SUSTAINABLE DRAINAGE SOLUTIONS FOR FLOOD MITIGATION IN DEVELOPING TROPICAL/SUB-TROPICAL REGIONS THROUGH RAINFALL-RUNOFF MODELLING: A CASE OF NAGPUR, INDIA

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Abstract. Climate change and urban development are leading to the dichotomy of flood and drought in the same geographical locations, especially in the tropical/sub-tropical regions of the world. These areas have high rainfall intensity, an ever-increasing urban population, and partly existing infrastructure systems, resulting in waterlogging and subsequent floods. Interestingly, these tropical/sub-tropical regions are mostly developing countries. The United Nations states that developing countries have different drainage system requirements than developed countries. Through literature, this study has identified differentiating factors for designing sustainable drainage in developing countries such as climatic conditions, land use and density, socio-culture, pollution levels, runoff quantity, and quality, economics, lack of appropriate technology, governance, and political scenario. Consequently, recommendations for the implementation of sustainable drainage solutions have been made through the rational method for runoff calculations and Storm Water Management Model (SWMM) simulations. Utilization of public parks and participation from the surrounding street vendors have been demonstrated. This comprehensive approach provides sustainable solutions to flooding and drought in Nagpur.
Keywords: *SuDS, drought, land availability, sustainable infrastructure, flood, tropical/subtropical, developing countries, drainage, parks, SWMM*

Introduction

Disasters have had the power to wipe out entire civilizations, like Mesopotamia in the likely storms, London in the great fire, Bhuj in the earthquake, and countless more. In modern urban areas, a combination of climate change and urban development is leading to the dichotomy of flood and drought in the same area (World Bank, 2008). Singapore, the UK, Australia, China, India, and many more countries have cities facing the issue of excess and scarce water (Dąbrowska et al., 2023). Cities like Mumbai, Kolhapur, Amravati, Bangalore, Lucknow, Indore, Guwahati, and many more in India are facing such disasters (Tiwari, 2019). Flood is the most common disaster worldwide, and drought is the third most common disaster (CRED, 2021). According to the US News on *Nov. 20, 2018*, four of the top ten disaster events are floods, claiming 932 lives in a year, including Indian casualties. As India is moving from being an agrarian to an industrial and service-based economy, disaster events harm the country’s Gross Domestic Product (UN-ESCAP and APDIM, 2019).

This issue of flooding and water scarcity can be witnessed in several cities, especially in developing countries (Kurosaki, 2015). Interestingly, most of these developing countries are tropical/sub-tropical regions of the world (Goncalves et al., 2018; Haji, 2021). The tropical/sub-tropical areas have rainfall and temperature

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patterns, ranges, and intensities different from those of temperate zones which are further amplified due to climate change. Also, these developing countries have higher population growth compared to developed ones (Aragão and Júnior, 2019). For example, the global population is anticipated to expand by 32.85% between 2011 and 2050, and cities in Asian and African developing countries will see the highest urbanization (Mguni et al., 2016). A combination of these two factors creates pressure on the partially existing infrastructure systems like water supply, sewage, drainage systems, and others. This often results in floods and waterlogging primarily due to under-designed and unplanned infrastructure. This happens during the monsoon season, preceded by the summer season when drought-like situations are experienced in so many of these cities (Deshkar, 2019). The expected effects of climate change including drought, river and inland flooding, extreme rainfall events, cyclones, storm surge, coastal flooding, sea-level rise, and environmental health risks, are expected to extremely pressure the infrastructure provisioning in Indian cities (Deshkar and Adane, 2016).

The flooding issue was seen and studied predominantly in coastal areas or areas where a major river would flow through (Rosenzweig et al., 2018). However, a recent concern is the increase of water-related disasters in inland cities, which were once considered "safe-from-disasters." Water has always been one of the world's most "in-demand commodities" (Eckart et al., 2017). Thus, water needs to be treated as an asset, rather than a burden in the urban areas.

Nagpur city, the geographical center (21˚45' N to 20˚30 N and 78˚15' E to 79˚45, E,) of the Indian sub-continent, is one of the examples of water-related disasters. It has a typical sub-tropical climate, historically characterized by severe water scarcity situations (Deshkar, 2019) with alarming regularity, just before monsoon season, however, it has been witnessing flooding issues for the past ten years (DMC-NMC, 2022). Nagpur had a population growth of 17% from 2001-2011 (MoUD, 2015) and continues from 2011-2021. It has a high population density of 10,873 persons/km^2. (MoUD, 2015) with a decadal growth rate of 15%. In 2008, approximately 36% of Nagpur's residents resided in slum areas (NMC, 2008), while 28% of the housing units were classified as slum dwellings (MoUD, 2015). The high urbanization rate and density increase the vulnerability level in the city.

Only 40% of Nagpur city is covered with a drainage system which is a combined sewer system (MoUD, 2015). The built density in the city has increased from 59% to 74%. in the last decade. From 1969-2012, the maximum daily rainfall in Nagpur was recorded at 207.1 mm in 1994, which did not lead to any flooding. However, only 144.6 mm and 163 mm of rainfall in 2013 and 2015 respectively, led to flood-like situations (Ansari et al., 2016). In 2013, 233 houses were submerged and four lives were lost (DMC-NMC, 2022). This altered situation can be attributed to changes in land cover, density, and lack of drainage infrastructure. This points to the fact that there is an urgent need for an integrated water management system.

Developed nations with mostly temperate climates have their versions of Sustainable Urban Drainage Systems (SuDS) to handle these disasters in an integrated manner (Lashford et al., 2019). Most of the related studies have been carried out in developed countries having temperate climates and not in tropical countries (Charlesworth and Mezue, 2017). Due to their economic status, cities in developing countries lack adequate and modern drainage infrastructure (Inderst and Stewart, 2014). The United Nations in the early 2000s extensively pointed out that studies need to be carried out to

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understand the differentiating factors for planning drainage infrastructure in developing countries (Charlesworth and Mezue, 2017; Lashford et al., 2019; Vasconcelos et al., 2022).

This indicates the requirement for the upgradation of the drainage system but SuDS will reduce this demand for piped drainage systems. The piped drainage systems with increasing size requirements, combined sewer and drainage systems, are gradually becoming outmoded (Wong, 2006). Thus, Nagpur and other inland cities newly prone to floods will also benefit from this study.

Also, there is a need to make simplified methodologies and models for the government to implement SuDS in all cities. The paper represents the runoff calculation of selected SuDS interventions through a rational method. To assess the actual runoff reduction and infiltrations, these interventions were simulated in the Storm Water Management Model (SWMM), as open source software by the United States Environment Protection Agency (US-EPA).

This research paper aims (a) to identify these differentiating factors for drainage systems in tropical/sub-tropical climates and developing countries through literature; (b) propose sustainable drainage measures for these countries (c) apply SuDS measures in a pilot area of Nagpur through stormwater modelling.

Research methodology

Literature review has been carried out through the Science Citation Index and Social Science Citation Index published relevant papers in three stages to, (a) understand the issues of water-related disasters, floods, and water scarcity, a common problem in developing countries and tropical climates. (b) study integrated water management (SuDS) to understand its functioning, potential, and constraints. (c) identify differentiating factors for designing and implementing SuDS in developing countries. Based on the Nagpur city (as a case study) has been considered for designing the SuDS infrastructure. Data collection from the Nagpur Municipal Corporation (NMC), and Maharashtra Remote Sensing Agency (MRSAC) for the preparation of relevant maps was carried out. Problem areas and available parks for SuDS installations have been identified through these maps. One of the parks of Nagpur has been selected to indicate the solution options and stormwater modelling through the rational method and SWMM modelling.

Literature overview

The concept of sustainable drainage systems for planned flood mitigation

SuDS is a modern approach to urban planning and stormwater management that aims to rebuild the natural water cycle by storing runoff water, recharging groundwater, and using collected water (Ballard et al., 2015). It integrates urban planning with stormwater management, protecting the environment and creating high-quality urban places for the future (Melville-Shreeve et al., 2017) SuDS mimics natural hydrological processes in areas altered due to urbanization, creating sponge areas and providing opportunities to capture and treat runoff by intercepting, filtering, and degrading pollutants. It has benefits such as water purification, reduced heat island effect, habitat enhancement, reduced peak flow during floods, better sediment

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control, restoration of soil moisture, natural base flows, and natural drainage, and managing rainfall (Tang et al., 2018).

The term SuDS was coined in the United Kingdom in 1999 but its genesis was in 1972 in the USA called Best Management Practices. It has been adopted successfully in developed countries like France, Australia, Singapore, China, New Zealand, the Netherlands, Denmark, Sweden, Germany, South Africa, and many more under different names. SuDS was introduced and has adopted the concept successfully while some others are still struggling to provide likely implementable solutions (Parkinson et al., 2007).

The scope of SuDS has expanded over the years, offering multiple benefits such as recreation and aesthetics, water quality, restoration of flow regime, ecology of receiving water, water quantity -stormwater as a resource resilience, micro-climate, drought management, and integrated water management (Melville-Shreeve et al., 2017).

