Socio-Ecological Landscapes: A Mixed Methods Approach to Studying Urban Floods in Bengaluru, India

By

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List of Acronyms and Abbreviations

ArcGIS	Geographic Information system developed by ESRI
BBMP	Bruhat Bengaluru Mahanagar Palike
BDA	Bengaluru Development Authority
BMA	Bengaluru Metropolitan Authority
BSR	Block Shape Regularity Index
BSU	Block size uniformity index
BWSSB	Bengaluru Water Supply and Sewerage Board
CN	Curve Number
DAPP	Dynamic Adaptive Policy Pathways
DEM’s	Digital Elevation Model
DPR	Detailed Project Report
ENVI	Image analysis software developed by Harris Geospatial Solutions
EUDASM	European Digital Archive of Soil Maps
KC watershed	Koramangala Challaghatta Watershed
KSNDMC	Karnataka State Natural Disaster Monitoring Centre
KTCP Act	Karnataka Town and Country Planning Act
LDA	Lake Development Authority
LPA	Local Planning Area
MLA	Member of Legislative Assembly
MPA	Mean Patch area
MPAR	Mean Perimeter Area Ratio
NDMA	National Disaster Management Authority
NGT	National Green Tribunal
NumP	Number of Patches
PIL	Public Interest Litigation
PLU	Proposed Land-Use
RCDP	Revised City Development Plan
RMP 2015	Revised Master Plan 2015
RWH	Rain Water Harvesting

SDG	Sustainability Development Goals
SDI	Street Density Index
SLB	Street Level Bureaucrats
STP	Sewage Treatment Plant
SWMM	Storm Water Management Model
USDA	United States Department of Agriculture
USGS	United States Geological Survey

1. Introduction

The city of Bengaluru has been witness to the phenomenon of urban flooding every alternate year since 2005.Situated in the heart of southern India, Bengaluru is the fastest-growing metropolis approaching a population of 12.34 million. Situated at an elevation of 920m above sea level, the city is perched at one of the highest elevations in the Deccan plateau and about 225 kms from the closest perennial water source, the Cauvery River. Given its elevated geography, the phenomenon of flooding is one that is highly unlikely to occur and yet has been crippling the city quite frequently in the past two decades.

A large part of understanding the production of urban floods in Bengaluru lies in how the land use-hydrology nexus has morphed to restructure the hydrology of the urbanized watershed. From the lakes and channels built by the Wodeyars in 1800 to the residential layouts and public amenities that sit on historical lake beds, the ongoing practice to restrict hydrologic flows as development occurs has been an ongoing practice (Nair,2005; Ranganathan,2015; Unnikrishnan and Nagendra,2014). Where the city stands today is a landscape of diminished lakes, increased urban land use and encroached channels that have been linked to the production of urban floods by various studies. Lakes in Bengaluru city have decreased in its spatial extent by 17% from 1960 to 2012 (Prasad and Narayanan,2016) and urbanization has led to an increase in impervious areas accounting for increased runoff and peak flows(Nagendra,2012).

As planning practice has tried to discipline and formalize regulations around conserving ecology and hydrology of the city, increasing instances of deviation from those regulations have been noted by various scholars (Sundaresan,2013;Pellicherry et al,2016). These deviations or irregularities in planning the city have created a policy-implementation gap of which urban floods are a clear consequence. Often entire residential layouts are situated on top of channel and lake beds that face flooding by the simple nature of their elevation (Ranganathan,2015). Studies around tracing the process behind production of these irregularities/deviations, have attributed them to interactions between public agency officials that work in close contact with on-ground processes and actors (Sundaresan,2013). Cases of this practice have been observed both in land use compliance, granting development clearances as well as in granting environmental clearances around lakes and channels (Ranganathan,2015; Sundaresan,2013). However, these actors have had little access to understanding the interconnected nature of ecological processes at play in the watershed as observed from reports like the *N.K Patil report on Lake preservation in Bangalore city* (Lokare,2018).

In this context I argue that a study of the floods and storm water systems for an urbanized watershed like Bengaluru must be inherently socio-ecological in nature. Taking into account both ecology of the watershed that acts as the natural driver for the disaster and also the human actors that physically shape the watershed to exacerbate it. To achieve this I employ a mixed methods approach that consists of qualitative data collection and spatial mapping to visualize flood risk and possible sites of intervention in the watershed.

The merits of this two pronged approach to studying urban floods also lies in the fact that the actors that shape the watershed to exacerbate flood risk, also have the potential to devise locally suited solutions to handle storm water drainage better. Understanding their decision making processes and networks, can be a possible entry point to an adaptive environmental planning approach that acknowledges and tackles the changing climate through flexible pathways of planning and design.

The thesis is divided into 5 chapters. The first chapter gives a quick overview on urban floods as an emerging area of study and some observations from existing literature that prompt my approach to studying floods in Bengaluru. The second chapter unpacks the historical processes specific to planning practice in Bengaluru and sets the stage for how I arrive at the central argument for the thesis. The third chapter covers the qualitative component of my study including the methods used, findings and observations derived and its implications for spatial analysis. This chapter concludes with the decision of producing a Degree of Discretion map for the watershed to identify where a high degree of discretion could occur on the part of the local representatives and public officials. This map would help visualize the social component of flooding in the city. The Fourth chapter then attempts to spatially map the social and ecological factors in tandem, superimposing the degree of discretion map with a basic map of flood hazard. The final product of the spatial analysis is a map that helps us identify areas that can be prioritized for locally driven physical interventions due to their high flood hazard index and high degree of discretion index.

Lastly I summarize my observations and results and suggest recommendations in the fifth and final chapter of the thesis.

2. Urban floods in India: a specific case of flooding

Defining Urban Floods

In the past few decades, as existing urban centers have expanded and there has been a proliferation of new second and third tier cities in India, the phenomenon of urban floods has become increasingly common (Anjaria,2006;Gupta and Nair,2011;Ramachandraiah,2011). Flooding in an urbanized catchment with a dense built environment, higher population density and greater density of economic assets and infrastructure, equates to exponentially more loss per unit area as compared to rural landscapes. As a result, studying the production and impacts of urban inundation has been crucial to planners and city governments.

For a large part of the post-independence era the government of India has treated floods as riverine or coastal phenomena and addressed them at the scale of a river basin (Mohapatra and Singh,2003). The National Disaster Management authority of India in its first disaster management manual of 2008 classified floods as a natural hydrological disaster or event. Although the manual focused largely on basin scale management it did recognize urban flooding as a special category of disaster for which separate guidelines would be prepared in the future. The subject of urban flooding has been recognized by the NDMA as one meriting exclusive attention and separate guidelines for its management because of the fact that the 2008 manual was preceded by some extreme urban flood event such as the Mumbai floods of 2005 that saw an exponentially larger loss of life, assets and urban infrastructure per unit area than before. In 2010 the NDMA came out with a separate manual for urban flooding that tackled the various aspects of its production, management, response, recovery and mitigation. This classification carried through even in the most recent NDMA Manual 2016 that states : "The problem of urban flooding is a result of both natural factors and land-use changes brought about by urban development. Urban flooding is significantly different from rural flooding as urbanization leads to developed catchments which increases the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times. Consequently, flooding occurs very quickly due to faster flow times, sometimes in a matter of minutes."(*NDMA Guidelines Management of urban flooding,* 2016). Thus it is safe to establish that urban floods need to be understood from a unique lens that takes into account the ecological and urban processes to assess the extent of damage and suggest strategies for mitigation.

Literature review

As the NDMA manual aptly categorizes urban floods as both a natural and manmade disaster, extensive research has been conducted about the human processes that operate in the scenario of an urban flood (McFarlane,2012; Chatterjee,2010). These processes play a crucial role in both the production and response to the flood event. Various lenses have been used to talk about urban floods including that of political ecology (Ranganathan, 2015), public health (Zaki and Shanbag,2010), water and utilities management (Malekpour et al,2015), geospatial analysis (Sanyal and Lu,2005) and international development (Mahadevia,2006). For the purpose of this thesis I would like to explore 2 themes across the literature reviewed : research methodologies and environmental planning frameworks. Both these themes have guided my understanding on how to frame the urban floods question for a city like Bengaluru which has a unique geography, limited environmental and demographic data and a long-standing history with storm water management that dictates my study.

If we look across recent literature related to floods, flood modelling and geospatial analysis have been commonly used methods to study the impact and extent of flooding. Quantitative modelling that delineates floodplains based on environmental data has been the basis of many policy and management decisions for tackling floods in western countries (Harris et al, 1993). This has often been possible due to availability for reliable and regularly collected data about precipitation, water levels and other environmental factors such as soil type, vegetation etc. Furthermore the application of these methods in urban environments using modelling techniques such as SWMM have been dependant on network data for stormwater utilities and high resolution topographic data that allow us to model the behavior of water within an urban storm water system. For the global south, the absence of reliable data collection, monitoring efforts and high resolution DEM's has led to use of tools like remote sensing and aerial imagery to probe into the possible impacts and causes for urban floods (Nagarajan and Basil, 2014). What is the most fascinating however is the fact that the study of urban floods has not been limited to the field of environmental planning. It has been taken up by a variety of disciplines, that have used innovative quantitative and qualitative techniques to fill the gaps left by data scarcity. Public health indicators, socio economic surveys, interview and focus groups have given a more clearer picture about the human processes at work around the production and response to urban flooding. Emergence of mobile phone devices have also led to studies that use these technologies to co-produce knowledge about flood incidence and impacts by engaging the community (Laituri and Kodrich,2006). By the use of these alternative methods we can answer the question in a more nuanced way addressing uncertainties of urban India.

Using alternate methods to trace processes around urban floods is an especially useful approach to the study of the topic. Traditional riverine flood mapping approaches, which are done at a river basin scale find it easier to physically map floodplains to define the extent of inundation. However, for cities with a complex urban fabric of intersecting utilities and minor variations in topography, urban inundation becomes much harder to map given the resolution of aerial imagery or data available for the Indian subcontinent. Also in contrast to riverine flooding where the overflow of a main stream channel is the main cause of inundation, urban floods often tend to be more complex in the physical processes that produce them such as intersecting sewer lines, solid waste blockages and obstructions in stream channels. (Ramachandra and Mujumdar,2004). Not to mention the dynamic nature of an urban environment that is constantly under construction. This demands for more innovative approaches and methodologies to understand and tackle urban flooding.

The second theme I address in my literature review is that of environmental planning frameworks. Conceptual frameworks being used to understand the nexus of urban and environmental processes have shifted quite significantly in the past century. Increasing awareness around climate change has shaped these frameworks making their way onto global platforms and entering into the development discourses of the global south (Weisser et al, 2014). Hill lays out the four distinct periods as suitability, sustainability, resilience and adaptation (Hill,2016). Although Hill outlines these frameworks for a US centric context, their core concepts seem to imitate those in agendas set by international bodies such as the United Nations Development programs which use the SDG's as a tool to measure development across the globe. Consequently it becomes a channel through which this discourse has reached the Global South, not just in research but also in practice. The four conceptual frameworks can be described briefly as follows:

Goals and conceptual frameworks

Suitability	Goal was to put things in the right place,given long term historical conditions
Sustainibility	Goal was to keep what we have, while mitigating/reducing carbon emissions
Resilience	Goal was to recover quickly with fewer losses after disaster events
Adaptation	If we can sustain some things ina new world, then the new goal is to accpet new forms for cities and new characteristics of ecosystems that are daadapted to new conditions, that are resilient to extreme events, and that reduce carbon emissions.

Table 1: 4 Conceptual frameworks in environmental planning practice (Hill,2016)

Literature around urban floods for the global south and discourses about urban floods by the Government of India are still largely somewhere between sustainability and resilience frameworks. A significant portion of the literature focuses on response, recovery and risk assessment of various populations to mitigate the impact of the disaster (Urban flood) . For example, in her paper, Chatterjee demonstrates the complex networks of assistance that are employed by different communities within 2 slum settlements in Mumbai to recover from floods (Chatterjee 2010). Hallegatte et al, draw attention to not only the massive loss to life and assets that resulted from the 2005 floods in Mumbai and go on to talk about the inevitable impacts of the floods on vulnerable populations. The authors look at how targeting the indirect costs of extreme events can reduce the losses associated with floods by about 70%. Furthermore targeting the marginalised populations to help reduce indirect losses will only strengthen this approach to adaptation (Hallegatte et al,2010). Public health studies such as the one investigating cases of dengue and malaria post-floods also look at a post-disaster scenario that needs response and aid (Zaki and Shanbag,2010). However a new set of studies has also emerged to indicate that urban floods are not a product of short term failures but long term changes in the form of violations, urban growth or possibly changing climate patterns that now collectively produce these events. This idea has been in some ways reinforced by classifying urban floods as separate category by the NDMA and the publication of a set of guidelines elaborating on what causes and impacts are unique to an urban situation. Many of these studies have been done specifically for the city of Bengaluru examining the correlation of loss of historic lakes to floods, loss of vegetation and wetlands to inundation and examining the gradual violation of land-use regulations on floodplains and channels. I talk about these in detail in the next chapter. Although these establish some vital causal relationships, "managing the flood" by the city and state is still largely a short-term response-based operation and involves mitigation strategies that are rooted in the belief of a one-time upgrade to the existing infrastructure.

The discourse about urban floods at a national level indicates the persistence of a disaster management approach for intervention with 'mitigation- preparedness- response- recovery' as the four main stages of disaster. For an urban context like Bengaluru this is a rather reactive approach that addresses a short cycle around a phenomenon occurring due to anthropogenic changes to the landscape over a long period time. A more proactive approach that could incorporate planning as a vital part of solution to generate a long-term strategy seems more apt. With changing precipitation patterns and shorter and more frequent rainfall events it becomes even more urgent to look for an alternative approach that is conscious of the unprecedented trajectories of climate change.

At the end of this section the two key learning I carry forward in this thesis are :

A. Exploring the use of a hybrid research methodology as a means to comprehend the complex nature of the urban fabric and also to compensate for the lack of high resolution data to implement conventional flood modelling approaches.
B. A conscious shift towards an alternate conceptual framework to tackle urban floods that is conscious of changing climate patterns and their implications on how we invest in urban infrastructure and development.

I carry through these objectives most prominently in designing the research methodology for this study and in my final chapter where I propose design and planning recommendations for a landscape prone to urban floods.

3. The production of floods in Bengaluru city

Background:

Bengaluru has been witness to the phenomenon of urban flooding every alternate year since 2005. Situated in the heart of southern India, Bengaluru is the fastest-growing metropolis approaching an estimated population of 12.34 million. Situated at an elevation of 920m above sea level, the city is perched at one of the highest elevations in the Deccan plateau and about 225 kms from the closest perennial water source, the Cauvery River. Given its geography, the phenomenon of flooding is one that is highly unlikely to occur due to an expected channel overflow and yet has been crippling the city quite frequently in the past two decades.

Flooding is largely due to the incident rainfall and the inability of the city's infrastructure to manage the resulting stormwater. The annual rainfall for Bengaluru varies from 1500mm to 473mm. and peaks at two seasons of the year in May and September (Prasad and Narayanan, 2016). Bengaluru is characterized by short intense bursts of rain that cause flooding (Bhandiwad,2015). However, these intensities of rainfall can be characterized as moderate at best as compared to other Indian cities like Cherapunji that sees an annual average rainfall of 11,430mm (Deka,2009). This makes us question whether it is the intensity of rainfall alone that causes flooding, or could we benefit by looking at this as "not just a natural but an equally manmade disaster" (*NDMA Guidelines Management of urban flooding,* 2016).

A large part of understanding the production of urban floods in Bengaluru lies in the exploration of the Land Use-hydrology nexus. The land use and topography of a particular watershed forms the basis for predicting the behaviour of surface water. The change in the land use and topography of a watershed has the potential to impact the rates at which incident rainfall flows over the surface, the rates of infiltration of water and the areas at which it will accumulate and flow (Dunne and Leopold,1978). The merits of understanding how this nexus has evolved historically lies in the fact that fragments of these systems built in different eras still exist today and come together to form the stormwater network for Bengaluru, like many other Indian cities. It also helps us identify the ideological frameworks of water management that influenced actors and decision makers that built it, an understanding that is key if we are to recommend a shift in that approach.

The change in landuse and planning of the city has significantly altered its hydrological regime for over a century. As stated above, Bengaluru lies at an elevation of 920m from the sea level, equidistant from both the Arabian sea and the Bay of Bengal. This uniquely elevated central position, and significant distance from the perennial water source- the Cauvery- made rainfall the primary source of water for Bengaluru as a historical city. In order to capture water, the very first changes to the natural hydrology of the area were made by Kempegowda of the Wodeyar dynasty in 1800 by building a series of check dams on the gently undulating topography to create a series of cascading lakes joined by channels (Nair,2005). This restructured hydrological system served the purpose of irrigating agricultural fields and orchards that surrounded the walled city and supplied water to a modest population that lived within the city walls (Harini Nagendra 2010).

With the coming in of the British, the colonial era saw the gradual expansion of Bengaluru as a cantonment town (Nair,2005). The lakes and channels that formed a continuous and seasonal hydrological system, were compromised in three ways by the British regime. One, the dynamic boundary of a lake, that was in-fact simply water that was collected behind the check dam which could vary from a small area in low-rainfall years to a significantly large area in years with high rainfall, was enclosed and defined using embankments (Unnikrishnan and Nagendra, 2014). Secondly, the channels, within which water could only be found if the lakes upstream happened to overflow cascading the excess water to the next lake, were built over in many cases to house residential and administrative buildings. Thirdly, many of the smaller lakes were built over completely owing to the fact that the seasonal system might not have seen enough rainfall to fill them during the years, rendering them disposable for development (Nair,2005). This was the second time that the hydrology of the city was altered. It is important to highlight here that besides simple alteration, there was significant shift in the paradigm of how water could be controlled, enclosed and disciplined by the British, a paradigm that continues to operate in present planning practice (See Fig1).

As the colonial era came to a close, post-independence India invested in public sector industries and institutions for which Bengaluru became a center. Providing jobs and education for hundreds of people that migrated to the city, this era saw a fairly planned development of housing layouts and public infrastructure that was implemented through the 1960's to the 1980's (Nair,2005). A number of lakes were further converted to built development, most of them made into public facilities like the Kempegowda bus terminus, rerouting water out of the lake bed and into a structured stormwater system (Sundaresan,2013). In addition, with the coming in of piped water connections from the Cauvery in 1974, the lakes that were situated within the developed portions of the city now served a merely recreational purpose. Thus the hydrology of the city was further engineered into a channelled stormwater system of pipes and a number of lakes disappeared fragmenting the initially connected lake-channel system (Mathur and Dacunha,2006).

The third era of change has been marked by coming in of the IT sector into the city in 2000. To accommodate such a rapid rate of migration and expansion into the city, a significant shift in planning that the city saw was the development of large parcels of land by private developers. The earlier era that saw land use sanctions given out for planned public sector housing now gave way to a system of planning where corridors of road and utility infrastructure were laid, and zones demarcated for commercial activity on the periphery of the city (Chadchan and Shankar,2012). The vacant lands that filled in with housing and development in the subsequent years saw an ad hoc planning of utilities and micro-level changes to the existing hydrological network (Pellissery et al, 2016). There is also something to be said about the process of development that took place after the coming in of the IT sector. Concurrency of utilities and violation of land-use designations through the creation of revenue layouts and the further regularization of these developments was another cause that has added to the present day condition and pressures on the stormwater network (Pellissery et al, 2016).

Where the city stands today is a landscape of diminished lakes, increased urban land use and encroached channels that have been linked to the production of urban floods by various studies. Lakes in Bengaluru city have decreased in its spatial extent by 17% from 1960 to 2012 (Ramaprasad and Narayanan 2014). Even now, in the name of development and demand for land, lakes are transformed for urban infrastructure and floodplains are occupied making the watershed a constant site for change. With the added pressures of urbanisation that has led to an increase in Impervious areas accounting for increased runoff and peak flows, the landuse-hydrology nexus is an area ripe to inform production of urban floods.

