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Policy interventions to address urban water problems in highly urbanised areas due to climate change

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सार – इस शोध पत्र में सबसे पहले भारत के गुजरात राज्य में तेजी से बढ़ते शहरी क्षेत्रों में अहमदाबाद और सूरत के वर्षा पैटर्न का अध्ययन और तुलना की गई है। यह पता लगाया गया है कि किस वजह से सूरत शहर में बाढ़ का खतरा अधिक है। फिर, पिछले तीन दशकों में सूरत में वर्षा परिवर्तन का विश्लेषण किया गया है। यह देखना दिलचस्प है कि सूरत का वर्षा पैटर्न स्थानीय कैलेंडर, यानी ग्रेगोरियन कैलेंडर के बजाय भारतीय कैलेंडर का पालन करता है। भारतीय कैलेंडर के साथ वर्षा पैटर्न का यह संबंध दर्शाता है कि वर्षा के लिए जिम्मेदार पूर्वानुमान और जलवायविक स्थिति ग्रहों की स्थिति के आधार पर स्थानीय कैलेंडर का पालन करती है। जल संवेदी शहरी डिजाइन के लिए, सूरत नगर निगम (एसएमसी) में अदजान, पिपलोद, अंजना और पांडेसरा नाम के चार अलग-अलग वार्डों का अध्ययन किया जा रहा है। इन वार्डों का चयन भूमि उपयोग के आधार पर किया जाता है, जिसमें कुल एसएमसी क्षेत्र में वाणिज्यिक, आवासीय, औद्योगिक और संस्थागत क्षेत्र सबसे अधिक हैं। प्रत्येक वार्ड के लिए पिछले और अभेद्य क्षेत्र की गणना की जाती है, और अपवाह निर्धारित किया जाता है। भवन स्तर, सड़क स्तर और वार्ड स्तर पर जल संवेदी शहरी डिजाइन का अध्ययन करने के लिए योजना हस्तक्षेप क्षेत्र को दिया गया है। यह अध्ययन निर्णय लेने वालों के लिए मॉनसून प्रोटोकॉल को संचालित करने के लिए स्थानीय कैलेंडर का पालन करने और जल संग्रहण गतिविधियों की योजना सहित जल संसाधन के बुनियादी ढांचे का प्रबंधन करने के लिए एक नीति तैयार करने में सहायक होगा।

ABSTRACT. In this research first, the rainfall pattern of Ahmedabad and Surat, the fast-growing urban areas of Gujarat state of India, have been studied and compared. It is detected what makes Surat city more prone to floods. Then, analysis of rainfall shifts in Surat over the last three decades has been carried out. It is interesting to observe that the rainfall pattern of Surat follows the local calendar, *i.e*., the Indian calendar rather the Gregorian calendar. This relation of rainfall pattern with the Indian calendar shows that the prediction and the climatic condition responsible for rain follows the local calendar based on the planetary position. For the Water Sensitive Urban Design, four different wards in Surat Municipal Corporation (SMC) named Adajan, Piplod, Anjana and Pandesara are being studied. These wards are selected based on land use, having the highest areas in commercial, residential, industrial and institutional in total SMC area. For each ward, the previous and impervious area is calculated, and the runoff is determined. Planning interventions for water sensitive urban design at building level, street level and ward level have been given to the study area. The study will be helpful for the decision-makers to prepare a policy to follow the local calendar to operate the monsoon protocol and to manage water resource infrastructure, including the planning of harvesting activities.

Key words – Water sensitive urban design, Rainfall shift, Climate change.

1. Introduction

With urban growth, increasing use of resources and the effect of climate change, freshwater is becoming scarcer in many cities, and also flood risk is rising. The whole world is paying attention to the phenomenon of climate change as it is something that humans are accountable for (Baulraj, 2012). The Earth's climate is changing continuously. However, in the last century, the climate has changed severely. The temperature of the earth has become warmer than before, and it has shown instant effects on areas such as small islands, food security, coastal areas, and health (Joshi & Linke, 2011). According to Puthucherril (2013), India in South Asia is going to be one of the major areas which will be affected by climate change in the coming period, due to its diverse terrain. It was predicted that the shift in rainfall pattern across India would leave some areas under water and

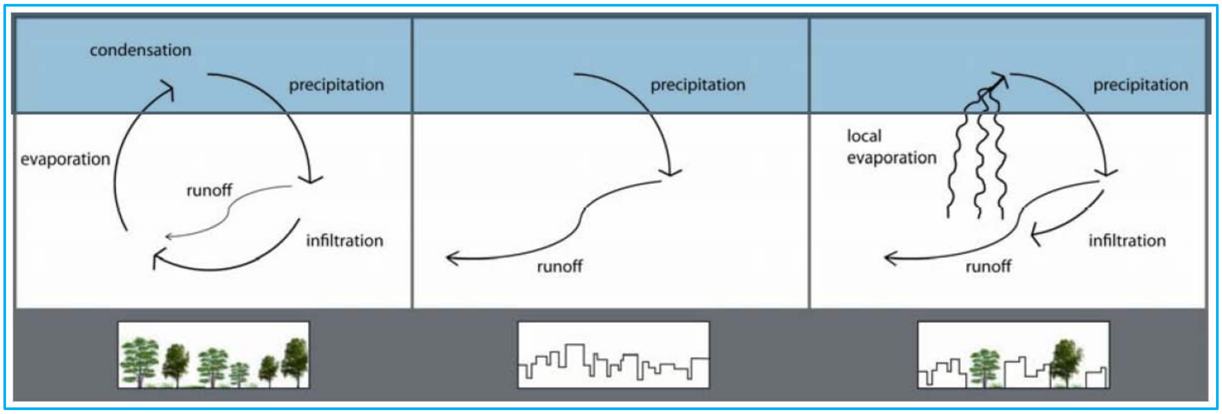

Fig. 1. Water cycle in natural systems (left); in an urban area without sustainable stormwater management (middle); and in an urban area with sustainable stormwater management (right) (*Source* : HCU Hamburg)

