Urban Planning and Energy Consumption in Storm Water Management: Case Study of Ahmedabad

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ABSTRACT

Rapid urbanization has resulted in fast development and stress on the water cycle and energy consumption. Increased built and paved surfaces lead to increased surface runoff and urban flooding. This also increases the inflow in conduit-based, electromechanical stormwater systems of a city, resulting in more energy consumption. This research establishes an empirical relation between energy consumption in stormwater management and urban characteristics like vegetation, surface pattern, built-up area, etc. for the city of Ahmedabad. Urban planning with due consideration to these factors could facilitate decisions on the proportion of conduit-based systems and optimize the presence of blue-green infrastructure, surface pattern, and other urban factors like built vs open, land use, etc. Also, these factors would help achieve sustainable development goals in the long term like SDG 6: Clean water and sanitation, SDG 11: Sustainable cities and communities, SDG 13: Climate Action, and SDG 15: Life on land.

Key Words: *Energy Consumption; Municipal Service; Stormwater management; Urban Planning; Energy Efficient; Urban factors*

1. INTRODUCTION

Urbanization has led to, more than half of the world's population living in urban areas, which makes secure and efficient energy as a global concern, most importantly at the municipal level (Pradeep Kumar, 2012).

Indian municipal sector being the second largest municipal system in the world contributes 4 percent to the overall energy consumption of the country (IEA, 2015) Optimizing energy consumption and energy audits are mandatory reforms under Atal Mission for Rejuvenation and Urban Transformation (AMRUT) mission, although bothering issue is the high operating expenses in the water system, on an average 40-60% of energy cost arises from supplying and pumping water.it has been estimated that around 4800 million units of electricity is wasted every year on the inefficient pump (Gateway, 2021).

As per the Central Electricity Authority report, energy consumption by public water works was around 18,364 million units (MUs) in 2011–12. The report also projected the energy consumption for the year 2021–22 at around 36,861 MUs, with significant growth of approximately 100 percent in 10 years.

Several policies and programs aim towards energy conservation and efficient supply and the scope and scale of such programs are increasing. however, very limited attention is being given to evaluate these programs (Mrudula kelker, 2018), and thus taking into consideration the importance of energy efficiency in ULB's, this study is carried out to assess city-wide energy consumption in stormwater management.

In case of the Ahmedabad city, as it does not have full coverage of stormwater networks and has separate drains for stormwater and wastewater. The study caters to the factors responsible for city wide and sub city wide energy consumption and further calculations and analysis based

on these factors. The study caters assessment of energy consumption in stormwater management in Ahmedabad.

Objective

1. Review of studies related to energy efficiency, in relation to stormwater management in municipal services.
2. Identifying the factors that affect energy consumption for the water pumping system. /Assessment of factors.
3. Establishing a relation between urban characteristics and energy consumption

2. MATERIALS AND METHODS

The research methodology consists of four sections, as shown in Fig. 1, which includes reviewing energy efficiency in stormwater management, followed by then identifying the urban factors that affect energy consumption in stormwater systems based on various literature studies done. Further establishing a relationship between these factors and surface runoff and energy consumption., which is backed up by journals, research papers, and articles published. Further, the factors were divided as per city level and sub city level. As the study was done for the city of Ahmedabad, sub city level factors were selected, and further assessment was carried out.

Further, various discussions with officials were done, about the existing situation of stormwater management in Ahmedabad, data was collected from AMC, and various other reliable sources like monsoon control room, zonal administration office, Central workshop, SCADA.