This understanding of the physical hydrological system of the city sets the stage for us to explore the actors that are changing this landscape and their decision making processes. The next section section focuses on the present state of landuse and hydrology in Bengaluru and tries to explore how different actors including city government, civil groups and public agencies are related to this nexus.

Violations

In recent years planning and regulating stormwater infrastructure and the land use surrounding it has been done mainly through the Revised Master plans prepared by the Bengaluru Development Authority (BDA). After the floods of 2005 in Bengaluru and many other cities across India, the city started making notable changes in it's agency structuring and regulations to focus on water related issues. Setting up of the lake development authority in 2005, the Revised Master plan for 2015 released in 2007 (Updated 2011) that stated the conservation of the lake valley system as one of the key goals (RCDP 2015) and passing of the Amendment to the Bengaluru Water supply and sewerage Boards Act to include rain water harvesting and STP mandates for larger properties(BWSSB Act) have been some of the key changes that were aimed at rectifying the malfunction of water supply and stormwater in the city.

Newspaper articles and government statements that were released post the 2005 flood stated the main cause for the city's flooding as the encroachment that had happened on the city's historical water channels called the rajakaluves. Clearing "illegal" encroachment was the low-hanging fruit that the city turned to rectify the floods. However, floods continued to reign havoc over the city every other year and as the city continued to grow with the increasing pressure to accommodate migrants who came to the city with the IT boom, a middle way was found to convert agricultural land in the periphery to residential layouts by exploiting a loophole in the Karnataka Land Revenue Act (Pellissery et al, 2016). If we were to look at a historical trend of compromising ecologically sensitive areas such as the channels and the agriculture belt around the city, there exists plenty of evidence to indicate that ecological violations had been underway for several years before 2005, most taking place within the offices of the city itself. By the early 1980s, the problem of encroachments on lands belonging to Municipalities, BDA, Improvement Boards and other local bodies had assumed serious proportions (Pellissery et al, 2016). Laws to penalise such encroachment failed to act as a deterrent to the practice of landuse violation and in response the city passed the AkramaSakrama Act in 2014 (literal translation in local language means 'regularising irregularities') is the amendment to various acts including Karnataka Town and Country Act (Sundaresan,2013).

In their work around how these landuse irregularities were produced Pellissery et al, trace the creation of revenue layouts that took place on the peripheral agricultural belt of the city that was meant to be a green buffer. Their study identifies the practice of obtaining development approvals for these layouts through public employees such as the DC, approval of the local bodies and other public agency actors that were able to exploit the ambiguous nature of regulations and locationality of the peri-urban status of land (See Fig 2). Today 90% of settlements in Bengaluru's periphery form revenue layout (Ranganathan 2011).

These planning violations are observed in greater detailed by Sundaresan and tries to actively examine them beyond the domain of the urban poor alone. Senior officials politicians and activists interviewed by the author estimated anything from 50-75% of the entire building stock in Bengaluru could have been built deviating from the set planning norms as per the master plans (Sundaresan,2013). The statement "there is no planning in Bengaluru" became one that was frequently repeated by his participants. Describing deviation as the norm, the author goes on to say that Encountering different forms of violations directly or indirectly is part of everyday life that it is almost invisible and a large number of people have become in some way stakeholders to that order (Nair 2005).

Phase	Revenue Layout formation		Revenue Layout regularisation	
Stakeholder	**Type of involvement**	**Interest displayed**	**Type of involvement**	**Interest displayed**
Politician	(Active) permit through local bodies; passive collusion by realtor nexus	Gaining Public support politically, financial gains from realtors	(Active) legislation for regularisation to re-establish state authority	Revenue generation, political support from residents
Bureaucrat	(Passive) collusion by rent seeking from illegal property	Financial gains from realtors	(Active) promotion of regularisation by onetime payment	Exertion of authority, revenue generation
Realtor	(Active) provision of housing	Revenue generation from selling property without legal hassles	(Active) support since no penalty on the builders	Opportunity of non penalty for illegal activity
Resident	(Active) purchase of property	Access to affordable housing, amenities	(Opposition) since penalty entirely borne by them, demand for accountability of political and bureaucratic class	Concern about shouldering entire financial liability, corruption

Table 2 : Table showing stakeholder interest in revenue layout formation considered as a land-use irregularity (Pellisery et al,2016)

The amendment of the Revised master plan of the city for 2015 (published in 2011) also acknowledges these violations, and sets forth a strategy of mixed use development for the city. It states that “Critically, and perhaps for the first time ever in the planning history of the BMA, the plan recognised that mixed land-use is already a feature of the existing land use at the time and instead of placing land in sharply demarcated land use zones, the RMP 2015 sought to preserve the character of the BMA by allowing and encouraging mixed uses.” This has however, only lead to further ambiguity in land use compliance with the PLU under RMP 2015 having introduced land use sub-categories such as mutation corridor, Commercial Axis and Residential (mixed). Given that these categories are not embedded in the KTCP Act, 1961 and the accompanying rules of the Authority, there have been several court litigations challenging this (RCDP 2031).

This only reinforces the nature of a system where power of shaping planning policy and practice lies at the bottom most tier of the planning pyramid, one that is closest to the ground and urges the exploration of the urban landscape outside the boundaries of formal planning.

Violations in the face of ecological risk

The impact of a section of the land use violations is the phenomenon of urban flooding that has consistently plagued the city for a number of years. In her study of the flood prone neighborhood of Madina Nagar, Ranganathan examines how developments based on dubious land and environmental clearances face serious ecological issues. In fact, she argues, the move by the city to decongest Madina Nagar by selectively labeling and disciplining poorer “encroachers” is a narrow reading of the much more complex and historic assembling of flood risk, and one that further exacerbates the precarious conditions of its residents (Ranganathan,2015).

Figure 1: Photo showing water inundation in Madina Nagar (Ranganatha,2015)

For this reason, I argue that the study of urban flooding cannot be undertaken from a formal planning perspective alone. When various actors in the field are shaping policy every day, it would be naive to fixate on how a formal planning document could be improved, without acknowledging the existence and contribution of these actors. This is the key observation that drives my thesis.

On further exploration of how actions of decision makers impact the physical landscape, I observe that there is a need for the acknowledgement of a larger ecological analysis and the idea of cascading and networked impacts that tend to happen in an ecological unit such as the watershed that are missing amongst public agencies of the city. I conclude this through study of the Public interest litigations (PIL's) filed by resident groups against practices of lake pollution and encroachment and the subsequent lake conservation committee report produced by the city in response. The action plan items, project goals and monitoring directives issued through the report's recommendations is only aimed at dividing responsibility of tasks between the host of public agencies that operate on the same geography (Lokare,2017). However the report lacks the understanding of ecological connections between various water systems that combine to dictate the hydrological regime of a watershed. Including hydrological processes and understanding their interconnectedness is a step that does not require any additional time or resources but a shift in the heuristic framework that needs to be introduced while facilitating discussion between the various agencies. Therefore, the second part of my thesis highlights the importance of spatially visualizing this socio-ecological landscape in order to comprehend the nature of urban floods.

4. Study design

Following my argument of treating the landscape as a socio-ecological one in order to understand urban flooding, I choose to explore the nature of urban floods using a combination of research methods. This approach also emerges from the literature review covered in chapter 2. In order to capture the sociological and ecological aspects of the site, I employ a sequence of qualitative methods, such as short and in-depth interviews, followed by geo-spatial analysis. The objective of the qualitative methods is to trace the process of decision making in order to examine at which level of governance do the deviations occur that result in the policy-implementation gap. It also tries to examine the degree of deviation that takes place and whether it occurs uniformly over the site. Chapter 3 elaborates in detail my research methods, sampling strategy and findings for this part of the study. I then use these findings to try and visualise the heterogeneity in deviations using geospatial analysis in ArcGIS. I call this the degree of discretion map. Using geo-spatial analysis, I then overlay the environmental drivers that contribute to flooding in order to examine where different degrees of deviation intersect with flood hazard. The objective of the geospatial analysis is to identify sites that emerge as priority areas due to high flood hazard and a high probability of planning deviations. Chapter 4 covers the data, sources, workflows and processing used in ArcGIS to generate these maps.

Site

Due to limitations of time the thesis focuses on the Koramangala Challaghatta Watershed (also referred to as *Site or KC watershed* hereafter) which constitutes approximately 50% of the city's area and covers the south-eastern part of the city. It includes the Bellandur-Varthur system of lakes which have been the center of debate and ecological activism over the past few years. As observed from the NDVI imagery for 2001 and 2018 for the city, a significant increase in impervious area can be observed around this lake system indicating a strong morphing of the hydrological regime. Although local variation in lake system behaviours can be observed in different watersheds of the city due to soil characteristics, elevation differences and size, the Koramangala Challaghatta watershed proves to be a good test-site for the methods explored in this thesis.

Laying out the stormwater system and current planning regulations

The Local Planning Area or LPA for Urban Bengaluru consists of three main watersheds that each contain a system of interconnected lakes (See Fig 4). As described in the earlier section, the stormwater network of the city consist of several parts that have been built over time. The oldest parts of this system are the historical lakes and channels or rajakaluves that connect them to each other. In addition, the network of rajakaluves also collect rainwater from the watershed to channel it into the lake system. The network of rajakaluves has been modified over time by adding a number of box and U-shaped concrete drains in order to serve an urbanising landscape.These old and new drains have collectively been classified as primary and secondary drains as per the city's recent revised master plan for 2031. The RCDP 2031 further goes on to define a third category of tertiary stormwater drains that consist of street-side drainage for each locality/neighborhood. This classification of drains into primary, secondary and tertiary forms the basis of mapping stormwater across the watershed, and for associating each with the actors responsible for their design and maintenance. The actors and their roles in managing this system is discussed in detail in Chapter 4.

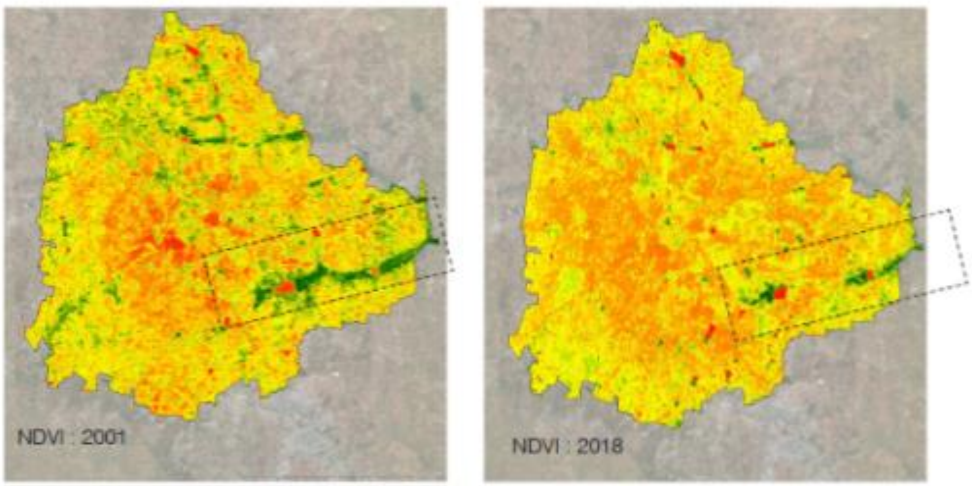

Figure 2:NDVI classification of LANDSAT imagery for Bengaluru for years 2001 and 2018. Dotted box highlights observed loss in vegetation due to urbanisation.
Map By: Sayali Lokare ; Source: LANDSAT ; Year: 2001&2018

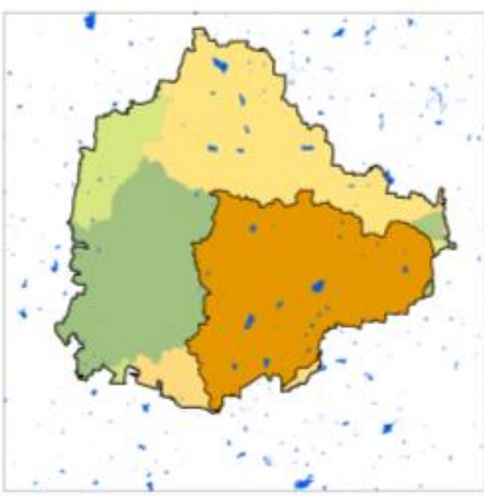

Figure 3 : Map showing major watersheds that lie within the BBMP City boundary. Koramangala Challaghatta watershed highlighted in orange
Map By: Sayali Lokare ; Source: Bhuvan ; Year: 2018

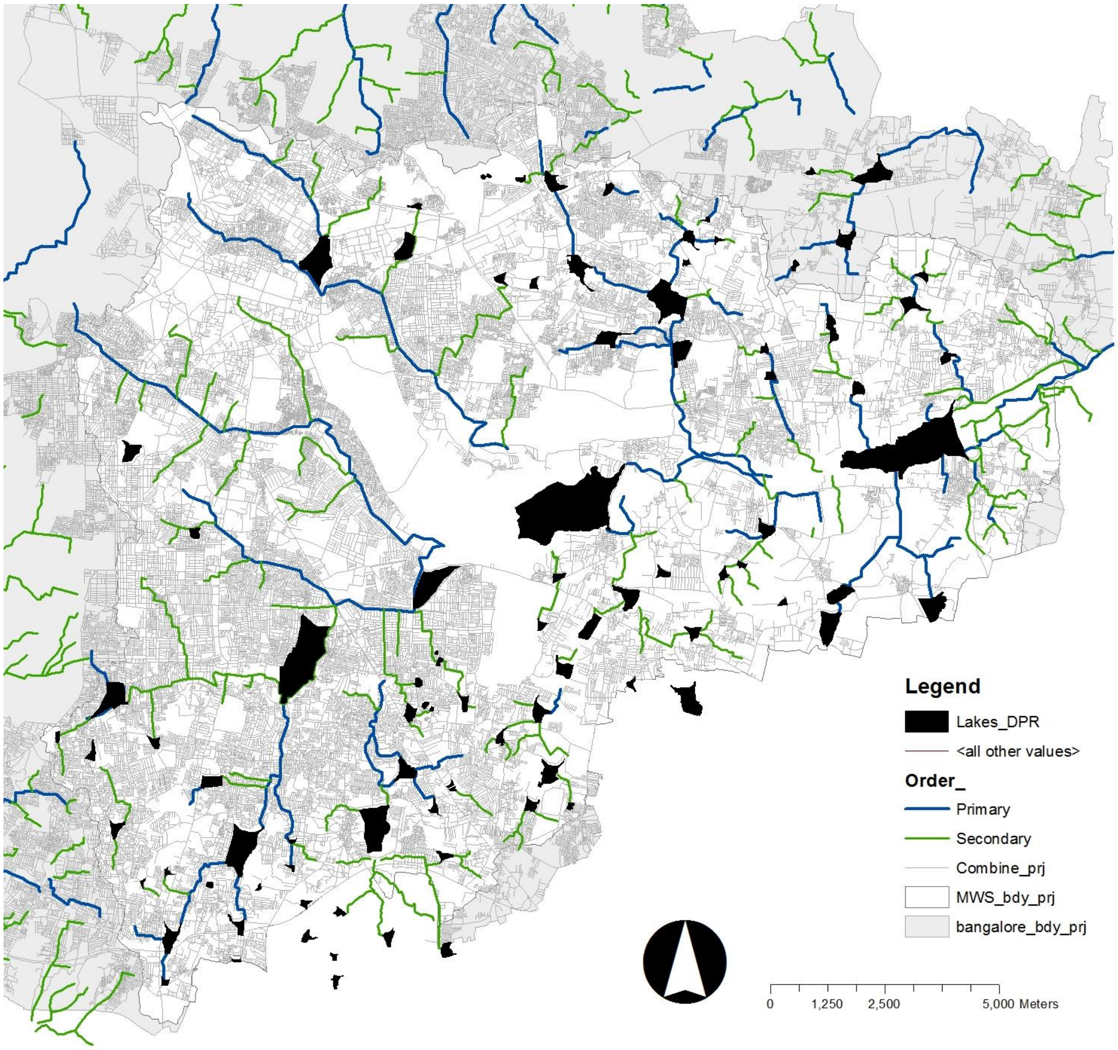

Figure 4: Map showing primary, secondary and tertiary/street drains for the Koramangala Challaghatta Watershed
Map By: Sayali Lokare ; Source: BBMP Stormwater Dept. ; Year: 2011

The classification also carries through into the main regulations that currently govern the city's development as per 2 key documents. First the Revised master plans for the year 2015 and 2031. I take into consideration both these documents in order to acknowledge that in the case that any ambiguities arise in interpreting the recently released RCDP 2031, public agencies are likely to fall back on the RCDP 2015 for clearer definitions. The second regulation that dictates development of stormwater channels and surrounding land use is the NGT judgment dated may 04, 2016. This states that that the buffers assigned by RMP 2015 around rajakaluves are unscientific. It directs that all the water bodies and streams in Bengaluru must have the following buffers (from the edge of the water body/stream)

- In case of lakes, 75m from the periphery of all water bodies to be maintained as green belt and buffer zone for all the existing water bodies i.e, lakes / wetlands.
- 50m from the edge of the primary Rajakaluwas.

- 35m from the edges in the case of secondary Rajakaluwas.
- 25m from the edges in the case of tertiary Rajakaluwas.

The NGT also orders that this buffer/ green zone would be treated as no construction zones for all the intent and purposes. As seen above the conflict of defining what a tertiary drain signifies already arises between the NGT orders and the RCDP classifications. A buffer of 25m to be applied to street drains (the city's definition of tertiary drains) seems extremely unfeasible. Thus for the purpose of this paper, we shall assume the NGT order to be applicable to the primary and secondary drains alone.