some without enough water, even for drinking purpose (Mitra, Wright, Santra, & Ghosh, 2015), (The World Bank, 2013). As per the National Commission for Integrated Water Resources, the annual per-capita surface water availability in India dropped from 2309 cubic meters in 1991 to 1902 cubic meters in 2001. Also, the groundwater level is dropping by 20-30 meters every decade. Due to the lowering of the water table, water has to be pumped further to reach the surface. This requires more energy and leads to an increase in cost. Also, at lower depths, the salinity of water increases, which makes it non-potable. It has projected that if groundwater recharging measures are not taken, then the water level will drop to 80-200 m below ground level by 2050, which was 50-60 m below ground level in the year 2000. In such a scenario, the cost of the availability of water will rise to □100/litre by the year 2050 from □12/litre in 2000. Therefore, sustainable urban water management infrastructure is gradually been applied worldwide to counter the impacts of climate change, along with providing a range of benefits to the ecosystem. The technique is known as Water Sensitive Urban Design (WSUD) in Australia, Nature-Based Solutions (NBS) in Europe, Low Impact Development (LID) in the USA and Sponge City systems in China.

In this research first, the rainfall pattern of Ahmedabad and Surat, the fast-growing urban areas of Gujarat state of India, have been studied and compared. It is detected what makes Surat city more prone to floods. Then, analysis of rainfall shifts in Surat over the last three decades has been carried out. It is interesting to observe that the rainfall pattern of Surat follows the local calendar, *i.e.*, the Indian calendar rather the Gregorian calendar. This relation of rainfall pattern with the Indian calendar shows that the prediction and the climatic condition responsible for rain follows the local calendar based on the planetary position. For the Water Sensitive Urban Design, four different wards in Surat Municipal Corporation (SMC) named Adajan, Piplod, Anjana and Pandesara are being studied. These wards are selected based on land use, having the highest areas in commercial, residential, industrial and institutional in total SMC area. For each ward, the previous and impervious area is calculated and the runoff is determined. Planning interventions for water sensitive urban design at building level, street level and ward level have been given to the study area. The study will be helpful for the decision-makers to prepare a policy to follow the local calendar to operate the monsoon protocol and to manage water resource infrastructure, including the planning of harvesting activities.

2. Literature review

Water plays a vital role in everyday life. Apart from exceptional experiences such as flood and drought disasters, most people are not aware of the function of water. Naturally, water goes in a cycle of precipitation, infiltration, surface runoff and evaporation (Fig. 1, left). However, in urban areas, this natural cycle is disturbed and cannot run its sequence.

During urbanisation, there are changes in watershed characteristics, which includes an increase in impervious area and drainage system improvements, that leads to increased volume and rates of runoff stormwater (Karamouz & Nazif, 2013), (Walsh, *et al*., 2012). Due to paved surfaces in urban areas, water cannot infiltrate the ground and is rapidly collected and discharged to the community draining systems, leaving no time for evaporation (Fig. 1, middle). This disturbance in the natural water cycle adversely affects groundwater recharge, water supplies, quality and quantity of water in receiving rivers and urban climate (Hoyer, *et al*., 2011). Another factor that affects the future urban runoff is modified rainfall pattern due to climate change. Already, existing problems of floods and wet weather pollution are worsened by the impact of climate change on rainfall (Dale, *et al*., 2015).

Zahmatkesh (2015) studied the effect of climate change on urban storm water runoff based on the characteristics of subwater sheds. The results revealed that the high value of imperviousness does not show notable sensitivity to climate change scenarios. Whereas, runoff in sub-watersheds with steeper slopes and the high value of the width parameter contributes to high sensitivity to climate change (Zahmatkesh, *et al*., 2015). Therefore, it is necessary to consider the effects of climate change while designing and developing stormwater management tools to mitigate the negative impact of climate change.

Since urban development will not stop for water consideration, it is the need of the urban planners to manage urban development with minimum damage to groundwater (Mukherjee, 2016). All the problems listed make it clear that more effective solutions are needed in managing urban water (Nagaveni & Anand, 2012) (ADB Institute, 2012). Dale (2015) suggested in his/her literature that a substantial increase in storage capacity will be required to avoid sewer flooding and manage urban water quality outcomes. Waghwala & Agnihotri (2019) suggested the diversion of floodwater to the existing creeks, bringing back natural drains into urban landscape and construction of storage detention ponds where floodwater could spread. Summing up, to ensure the liveability, resilience, sustainability and productivity of future cities, civil engineers need to be more water-sensitive (Kuller, Bach, Roberts, Browne, & Deletic, 2019), (Zevenbergen, Fu, & Pathirana, 2018), (Dolman & Ogunyoye, 2018), (Hasse & Weingaertner, 2016), (Ferguson, Frantzeskaki, & Brown, 2013).

3. Climatological data

Analysis of the Indian monsoon over the past century indicates a decrease in the number of rainy days as well as more extreme precipitation events across the country (Anon., 2011). The following section describes the climatology of two cities: Ahmedabad and Surat in Gujarat State of India. Only two cities that have experienced heavy rain and a change in rainfall pattern are considered for the analysis. The climatology data used in the study applies to the entire city.

3.1. *Ahmedabad*

Ahmedabad lies at 23.03° N 72.58° E in western India at 53 metres (174 ft) above sea level on the banks of the Sabarmati River, in north-central Gujarat. It covers an area of 464 km^2. The Sabarmati frequently dried up in the summer, leaving only a small stream of water, and the city is in a sandy and dry area. However, with the execution of the Sabarmati River Front Project and Embankment, the waters from the Narmada River have been diverted through a river-linking project to the Sabarmati to keep the river flowing throughout the year, thereby eliminating Ahmedabad's water problems. Ahmedabad has a hot, semi-arid climate, with marginally less rain than required for a tropical savanna climate. There are three main seasons: summer, monsoon and winter. Ahmedabad receives annual rainfall ranging between 650-900 mm and the mean number of rainy days is 33.6. Aside from the monsoon season, the climate is arid. The graphical representation that follows gives a brief idea of the average climate of Ahmedabad.