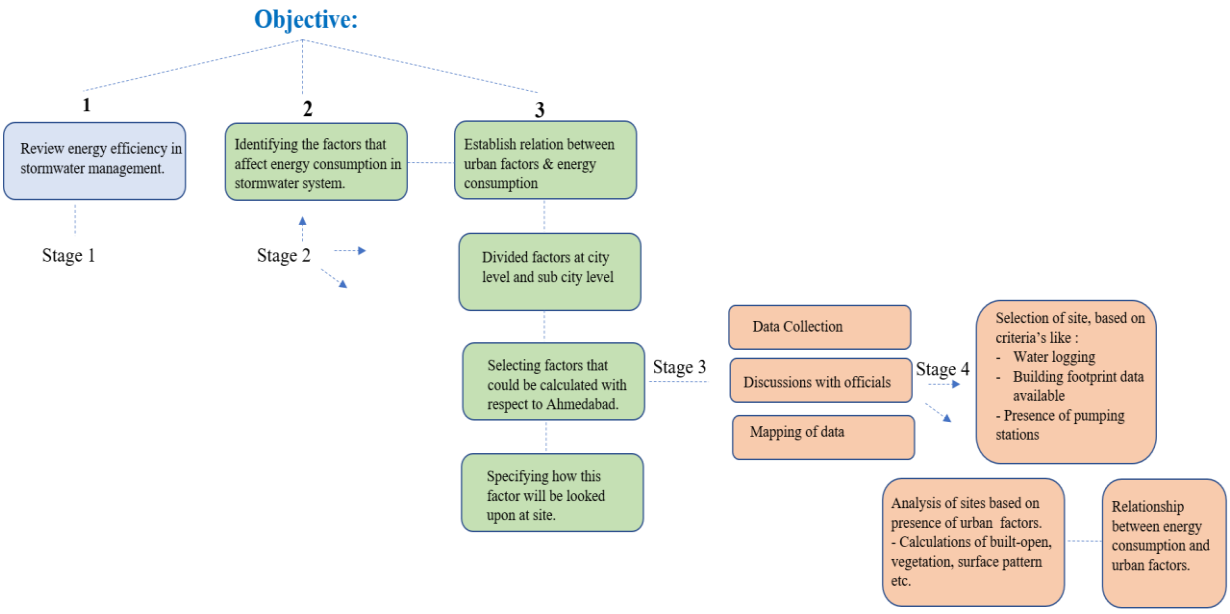

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Fig. 1 Research Methodology

Since, Ahmedabad experiences average rainfall for 30 days for four months, energy consumption data for June, July, August, and September were received and then was mapped. Furthermore, existing drainage network maps were received from Ahmedabad municipal corporation. Followed by site selection within Ahmedabad municipal corporation based on overlapping a few criteria's like waterlogging areas, building footprint data available, and presence of stormwater pumping stations.

The selected sites were then visited to analyze the presence of urban factors on site like vegetation, surface pattern present, built vs open spaces on site were observed and the

calculations were carried out for ground coverage, vegetation cover, surface runoff, surface pattern. Sites assessment from the lens of these urban parameters was then followed by an estimation-based analysis of how these factors were responsible for energy consumption as compared to other samples.

Relationship between Factors Responsible for Energy Consumption:

As cities have different urban parameters, which differ as per their physical and climatic conditions, based on these parameters a city's conduit and non-conduit systems are planned. To understand that various urban factors were identified, which could be responsible for energy consumption in stormwater management.

As surface runoff has a direct relation with energy consumption, more the surface runoff, more will be the energy consumption, hence those factors which would affect surface runoff and energy consumption were identified:

Urban Factors Affecting Energy Consumption

Based on the literature study, various urban characteristics were identified like:

Topography: Topography plays an important role as the valleys which have steep slopes, would result in increased runoff. On a flatter surface, the surface runoff is less likely to happen, as it will be easy to infiltrate in the soil. Thus, earth, surface, and topography would allow water to either collect, infiltrate, or increase runoff. Thus, to predict the surface runoff, the link between topographic attributes and hydrologic connectivity can be used (Dennis W. Hallema, 2016).

Average rainfall: In designing the stormwater system, estimating the average rainfall is the initial step. Rainfall intensity also influences both rate and volume of runoff, the rate and volume of runoff will be greater for an intense rainfall event (Yue Zhai, 2020). A city with less average rainfall is less likely to have surface runoff and waterlogging issues, and thus less energy consumption in pumping the stormwater.

Rainfall Intensity: Rainfall intensity plays an important role, as very intense rainfall can lead the soil to become saturated quickly, intense rain in a short time can bounce the water, which then flows through the surface of the earth as runoff.

Soil type and seepage capacity: The surface runoff tends to be more for soil with less infiltration capacity whereas, for soil with high infiltration capacity, the runoff will be less. At times soil type results in water logging as water tends to stagnate in different layers of soil (Mati, 2000).

Vegetation: Vegetation shows a strong direct relationship with surface runoff and energy consumption, a study conducted in Portland, Oregon, US, concludes that the coefficient on grass and shrubs IS -0.5, which means that a one percentage point increase in grass and shrubs would result in 0.5 percentage point decrease in flow (Geoffrey H. Donovan, 2016).

Storage Characteristics: The presence of storage characteristics in the surrounding like a lake, pond, water body etc. tend to reduce surface runoff. It has been proved in a study that raising the storage from 1mm to 15mm, results in reducing the runoff from 36 to 11mm. This is because surface storage is a dynamic parameter with respect to runoff (Morin, n.d.).

Land Use: From the results of a literature study done in sub basin in Iraq, it was observed that the runoff from farmland cover decreased from 65% in 1984 to 30% in 2014, while the runoff from built up cover increased from 6% in 1984 to 37% in 2014.The relationship was shown with respect to time that how land use changed and it affected runoff (Hameed, 2017).