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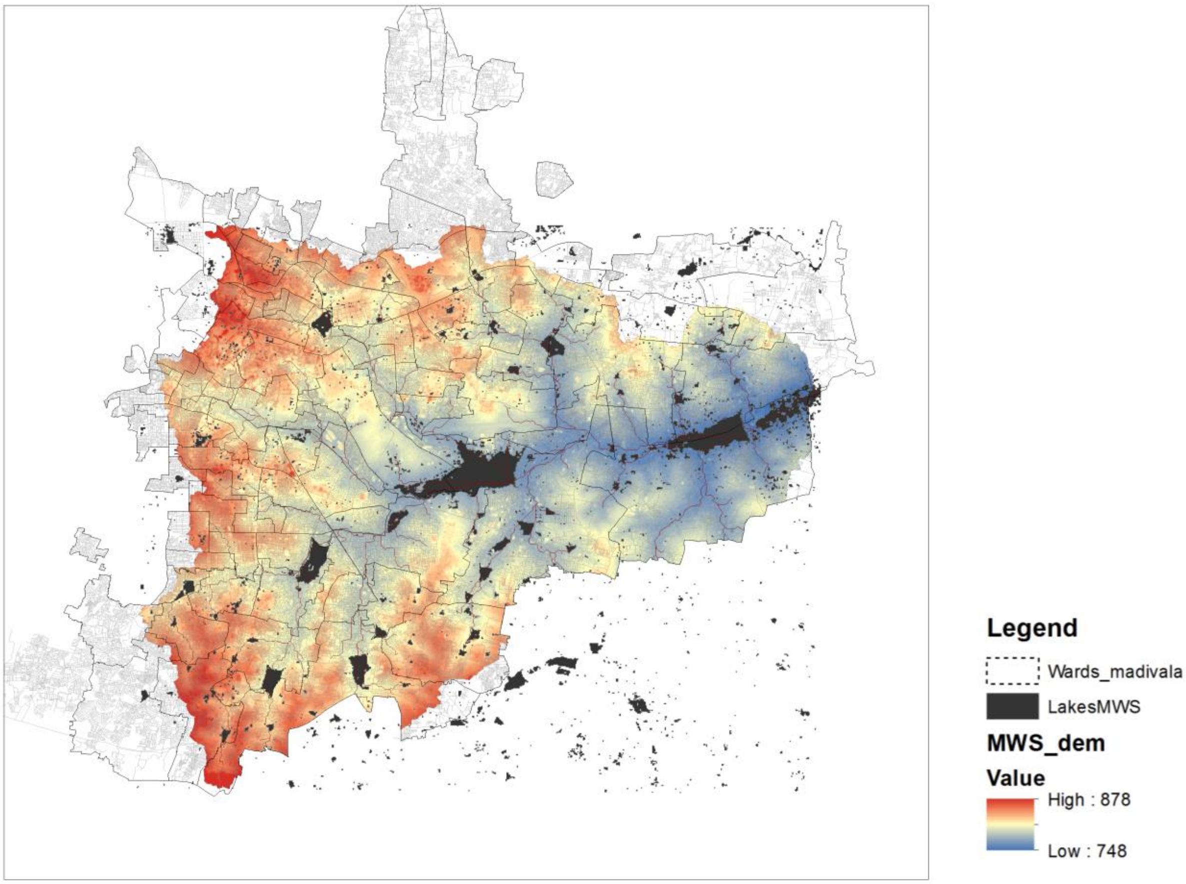


Figure 5 : Map showing the topographical variation for the Koramangala Challaghatta watershed. The watershed contains the Bellandur,Varthur series of lakes and consists of 88 ward boundaries
Map By: Sayali Lokare ; Source: Bhuvan, BBMP ; Year: 2018

5. Street Level Bureaucrats in storm water management

Who is an SLB

In order to probe into the question of the policy-implementation gap in stormwater infrastructure in Bengaluru I use the street level bureaucrat framework laid out by Michael Lipsky in his book *Street level bureaucracy- Dilemmas of the individual in public services* (Russell Sage Foundation, 1983). The book attempts to outline and define the characteristics and behaviour of the individual in public services the author terms as street level bureaucracies." These are schools police and welfare department lower courts legal service offices etc. whose workers interact with and have a wide discretion over the dispensation of benefits of the allocation of public sanctions. "By definition Street Level Bureaucrats (SLBs) work at jobs that are characterised by a high level of discretion and regular interaction with citizens. When this framework is applied to a stormwater agency for a city like Bengaluru, two diversions from the conventional definition of a street level bureaucracy can be observed. Firstly, unlike other agencies where policy to implementation follows a strict top down approach in which the final delivery of services is done by the bottom-most tier of public agents, the hierarchy of the stormwater agency for Bengaluru is organised a little differently. The different tiers of public agents look into the implementation and operation of different parts of the stormwater network, all of which forms a complete on ground system (See Fig5). In this way most of the agency employees shape on-ground actions related to stormwater. Secondly, both possibilities of the client approaching the street level bureaucrat or vice-versa can occur due to the on-site nature of service delivery. Keeping these two factors in mind I go on to design my study to include interviews and data collection from public employees at various hierarchies in the stormwater departments as well as residents in different neighborhoods within the study area.

Why the SLB Approach

As mentioned earlier, the SLB framework is used mainly to explain gaps between policy and implementation around stormwater design, maintenance and operation over the last few decades in Bengaluru. This framework argues that the decisions of SLB's ,the routines they establish and the devices they invent to cope with uncertainties and work pressures, effectively become the public policy they carry out (Lipsky, 1983). The reason why SLB behaviour is such an integral part of planning practice in burgeoning cities like Bengaluru is the tremendous pressure on public agencies to control, plan and organise a rapidly expanding urban landscape. Through their ability and experience to handle a large volume of workload, the SLB's command a degree of expertise and indeed of deference in some policy areas. Their constant interaction and understanding with the complex tasks at hand is a characteristic that critically affects their agency's dependence on them. This makes the actors indispensable to the organisation even though some of their discretionary policy implementation is seen as non-compliant (Sundaresan,2013). In situations like these where relationships between policy deliverers and managers could be conflicting and reciprocal, policy implementation analysts must question assumptions that influence flows with authority from higher to lower levels, and that there is an intrinsic shared interest in achieving agency objectives (Lipsky, 1983, Pg25).

Why do they make policy?

With a heavy volume of workload in expanding cities like Bengaluru, especially within the Stormwater Dept. that has in recent years seen an expansion of roles to handle the phenomenon of urban floods, SLB's inadvertently shape policy. SLB's often spend their world in situations full of uncertainty and translating human interactions to fit prescribed categories of policy. They believe themselves to be doing the best they can under adverse circumstances. For this they develop techniques to salvage services and decision making values within limits imposed upon them by the structure of their work. Although in an ideal scenario, a greater degree of information available to the SLB might help overcome some of these policy diversions, reliable information is costly and difficult to obtain. In addition, the SLB's high caseloads, episodic encounters and the constant press of decisions force them to act without even being able to consider whether an investment in searching for more information would be profitable (Lipsky, 1983, Pg29).

While on one hand public employees are found to "violate" policy decisions with discretionary practices, leading to cases of land-use noncompliance in Bengaluru (Sundaresan,2013) ,SLB's have also often championed client rights and benefits due to their frequent interaction with the clients. Ironing out the discretionary variations across a public agency by setting strict policy guidelines alienates the SLB from their work which allowed them to exercise their creative and human impulses and can contribute to separating the client from the public service worker (Lipsky 1983). With weak and ambiguous policy, understanding the SLB's ability to put out fires is vital to understanding the process of planning (Lipsky, 1983, Pg79). This is not to say that some discretionary decisions taken by the SLB might be counterproductive to the overall policy intent. This is clearly seen in the case of Bengaluru where these small discretions might have cumulatively been responsible for the emerging hydrological landscape. However, in a resource constrained city, the discretion of the SLB who is well informed about on-ground situations, can hold tremendous potential in achieving policy targets faster and at a lesser financial cost.

Another important phenomenon related to planning practice in rapidly expanding cities is the dynamic nature of planning regulations and overlap of jurisdictional powers of various agencies on the same geography. With encyclopedic regulations to check for compliance, those that are subject to change, interpretation of policy comes and stops at the SLB. As mentioned by Ranganathan in her work about the political ecology of floods in Bengaluru,
“ I was struck by the number of different labels the engineer used verbally to describe what appeared to be a uniform feature on the map. Interchanging English and vernacular (Kannada) words, the engineer referred to the wavy blue lines on the map variously as “rivers”, “irrigation canals”, “rajakaluves” (large drains), “katcha (unfinished) drains”, “sanitary drains”, “boxdrains”, and even “roads” and “residential layouts” (Ranganathan,2015).

The sheer ability of the engineer to navigate such a document to then take decisions about the physical landscape underlines the significance of this study. Lastly, I would like to touch upon our role as planners who attempt to balance the understanding of for compassion and flexibility on one hand and impartiality and rigid rule application on the other in public service reform. To the extent that tasks remain complex and human intervention is considered necessary for effective service, discretion will remain characteristic of many public jobs (Lipsky, 1983, Pg16).

Taken in concert, their actions add up to agency behaviour and their ability to re-shape an entire ecological geography such as the watershed. Through this study I attempt to not only understand the nature of that behaviour but go on to visualise it spatially in order to highlight its collective impact.

4 kinds of behaviours in street level bureaucrats

Using Lipsky’s framework, I explore 4 key behavioural practices in the street level bureaucrats I interview within the BBMP storm water department. I hope to understand how these behaviours vary in degree and in incidence across different designations. I ask the question, could the heterogeneity in production and response to flood risk be explained using these four characteristics as broad buckets that often overlap and share a close relationship with each other.

- Understanding client interaction

Interaction with the clients is one of the main actions that generate a complexity in the tasks at hand for the SLB’s that lead them to take discretionary decisions (Lipsky, 1983, Pg22). People come to street level bureaucracies as unique individuals with different life experiences, personalities and current circumstances. In their encounters with bureaucracies they are transformed into clients, identifiably located in a very small number of categories, behaving as is they fit standardised definitions of units consigned to specific bureaucratic slots. The assigning of these people into categories and treating them accordingly as per the category is done by the SLB, and is a socia process (Lipsky 1983,Pg59). It is essential to understand these interactions to investigate whether deviations in assigning those categories occur and are finally able to influence the physical landscape of stormwater in the city.

- Discretion

Discretion in the context of this study is the central behavioural characteristic that is closely associated with the other three yet vital to the actual process of implementation of a public utility project. There are certain characteristics of the jobs of SLB's that involve complex tasks for which elaboration of rules, guidelines or instructions cannot circumscribe the alternatives (Lipsky 1983). It is these alternatives that operate on a micro-scale to produce macro-level changes over larger geographies such as watersheds and become central to our understanding of flood risk creation as planners.

- Dissent

Dissent is a mechanism used by the SLB to adjust divergent or interests between either them and their superiors, or between formal regulation and on-ground realities.

- Rationing services: Problem of resources

Scarce resources can manifest in many forms during the SLB's work routine. The imbalance in the demand of public services and their supply makes heavy caseloads a reality for the SLB, constraining them for time. Decision makers are also typically constrained by the costs of obtaining information relative to their resources, by their capacity to absorb information and by the unavailability of information. These scarce resources and limited services lead the SLB to practice a rationing of resources that are available to them. This could be through rapid decision making or selective discretionary decisions made by the SLB in certain cases that could be explored through the study.

The non-voluntary client:

Lipsky writes: "Clients in street level bureaucracies are non-voluntary" (Lipsky 1983). This means that the client has no other choice but to approach the public agency for the service in question. This might happen for several reasons, government agencies might have a monopoly over the service, clients may not be able to afford private services, or they may not have ready access to them. Besides the implication the non-voluntary nature of the client has on the SLB's behaviour that gives them a certain power to exercise their discretion, I would like to highlight that in order for client interaction to even take place, the very existence of the non-voluntary client is necessary. In the case of public services such as water supply and sewage connections in a city like Bengaluru, development of a property begs the client to seek contact with the public agency official in order to ensure delivery of these services to a household. However, in the case of stormwater, failure of "delivery" of this service is not felt unless the consequence of that failure is significant. In other words an inefficient stormwater system that produces flooding in the neighborhood with potential loss to property and assets, is what can possibly trigger the client to interact with a stormwater SLB. In the following sections I conduct studies using qualitative methods to trace these very situations that could lead to client interaction. This would consequently lead to the SLB exercising some degree of the above mentioned behavioural characteristics to implement policy into on-ground action.

Methods:

For studying SLB behaviour related to stormwater in Bengaluru I used in depth interviews with 5 decision makers and short structured interviews with approximately 50 residents. The in-depth interviews were conducted with various actors involved in stormwater governance to try and trace the process of decision making related to construction, maintenance and repair of stormwater infrastructure. Selection of participants for this component employed a snowball sampling strategy that began with contacting Subdivision engineers in the BWSSB using publicly available contact details from their website. The focus was to interview at least one actor at every level of stormwater governance (See Fig 8). Interviews lasted for a maximum of 1 hour and one of six participants agreed for an additional session for clarifications.

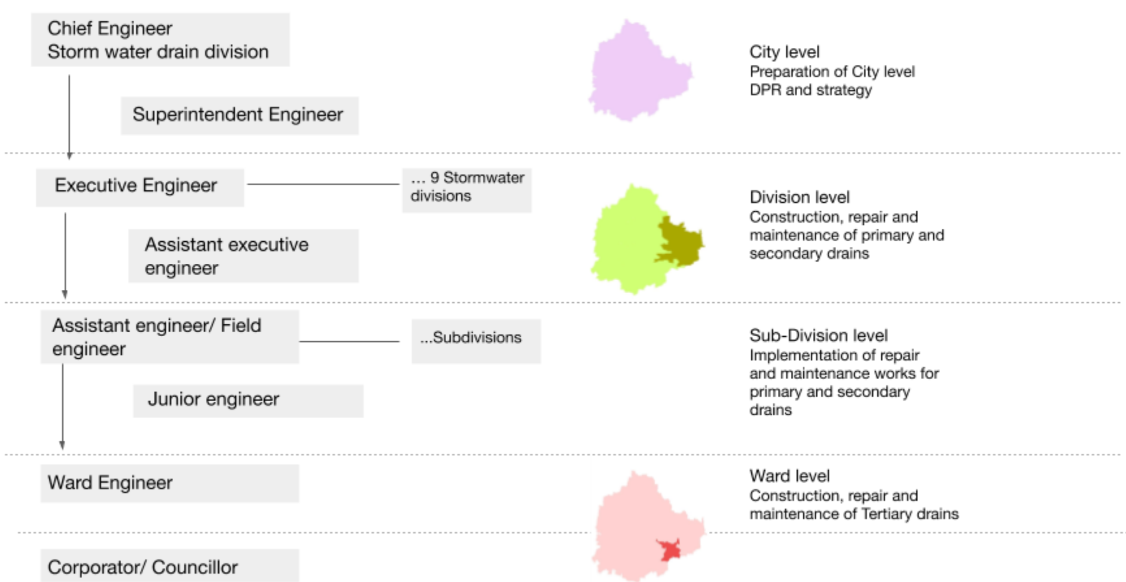


Figure 6: Chart showing organisational structure of stormwater management (BBMP)
By: Sayali Lokare ; Source: BBMP Stormwater Dept. ; Year: 2018

services they received, their experience during the monsoon of 2017 and mechanisms they used to cope with the issues they faced during the monsoons. For this component of the study I divided the study area into 100 ha hexagonal units. For these I used street grid data to study the density of the urban fabric. A street density index was calculated for each hexagonal unit based on which the hexagons were classified into 5 types that defined distinct urban fabrics. 2 hexagons were chosen at random from type 1-4, with type 5 studied though photo documentation due to scarce or no residents in those areas. Within each chosen hexagon, a random sample of 10 households was chosen who were approached for the interview. I chose 10 sample households expecting a possibility that some of those might decline to participate (See Fig 9). This clustering was based on the assumption that variation in type of urban fabric might contain a different socio economic demographic where quality of delivered services, built infrastructure, ability to cope with floods might differ. Translators that were fluent in Kannada and Tamil were used to help conduct the interviews. The interviews were short and structured and asked about:

1) Stormwater and flooding
2) Mechanisms used to cope with flooding
3) Water supply
4) Garbage disposal
5) Sewage connections
6) Interaction with public agencies

Quality of built infrastructure was documented through photographs. Three pilot interviews were done prior to the study over the phone, two with residents and one with an employee in the stormwater division to refine interview keys used for the main study.

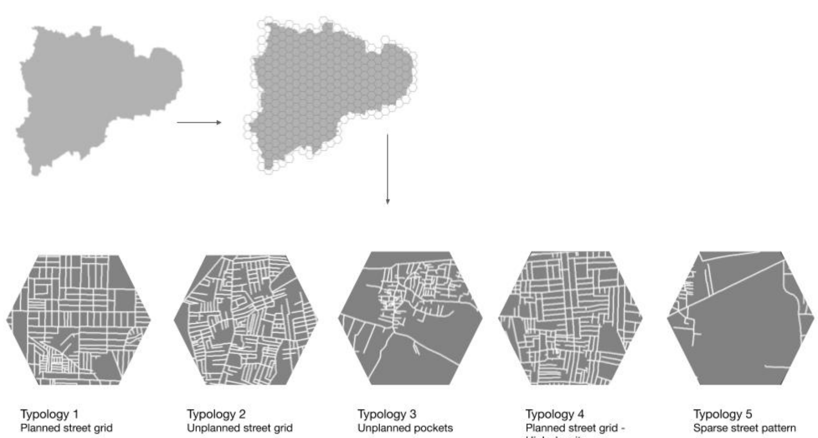


Figure 7: 5 Types of urban fabrics in the KC Watershed
By: Sayali Lokare ; Source: BBMP OpenCity Portal ; Year: 2018

Findings:

Part 1 : In depth interviews

Interviews that were collected were coded to identify main themes and processes. The in depth interviews were analysed on the basis of the 4 key SLB behaviors :

1) Understanding client interaction
2) Dissent
3) Discretion
4) Rationing services / resource scarcity

The observations across different levels of governance are tabulated below.(See Fig10)

Executive engineers:

The executive engineers in the BBMP stormwater office are each in-charge of a stormwater division within the BBMP city limits. The BBMP city boundary divided into 9 divisions (see map). The interviews revealed that the main responsibilities that the executive engineer handles involve construction of approved projects related to primary and secondary stormwater drains, their maintenance and rescue and disaster response operations within their division during monsoons. Thus their opportunities for client interactions were observed to be the most during these rescue operations. Informal interactions with the client (or the resident) also happened during their regular site visits and maintenance operations where residents might have lodged a complaint about a specific segment of the drain or when the engineer might need to navigate the machinery used for maintenance through densely built areas with narrow street widths. This increases the engineers familiarity with their division and their knowledge of which areas and residents might be most susceptible and vulnerable to floods. This is is reflected in their practice of acute discretion while prioritizing areas for disaster response and evacuation, that may not always coincide with areas that are formally declared as “low-lying areas” as per the DPR prepared by the agency. A detailed project report or DPR was prepared by the agency in 2011 to study the existing stormwater system and identify major construction and maintenance works, identify vulnerable areas and map flood incidence for the city. This DPR served to be the master document that guided the designs for upgradation of primary and secondary drains tendered out to various contractors through the BBMP. The executive engineer revealed little/ no dissent with the DPR and referred to it as their main handbook while executing any of their responsibilities. They did however express dissent towards the NGT orders that were not covered while the DPR was being made and present a conflict in decision making for the engineer as they go about executing construction projects that might violate code as per the NGT orders. Dissent was also expressed towards other agencies such as the solid waste management division and the BWSSB sewage division, whose utilities and services often intercept the stormwater drains and cause floods and impact the executive engineers main responsibilities adversely. Lastly, rationing of services was seen while asking for additional grants to desilt drains and solve interagency conflicts that are key to production of urban floods. The engineer employed a strategy of need based requests, where they used their discretion to identify the urgency involved in a particular task and request grants on a "need-to-need basis", in other words in an ad-hoc manner.

Field Engineer:

Field engineers are associated with a particular subdivision that lies within one of the 9 main stormwater divisions. They are responsible to supervise and execute onsite construction of projects as approved in the DPR and report to the Executive engineer and his team with site specific updates. They work in close interaction with the contractor that is hired to implement the designs and client interaction does not happen very often except when the works might be causing inconvenience to the residents of a neighboring locality. The field engineer does however, exercise a considerable amount of discretion during his job especially with matters related to interpretation of documents, maps and drawings. In a way the field engineer translates policy plans and strategies formulated at higher levels and aligns them with the site drawings used by the contractor for actual implementation. With civil work projects taking a year or more to execute, changing strategies , masterplans and policies must be aligned with ongoing site constructions. I would like to cite a quote from the interview here where the field engineer is describing how primary secondary and tertiary drains are classified :

"See, actually there no norms per se, Usually if there is a lake and it goes from one lake to another lake, we classify it as primary drain. Lake to lake. Suppose from lake to lake, the distance is very small and the discharge is very small we consider it to be secondary. Secondary or tertiary depending on discharge and width available and government land available."

The definition of primary secondary and tertiary drains has been ambiguous and shifting from each city masterplan to the next and no clear mapping of these drains was undertaken until 2011. In such a scenario, the field engineer preferred to refer the older more reliable village maps that demarcated public land left between private parcels for the *nala* or the drain to flow. Thus for the field engineer to execute the project unhindered, the baseline for reference was not a formal classification of the drains as recently issued by the BBMP or the masterplan, on which future policy decisions are likely to be based such as definition of buffer zones. Lastly, dissent as a distinct behavioral trait was not observed strongly for the field engineer. Minor concerns over agency overlap were expressed, but the field engineer considered these interactions as a part of his job to bridge the gap between policy and execution.