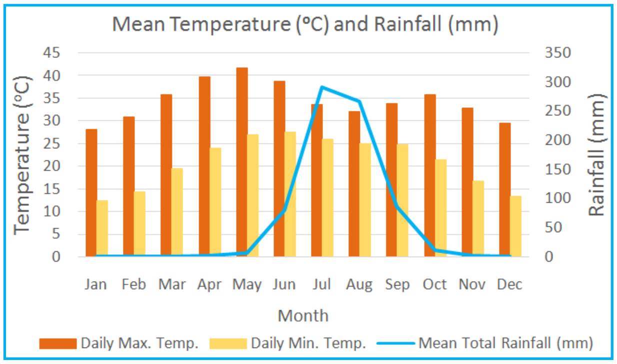

Fig. 2. Mean Temperature and Rainfall curve of Ahmedabad for period: 1981-2010 (*Source* : Indian Meteorological Department)

The "daily maximum temperature" shown in Fig. 2 represents the average daily maximum temperature for every month. Similarly, "daily minimum temperature" represents the average of the daily minimum temperature of that month. It can be observed here that April and May are hottest, followed by June. May's end and June's start experience some rainfall which eventually lowers the temperature. The month of July experiences maximum rainfall which gradually decreases in August. After the end of the monsoon, the temperature is seen rising again.

3.2. *Surat*

Surat is India's ninth most populated city, having a population of 4.5 million with an area of 326.515 sq km. It lies between 21.170° North latitude and 72.831° East longitudes. Surat is the commercial capital of Gujarat State and rests on the bank of the Tapi River, 20 m above sea level, which flows into the Arabian Sea. The seasons of Surat city is broadly divided into summer, winter and monsoon with fluctuations in temperature. Due to its

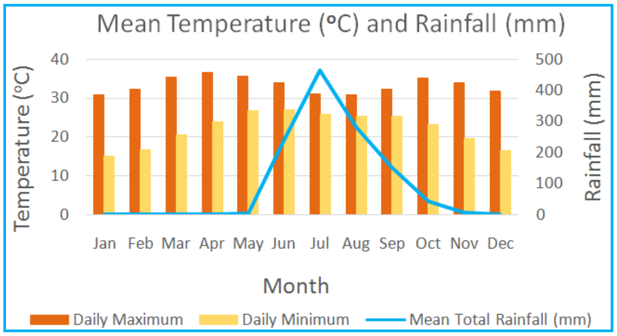

Fig. 3. Mean Temperature and Rainfall curve of Surat for period: 1981-2010 (*Source* : Indian Meteorological Department)

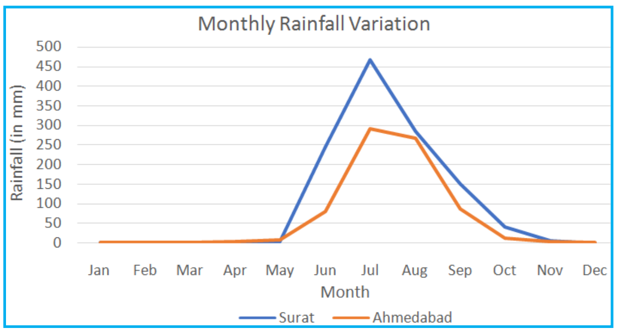

Fig. 4. Variation in 30 yr. mean monthly rainfall for Ahmedabad and Surat

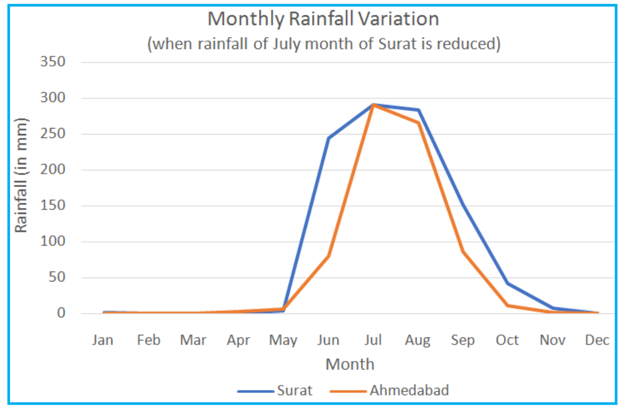

Fig. 5. Variation in 30 yr. mean monthly rainfall for Ahmedabad and Surat when rainfall of July month for Surat is reduced to that for Ahmedabad

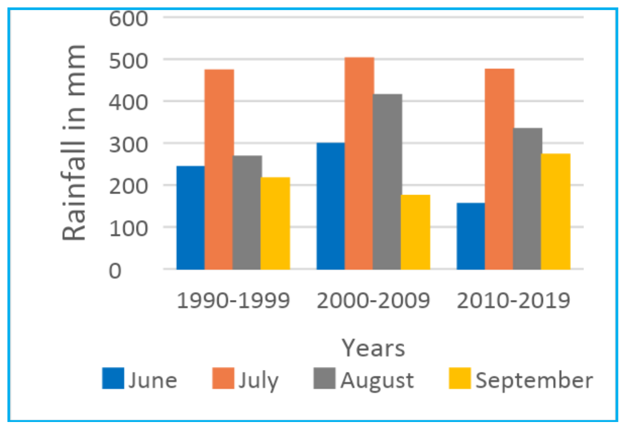

Fig. 6. Average decadal rainfall of Surat City (*Source*: indiawris.gov.in)

proximity to the sea, it is predominantly humid and hot and represents the sub-humid of the tropical climate. Surat receives annual rainfall ranging between 950-1200 mm with a mean number of rainy days equal to 43.8. About 90% of the rainfall occurs in the period between June to September. The graphical representation that follows gives a brief idea of the average climate of Surat.