Surface Pattern: The runoff depends on the type of surface pattern it flows on. As per a literature study, urbanization of the area increased the impervious land cover by 71% for the period from 1984 to 2004 (Hameed, 2017). For this study surface pattern is restricted to the paved and unpaved surface.

Ground coverage Vs Open Spaces: At a city level and sub city level, the share of open spaces and built helps to understand the relationship between surface runoff and infiltration. As more ground coverage would mean more roof area, and less open space, thus the ratio of open spaces and ground coverage would help to understand, space an area would have for infiltration.
Stormwater Design/System: Despite all the other factors, existence of drainage network pattern and stormwater system design, plays an important role, if the stormwater is directed and collected towards a tank for storage, or drainage network leads to re-use of runoff water, or any other stormwater harvesting system is implemented within the stormwater system, energy consumption would be reduced.
After identifying the above factors, the relationship between these urban factors and surface runoff and energy consumption was established based on various research papers and journals.

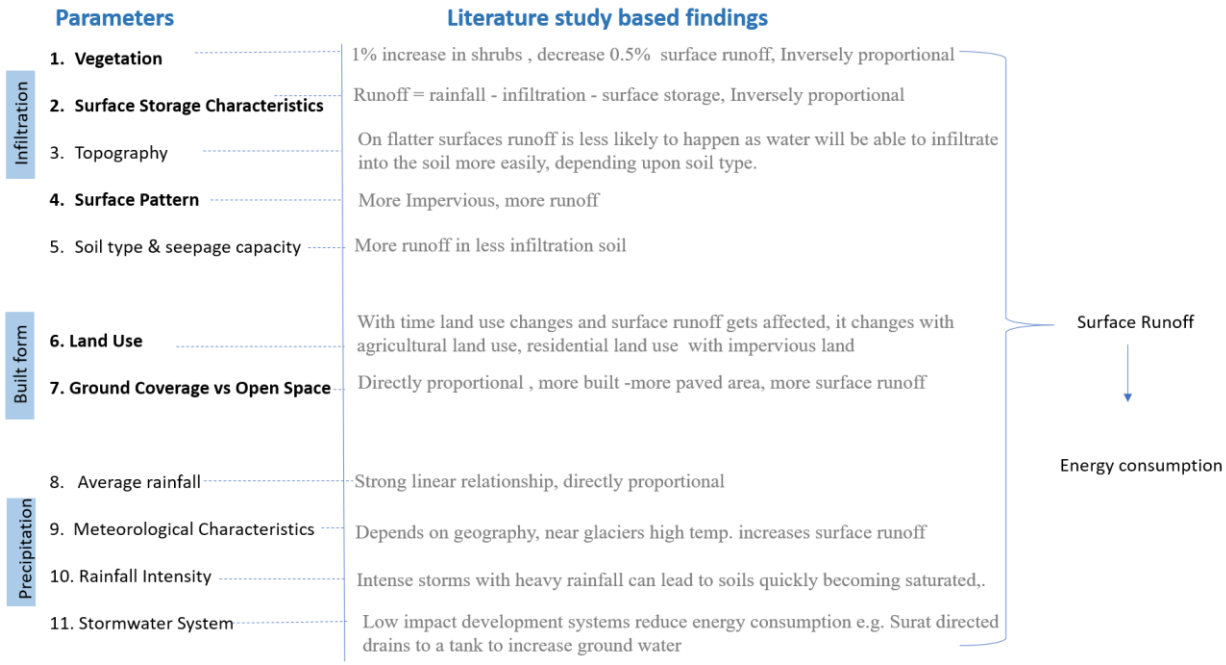

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Fig. 2 Urban Factors affecting energy consumption

Fig. 2 represents identified urban factors that are classified in terms of factors related to infiltration, built form, and precipitation. It concludes the relationship of urban factors with surface runoff, and since surface runoff is directly proportional to energy consumption, it shows an indirect relationship of urban factors with energy consumption.
A city's conduit and the non-conduit system are planned as per its physical and climatic parameters; since, Ahmedabad already has conduit-based stormwater system, the identified urban factors are divided as city level and sub city level factors.

As shown in Fig. 3, Out of all the identified urban factors, topography, soil type, and seepage capacity, average rainfall, rainfall intensity, meteorological characteristics, stormwater systems are all city-wide factors, which would remain quite similar all over the city, whereas those factors which could differ within a city and would affect surface runoff and energy consumption were classified as sub city level factors. Further sub city level factors were looked upon for the city of Ahmedabad.