Ward engineer:

The ward engineer, as a part of his overall responsibilities, is in charge of maintenance, repair and construction of street side stormwater drains also known as tertiary drains within a ward. This is a part of a larger basket of responsibilities that might include maintaining and constructing roads, utilities, providing new connections, building public amenities such as parks and community centers etc. The ward engineer handles a smaller area than previously described officials with several wards often forming a stormwater subdivision.(See map) Client interaction is significantly more in this role, with clients approaching the engineer for various service related queries, complaints and applications that the engineer can exercise his discretion in. The engineer often also undertakes personal visits to and inspection of a particular issue in the ward on a case to case basis, which can influence his understanding of a particular client's need or a particular part of the ward that would require attention during an event such as a flood. This is also a good example of how the SLB in this case rations his time to cater to particular clients. This behaviour can further influence distribution of funds towards a particular work or project based on the ward engineer's understanding of client needs. The funding for projects at a ward level are proposed through an action plan that is formulated by a ward committee - a team of decision makers, citizen representatives and citizens themselves. Once sanctioned, a small portion of the total funds is open to use in "emergency" situations and similar works that might not have clear definitions in the action plan. These are the funds that are at the disposal of the ward engineer to exercise their discretion and allocate for repair of street drains, emergency desilting and flood compensation. A distinct trait I would like to highlight here is the practice of engaged negotiation with various actors that involves both dissent and discretion from the side of the SLB, in this case the ward engineer. Unlike the field engineer, whose discretion is based more on personal interpretation of documents, a larger number of actors have agency at the ward level that can be exercised through the ward committee, through councilors and MLA's for the ward. This leads to engaged negotiations and collective decision making that can translate to on ground action in favor of citizens that are vulnerable to flooding.

Corporator:

Although not in charge of any specific part of the stormwater system, the corporator forms a crucial part of the decision making around stormwater drains at a local scale. A corporator or councilor for a particular ward is the elected member that represents the ward in the municipal corporation and in ward committees. They see the highest degree of citizen interaction and have the ability to push citizen driven agendas in the decision making processes. The interview conducted with the corporator demonstrated a clear discretionary approach towards different demographics within the ward, particularly those that were low-income communities, those that were vulnerable to flooding and those that were visibily safe both financially and physically from inundation. Citizens that had a tendency to engage more with the councilor saw their concerns being inculcated into the decision making process. For the ward in question, the monsoon floods of 2017 were a big reason for those affected by the flood to approach the councilor for help. In addition, the land revenue department was to demolish certain legal properties that were built on buffer zones as demarcated by the NGT. These property owners also chose to approach the councillor to negotiate an alternative approach to the proposed stormwater drain that ran through the ward. Once again, we can observe an engaged negotiation that took place between the citizens, the councilor and the decision makers for the stormwater drain that was eventually rerouted through a channel under a public street. Citizens collectively surrendered small portions of their property to accommodate the new proposal. In addition the councilor was able to secure flood compensation for slum dwellers who would not have been eligible for government aid without property papers and proof of flood damage.In this case the three behaviours of discretion, dissent and rationing of services hinge on the corporators interaction with various citizens in her ward and can result in tangible physical planning interventions at the local level that protect the interest of vulnerable populations.

Part 2 : Resident interviews

The main themes related to flooding and stormwater that emerged from resident interviews were:

1) Government action and trust
2) Flood production processes
3) Agency in voicing issues
4) Collective resources, coping strategies and support systems
5) Additional fees and assets

The main themes are summarised for each type in the table below. Variation across these themes for different typologies indicated that the degree of engagement and response by public representatives and agencies is different in across typologies. This implies that scope for discretionary behaviour of SLB’s cannot be assumed to be uniform over all wards or units. As seen from the in-depth interviews, a key part of taking discretionary decisions is interaction with clients. Similar to other bureaucratic services, it is mandatory that the client seeks the involvement of the SLB to ask for a particular service. In other words, it is crucial for the resident to engage with their local representatives or agency officials (Due to a flooding issue or other service delivery failures) to result in discretionary behaviour on the part of the SLB. I was able to draw some relationships between willingness to engage with the SLB and other factors from resident interviews as outlined below:

Socio-economic status and willingness to engage:
A key observation we can draw from the resident interviews is the variation in the residents' socio-economic status across the four types. Assuming that the residents interviewed were representative of the population within each type, one could associate a particular socio-economic status to each type based on the responses about the residents' capacity to recover from flooding. This is indicated by how the residents express different degrees of measures they are able to take to cope with the floods, like construct built renovations that range from raising the entire plinth level of the built structure to placing a handful of bricks with mortar at the main door frame which could be indicative of the economic capacity of the household. The nature of loss of assets and expenditures that they have had to recover from after the floods is also seen to vary across the 4 types. Not only is the loss of assets different, the residents' perspective of how financially significant the same kind of loss was to the household also varies. Lastly, a difference is seen in the ability of the residents of type 1 and 4 to pay excess fees to public servants and hire external services to make up for the failure of public utilities. Residents of types 2 and 3 did not report payment of any excess fees and in fact engaged with the local representative when such failures arose (See Fig5). From these observations, I conclude that lower socio-economic status of a household might in fact increase change of engagement with the local representative, in other words lead to greater chance of client interaction with the SLB and thus a greater possibility of exercising discretion to address the issues at hand.

Flood incidence and Willingness to engage:
Across the same type, variation in engagement was seen based on whether the residents experienced flooding or not. Both in Type 2 and 4, one of the two neighborhoods did not experience flooding. The residents who experienced flooding expressed a strong dissatisfaction with the stormwater agencies response to rectify the cause of flood. For type 4, residents who had seldom approached the local representative, did so by organising themselves as neighborhood citizen groups and approaching the MLA or councillor as a collective voice. This indicates that previous incidences of flood might be associated with stronger engagement within residents and consequently a higher possibility of the SLB exercising discretion with respect to local projects such as stormwater drainage.

Flood production processes and flood incidence:
Most residents described the flood being caused by a failure of the nearest primary or secondary drain. Although tertiary/street drains were the ones that experienced drainage backflow and overflow of sewage systems inside individual households were also a cause of flooding, the root of the issue was described as a block or overflow in the primary/secondary

drain nearby. In a few cases tertiary drains seemed to be missing altogether. From these observations, one could assign all primary and secondary drains as possible sites of failure in the future. Also neighborhoods in close proximity to these drains can be possible sites of tertiary drain failures to various degrees depending on the quality of existing street drains. This reverts back to the conclusion that a possible site of drain failure could lead to future flood incidence and thus a larger possibility of engagement as demonstrated above. Although quality

of street drains did vary from one type to another, a large degree of variation was seen within a particular type as well. This makes it difficult for us to assign a "quality of infrastructure" index to a particular type. Thus for the spatial analysis we consider all identified drains (Primary, secondary drains, and tertiary drains within 240m of a larger drain) to be equally at risk of failure during a rainfall event.

Conclusion

The findings from the qualitative methods section of this study help us understand the decision making behaviours of some key actors involved in the stormwater management of the city. Using the street level bureaucrat framework outlined by Lipsky, I analyse the in depth interviews conducted with public agency employees. I use 4 key behavioural characteristics for this analysis: Client-interaction, discretion, dissent/ decision conflicts and rationing of services.

The observations from this study indicate that discretion is practiced differently at different levels of governance. For SLB's in higher levels of governance (Executive Engineers), discretion is often seen either in the use of funds for maintenance of primary and secondary drains or in decisions taken during evacuation, flood response and recovery. They exhibit low levels of client interaction (except during evacuations) and often face decision conflicts while aligning higher level policies such as the NGT orders with ground scenarios. With mid-level SLB's (Field Engineers) discretion is most often exercised in translating policy documents and plans from various sources into on-site projects. Client interaction is low and decision conflicts are resolved by referring to documents from varying sources such as land revenue records, village maps etc. This could result in a policy-implementation gap with respect to exact alignment of drains that could subsequently affect the definition of buffer zones around them. For SLB's at the lowest ring of governance i.e, at the ward level, client interaction is the highest. High levels of discretion are exercised in planning, design of primary and secondary sewers and design and maintenance of tertiary sewers. This can even result in rerouting entire drains from their original alignment. The process behind these decisions involves negotiation and high levels of engagement between local level representatives, citizens and sometimes higher public authorities through ward committees. These are the SLB's that have the greatest potential in influencing the physical design of the stormwater system at a local level. Policy implementation gaps that happen through this process can be spatially significant. They could also be highly contested where the ecologically non-compliant design is the preferred option by residents and local representatives.

The degree of discretion was also observed to vary across the Site (KC Watershed). This observation was derived from resident interviews conducted in neighborhoods with 4 different urban fabric typologies. Observations indicated that flood incidence and socio-economic status were important drivers for client-SLB interaction at lower levels of governance and could result in SLB's at the ward level vocally advocating for negotiated designs.

Implications for spatial analysis:

Following the qualitative section of my study I attempt to spatially map my observations around discretionary practices related to stormwater systems. As seen previously, discretionary practices that lead to policy implementation gaps vary at different levels and governance and also across the watershed. The gaps that have the most spatially significant consequences are observed at local levels of governance and involve ward-level SLB's (Ward engineers and councilors) and their interaction with clients/residents. For this reason and due to limitations of time, I will be focusing on mapping discretionary practices that are specific to ward level governance across the KC watershed. Such a map would be extremely relevant for planning site scale interventions and tracking buffer zone compliance and deviations. I call this the Degree of discretion map (Ward level).

Degree of discretion can be mapped for other levels of governance (Division level, sub-divison level etc.) as well and can inform other aspects of planning handled by higher level SLB's such as primary and secondary drain maintenance plans, evacuation planning etc. Through the Degree of Deviation map (Ward level) we can also assess the impacts of local level actions that are considered "non-compliant", a recommendation that I elaborate more on in the final chapter of this thesis .

The degree of discretion of a neighborhood or location is the probability of whether an SLB could influence physical design or changes to the stormwater infrastructure present at that location. Listed below are the various relationships observed from the qualitative analysis and how I plan on mapping them spatially (See Fig 12). I then plan to integrate these maps into one single map called the Degree of discretion map. The data and methods used to generate these maps is described in the following chapter.

S.No	Source of observation	Factors influencing discretionary behaviour	Map description
1	In-depth interviews	Land-use conflicts with newly laid out NGT and masterplan regulations around rajakaluves(drains) and buffer zones might lead to citizens (client) engaging with local representatives (SLB) which could lead to discretionary actions	Map1 : Anticipated Land use - Stormwater conflicts
2	Resident interviews	Lower socio-economic index impacts ability of residents to cope with loss of assets and failure of public delivery systems leading to active engagement with local representatives for action; increased client-SLB interaction and consequently higher chance of discretionary actions	Map 2: Socio-Economic index map
3	Resident interviews	Flood incidence leads to a greater willingness to engage with local representatives and consequently higher chance of discretionary actions (See typology 4)	Map 3 : Flood incidence
4	Resident interviews	Flood processes described by residents involved failure of primary/secondary drain as the root cause in all cases. Tertiary drain failure was described as a corollary because the neighborhood was in close proximity to Primary/secondary drains	Map 4 : Flood risk for Tertiary/ street drains
5			Map 5 : Population Density

Table 3: Table listing relationships between discretionary behavior and other factors and spatial implications

	Client interaction	Dissent	Discretion	Rationing services
Executive Engg.	**Disaster response** and evacuation Navigating dense neighborhoods with machinery used to access drain to desilt/unblock it	**NGT Orders for buffer clearance** around rajakaluves/drains conflict with onground building clearances given before NGT orders. **Agency overlaps:** Sewer lines, electricity lines and solid waste blockages that hinder smooth functioning of drains	**Low degree of discretion for new construction** or works, adherence to DPR Discretion in addressing **agency conflicts**, urgency of an issue decided by EE ona case to case basis Prioritizing disaster evacuation ("low-lying" areas) also identified as per EE and team's prior experience	Additional **funds** and grants to **desilt/ remove blockages** from rajakaluves requested on a "need to need" basis
Field Engg.	Negligible client interaction Site inspection and execution involving more **interaction with contractor** than client	Mild dissent in cases of agency/**utility overlap** Negotiating with agencies taken as the main approach	Discretion exercised in **interpreting maps and documents** issued by planning authorities/head agency in order to align them with ground conditions and drawings	Funding was mentioned as a scarce resource, but not something that directly affects the role of the fE
Ward Engg.	**High degree of client interaction** in order to sanction new connections, address complaints and queries. Complaints are occasionally addressed by visiting the site in which case the WE also **interacts with the clients' neighborhood**	Dissent is not strongly expressed in this role, in fact it is treated as an opportunity for **engaged negotiation** through ward committee meetings	Discretion is exercised while **suggesting action plan items** for the ward as per the WE experience that is built through interactions with client and neighborhoods Discretion is also exercised in order to **release funds** under the "emergency fund" bucket for ad hoc **desilting and repair** of street stormwater drains and allocating **flood compensation.**	**Limited funds available for the ward** as a whole are often rationed out towards other more urgent works such as road repairs, street lighting, building community amenities etc.
Corporator	**High degree of client interaction**s and high degree of sense of accountability towards client	Less dissent, more of strong **engaged negotiations** that involve decision makers, representatives such as MLA, commissioner, ward engineers etc. Dissent expressed with quality of work of contractors Councillors can report the inefficient execution of these projects by blacklisting contractors at monthly council meetings	The councillor is not responsible for executing projects or delivery of services per se, however, the councillor can change the course of **projects in favor of citizens** and to suit the local context and conditions through ward committee meetings and other **structures of engagement with the stormwater agency** Especially significant while addressing **land and stormwater conflicts**	N/A

Table 4: Table listing findings from in-depth interviews

	Government action and trust	Flood production processes	Agency in voicing issues	Collective resources, coping strategies and support systems	Additional fees and assets
Typology 1 : Planned street grid	**Satisfied** with overall delivery of services **Satisfied with response** to complaints and response times which is usually 1-2 days Usually **contact MLA or local councillor** with issues of garbage Take pride in neighborhood maintenance by govt.	**Did not face flooding** in their properties or neighborhoods.	Did not seem to bring this up as a major issue in their responses. Complain mechanisms rarely needed to be used and response times were satisfactory	Property owners **upgraded** water storage and harvesting systems in the last 2 years. Called upon **external services or contractors** such as sump cleaners, water tankers etc. in case of **breakdown of public utilities.**	**Pay excess fees** to ensure regular garbage collection Vehicle ownership seen and size of dwelling significantly larger.
Typology 2 : Unplanned street grid	Slightly dissatisfied with government's response to flooding Confirmed evacuation and flood water removal by BBMP **Excess fees demanded for long term repairs** and connections by public agencies **Aware of elected councillor** and avenues to contact them	Of the two neighborhoods interviewed one faced flooding. Flooding was due to the nearest **drain being under construction** and negligence of contractor to close it on time **Sewage backflow** also a cause for flooding Drain **blockages due to garbage** and **incapacity of street drains** a cause for flooding	**Sense lack of agency** in demanding long term government action	Used **personal savings to recover** and cope from financial losses from floods, **constructing built features** to protect property from floods also seen as coping strategy **Call upon water tankers and other services** more **reluctantly,** with water supply and flooding a regular issue in the neighborhood.	**No additional fees paid**- irregular garbage collection leads to disposal of garbage at nearest available garbage dumps/piles. **Loss of assets** such as vehicles, commercial goods in shops and basic household items - expressed as **significant expenditure** incurred by family/household.
Typology 3 : Unplanned pockets	**Dissatisfaction expressed with agency** response to complains (BWSSB, BBMP) **Extremely satisfied with councilors response to address issues within neighborhood.**	Sewage backflow and blockage a major cause for flooding **Drains getting blocked** with garbage and debris a cause for flooding **Missing street drains** or insufficient capacity of street drains also stated as cause	This was **not brought up as major issue** perhaps due to the community's **strong engagement with local representatives.**	**Collective use of systems such as water tankers** for multiple houses and sharing of drinking water between households in case of breakdown of public utilities seen as a commonly described phenomenon. Seeking **shelter at neighboring houses** in case of inundation also described as commonplace Few/no residents undertake new construction of walls or raising of floor level as a way to stop flooding.	**No additional fees paid**- irregular garbage collection leads to disposal of garbage at nearest available garbage dumps/piles **Loss of assets** such as food supplies, basic furniture and clothes described as **big setbacks** for the household **Medical expenses** also associated with monsoonal flooding and as major expense incurred by the household
Typology 4 : Planned street grid - high density	**Highly dissatisfied with government response** and public agency action in neighborhood where **flooding** occured Neighborhood where flooding did not occur saw mild dissatisfaction with issues such as garbage collection	Of the two neighborhoods interviewed one faced flooding Flooding was due to the **nearest drain being under construction** and negligence of contractor to close it on time **Garbage blocking drain** also a major cause for backflow of water into neighborhood Also mentioned **conversion of tank bed to layout** as a possible reason for flooding	**Sense lack of agency** in demanding long term government action in neighborhood with **flooding** The other neighborhood did not seem to bring this up as a major issue in their responses.	**Called upon external services or contractors** such as sump cleaners to clear flood water **Used personal savings to recover** and cope from financial losses from floods, **constructing built features** to protect property from floods also seen as coping strategy	**Pay excess fees** to ensure regular garbage collection Vehicle ownership seen and size of dwelling significantly larger than Typology 2 and 3.

Table 5: Table listing findings from resident interviews

6. Spatial Analysis

As discussed in chapter 2, developing a hybrid methodology to explore the question of urban flooding was one of the key objectives of this study. Besides being informed by the literature review done around the topic of urban flooding, Bengaluru city in particular begged for a hybrid approach to address the question. Bengaluru is situated on a plateau with relatively subtle topography and the absence of a perennial channel or river around which the floods occur. This means that in order to model floods using a conventional hydrological approach would require a high resolution DEM to identify flood zones. The Government of India provides us with a DEM of 30mts resolution that is unable to serve this purpose. Moving away from a hydrologically driven flood modelling approach that often delivers high resolution floodplain delineation, I use the available ecological data to map flood hazard to a coarse resolution. In addition, following my findings from the qualitative component of the study described in the previous chapter, I go on to spatially map those relationships as a "Degree of Discretion map" to variation in discretionary actions in the Koramangala Challaghatta watershed.

As a result, the spatial analysis component of this study attempts to bring together two aspects of understanding the ecological and social landscape of urban floods in the Koramangala Challaghatta watershed (See fig7). On a larger scale, I attempt to map urban flood hazard using ecological and topographical datasets that give us a coarse resolution of varying degrees of flood hazard in the watershed. On a more local scale, I use the Degree of Discretion map (Fig13) described in the previous section as an indicator of planning deviations around stormwater caused due to discretionary actions of local actors. This helps us visualise where a larger regional strategy or policy around stormwater can start to become flexible to accomodate and

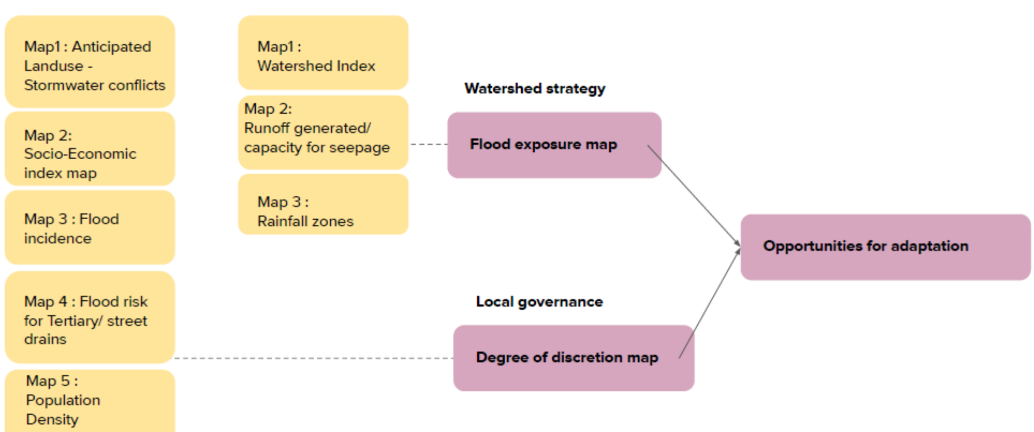


Figure 8: Workflow for spatial analysis-1

take advantage of local level governance structures and practices. It can also help decision makers at a more local scale visualise, the opportunities for intervention within their jurisdictional boundaries that can be prioritized and the extent of flood hazard as compared to neighboring units. The Final map is a product of the Flood hazard map and the Degree of discretion map. This map is labelled as Priority areas map (Fig15), which I use in the last section of this study to briefly suggest how it could shape planning and design decisions.