The "daily maximum temperature" shown in Fig. 3 represents the average of daily maximum temperature for every month of the past 30 years (1981-2010). Similarly, "daily minimum temperature" represents the average of the daily minimum temperature of that month for the past 30 years. It can be observed here that March, April and May are hottest followed by June. May's end and June's start experience some rainfall which eventually lowers the temperature. The month of July experiences maximum rainfall which abruptly decreases. After the end of the monsoon, the temperature is seen rising again.

3.3. *Comparison between rainfall variations in Ahmedabad and Surat*

Monthly variation of 30 years means the total rainfall of Ahmedabad and Surat is shown together in Fig. 4. It is observed that the rainfall pattern of Ahmedabad is similar to Surat except for July month where the peak in the case of Surat is 60.1% higher than in Ahmedabad. This is the period when precipitation is more intense in Surat than Ahmedabad. Further, as discussed in section 3.1 and 3.2, Ahmedabad, a land locked city, is at a higher elevation than Surat, a coastal city above mean sea level. Therefore, more floods are experienced in Surat.

If the rainfall in July month for Surat is reduced to that for Ahmedabad, then the rainfall pattern for both the cities is similar as shown in Fig. 5. Therefore, stormwater planning can resemble in both the cities except for peak rainfall in Surat. This rainfall is just waste and flowing back to sea by the stormwater network, and hence extra planning interventions are required. For that, the rainfall pattern of Surat is further analysed, and proposals are presented for the same.

3.4. *Shift in rainfall*

In addition to the rainfall intensity, a shift of rainfall pattern is also essential to know before planning the WSD.

TABLE 1

Rainfall according to Western as well as Indian calendar

Rainfall (in mm) according to Western as well as Indian calendar								
Year	June	Indian Month	July	Indian Month	August	Indian Month	September	Indian Month
1979	206.14		277.93		**661.43**	Shravana - Bhadarvo	97.35	
1990	84.38		152.95		**471.91**	Shravana - Bhadarvo	349.2	
1991	114.99		**426.39**	Jyeshta - Ashadha	206.77		42.71	
1992	**374.68**	Vaishakha - Jyeshta	265.91		**362.8**	Shravana - Bhadarvo	**398.07**	Bhadarvo-Aso
1993	283.33		**566.18**	Ashadha - Shravana	108.34		285.45	
1994	628.42		**830.33**	Jyeshta - Ashadha	262.74		234.86	
1995	7.14		**753.46**	Ashadha - Shravana	181.05		78.17	
1996	223.52		**517.27**	Ashadha - Ashadha	227.77		134.6	
1997	393.14		261.36		**426.26**	Ashadha - Shravana	100.08	
1998	125.33		**579.73**	Ashadha - Shravana	321		408.96	
1999	200.16		**386.08**	Jyeshta - Ashadha	115.68		133.77	
2000	144.95		**442.52**	Jyeshta - Ashadha	139.76		31.85	
2001	433.45		**450.22**	Ashadha - Shravana	411.37		42.16	
2002	357.09		74.92		**453.12**	Ashadha - Shravana	170.82	
2003	470.95		**701.55**	Ashadha - Shravana	452.55		191.83	
2004	244.79		467.13	Ashadha - Shravana	**845.02**	Shravana - Shravana	74.74	
2005	**714.50**	Vaishakha - Jyeshta	341.95		256.26		352.63	
2006	210.43		**795.00**	Ashadha - Shravana	434.09		114.26	
2007	152.21		572.73	Jyeshta - Ashadha	**576.76**	Ashadha - Shravana	359.04	
2008	234.85		**431.01**	Jyeshta - Ashadha	387.29		267.58	
2009	24.38		**746.29**	Ashadha - Shravana	196.83		144.14	
2010	71.94		428.36		427.20		**430.30**	Shravana - Bhadarvo
2011	99.68		471.81		**514.13**	Shravana - Bhadarvo	149.58	
2012	82.41		178.38		191.43		**405.82**	Bhadarvo-Bhadarvo
2013	383.69		**671.53**	Jyeshta - Ashadha	319.40		466.70	
2014	37.77		**452.86**	Ashadha - Shravana	222.71		236.68	
2015	268.17		**326.93**	Ashadha - Ashadha	43.73		240.36	
2016	47.88		**379.85**	Jyeshta - Ashadha	318.71		222.23	
2017	246.57		**542.27**	Ashadha - Shravana	298.25		110.09	
2018	144.16		**817.84**	Jyeshta - Ashadha	269.94		73.29	
2019	173.65		486.74	Jyeshta - Ashadha	**735.48**	Ashadha - Shravana - Bhadarvo	393.33	

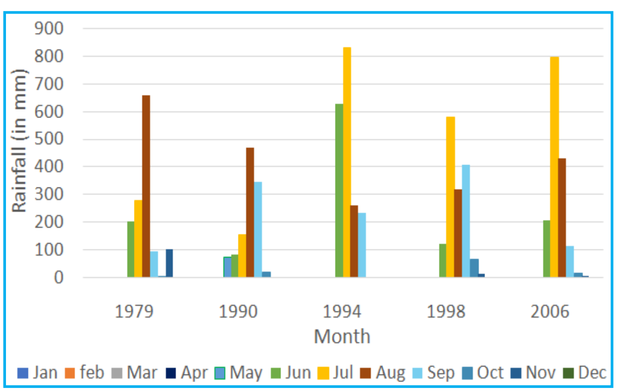

Fig. 7. Rainfall in Flood years of Surat City

The months of June through September see around 90 percent of the annual precipitation. Average decadal rainfall of these four months for decade - 1990-1999, 2000-2009 and 2010-2019 has been plotted in Fig. 6. Out of these four months, July receives the highest rainfall. The rainfall of June has decreased in the third decade by 36% and 47.91% with respect to the first and second decade respectively. While, the rainfall of September month has increased in the third decade by 25.97% and 55.99% as compared to the first and second decade, respectively. Therefore, it can be inferred that there is a significant shift in rainfall pattern towards August and September.