SuDS has a wide range of components, including rainwater harvesting, green roofs, infiltration systems, treatment systems, filter strips, swales, bioretention systems, trees, pervious pavement, attenuation storage tanks, filter drains, detention basins, and ponds and wetlands (Ballard et al., 2015). The selection of these components depends on their multi-functional benefits, compatible land use (Vasconcelos and Barbassa, 2021), governance factors cost (Chan et al., 2018), land availability (Melville-Shreeve et al., 2017), operation and maintenance requirements (Melville-Shreeve et al., 2017), social factors (Sörensen et al., 2016) and most importantly its retrofitting potential (Lashford et al., 2019) in brownfield development.

There is a much-needed paradigm shift from conventional drainage to a modern approach (Nie and Jia, 2018), focusing on finding sustainable and environmentally friendly stormwater management techniques. The traditional mindset of treating stormwater as a nuisance has been discarded, and a new mindset of treating stormwater as a valuable resource (Radcliffe, 2018) is taking shape worldwide. Municipalities in many countries have been encouraged to increase the use of SuDS for decades. However, the benefits of SuDS are not fully appreciated (Tang et al., 2018). To implement SuDS effectively, existing locations in cities must be retrofitted (Lashford et al., 2019), focusing on potable water, amenity value, and runoff reduction not just in greenfield projects (Radcliffe, 2018).

Developed countries formulate guidelines for the incorporation of SuDS and make financial arrangements for their implementation. However, developing countries lack drainage systems or combined sewer systems (Vasconcelos and Barbassa, 2021), are still unsure of the concept, and lack sufficient direction to take action on the concept. To harness the benefits of SuDS, developing countries must understand their existing drainage system and simplified ways to implement it, based on experiences from case studies.

Key findings: differentiating factors in planning, implementation, operation, and maintenance for stormwater drainage in developing countries

Developing countries are facing serious water-related problems including pollution, eutrophication, salinization, missing wastewater treatment, and, perhaps most importantly, a scarcity of clean water (Haase, 2015). An extensive literature study of the drainage systems in developing countries and the challenges faced by them in planning and implementing drainage systems was conducted through research articles

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published in Science Citation Index-ed journals. The findings have been categorized under seven factors:

(a) Climatic conditions

Most of the developing countries have predominantly tropical and subtropical climatic conditions as opposed to the temperate climate in the developed nations. Tropical climates are usually characterized by a higher quantity of rainfall, higher intensity, higher temperatures, and longer wet days (Chen et al., 2021). The rainfall in tropical regions is more than 1800 mm/year, in sub-tropical is more than 1200 mm/year, and in temperate is 300-1000 mm/year (Haque, 2005). The rainfall in sub-tropical regions is concentrated in a short season of four months contrary to temperate zones where rainfall is distributed throughout the year (Haque, 2005). Some tropical/subtropical countries are Australia, Malaysia, Sudan, Bangladesh, Ghana, Brazil Uganda, India, Vietnam, Colombia, and many more (Tak et al., 2013). The temperate climate countries are Germany Netherlands Portugal Canada Austria UK, USA, and others (Tak et al., 2013).

Lashford et al. (2019) have discussed the need for a climate-based approach for the best results of SuDS. Most of the drainage studies have been carried out in temperate climates and not in tropical areas (Chow and Yusop, 2014). Sustainable drainage has gained popularity in developed countries and includes large blue and green open spaces with stagnant waters (Vasconcelos and Barbassa, 2021). Such solutions, with higher temperatures in tropical climates, lead to the breeding of mosquitoes, which becomes a barrier to the adoption of open drainage systems (PUB, 2018). Water-related epidemics result from water retention techniques in tropical climates due to climatic and socio-economic factors (Charlesworth and Mezue, 2017). 65% of hospitalizations in Brazil are due to waterborne diseases (Tucci, 2007). This problem has been acknowledged by Singapore Authorities (PUB, 2018) in their guidelines for ABC waters.

Also, surface runoff is unevenly distributed over the year in tropical/subtropical cities (Chen et al., 2021) leading to unpredictable quantities making runoff management even more difficult. Thus, certain components of SuDS, such as the multifunctional open retention ponds, cannot perform to their fullest. They require additional design measures to ensure water retention during summer (Tiwari et al., 2018).

(b) Land use and density (urbanization)

The global problem of urbanization is felt much more in developing countries, due to haphazard developments, both authorized and unauthorized (Cohen, 2006). The built and population density in cities of developing countries is higher compared to developed nations (Radcliffe, 2018). High built density means more ground coverage more load on the infrastructure and higher runoff (Sriwongsitanon and Taesombat, 2011). According to a study conducted for built-up area expansion from 2000-2018, by (Sun et al., 2020) China ranked first (47.5%,), Nigeria (5%), India (3.6%) and Indonesia (2.8%), Russia (1.8%), and Mexico (1.7%), Malaysia (1.6%), Vietnam (1.5%), Ghana (1.3%) ranked third to tenth in the respective order. Only the second position is taken up by the USA, a developed country.

The built density affects the land use pattern and thus, vacant, agricultural, and forest lands and planned open spaces are less common in urban areas in developing countries. For example, Australia and India had respective population densities of 3.1 persons/km^2

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and 445.371 persons/km^2 in 2016 (Aragão and Júnior, 2019). The population density directly affects the land demand, its value, and thus its vulnerability. It also puts undue pressure on weak urban infrastructures. Encroachments along river basins and the mixing of land uses like industrial with commercial or residential leads to environmental degradation (Gaurkhede et al., 2021). This creates unhygienic living conditions.

(c) Socio-cultural

Waterbodies are of grave importance in developing countries, as history tells us that all human settlements started along them. Over time, water bodies have been losing their importance (Xu et al., 2019) in the life of the urban population due to the facility of piped systems. The population growth in developing countries is high due to migration leading to increased unauthorized settlements (Charlesworth and Mezue, 2017). Due to the paucity of land and high land costs, the floodplains of waterbodies, which were left undeveloped by the government are now being built up in both planned and unplanned manners (Ekeu-wei and Blackburn, 2018; Velasquez et al., 2012). This results in increased slums (Parkinson et al., 2007) and hence the vulnerability in these sensitive areas (Parkinson et al., 2007). In 2003, while the global slum population stood at 32%, it reached 43% specifically in developing nations (Arimah, 2011). Based on the 2011 Census of India, the slum populace totaled 65.49 million individuals, representing 17.45% of the urban population (Sinha et al., 2011).

There are low literacy rates and a lack of environmental education in developing countries resulting in the masses not understanding the importance of water bodies. Even if some solution is worked out in these areas, the acceptance of new systems and infrastructure can be a problem. The waterbodies are used for multiple reasons other than drainage like dumping of solid and religious waste (Parkinson et al., 2007), raw sewage discharge (Tucci, 2007), and being occupied by stray animals. Socioeconomic factors are more pressing in developing countries (Vasconcelos and Barbassa, 2021) rather than climate ones.

(d) Pollution levels and runoff quantity and quality

Urbanization leads to increased waste generation and tropical regions require less rainfall runoff compared to temperate urban regions to transport the same amount of pollutants downstream (Chen et al., 2021). Direct dumping and flow of uncollected into the drainage network and waterbodies, and discharge of untreated sewage (Xu et al., 2019) increase pollutant load. The pollutant load and its composition depend on the land uses (Chow and Yusop, 2014). Only 10% of the population in the 1990s had a sewer connection in Africa (Tucci, 2007); only 30% of the urban households had a sewer connection in 2017 India according to national policy on Faecal Sludge and Septage Management by the Ministry of Housing and Urban Affairs, Government of India 2017 and similar cases can be seen in other developing countries.

This also leads to water-related diseases, which still exist in developing countries, especially where sewage systems are limited or absent (Haase, 2015). The developing countries including South America and Brazil focus on the quantitative aspect of drainage rather than the quality of stormwater collected (Tucci, 2007). This is contrary to the concept of SuDS in developed countries like the UK, the Netherlands, Japan, and

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others where water quality (Ballard et al., 2015) is an equally important criterion for stormwater management.

(e) Economics aspects

Economic issues are a major obstacle in implementing SuDS UK (Ossa-Moreno et al., 2017) and is being reviewed for its economic benefits in Australia (Torgersen et al., 2015) and the USA, which are developed countries. The developing countries lack funds for basic infrastructure like water supply, electricity, sanitation, etc. vital for flood disaster management (Inderst and Stewart, 2014; Tingsanchali, 2012). The urban local bodies in these countries have taken funds and loans from international organizations like the United Nations, Asian Development Bank, World Bank, and many more, to construct the infrastructures. Thus, sanitation and drainage are being ignored in most cities (Tucci, 2007; Vasconcelos et al., 2022). Construction of piped drainage systems is an expensive concern; thus, they are absent in most cities. Even if they are installed, it is a combined sewer system (Vasconcelos and Barbassa, 2021), which has its share of problems such as backflush, blocking, etc. Installing the infrastructure is only one part of the problem, the other part is the huge operation and maintenance cost (Lashford et al., 2019) and trained manpower.