Flood hazard mapping:

The UNISDR (2004, vol. II, p. 4) defines “hazard” as “A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.” (Kelman, 2018). Hazard mapping for disasters has since shifted to risk-assessment in order to acknowledge the heterogeneity in damage to life and property given a similar degree of hazard. Of the three key steps to risk assessment , hazard mapping/identification is the first (Ologunorisa, 2005). Risk is often defined by the formula : risk= hazard x vulnerability where vulnerability overlays the socio-economic characteristics of the population at risk and the physical characteristics/value of objects exposed to the hazard that are likely to face damage (Ologunorisa, 2005). For the purpose of this study, I shall be concentrating on mapping hazard alone. The objective here is to map the ecological drivers for flooding impacting the watershed and characteristics of the watershed that increase the probability of the occurrence of a hazard (flood). This study chooses to look at the characteristics of the populations in the hazard zone, through the lens of decision making processes and not through the lens of vulnerability. This stems from the fact that the objective of the study is not to assess the degree of damage and loss to property and life, but to identify opportunities where existing decision making processes can be used to reimagine the long term planning and maintenance of stormwater infrastructure.

For hydrological modeling efforts, GIS, especially through their powerful capabilities to process DEM (Digital Elevation Models) data, have provided modelers with new platforms for data management and visualization. Surface hydrological modeling techniques, however, rely on 3 factors that can accurately visualize the behaviour of surface water and successfully calibrate the models- resolution of the DEM raster being used, the extent of topographic variations in geography and availability of discharge data. For a subtle topography like Bengaluru where the elevational difference between its highest and lowest points in the watershed is merely 130 mts with an average slope of 18 degrees, this proves to be a challenge. A DEM of 30mt resolution that is made publicly accessible by the Bhuvan portal managed by the Govt. of India, might be able to inform hydrological modelling for steeper topographies and channel geometries like the Mithi River in Mumbai (Wasankar, 2018). However, for a topography like

Bengaluru, it is unsuccessful in defining accurate channel geometries that could be used for floodplain delineation.
Also, insufficient streamflow or discharge data poses an issue for calibration. Although the KSNDMC has installed a dense network of telemetric rain gauges and weather stations to monitor hourly data, the installation of telemetric flow gauges that measure water levels are still a pipeline plan (The Hindu, Aug2018). The closest station that collects discharge rates and flow related data is situated at the Harohalli reservoir that is a part of the 6 telemetric gauges and flood forecasting stations set up by the Govt. of India for the Cauvery division of the Krishna basin (Govt. of India,2016).

Taking into account these limitations, I choose to use an overlay method in ArcGIS to map the environmental factors that contribute to creation of flood hazard in the KC watershed. The main datasets I use are :

1. Soils (EUSDAM)
2. Land use (LANDSAT Imagery)
3. Elevation (DEM raster, Bhuvan portal)
4. Drainage network
5. Rainfall (KSNDMC)

Several other studies that use overlay methods to identify flood hazard in GIS have used a similar combination of datasets that can inform the behaviour of surface water (Dewan et al, 2007;Pradhan,2010; Kourgialas and Karatzas 2011;Ouma and Tateshi,2014). Unlike other models such as Multi-criteria Evaluation and Analytical hierarchy processing that assign weights to each layer as per decision-making scenarios, I do not use a weighted suitability index to overlay the different layers. I process the datasets using the hydrology toolbox in ArcGIS and the SCS Curve Number model to create a Watershed index map and a Runoff potential map. These are then overlaid with the Rainfall variability map to produce the final flood hazard map.

Event frequency and rainfall data

Urban floods are usually caused by short intense bursts of rainfall that result in high peak discharges from an urbanised watershed into the storm drain systems resulting in overflow and consequently flooding. India has two cycles of monsoon both of which affect Bengaluru city due to its location. According to a precipitation study done by Prasad and Narayanan aggregating daily rainfall data from 1904 to 2013, the variability shows two peaks one in May and one in September(Fig 8). These peaks lie in the Southwest and northeast monsoon periods respectively, a more common way to classify monsoon seasons in South-Asia (Chang, 2004). A dense network of telemetric gauges that collect hourly rainfall data for Bengaluru since 2009 have led to better understanding of a single rainfall event that has led to flooding (Bhandiwad, 2015). The results of the study by Bhandiwad indicate that the core built-up and the low lying areas are inundated quickly, the rainfall intensity is more in the core areas than compared to the outskirts.

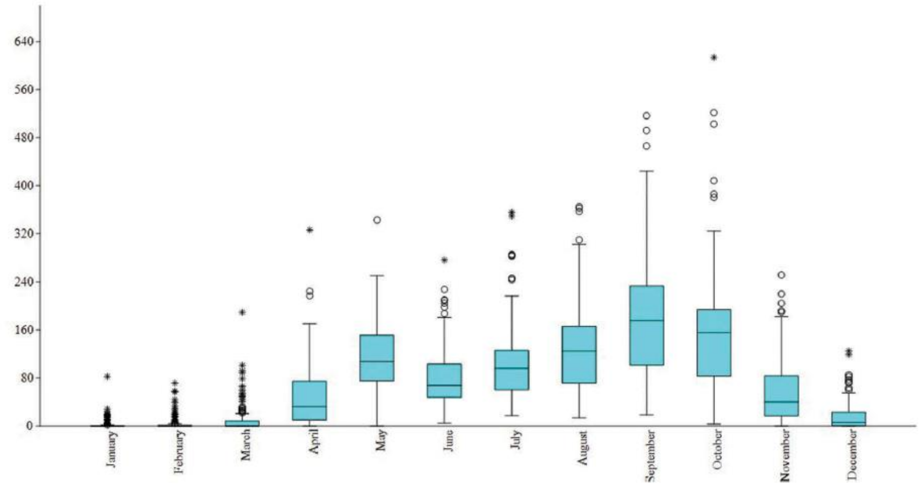


Figure 9 : Box plot showing the rainfall dispersion (monthly distribution of rainfall) aggregated from 1904 to 2013 (Prasad and Narayanan, 2016)
Map By: Prasad and Narayanan ; Source: District Statistical Office of Bangalore; Year: 1904-2013

For this analysis, I use the rainfall distribution map created by Prasad and Narayanan in their paper. The map is generated by aggregating rainfall data for the year 2013 collected by 17 stations. The data for each station is then interpolated spatially to create an isopluvial map for the city. A more preferred approach to generating isopluvial maps for Bengaluru should involve rainfall data for a year that displays significant departure from the normal rainfall average in the south-west monsoon season. As per Fig 9, 2013 shows a departure of only 12% as compared to a more recent 45% departure in 2017 (KSNDMC, annual report 2017). Another limitation to the rainfall map used for this study is the number of stations used for interpolation. There now exists a dense network of telemetric gauges for Bengaluru city that could further improve the resolution of spatial variability of rainfall within the city (KSNDMC).

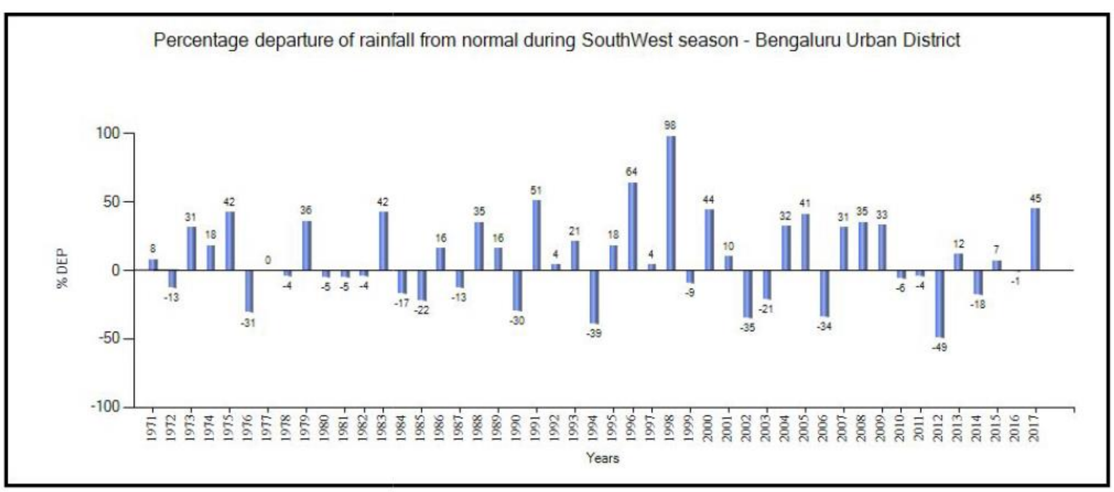


Figure 10: Percentage departure of Rainfall from normal during Southwest monsoon season (KSNDMC)

Data and Methods:

The table below indicates the datasets that have been used for the study and their sources.

SN.	Name	Source	Resolution	Year of publication
1.	Landsat ETM : Surface reflectance dataset	USGS LandSat missions	15 mt	2017
2.	Street Network	BBMP (City authority of Bengaluru)	-	2017
3.	Jurisdictional boundary	BBMP	-	2017
4.	Ward Boundaries	BBMP	-	2017
6.	DEM : 30 mt resolution	Bhuvan Database, Govt. of India	30mt	2017
7.	Soils	EUDASM, Archived maps for India	-	1985
8.	Land Use Maps:Revised CDP 2015 for Bengaluru City	BBMP (City authority of Bengaluru)	-	2009
9.	Rainfall (IDF Curves)		-	
10.	Rainfall Zones	Prasad and Narayanan,2016	-	2016
11.	Revised Master Plan for Bengaluru 2015	Bengaluru Development Authority	Parcel level	2011
12.	Existing landuse Map 2015 (Revised Master Plan for Bengaluru 2031)	Bengaluru Development Authority	-	2018
13.	Household data, ward-	2011 Census of India	Ward wise	2011

	wise for Bengaluru Urban	Household Data		
14.	Population data, ward-wise for Bengaluru Urban	2011 Census of India Household Data	Ward wise	2011
15.	Primary and secondary drain location	BBMP Stormwater Dept. DPR		2011
16.	Flood incidence Data	Karnataka State Disaster Management Centre (KSNDMC)	Point dataset	2016
17.	Official Lake boundaries	BBMP Stormwater Dept. DPR		2011

Table 6 : Datasets and sources used for study

Workflow and processing:

Fig 15 to 17 show the workflow for the analysis of the flood hazard map, the degree of discretion map and the Final opportunities for adaptation map. All tools in this model were developed in ArcGIS using ModelBuilder or as python scripts using the arcpy library. ENVi 6.4 was used to classify the LANDSAT aerial imagery to obtain a classified image vector containing lakes, built, vegetation and open ground land covers. A Principal component analysis was done on the image using 6 components, the first 4 of which were used to extract land cover data by manually setting threshold values in ENVI.The online georeferencing software Map Warper was used to create geotiffs from the soil maps and land use maps that were available in pdf format. The patch analyst plug-in ArcGIS was used to calculate street grid related metrics like street density index and Block size uniformity index that I have used in generating the degree of discretion map and the runoff volume map respectively.

In addition, the hydrology toolbox was used to determine flow accumulation and stream order using the DEM raster to assign a watershed index to each hexagonal unit that indicates its location in the watershed. A hexagon that is located in the upstream areas of the watershed,i.e, containing lower stream order is likely to have runoff being contributed to it. Similarly, a hexagon located downstream is likely to accumulate a higher volume of runoff and contain a stream of higher order. The runoff map was calculated based on the SCS Curve number model outlined by the USDA for urban watersheds.

Patch analyst extension and landscape metrics:
For the patch analyst processing The watershed being studied was overlaid with a hexagonal lattice of 100ha each. The analysis that follows, calculated landscape metrics for each hexagon separately based on the street grid pattern it contained. The Patch analyst extension available for ArcMap was used to calculate landscape metrics. Of the calculated metrics, the Total number of patches (NumP), Mean Patch area(MPA) and Mean Perimeter area ratio (MPAR) were used to create 3 metrics : street density index(SDI), Block size uniformity index(BSU) and block shape regularity index(BSR) respectively. Each landscape metric was classified using a natural (Jenk's) classification and assigned index values 1-4.

For the runoff model, data about soil, land use, 3 generated metrics and landcover type was added to the hexagonal lattice to calculate the final Area weighted curve number for each hexagon.

Mathematical model to calculate runoff:
The conceptual model to calculate runoff aims to map how much is a particular area within the watershed capable of contributing to the overall runoff volume. This is done using the SCS runoff Curve number method as the mathematical model. This model is based on equ 2-1 that correlates runoff volume with land use characteristics and rainfall.

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{[eq. 2-1]}$$

where

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in) and
I_a = initial abstraction (in)

Where,

$$S = \frac{1000}{CN} - 10$$

Here, the CN or Curve number is assigned to each land use characteristic using Table 7. The curve number for a homogenous part of the watershed is based on the land use, soil character, percent impervious area, street type etc.(USDA,1999). Through this model I map CN distribution for every 100ha area of the watershed. Using the CN distribution map, I then calculate the contribution of each part of the watershed to the resulting runoff. This map indicates the runoff generated or capacity for seepage of each of the hexagonal units across the KC watershed.

Table 7: Table used to assign Curve number values as per SCS CN method, TR-55 handbook, USDA

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Suitability analysis:

Both the degree of discretion map and the flood hazard map are generated using a simple overlay method or suitability analysis where the component maps have been given index scores from 1 onwards. These have then been converted to rasters of a cell size of 20 and a simple addition function has been used to calculate a cumulative score for each pixel to generate the degree of discretion map and flood hazard map. A similar process has been employed to integrate the two maps using the raster calculator tool to produce the final raster for opportunity areas.

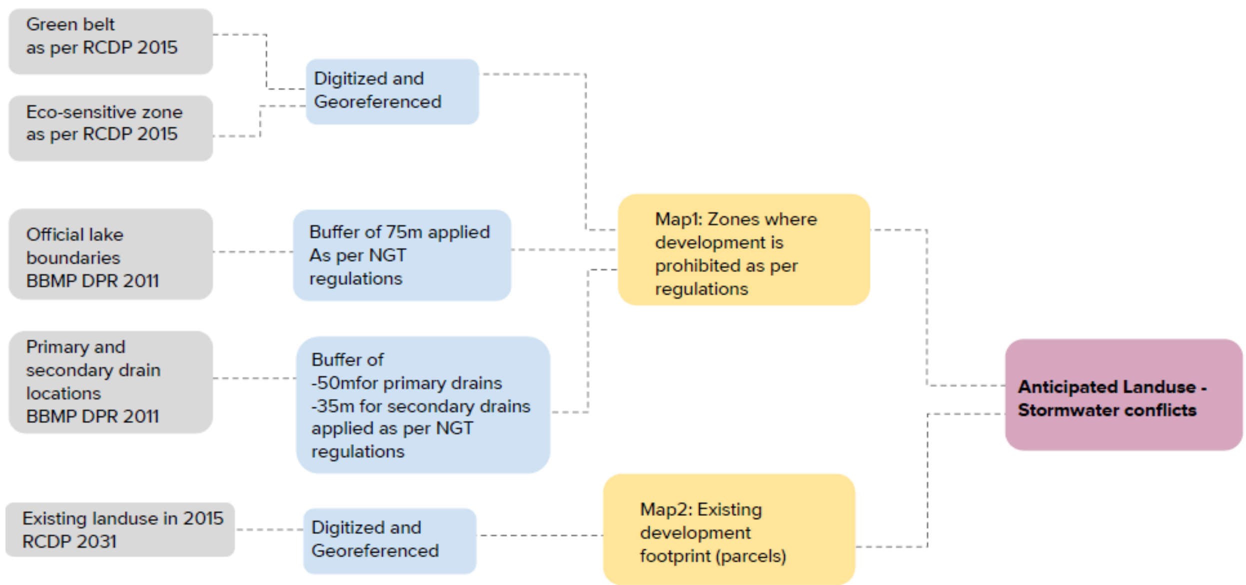


Figure 11: Workflow for processing -2

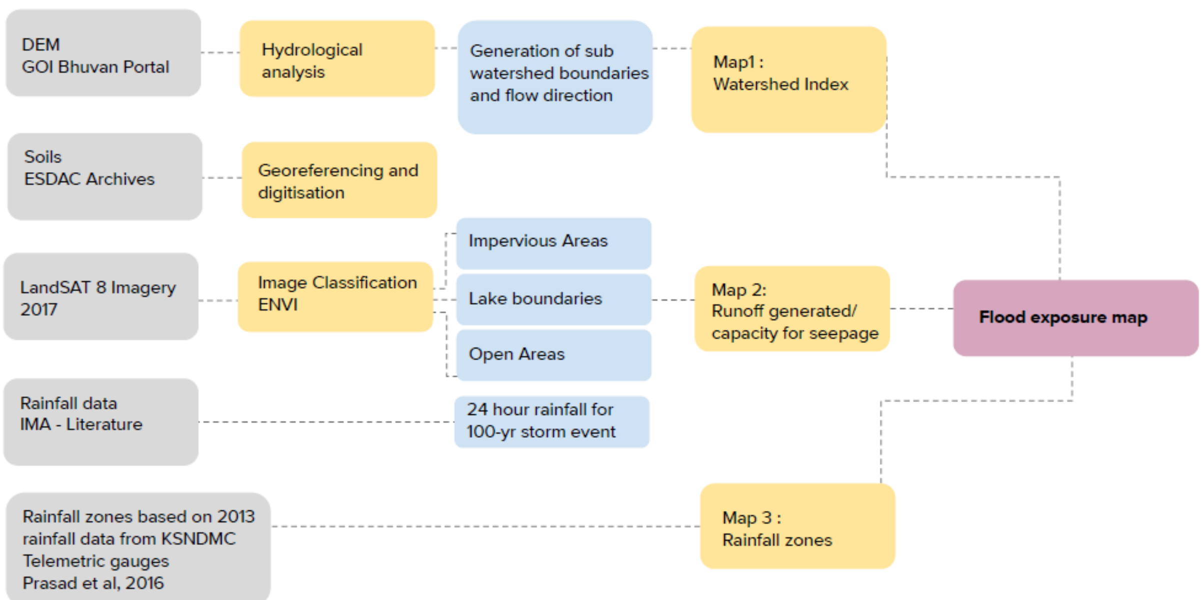


Figure 12: Workflow for processing -3

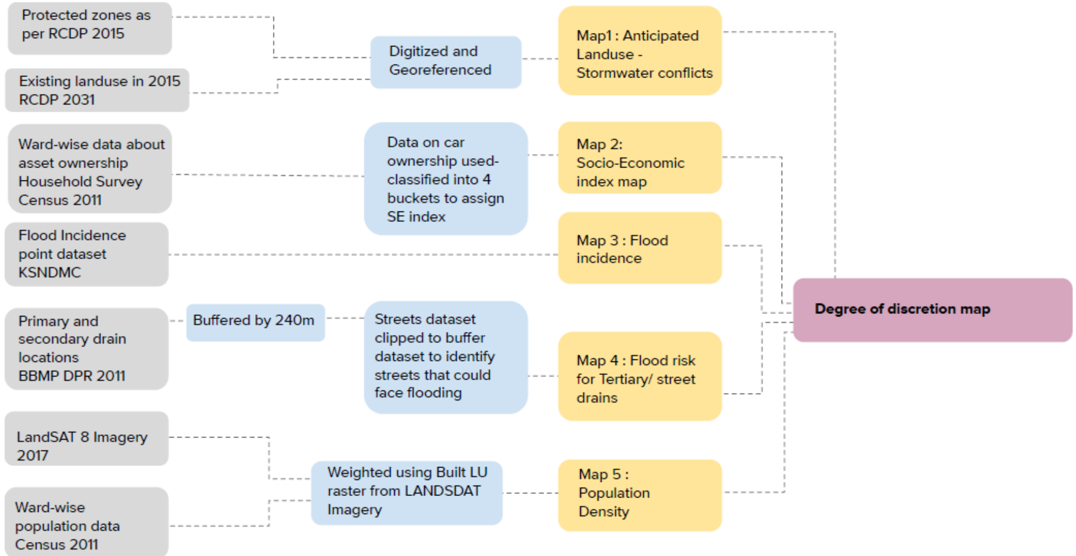


Figure 13: Workflow for processing -4

Results:

The final raster indicates clear priority areas that need attention due to high flood hazard and that display a high degree of discretion. A high degree of discretion would mean greater client-SLB interaction. For projects proposed in these areas, this would mean possible changes in design through engagement and site level negotiations (Fig 20). A concentration of areas with high suitability scores can be seen in 13 clusters of hexagons.

