analysis done by Profiles and buffer around Wadki Nala (Rivulet)

5.2.5.2. Longitudinal Slope/Degree/Gradient analysis of Wadki -Nala (Rivulet)

Table 47 : Longitudinal Slope/Degree/Gradient analysis of Wadki -Nala (Rivulet)

	HEIGHT	SLOPE (DEGREE)	%
Longitudinal Profile	370	37	74

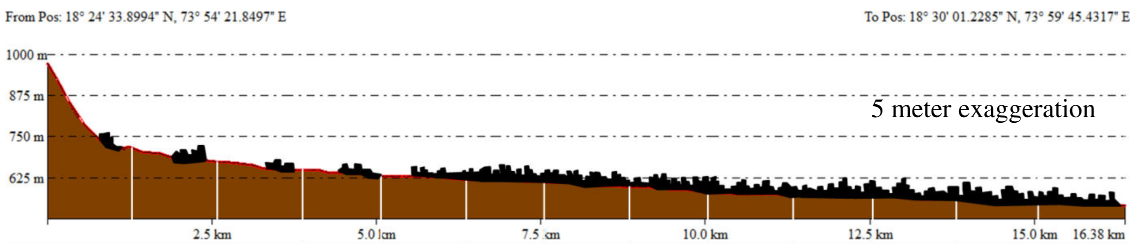


Figure 81: Longitudinal Profile of Wadki -Nala (Rivulet)

Table 48: Longitudinal Profile of Wadki -Nala (Rivulet)

PROFILE	HEIGHT (m)	LENGTH (m) (FROM SOURCE)	SLOPE (%)	SLOPE (DEGREE)
W1	780	1100	70.91	35.34
W2	704	2200	32.00	17.74
W3	668	3300	20.24	11.44
W4	640	4400	14.55	8.28
W5	629	5500	11.44	6.52
W6	618	6600	9.36	5.35
W7	599	7700	7.78	4.45
W8	593	8800	6.74	3.86
W9	575	9900	5.81	3.32
W10	569	11000	5.17	2.96
W11	566	12100	4.68	2.68
W12	553	13200	4.19	2.40
W13	546	14300	3.82	2.19

Wadki Nala (Rivulet) has a source elevation of around 990 m from the mean sea level. The graded profile of this rivulet explains that it has been altered by the anthropogenic activities in a stretch of 5.5 km to 16 km area.

The source region at an elevation of 618 m (W1 to W5) having steep slopes i.e. 3.5 to 6.55^0slope are occupied by scattered settlements. The area below 618 m gently sloping towards confluence. The distance 5.5 km to 16 km from the source is highly populated with dense settlements. Spurs, hill slopes of this area were altered. The land use pattern of this area is totally changed.

Most of the settlements in this basin lie in between 2^0 to 4^0 slope. There are some settlements which lie between 3^0 to 6^0 slope. All though these slopes are not favorable for settlements, they are altered due to continuous construction activities causing natural harm to environment/micro climate.

5.2.5.3. Built-up area analysis of Wadki -Nala (Rivulet) Watershed area

Table 49 : Built-up area analysis of Wadki -Nala (Rivulet) Watershed area

PROFILE / REGION	REGION AREA (Ha.)	B/U AREA 1991 (Ha.)	B/U AREA 2015 (Ha.)	INCREASE IN SETTLEMENT AREA 1991-2015 (Ha.)	% INCREASE FROM 1991 TO 2015
W1	200	5.16	98.2	93.04	1803.10
W1 to W2	152	35.44	124.23	88.79	250.54
W2 to W3	283	106.14	214.15	108.01	101.76
W3 to V4	428	112.95	229.17	116.22	102.90
W4 to W5	504	161.4	357.24	195.84	121.34
W5 to W6	544	115.38	364.75	249.37	216.13
W6 to W7	431	51.1	136.26	85.16	166.65
W7 to W8	331	11.46	174.59	163.13	1423.47
W8 to W9	343	30.78	106.19	75.41	245.00
W9 to W10	228	26.64	97.95	71.31	267.68
W10 to W11	138	23.9	85.37	61.47	257.20
W11 to W12	193	31.9	80.29	48.39	151.69
W12 to W13	122	87.7	116.55	28.85	32.90
Total	**3895.6**	**799.95**	**2184.94**	1384.99	

It is observed that during last 25 years settlement has developed rapidly between the profile region area W1 and W12, settlement locations are populated. Entire area crossed two times settlement area as compared to 1991 in 2015. Almost 475 ha. of vacant land got converted into settlement area between regions W5 to W13, which has changed the whole scenario of land cover in this area.

5.2.6. Wagholi Watershed Area

The Wagholi watershed area is divided by ten cross profiles (North to South) and one longitudinal profile to understand spatio temporal changes in slope due to urbanization. The growth of urban settlements increased along both the banks of stream Nandoshi during 1991to 2015.

The stream originates at an elevation of 680 m (AMSL) near the Dighi hill range of and flows in southern direction to join the Mutha River at 550 m (AMSL). Lohegaon, Wagholi and some part of Kharadi are located in this watershed. The area between W1 and W8 is under Pune Municipal Corporation shows rapid growth of urbanization with high density of settlement, population.

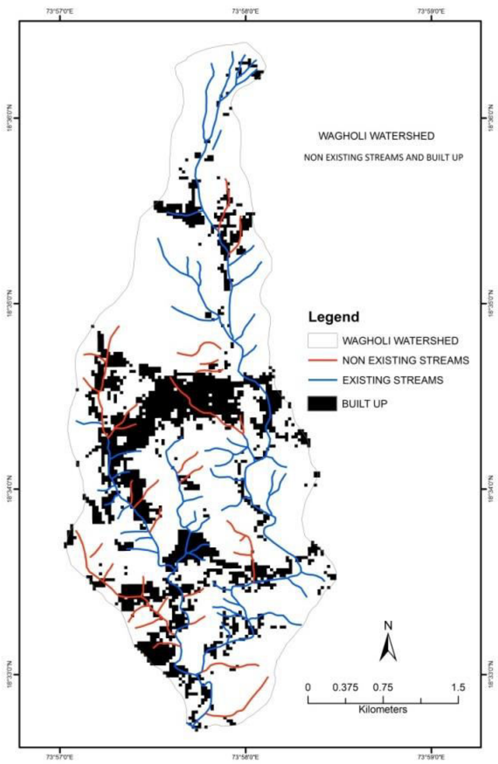


Figure 82 : Built-up area and Non Existing Streams in Wagholi (Rivulet)

5.2.6.1. Latitudinal Slope/Degree/Gradient analysis by Profiles and buffer around Wagholi (Rivulet)

Table 50 : Latitudinal Slope / Degree / Gradient analysis of Wagholi (Rivulet)

PROFILE	NORTH_A (AMSL)	Relative Height (m) (A-R)	GRADIENT (RUN -500m)	Slope DEGREE	Slope %	RIVER (AMSL)	Relative Height (m) (B-R)	GRADIENT (RUN -500m)	Slope DEGREE	Slope%	SOUTH_B (AMSL)
W 1	**549**	11	1:45	0.84	1	**538**	14	1:36	1.07	2	**552**
W 2	**560**	10	1:50	0.76	1	**550**	-8	1:-63	-0.61	-1	**542**
W 3	**567**	7	1:71	0.53	1	**560**	0	-	0.00	0	**560**
W 4	**570**	1	1:500	0.08	0	**569**	1	1:500	0.08	0	**570**
W 5	**580**	10	1:50	0.76	1	**570**	-2	1:-250	-0.15	0	**568**
W 6	**590**	11	1:45	0.84	1	**579**	2	1:250	0.15	0	**581**
W 7	**590**	1	1:500	0.08	0	**589**	-3	1:-167	-0.23	0	**586**
W 8	**600**	1	1:500	0.08	0	**599**	1	1:500	0.08	0	**600**
W 9	**609**	-3	1:-167	-0.23	0	**612**	31	1:16	2.37	4	**643**

Areas such as Wagholi, Kharadi and eastern part of Viman-Nagar and major part of Yerawada are located in this watershed study area. Most of the watershed area is under Pune Municipal Corporation. Area between profiles W7 to W9 are more prone to problems as the slope of average 5° -15° (i.e. 1:5) is feasible for construction, and most of the development in recent years has been seen in this parts of study area, causing various environmental problems including flash floods, obstruction to natural flow of streams and also has initiated non-existence of many streams. Due to plain plateau region, the settlements in this area developed very rapidly. Although this area is developed very rapidly, area around defense lands are still undeveloped. Many streams near confluence are either blocked or there course are changed by builders and land owners. A good amount of area is still undeveloped due to restrictions of Airport and Defense Zone. Mouth of rivulet is getting blocked towards south at the tip of watershed area due to uncontrolled development.

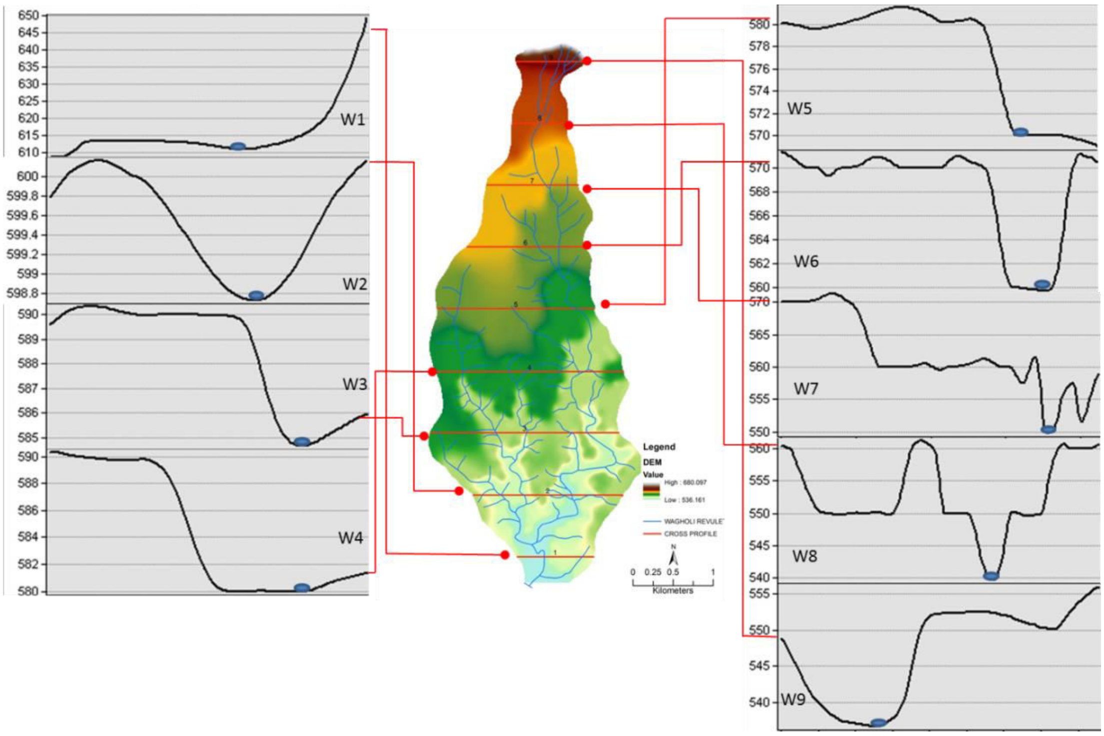


Figure 83 : Latitudinal Slope / Degree / Gradient analysis done by Profiles and buffer around Wagholi (Rivulet)

5.2.6.2. Longitudinal Slope/Degree/Gradient analysis of Wagholi (Rivulet)

Table 51 : Longitudinal Slope/Degree/Gradient analysis of Wagholi (Rivulet)

	Height	Slope (Degree)	%
Longitudinal Profile	225	17	30

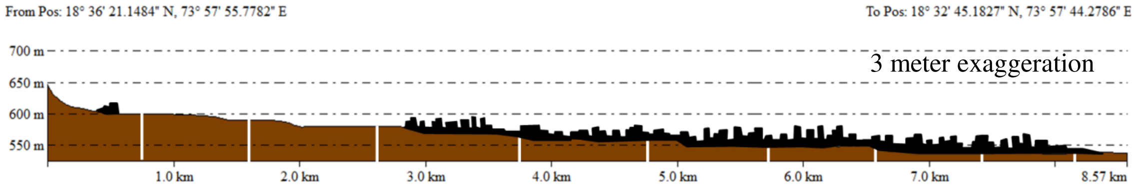


Figure 84: Longitudinal Profile of Wagholi (Rivulet)

Table 52: Longitudinal Profile of Wagholi (Rivulet)

PROFILE	HEIGHT (m)	LENGTH (m) (FROM SOURCE)	SLOPE (%)	SLOPE (DEGREE)
W1	538	770	69.87	34.94
W2	550	1540	35.71	19.65
W3	560	2310	24.24	13.63
W4	569	3080	18.47	10.47
W5	570	3850	14.81	8.42
W6	579	4620	12.53	7.14
W7	589	5390	10.93	6.24
W8	599	6160	9.72	5.55
W9	612	6930	8.83	5.05

Wagholi Nala (Rivulet) originates at elevation of 680 m from the mean sea level. The graded profile of this rivulet explains that it has been altered by anthropogenic activities in a stretch of 4 km to 8 km from source. Below 580 m the land surface is almost flat with very low gradient sloping towards confluence, this favor the rapid urbanization in this area. The state highway (Pune-Nagar)

Below 580m the land surface is almost flat with very low gradient sloping towards confluence, this favor the rapid urbanization in this area. The state highway (Pune – Nagar), IT industries and service industry occupied this area. The built up area 116 Hectare is increased since 1991. Area between W5 to W7, W7 toW8 and beyond W9 show very rapid growth in built up area by 233.33 %, 550 % and 361.54 % respected during the period 1991 to 2015. The gently sloping land has favored the human activities in the form of construction of buildings and infrastructure along with its expansion. As far as infrastructure is concerned state highway and IT industries have occupied most of the land in this profile. From source region, 4 km to 8 km area is highly dense settlement and population growth in this section of topography. It also explains that the human intervention is more in this region.

Below 580 m the profile has a gentle slope, favoring expansion of human settlements and infrastructure.

Most of the settlements in this basin are lie in between 5^0 to 7^0 slope. There are some settlements, which lie between 13^0 to 8^0 slope. All though these slopes are not favorable for settlements slopes are altered to form settlements and this development increasing in early years from confluence to source.

5.2.6.3. Built-up area analysis of Wagholi (Rivulet) Watershed area

Table 53 : Built-up area analysis of Wagholi (Rivulet) Watershed area

PROFILE / REGION	REGION AREA (Ha.)	B/U AREA 1991(Ha.)	B/U AREA 2015 (Ha.)	INCREASE IN SETTLEMENT AREA 1991-2015 (Ha.)	% INCREASE FROM 1991 TO 2015
W1	25	0.52	6.21	5.69	1094.23
W1 to W2	101	10.88	31.07	20.19	185.57
W2 toW3	176	18.13	31.11	12.98	71.59
W3 to W4	167	5.7	25.95	20.25	355.26
W4 to W5	166	37.23	77.69	40.46	108.68
W5 to W6	134	10.36	25.89	15.53	149.90
W6 to W7	97	1.6	13.48	11.88	742.50
W7 to W8	64	1.55	10.26	8.71	561.94
W8 to W9	46	1.03	12.55	11.52	1118.45
W9 to next	18	0.21	1.55	1.34	638.10
Total	**993.87**	**87.21**	**235.76**	148.55	170.34

It is observed that during last 25 years settlement has developed rapidly between the regions from W1, W3 to W4, W4 to 8 while profiles W2 to W3 are less populated due to restriction by air force authority for construction. Almost 130.66 ha. of vacant land got converted into settlement, which changed the whole scenario of land cover in this area.

The area from W1 to W2, W3 to W4, W4to W5 and W6 show the growth in built up area greater than 100% during the last 25 years. This gently sloping river valley in now occupied by dense settlement with many multistoried buildings.

CHAPTER – 6: FINDINGS AND CONCLUSION

Relationships between development or built up areas and their impacts on environment along river were explored with the help of remotely sensed data in this research. This study demonstrated a new approach to analyze urban growth patterns of human settlements from a wide geographical perspective.

The growth of one major and six sub watersheds and its geographic conditions are ideal for expansion of development which has caused conversion of agricultural lands into built-up area. Along streams transportation routes as various types of services are easily available.