3.5. *Rainfall in flood years of Surat*

Surat has experienced major floods in the year 1979, 1990, 1994, 1998 and 2006 (Bhat, *et al*., 2013). As per Fig. 7, in 1979, the maximum rainfall occurred in August and also there was significant rainfall in June, July, September and November. Whereas, in the case of 2006 maximum rainfall occurred in July with higher intensity and most of the rainfall was concentrated in 4 months. In 1994, the increase in rainfall from June to July was gradual, while, in 2006, there was an abrupt increase in rainfall from June to July. This decrease in the number of rainy days and increase in the intensity of rainfall makes it critical for stormwater to run off and may cause flooding,

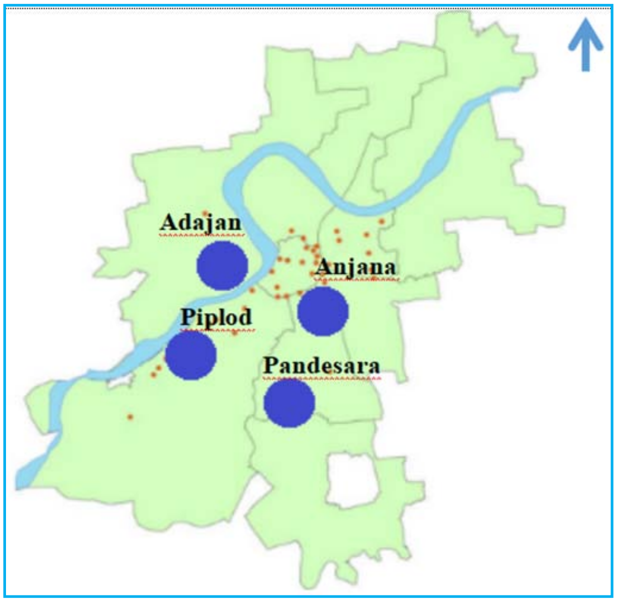

Fig. 8. Location of study area in Surat

and effective water can be drained away. If this water could be stored in a flood detention pond/reservoir, the summer water scarcity problem could be solved.

3.6. *Rainfall shift in comparison with Indian months*

In order to understand the shift in rainfall pattern, the Indian monsoon month's, *i.e*., Jyeshta, Ashadha Shravana and Bhadarvo are mapped with Gregorian calendar months and shown in Table 1. It is also a belief in India that the Shravana is the month for monsoon as it is connected to the arrival of the South-West monsoons.

Table 1 shows the rainfall (in mm) in the months of June, July, August and September for a period of 30 years from 1990 to 2019. The highest rainfall in every year has been highlighted and the respective Indian month is mentioned in the adjacent right to it.

In most years, the highest rainfall occurs in July, followed by August. Jyeshta, Ashadha, and Shravana are the Indian months that fall primarily in July month of Gregorian calendar. Maximum rainfall shifts to August is observed in the year 1997, 2002, 2007, and 2019. There was also a shift from the Ashadha - Shravana months to August. Furthermore, peak rainfall can be seen for combinations such as Ashadha - Ashadha, Shravana - Shravana, and Bhadarvo - Bhadarvo. As a result, there is a similarity between the shift in rainfall and the shift in Indian months. As a result, when predicting precipitation, researchers should use both the Gregorian calendar and the Indian calendar. In addition, when developing protocols for dam and reservoir operations, the Indian state calendar should be considered. Furthermore, based on the preceding significant observations, it is clear that understanding the runoff characteristics of water and how it can be used effectively so that it does not drain into the sea is essential. It is critical to understand which months have the most rain. This inference indicates that the Indian months have more significant rain, and thus proper runoff mapping for this duration will assist in making the water more useful. For that purpose, a GIS-based ideal location is mapped in four different areas of Surat city where water can be tapped and water-sensitive planning can be made.

4. Study area

The study considers four different wards in Surat Municipal Corporation (SMC) as shown in Fig. 8, to understand the impact of urbanisation on runoff pattern. Adajan, Piplod, Anjana and Pandesara are the area chosen based on landuse. The methodology is divided into two parts, one is to calculate runoff from the previous 20 years annual rainfall, and second is to map the potential groundwater areas for the study area. For this first, the percentage of impervious and pervious surfaces are calculated using spatial analysis tools of the Geographic Information System (GIS), from ArcMap 10.4. Then, runoff is calculated for every ward by the SCS-CN curve method. It is found that on an average 94% to 97% of water flows as runoff in the study area. To utilise this water, we should know the exact locations for water sensitive urban design (WSUD) components. These components are recharge wells, street rechargers, infiltration and vegetation basins which will convert runoff to the groundwater. These locations are found out from groundwater potential map of Surat, with the help of six component maps like aspect, slope, soil, geology, drainage density and lithology using a weighed overlay model in ArcMap 10.4.

The wards are chosen based on the land use pattern. This study includes the wards with the most commercial, residential, industrial, and institutional area in the total SMC area. Adajan has the highest residential land use, with 62.54% of its area built up. Anjana has a total area of 2.02 km^2, with commercial land accounting for 28.2% of the total. Pandesara has the highest percentage of industrial land use, at 54.64% and Piplod has the highest percentage of institutional areas, at 37.88%. The available open area may vary depending on land use, and thus the chances of water percolation may vary accordingly.