Location of clusters:

In contrast to the commonly held notion that downstream parts of the watershed are in more urgent need of flood control measures, the map indicates a higher need and opportunity for projects in the upstream areas of the watershed where resources can be allocated. 8 of the 13 opportunity clusters (C1-3, C9,11,12,13) lie in upstream areas of the watershed as compared to the other 5 .

Cluster size and stakeholders:

The cluster sizes range from 1-10 hexagons. However, the number of hexagons is not always indicative of the number of wards that might be engaged within that cluster. For example, Clusters 1 and 2, although comparable in size to cluster 6 and 10, contain multiple ward boundaries intersecting with the cluster. This would require a very different approach to the project with multiple stakeholders belonging to each ward, who can exercise their discretion on the site as a whole.

We can also observe the variation in urban fabric across the 13 clusters. Observations about urban fabric can be indicative of the characteristics of the population and land use. Cluster1-4 and Clusters 10-13 have a dense street grid indicating smaller plot sizes and possibly a greater population density. Clusters 5-8 have a much sparser street grid and lie on the outer edge of the city. These areas will most likely see further built development in the future and strategies to tackle stormwater could be incorporated into new constructions.

On laying the cluster locations over land-use as of 2015 (RCDP 2031), we can also observe that Cluster 1 intersects a large portion of commercial land-uses in the core areas of the city. In comparison, C2-4 and C12-13 contain residential land-uses. C6, 7 and 9 contain areas classified under the Green Belt/Agriculture belt and Cluster 8 contains landuse classifies as Hi-tech, that include campuses owned by info-tech companies along the IT corridor of the city.

All clusters, Except C1, 13 and 7, are located close to official lake boundaries. This could mean that the Lake Development authority could also be involved as a possible actor and funds available for lake redevelopment can be integrated with stormwater infrastructure projects.

Area for intervention:
Another important observation that we can draw from the clusters and their surrounding urban fabric is the land that might be available for stormwater infrastructure projects. Land acquisition is a contentious issue that often leads to delays in project execution and could also work against the interest of the most vulnerable populations that live in flood hazard zones. Imagining multiple typologies of stormwater interventions depending on the land available can allow for sensitive and sustainable action towards flood mitigation. For the clusters identified, the first category of clusters have very limited land available for intervention (C1, 13, 10, 12) and acquisition of buffer areas around drains can also be contentious involving a number of stakeholders. The second category of clusters contains land belonging to the Indian defense (C2, 4, 5) which could indicate availability of land and engagement with one central stakeholder. The third category of clusters lies on the fringes of the city, with large properties and agricultural lands.(C 6,7,8,9,11) This could mean vacant land available for possible intervention and lesser stakeholders that own larger properties that would be engaged in the process.

Degree of discretion map:
Besides being an important input raster to identify priority areas for intervention, the degree of discretion map can also indicate areas where local SLB’s will be willing to engage and negotiate in interventions. As per the degree of discretion raster, two spatial patterns can be observed for

areas with a high DOD index. Firstly near cluster 1 and 2 high DOD areas form a linear pattern, along primary/secondary drains. However for areas closer to the periphery (near clusters 3-4, 7-8) high DOD areas are more uniformly spread out. A reason for this might be that these areas contain regulatory zones such as the green belt and eco-sensitive areas as per the RCDP that might make future development contentious. This uniform spatial pattern presents an opportunity to recommend secondary stormwater interventions that do not lie along main drains, but capture stormwater further upstream in detention ponds or green infrastructure systems. These secondary projects could ease the pressure on interventions along the main drains to control floods.

Conclusion:

To summarise the results from the spatial analysis, the final raster indicates 13 clusters of hexagons that can be looked at as priority areas for intervention. This is owing to the fact that they have both, a high degree of flood hazard and a high degree of SLB discretion that can be used in favor of implementing stormwater projects. The 3 main aspects of these clusters that vary across the watershed are: Stakeholders involved, area available for interventions and possibility of secondary upstream interventions.

The key stakeholders vary across clusters due to intersection of multiple ward boundaries as in the case of cluster 1 that lies closer to the core area of the city. Stakeholders can also be determined from the surrounding urban fabric near the priority areas. Some clusters show a highly residential fabric, while some clusters like cluster 1 and 8 indicate commercial properties and Info-tech campuses as major stakeholders that can be involved in the projects. In addition 10 out of 13 clusters lie in close proximity to official lake boundaries, making the LDA a possible stakeholder as well.

Area available for intervention is observed to be more limited in clusters that lie closer to the city centre. These clusters already contain dense built development that would call for interventions that are compact and area efficient. Clusters along the periphery have lesser built development and a possibility of incorporating stormwater solutions in new constructions in the future.

Lastly, using the degree of discretion map we can observe a distinct spatial pattern in peripheral areas, where high degree of discretion is seen over uniform blocks around priority area clusters. This could mean that local SLB's could be willing to implement a secondary set of stormwater interventions that can be proposed upstream from the actual priority sites. Both the priority sites and secondary interventions could work together to mitigate flood incidence.

Figure 14: Degree of Discretion Map
Map By: Sayali Lokare ; Source: Refer Table 6

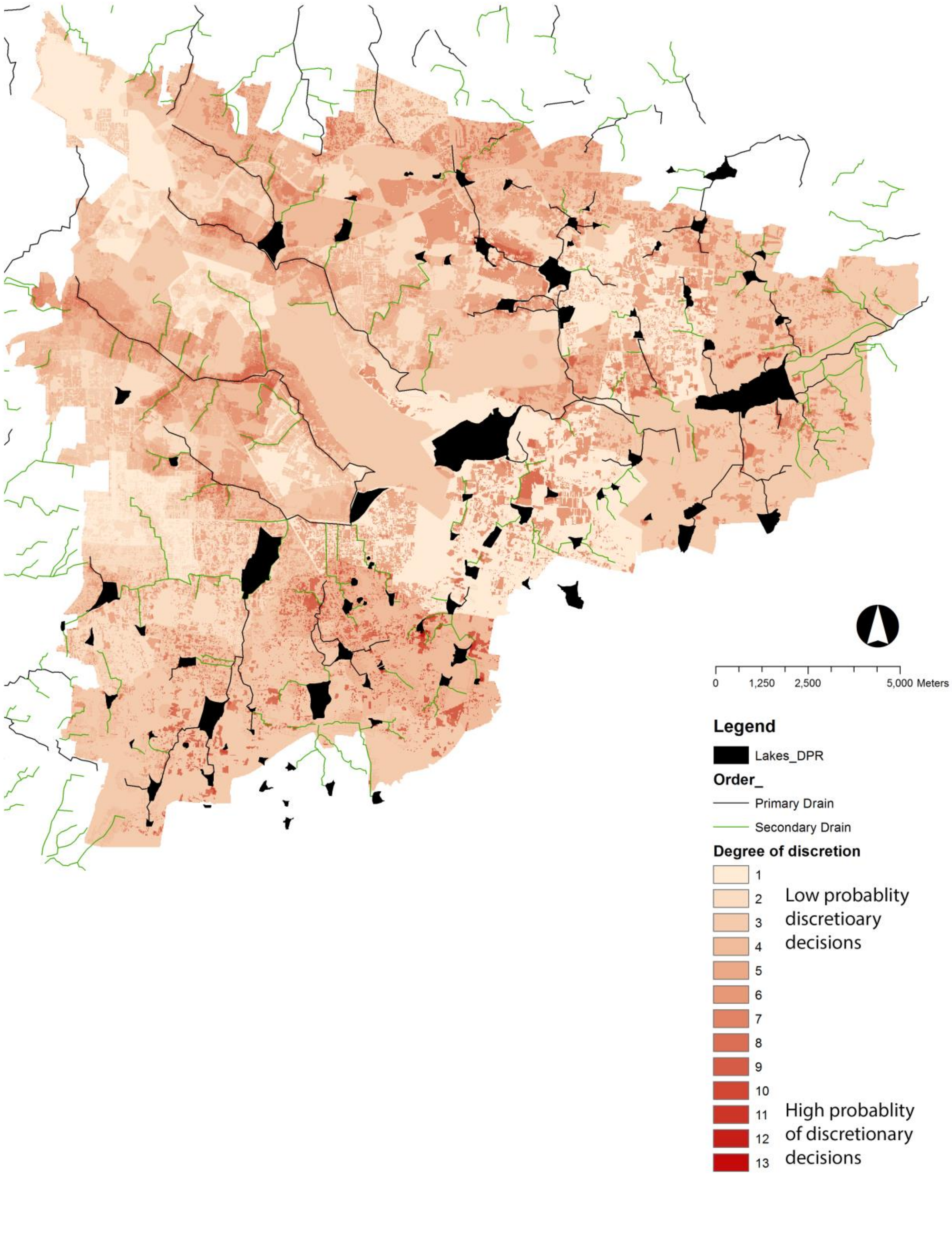


Figure 15: Flood hazard map
Map By: Sayali Lokare ; Source: Refer Table 6

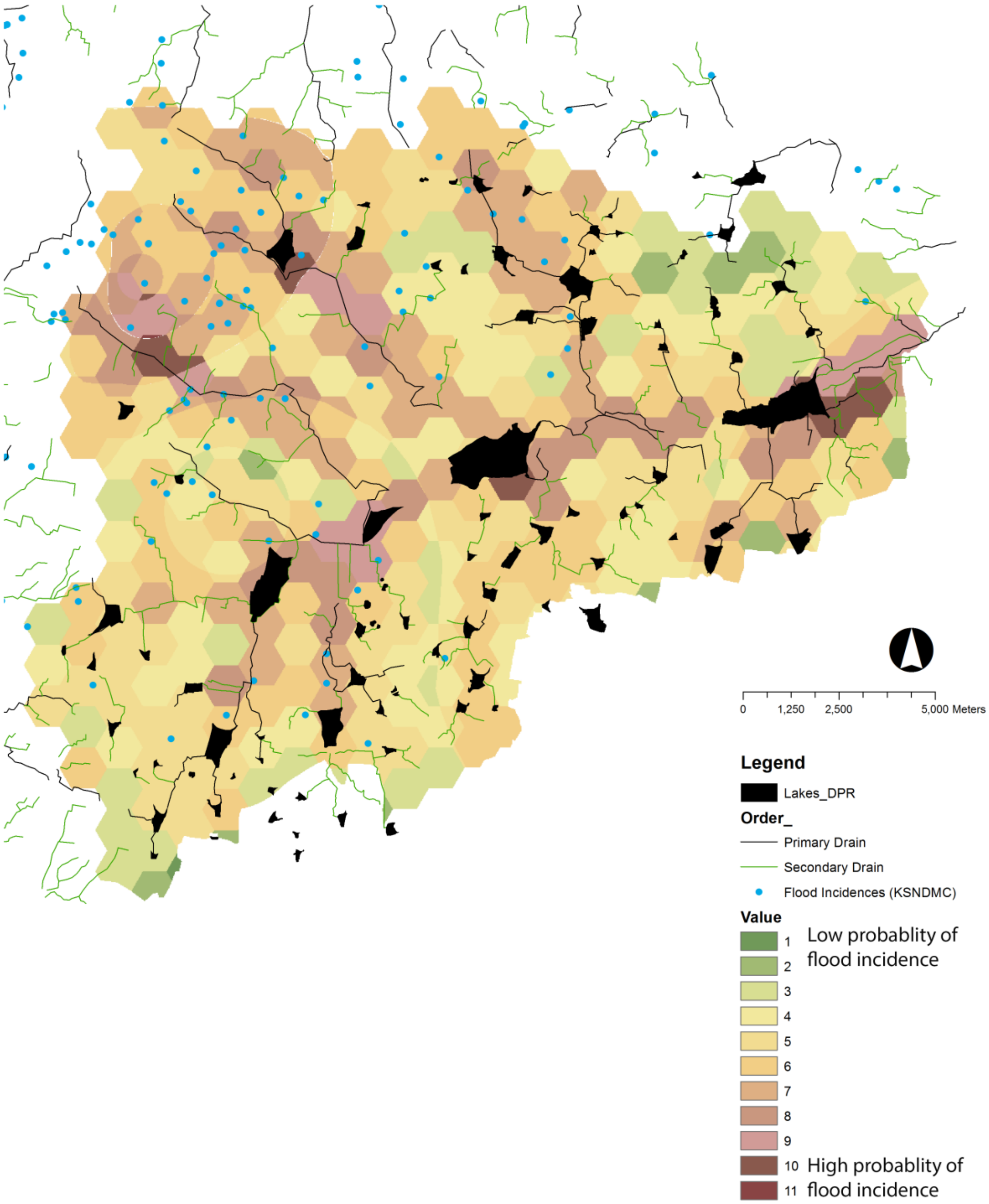


Figure 16 : Fig 20: Opportunities for Adaptation Map
Map By: Sayali Lokare ; Source: Refer Table6