As development expanded settlement started creeping on foot hill slopes. Cutting and filling of hill slops cause disturbance in natural flow of streams and blocking it due to dumping of construction debris/waste which indirectly were responsible for non existence of streams.

Dumping material in the streams / river is responsible for restriction of infiltration of surface water. It also causes breaking of stream links which triggered water logging on sites and also flash floods in rainy season.

Out-growth of development in Peri-urban areas is applying pressure on vegetation cover to diminish and also show under use of potential available space for tree plantation.

Change detection analysis shows that increase in urbanisation is responsible for decrease in Agricultural land and Barren Land, the growth of real estate activities and emergence of new educational institutes in and around the city.

Morphometric Analysis

The sub-watersheds of the study area are 5^{th} order drainage basin. The mean bifurcation ratio indicates that the area is having homogenous rock type and have structural control on the drainage pattern. The drainage density, stream frequency and the drainage intensity are correlated with the degree of dissection in the area. Hence it is clear that intensity of dissection varies from low to moderate in the study area and this can also be determined by the low to moderate dissection index value. Drainage density indicates that the study area is in humid region.

From the Form Factor ratio, Circularity ratio and Elongation ratio it is clear that the sub-watershed basins are elongated in shape. This fact emphasises that there is low and delayed discharge of runoff. From the present study, it is clear that the area is not susceptible to flooding but this is true only in natural conditions, as increasing anthropogenic activity the present day situation is different. The study area is having coarse to very fine drainage texture which is an indication of fine grained rocks with lesser permeability. The drainage density and stream frequency have a low to moderate effect on the surface denudation in the present area.

Impervious surface tends to affect the infiltration capacity of the land and increases the flow transmission in the streams. Thus, direct human impact in the area will modify the character and behaviour of the streams. It may either expand or suppress the capacity of the river to adjust.

Land Use and Land Cover

During the last two and half decades (1991 to 2015) the area under vegetation has been decreased by approximately 11.54% (62.48 Sq.km) probably due to development in core and peri-urban areas of city. During the stipulated period, the area under settlement area has increased by 20.23% (109.54 sq.km) due to conversion of vegetation and Open/Barren land due to human interventions.

Open/barren land have decreased by 4.34% (23.50 Sq.km) due to urbanization while agricultural land and area under water bodies has been decreased by considerable amount i.e. 3.57% (19.33 Sq.km) and 0.78% (4.22 Sq.km) respectively causing depletion of good fertile land, heavy development along water bodies and Non-existing of existing streams.

Non-existing Streams in Selected Watershed Areas

- **Ram Nadi** : Around **25.48%** of streams have non-exist in watershed area.

- **Nandoshi:** The southern part of the watershed region has a highly terrain and there is no sign of urbanization as a result only **3.73 %** streams are reduced during last 25 years.
- **Ambil Odha:** Rapid growth of urbanization is responsible for loss of 48 first order streams out of 235 during this period. This shows that around **21.13%** streams are non-existing streams
- **Bhairoba Nala:** Total 198 streams are present in the area but 45 of them are presently vanished which is almost **22.73%** of the total streams. These streams vanished specifically in Yewalewadi and Kondhwa part due to enormous construction activities in the concerned area.
- **Wadki Nala:** Around 16.56% streams are non-existing streams. Most of the streams passed through borders of agriculture land holding in past but presently paddy agricultural fields were observed on these streams.
- **Wagholi** : Wagholi, is located on the Pune-Nagar Highway close to the Kharadi IT hub, has been experiencing rapid development in terms of real estate, social infrastructure and education sectors. Almost **39 %** streams area occupied by built-up area.

Slope Analysis

- **Ram Nadi** : Due to saturation and unavailability of plain land there are some settlements which in between 9 to 30 degree slope region. Allthough these slopes are not favorable for settlements but slopes are altered to form settlements and this development increasing in early years from confluence to source.
- **Nandoshi:** It is observed that during last 25 years settlement has developed slowly at Southern region (source) with less populated due to influences of local relief factors (elevation, slope and aspect) as settlements are less across the steep slopes. Almost 120 ha. of open land converted into settlements at confluence region due to radical growth.
- **Ambil Odha:** Above 704m, the terraced profile clearly indicates that humans have changed it because of massive construction activities from Source region (Mangalewadi and Bhilarewadi). These regions having 7 to 19 degree slope. In this particular area, construction activities have been increasing from last 20 years.

- **Bhairoba Nala:** There are some settlements which lie between 7 to 29 degree slope (Yewalewadi and Upper Kondwa). Allthough these slopes are not favorable for settlements but slopes are altered to form settlements and these developments increasing in early years from confluence to source
- **Wadki Nala:** The area below 618 m gently sloping towards confluence. The distance 5.5 km to 16 km from the source is highly populated with dense settlements. Spurs, hill slopes of this area were altered. The land use pattern of this area is totally changed.
- **Wagholi** : There are some settlements which lie between 13 to 8 degree slope. All though these slopes are not favorable for settlements but slopes are altered to form settlements Area at confluence region are more prone to problems as the slope of average 5º -10º (i.e. 1:5) is feasible for construction, and most of the development in recent years has been seen in this parts of study area, causing various environmental problems including flash floods, obstruction to natural flow of streams and also has initiated non-existence of many streams.

Residual Plotting Analysis

Residual plots can be used to assess the quality of the regression. One can examine the underlying statistical assumptions about residuals such as constant variance, independence of variables and normality of the distribution. For these assumptions to hold true for a particular regression model, the residuals would have to be randomly distributed around zero.

Different types of residual plots can be used to check the validity of these assumptions and provide information on how to improve the model. For example, the scatter plot of the residuals will be disordered if the regression is good. A trend would indicate that the residuals were not independent. On the other hand, a histogram plot of the residuals should exhibit a symmetric bell-shaped distribution, indicating that the normality assumption is likely to be true.

The statistical analysis of data was carried out Multivariate as well as Bivariate Regression analysis results were plotted. Residual plotting's of different variable were compared and the patterns of distribution with maps were prepared for change detection as well as to understand future trends of urbanization.

Rama Nadi Watershed

Built Up : The residuals of built up area shown in fig. no. 86 clearly suggest 3 pockets of residuals. The central pocket is basically pocket of negative residuals developed around Pashan road (Pashan hill) area. The built up area near Pashan hill is very low with reference to the expected built up area. This may be due to the reasons that this region is occupied by government as well as military organization with huge green campuses. Area still not occupied with built up because of the restriction on construction and security reason for military campus. However due to these restrictions there is hardly any space for the increased the built up in this area.

As one moves in the downstream direction built up in this pocket is not as low as expected, therefore a slight built up may come up in future. It is interesting to note that built up area is very high in the downstream area of the catchment near around Baner and the upstream area around Bhugav.

Around Bhugav the built up area is increased compare to Baner, therefore the future planning must concentrate on restriction on the built up area at this two ends within the catchment.

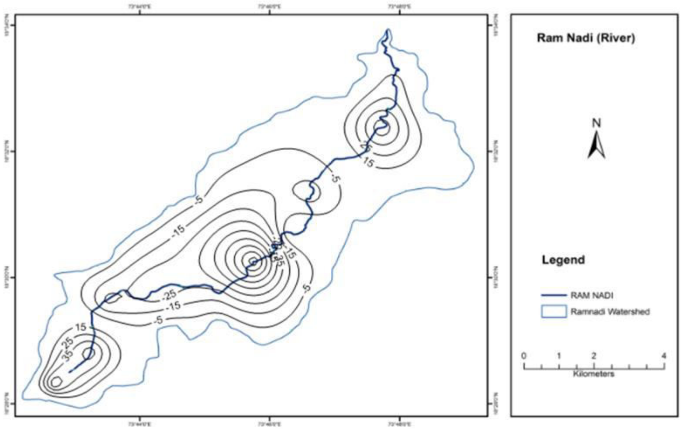


Figure 85: Residuals of built-up area in Ram Nadi watershed

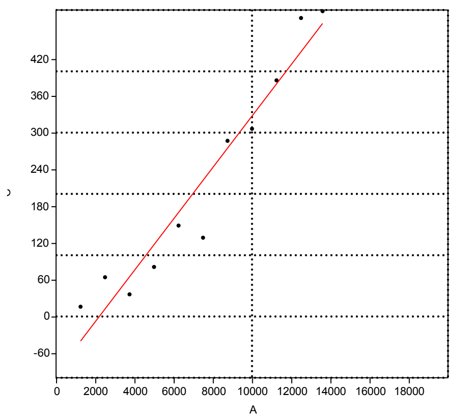


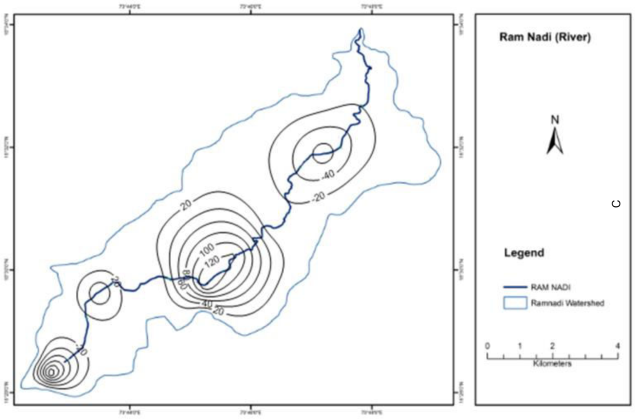
Figure 2: Residual plot: Distance from source vs. buil-up

Table 54: Residuals of built-up area

Profile	Distance from Source (Meters) x	B/U (Ha.) y	Regr. x	Regr. y	Err x	Err y
R1	1250	16	2586.2	-40.057	-1336.2	56.057
R2	2500	64	3730.4	12.383	-1230.4	51.617
R3	3750	36.18	3067.2	64.824	682.77	-28.644
R4	5000	80.82	4131.3	117.26	868.7	-36.444
R5	6250	148.36	5741.2	169.7	508.78	-21.345
R6	7500	128.6	5270.2	222.15	2229.8	-93.545
R7	8750	286.6	9036.4	274.59	-286.38	12.014
R8	10000	306.26	9505	327.03	495	-20.766
R9	11250	385.3	11389	379.47	-139.04	5.8332
R10	12500	487	13813	431.91	-1313.2	55.093
R11	13600	498.2	14080	478.07	-479.82	20.13

Barren Land : The residuals of barren land area shown in fig. no. 88 clearly suggest 4 pockets of residuals. The central pocket is basically pocket of positive residuals developed around Pashan road (Pashan hill) area. According to this pocket, barren land near Pashan hill is very high with reference to the expected barren land area. However due to restrictions there is hardly any space for the construction in this area. Chandani Ckowk pocket shows the positive residuals developed of barren land. This particular area is covered with hill terrain that restricts the urbanization.

As we move in the downstream direction towards Baner and Pashan area, barren land in these pockets are very low as expected. There would be very less chance of barren land avaibility in future as most of the land would have already been converted to settlements. It is interesting to note that barren land area is very low in the downstream area of the catchment near around Baner and Pashan and the upstream area around Bhukum. Around Baner and Aundh the barren land area decreased as compared to Bhukum, therefore the future planning must concentrate on restriction on the built up area at this two ends within the catchment.



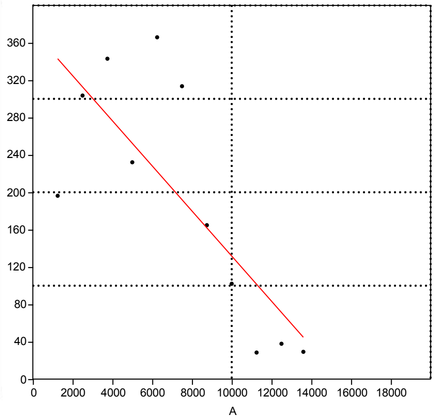


Figure 3: Figure 3: Residuals of barren land area in Ram Nadi Watershed

Figure 4: Residual plot: Distance from source vs. barren land

Table 55: Residuals of Barren land area

Profile	Distance from Source (Meters) x	Barren Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
R1	1250	196.29	7327.7	342.99	-6077.7	-146.7
R2	2500	303.57	2883.2	312.82	-383.21	-9.2498
R3	3750	343.02	1248.8	282.65	2501.2	60.372
R4	5000	232.13	5842.9	252.48	-842.88	-20.345
R5	6250	365.94	299.29	222.3	5950.7	143.64
R6	7500	313.56	2469.3	192.13	5030.7	121.43
R7	8750	164.82	8631.5	161.96	118.55	2.8615
R8	10000	102.12	11229	131.79	-1229	-29.666
R9	11250	28.48	14280	101.61	-3029.9	-73.134
R10	12500	37.87	13891	71.442	-1390.8	-33.572
R11	13600	29.25	14248	44.881	-647.58	-15.631

Water: The residuals of water area shown in fig. no. 90 clearly suggest 4 pockets of residuals. The upstream pocket is pocket of positive residuals developed in between Bhukum and Bhugaon area due to Manas Lake and at downstream near Pashan area due to Pashan Lake. The area under water bodies of Pashan Lake is higher than Manas Lake. However, due to these two lakes residuals plot for water body indicate positive residuals in this area. As one moves in the downstream direction towards Baner and Aundh residuals clearly indicate negative signs of availability of water bodies. These pockets are very small as expected. There would be need to occupy almost 3 Hectares of land having water body in their pockets. No scope of water body formation may come up in future as most of the land is already converted in built up areas. But in Ram Nadi stream it is necessary to concentrate on river restoration process. It is interesting to note that water bodies are very low in the central part of the catchment near Sus and Bavdhan area.

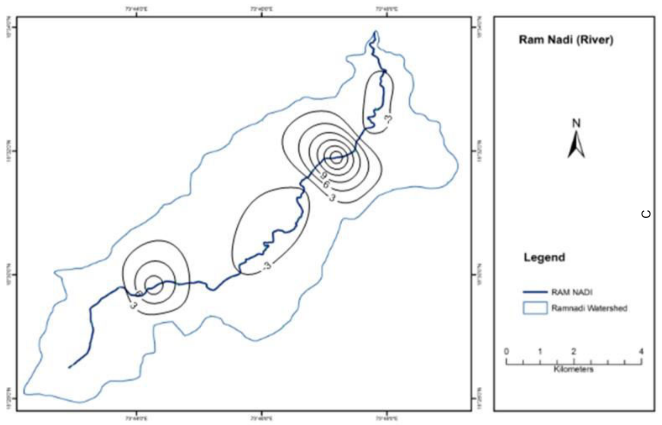


Figure 5: Residuals of water bodies area in Ram Nadi Watershed

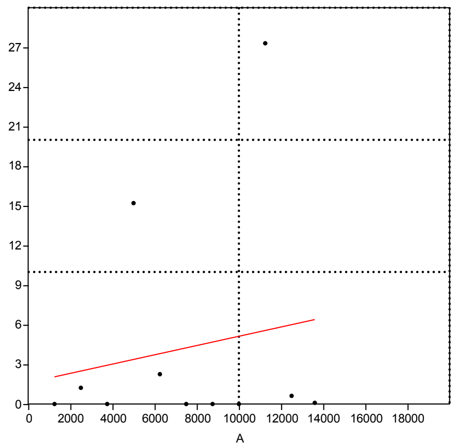


Figure 6: Residual plot: Distance from source vs. Water bodies

Table 56: Residuals of Water bodies area

Profile	Distance from Source (Meters) x	Water Bodies (Ha.) y	Regr. x	Regr. y	Err x	Err y
R1	1250	0	-4610.4	2.0576	5860.4	-2.0576
R2	2500	1.23	-1107.2	2.4965	3607.2	-1.2665
R3	3750	0	-4610.4	2.9354	8360.4	-2.9354
R4	5000	15.21	38710	3.3743	-33710	11.836
R5	6250	2.26	1826.4	3.8132	4423.6	-1.5532
R6	7500	0	-4610.4	4.252	12110	-4.252
R7	8750	0	-4610.4	4.6909	13360	-4.6909
R8	10000	0	-4610.4	5.1298	14610	-5.1298
R9	11250	27.31	73172	5.5687	-61922	21.741
R10	12500	0.62	-2844.5	6.0076	15345	-5.3876
R11	13600	0.09	-4354.1	6.3939	17954	-6.3039

Vegetation: The residuals plot of vegetation cover in Ram Nadi watershed area show negative residuals near Pashan – Baner area than the expected residuals in this area. Recently many housing complex as well as commercial complex are developed in this area, which has affected the vegetation cover of these regions. But area around Pashan Lake shows positive residuals as compared to residual area expected as this region occupied by government as well as military organization with extensive green campus. The restriction on construction activities on military campus for security reason has increased the overall natural vegetation percentage in this region. Remaining part or source region of this watershed area is matching with expected residuals as it indicates natural growth of vegetation.