City level factors

- Topography
- Soil Type & seepage capacity
- Average rainfall
- Rainfall intensity
- Meteorological characteristics
- Stormwater System

Sub city level factors

- Vegetation
- Storage Characteristics
- Land use
- Surface Pattern
- Population density & building density
- Built Vs Open

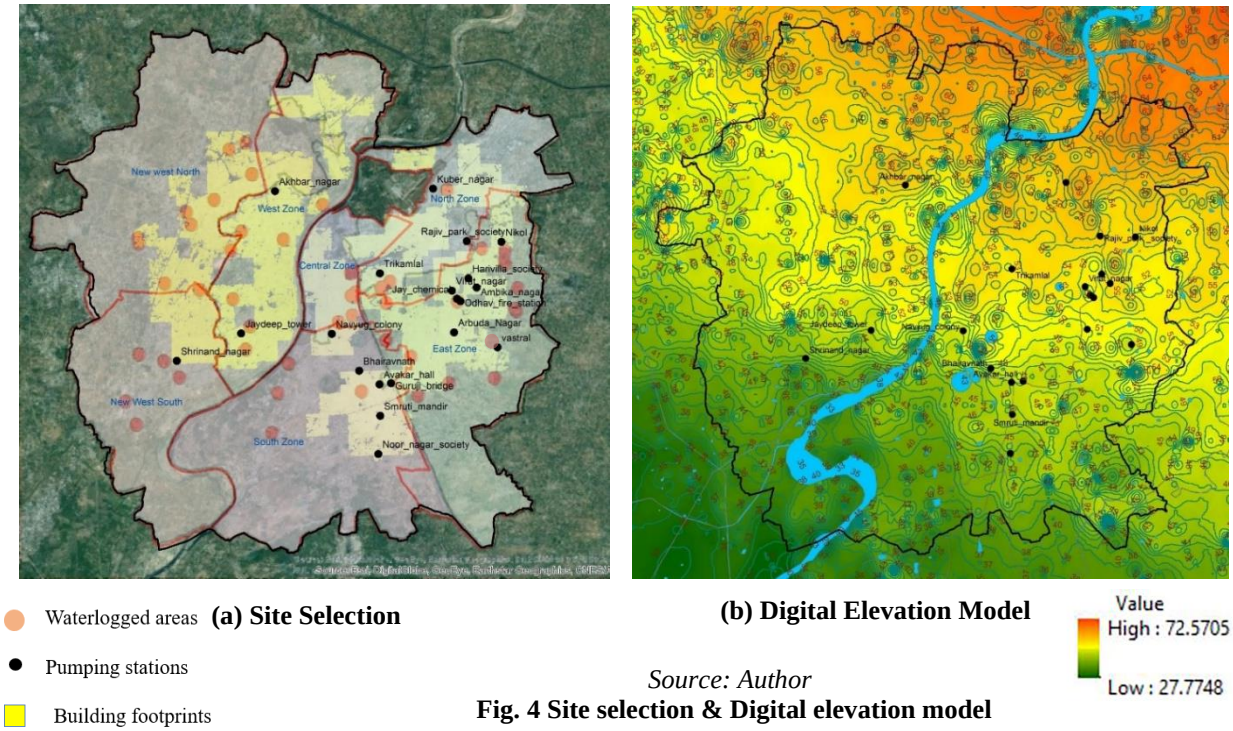
Source: Author

Fig. 3 City and sub-city level factors

After identifying the city level and sub city level factors, site selection was carried out. Within the Ahmedabad municipal corporation, 19 sites were selected, as shown in ***Source***: Author

Fig. 4 (a), based on the location of the pumping station, waterlogging areas, and building footprint data available. Further, these sites were looked upon, and assessment of urban factors like vegetation, surface pattern, built vs open, surface runoff, energy consumption was carried out. Digital model elevation was created as shown in Source: Author

Fig. 4 (b), which helped in understanding the nature of sites during analysis.



(a) Site Selection **(b) Digital Elevation Model**

Source: Author

Fig. 4 Site selection & Digital elevation model

3. RESULTS AND DISCUSSIONS

Based on the assessment of urban factors present on site, further analysis was carried out and a comparative assessment of sites was done with respect to energy consumption. For each urban factor present on site, in comparison with energy consumption, few outliers were observed. Majorly there were two reasons: one due to low-lying areas, and other due to areas nearby

water body, which has a natural topographic advantage. There were few outliers due to local constraints as well, which are discussed below. The following questions were answered by the assessment of these urban characteristics:

What is the Impact of Ground Coverage on Energy Consumption?

As per the literature study, the study (Hameed, 2017) indicates that the change in urban growth results in runoff increment. As the runoff increases, energy consumption increases.