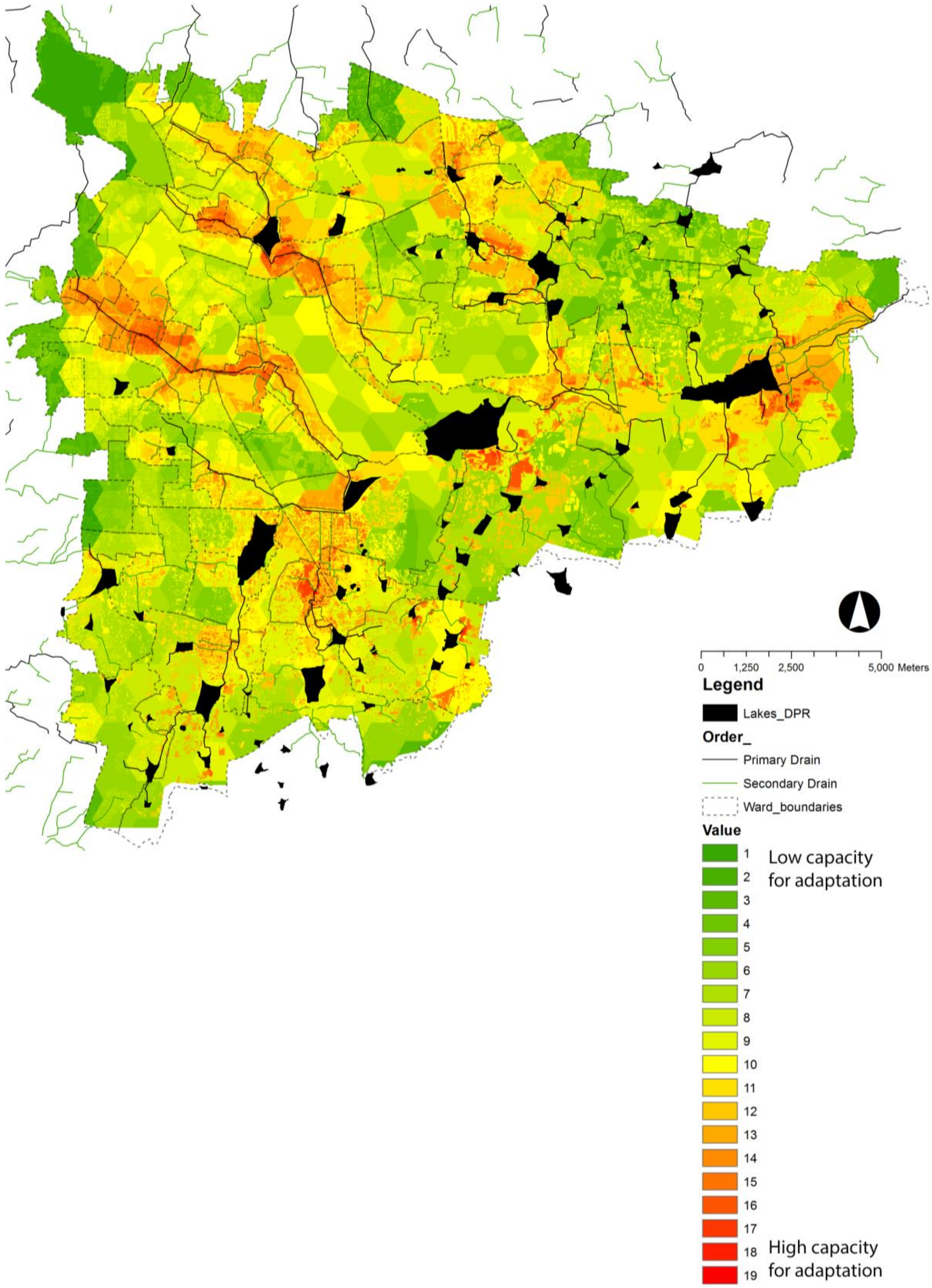


Figure 17: Map showing 13 identified clusters in high priority zones

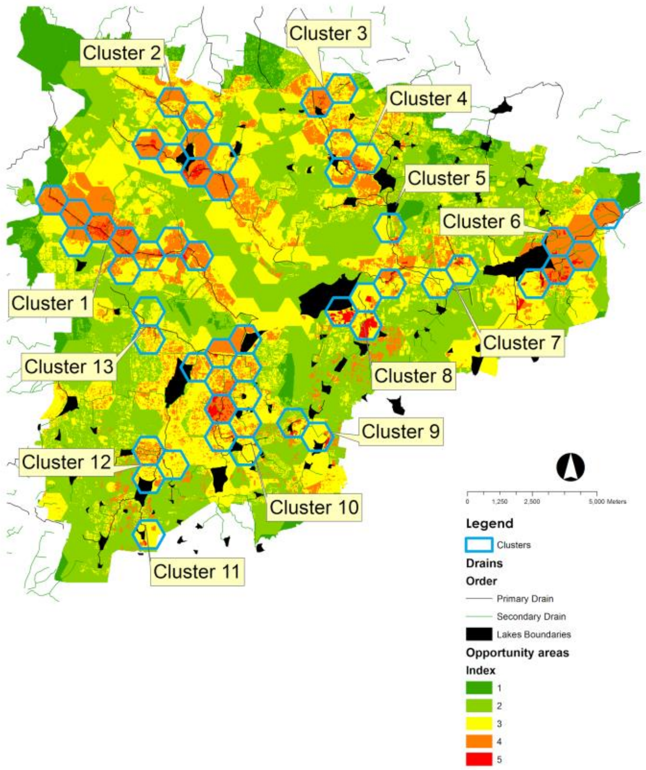


Figure 18: Map showing location of clusters with ward boundaries

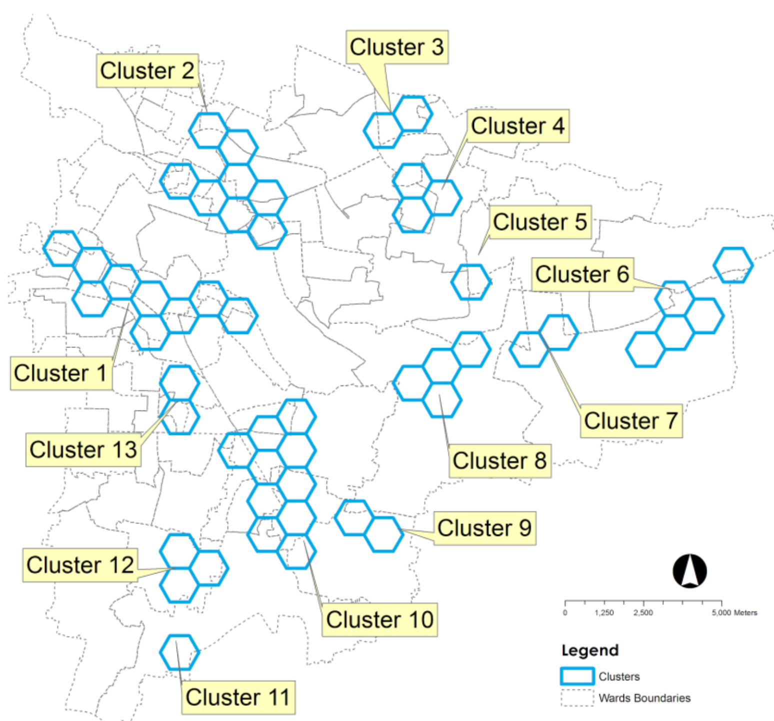


Figure 19: Map showing location of clusters with street grid

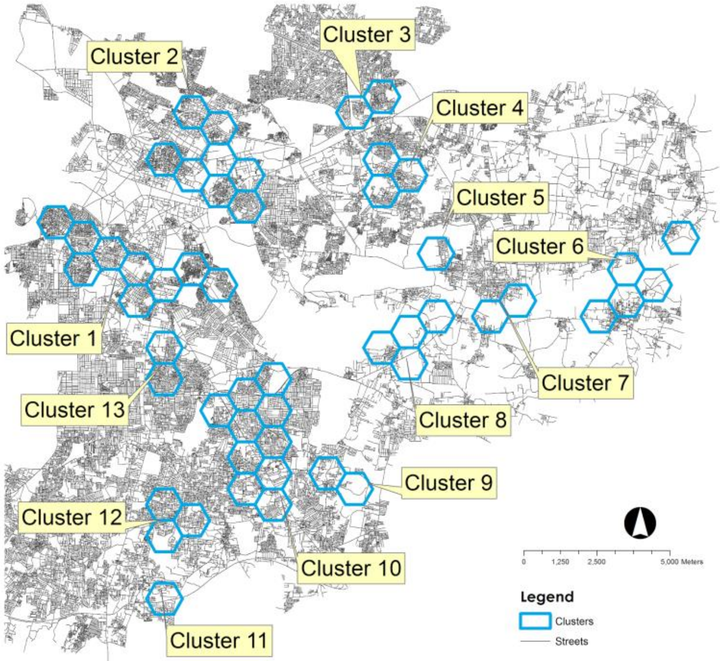
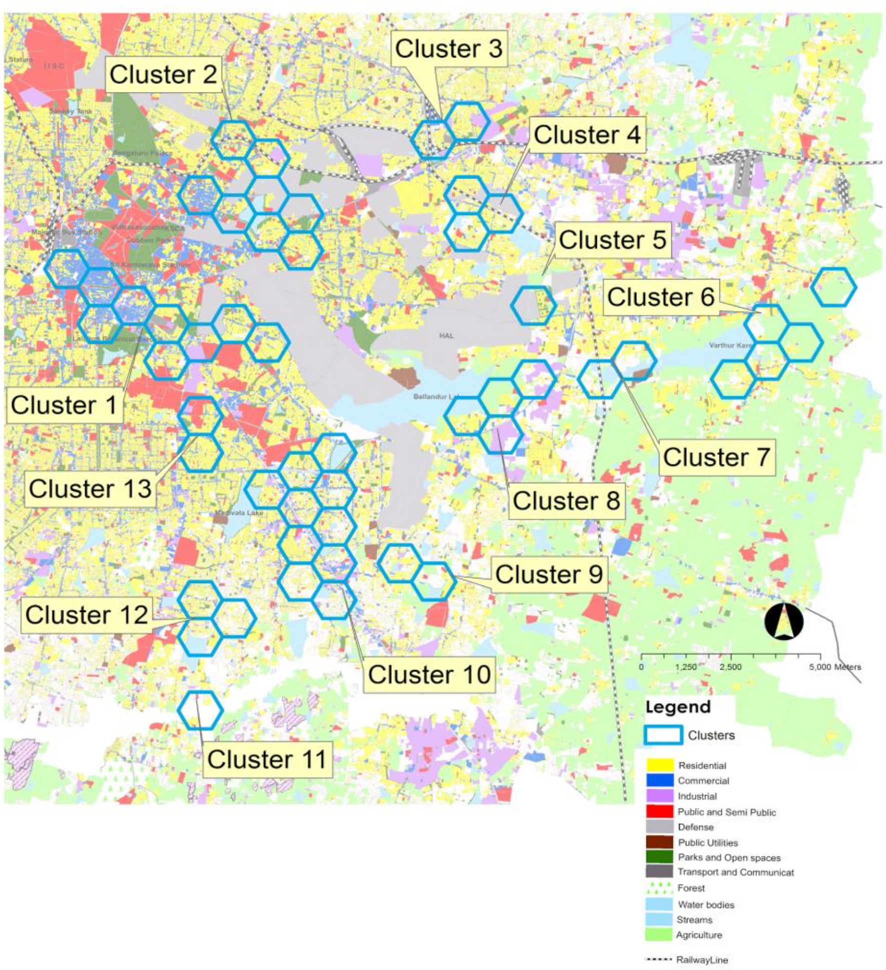


Figure 20 : Map showing location of clusters with existing landuse as of 2015 (RCDP 2031)



7. Recommendations

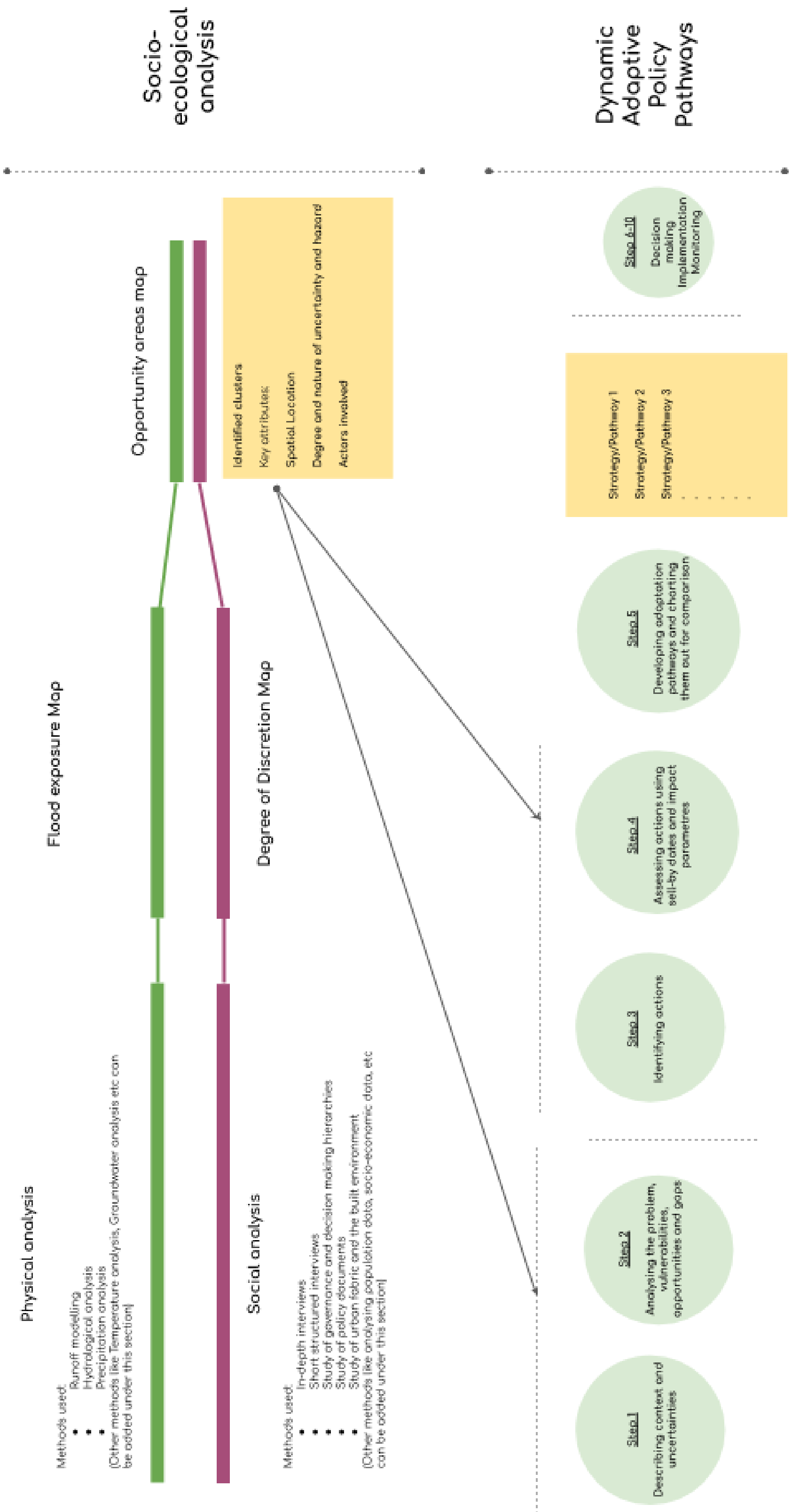
The current planning practice in Indian cities relies on Master Plans as the key tool to guide development and planning decision. Master Plans for cities like Bengaluru are prepared once every 10 years that are interspersed with policy and infrastructure decisions that often follow the development agendas of the government in power. In addition to this political uncertainty, uncertainties that come with changing climate patterns and local decision making processes, make strict compliance to a rigid planning document, a questionable endeavor. A natural shift toward an adaptive approach is seen where discretionary decisions and deviations from the main document start seeping into the planning process.

This thesis was undertaken as a response to this observation. The scientific methodology outlined in this study holds a lot of potential to acknowledge and formalize and adaptive frameworks for flood and stormwater management. The study demonstrates the use of scientific analysis using social and physical sciences combined with pattern recognition. This methodology combined with a chosen framework for adaptive management can be used to develop a strategy where various alternatives can be compared to attain a main objective (in this case flood mitigation).

In this chapter I demonstrate how the study can be combined with a chosen adaptive management framework to arrive at a strategy. I choose the Dynamic Adaptive Policy Pathways (DAPP) framework outlined by Hasnoot *et al* which I briefly go over in the next section.

Figure 21 summarizes my proposal of how this study combined with an adaptive management framework can be used to arrive at a planning strategy.

Figure 21: Figure showing how the study can serve as a useful input into an Adaptive management framework



Dynamic adaptive Policy Pathways framework (DAPP)

Nowadays, decision makers face deep uncertainties about a variety of external factors, like climate change, population growth, new technologies, economic developments etc. To address these deep uncertainties, a new planning paradigm has emerged. This paradigm holds that, in light of the deep uncertainties, one needs to design dynamic adaptive plans (Hasnoot et al,2013)**.** Such plans contain a strategic vision of the future, commit to short-term actions, and establish a framework to guide future actions (Ranger et al., 2010).

Reeder et al address this question of socio-economic and scientific uncertainties at a local level for the Thames Estuary 2100 project (Reeder et al,2011). They propose a strategy to deal with deep uncertainty in long-term decisions that incorporates flexibility into adaptation measures from the start. Haasnoot proposes a Dynamic Adaptive Policy Pathways approach that consists of a vision where a planner can commit to short-term actions while creating a framework to guide future actions. Both Hasnoot and Reeder, chart out route-maps that lay down possible actions and trace combinations of decision making pathways to generate a particular scenario. Each action is scored according to certain predetermined parameters, and cumulative scores for pathways can be calculated to assess their effectiveness. Here I will be focusing on the framework laid out by Hasnoot et al in their paper *Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world,* 2013.

As per Hasnoot's approach (Fig20) a 10 step cycle is involved in adaptive policy making.
The first step is to describe the study area, including the system's characteristics, the objectives, the constraints in the current situation, and potential constraints in future situations. The result is a definition of *success* or a larger overarching objective. The description of the study area includes a specification of the major uncertainties that play a role in the decision making problem. The second step is the problem analysis where one can start identifying the gaps in the current scenario with respect to the specified objective. A gap indicates that actions are needed. In the third step, one identifies possible actions that can be taken to meet the definition for success. The aim of this step is to assemble a rich set of possible actions. An identification of actions for different perspectives could enforce this (Hasnoot et al,2013). The fourth step is to evaluate the actions. The effects of the individual actions on the outcome indicators are assessed for each of the scenarios and can be presented using scorecards. The results are used to identify the sell-by date for each of the actions. The fifth step is the assembly of pathways using the information generated in the previous steps. It is conceivable that the reassessment of the vulnerabilities and opportunities in the previous step triggers an iterative process (back to step 3) wherein new or additional actions are identified. Once the set of actions is deemed adequate, pathways can be designed. The result is an adaptation map,

which summarizes all logical potential pathways in which 'success' (as defined in step 1) is achieved. Note that actions need not be a single action, but can be a portfolio of actions, constructed after iteration of steps 3–5 (Hasnoot et al,2013).

I do not go on to elaborate on steps 6-10 because these steps involve decision makers and processes of governance to deliberate on the results arrived at in step 5. This study does not address the decision making process itself, although it does aim to be a tool that can be used to aid it.

Using DAPP Approach to mitigate urban flooding

Looking at this 10-step cycle, the first 5 steps can be laid out for urban flooding in Bengaluru. Previous chapters of this thesis outline the current situation of urban flooding and the associated uncertainties (in terms of discretionary behavior) i.e Step 1 and 2. I use this information to generate the Opportunities for Intervention map that can be plugged-in to spatially identify clusters and associated actors within each cluster that can inform the next steps of this cycle. For the identified clusters and associated actors, using the interviews conducted and existing literature/ reports on the stormwater system for the city, we are then able to outline:

- Possible actions that are likely to be implemented by the actors in question (Step3)
- A scorecard to assess the efficacy of those actions (Step 4)
- Chart the Adaptation Pathways map for various strategies (combination of actions) (Step 5)

Having based this study on the discretionary actions of actors in the field as well as ecological factors impacting the watershed, we can use the Opportunities for adaptation map to imagine what different design pathways could look like if policy was to be made flexible enough to accommodate for discretion. Discretion and flexibility are central to this study and for this reason, exploring adaptation pathways and not a single rigid solution is more suited to this study.

I will now go on to outline these three steps based on the results and findings of the previous chapters of this study. I would like to highlight that this exercise is only a demonstration of how the study can be potentially used. The actions listed, their sell-by dates and the suggested strategies are in no way exhaustive or final recommendations and are not to be taken as direct proposals for implementation.

Figure 22: Dynamic Adaptation Policy Pathways approach by Hasnoot et al,2012

Step 3 - Identifying Actions:

A basic set of actions pertaining to primary and secondary drains, tertiary drains and upstream areas have been identified and listed.

1. Naturalise drain to accomodate 20 year storm
   Removing concrete channels and naturalising the drain channel and it's floodplain to accommodate a 20 year storm. This step will likely involve land acquisition if action 2 has not already been implemented and can add monetary costs to the project.

2. Clear and secure buffer zone as per NGT guidelines
   As per the NGT Guidelines a buffer zone of 35 m for secondary and 50 m for primary drains must be maintained, in which no built development is permitted. Currently there are multiple locations where built structure (legal and illegal) stand in the buffer zones. Clearing and securing buffer zones will involve displacing these populations, demolishing the structures and securing the zone from development in the future.

3. Reconstruct drain
   Reconstructing the concrete channel to increase capacity to handle larger storms has been a commonly implemented solution to stormwater woes of the city. The DPR

prepared by the BBMP Storm Water department in 2011, already proposes reconstruction of several parts of the drain network and has allocated funding and tenders based on the DPR analysis.

4. Re-align drain
   Re-aligning the drain to try and displace the minimum number of properties has been used by local SLB's to negotiate the interests of their clients/residents. It still involves the construction of a concrete channel that could be rerouted through a path where land is easier to acquire or already available.

5. Tertiary drain maintenance
   Clearing blockages in tertiary drains, desilting and solid waste management in wards can be undertaken to improve the flow of stormwater in tertiary drains. In this case, I list this action as a systematic and regular process that is set up by the local SLB instead of a ad-hoc need based step that is currently practiced.

6. Tertiary drain reconstruction
   Reconstructing tertiary drains where they are absent, upgradation of open street drains to covered or underground ones and increasing the capacity of existing tertiary drains all fall under this action.

7. Road level corrections

A common reason given during resident interview for flooding was the process of laying and tarring roads without de-surfacing the previous layers of asphalt. This tends to increase the resulting road level each time the asphalt is laid, making street pavements and street side drains inadequate. This action is considered as a single event to de-surface the many layers of tar that are currently present on the streets such that a more accurate datum can be set for tertiary drain design and construction.

8. Rain water harvesting (RWH) mandates

As per the BWSSB amendment act of 2009, every existing property more the 2400 sq mts and every newly built property is required to have a rain water harvesting system. Ensuring the implementation of this mandate and assisting, advocating and spreading awareness about RWH are the key components of this action. More number of RWH systems will help in capturing greater volume of stormwater runoff for seepage and can reduce the inflow of stormwater into the drain network.

9. Green infrastructure (Streets)
   This action entails the implementation of swales , permeable pavements and green infrastructure along streets to capture and infiltrate stormwater runoff.

10. Detention ponds
   Although the existing lakes are the largest detention ponds for the entire lake channel system, opportunities for detention ponds in upstream areas that can double up as recreational parks or local *maidans* is also a possible intervention.

Step 4 : Assessing the efficacy of actions

4a: Listing Impact parameters
Impacts of the listed actions are commonly seen through the lens of flood incidence and financial project costs. In this list, I include additional social impacts such as displacement, transportation disruptions, creation of public amenities and ecological impacts such as water quality, ground water recharge and impact on habitat/ecology. The impact parameters considered are:

1. Flood Incidence
2. Social impact (Displacement)
3. Built fabric (Demolition of public/civic/heritage structures)
4. Transportation
5. Public facilities/recreation
6. Groundwater recharge
7. Water Quality
8. Habitat and Ecology

4a: Determining sell-by dates for each action:
3 criteria drive the determination of sell-by dates for each given action: Design life, Increase in built area and frequency of storm events. For each given action, after assessing the sell-by date under all three criteria, I apply whichever has the shortest duration.