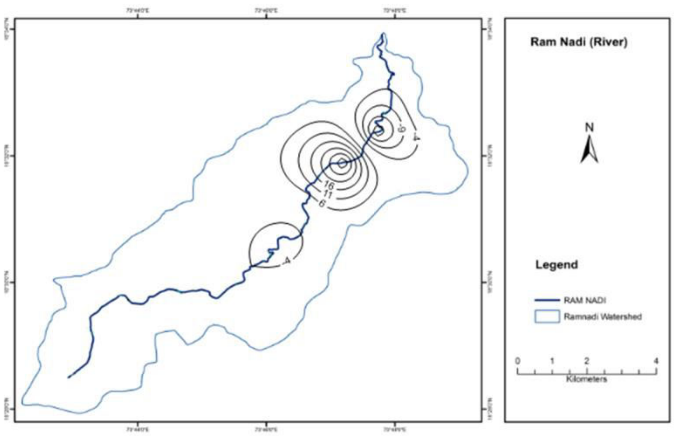


Figure 8: Residuals of vegetation cover in Ram Nadi Watershed

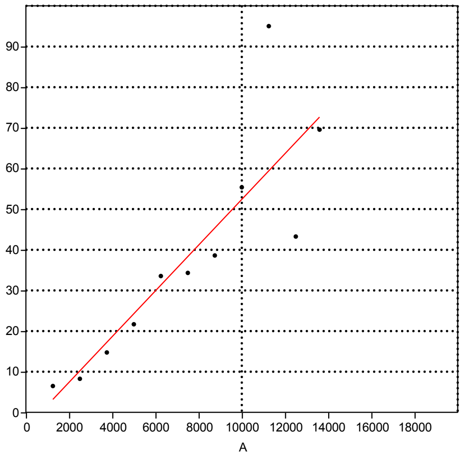


Figure 7: Residual plot: Distance from source vs. Vegetation cover

Table 57: Residuals of Vegetation cover area

Profile	Distance from Source (Meters) x	Vegetation covers (Ha.) y	Regr. x	Regr. y	Err x	Err y
R1	1250	6.48	1836.1	3.184	-586.11	3.296
R2	2500	8.26	2152.6	10.213	347.36	-1.9534
R3	3750	14.74	3304.9	17.243	445.06	-2.5028
R4	5000	21.67	4537.3	24.272	462.74	-2.6022
R5	6250	33.54	6648	31.302	-398.04	2.2384
R6	7500	34.32	6786.7	38.331	713.26	-4.011
R7	8750	38.59	7546	45.36	1204	-6.7705
R8	10000	55.37	10530	52.39	-529.94	2.9801
R9	11250	95.01	17579	59.419	-6328.9	35.591
R10	12500	43.26	8376.5	66.449	4123.5	-23.189
R11	13600	69.56	13053	72.637	547.1	-3.0767

Agricultural: The residual plot of agricultural land cover at Ram Nadi watershed area show negative residuals at Pashan, Bavdhan and Sus Road area than the expected. As this area recently developed many housing complexes on agricultural land. This land converted to non-agricultural land in the form of built-up area. The area around Bhukum having small settlement of farmers, the main occupation of this population is agriculture. No sign of urbanization observed in this region, traditional agricultural practices can be observed in this area. Hill slopes area converted into small agricultural fields. It is interesting to note that the area around Someshwar nagar, a patch of a land is still under agricultural practice and vegetation.

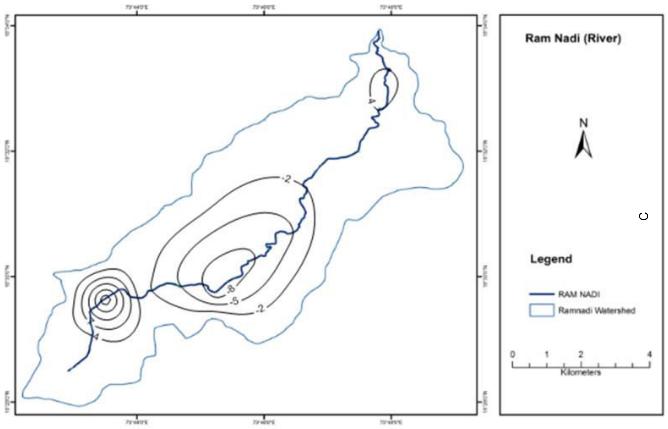


Figure 10: Residuals of Agricultural area in Ram Nadi Watershed

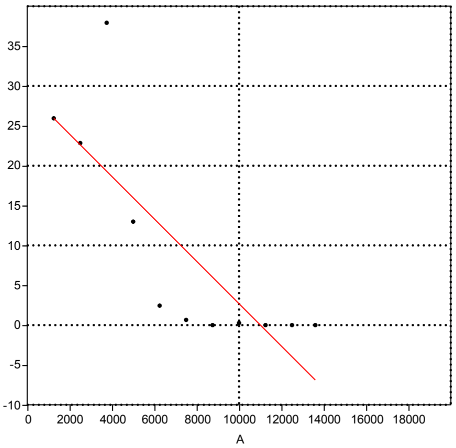


Figure 9: Residual plot: Distance from source vs. Agriculture Land

Table 58: Residuals of Agriculture land area

Profile	Distance from Source (Meters) x	Agricultural land (Ha.) y	Regr. x	Regr. y	Err x	Err y
R1	1250	25.94	1251	25.943	-0.97409	-0.00259
R2	2500	22.83	2421.1	22.62	78.901	0.20971
R3	3750	37.92	-3256.5	19.298	7006.5	18.622
R4	5000	12.98	6127.1	15.976	-1127.1	-2.9957
R5	6250	2.44	10093	12.653	-3842.8	-10.213
R6	7500	0.66	10762	9.3311	-3262.5	-8.6711
R7	8750	0	11011	6.0088	-2260.8	-6.0088
R8	10000	0.27	10909	2.6865	-909.21	-2.4165
R9	11250	0	11011	-0.63576	239.2	0.63576
R10	12500	0	11011	-3.9581	1489.2	3.9581
R11	13600	0	11011	-6.8827	2589.6	6.8827

Nandoshi Watershed

Built Up: The residuals of built up area shown in fig. no. 95 suggest 4 pockets of residuals. The central and upstream pockets are pockets of negative residuals developed around Nandoshi, Wanjalewadi and Kirkitwadi areas. These pockets show low built up area are with reference to the expected built up area. This may be due to hilly area with fairly dense mixed jungle covered in upstream area. This area is under reserve forest area of Sinhgad – Bhuleshwar hilly range. Sanaswadi and Wanjalewadi located in spur zone at upstream area with scattered settlement. However due to these restrictions and hilly area there is no sign of urbanization. At Nandoshi to Kirkatwadi having still village settlements. The impact of urbanization is very low in this fringe zone. It is interesting to note that built up area is very high in the downstream area of the catchment in Nanded village. A 700 hectares of Nanded city at Nanded village, with wide road, huge shopping complexes, high-rise buildings and luxurious bungalows indicates increasing rate of urbanization in fringe zone.

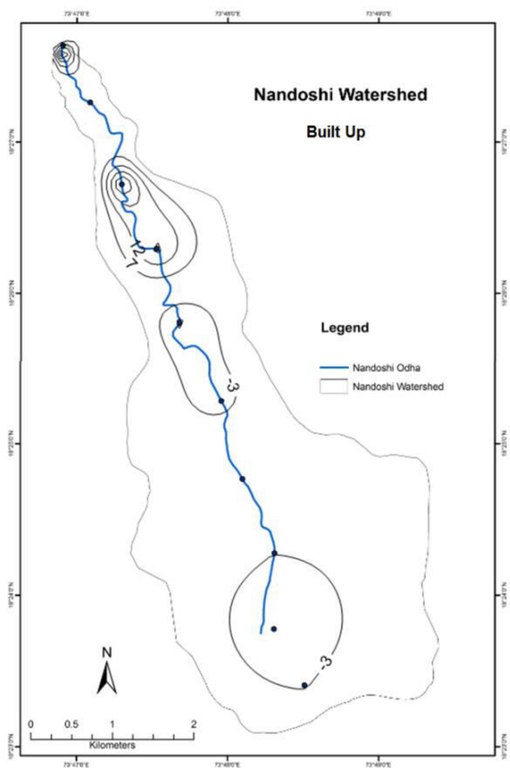


Figure 11: Residuals of Built-Up Land area in Nandoshi Watershed

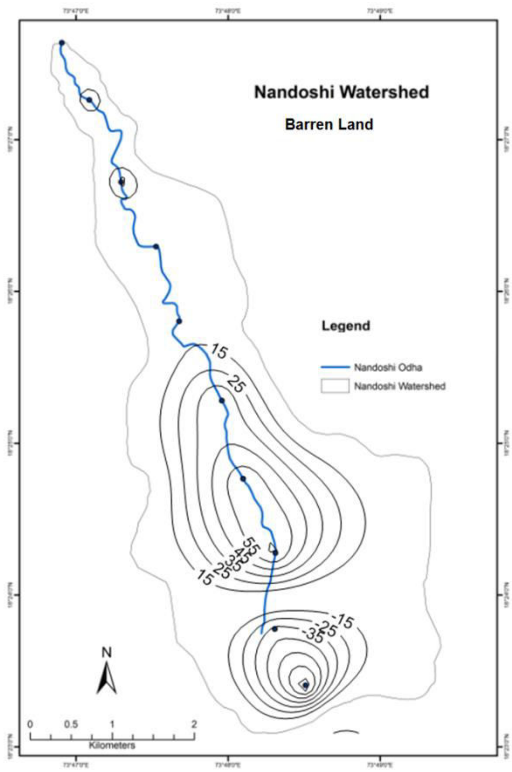


Figure 12: Residuals of Barren area in Nandoshi Watershed

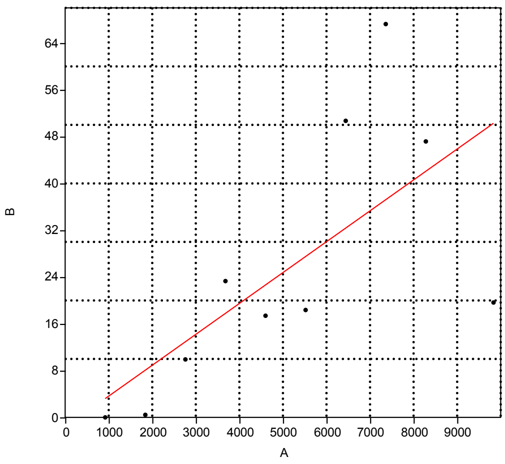


Figure 13: Residual plot: Dist. from source vs. Built-Up

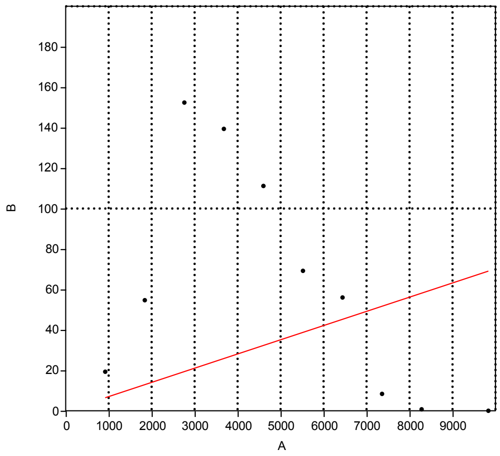


Figure 14: Residual plot: Dist. from source vs. Barren Land

Table 59: Residuals of Built - up

Profile	Distance from Source (Meters) x	Built Up (Ha.) y	Regr. x	Regr. y	Err x	Err y
N1	920	0.01	310.82	3.226	609.18	-3.216
N2	1840	0.44	392.28	8.0828	1447.7	-7.6428
N3	2760	9.91	2186.1	12.94	573.89	-3.0297
N4	3680	23.31	4724.4	17.797	-1044.4	5.5135
N5	4600	17.38	3601.1	22.653	998.9	-5.2734
N6	5520	18.36	3786.7	27.51	1733.3	-9.1503
N7	6440	50.69	9910.8	32.367	-3470.8	18.323
N8	7360	67.24	13046	37.224	-5685.7	30.016
N9	8280	47.18	9245.9	42.081	-965.9	5.0992
N10	9833	19.64	4029.2	50.279	5803.8	-30.639

Table 60: Residuals of Barren Land

Profile	Distance from Source (Meters) x	Barren Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
N1	920	19.33	9283.2	103.37	-8363.2	-84.044
N2	1840	54.69	5764.5	94.129	-3924.5	-39.439
N3	2760	152.41	-3959.5	84.884	6719.5	67.526
N4	3680	139.38	-2662.9	75.638	6342.9	63.742
N5	4600	111.16	145.25	66.393	4454.8	44.767
N6	5520	69.21	4319.7	57.147	1200.3	12.063
N7	6440	56.04	5630.2	47.902	809.8	8.1379
N8	7360	8.38	10373	38.657	-3012.8	-30.277
N9	8280	0.74	11133	29.411	-2853.1	-28.671
N10	9833	0	11207	13.805	-1373.7	-13.805

Barren Land: The residuals of barren land area shown in fig. no. 96 show 2 pockets of residuals. The upstream pocket is basically pocket of negative residuals developed at open jungle hill slope on Sinhgad – Bhuleshwar hilly range. This pocket is very low as expected because of steep no scope of built-up.

The upstream to central pocket is basically pocket of positive residuals developed around Sanaswadi, Wanjalewadi and Nandoshi area. According to these pocket, barren land is very high with reference to the expected barren land area. This may be due to the agricultural land converted in non-agricultural land. In future this barren land area of these villages will convert into settlement.

Water: The residuals of water area shown in fig. no. 100 clearly suggest 2 pockets of residuals. The upstream pocket is basically pocket of positive residuals developed near Sanaswadi. But as we go downstream of watershed area, region show negative residuals. Stream in Nandoshi and Wanjalewadi village area residuals clearly indicate negative signs for water bodies cover. These pockets are very low as expected. This region is occupied by villages with rural settlements.