(f) Lack of appropriate technology

Technical knowledge and expertise, especially for modern techniques in developing countries are not available. China, Ghana, and India are facing this issue in pursuing smart city programs (Tan and Taeihagh, 2020). Similarly, there is a lack of technical know-how and research in sustainable drainage for tropical climates (UNDRR, 2019). The success of the drainage system can be guaranteed by the change in technical thinking, to incorporate storm drainage into the complete urban and environmental picture (Melville-Shreeve et al., 2014; Radcliffe, 2018). Drainage systems require data on catchment areas and there is a lack of information on urban catchments in developing countries (Hagen and Lu, 2011) and tropical areas (Chow and Yusop, 2014). Researchers have to depend on open-access data and thus, with limited result possibilities (Ekeu-wei and Blackburn, 2018). This combined with a lack of the latest technology and research and innovation is discouraging for infrastructure planners to take up projects in these countries (Gaurkhede and Adane, 2023).

(g) Governance and political scenario

The backbone of efficient infrastructure and disaster management is good governance (Radcliffe, 2018). The developing countries lack environmental law creation (Vasconcelos and Barbassa, 2021), and even if they exist, their enforcement related to drainage systems is not in place (Cotterill and Bracken, 2020; Mezue, 2017). Recently, the Government of India published the Manual on Storm Water Drainage Systems (CPHEEO, 2019) which barely touches on the need for upgradation from piped drainage to sustainable systems. But in developed nations, such as Singapore (PUB, 2018), Australia (Department of Planning and Local Government, 2010), Netherlands, and many others, the guidelines for sustainable drainages are in place.

Land limitations are there in densely populated subtropical cities (Chen et al., 2021). This leads to increased cost of infrastructure implementation if the land needs to be

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procured from non-government parties. Thus, land availability is a major hindrance to the implementation of SuDS (Jayasooriya et al., 2020).

Many researchers around the world have suggested involving the community (Ballard et al., 2015; UNEP and METC, 2000) in infrastructure building and maintenance. In developing countries, the slum population is high, located in hazardous areas, and is the most vulnerable population (Velasquez et al., 2012). Their participation is suggested by researchers in building up the infrastructure but it becomes difficult due to their socio-economic status (Vasconcelos and Barbassa, 2021).

Maintenance issues in drainage systems like encroachments by street vendors on drainage channels, accumulation of solid and liquid waste, and many more need immediate attention for flood mitigation (Charlesworth and Mezue, 2017). Economic instruments like insurance systems can improve community resilience, for which the enforcement of the system needs to be done by the local government (World Bank, 2008).

Case study: Nagpur, India

City profile

Nagpur, the fourth biggest city of Maharashtra State, is the Orange City and the Tiger Capital of India. The jurisdiction of NMC extends over an area of 225.08 km^2. with a population of about 22 lakhs. The Nagpur Metropolitan Development area is spread over 3,567.37 km^2. NMC has three rivers, the Nag River (15.73 km long), the Pili River (12.11 km long), and the Pora River (short length) passing through the city. They have their five nallahs, namely Chamar Nallah, Shakti Nagar Nallah, Hudkeshwar Nallah, Swawalabmi Nagar Nallah, and Shankar Nagar Nallah also flow through the city. Twelve lakes namely, Gorewada, Futala, Ambazari, Sonegaon, Sakkardara, Gandhisagar, Lendi Talao, Naik Talao, Dob Talao, Pandrabodi, Sanjay Nagar Khadan, and Pardi, cover an area of about 3.13 km^2. These water bodies are indicated in *Figure 2b*. Some of the lakes have been filled for development purposes, especially by slums. Intensive activities around the river bodies are also adversely affecting biodiversity.

Flooding in Nagpur City and region

According to (DDMA Nagpur, 2018) for Nagpur District:

The Nagpur district is mainly prone to floods drought, fire, and other hazards. It faces a significant risk of flooding during the monsoon season, primarily due to the presence of perennial rivers flowing through the district. Urban flooding in Nagpur city is largely stemming from inadequate sewerage systems and insufficient management of water flow. In rural regions, villages situated in low-lying areas near rivers are particularly susceptible to flooding during monsoons. From 1998-2018, there were seven major flood events, affecting approximately 13% of the population residing in flood-prone zones. Thus, Nagpur district and city face flooding as the main emergency chronically.

In the Nagpur Metropolitan Area, with changing climate and decreased water resource availability, water stress in the summer and flooding during the rainy season have become the new normal (Thapa et al., 2020). With the anticipated rise in monsoon

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rainfall by the 2030s and 2050s, the Konkan and Nagpur divisions get and are expected to receive more rainfall (Government of Maharashtra, 2020).

According to (MoUD, 2015) for Nagpur city:

The situation becomes most critical in the rainy season when these drains are flooded and water/wastewater enters into the nearby locality due to the unprotected edges of these rivers. Natural heavy rains and recent development activities that have damaged the natural drain pattern in the city resulted in water logging problems and incidents of flooding. Due to such incidents, the day-to-day activities of the people residing in affected areas get hampered. It was observed that many of the areas that are getting affected are low-lying areas and natural drain patterns. NMC identified water logging and flooding areas.

Nagpur city, the metropolitan area and the district have recently been facing flooding issues (Deshkar, 2019). Local floods during heavy downpours, notably in places next to river systems and low-lying areas, have become a recurrent feature of Nagpur (Deshkar, 2019). This is due to a significant increase in impervious zones from 2000-2012 from 0.9 to 34%. (Ansari et al., 2016). Due to rapid urban expansion and resulting alterations in land use, urban residents are experiencing heightened levels of air and water pollution, diminishing green spaces, more frequent instances of flash flooding due to expanded built-up areas, and the emergence of urban heat island effects. (Lahoti et al., 2019).

The Indian Meteorological Department (IMD) records daily rainfall, thus the severity of flash floods in urban areas gets diluted. For example, in 2018, 267.5 mm occurred in 6 h whereas the IMD reported it for 24 h. As the rainfall data portrays misleading figures, *Appendix 1* displaying actual figures and severity of rainfall events in Nagpur has been studied from new articles.

Every flood brings with it several damages, such as house submerged, house collapse, tree felling, walls breaking, persons injured, and deaths. According to the local news of Nagpur, on 23rd September 2023, four fatalities were recorded, and over 400 individuals were evacuated from their residences by rescue and relief teams. Approximately 10,000 houses were impacted. A bridge spanning the Nag River collapsed, obstructing a major city highway, while various sections of the Nag River's retaining wall also collapsed. The Disaster Management Cell of NMC records these incidents (DMC-NMC, 2022), as presented in *Figure 1* for Nagpur city. It has been observed in the Disaster Management Plans of Nagpur that they are focused on response mechanisms rather than mitigation. Thus, it requires some proactive measures to avoid catastrophes like 2013 and 2023.

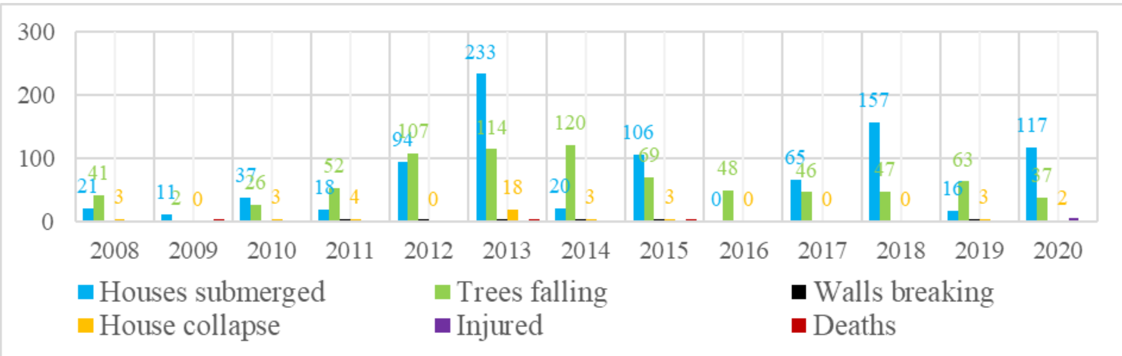

Figure 1. *No. of incidents due to heavy rainfall from June to October of each year 2008-2020 (Source: based on data available in (DMC-NMC, 2022))*

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Data collection, maps, and observations for differentiating factors in Nagpur

A comprehensive study of Nagpur was undertaken using data from diverse sources, including NMC, IMD, MRSAC, and the United States Geological Survey. Maps were crafted on ArcMap 10.8, encompassing maps of NMC boundary, watersheds, waterbodies, soil quality, drainage, satellite imagery (Ikonos, 1.5 m resolution), Digital Elevation Model (DEM), slope and landcover, reports including the Annual Disaster Events (for flood hotspots), Storm Water Drainage Plan (Nagpur) 2009 and Nagpur City Development Plan 2015, a list of open spaces, and rainfall patterns in NetCEF.

