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 (McIntyre et 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).
Table 18: Morphometric parameters of Major Watersheds

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameters</th>
<th>Abbreviation</th>
<th>Formula</th>
<th>Ram Nadi</th>
<th>Nandoshi</th>
<th>Ambil Odha</th>
<th>Bhairoba Nala</th>
<th>Wadki Nala</th>
<th>Wagholi</th>
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<tbody>
<tr>
<td>A</td>
<td>DRAINAGE NETWORK</td>
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<td></td>
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<td></td>
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<tr>
<td>1</td>
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<td></td>
<td>1 to 5</td>
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<td>1 to 5</td>
<td>1 to 5</td>
<td>1 to 5</td>
<td>1 to 5</td>
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<tr>
<td>2</td>
<td>Stream Number</td>
<td>Nu</td>
<td>Nu=N1+N2+...Nn</td>
<td>311</td>
<td>155</td>
<td>237</td>
<td>153</td>
<td>262</td>
<td>61</td>
</tr>
<tr>
<td>3</td>
<td>Stream Length</td>
<td>Lu</td>
<td></td>
<td>136.73</td>
<td>63.77</td>
<td>95.71</td>
<td>70.38</td>
<td>128.26</td>
<td>23.28</td>
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<tr>
<td>4</td>
<td>Bifurcation Ratio</td>
<td>Rb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Length of main channel</td>
<td>Cl</td>
<td></td>
<td>19.20</td>
<td>10.17</td>
<td>15.96</td>
<td>17.01</td>
<td>17.24</td>
<td>9.03</td>
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<tr>
<td>6</td>
<td>Rho coefficient</td>
<td>ρ</td>
<td>ρ=Lur/Rb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>BASIN GEOMETRY</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Length of the basin</td>
<td>Lb</td>
<td>Lb=1.312*A^0.568</td>
<td>10.70</td>
<td>7.63</td>
<td>9.06</td>
<td>9.65</td>
<td>9.65</td>
<td>7.63</td>
</tr>
<tr>
<td>8</td>
<td>Basin Area</td>
<td>A</td>
<td></td>
<td>40.23</td>
<td>22.18</td>
<td>30.02</td>
<td>33.52</td>
<td>33.52</td>
<td>22.18</td>
</tr>
<tr>
<td>9</td>
<td>Basin Perimeter</td>
<td>P</td>
<td></td>
<td>50.95</td>
<td>15.93</td>
<td>33.56</td>
<td>27.78</td>
<td>38.96</td>
<td>15.93</td>
</tr>
<tr>
<td>10</td>
<td>Lemniscate</td>
<td>k</td>
<td>k=Lb^2/A</td>
<td>2.85</td>
<td>2.62</td>
<td>2.73</td>
<td>2.78</td>
<td>2.78</td>
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<td>11</td>
<td>Form Factor Ratio</td>
<td>Ff</td>
<td>Ff=A/Lb^2</td>
<td>0.35</td>
<td>0.38</td>
<td>0.37</td>
<td>0.36</td>
<td>0.36</td>
<td>0.38</td>
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<tr>
<td>12</td>
<td>Elongation Ratio</td>
<td>Re</td>
<td>Re=(2/Lb)*(A/π)^0.5</td>
<td>0.67</td>
<td>0.70</td>
<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
<td>0.70</td>
</tr>
<tr>
<td>13</td>
<td>Texture Ratio</td>
<td>Rt</td>
<td>Rt=N1/P</td>
<td>8.16</td>
<td>10.11</td>
<td>7</td>
<td>7.13</td>
<td>8.06</td>
<td>6.15</td>
</tr>
<tr>
<td>14</td>
<td>Circularity Ratio</td>