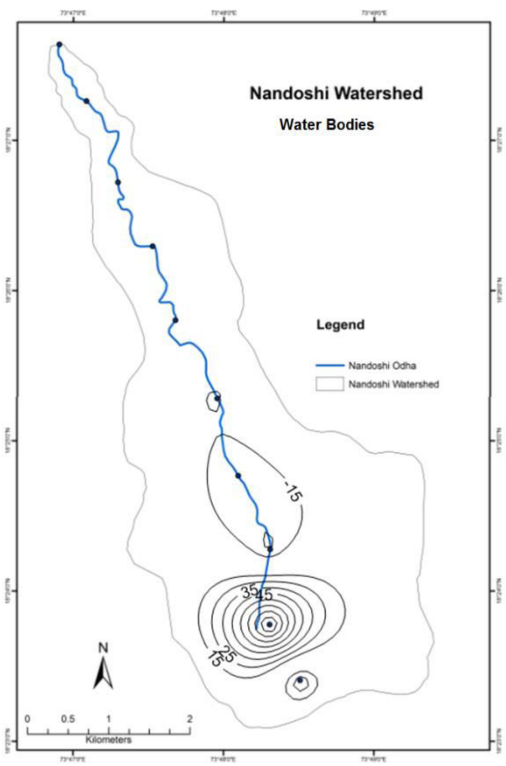


Figure 16: Residuals of Water bodies in Nandoshi Watershed

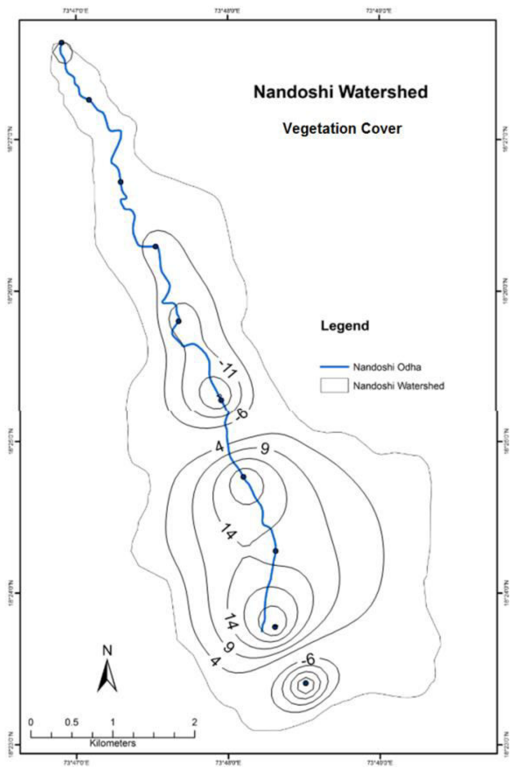


Figure 15: Residuals of Vegetation cover in Nandoshi Watershed

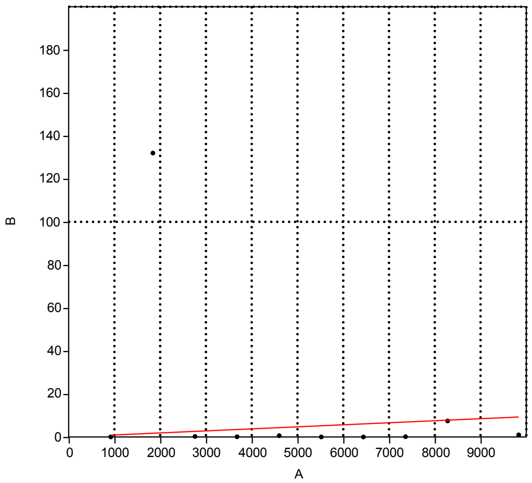


Figure 18: Residual plot: Distance from source vs. Water Bodies

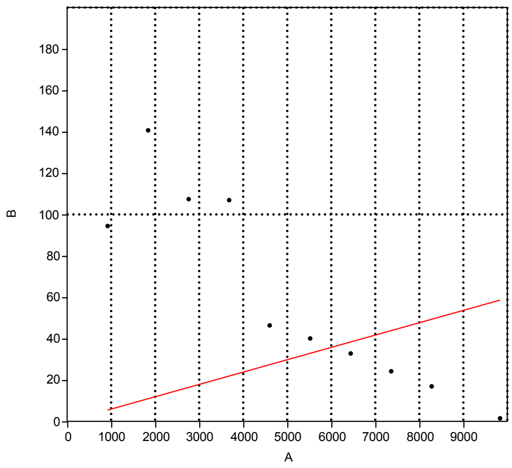


Figure 17: Residual plot: Distance from source vs. Vegetation Cover

Table 61: Residuals of Water bodies

Profile	Distance from Source (Meters) x	Water Bodies (Ha.) y	Regr. x	Regr. y	Err x	Err y
N1	920	0.06	6108.1	74.37	-5188.1	-74.31
N2	1840	132	-3103.5	61.192	4943.5	70.808
N3	2760	0.25	6094.8	48.015	-3334.8	-47.765
N4	3680	0.13	6103.2	34.838	-2423.2	-34.708
N5	4600	0.6	6070.4	21.66	-1470.4	-21.06
N6	5520	0	6112.3	8.483	-592.25	-8.483
N7	6440	0	6112.3	-4.6944	327.75	4.6944
N8	7360	0.14	6102.5	-17.872	1257.5	18.012
N9	8280	7.47	5590.7	-31.049	2689.3	38.519
N10	9833	1	6042.4	-53.293	3790.6	54.293

Table 62: Residuals of Vegetation Cover

Profile	Distance from Source (Meters) x	Vegetation Cover (Ha.) y	Regr. x	Regr. y	Err x	Err y
N1	920	94.41	2877	123.4	-1957	-28.989
N2	1840	140.65	-244.52	109.77	2084.5	30.879
N3	2760	107.42	1998.7	96.143	761.29	11.277
N4	3680	106.94	2031.1	82.514	1648.9	24.426
N5	4600	46.39	6118.6	68.886	-1518.6	-22.496
N6	5520	40.08	6544.6	55.257	-1024.6	-15.177
N7	6440	32.82	7034.7	41.629	-594.67	-8.8091
N8	7360	24.21	7615.9	28.001	-255.9	-3.7907
N9	8280	16.92	8108	14.372	171.98	2.5477
N10	9833	1.5	9149	-8.633	684.04	10.133

Vegetation: The residuals of vegetation area shown in fig. no. 99 clearly suggest 3 pockets of residuals. The residuals plot of vegetation cover at Nandoshi basin show negative residuals at upstream and downstream area than the expected in this area. Fairly dense mix jungle converted in open jungle in last 25 years. Almost 6 Hectares area at upstream and 11 Hectares area at downstream region shows the negative residuals vegetation cover compared to expected vegetation cover. Recently developed housing complex as well as commercial complex or built up in Kirkatwadi village area, which affect the vegetation cover of these regions. Remaining part or source region of this watershed area is matching with expected residuals indicate natural growth of vegetation.

Agricultural: Agricultural land use change as residential and commercial activities well indicated as negative residuals all over the Nandoshi watershed area. In 1991 most of the land was under agriculture but rapid growth of urbanization till 2015 changes the landuse pattern of this area. The builtup area increased remarkably in this region.

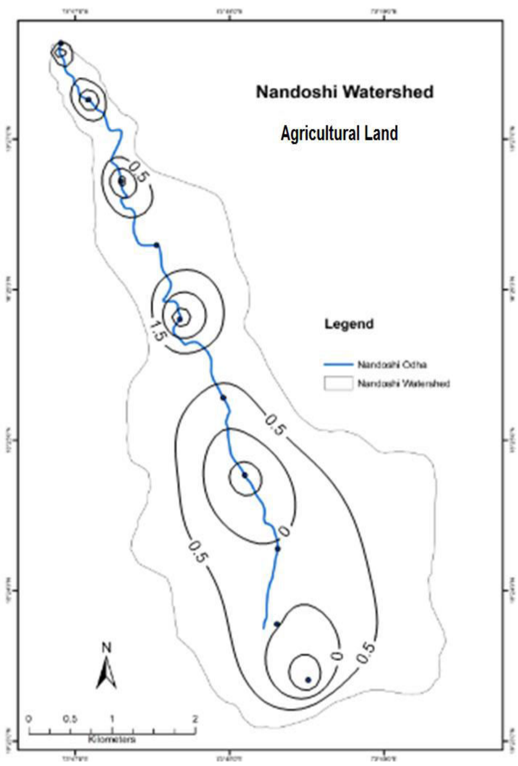


Figure 19: Residuals of Agricultural land in Nandoshi Watershed

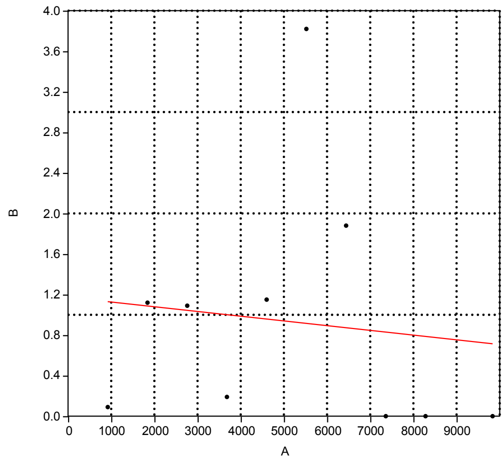


Figure 20: Residual plot: Distance from source vs. Agricultur land

Table 63: Residuals of Agricultural land

Profile	Distance from Source (Meters) x	Agricultural Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
N1	920	0.09	23226	1.13	-22306	-1.04
N2	1840	1.12	1133.9	1.0871	706.08	0.03292
N3	2760	1.09	1777.4	1.0442	982.64	0.045814
N4	3680	0.19	21081	1.0013	-17401	-0.81129
N5	4600	1.15	490.47	0.9584	4109.5	0.1916
N6	5520	3.82	-56776	0.9155	62296	2.9045
N7	6440	1.88	-15167	0.87261	21607	1.0074
N8	7360	0	25156	0.82972	-17796	-0.82972
N9	8280	0	25156	0.78682	-16876	-0.78682
N10	9833	0	25156	0.71442	-15323	-0.71442

Ambil Odha Watershed

Built Up : The residuals of built up area shown in fig. no. 106 clearly suggest 2 pockets of residuals. The upstream pocket is basically pocket of negative residuals developed near to old Katraj tunnel area. The built up area near Katraj tunnel area is very low with reference to the expected built up area. As this region under the reserve forest and hilly region. This particular area under Sinhgad – Bhuleshwar range and covered with high slope and fairly dense mixed jungle. Bhilarewadi, Mangadewadi and Gujar nimbalkarwadi rural settlements are observed. In future these settlements may convert in urban sprawl.

As one moves in the downstream direction construction activities in this area is very high as expected. It is interesting to note that built up area is very high in the downstream part of the catchment area from Katraj to confluence of Ambil Odha pocket.

Barren Land: The residuals of barren land area shown in fig. no. 105 clearly suggest 2 pockets of residuals. The central pocket show negative residuals. The area from Katraj to Parvati hill area is occupied by dense settlements and do not show any barren land. Most of the agricultural land as well as hill slopes of this area are covered with urban settlements since last 15 years.

The area of barren land around villages Bhilarewadi, Mangadewadi and Gujar nimbalkarwadi is decreasing since last 25 years. The urban settlements are spreading in upstream direction which may create the problems of unplanned urban sprawls and environmental issues. Restrictions on unplanned and unauthorized constructions could prevent these problems in future.

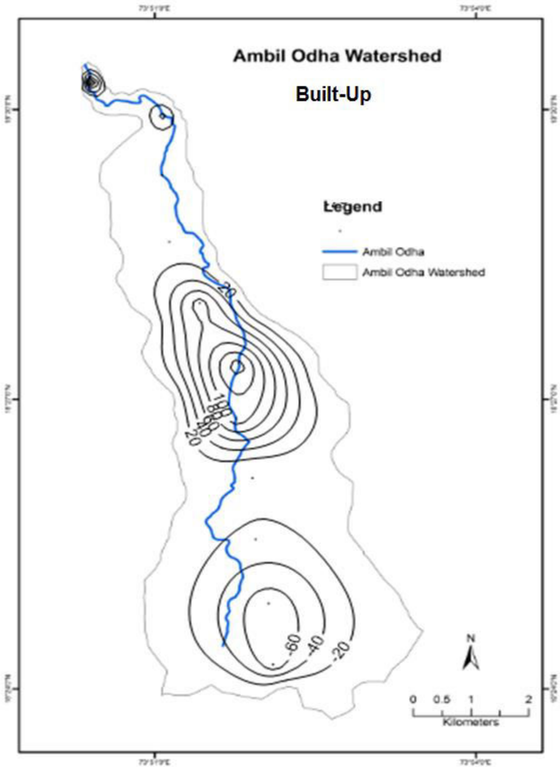


Figure 22: Residuals of built-up area in Ambil Odha Watershed

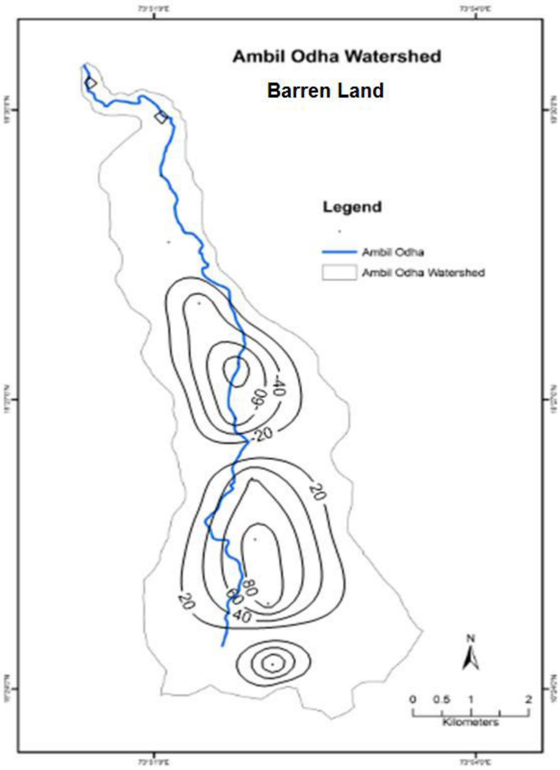


Figure 21: Residuals of barren land area in Ambil Odha Watershed

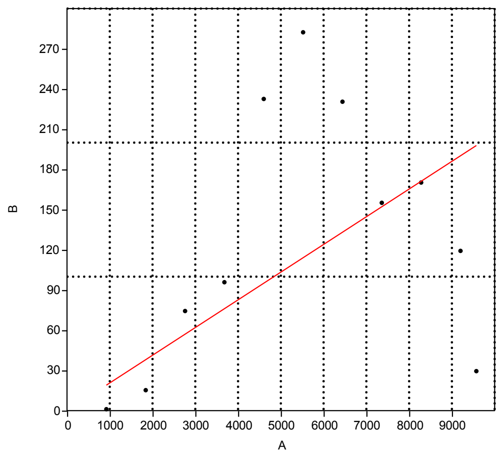


Figure 23: Residual plot: Distance from source vs. Built Up

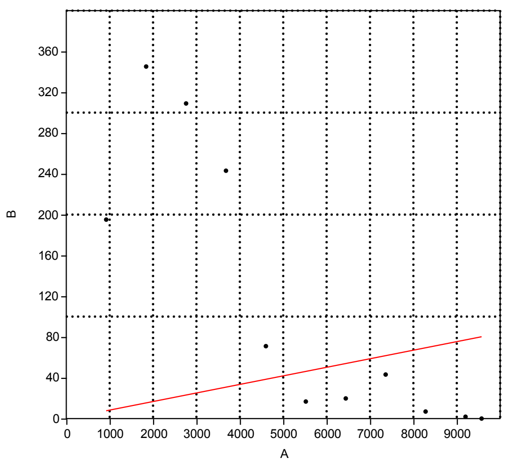


Figure 24: Residual plot: Distance from source vs. Barren Land

Table 64: Residuals of Built-up

Profile	Distance from Source (Meters) x	Built up Area (Ha.) y	Regr. x	Regr. y	Err x	Err y
A1	920	1.09	-6451.9	79.447	7371.9	-78.357
A2	1840	15.28	-5116.9	89.226	6956.9	-73.946
A3	2760	74.33	438.58	99.005	2321.4	-24.675
A4	3680	95.83	2461.3	108.78	1218.7	-12.954
A5	4600	232.57	15326	118.56	-10726	114.01
A6	5520	282.31	20005	128.34	-14485	153.97
A7	6440	230.51	15132	138.12	-8692.1	92.39
A8	7360	155.1	8037.5	147.9	-677.46	7.2009
A9	8280	170.2	9458.1	157.68	-1178.1	12.522
A10	9200	119.2	4660	167.46	4540	-48.257
A11	9571	29.5	-3779	171.4	13350	-141.9

Table 65: Residuals of Barren Land

Profile	Distance from Source (Meters) x	Barren Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
A1	920	195.13	3324.4	286.26	-2404.4	-91.127
A2	1840	345.23	-636.02	251.39	2476	93.84
A3	2760	309.04	318.87	216.52	2441.1	92.518
A4	3680	243.06	2059.8	181.65	1620.2	61.405
A5	4600	71.03	6598.9	146.79	-1998.9	-75.757
A6	5520	16.72	8031.9	111.92	-2511.9	-95.199
A7	6440	19.75	7951.9	77.052	-1511.9	-57.302
A8	7360	43.2	7333.2	42.184	26.803	1.0158
A9	8280	6.92	8290.5	7.3166	-10.464	-0.39659
A10	9200	1.84	8424.5	-27.551	775.5	29.391
A11	9571	0	8473.1	-41.612	1097.9	41.612

Water: in this watershed there are four water reservoirs Bhilarewadi, Gujar Nimbalkarawadi, New Katraj and old Katraj. The residual map for water bodies show 3 pockets of residuals one in upstream area clearly indicate negative residuals for water bodies. Bhilarewadi and Gujar Nimbalkarawadi reservoirs in the upstream area having limited Arial coverage of water body. Small check dams and bunds may increase water bodies in this region.

The central part of this watershed area show positive residuals in between Katraj to Balajinagar area as this area occupied two prominent water reservoir old Katraj and New Katraj reservoir, but area around these water bodies are highly populated with dense unplanned settlements.