4.1. *Impervious and pervious area of the study area*

To understand the water percolation capacity of different area pervious and impervious area is calculated

TABLE 2

Impervious and pervious area of the study area

Name	Area (sq.km)	Road Area (%)	Area of Roof and Pavement (%)	Impervious Area (%)	Pervious (%)	Ratio of Imp/per	Ratio of Roof/per
Adajan	6.78	33.37	46.10	79.47	20.53	3.87	1.18
Piplod	1.83	13.80	22.68	36.48	63.52	0.57	0.17
Anjana	2.03	28.63	55.34	83.97	16.03	5.23	1.49
Pandesara	2.82	24.49	47.93	72.42	27.58	2.63	1.12

From Table 2, it is found that the most impervious area is present in Anjana and the lowest in Piplod.

TABLE 1

Calculation of Runoff for Study Area

Year	Rainfall in mm	Q (Adajan)	% runoff	Q (Piplod)	% runoff	Q (Anjana)	% runoff	Q (Pandesara)	% runoff
2000	785.8	757.240	96.36	724	92.13	761.3	96.87	727.9538	92.6
2004	1962	1933.201	98.52	1898	96.74	1937	98.73	1902.519	97
2009	1525	1496.286	98.10	1462	95.84	1500	98.37	1465.879	96.1
2014	849.6	820.9861	96.63	787.5	92.69	825	97.10	791.5299	93.2
2018	1192	1163.192	97.58	1129	94.71	1167	97.92	1133.124	95.1

From Table 3, it is seen that runoff for all four wards ranges from 92 to 98%.

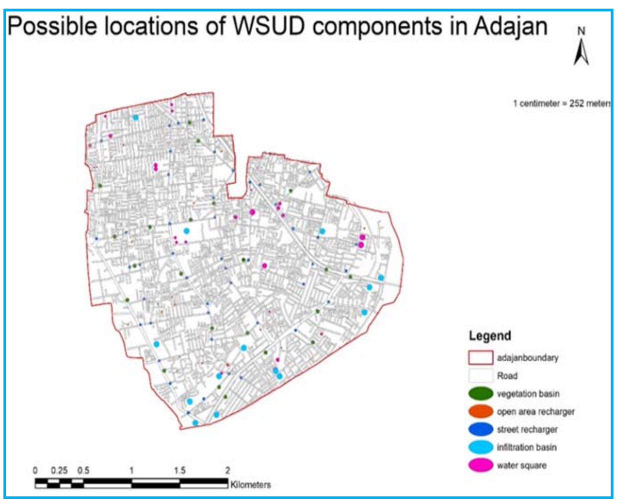

Fig. 9. Locations of WSUD components in Adajan

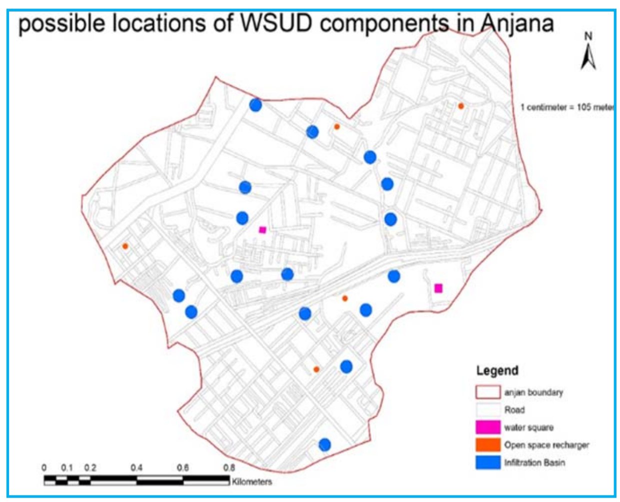

Fig. 10. Locations of WSUD components in Anjana

for each ward, for which CN value is computed which is used to calculate runoff in each land use.

From Table 2, it is found that the most impervious area is present in Anjana and the lowest in Piplod.

From Table 3, it is seen that runoff for all four wards ranges from 92 to 98%.

4.1.1. *Adajan*

Adajan has highest road percentage of all the wards, so the emphasis is given to the street. The street recharger in street and vegetation basin is also provided on the street where vegetation is present, the areas in Adajan which have the highest water storage potential are provided with infiltration basin. The areas which are reserved for public

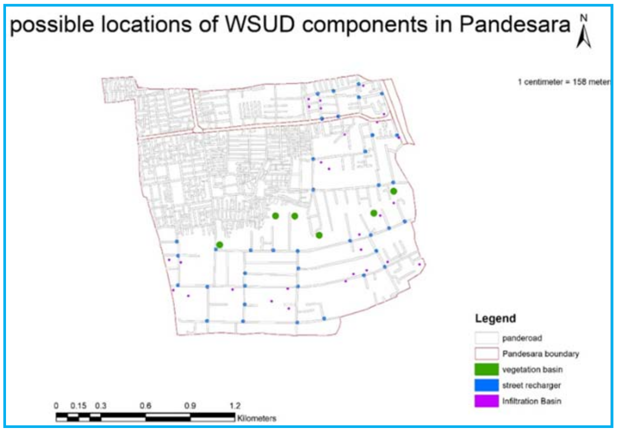

Fig. 11. Locations of WSUD components in Pandesara

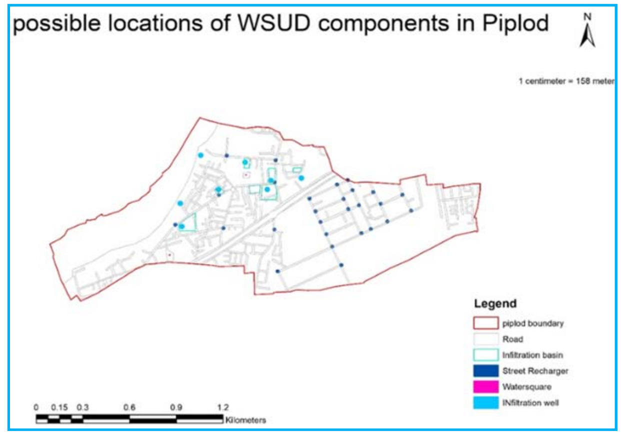

Fig. 12. Locations of WSUD components in Piplod

purpose are identified from the SUDA 2035 DP as shown in Fig. 9 and those areas are provided with water square. Water and open space rechargers are given in the location of reserved areas for garden and recreation by authorities the combined with high groundwater potential areas.