Nagpur, at an elevation of 319 m, faces environmental challenges such as air and water pollution, reduced green spaces, and heightened flood risks due to urban expansion (Lahoti et al., 2019). The contour map (*Fig. 2b*) indicates the slope from west to east. Its climate exhibits sub-tropical wet and dry conditions, marked by a substantial annual average rainfall of 1161.54 mm. June-September constitutes 90% of total annual rainfall, and the average daily rainfall in monsoon is 92 mm approximately. Spatial analyses on ArcMap 10.8 based on DEM delineate flood-prone areas, indicating coverage ranging from 12.22% to 52% (*Appendix 2*). Many of these areas do not coincide with the chronic flood hotspots *Figure 2a*, highlighting urbanization as the major cause of flooding.

The landcover map (based on Ikonos satellite imagery with 1.5 m resolution) and chart (*Fig. 2c, d*) indicate that over the last decade, there has been a reduction in open spaces and an increase in built from 59.02% in 2011 to 74.16% in 2022. Urbanization has led to a reduction in agricultural land by 5%, forests by 2%, wastelands by 7.2%, waterbodies by 0.75%, and wetlands by 0.3%, impacting the city’s flood resilience. The soil texture (*Fig. 2e, f; Table 1*) in Nagpur is clayey, with 35% to 75% clay content, classified in Group D by the United States Department of Agriculture with moderate to low infiltration characteristics.

Table 1. *Soil Quality, Nagpur (Source: MRSAC, 2023)*

Taxonomy	Depth	Texture	Erosion	Drainage	Temp regime	Area (km^2)
Clayey, Montmorillonitic, Typic Haplustepts	Moderately deep (25-50 cm)	Clayey	Moderate to severe	Moderately well drained	Hyper-thermic	1.082
Fine, Montmorillonitic, Chromic Haplusterts	Very deep (>100 cm)		None to slight	Well drained		11.669
Fine, Montmorillonitic, Typic Haplusterts			Slight to moderate	Moderately well drained		8.775
Fine, Montmorillonitic, Vertic Haplustepts		Silty clay loam	Moderate	Well drained		46.583
Habitation Mask	136.265					
Loamy, Montmorillonitic, Lithic Ustorthents	Shallow (10 to 25 cm)	Gravelly clay loam	Severe	Excessively drained	Hyper-thermic	1.494
Very fine, Montmorillonitic, Udic Haplusterts	Very deep (>100 cm)	Clayey	None to slight	Somewhat imperfectly drained		1.708
Waterbody Mask	3.663					

Nagpur’s annual groundwater supply is more than 25 million m^3, with less than 2 m below ground level (bgl) of water present in the aquifer in the city’s central sections during both seasons. The majority of the city is located in a zone with water levels below 4 m bgl (NEERI, 2019). A study by NEERI (2019) concluded that even if the rainfall, the GWL decreases due to a lack of groundwater recharge and high extraction of groundwater

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even with high rainfall. The water demand is projected to increase exponentially with vast developmental activities and population growth, necessitating prioritizing the use of groundwater sources for potable or non-potable usage (Deshkar, 2019).

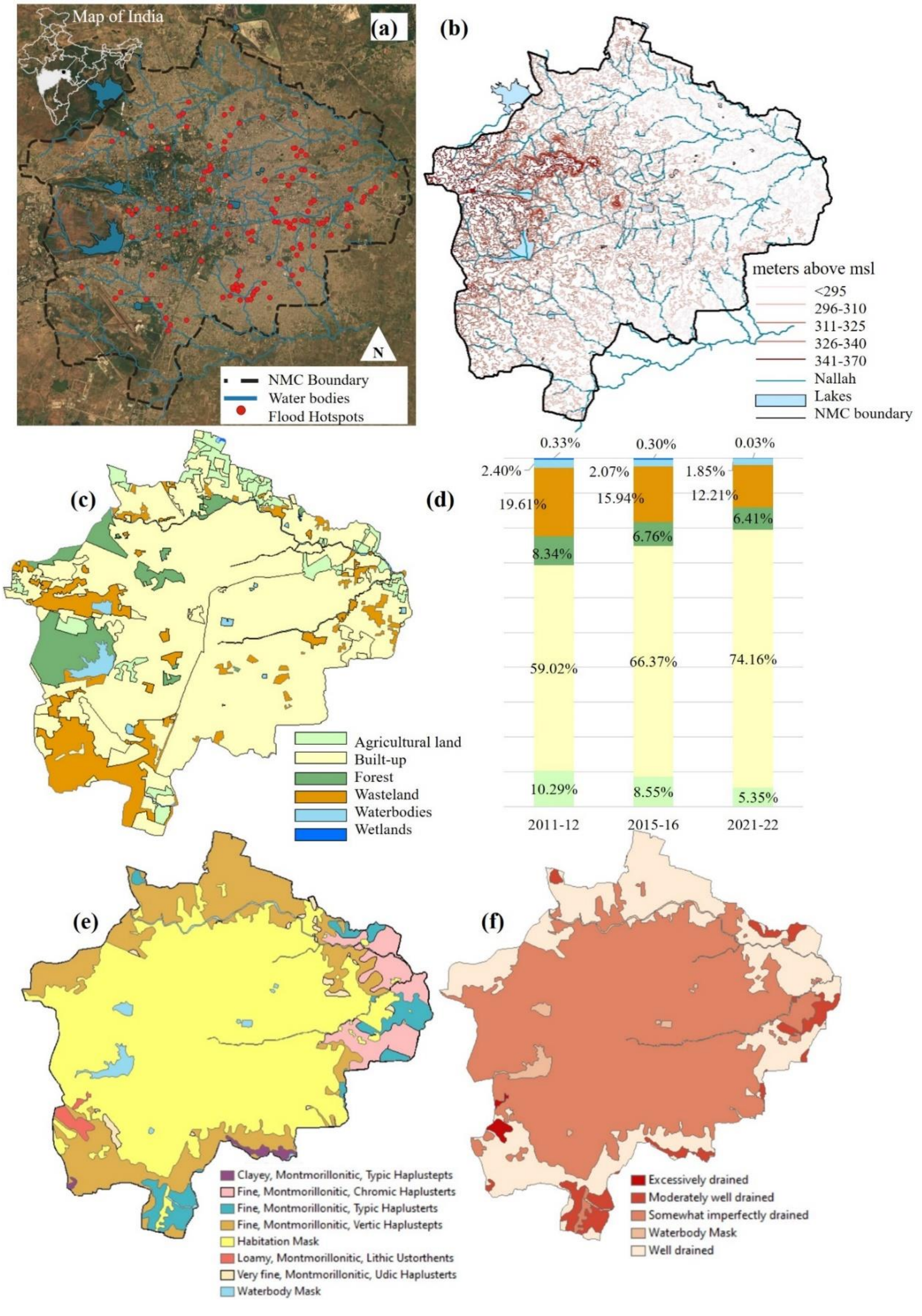

Figure 2. *(a) Locational setting of Nagpur. (b) Slope, Nagpur. (c) Landcover, Nagpur 2021-22. (d) Change in landcover. (e) Soil texture. (f) Soil drainage, Nagpur*

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Localized flooding during periods of heavy rain, particularly in low-lying areas and places along river channels, has become a common occurrence in Nagpur city. Flash floods and extreme water scarcity are two water-related calamities that Nagpur has been especially susceptible to Deshkar (2019). The partially combined drainage and sewage system leads to backflushing and blockages during heavy rains (MoUD, 2015).

Nagpur faces chronic water scarcity characterized by inadequate availability and poor water quality, a problem persisting during both monsoon and summer seasons (Deshkar, 2019). 85% of Nagpur is covered with piped water supply, with 103 liters per day per day, necessitating dependence on groundwater. The population density has also increased in Nagpur (MoUD, 2015). Nagpur has 446 slum pockets, mostly situated in low-lying areas, lacking basic infrastructure facilities (MoUD, 2015), indicating fragile socio-cultural settings. Nagpur faces elevated pollution levels due to domestic and industrial wastes (MPCB, 2011).

Nagpur struggles with inadequate funds for operation and maintenance, prompting investments in water supply projects, often with support from the World Bank and other organizations (Ranade and Katpatal, 2015). Nagpur encounters a lack of technical expertise (Gaurkhede and Adane, 2023) for disaster planning. Critical urban-level maps, including infrastructure, land use, slums, and disasters, are either not prepared or not readily available in GIS. Addressing water-related infrastructure in Nagpur necessitates a multi-level governance approach (Thapa et al., 2020). The city has a strong political backing but the absence of a plan for the drainage system indicates the lack of its importance for the bureaucrats.

Proposed simplified method for the application of SuDS in Nagpur

SuDS has a wide range of solution options ranging from source to site to regional control. The design and implementation of SuDS in Nagpur will have to include the considerations and background discussed in the previous sections. As there are increased frequencies of floods and droughts, water harvesting structures (Maurya et al., 2023) can be a worthwhile investment for local governments (Ranade and Katpatal, 2015). Thus, this study suggests constructing infiltration and water retention areas at various locations in the city. Nagpur, like other cities in developing counties, has high land values, and the land procurement process, even for public benefit is a tedious and expensive task. Hence, it becomes a deterring factor for government organizations, planners, and engineers to come up with solutions to handle these disasters. This study proposes the SuDS interventions in urban green spaces (UGS).