<td>Rc</td>
<td>Rc=12.57*(A/P^2)</td>
<td>0.19</td>
<td>1.10</td>
<td>0.34</td>
<td>0.55</td>
<td>0.28</td>
<td>1.10</td>
</tr>
<tr>
<td>15</td>
<td>Drainage Texture</td>
<td>Dt</td>
<td>Dt=Nu/P</td>
<td>6.10</td>
<td>9.73</td>
<td>7.06</td>
<td>5.51</td>
<td>6.73</td>
<td>3.83</td>
</tr>
<tr>
<td>16</td>
<td>Compactness Coefficient</td>
<td>Cc</td>
<td>Cc=0.2841*P/A^0.5</td>
<td>2.28</td>
<td>0.96</td>
<td>1.74</td>
<td>1.36</td>
<td>1.91</td>
<td>0.96</td>
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<td>17</td>
<td>Fitness Ratio</td>
<td>Rf</td>
<td>Rf=Cl/P</td>
<td>0.31</td>
<td>1.00</td>
<td>0.48</td>
<td>0.57</td>
<td>0.41</td>
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<tr>
<td>18</td>
<td>Wandering Ratio</td>
<td>Rw</td>
<td>Rw=Cl/Lb</td>
<td>1.49</td>
<td>2.09</td>
<td>1.76</td>
<td>1.65</td>
<td>1.65</td>
<td>2.09</td>
</tr>
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<td>C</td>
<td>DRAINAGE TEXTURE ANALYSIS</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>19</td>
<td>Stream Frequency</td>
<td>Fs</td>
<td>Fs=Nu/A</td>
<td>7.73</td>
<td>6.99</td>
<td>7.89</td>
<td>4.56</td>
<td>7.82</td>
<td>2.75</td>
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<tr>
<td>20</td>
<td>Drainage Density</td>
<td>Dd</td>
<td>Dd=Lu/A</td>
<td>3.40</td>
<td>2.88</td>
<td>3.19</td>
<td>2.10</td>
<td>3.83</td>
<td>1.05</td>
</tr>
<tr>
<td>22</td>
<td>Drainage Intensity</td>
<td>Di</td>
<td>Di=Fs/Dd</td>
<td>2.27</td>
<td>2.43</td>
<td>2.48</td>
<td>2.17</td>
<td>2.04</td>
<td>2.62</td>
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<tr>
<td>D</td>
<td>RELIEF CHARACTERISTICS</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Total basin relief</td>
<td>H</td>
<td>H=Z-z</td>
<td>410.00</td>
<td>560.00</td>
<td>550</td>
<td>460.00</td>
<td>450.00</td>
<td>140.00</td>
</tr>
<tr>
<td>26</td>
<td>Relief Ratio</td>
<td>Rh</td>
<td>Rh=H/Lb</td>
<td>38.32</td>
<td>73.41</td>
<td>60.71</td>
<td>47.69</td>
<td>46.66</td>
<td>18.35</td>
</tr>
<tr>
<td>27</td>
<td>Absolute Relief</td>
<td>Ra</td>
<td></td>
<td>960.00</td>
<td>1120.00</td>
<td>1100</td>
<td>1000.00</td>
<td>990.00</td>
<td>680.00</td>
</tr>
<tr>
<td>28</td>
<td>Dissection Index</td>
<td>Dis</td>
<td>Dis=H/Ra</td>
<td>0.43</td>
<td>0.50</td>
<td>0.50</td>
<td>0.46</td>
<td>0.45</td>
<td>0.21</td>
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</tbody>
</table>
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 to 1164. 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 is 181.65 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 $k = \frac{L_b^2}{4} \times A$, $L_b$ is the basin length and $A$ is the area of the basin. The lemniscate value for the study area ranges from 2.62 to 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 Pareta 2011). 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 coarse 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 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 73.41 for 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