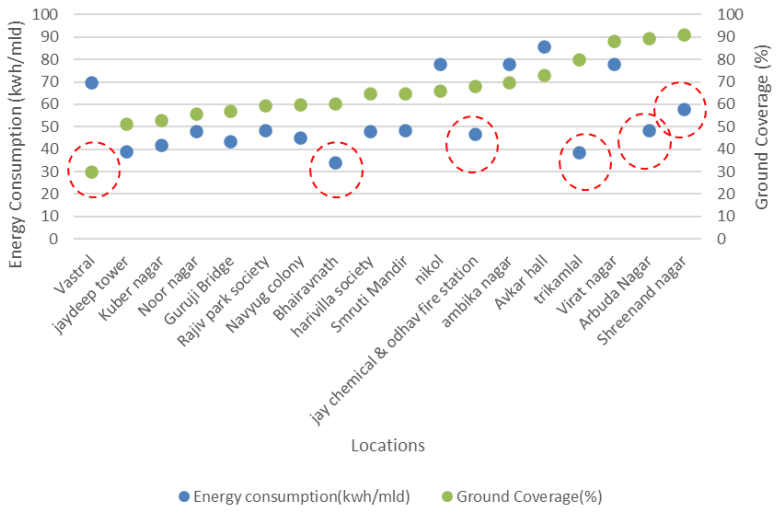


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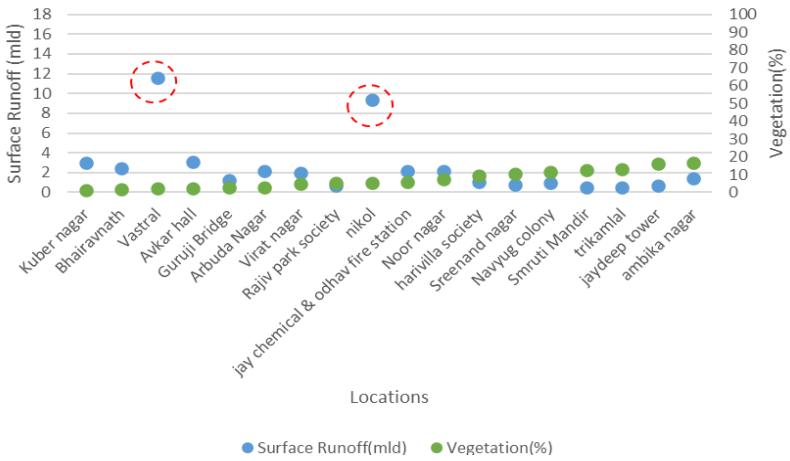
Fig. 5 Relationship between ground coverage & energy consumption

In Fig. 5, it is evident that as the ground coverage increases, energy consumption also increases. Here Vastral has exceptionally high energy consumption as it is at a lower elevation level as compared to areas surrounding it, which could be seen in Fig. 5. which might also be the reason for water logging, Vastral records water logging issues and thus, more surface runoff and high energy consumption. Bhairavnath has less energy consumption compared to ground coverage, as it has all existing drainage in place, with no water logging issues. Also, it is near Chandola lake, so not much energy is consumed in pumping water to the nearby waterbody. Jay Chemical Industries and Odhav fire station have less energy consumption comparatively as it is located very close to kharicut canal. so, the energy consumed in pumping water to near water bodies would be less. Trikamlal along with Bhairavnath has less energy consumption in spite of high ground coverage as it has 17% of the unpaved area, which is more comparatively. Also, Bhairavnath has the lowest surface runoff as compared to other sites, of 0.5 mld because of the same reason. Arbuda Nagar has less energy consumption as it shows a similar trend to that of jay chemical industries and Odhav fire station, it is very close to kharicut canal, and thus energy consumption in pumping water to nearby water body would be less. Here, all the sites close to the water body follow the same pattern of having less energy consumption. Shreenand Nagar does not follow the relationship of directly proportional as it has very little surface runoff and there are no water logging issues, one of the reasons might be that it has the drainage network in place.

What is the Impact of Vegetation on Surface Runoff?



Source: Author

Fig. 6 Relationship between vegetation & surface runoff

As per the literature study, the research showed that with a one percent increase in grass and shrubs there was a 0.5 percent decrease in the surface runoff (Geoffrey H. Donovan, 2016). In the Fig. 6, it could be seen that as the vegetation increases, surface runoff decreases. Although Nikol and Vastral has exceptionally high surface runoff, and the reason behind that would be, that both Vastral and Nikol are at lower elevation level as shown in Fig. 4. Apart from these two areas, the graph evidently satisfies the relationship of vegetation and surface runoff being inversely proportional. At Ambika Nagar, the surface runoff is a bit more as it is at low lying area similar to Vastral. Thus, more surface runoff.