Groundwater resources are available in the north-eastern part of the city and can be used as supplementary water sources (NEERI, 2019). Considering the shortage of water in summer and in the suburbs of cities, it is necessary to pay attention to the use of groundwater resources (NEERI, 2019). The annual runoff generated in Nagpur is 5993 kiloliters (KL) considering the average rainfall.

Nagpur has 135 parks and gardens covering an area of about 3.51 km^2 (MoUD, 2015). Lahoti et al. (2019) have categorized UGS of Nagpur into five typologies: (1) recreational spaces including parks, gardens, playgrounds, lakes, and forests; (2) open spaces including rivers; (3) public institutionalized including government institutions; (4) infrastructure and Utility Corridor including road networks; and (5) vacant land in peripheries. A map of open spaces (*Fig. 3a*) has been prepared by combining a land

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map from MoUD (2015), a UGS map from Lahoti et al. (2019), and Ikonos satellite imagery procured from MRSAC with 1.5 m resolution from 2022.

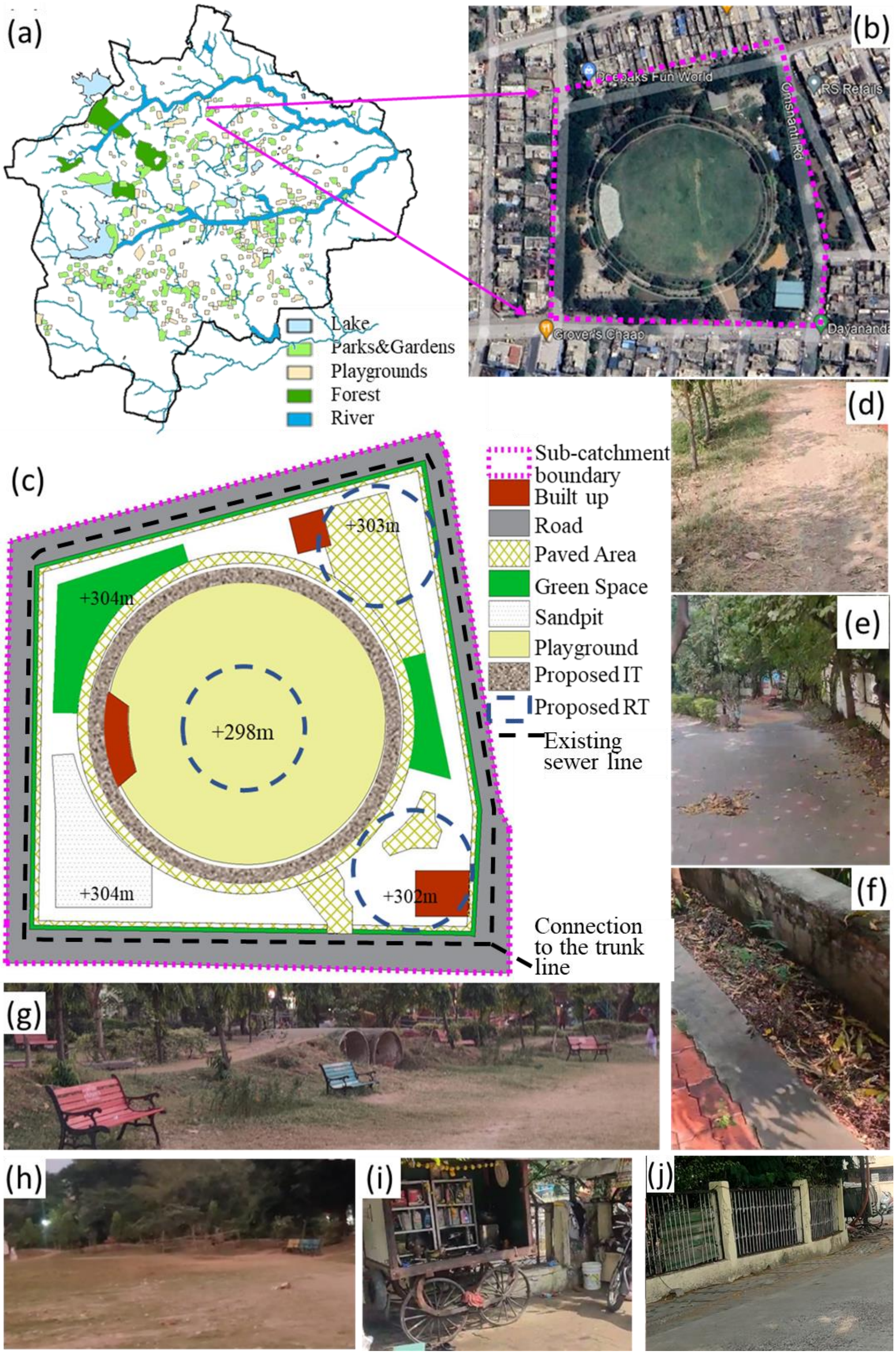

Figure 3. *(a) Open spaces, Nagpur. (b) Location of DP. (c) Landcover of DP. (d) Unpaved track. (e) Paved track. (f) Paved walking track and surrounding semi-pervious area. (g) Level difference of playground with the rest of the park. (h) Playground. (i) Vendor encroachment and (j) sewer line along the catchment road coverage*

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Case study: Dayanand Park (DP), Nagpur

The northeast part (low-lying) of the city, near Chamar Nala, a tributary of the Pili River has several flood-prone areas. Thus, Dayananda Park in the northern part of the city (*Fig. 3b*), listed as a major park by the Gardens Department of NMC, has been considered for the design of the retention area for this study. DP (21°11’3.60” N, 79°5’24.61” E) in Nagpur covers an area of 27600 m^2, including the adjoining roads on all four sides. The locality of the park has an existing combined sewage/drainage line along the surrounding road and has perforated cement covers on them (*Fig. 3j*). This line collects wastewater from the surrounding residential area and has an outlet towards the south-eastern corner.

The water retention structure has been proposed in the center at the lowest point of the park. It will require water intel points such as grating to feed the underground tank. An infiltration trench has been planned at a level higher than the retention, along an existing pathway. The supporting runoff supply and partial infiltration systems that can be proposed in and around the park such as footpaths, along jogging tracks.

In this study, two approaches have been made, one approach is the rational method which supports in the calculation of the size proposed SuDS (*Table 2*). The rational method (*Eq. 1*) of runoff has been used in this study to calculate the size of interventions for harvesting.

$$\text{Runoff (m}^3\text{/year)}, \; \boldsymbol{Q = C.I.A} \tag{Eq.1}$$

where C is the runoff coefficient which is a constant for a particular landcover, I is the rainfall intensity (rainfall per year) in m/h and A is the area of the sub-catchment in m^2.

Thus, for a 3-m deep retention tank (RT) in clayey soil, the area required for retention will be around 1645 m^2. which is 5.81% (blue circle in *Fig. 3c*) of the total area of the park. For the infiltration trench (IT) to work, the peak rainfall for Nagpur can be assumed to be 95 mm/h. Thus, the area required for any infiltration structure is 202 m^2. covers only 0.71% (brown grains *Fig. 3c*) of the park area.

Table 2. *Size of SuDS intervention as per the rational method*

Proposed SuDS intervention	C (for parks)	I (m/h)	A (m^2)	Q (m^3/year) (KL/h)	Proposed structure	
					Depth (D) (m)	Area (m^2) (Ai. = Q.D)
RT	0.15	1.161 (total)	28328	4936	3	1645
IT	0.15	0.095(peak)	28328	404	2	202

The SWMM input data for simulations in the software include landcover area distribution (*Table 3*), the catchment properties (*Table 4*), rainfall intensity for return periods of two, five, ten, 25, and 100 years (*Table 5*), and the properties of proposed SuDS structures (*Table 6*). The proposed input for RT is based on Ballard et al. (2015), Guan et al. (2015), Rossman (2015), and Taji and Regulwar (2021). The proposed input for IT is based on Ahmed et al. (2017), Ballard et al. (2015), Goncalves et al. (2018), Rossman (2015) and Song and Chung (2017).

Rainfall-runoff simulations were carried out for four scenarios for DP i.e., first with IT only, second with RT only, third with both RT and IT, and fourth with IT and three RT structures. As the fourth scenario is the largest SuDS in size, it is expected to have the best results. It has a maximum runoff reduction of almost 43% (*Fig. 4*) and the

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runoff coefficient (*Fig. 5*) reduces from 0.984 to 0.561 for a 100-year return period. IT performs better in terms of reduction in runoff as compared to RT. This could be due to the functional difference between the two where the RT scenario is trying to keep maximum rainwater for collection instead of letting it infiltrate.