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 basins...
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 (Landsat 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

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.
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)

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

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.

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° 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.
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.
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)](image1)

![Figure 10: Change Detection of Nandoshi Watershed (2015)](image2)

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
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.
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.
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)

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

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 $40^0$ slope 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](image)

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.
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 encroachment. 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

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)

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

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° to 30° slope 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](image)

![Photo 23: Construction material along the road (Kondhwa)](image)

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.
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.
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
4.3.5.1. Supervised Classification (LANDSAT 5) and Change Detection

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)](image)

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)

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

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 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](image1)
![Photo 29: Construction at hill slope](image2)

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

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

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

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.
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.

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.
### 4.4 Existing Scenario of Streams in Watershed Areas

**Table 25: Existing Scenario of Streams in Watershed Areas**

<table>
<thead>
<tr>
<th>Watersheds</th>
<th>Stream Order</th>
<th>Total Streams</th>
<th>No. of Vanished Streams</th>
<th>No. of Present Streams</th>
<th>Vanished Streams (%)</th>
<th>Present Streams (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ram Nadi</strong></td>
<td>1</td>
<td>323</td>
<td>86</td>
<td>237</td>
<td>26.63</td>
<td>73.37</td>
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<td></td>
<td>2</td>
<td>67</td>
<td>16</td>
<td>51</td>
<td>23.88</td>
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<tr>
<td></td>
<td>3</td>
<td>21</td>
<td>3</td>
<td>18</td>
<td>14.29</td>
<td>85.71</td>
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<td>4</td>
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<tr>
<td><strong>Total</strong></td>
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<td>74.52</td>
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<tr>
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<td>1</td>
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<td>6</td>
<td>155</td>
<td>3.73</td>
<td>96.27</td>
</tr>
<tr>
<td><strong>Ambil Odha</strong></td>
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<td>235</td>
<td>48</td>
<td>187</td>
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<td>(Rivulet)</td>
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<td>11</td>
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<td></td>
<td>3</td>
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<td>0.00</td>
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<td>0</td>
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<td>0.00</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>284</td>
<td>60</td>
<td>224</td>
<td>21.13</td>
<td>78.87</td>
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<tr>
<td><strong>Bhairoba</strong></td>
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<td>145</td>
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<td>106</td>
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<td>73.10</td>
</tr>
<tr>
<td>Nala</td>
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<td>85.00</td>
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<td><strong>Total</strong></td>
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<td>45</td>
<td>153</td>
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<td>77.27</td>
</tr>
<tr>
<td><strong>Wadki Nala</strong></td>
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<td>42</td>
<td>199</td>
<td>17.43</td>
<td>82.57</td>
</tr>
<tr>
<td></td>
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<td>57</td>
<td>10</td>
<td>47</td>
<td>17.54</td>
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<td>262</td>
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<td>5</td>
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<td>41.67</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>98</td>
<td>38</td>
<td>60</td>
<td>38.78</td>
<td>61.22</td>
</tr>
</tbody>
</table>
Table 26: Existing Status of Streams in Pune City

<table>
<thead>
<tr>
<th>Over all</th>
<th>Stream Order</th>
<th>Total Streams</th>
<th>No. of None Existing Streams</th>
<th>No. of Existing Streams</th>
<th>None Existing Streams (%)</th>
<th>Existing Streams (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pune City</td>
<td>1</td>
<td>1151</td>
<td>251</td>
<td>900</td>
<td>21.81</td>
<td>78.19</td>
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<td></td>
<td>2</td>
<td>238</td>
<td>49</td>
<td>189</td>
<td>20.59</td>
<td>79.41</td>
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<td></td>
<td>1471</td>
<td>307</td>
<td>1164</td>
<td>20.87</td>
<td>79.13</td>
</tr>
</tbody>
</table>

Existing Status of Streams in Pune City

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

<table>
<thead>
<tr>
<th>WARDS</th>
<th>Lowest</th>
<th>Highest</th>
<th>Contour (m)</th>
<th>Slope (Degree)</th>
<th>Streams</th>
<th>Watershed Area</th>
<th>Geology</th>
<th>Geomorphic Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Aundh</td>
<td>550</td>
<td>790</td>
<td>0.05</td>
<td>15.75</td>
<td>1st</td>
<td>152</td>
<td>Ram Nadi</td>
<td>BDD,BDK SPUR,ESCARPEMENT,PEDIMENT,RI VER BANK</td>
</tr>
<tr>
<td>2  Kotharud (Karve Road)</td>
<td>570</td>
<td>750</td>
<td>0.03</td>
<td>13.29</td>
<td>2nd</td>
<td>80</td>
<td>Ram Nadi</td>
<td>BDD,BDK SPUR,ESCARPEMENT,PEDIMENT</td>
</tr>
<tr>
<td>3  Ghole Road</td>
<td>550</td>
<td>710</td>
<td>0.04</td>
<td>14.41</td>
<td>3rd</td>
<td>29</td>
<td>BDD,BDK</td>
<td>SPUR,ESCARPEMENT,PEDIMENT,RI VER BANK</td>
</tr>
<tr>
<td>4  Warje Karve nagar</td>
<td>550</td>
<td>720</td>
<td>0.02</td>
<td>12.15</td>
<td>4th</td>
<td>12</td>
<td>BDD,BDK</td>
<td>SPUR,ESCARPEMENT,PEDIMENT,RI VER BANK</td>
</tr>
<tr>
<td>5  Dhole Patil Road</td>
<td>540</td>
<td>570</td>
<td>0.01</td>
<td>2.62</td>
<td>5th</td>
<td>12</td>
<td>BDI,BDK</td>
<td>PEDIMENT,RIVER BANK</td>
</tr>
<tr>
<td>6  Hadpsar</td>
<td>560</td>
<td>660</td>
<td>0.02</td>
<td>8.72</td>
<td>6th</td>
<td>24</td>
<td>BDI,BDK</td>
<td>SPUR,PEDIMENT</td>
</tr>
<tr>
<td>7  Nagar Road</td>
<td>540</td>
<td>590</td>
<td>0.02</td>
<td>19.35</td>
<td>7th</td>
<td>103</td>
<td>BDI</td>
<td>SPUR,ESCARPEMENT,PEDIMENT,RI VER BANK</td>
</tr>
<tr>
<td>8  Sangam Wadi</td>
<td>540</td>
<td>750</td>
<td>0.01</td>
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### Land Use and Land Cover in 2015

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

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