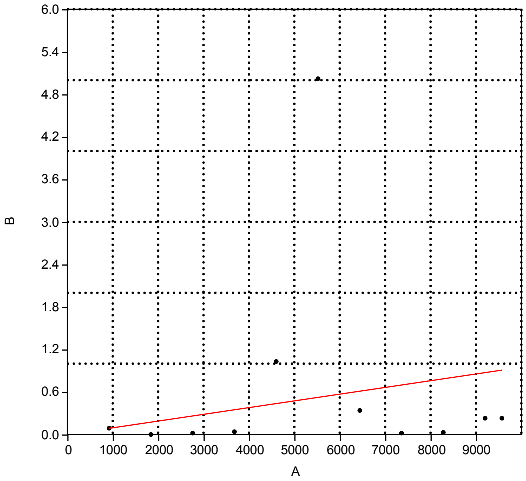


Figure 25: Residual plot: Distance from source vs. Water bodies

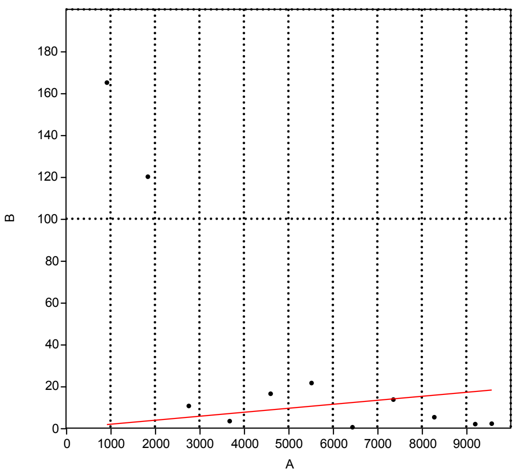


Figure 26: Residual plot: Distance from source vs. Vegetation cover

The third pocket near the confluence area of negative residuals indicates absence of water bodies as compared to the expected. As this area is a part of an old city with old as well as newly constructed settlements. A major water body Ambil odha stream need to be restored and water pollution need to be restrict.

Table 66: Residuals of Water bodies

Profile	Distance from Source (Meters) x	Water Bodies (Ha.) y	Regr. x	Regr. y	Err x	Err y
A1	920	0.09	-39922	0.58569	40842	-0.49569
A2	1840	0	-47338	0.59685	49178	-0.59685
A3	2760	0.02	-45690	0.60802	48450	-0.58802
A4	3680	0.04	-44042	0.61918	47722	-0.57918
A5	4600	1.03	37529	0.63035	-32929	0.39965
A6	5520	5.02	3.66E+05	0.64151	-3.61E+05	4.3785
A7	6440	0.34	-19323	0.65268	25763	-0.31268
A8	7360	0.02	-45690	0.66385	53050	-0.64385
A9	8280	0.03	-44866	0.67501	53146	-0.64501
A10	9200	0.23	-28387	0.68618	37587	-0.45618
A11	9571	0.23	-28387	0.69068	37958	-0.46068

Table 67: Residuals of Vegetation cover

Profile	Distance from Source (Meters) x	Vegetation Cover (Ha.) y	Regr. x	Regr. y	Err x	Err y
A1	920	165.04	-4447.7	93.458	5367.7	71.582
A2	1840	120.1	-1077.8	81.189	2917.8	38.911
A3	2760	10.62	7131.7	68.92	-4371.7	-58.3
A4	3680	3.37	7675.4	56.651	-3995.4	-53.281
A5	4600	16.44	6695.3	44.382	-2095.3	-27.942
A6	5520	21.56	6311.4	32.114	-791.38	-10.554
A7	6440	0.45	7894.3	19.845	-1454.3	-19.395
A8	7360	13.65	6904.5	7.5759	455.48	6.0741

A9	8280	5.23	7535.9	-4.6929	744.09	9.9229
A10	9200	1.95	7781.9	-16.962	1418.1	18.912
A11	9571	2.16	7766.1	-21.909	1804.9	24.069

Vegetation:

The residuals plot of vegetation cover at Ambil Odha watershed area show negative residuals at central pocket of basin than the expected in this area. Developments of housing complex as well as commercial complex or built up in this area, which affect the vegetation cover of these regions. Bhilarewadi, Gujar Nimbalkar Wadi village are now becoming new urban centers, the urban settlements increasing very rapidly in this region which may create threats for natural vegetation as this region is surrounded by hills with vegetation cover.

The source region up to the Katraj tunnel shows high positive residual pocket as this hilly terrain is covered by natural vegetation and protected as reserve forest. Sinhgad – Bhuleshwar range of this area with high slope and covered with fairly dense mixed jungle. Bhilarewadi, Mangadewadi and Gujar Nimbalkarwadi villages are now become attraction destinations for builders, the process of plotting and construction increased in last few years may create problems to this upstream vegetated area.

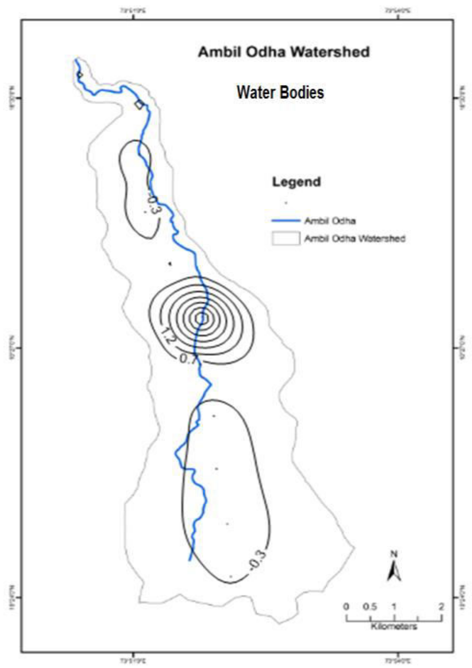


Figure 27: Residuals of Water bodies area in Ambil Odha Watershed

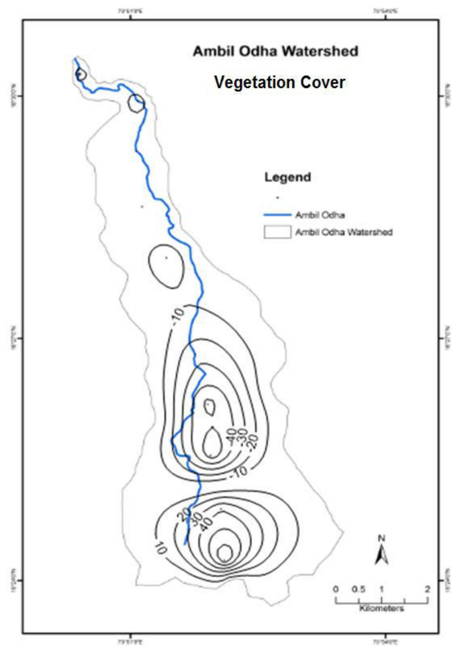


Figure 28: Residuals of Vegetation cover area in Ambil Odha Watershed

Agricultural: The total Ambil odha watershed area is occupied by urban as well as rural settlements, the agricultural land is converted into settlements only few pockets around rural settlements having agricultural land use which is shown by negligible or very low negative residuals.

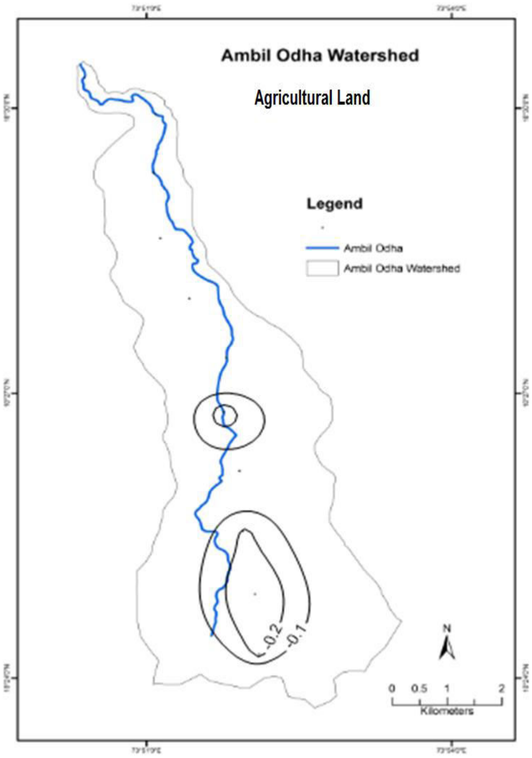


Figure 30: Residuals of Agricultural land area in Ambil Odha Watershed

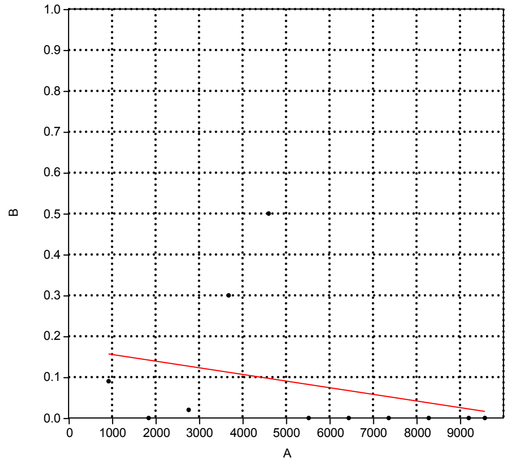


Figure 29: Residual plot: Distance from source vs. Agricultural Land

Table 68: Residuals of Agricultural area

Profile	Distance from Source (Meters) x	Agricultural Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
A1	920	0.09	5022.7	0.15669	-4102.7	-0.06669
A2	1840	0	10559	0.14174	-8719.3	-0.14174
A3	2760	0.02	9329	0.12678	-6569	-0.10678
A4	3680	0.3	-7896.2	0.11183	11576	0.18817
A5	4600	0.5	-20200	0.096871	24800	0.40313
A6	5520	0	10559	0.081916	-5039.3	-0.08192
A7	6440	0	10559	0.066961	-4119.3	-0.06696
A8	7360	0	10559	0.052006	-3199.3	-0.05201
A9	8280	0	10559	0.037051	-2279.3	-0.03705
A10	9200	0	10559	0.022097	-1359.3	-0.0221
A11	9571	0	10559	0.016066	-988.35	-0.01607

Bhairoba Nala Watershed Area

Built Up: The residuals of built up area shown in fig. no. 115 clearly suggest 2 pockets of residuals. The upstream pockets of negative residuals developed near source region of Bhairoba Nala area. The built up area near Bapdev Ghat to Yawalewadi village area is very low with reference to the expected built up area. As this region under the reserve forest and hilly region and fairly dense mixed jungle. No built up sign are seen up to spur zone of sinhgad- bhuleshwar range. Yavalewadi village is small rural settlement do not show any signs of urbanization but stone quarries around the settlements are increasing from last couple of years.

In the downstream direction built up the settlements Kondwa Budruk, Kondwa Khurd, Lulla nagar, Netaji Naga and Wanawardi area are developing very rapidly with huge residential and commercial constructions. This result in very high built up area in a central part of this watershed area. This area extent from Kondwa Budruk to Pune- Solapur Highway (NH9) is under dense settlements and occupied by slums like Lulla nagar. After crossing NH9 (Pune- Solapur Highway) Pune containment which show very low density of settlements.

Barren Land: The residuals of barren land area show 2 pockets (fig. no. 116) of residuals. These centrally located pockets are of negative residuals from north Yevalewadi to Kondwa Khurd area. The area under barren land from north Yevalewadi to Kondwa Khurd is very low as compared to expected barren land. As most of the barren land is utilized for built up area in this region. Kondwa, Lullanagar, Netajinagar areas are conjested areas in the city.

In the upstream area of watershed positive pockets of residuals indicate high percentage of barren land as this region is a hilly terrain with scarcity of water. In last 15 to 20 years the number of stone quarries are increasing in Bapdev ghat region. The barren land percentage of Yevalewadi village is decreasing in last 10 years as urban spread from Kondwa to upstream direction is seen. In future, this may create problems of urbanization in this region.

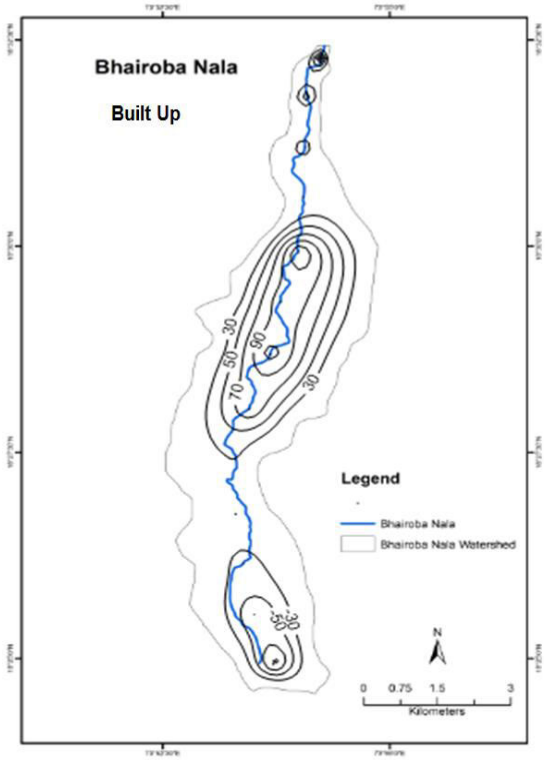


Figure 31: Residuals of Built-Up area in Bhairoba Nala Basin

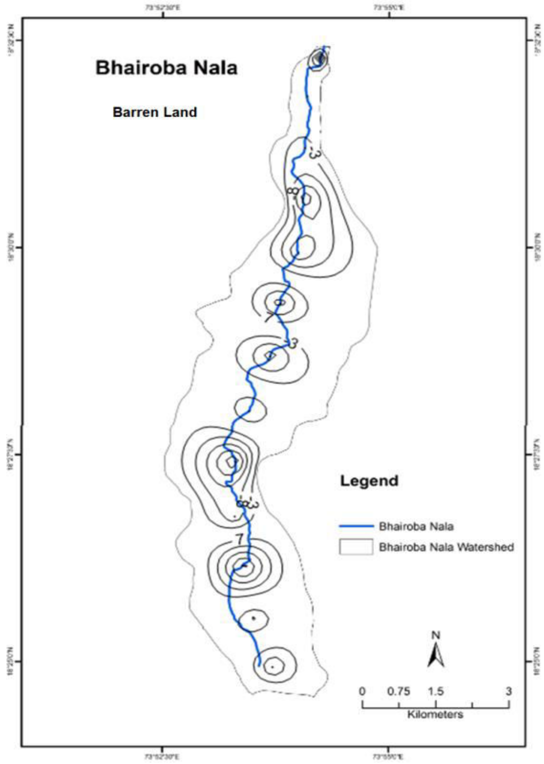


Figure 32: Residuals of Barren Land area in Bhairoba Nala Basin

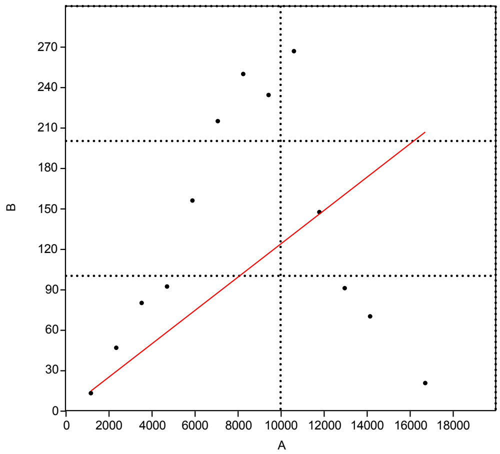


Figure 34: Residual plot: Distance from source vs. Built Up

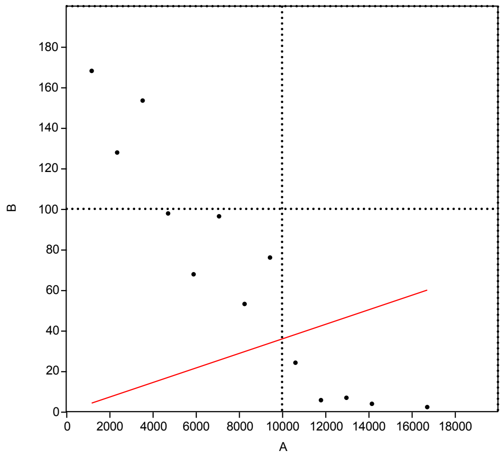


Figure 33: Residual plot: Distance from source vs. Barren Land

Table 69: Residuals of Built Up

Profile	Distance from Source (Meters) x	Built Up (Ha.) y	Regr. x	Regr. y	Err x	Err y
B1	1180	12.95	-47521	114.34	48701	-101.39
B2	2360	46.63	-31343	116.8	33703	-70.167
B3	3540	79.87	-15377	119.25	18917	-39.384
B4	4720	92.06	-9521.9	121.71	14242	-29.65
B5	5900	155.81	21099	124.17	-15199	31.643
B6	7080	214.71	49390	126.62	-42310	88.086
B7	8260	249.67	66183	129.08	-57923	120.59
B8	9440	234.1	58704	131.54	-49264	102.56
B9	10620	266.61	74319	133.99	-63699	132.62
B10	11800	147.27	16997	136.45	-5197	10.82
B11	12980	90.85	-10103	138.91	23083	-48.057
B12	14160	69.93	-20152	141.36	34312	-71.434
B13	16721	20.46	-43913	146.7	60634	-126.24