Table 3. *Landcover area distribution, DP sub-catchment, Nagpur*

Area of	**m^2**	**Surface (*Fig. 3d-h*) consideration as**
Sub-catchment	27,621	-
Built up	826	Impervious
Road	5,912	Impervious
Paved area	3,733	50% pervious + 50% impervious (assuming)
Green space	2,170	Pervious
Sandpit	1,107	Pervious
Playground	7,279	50% pervious + 50% impervious (assuming)
Leftover space/planned unplanned	6,594	50% pervious + 50% impervious (assuming)

Table 4. *Defining the DP catchment*

Property	**Value**	**Description**
Width	117.04	Width of the overland flow path (m)
% slope	0.85%	Average surface slope %
% imperv	56%	% of impervious area
N-imperv	0.012	Manning’s N for impervious area
N-perv	0.025	Manning’s N for the pervious area
Dstore-Imperv	1.5	Depth of depression storage on impervious area (mm)
Dstore-Perv	7.6	Depth of depression storage on the pervious area (mm)
%Zero-Imperv	25	% of the impervious area with no depression storage
Subarea Routing	Pervious	Choice of internal routing between pervious and impervious areas
Percent Routed	100	% of runoff routed between sub-areas
Infiltration Data	HORTON	Infiltration parameters (drop-down and editable)

Table 5. *Rainfall intensity (mm/h) for various return periods (RP) and duration as per Gumbel’s extreme value*

Time in minutes	**Rainfall intensity (mm/h)**				
	RP 2 years	**RP 5 years**	**RP 10 years**	**RP 25 years**	**RP 100 years**
15	99.94	119.88	137.56	165	217.27
30	62.82	75.35	86.46	103.71	136.56
45	47.87	57.42	65.89	79.04	104.07
60	39.48	47.36	54.34	65.18	85.83
75	34.085	40.88	46.91	56.265	74.09
90	30.09	36.09	41.41	49.67	65.41
105	27.17	32.59	37.395	44.86	59.065
120	24.81	29.76	34.15	40.97	53.94

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Table 6. *Properties of proposed infiltration trench and retention tank*

Layers	Component	IT	RT
Surface	Berm height (mm)	150	N/A
	Vegetation volume fraction	0	
	Surface roughness (Manning's n)	0.013	
	Surface slope (percent)	5	
Storage	Barrel height (mm)	N/A	3000
	Thickness (mm)	750	N/A
	Void ratio (voids/solids)	0.4	N/A
	Seepage rate (mm/hr)	210	N/A
	Clogging factor	0	N/A
Drain	Flow coefficient	0	4.56 (calculated)
	Flow exponent	0.5	0.5
	Drain delay (h)	N/A	6 (standard)
Planning parameters	Area of each unit (m^2)	1830.45	1645
	No. of units	1	1 for the second and third scenario
			3 for the fourth scenario
	Surface width per unit (m)	1	42.5
	% of impervious area treated	11.78%	5.29%
	% of pervious areas treated	0	6.81%

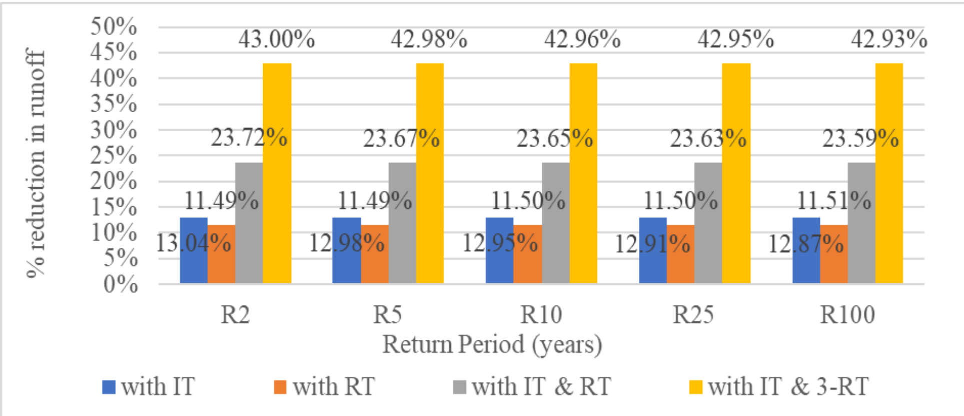

Figure 4. *Simulation results for percentage reduction in runoff*

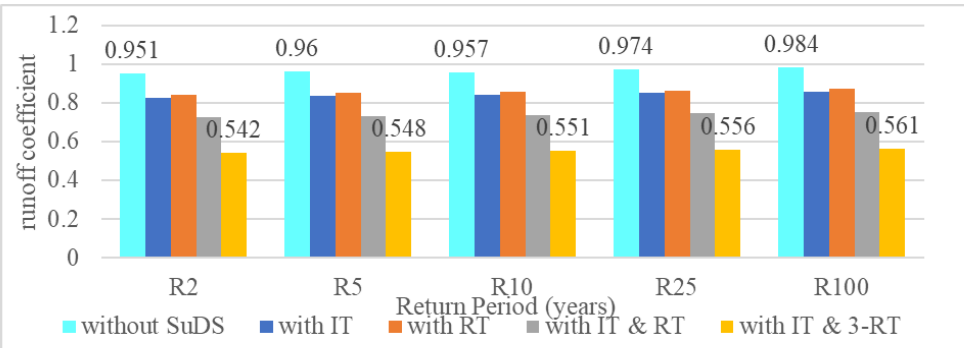

Figure 5. *Simulation results for runoff coefficient*

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Infiltration increases maximum, up to 752% for a 2-year return with IT only but it increases by only 6% in RT-only installation, as the rainwater is meant for collection and not for infiltration (*Fig. 6*). With the third scenario, a combination of RT and IT, infiltration is increased by 723%, and with the fourth scenario, it is up to 665% for a 2-year return.

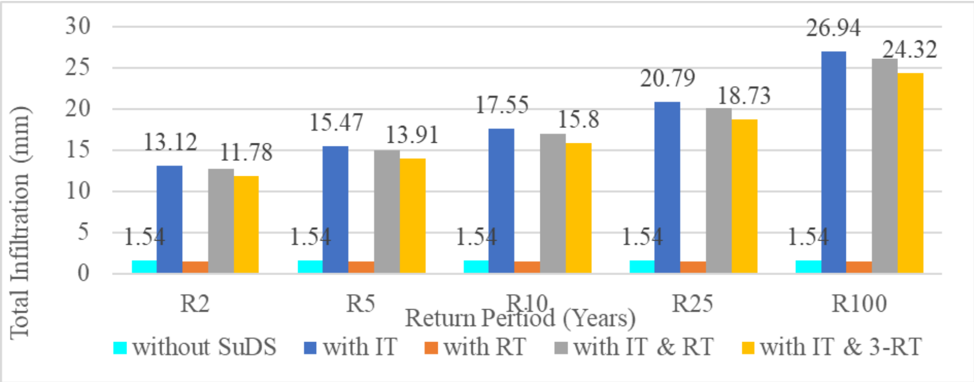

Figure 6. *Simulation results for total infiltration*

Considering the infiltration of stormwater for groundwater recharge, the reduction in runoff in the catchment, and the creation of a water bank for summer months, SuDS installations can be carried out. This will reduce the load of water procurement on the park maintenance vendor appointed by NMC. These parks are surrounded by street vendors (*Fig. 3i*, living in nearby slums, which can be formalized as a community by the government. These vendors, as they will benefit from the increased footfall in a greener garden, can contribute towards building these infrastructures. Another option can be building one retention tank (covered in the center) and two retention ponds for increasing visitors.

Discussion and suggestions

The idea of sustainable drainage systems in developing countries has been introduced two decades back. For the first decade, developing countries were coping with the global economic meltdown and thus, did not focus on the disaster risk profile of their area. SuDS has not been experimented upon on a full scale in tropical/sub-tropical climates. Certain countries that have implemented a version of SuDS in trial scales have failed to address the socioeconomic and governance factors (Vasconcelos and Barbassa, 2021).

In the past decade, the need for SuDS in tropical developed countries started gaining importance like Singapore, Japan, etc. Taking them as examples China started its ambitious sponge city program in 2014 (Lashford et al., 2019). The scale of implementing SuDS in China inspired other developing countries to explore the idea of SuDS. This has led to small interventions in a few Indian cities, but a holistic vision for integrated water management is still missing in developing countries. Integrated water management is of high importance in these countries, as they have a dual situation of flood and drought in the same area (Chan et al., 2018).

In India, disaster resilience is a difficult task as most of the cities are not equipped to handle disasters of any kind (Gaurkhede et al., 2021). The large urban areas are a result

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of poor planning (due to piecemeal planning), and little/no consideration for natural water resources, drainage, surrounding development, and open spaces (Parkinson et al., 2007). The natural sponges of cities like waterbodies and open spaces are not being taken up for planned development (SEEDS and CRED, 2018).

The paper highlights the key findings as the differentiating factors for considerations in designing SuDS in developing countries. A simplified methodology to implement SuDS in public parks has been displayed in this paper. Infrastructure Planners should work in coordination with landscape designers to incorporate various SuDS components in public parks. Bioretention areas and detention basins can also be good options for a slower release of water into the surrounding natural and manmade drainage system and recharging the ground.