4.1.2. *Anjana*

Areas which have the most groundwater potential are identified, and that area can be provided with an infiltration basin, water square possible location is in the public purpose reserved areaas shown in Fig. 10. Open spaces are provided with open space rechargers.

4.1.3. *Pandesara*

Pandesara has one canal present in the area, it has the highest water potential so suitable. The Vegetation basin location is near that canal so that purified water can be transferred to groundwater and canal, location of street recharger on every street is markedas shown in Fig. 11. Rest areas with potential water can be used as the infiltration basin.

4.1.4. *Piplod*

Locations of infiltration basins are finalised with high water potential areas and gardens present in the ward, street recharge on the street and water square in the reserved land for a public purpose as shown in Fig. 12.

5. Implementation strategies and outcome of WSUD

More impervious areas in urban areas are construction of roads, parking lots, and buildings which, result in more runoff water; as a result, less water is available for infiltration and groundwater recharge, leading to a problem of channel erosion, flooding and loss of riparian habitat. Ground water preservation is a top priority for sustainable development. Within the urban area, there are enough groundwater resources to meet the city's entire water demand. If new water supply systems are not planned, serious aquifer depletion can occur, resulting in quasi-irreversible side effects such as contaminated water from seepage and coastal saline intrusion. As a result, groundwater storage must be coordinated with surface water supply. Groundwater as a source of water combined with surface water will reduce water scarcity, satisfy the needs of the city's population, and increase the city's sustainability. Based on an analysis of rainfall intensity and patterns, it is worth noting that useful water is being wasted as runoff in the sea, and that very little water is being infiltrated as groundwater due to more impervious layers. Furthermore, Surat is located on the Arabian Sea and as a result of seawater intrusion, both soil and underground water become saline; therefore, if excess runoff water is diverted to existing saline soil areas, saline soil reclamation through leaching may be possible. The following section discusses water - sensitive urban design proposals at the building, street, and ward levels.

5.1.1. *Building level water management*

When rainwater reaches the roof surface, it is transferred to the roof garden excess water from roof garden is then directed to ground level where the system is located it is a vegetated place where plants grow and the area stores water for a temporary basis and then water infiltrates into the ground slowly, and from another pipe, it is transferred to the collector tank located on ground level water from which is used for gardening, car washing. Runoff coming from the streets to housing areas can also be collected in the system. Providing a roof garden as shown in Fig. 13, will increase the aesthetic of a house,

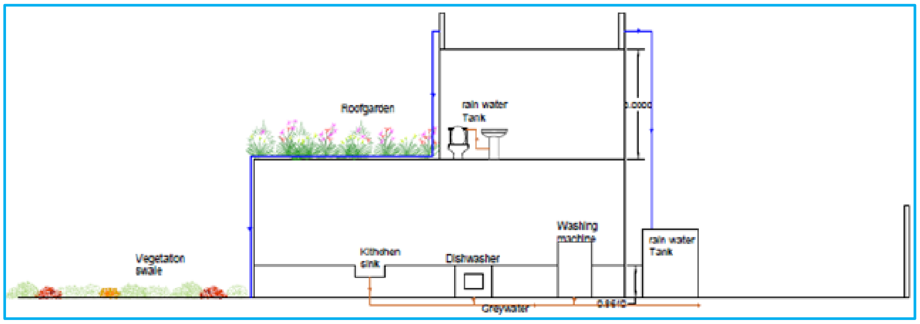

Fig. 13. Building level green roof technology

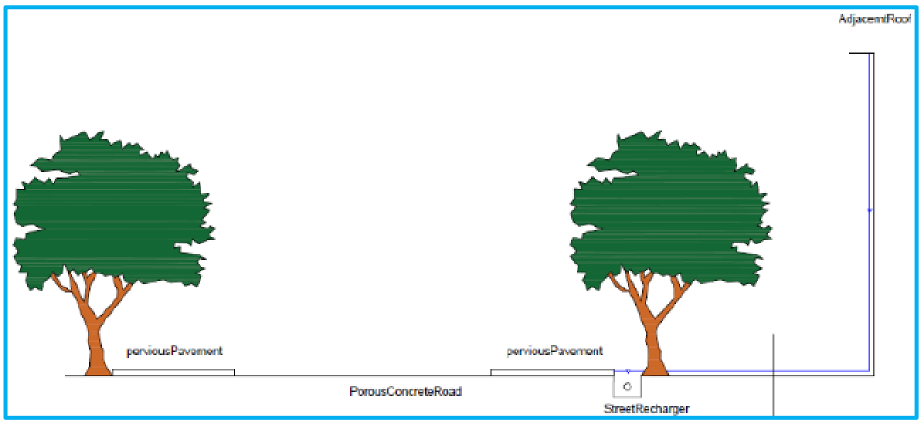

Fig. 14. Street level proposal for WSUD

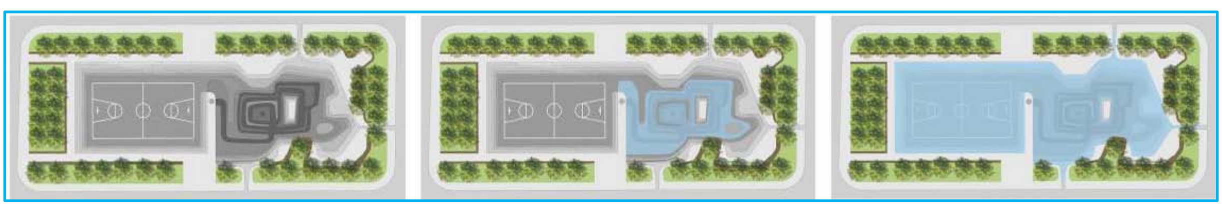

Fig. 15. Top view of the pilot water square - during dry periods, medium rain, and heavy storms (left to right)

along with reducing the urban heat island effect (UHI) and increasing the green space of a city. Building level water management also includes reusing greywater for a non-potable purpose such as flushing. The used water in the sink is directly connected to the cistern, which can be used for flushing. Water from a washing machine, dishwasher, the kitchen sink is conveyed to greywater treatment at house level, and the second time, this water is transferred to the drainage system of the city.