Table 70: Residuals of Barren Land

Profile	Distance from Source (Meters) x	Barren Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
B1	1180	168.07	-393.59	150.08	1573.6	17.988
B2	2360	127.81	3128.3	136.59	-768.32	-8.7828
B3	3540	153.43	887.1	123.1	2652.9	30.326
B4	4720	97.77	5756.2	109.61	-1036.2	-11.845
B5	5900	67.75	8382.3	96.126	-2482.3	-28.376
B6	7080	96.37	5878.7	82.637	1201.3	13.733
B7	8260	53.11	9663	69.148	-1403	-16.038
B8	9440	76.01	7659.7	55.659	1780.3	20.351
B9	10620	24.14	12197	42.17	-1577.3	-18.03
B10	11800	5.68	13812	28.681	-2012.1	-23.001
B11	12980	6.86	13709	15.192	-728.92	-8.3325
B12	14160	3.87	13970	1.7036	189.52	2.1664
B13	16721	2.27	14110	-27.572	2610.6	29.842

Water: The residuals of water body area (fig. no. 120) clearly suggest 3 major pockets of residuals. In the upstream area negative residuals of water body indicate absence of major water bodies like natural or artificial reservoir in this region. The central pocket of positive residuals in Kondva area indicate availability of water bodies but the streams with water are not actually fresh water, its sewage discharge in the streams creating a false impression of water bodies. The Bhairoba Nala major stream of this region can be restoring by channel deepening, restriction of dumping material, ban on sewage discharge in channel, restriction on encroachment. These majors may improve availability of water in this watershed area.

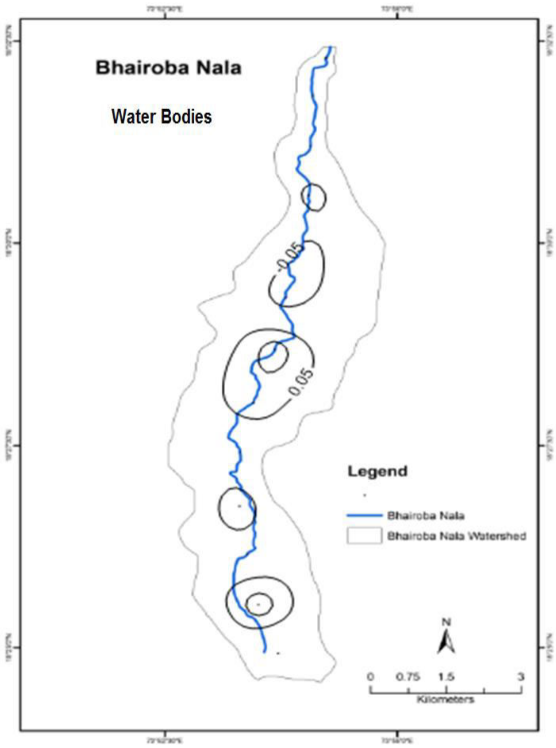


Figure 36: Residuals of Water bodies in Bhairoba Nala Basin

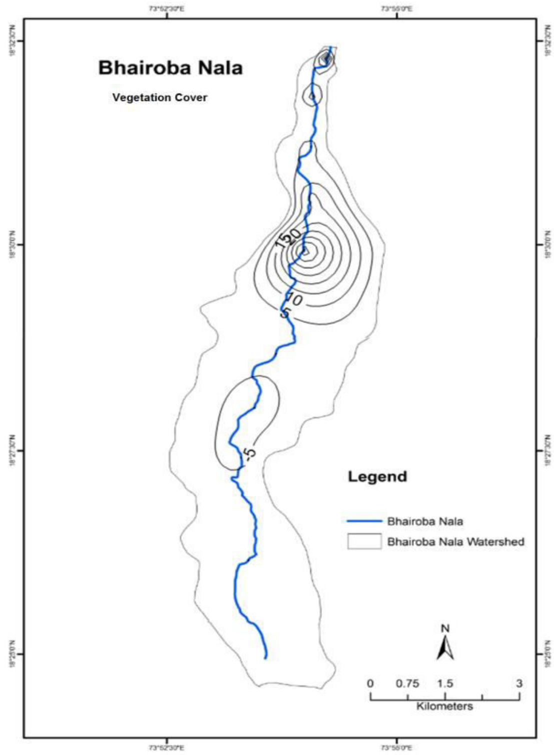


Figure 35: Residuals of Vegetation cover in Bhairoba Nala Basin

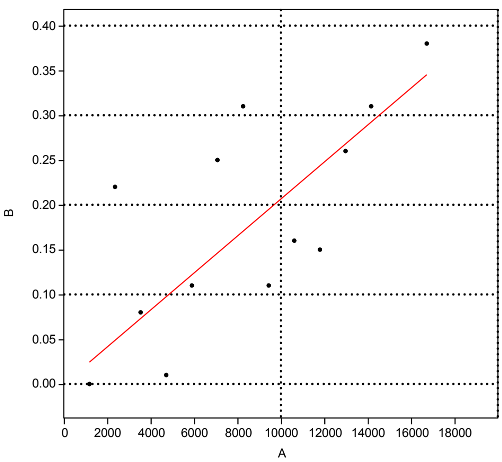


Figure 38: Residual plot: Dist. from source vs. Water Bodies

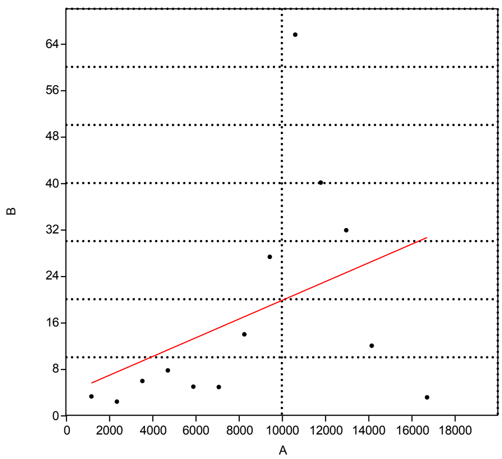


Figure 37: Residual plot: Dist. from source vs. Vegetation Cover

Table 71: Residuals of Water Bodies

Profile	Distance from Source (Meters) x	Water Bodies (Ha.) y	Regr. x	Regr. y	Err x	Err y
B1	1180	0	-1992	0.055357	3172	-0.05536
B2	2360	0.22	10614	0.07595	-8254.2	0.14405
B3	3540	0.08	2592	0.096543	947.96	-0.01654
B4	4720	0.01	-1419	0.11714	6139	-0.10714
B5	5900	0.11	4311.1	0.13773	1588.9	-0.02773
B6	7080	0.25	12333	0.15832	-5253.2	0.091678
B7	8260	0.31	15771	0.17892	-7511.3	0.13108
B8	9440	0.11	4311.1	0.19951	5128.9	-0.08951
B9	10620	0.16	7176.1	0.2201	3443.9	-0.0601
B10	11800	0.15	6603.1	0.24069	5196.9	-0.09069
B11	12980	0.26	12906	0.26129	73.76	-0.00129
B12	14160	0.31	15771	0.28188	-1611.3	0.02812
B13	16721	0.38	19782	0.32657	-3061.4	0.053426

Table 72: Residuals of Vegetation Cover

Profile	Distance from Source (Meters) x	Vegetation Cover (Ha.) y	Regr. x	Regr. y	Err x	Err y
B1	1180	3.26	-250.25	5.5655	1430.3	-2.3055
B2	2360	2.36	-808.58	7.4676	3168.6	-5.1076
B3	3540	5.91	1393.7	9.3696	2146.3	-3.4596
B4	4720	7.74	2529	11.272	2191	-3.5317
B5	5900	4.94	791.97	13.174	5108	-8.2338
B6	7080	4.88	754.75	15.076	6325.2	-10.196
B7	8260	13.95	6381.5	16.978	1878.5	-3.028
B8	9440	27.29	14657	18.88	-5217.3	8.4099
B9	10620	65.56	38399	20.782	-27779	44.778
B10	11800	40.08	22592	22.684	-10792	17.396
B11	12980	31.88	17505	24.586	-4524.8	7.2937
B12	14160	11.99	5165.6	26.488	8994.4	-14.498
B13	16721	3.1	-349.51	30.617	17071	-27.517

Vegetation: The residuals plot of vegetation cover at Bhairoba watershed area show positive residuals near in Pune cantonment board area. Pune cantonment board under military administration, having strict rules and regulation regarding constructions. Extensive green military campus and famous Bund garden, Race-course area with dense vegetation cover are responsible for positive residuals of vegetation in this region.

The central part of watershed area show negative residual of vegetation due to extreme urbanization in this area. The upstream area of this watershed region is a hilly terrain with barren hill slopes with some patches of green vegetation shows negative residuals. The scarisity of water and no perennial waterbody in the area is responsible for negative residuals for vegetation plot in this area.

Agricultural: The residual plot of agricultural land cover at watershed area show area slightly positive residuals from upstream to central part of watershed. The agricultural land in this area has continuously decreased due to rapid growth of urbanization. But area from Cantonment board of this watershed is available for agriculture.

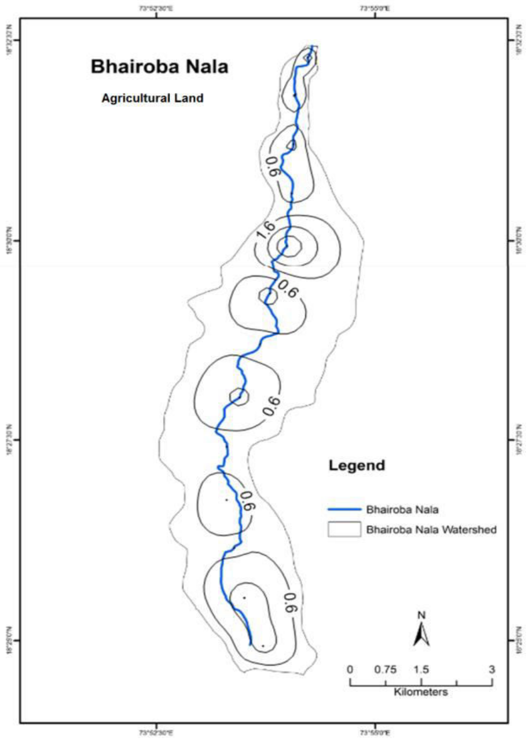


Figure 39: Residuals of Agricultural Land in Bhairoba Nala Basin

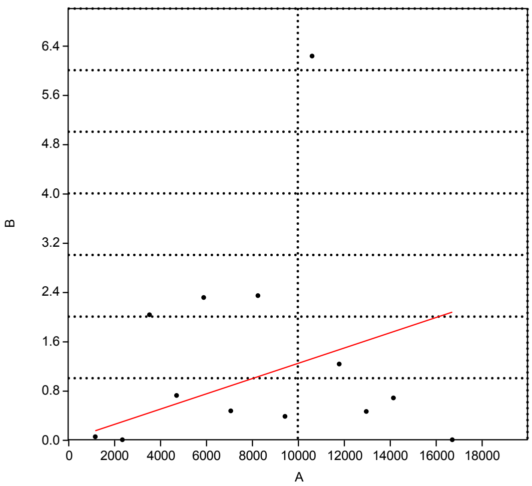


Figure 40: Residual plot: Distance from source vs. Agricultural land

Table 73: Residuals of Agricultural area

Profile	Distance from Source (Meters) x	Agricultural area (Ha.) y	Regr. x	Regr. y	Err x	Err y
B1	1180	0.05	-55197	1.1587	56377	-1.1087
B2	2360	0	-57740	1.1819	60100	-1.1819
B3	3540	2.03	45487	1.2051	-41947	0.82491
B4	4720	0.72	-21127	1.2283	25847	-0.5083
B5	5900	2.31	59726	1.2515	-53826	1.0585
B6	7080	0.47	-33840	1.2747	40920	-0.80471
B7	8260	2.34	61251	1.2979	-52991	1.0421
B8	9440	0.38	-38417	1.3211	47857	-0.94112
B9	10620	6.23	2.59E+05	1.3443	-2.48E+05	4.8857
B10	11800	1.23	4806.7	1.3675	6993.3	-0.13753
B11	12980	0.46	-34349	1.3907	47329	-0.93073

B12	14160	0.68	-23161	1.4139	37321	-0.73394
B13	16721	0	-57740	1.4643	74461	-1.4643

Wadki Nala Watershed

Built Up: The residuals of built up area shown in fig. no. 125 clearly suggest 3 pockets of residuals. The central pocket of Positive residuals developed around Autadewadi, Holkarwadi, Vadachivadi, Shewalewadi, Handewadi and Uruli Dewachi village areas. According to these pockets built up area are high with reference to the expected built up area. During last 10 years these land value increased tremendously, the farmers are provoked to sale their agricultural land for builders and developers. Many farmers sold their fertile agricultural land to builders, and some of the farmers are getting involved in real estate business. As move in the upstream direction built up shows negative residuals. This is area with fairly dense mixed jungle covered in upstream area. This area is under reserve forest area of Sinhgad – Bhuleshwar hilly range.

At downstream area built up area show negative residuals. Phursungi area has a massive agricultural activity, so concentration of built up is comparatively low. The solid waste deposit at Uruli Dewachi creates problems of air pollution and water pollution, which affect the growth of urbanization in this area.

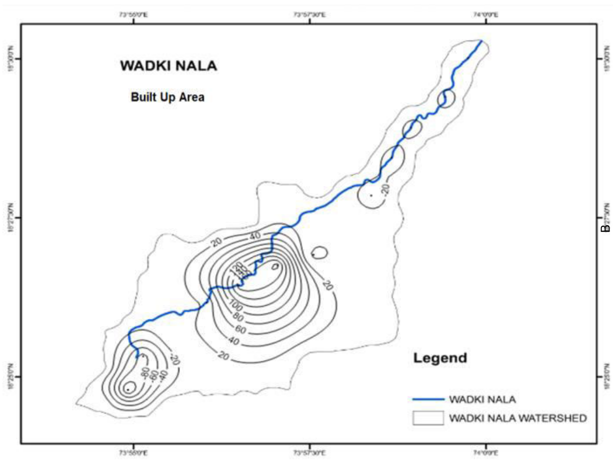


Figure 41: Residuals of built-up area in Wadki Nala watershed

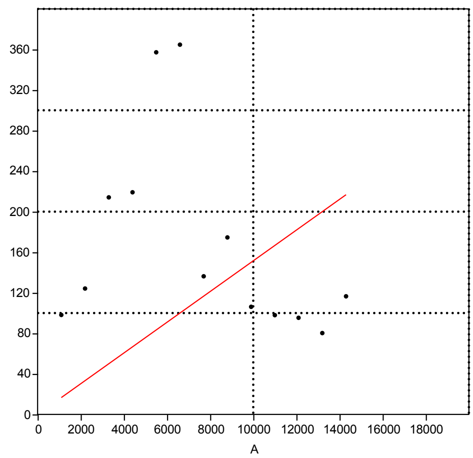


Figure 42: Residual plot: Distance from source vs. Built up

Table 74: Residuals of Built Up

Profile	Distance from Source (Meters) x	Built-up area (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	1100	98.2	16226	222.16	-15126	-123.96
W2	2200	124.23	13050	213.14	-10850	-88.915
W3	3300	214.15	2077.3	204.13	1222.7	10.02
W4	4400	219.17	1464.8	195.12	2935.2	24.054
W5	5500	357.24	-15383	186.1	20883	171.14
W6	6600	364.75	-16300	177.09	22900	187.66
W7	7700	136.26	11582	168.07	-3881.9	-31.812
W8	8800	174.59	6904.7	159.06	1895.3	15.532
W9	9900	106.19	15251	150.04	-5351.2	-43.853
W10	11000	97.95	16257	141.03	-5256.7	-43.079
W11	12100	95.37	16572	132.01	-4471.5	-36.644
W12	13200	80.29	18412	123	-5211.7	-42.71
W13	14300	116.55	13987	113.99	312.96	2.5647

Barren Land: The residuals of barren land area (fig. no. 128) clearly suggest 2 pockets of residuals. The central pocket of Autadewadi, Holkarwadi, Vadachivadi, Shewalewadi, Handewadi and Uruli Dewachi villages are basically pocket of positive residuals. Geographically these villages situated on plane area and as urban fringe zone. According to these pocket, barren land is very high with reference to the expected barren land area. Agricultural land is converted in non-agricultural land. In future, these villages may converted in to urban settlements.