The SuDS Manual highlights that all urbanization processes are the same in all countries including tropical countries, however, each country has various ways of approaches to their mitigation strategies that suit their specific conditions (Ballard et al., 2015). This has led to four prescriptive non-structural measures for flood and drought mitigation:

(a) Land use and infrastructure planning

Understanding the spatial scale of disasters through land use mapping (Hagen and Lu, 2011; Singkran and Kandasamy, 2016) is the most important step in disaster management planning. This needs to be followed up with spatial overlapping of these disaster-prone areas and identifying the most critical ones. The initial analysis can be made using freely/easily available spatial data sources like the EarthExplorer, Google Earth, Bhuvan, Geological Survey of India, and many more. This will enable faster mapping of further datasets. Urban local bodies can hire research institutes (Smedema and Ochs, 1998) (located close by but of national standing) to carry out such works.

The vulnerable areas should become a part of the development plans and infrastructure plans (Sörensen et al., 2016). They should not be used in isolation in disaster management plans. A comprehensive development plan for all cities, irrespective of their disaster status needs to be prepared. The output of these development plans should be the regulations and by-laws for different authorities and the public to follow (Tingsanchali, 2012).

(b) Public participation

Disaster risk mapping of identified areas can be done with the community, to ensure the inclusion of micro hotspots into planning (Sörensen et al., 2016). The development plans should involve the locals (Mashi et al., 2020), from the very beginning of the planning process (Charlesworth and Mezue, 2017). An updated map of slums, the most vulnerable areas in any city with high built density (Neil et al., 2014) needs to be prepared. This can lead to possible SuDS options with minimum interventions to prevent them from chronic submergence. Community participation is inevitable in slums; thus, they should be involved in the building, operation, and maintenance of the infrastructure systems (Neil et al., 2014) through awareness campaigns.

Blocked drains are a major cause of flooding in developing countries. Creating simple boulder paths and roads for water can reduce runoff and pollutant load in the drainage system (Chen et al., 2021). Solid waste management, Community-level cleanliness awareness, and drives can help reduce the blocking of drains (Tingsanchali, 2012).

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(c) Proper utilization of public resources

Stormwater detention and retention measures are vital for the mitigation of floods, recharging groundwater, and collecting surface water. SuDS has a management train that includes the entire path of rainwater management. The options of management trains can be simulated in hydrological models to understand their benefits profile.

Rejuvenation of water bodies through the creation of SuDS around them can enhance the amenity value of any area and further increase the land value of surrounding properties (Ballard et al., 2015). The first step for this would be the disconnection of direct sewage system discharge into the water bodies.

The availability of land for sustainable infrastructure development is one of the key concerns (Ekeu-wei and Blackburn, 2018). Converting green space into storage space is an effective method for multi-functional stormwater storage in high-density built-up areas. To maximize the runoff control effect of multi-functional rainwater storage space, selecting a good location is a crucial issue in the construction of a sponge city (Jing et al., 2022). Government and public-owned land areas like parks, playgrounds, vacant land, etc., and buildings like offices, institutes, and residential areas can be put to use for SuDS pilot projects.

(d) Good governance

Governance and politics are crucial for citizens demanding infrastructure facilities from ULBs and politicians. Private developers should provide land and costs associated with SuDS construction under government guidance (Charlesworth and Mezue, 2017). Incentivization can be provided in exchange for an increased built-up area in exchange for SuDS infrastructure. Awareness campaigns for source water control and usage should be proposed, and incentives for rainwater storage at households, housing corporations, and community levels should be proposed.

Based on these differentiating factors, a comprehensive national guideline to design and implement SuDS can be prepared by the National Public Health Engineering Department. It will be a planning and economic mobilization guide for the ULBs and citizens in selecting SuDS for their developments.

The criteria for the selection of SuDS for implementation may vary city-wise. For selected city of Nagpur, includes flood mitigation capabilities, water collection and recharge, climatic consideration, retrofitting potential, land availability, ease of implementation, adaptability, and public acceptance. The water collected can also be connected to the nearby water reservoir with existing water treatment facilities, like in the case of Singapore. After monitoring the results of these constructions in public parks for a few seasons, SuDS can be implemented in other government-owned land parcels and buildings.

Conclusion

Based on the above calculations, if rainwater harvesting structures are created in all the listed parks by the NMC, 69806 KL of water can be collected annually from 5.8% of 0.40 km^2. of total park areas. MoUD (2015) mentioned in their report that the development and maintenance of green spaces and roadside plantations especially in summer becomes an issue. This water can be utilized to maintain the greenery of Nagpur

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and help in its upgradation from the second greenest city to the first in India. Intervention calculations for the parks maintained by the NMC are provided in *Appendix 3*.

The proposed SuDS solutions of retention and infiltration have proven useful through simulations for the selected site, considering conditions. These solutions are cost-effective and be implemented in any public park. The study has highlighted the scenario of floods around the world, in India and the case study area of Nagpur. The study contributes towards highlighting the need for sustainable drainage systems in developing countries, and the identification of differentiating factors that will be the guiding factors for planning and implementation of SuDS in developing countries. The study gives a simplified method for the application of SuDS through a case study of Nagpur city in India, which faces both flood and water scarcity problems in summer as well as rainy seasons.

One of the major challenges in developing areas is the lack of availability of data to assess the severity of a calamity, for example, data for natural and manmade drainage systems useful for planning flood-related infrastructure and resilience building. Coastal Indian cities have started gaining importance in terms of the mapping of infrastructure and its further planning. Urban flooding in inland cities is yet to gain importance in India, especially due to the lack of existing data, expertise, time, and funds for infrastructure development.

The dataset prepared for the study used the maximum of freely available data and readily available GIS software. The method of identification of potential areas for handling disasters can be used by infrastructure/city planners, without the help of any other specialists, to plan for such areas in the city, ultimately making the city safe. The study handles the problem of flooding and provides potential solutions for water scarcity simultaneously for integrated water design.

The solution considers governance factors to implement the project, through the proper selection of SuDS components and their location. This model can be scaled and replicated in other cities with disaster risks in developed and developing countries. Some Indian cities facing similar issues as Nagpur are Kolhapur, Amravati, Bangalore, Lucknow, Indore, Guwahati, etc. This ideal solution will encourage city planners, engineers, and landscape architects to include disaster considerations in land use planning, infrastructure design, transportation planning, etc. The myth that anything sustainable is expensive, difficult to implement, and maintain can be broken through this simplified system of implementation of sustainable drainage systems.

The study suggests the future area of research as (a) mapping of disaster-prone areas for each disaster individually and then overlapping them. This can lead to the identification of immediate action points. This can be done by appropriate selection of parameters for each disaster, which can be easily mapped, through freely or easily available data (b) alternatively, a watershed level vulnerability analysis of cities can be carried out (c) disaster management planning should be incorporated in all master plans irrespective of the scale of disasters in any city (d) simulations to identify the best SuDS management trains for maximum water storage.

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APPENDIX

Appendix 1. *Rainfall data for various years as per news articles*

Year	Rainfall data	Source
1994	Highest 24-h rain record of 304 mm, was on 12 July 1994	https://www.firstpost.com/india/maharashtras-nagpur-records-265-mm-of-rainfall-in-nine-hours-several-localities-flooded-heavy-rain-expected-today-too-4685421.html
2013	144.6 mm daily rainfall	District Disaster Management Plan
2015	250 mm in 36 h	https://floodlist.com/asia/india-floods-5-dead-nagpur-maharashtra
2015	790.07 mm of rain during the season and 163 mm daily rainfall	https://www.rediff.com/news/report/pix-heavy-rains-leave-nagpur-in-a-watery-mess/20150814.htm
2018	267.5 mm rainfall in 6 h	https://www.thehindu.com/news/national/other-states/nagpur-receives-highest-rainfall-in-24-years/article24355038.ece
2023	119.5 mm in 24 h	https://timesofindia.indiatimes.com/city/nagpur/unprecedented-rainfall-but-it-wasnt-a-cloudburst/articleshow/103895455.cms

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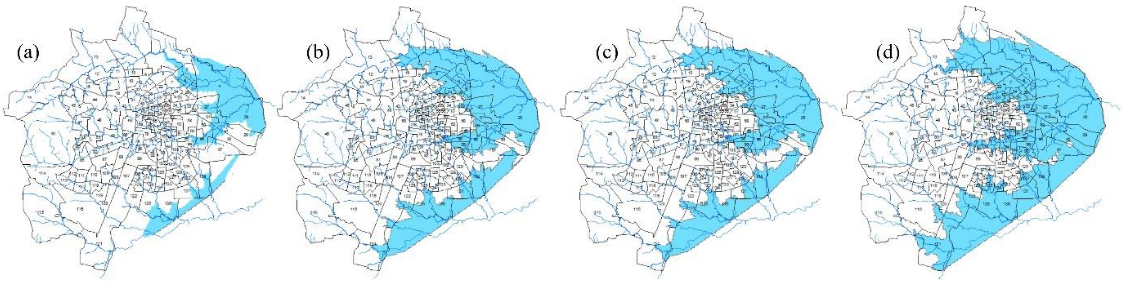
Appendix 2. *Spatial simulation on ArcMap 10.8 based on DEM*