5.1.2. *Street-level water management*

Streets are the primary source of runoff in the city. Every street is given a street recharger located at the lowest level, so that when runoff comes in contact with it from streets and adjacent roofs, it collects water, and then, through the permeable pipe, it is transferred to the ground below it. Trees present on the adjacent side of the road are provided with a pit so that, it can be collected in that pit and can be used for planting and then transferred to groundwater as shown in Fig. 14. Pervious pavements must be used for a footpath and porous concrete must be used to construct the road which would allow rainwater to get infiltrated to the ground, as soon as it touches the surface.

5.1.3. *Ward level water management*

Ward contains different elements of buildings, roads, gardens, open space, ponds the proposal is based on the condition and presence of these elements in each ward. The condition required for WSUD elements is matched

Fig. 16. Rainwater Harvesting system installed in the Residential and Institutional Building

with the current land condition and land use proposed by SUDA 2035 with the integration of groundwater potential area map.

Vegetation basin: It is a shallow basin with plants which hold water after rain and give time for settlement of pollutants and then purified water goes to the groundwater, increasing groundwater.

Infiltration basin: The basin without vegetation which is natural or artificial open spaces which collects water only for a short time and then transfer water into the ground.

Water square **:** It uses technical systems to manage stormwater and also contributes to the quality of public space. During dry periods, the square can be used as an open public space, while during heavy rains, the square can be used for temporary rainwater storage, as shown in Fig. 15 (Hoyer, *et al*., 2011).

For 90% of the year, the space is dry and can be used for recreation. After the rain ends, the rainwater will stay for a few hours and then is slowly discharged to sewer systems.

The proposal to reclaim water using rainwater harvesting (RWH) and water square are prepared. The Surat municipal corporation had implemented the project of RWH, and a total of 382 projects are completed and monitored by the SMC and around 60 community-based RWH schemes have been developed by the group of societies in the SMC area. Apart from that, it is also proposed that the water getting runoff from bridges will also be collected and using RWH groundwater can be recharged. In addition to this, a water square project along the river is proposed to reclaim the floodwater. Fig. 16 shows the existing RWH schemes installed in the residential and institutional areas.

Water has been collected from the entire 4500 sq m catchment area of building terrace, and groundwater has been recharged. The total cost of the project for community development is around 5.5 million, and the rise in groundwater level has increased from 1.15 m average within two years of development, and 57 million litres have been reclaimed. The cost of water sent back to nature is hardly in fractions of Rupees. Similarly, the RWH schemes installed by the SMC have shown a significant rise of 0.45 m in the average groundwater table in a single monsoon session. Because the scheme was only recently launched, the depth is also being recorded.

6. Conclusion

The importance of water in human life is undeniable. Most people don't understand the importance of water until it's taken away from them, as in a flood or a drought. Water follows a natural cycle that begins with precipitation and ends with evaporation. But the urban environment disrupts this natural cycle, so it can't continue. Water-sensitive urban design (WSUD) is a solution that can be implemented to fix the issues. It's crucial to know how long the peak rain will last before WSUD hits. This research is being undertaken to learn more about how water-efficient urban planning can help save millions of gallons of water each year, as well as the typical rainfall pattern in this region.

Adajan, Piplod, Anjana and Pandesara are the four wards being looked at by Surat Municipal Corporation (SMC) for the Water Sensitive Urban Design project. These districts were chosen because they have a disproportionate share of SMC's commercial, residential, industrial, and institutional land uses.

The peak of the Indian monsoon season moves about from year to year. Predictions of precipitation are typically made with the western calendar in mind. Rainfall patterns changed in relation to the months that are considered traditional in India. Therefore, while trying to anticipate rain, scientists should use both the Western and Indian calendars. Dam and reservoir operation protocols also need to be updated in this manner. More and more land is becoming uninhabitable as urbanisation spreads. There needs to be a plan in place to limit the amount of built up. A critical condition is a shortening of rainy periods accompanied by a heightening of rain's intensity. Water-sensitive urban architecture, which includes water square, is necessary in these cases because it allows rainwater to be collected from rooftops and flyovers and then transferred to recharging wells located in and around public spaces. With the WSUD, the rise in groundwater level has increased from 1.15 m average within two years of development, and 57 million litres have been reclaimed.

Water square is an example of a WSUD feature that might be implemented by both developed and developing countries; however, underdeveloped countries might have difficulty funding its implementation. Under a public-private collaboration, the price tag for addressing flood issues might be rolled into the creation of new public spaces. As a result, the city will be able to raise cash and invest them more wisely. Incorporating an integrative strategy and innovative methods for stormwater storage in densely populated metropolitan areas, water square can help make a city more appealing.

The expense of dealing with floods and droughts can be reduced if a city implements a water supply and utilisation plan (WSUD) that prioritises long-term sustainability. Further research could involve integrating WSUD components with the existing water distribution infrastructure to create a sustainable water network for the area under investigation.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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List of notations

BMP- Best Management Practices
GI- Green Infrastructure
GIS- Geographic Information System
IUWM-Integrated Urban Water Management
LID- Low Impact Development
NBS- Nature-Based Solutions
Q- Runoff
RWH- Rainwater Harvesting
SCS-CN- Soil Conservation Service- Curve Number
SMC- Surat Municipal Corporation
SUDA- Surat Urban Development Authority
SUDS- Sustainable Drainage Systems
WSC- Water Sensitive Cities
WSUD- Water Sensitive Urban Design