At confluence region pocket (Pune – Saswad Road) shows negative residuals because of most of the land occupied with agricultural land.

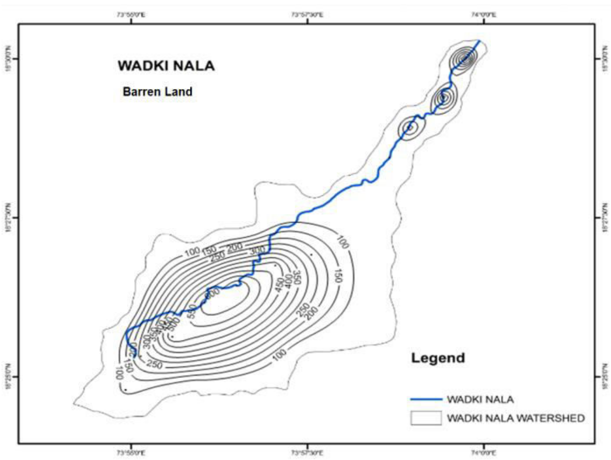


Figure 44: Residuals of barren land area in Wadki Nala Watershed

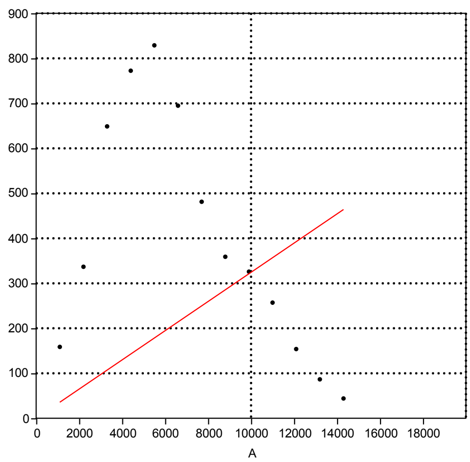


Figure 43: Residual plot: Distance from source vs. Barren land

Table 75: Residuals of Barren Land

Profile	Distance from Source (Meters) x	Barren Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	1100	158.67	4890	35.693	-3790	122.98
W2	2200	336.8	10380	71.385	-8179.7	265.41
W3	3300	648.8	19995	107.08	-16695	541.72
W4	4400	772.44	23806	142.77	-19406	629.67
W5	5500	828.96	25547	178.46	-20047	650.5
W6	6600	694.82	21413	214.16	-14813	480.66
W7	7700	481.24	14831	249.85	-7131.2	231.39
W8	8800	358.99	11064	285.54	-2263.6	73.449
W9	9900	325.99	10047	321.23	-146.59	4.7565
W10	11000	257.11	7923.8	356.93	3076.2	-99.816
W11	12100	153.88	4742.4	392.62	7357.6	-238.74
W12	13200	86.64	2670.1	428.31	10530	-341.67
W13	14300	44.01	1356.3	464	12944	-419.99

Water: The residuals of water area shown in fig. no. 130 clearly suggest 1 pocket of residuals. The central pocket is of positive residuals developed near Shewalewadi because of Shewalewadi Lake.

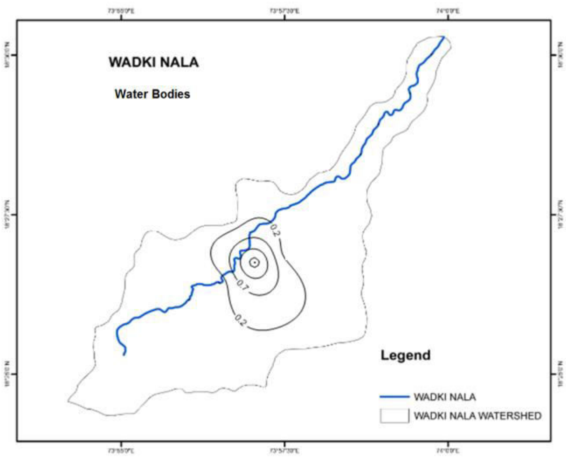


Figure 46: Figure 45: Residuals of Water bodies area in Wadki Nala Watershed

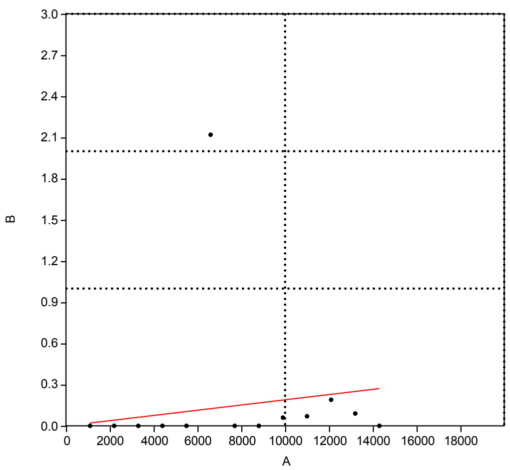


Figure 45: Residual plot: Distance from source vs. Water bodies

Table 76: Residuals of Water bodies

Profile	Distance from Source (Meters) x	Water bodies (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	1100	0	0	0.020916	1100	-0.02092
W2	2200	0	0	0.041832	2200	-0.04183
W3	3300	0	0	0.062747	3300	-0.06275
W4	4400	0	0	0.083663	4400	-0.08366
W5	5500	0	0	0.10458	5500	-0.10458
W6	6600	2.12	1.11E+05	0.12549	-1.05E+05	1.9945
W7	7700	0	0	0.14641	7700	-0.14641
W8	8800	0	0	0.16733	8800	-0.16733
W9	9900	0.06	3155.5	0.18824	6744.5	-0.12824
W10	11000	0.07	3681.4	0.20916	7318.6	-0.13916
W11	12100	0.19	9992.5	0.23007	2107.5	-0.04007
W12	13200	0.09	4733.3	0.25099	8466.7	-0.16099
W13	14300	0	0	0.2719	14300	-0.2719

Vegetation: The residuals of vegetation area shown in fig. no.132 clearly suggest 3 to 4 pockets of residuals. The residuals plot of vegetation cover in the watershed area show negative residuals at upstream and downstream area. Uruli devachi to Fursungi area has low vegetation cover. Pasture land converting in barren land in last 10 years.

In the central pocket, vegetation show positive residuals. Autadewadi, Holkarwadi, Vadachivadi, Shewalewadi, Handewadi and Uruli Dewachi villages located in this watershed area. Before 10 to 15 years these villages occupied open scrub land, but now vegetation cover is decreasing. Most of the area converted into the built up area. Remaining part or source region of this watershed area is matching with expected residuals indicated natural growth of vegetation.

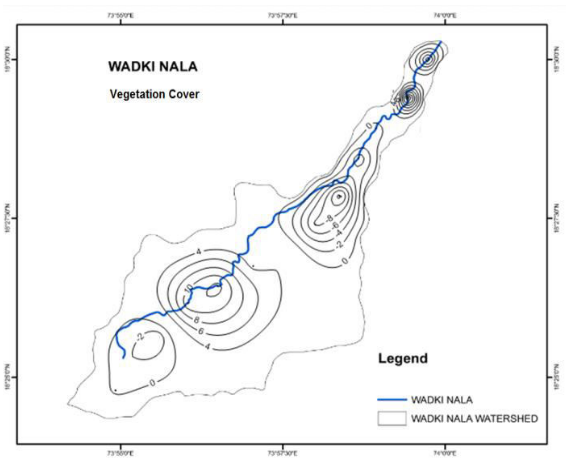


Figure 48: Residuals of vegetation cover in Wadki Nala Watershed

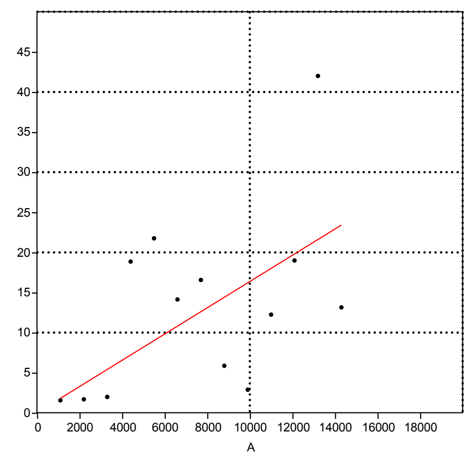


Figure 47: Residual plot: Distance from source vs. Vegetation cover

Table 77: Residuals of Vegetation Cover

Profile	Distance from Source (Meters) x	Vegetation cover (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	1100	1.55	946.96	1.8005	153.04	-0.2505
W2	2200	1.68	1026.4	3.601	1173.6	-1.921
W3	3300	1.98	1209.7	5.4015	2090.3	-3.4215
W4	4400	18.85	11516	7.202	-7116.2	11.648
W5	5500	21.75	13288	9.0025	-7788	12.747
W6	6600	14.13	8632.6	10.803	-2032.6	3.327
W7	7700	16.56	10117	12.604	-2417.2	3.9565
W8	8800	5.86	3580.1	14.404	5219.9	-8.544
W9	9900	2.88	1759.5	16.205	8140.5	-13.325
W10	11000	12.24	7477.9	18.005	3522.1	-5.765
W11	12100	18.99	11602	19.806	498.23	-0.81551
W12	13200	42	25660	21.606	-12460	20.394
W13	14300	13.14	8027.8	23.407	6272.2	-10.267

Agricultural: The residual plot of agricultural land cover at Wadki nala watershed area show positive residuals in overall basin area. As this area is occupied by many small rural settlements, the main occupation of the population is agriculture, but in last 10 years the rate of urbanization is increasing resulting conversion of agricultural land in to non – agricultural land.

The positive residual points of this watershed area are definitely changing to negative residuals to avoid this planning and restriction on construction is necessary.

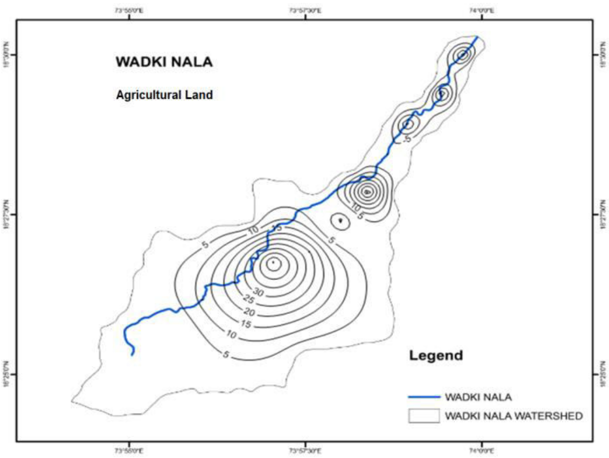


Figure 50: Residuals of Agricultural area in Wadki Nala Watershed

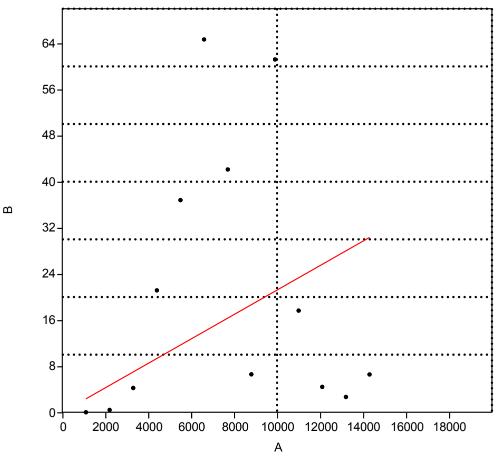


Figure 49: Residual plot: Distance from source vs. Agricultural Land

Table 78: Residuals of Agricultural area

Profile	Distance from Source (Meters) x	Agricultural area (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	1100	0	0	2.3335	1100	-2.3335
W2	2200	0.41	193.27	4.667	2006.7	-4.257
W3	3300	4.22	1989.3	7.0005	1310.7	-2.7805
W4	4400	21.16	9974.8	9.334	-5574.8	11.826
W5	5500	36.81	17352	11.667	-11852	25.143
W6	6600	64.68	30490	14.001	-23890	50.679
W7	7700	42.13	19860	16.334	-12160	25.796
W8	8800	6.59	3106.5	18.668	5693.5	-12.078
W9	9900	61.21	28854	21.001	-18954	40.209
W10	11000	17.64	8315.4	23.335	2684.6	-5.6949
W11	12100	4.41	2078.9	25.668	10021	-21.258
W12	13200	2.67	1258.6	28.002	11941	-25.332
W13	14300	6.57	3097.1	30.335	11203	-23.765

Wagholi Watershed

Built Up: The residuals of built up area (fig. no. 138) suggest 3 pockets of residuals. The central pocket of positive residuals developed around Pune – Ahmadnagar highway near Wagholi area. This pocket show high built up area concentrated along Pune – Nagar highway.

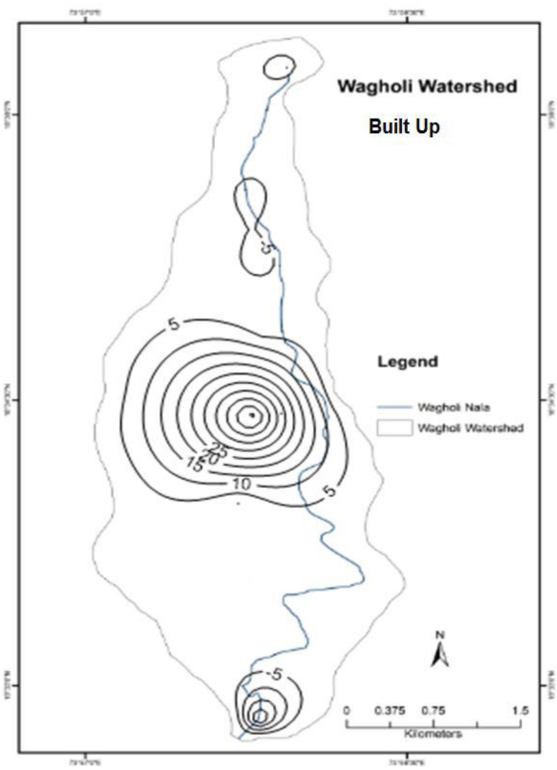
Lohgaon airport is located at upstream area of source region. Catchment area starts from Lohgaon, where upper part is covered with plain area. This area of negative residuals developed as Lohgaon airport authority restricted the constructions in its surrounding area.

In a downstream region built up area increasing day-by-day with positive residuals due to newly emerged Kharadi IT hub, has been enjoying rapid development in terms of real estate, social infrastructure and education sectors. Infrastructure development and proximity to IT hubs are the other influencing factors which are causing development. This region is comparatively dry than the other watershed regions.

Barren Land: The residuals of barren land area shown in fig. no. 137 clearly suggest 2 pockets of residuals. Source region of upstream area are basically pocket of negative residuals due to area of Lohgaon airport authority restricted high-rise building construction in its surrounding area. Total area is occupied with high barren land.

The confluence of downstream pocket is basically pocket of negative residuals developed at Kharadi to source region. This may be due some part of Kharadi IT hub and development of real estate and the area around these commercial centers are highly populated due to dense settlements.

The central part is basically pocket of positive residuals developed at from Pune-Nagar Highway to Kharadi. In last 10 years due to conversion of agricultural land into non-agricultural land, for real estate business and constructions. Many builders occupied the agricultural land plotting activity for future projects shows high amount of barren land residuals in this region.