- **Design life:**

The design life of a component or product is the period of time during which the item is expected by its designers to work within its specified parameters; in other words, the life expectancy of a project. It is the length of time between placement into service of a single item and that item's onset of wearout. Most engineered projects have an estimated design life after which the structure is expected to need repair or replacement due to certain predicted failures. In the case of stormwater drain channels, the BBMP storm water department considers 25 years as the expected design life of a newly/reconstructed channel.(DPR 2011, BBMP Stormwater dept.) For other design typologies or components that are listed in the actions, I consider the design life for a domestic/multi-use rain water harvesting system (Gould and Niessen, 1999) to be an realistic estimate of 20 years.(Gould and Niessen, 1999) For green infrastructure typologies, studies show a variation in life spans. For the purpose of this analysis, I assume “Green infrastructure” to mean porous concrete and linear rain gardens (bioswales) wherever width permits. For porous concrete the life-span is shown to be 40 years (Montalto et al, 2007) and for rain gardens and bio-filtration systems although studies show that life-spans tend to be 20-40 years (Payne et a,2015) a regular level of maintenance cannot be assumed. Therefore, the realistic lifespan in this case can be considered as 15 years after which a significant retrofit might be required.

- **Development**
  The rate of growth of the city and increase in built area determines the availability of vacant land that can be used to implement stormwater systems. This could have implications on implementing buffer zone mandates and land acquisitions for certain interventions. It is also indicative of the excess runoff that is generated in the watershed that would flow into the stormwater system. For the purpose of this study we consider the mapping study done by Ramachandran for Bengaluru city from 1973 to 2007. There has been a average increase of 1.5% in the built area of the city from 1992 onwards.(Ramachandra Based on this percentage and the percentage of existing built area on a given site we can use this table to determine the time-frame available to acquire land that is vacant. This is a much easier and relatively cheaper process than acquiring land that contains built development as assets. This time-frame can be considered as the “expiration” or sell-by date for initiating execution of certain actions that involve land acquisition such as naturalising channels and building detention ponds

Existing % built area	Time frame available for land acquisition of vacant land	Total % increase in built area with 1.5% increase per year
0-20%	30 years	45%
20-40%	20 years	30%
40-60%	10 years	15%
60% and above	0 years	-

Table 8 : Table for time frame available for different existing densities of built fabric

- **Storm event frequency and climate change:**

As per the precipitation calculations done in the 2011 DPR by BBMP stormwater department, precipitation analysis has been done on rainfall for the past 20 years to determine rainfall intensities for 1, 2, 5, 10 and 20 year storms. The report's base assumption is that we will continue to see this precipitation pattern in the future as well. However with changing climate patterns, studies predict a significant increase in the Annual mean precipitation (Bhowmick et al, 2019),increase in monthly precipitation for the Summer Monsoon (Bhowmick et al, 2019) and an increase in the frequency of extreme daily precipitation over the south indian ocean (Bhowmick et al, 2019). All three of these pertain to the short duration intense rainfall events that cause urban floods in Bengaluru during the peaks of May and September.(Prasad and Narayan, 2016)

These can be treated as two different scenarios for the purpose of this study : Scenario 1- Following historical precipitation patterns and Scenario 2- Following climate change scenarios (RCP 8.5, RCP 4.5 etc). Due to limitations of time, I will only be looking at Scenario 1. However, for any future studies on this topic, I urge the need to explore the various climate change scenarios and their impacts on the sell-by dates of the interventions. Under scenario 1, the widths for drain reconstruction projects that are sanctioned under the DPR are designed for 2-5 year storms. In the event of a 20 year storm, the design is likely to be insufficient. For this reason, I assume a sell-by date of 20 years after implementing the "reconstruct drain" or "realign drain" action. For the "Naturalise drain" action, which I assume to be designed for a 20 year storm due to land acquisition limitations, I use the sell-by date of 50 years.

Scorecard:

Table 9 : Score card for listed actions showing impact parameter scores, costs and sell-by dates.

S.No	Action	Impact Parameters								Sell by date	Life span	Factor for sell by date	Costs
		Flood incidence and loss of assets	Social impacts	Built Fabric	Transportation	Public facilities/Recreation	Groundwater recharge	Water Quality	Habitat/Ecology				
		1	2	3	4	5	6	7	8				
	Primary and secondary drains												
1	Naturalise drain to accomodate 20 year storm	++	--	-	-	++	+++	++	+++	2050	2070-80	Recurrence interval	+
2	Clear and secure buffer zone	++	--	--	-	NA	NA	NA	NA	>2100		-	+
3	Reconstruct drain	++	NA	-	-	-	--	--	--	>2100	25 years	Design life/Recurrence interval	+++
4	Realign drain	+	++	++	---	-	-	--	---	>2100	25 years	Design life/Recurrence interval	+++
	Tertiary drains												
5	Tertiary drain maintenance	++	NA	NA	NA	NA	NA	+	NA	>2100	-	-	+

S.No	Action	Impact Parameters								Sell by date	Life span	Factor for sell by date	Costs
		1	2	3	4	5	6	7	8				
6	Tertiary drain reconstruction	++	NA	+	--	NA	--	-	NA	>2100	25 years	Design life	++
7	Road level corrections	++	NA	-	--	NA	NA	-	NA	>2100	10 years	Design life	++
	Upstream actions												
8	Rain water harvesting mandates	+	NA	+	NA	NA	+++	+	++	>2100	20 years	Design life/Recurrence interval	0
9	Green infrastructure	+	+	++	+	++	++	++	+	>2100	15 years	Design life/Recurrence interval	++
10	Detention ponds	++	+	+	NA	++	+++	++	+++	2050	25 years	Design life	++

Table 10 contd. : Score card for listed actions showing impact parameter scores, costs and sell-by dates.

Step 5 : Developing adaptation pathways and map

Site : Cluster 8

I will be charting possible adaptation policy pathways for cluster 8, one of the 13 clusters of priority sites identified at the end of the spatial analysis section. Based on the 3 criteria of variability among the clusters (Stakeholders, area available for intervention and possibility for secondary interventions) The key characteristics of cluster 8 are:

- Cluster 8 lies on the peripheral belt of the city near the boundary of Bellandur lake
- The entire cluster lies within the boundary of one single ward: Bellanduru. Tis means that the decision making lies with local SLB's for one ward only, and some sort of uniformity can be expected across the entire cluster with respect to stormwater interventions.
- The cluster contains a sparse street grid patterns that indicates large property sizes, with a dense pocket in the south of the cluster.
- The land use indicates that the properties might be largely residential or High-tech, making Tech companies possible stakeholders in the project.
- The proximity of the cluster to the Bellandur Lake indicates that the LDA might also be a strong stakeholder in the process.
- With sparse development as compared to core areas of the city, the area available for intervention is also higher around the existing stormwater drains. A few segments of the drain in the northern and southern tips of the cluster have restricted area for development.
- Cluster 8 also lies in a zone with a uniformly high degree of discretion index making it possible to recommend secondary interventions(such as green infrastructure and detention ponds) that lie upstream from the identified cluster.

In the final step of the proposal, I map 3 decision pathways that constitute a combination of the actions listed above. Pathway 1 assumes that the city mandated regulations about buffer zone clearance, drain alignment, Rainwater harvesting etc. are strictly enforced by local SLB's without discretion. Pathway 2 follows a scenario where actions are subject to SLB discretion and those that work around client/resident interests instead of against them. Pathway 3 is a proposed pathway that tries to take advantage of all the possible actions to meet both client interests and ecological goals.

Comparing the scorecards for the three pathways

Using the scorecard we can calculate a score for each of the pathways as a cumulative of the actions it involves. Comparing the three score cards we observe that over a long term, the costs and for pathways 1 and 2 are not significantly different. However Pathway 2 has a better impact score by not implementing the buffer zone mandate. However both pathways require 2 rounds of reconstruction and terminate around 2070. We also observe that they do not take advantage of the fact that the detention pond and naturalise drain interventions could have been implemented sooner in the strategy when lesser built development existed on site. Pathway 3, takes advantage of both these actions before they “expire” and gains significantly more on its impact score, both actions having several positive ecological impacts. It also uses the opportunity of reconstruction to implement ecological sustainable solutions such as green infrastructure along streets, that can handle storms of greater intensity and hence are able to have a longer sell-by date. Delaying the clearing of the buffer zone for pathway 3, also gives time to implement a rehabilitation strategy before clearing out the properties inside the buffer zones.

Once again, I would like the reader to note that the purpose of this exercise is to demonstrate the process of charting out multiple pathways and their comparison. This does not imply that there will always be one single pathway that emerges as “optimal”. In fact there might be multiple pathways with different tradeoffs which will have to be deliberated on. This approach simply gives us a clear framework to assess those tradeoffs with an added insight into how they would play out - both spatially and temporally.

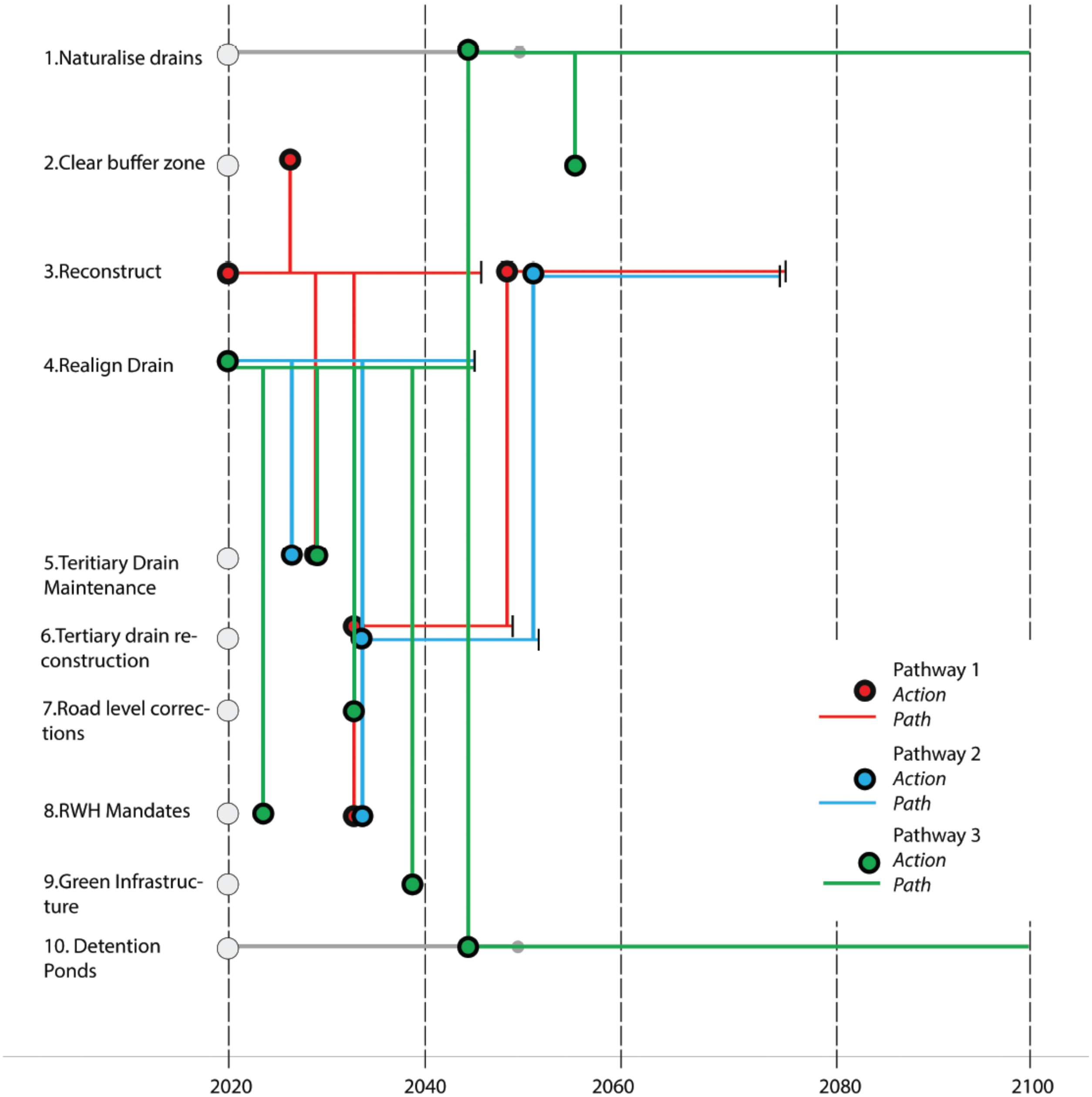


Figure 23: Figure showing 3 decision making pathways for Cluster 8

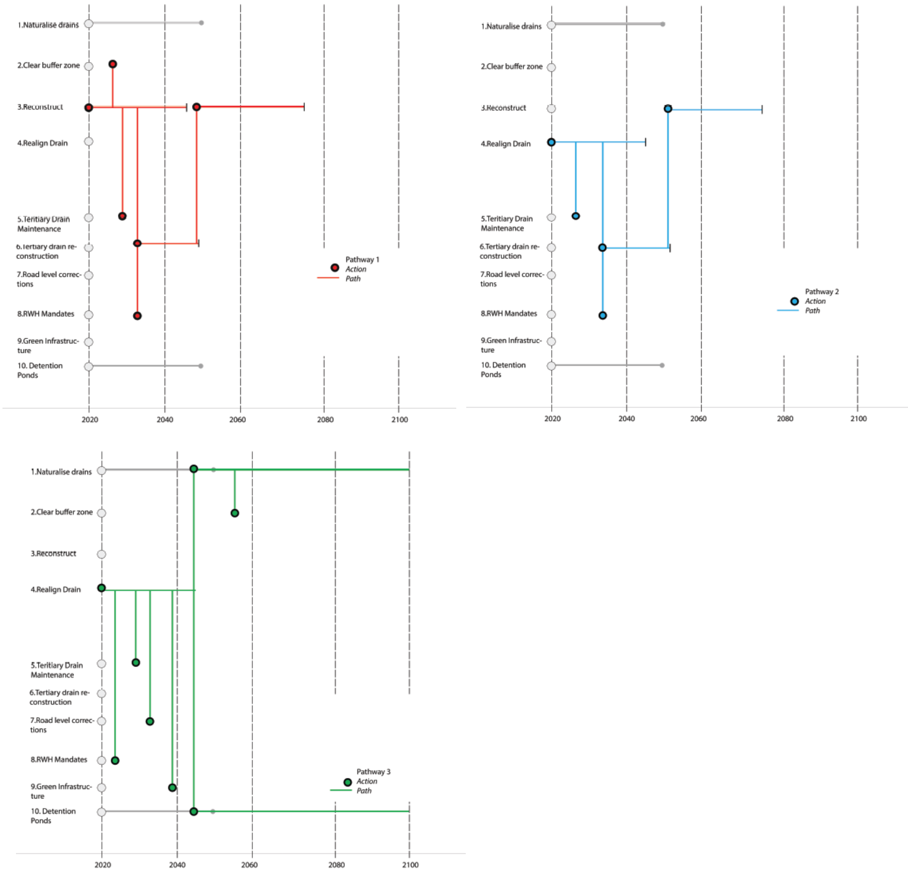


Figure 24 : Figures showing pathway 1, 2 and 3 (above) and their respective scorecards (below)

Pathway 1

Action	Impact score	Cost
Reconstruct drain	-7	3
Clear Buffer zone	-3	1
Tertiray drain maintenance	2	1
Tertiary drain reconstruction	-2	2
RWH Mandates	8	0
Reconstruct Drain	-7	3
Total score	-9	10

Pathway 2

Action	Impact score	Cost
Re-align Drain	-5	3
Tertiray drain maintenance	2	1
Tertiary drain reconstruction	-2	2
RWH Mandates	8	0
Reconstruct Drain	-7	3
Total score	-4	9

Pathway 3

Action	Impact score	Cost
Re-align Drain	-5	3
RWH Mandates	8	0
Tertiray drain maintenance	2	1
Road level correction	-2	2
Green Infrastructure (Streets)	12	2
Detention ponds	14	3
Naturalise drain	8	1
Clear Buffer Zones	-3	1
Total	34	12

Pathway 3 : Design strategies and typologies

Assuming Pathway 3 is the chosen pathway through the decision making process, I attempt to elaborate on possible physical interventions and strategies to achieve it . This can be achieved through 3 main strategies that builds on the strengths and characteristics of Cluster 8.

Strategy 1 : Stakeholder engagement
Actions: Re-Alignment + RWH Mandates
This strategy takes advantage of the fact that re-alignment of the drain will involve significant client/ stakeholder engagement on the part of the local SLB. Taking advantage of the continued engagement, pushing for larger properties and tech-campus to implement the rainwater harvesting mandate will reduce runoff significantly in very early stages of the plan.

Strategy 2 : A integrated streets proposal
Actions: Road level corrections + Green infrastructure (streets)
This strategy implements the action of correcting road levels, a much needed effort even to make existing tertiary drains function efficiently. Although a greater investment than just resurfacing roads, if this action could be paired with implementing permeable concrete or street side bioswales, the project can be tendered out as a integrated streets upgrade that can save costs if both actions were to be implemented independently at different points in time. This strategy is also possible because of the feasibility of secondary interventions as discussed earlier.

Strategy 3 : Land acquisition plan
Actions: Naturalising drains + Clearing buffer zones + Detention ponds
All three actions require a robust strategy for land acquisition, sensitive rehabilitation and fair compensation of property owners. Although implementation of these actions appears in the last stages of the plan, the time lag can be used to conduct studies about ownership, land values, suitability analysis for detention ponds and financial planning to acquire and rehabilitate in steady phases. This strategy is also possible because of the feasibility of secondary interventions as discussed earlier.

8. Conclusion and Significance

The central argument of this thesis was that, a study of floods and stormwater systems for an urbanised watershed like Bengaluru is inherently socio-ecological in nature. Taking into account both ecology of the watershed that acts as the natural driver for the disaster and also the human actors that physically shape the watershed to exacerbate it, presents a more complete picture of urban flooding. The occurrence of significant policy implementation gaps, or deviations related to stormwater and related land use, over the last two decades in Bengaluru city, was the main driver behind why we need to shift from a strictly ecological lens to a more socio-ecological one.

In order to examine this argument I employed a mixed methods approach, using qualitative methods followed by geo-spatial analysis to answer two main questions: First, which level of governance gives rise to deviations that result in the policy-implementation gap for stormwater infrastructure. Second, what is the degree of deviation that takes place and how does it vary across the watershed. Using the findings from the qualitative analysis I mapped the findings to generate a degree of deviation map. Superimposed on the flood hazard map, the final raster highlighted priority areas that faced both, a high probability of flood hazard as well as a high degree of discretion.

This thesis found that priority areas that emerge out of the analysis, do not always align with commonly held notions of flood hazard and risk zones. 8 of the 13 clusters that were identified were in upstream areas of the watershed. The spatial patterns of high discretion zones were more linear and along the drains in the core areas of the city, whereas, along the periphery, discretion zones were more uniformly spread over an area. Another observation that emerged out of the analysis was the presence of lakes in almost all the identified clusters making the Lake Development Authority a key stakeholder in intervention efforts.

The thesis went on to develop a possible policy pathway using the dynamic adaptive policy pathways framework to demonstrate how discretionary behaviour can be integrated with ecological goals to tackle flooding in the watershed. As per the final scores of the three mapped policy pathways, the suggested pathway fared better than conventional pathways in terms of impact parameters, although it was financially more costly. It also fared better possibly lasting for a longer time-span than technocratic solutions employed by Pathways 1 and 2.

The objective of this thesis was also to explore the application of a mixed research methodology that can serve as a useful approach to studying ecological phenomena that occur in urban contexts. Incorporating various climate change scenarios and population projections could be a possible direction to further refine the methods used in this thesis. A finer resolution of data and well-monitored recordings can also help in calibrating the models applied in this study and assess errors in their application.

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