What is the Impact of Vegetation on Energy Consumption?

As shown in the above analysis of surface runoff and vegetation, it was seen that surface runoff is inversely proportional to vegetation. Now as surface runoff and energy consumption are directly proportional, with an increase in surface runoff, energy consumption increases. Hence, if surface runoff reduces with an increase in vegetation, energy consumption also reduces with an increase in vegetation as shown in Fig. 7. Here the horizontal line shows average energy consumption i.e., 56 kwh/mld. All the sites having energy consumption above average are considered as outliers. Also, it could be seen that energy consumption decreases with an increase in vegetation. Looking at the outliers, Ambika nagar has exceptionally high energy consumption as it is analyzed that it lies at a lower elevation similar to Vastral and Nikol. Nikol has high energy consumption as discussed in the above relationships, it is at a lower elevation as compared to areas surrounding it (Fig. 4 b) Also, it has water logging issues and thus, more energy consumption. Virat Nagar, has 88% of built and only 6% of the unpaved surface, this gives way for more surface runoff and thus, more energy -consumption. It was observed that Avkar hall has the highest energy consumption, as it has only 5% of the unpaved surface and no existing drainage system in place, thus more surface runoff and high energy consumption. Vastral, as discussed in the previous analysis, is at lower elevation level (Fig. 4). Thus, more surface runoff and high energy consumption.

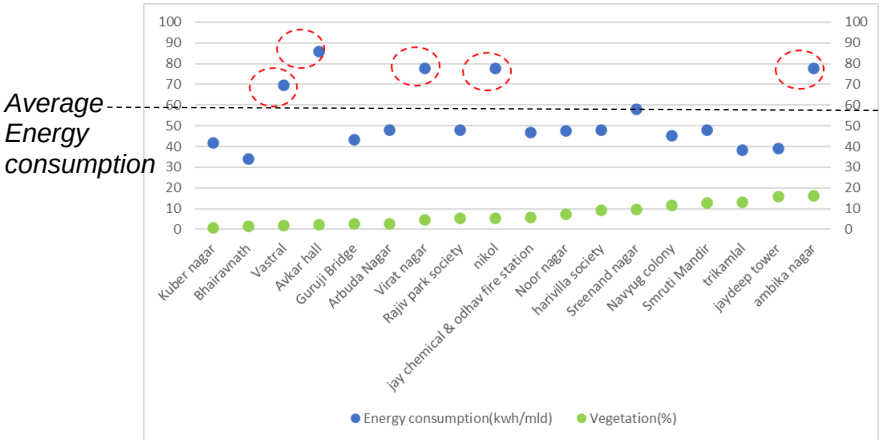


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Fig. 7 Relationship between vegetation & energy consumption

What is the Impact of Surface Pattern on Energy Consumption?