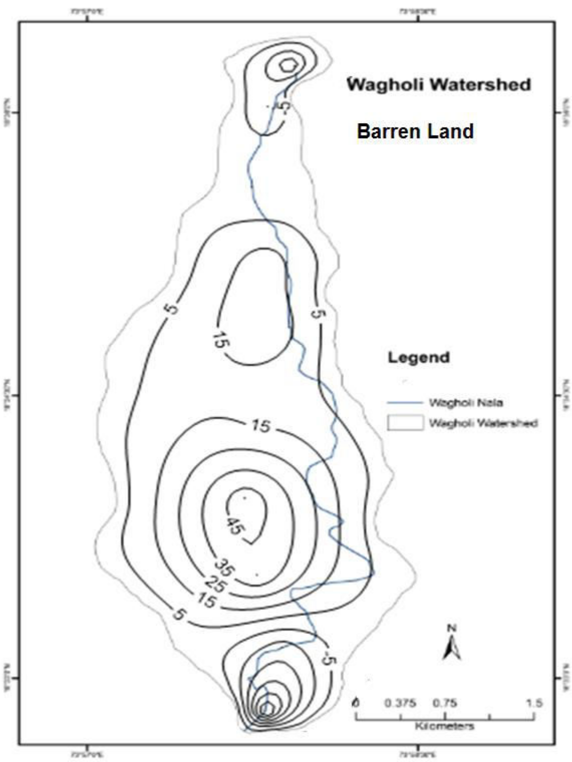
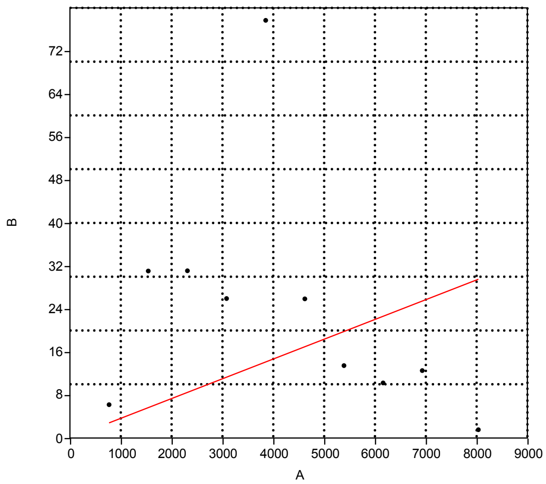


Figure 54: Residuals of built-up area in Wagholi Basin

Figure 53: Residuals of barren land area in Wagholi Basin



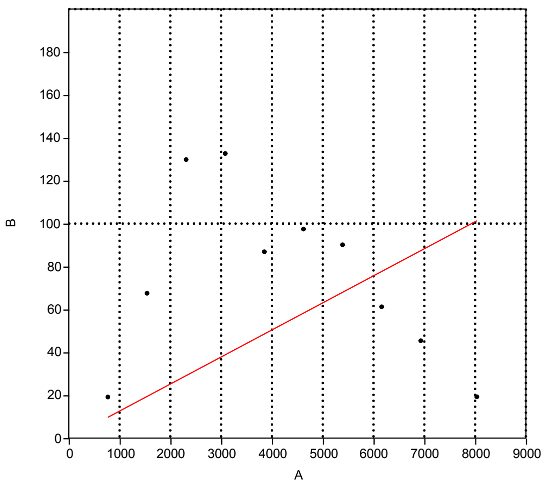


Figure 52: Residual plot: Distance from source vs. Built Up

Figure 51: Residual plot: Distance from source vs. Barren Land

Table 79: Residuals of Built Up

Profile	Distance from Source (Meters) x	Built-up area (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	770	6.21	10295	33.656	-9525.5	-27.446
W2	1540	31.07	1667.5	31.437	-127.53	-0.36745
W3	2310	31.11	1653.6	29.219	656.36	1.8912
W4	3080	25.95	3444.5	27	-364.48	-1.0502
W5	3850	77.69	-14512	24.782	18362	52.908
W6	4620	25.89	3465.3	22.563	1154.7	3.3271
W7	5390	13.48	7772.3	20.344	-2382.3	-6.8643
W8	6160	10.26	8889.9	18.126	-2729.9	-7.8657
W9	6930	12.55	8095.1	15.907	-1165.1	-3.357
W10	8034	1.55	11913	12.726	-3878.8	-11.176

Table 80: Residuals of Barren Land

Profile	Distance from Source (Meters) x	Barren Land (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	770	19.17	15499	92.354	-14729	-73.184
W2	1540	67.56	5760	88.528	-4220	-20.968
W3	2310	129.86	-6778.3	84.702	9088.3	45.158
W4	3080	132.68	-7345.9	80.876	10426	51.804
W5	3850	86.895	1868.7	77.05	1981.3	9.8446
W6	4620	97.46	-257.58	73.224	4877.6	24.236
W7	5390	90.15	1213.6	69.399	4176.4	20.751
W8	6160	61.25	7030	65.573	-869.95	-4.3226
W9	6930	45.41	10218	61.747	-3287.9	-16.337
W10	8034	19.28	15477	56.261	-7442.7	-36.981

Water: The residuals of water body area shown in fig. no. 140 clearly suggest only one pocket of residual. There is no water reservoir in this catchment area. As move in the upstream direction towards source residuals clearly indicate negative signs for water bodies cover. There is scope to increase water body area by constructing small check dams and bunds in this region. At confluence area most of the land has already been converted into built up. There is no scope for large water bodies to restore, but streams and odhas can be rejuvenate.

Vegetation: All over the watershed vegetation cover show positive residuals as this area is emerging in new townships, the open agricultural land with few patches of vegetation and open land with scanty vegetation.

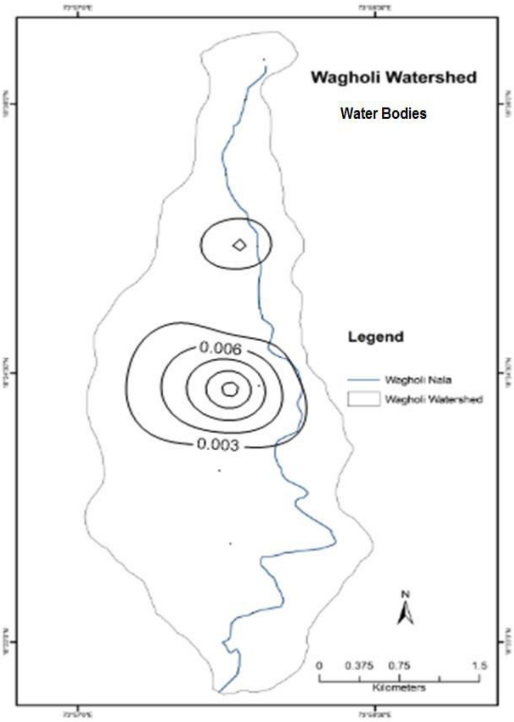


Figure 57: Residuals of water bodies in Wagholi Basin

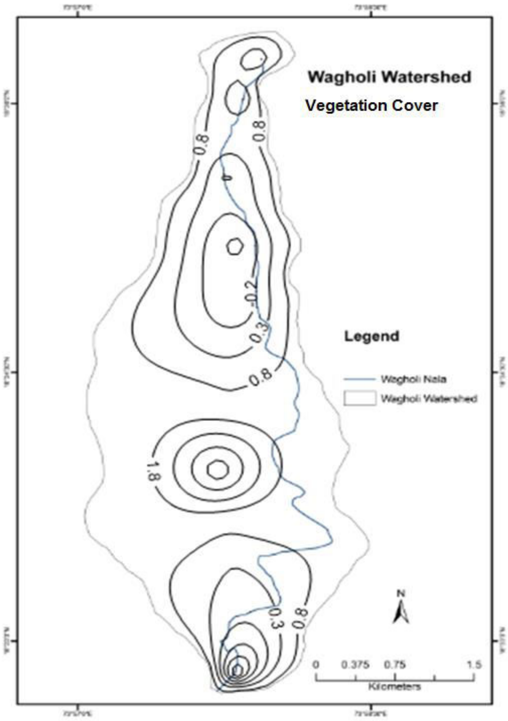
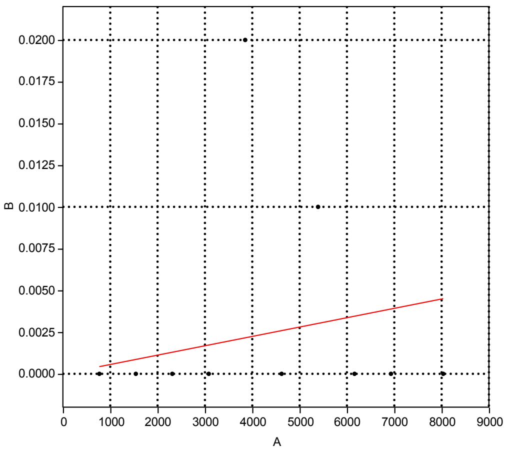


Figure 56: Residuals of vegetation cover in Wagholi Basin

Figure 55: Residual plot: Distance from source vs. Water bodies



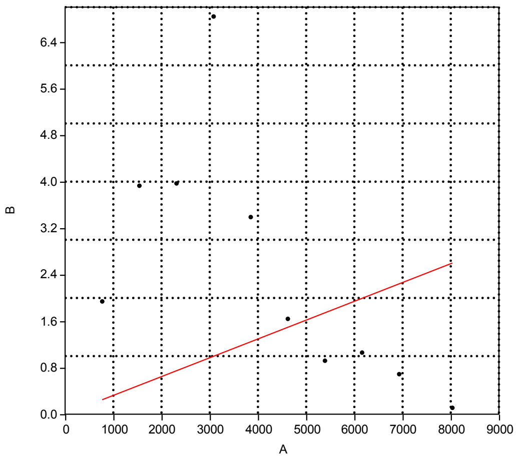


Figure 58: Residual plot: Distance from source vs. Vegetation area

Table 81: Residuals of Water bodies

Profile	Distance from Source (Meters) x	Water bodies (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	770	0	-49800	0.002806	50570	-0.00281
W2	1540	0	-49800	0.002849	51340	-0.00285
W3	2310	0	-49800	0.002891	52110	-0.00289
W4	3080	0	-49800	0.002934	52880	-0.00293
W5	3850	0.02	3.11E+05	0.002977	-3.07E+05	0.017023
W6	4620	0	-49800	0.00302	54420	-0.00302
W7	5390	0.01	1.30E+05	0.003062	-1.25E+05	0.006938
W8	6160	0	-49800	0.003105	55960	-0.00311
W9	6930	0	-49800	0.003148	56730	-0.00315
W10	8034	0	-49800	0.003209	57834	-0.00321

Table 82: Residuals of Vegetation cover

Profile	Distance from Source (Meters) x	Vegetation Cover (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	770	1.94	5170.3	4.4233	-4400.3	-2.4833
W2	1540	3.93	1644.1	3.9887	-104.09	-0.05874
W3	2310	3.97	1573.2	3.5542	736.79	0.4158
W4	3080	6.84	-3512.4	3.1197	6592.4	3.7203
W5	3850	3.39	2601	2.6851	1249	0.70488
W6	4620	1.64	5701.9	2.2506	-1081.9	-0.61058
W7	5390	0.92	6977.8	1.816	-1587.8	-0.89604
W8	6160	1.06	6729.7	1.3815	-569.69	-0.3215
W9	6930	0.69	7385.3	0.94696	-455.32	-0.25696
W10	8034	0.11	8413.1	0.32393	-379.08	-0.21393

Agricultural: Agricultural land along Pune Nagar highway is converted into residential and commercial area. Dense settlement growth is observed in last 5 to 6 years in this region. The small villages in the watershed area still practicing agricultural activity but the conversion of agricultural land in to non- agricultural land is increasing rapidly.

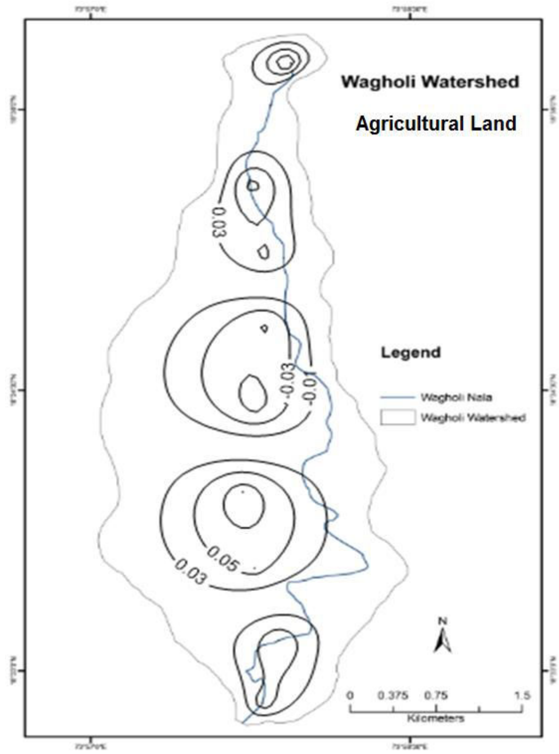


Figure 59: Residuals of Agricultural land in Wagholi watershed

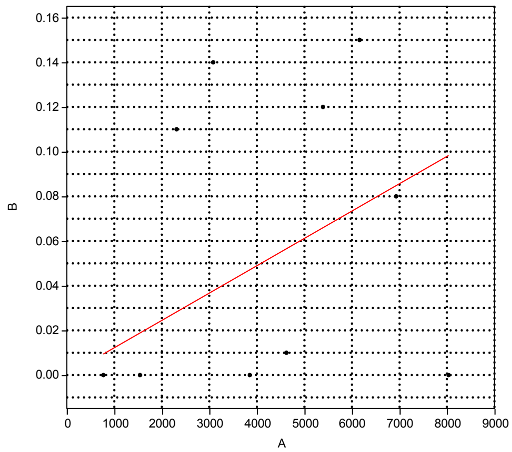


Figure 60: Residual plot: Dist. from source vs. Agricultural area

Table 83: Residuals of Agricultural area

Profile	Distance from Source (Meters) x	Agricultural land (Ha.) y	Regr. x	Regr. y	Err x	Err y
W1	770	0	-8108.6	0.043758	8878.6	-0.04376
W2	1540	0	-8108.6	0.047553	9648.6	-0.04755
W3	2310	0.11	14211	0.051348	-11901	0.058652
W4	3080	0.14	20298	0.055143	-17218	0.084857
W5	3850	0	-8108.6	0.058938	11959	-0.05894
W6	4620	0.01	-6079.6	0.062733	10700	-0.05273
W7	5390	0.12	16240	0.066528	-10850	0.053472
W8	6160	0.15	22327	0.070323	-16167	0.079677
W9	6930	0.08	8123.5	0.074118	-1193.5	0.005882
W10	8034	0	-8108.6	0.079559	16143	-0.07956

Recommendations

- Urban development intensity and spatial extent can be characterized by using satellite remote sensing data through mapping the impervious surface distributions.
- Adaptive mitigation which is supported by the integrated information on sensitive areas which are identified by analysis is assumed to be crucial in enhancing the resilience and sustainability of the Study area against uncertainties and potential degradation associated with socio-ecological and climate related dynamics.
- The spatial scope of this research and analysis, socioeconomic and demographic shifts in the region, zoning regulation changes, transportation investments, and central city revitalization initiatives, are the main reason due to which re-densification of core areas are important and avoiding horizontal or low development in fringe areas.
- Peri-Urban areas (Fringe villages) need to be well-planned considering concentration on geographical features so haphazard development can be avoided.
- It is must to restrict development in forest or dense vegetation areas, and raze structures which are obstructing natural flow of stream channels or find an alternative to it. Development on Hill top and hill slopes should be well thought considering slope and vegetation balance.
- Urban streams are getting deteriorated water quality, as well as habitat disturbances; contribute to degraded (flora and fauna) biological communities.
- Inclusion of urban stream restoration (channel development/repairs), watershed development in water budget of local governing bodies.
- Restrict new development along these small streams upto 5 m on both sides. In DCPR Bye laws of Maharashtra it is 9 m from well channelized streams.
- Create new water sources from existing streams channels/tracks as they are natural and will not cause any problems in future.
- Detail Channel Geomorphology and spatial study of Study area and upcoming peri-urban areas to find out Constructible and Non- constructible areas and there's also a growing need for channel evolution models that are specifically designed to capture the complexities of urban watersheds and account for the differences in physiographic settings for sustainable development of the region.

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