Appendix 3. *List of parks with infiltration and retention structures*

(a) Calculation of area for infiltration structures for all parks and playgrounds under Gardens Department, NMC							
S. No	**Name of the park**	**Runoff coefficient (C)**	**Rainfall/ year (I)**	**Area of the park (A)**	**Runoff (m^3/year) (Q = C.I.A)**	**Depth of structure (D)**	**Area of proposed structure (Ai. = Q.D)**
		For parks	**m/h**	**m^2**	**KL/h**	**m**	**m^2**
1	Sant. Dyaneshwar Sanjiwan Samadhi Udyan, Dattatraynagar	0.15	0.095	36422	519	2	260
2	Mahatma Phule Udyan, Suyognagar	0.15	0.095	34398	490	2	245
3	Rajiv Gandhi Udyan, Trimurti nagar	0.15	0.095	32375	461	2	231
4	Dr. Babasaheb Ambedkar Udyan, Sakkardara	0.15	0.095	32375	461	2	231
5	Dayanand Park, Jaripatka	0.15	0.095	28328	404	2	202
6	Lata Mangeshkar Udyan, Vaishali Nagar	0.15	0.095	26305	375	2	187
7	Sant Tukaram Udyan, Sakkardara	0.15	0.095	24281	346	2	173
8	Swatantrya Swarn Jayanti Udyan Deshpande Layout	0.15	0.095	14164	202	2	101
9	Banerjee Layout	0.15	0.095	8094	115	2	58
10	Deekshabhoomi	0.15	0.095	8094	115	2	58
11	Ramkrishna Nagar	0.15	0.095	8094	115	2	58
12	Binaki - HUDCO	0.15	0.095	7082	101	2	50
13	Chhatrapati Nagar	0.15	0.095	7082	101	2	50
14	Friends Colony	0.15	0.095	7082	101	2	50
15	New Subhedar Layout	0.15	0.095	6880	98	2	49
16	Sahakar Nagar	0.15	0.095	6394	91	2	46
17	Telecom Nagar	0.15	0.095	6354	91	2	45
18	Hiwari Nagar	0.15	0.095	6070	87	2	43
19	Laghuwetan Colony	0.15	0.095	5059	72	2	36
20	Bhagwan Nagar	0.15	0.095	5059	72	2	36
21	Gurudwara, Ashok Nagar	0.15	0.095	5059	72	2	36
22	Kukde Layout	0.15	0.095	5059	72	2	36
23	Gajanan Prasad, Wadi.	0.15	0.095	5059	72	2	36
24	Angulimal nagar	0.15	0.095	5059	72	2	36
25	Hill Top Layout	0.15	0.095	4856	69	2	35
26	Ashirwad Nagar	0.15	0.095	4047	58	2	29
27	Mahal Nagar	0.15	0.095	4047	58	2	29
28	Sandal Nagar	0.15	0.095	4047	58	2	29
29	Lashkaribagh	0.15	0.095	4047	58	2	29

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30	Raghuji Nagar	0.15	0.095	4047	58	2	29
31	Adivasi Lay-out	0.15	0.095	4047	58	2	29
32	Sadbhawana Nagar	0.15	0.095	4047	58	2	29
33	Kabir Nagar	0.15	0.095	3035	43	2	22
34	Udhay Nagar	0.15	0.095	2023	29	2	14
35	SaraiPeth	0.15	0.095	1895	27	2	14
36	Shankar Nagar	0.15	0.095	8954	128	2	64
37	Panchadeep	0.15	0.095	1653	24	2	12
38	P.M.G. Narendra Nagar	0.15	0.095	4309	61	2	31
39	Shastri Nagar	0.15	0.095	2831	40	2	20
40	Tapowan	0.15	0.095	1821	26	2	13
41	Kukreja Nagar	0.15	0.095	1619	23	2	12
42	Urvella Society	0.15	0.095	1619	23	2	12
43	Ambazari Basti Precinct	0.15	0.095	1619	23	2	12
44	Ujjwal Nagar	0.15	0.095	1619	23	2	12
45	Shiv Nagar	0.15	0.095	1619	23	2	12
46	Hill Top Layout	0.15	0.095	1012	14	2	7
47	Laxmi Nagar	0.15	0.095	809	12	2	6
48	Bezonbagh	0.15	0.095	809	12	2	6
	Total	-	-	400653	5709	-	2855

(b) Calculation of area for retention structures for all parks and playgrounds under the Gardens Department, NMC

S.No.	**Name of the park**	**Runoff coefficient (C)**	**Rainfall/ year (I)**	**Area of the park (A)**	**Runoff (m^3/year) (Q = C.I.A)**	**Depth of structure (D)**	**Area of proposed structure (Ai. = Q.D)**
		For parks	**m/year**	**m^2**	**KL/year**	**m**	**m^2**
1	Sant. Dyaneshwar Sanjiwan Samadhi Udyan, Dattatraynagar	0.15	1.16154	36422	6346	3	2115
2	Mahatma Phule Udyan, Suyognagar	0.15	1.16154	34398	5993	3	1998
3	Rajiv Gandhi Udyan, Trimurti nagar	0.15	1.16154	32375	5641	3	1880
4	Dr. Babasaheb Ambedkar Udyan, Sakkardara	0.15	1.16154	32375	5641	3	1880
5	Dayanand Park, Jaripatka	0.15	1.16154	28328	4936	3	1645
6	Lata Mangeshkar Udyan, Vaishali Nagar	0.15	1.16154	26305	4583	3	1528
7	Sant Tukaram Udyan, Sakkardara	0.15	1.16154	24281	4231	3	1410
8	Swatantrya Swarn Jayanti Udyan Deshpande Layout	0.15	1.16154	14164	2468	3	823
9	Banerjee Layout	0.15	1.16154	8094	1410	3	470
10	Deekshabhoomi	0.15	1.16154	8094	1410	3	470
11	Ramkrishna Nagar	0.15	1.16154	8094	1410	3	470
12	Binaki - HUDCO	0.15	1.16154	7082	1234	3	411
13	Chhatrapati Nagar	0.15	1.16154	7082	1234	3	411
14	Friends Colony	0.15	1.16154	7082	1234	3	411
15	New Subhedar Layout	0.15	1.16154	6880	1199	3	400
16	Sahakar Nagar	0.15	1.16154	6394	1114	3	371
17	Telecom Nagar	0.15	1.16154	6354	1107	3	369
18	Hiwari Nagar	0.15	1.16154	6070	1058	3	353
19	Laghuwetan Colony	0.15	1.16154	5059	881	3	294
20	Bhagwan Nagar	0.15	1.16154	5059	881	3	294
21	Gurudwara, Ashok Nagar	0.15	1.16154	5059	881	3	294

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22	Kukde Layout	0.15	1.16154	5059	881	3	294
23	Gajanan Prasad, Wadi.	0.15	1.16154	5059	881	3	294
24	Angulimal Nagar	0.15	1.16154	5059	881	3	294
25	Hill Top Layout	0.15	1.16154	4856	846	3	282
26	Ashirwad Nagar	0.15	1.16154	4047	705	3	235
27	Mahal Nagar	0.15	1.16154	4047	705	3	235
28	Sandal Nagar	0.15	1.16154	4047	705	3	235
29	Lashkaribagh	0.15	1.16154	4047	705	3	235
30	Raghuji Nagar	0.15	1.16154	4047	705	3	235
31	Adivasi Lay-out	0.15	1.16154	4047	705	3	235
32	Sadbhawana Nagar	0.15	1.16154	4047	705	3	235
33	Kabir Nagar	0.15	1.16154	3035	529	3	176
34	Udhay Nagar	0.15	1.16154	2023	353	3	118
35	SariPeth	0.15	1.16154	1895	330	3	110
36	Shankar Nagar	0.15	1.16154	8954	1560	3	520
37	Panchadeep	0.15	1.16154	1653	288	3	96
38	P.M.G.Ravindra Nagar	0.15	1.16154	4309	751	3	250
39	Shastri Nagar	0.15	1.16154	2831	493	3	164
40	Tapowan	0.15	1.16154	1821	317	3	106
41	Kukreja Nagar	0.15	1.16154	1619	282	3	94
42	Urvella Society	0.15	1.16154	1619	282	3	94
43	Ambazari Basti Precinct	0.15	1.16154	1619	282	3	94
44	Ujjwal Nagar	0.15	1.16154	1619	282	3	94
45	Shiv Nagar	0.15	1.16154	1619	282	3	94
46	Hill Top Layout	0.15	1.16154	1012	176	3	59
47	Laxmi Nagar	0.15	1.16154	809	141	3	47
48	Bezonbagh	0.15	1.16154	809	141	3	47
	Total	-	-	400653	69806	-	23269

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