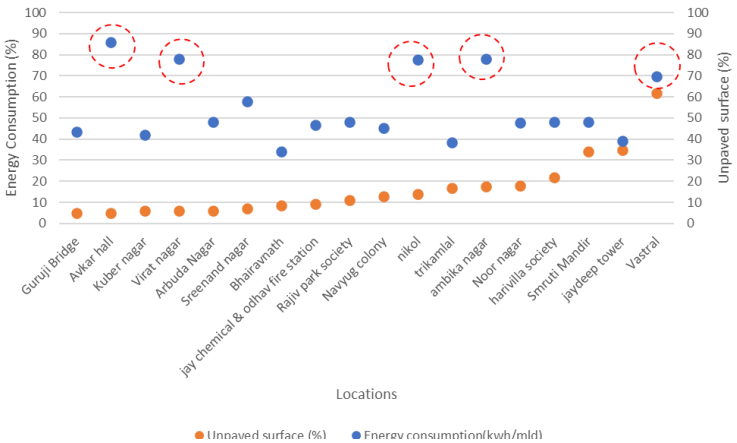

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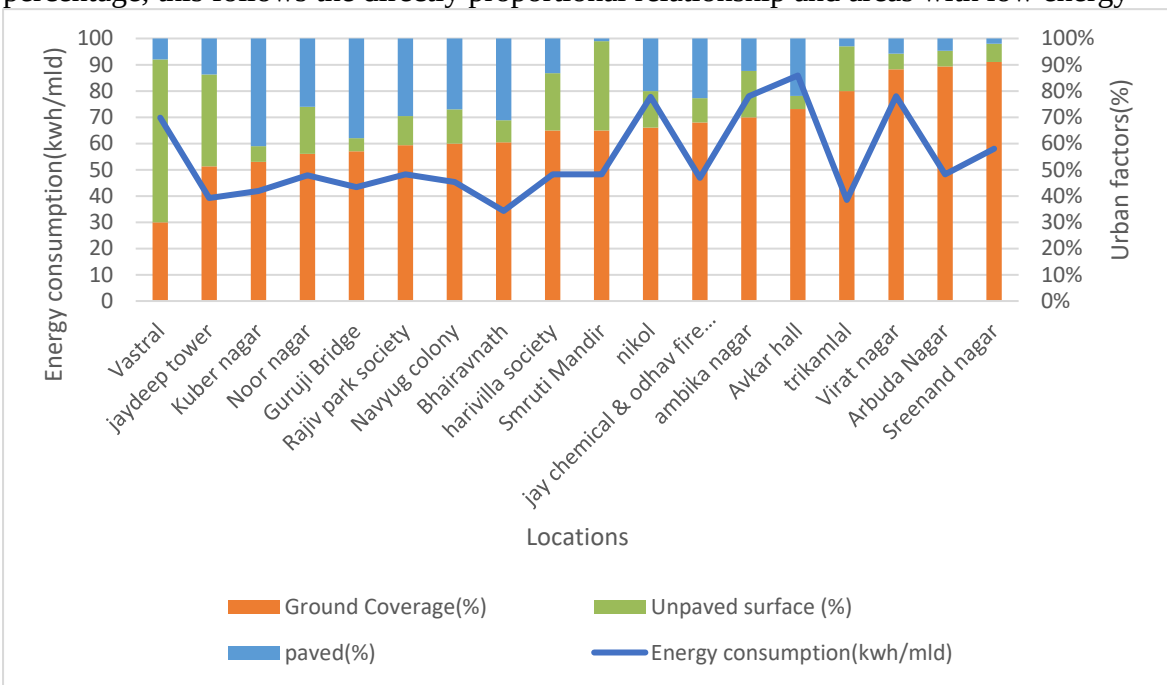
Fig. 8 Relationship between surface pattern & energy consumption

As per the literature study, surface runoff is positively correlated with the change in impervious and pervious land (Shanshan Hu, 2020). In Fig. 8, the graph shows that keeping the outliers aside, energy consumption decreases with an increase in the unpaved surface. Looking at the outliers, these are some of the common sites with high energy consumption which has been discussed in the above relationships like Vastral, Ambika Nagar, Nikol, Virat Nagar and Avkar hall. Reasons for these areas having high energy consumption is as discussed in the previous analysis. Shreenand Nagar is one of the outliers as it has the highest ground coverage of 91% and only 5% of vegetation, thus more than average energy consumption.

What is the Impact of overall Urban Factors on Energy Consumption?

Based on all the relationships of urban factors with energy consumption seen earlier, it could be concluded that the overall energy consumption is not affected by just one factor, when all the urban factors come together into the planning, then as whole energy consumption of that area is impacted. In Fig. 9, it could be seen those areas with more energy consumption like Ambika Nagar, Nikol, Virat Nagar, Avkar hall are the ones with high ground coverage percentage, this follows the directly proportional relationship and areas with low energy



Source: Author

Fig. 9 Relationship between urban factors & energy consumption

consumption like Jaydeep Tower, Smruti mandir, Noor Nagar, etc are the ones with more unpaved surface, thus showing the inversely proportional relationship.
Also, as discussed in the previous graphs, surface runoff shows a directly proportional relationship with energy consumption, so areas with high energy consumption like Nikol, Vastral are the ones with more surface runoff, confirming a directly proportional relationship. Here Vastral acts as an outlier, as it has exceptionally high energy consumption as discussed in previous relationships. Hence, it could be concluded that the overall energy consumption is impacted by the presence of all these urban factors together, and hence future development should be done from the lens of these factors, to reduce the overall energy consumption, which adds to the carbon footprint, leading to climate change at a large level.

4. CONCLUSION AND RECOMMENDATIONS

For the conventional conduit-based system, energy consumption per hectare was calculated followed by the overall cost involved in pumping the stormwater, 5.2 kwh/mld per hectare is the energy consumption as per present scenerio. To get the cost of pumping, Torrent municipal pumping electric charges were considered that is 4 Rs/unit, which gives total Rs**.**3,220 /mld. As per surface runoff calculation of these locations, approx. 46 mld stormwater would be pumped in a day i.e., 1,47,200 Rs. per day. Since the total annual rainy days are 30 for the city of Ahmedabad, 44,16,000/- per year (30 days) would be the cost of pumping stormwater. Hence, in order to reduce the cost, surface runoff needs to be reduced, and vegetation needs to be Increased, as per the current assessment in terms of cost if vegetation is increased by 20% it would reduce surface runoff by 10 mld and the cost will be reduced by significant amount, i.e**.,** Cost per day (30days) could be 1,15,920 Rs**.** Thus, for future development, planning needs to be done from the lens of urban factors that affect energy consumption, in such a way that energy consumption could be minimized.
For areas without drainage networks and SCADA monitoring, mobile pumps are used to drain out the waterlogged areas. In order to get the information about these areas, based on visits and interaction at the monsoon control room, central workshop office, zonal administration office and contractor hired for pumping waterlogged areas, the following assumptions were considered:

1. These mobile pumps are diesel based, that uses, almost 20 liters for 3 hours of pumping.
2. Rate of Diesel= 87.2 Rs per liter
3. Depending upon the rainfall, and its intensity, these pumps are used, at times they are used for 3-4 hours, whereas there are days, when they are not used at all.
4. Average pumping hours considered for calculations is 3 hours per day.

Further, calculations were carried out for cost involved in the non-conventional system, based on conversation with contractors, It was considered that per day diesel use is 20 liters. hence per hour, around 6.6 liters are used. Considering the total number of hours for one month, around 90 hours the pumps are being used to pump 6.6 liters thus, 594 liters of water is pumped per month for one zone. The total cost is 51, 832 Rs for 1 zone, considering same for all existing 7 zones, the total cost appears to be 3,62,827/-. Thus, the cost per day would be 12,094 Rs. This is just the operational cost considered.
It could be inferred that the conventional system costs more than the non-conventional system of stormwater management. However, In the non-conventional system of using mobile pumps, various factors like, increase in response time, short term inconvenience due to water logging, would exist. And thus, the stormwater system of a city should be planned from the lens of urban factors, and its relationship with energy and cost involved. Planning level interventions involving green cover and pervious surface patterns would reduce the surface runoff and minimize the overall energy consumption and cost involved in stormwater management of a city. For further development, various development control regulations would be required, low

impact development strategies and initiatives like Information, education, and communication (IEC) would be required to bring the overall change in the existing and future development of the city.

Also, through planning based on urban factors, a city can reduce the proportion of conduit-based systems and optimize the presence of blue-green infrastructure, surface pattern etc. to reduce energy consumption. Further, as per the existing assessment, to reduce the average surface runoff at least by half of the quantity, vegetation needs to be increased by 46% as per the existing situation. This gives us an idea that how important it is to consider vegetation in future development. Also, the presence of these factors and depending on the relationship they hold with each other, further 'area-based development' with 'do minimum approach' based interventions could be carried out, to reduce the overall impact and cost.

Sustainable Development Goals:

The stormwater system of a city could be used to achieve sustainable development goals in a long term. The development goals, directly related to stormwater management are SDG 6: Clean water and sanitation, SDG 11: Sustainable cities and communities, SDG 13: climate action, and SDG 15: life on land. SDG 6- Clean water and sanitation aim to improve the water quality and substantially increasing the water use efficiency across all sectors, it includes access to improved sources of drinking water to all. Stormwater management is related to this SDG, as underground water is a source of drinking water, and it can be recharged by improving the green and blue infrastructure at city and sub city level. Stormwater could be used to recharge ground water and would also improve the ground water quality thus, catering to the aim of clean water and sanitation SDG. SDG 11- Sustainable cities and communities includes sustainable urbanization and reduce the adverse environmental impact of cities. It aims at building up sustainable and inclusive cities that provide, a clean and sustainable environment and a decent quality of life to its citizens. The strategic component is city extension with smart solutions applied in service delivery and governance. If planning is done through the lens of urban factors like vegetation, paved and unpaved spaces, presence of storage characteristics like a lake, ponds, etc, which would reduce the overall surface runoff, it would act as a sustainable smart solution towards energy efficient service delivery. SDG 13- Climate change talks about integrating climate change measures into national policies, strategies, and planning, and reducing CO2 emissions. Stormwater management of a city might help achieve this sustainable development goal by reducing energy consumption in stormwater management; hence, the overall carbon emissions could be reduced. SDG 15- Life on land, highlights forest and green cover and decadal change in the extent of water bodies, it aims to ensure the conservation, restoration, and sustainable use of the terrestrial and inland freshwater ecosystem. life on land would be positively affected by improving the green infrastructure in many ways. Water logging issues can severely damage and contaminate the environment if sanitation facilities are flooded. Planned stormwater management of a city would reduce waterlogging issues, thus improving, and conserving the life on land.

Thus, it could be concluded that future development should be planned through the lens of urban factors, in order to minimize the overall cost and energy consumption in stormwater management. Also, a planned city with respect to stormwater management would help to achieve sustainable development goals in long term.

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