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Reservoirs Beneath

Rural-urban linkages in groundwater sustainability at India's Ramganga river basin

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Groundwater sustainability in India's Ramganga river basin

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Abstract

This research studies groundwater sustainability in the Ramganga river basin of northern India. This region experiences a trifecta of hydrological stressors from groundwater over-extraction, frequent flooding during wet seasons, and agricultural droughts during dry seasons. There is a growing body of interventions known as Managed Aquifer Recharge (MAR) which attempts to co-manage these three concerns. One such example is a technology known as Underground Transfer of Floods for Irrigation (UTFI) proposed by the International Water Management Institute (IWMI.) The most common mode of UTFI is recharge ponds and IWMI has technically proven its validity along with extensive piloting work in rural regions of the upper Ramganga basin. When it comes to groundwater planning, what is missing is a holistic approach that encompasses rural and urban (R & U) to study their collective demand for groundwater and plan for implementation of recharge structures; thereby ensuring better groundwater sustainability. Considering this, this thesis analyzes opportunities and barriers for UTFI's scale-up in growing rural-urban regions of the Ramganga basin by unpacking rural-urban linkages. It proposes a holistic R+U approach for land-use planning to incorporate recharge infrastructures and in so doing, identify rural & urban implementation zones like existing ponds and parks for mixed interventions. This work adopts mixed-methods of qualitative and quantitative to conduct desk research and fieldwork, backed by relevant academic theories. The thesis culminates in land-use planning recommendations for the rural and urban to cohesively take steps towards groundwater sustainability and hydrological disaster resilience within a chosen study region. These recommendations are useful for planners and policy makers in the field, along with specific spatial, community, institutional and planning strategy aimed for IWMI's use.

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Acknowledgments

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Next, I am grateful to the International Water Management Institute (IWMI) for allowing me to build a thesis around their long-running work on the Underground Transfer of Floods for Irrigation (UTFI) under their *Water x Food x Energy* nexus research. Paul Pavelic, Faiz Alam, and Navneet Sharma were endlessly insightful and ready to offer content & context-specific knowledge, along with on-field support, throughout the 7 months.

I would also like to thank the funding bodies that made my fieldwork possible. These were IWMI, TU Delft's Global Initiative, the University Fonds FAST fund, and the AMS Institute. The fieldwork portion was fundamental to my final recommendations without which this thesis would be incomplete. My experiences in the field reach far beyond the results of this work and helped to expand my worldview as I embark on a career in city planning.

On the field, I was also met with a host of willing interviewees who shaped my stakeholder engagement. From officials to village and urban inhabitants, and experts from private and public organizations, I was able to conduct over 26 interviews during a short period of time. This would not have been possible without their openness and interest in my work.

And most importantly, I owe my deepest gratitude to my dear friends and family. Friends old and new, and my parents & sister all helped by encouraging me through challenges, troubleshooting when I got stuck on content matter, and ultimately pushing me to the finish line.

Motivation

I am keen on studying urbanization with the aim of planning for future development. Since the liberalization of our economy in my home country of India, we have seen rapid growth in various economic spheres - and with it, a rapid growth of our cities. In this century, India is only set to grow further. In my experience from my hometown of Coimbatore, south India, I have seen many inner and outer-city communities, ecosystems and resources being overlooked during planning. This also comes with inefficiencies in resource allocation of current resources, let alone future needs. And many Indian cities share this – rapid growth that might be faster than the planning system to catch up to and efficiently accommodate. In my education and professional experience thus far, I have studied engineering systems and planning approaches to urban design in the US and now here in the Netherlands - be this for urban energy or water management. Therefore, as part of my penultimate project in my MSc. MADE career, I wish to bridge my experience to the context of India.

While exploring thesis topics, I was interested in water management and innovative approaches that co-manage different challenges, i.e., more efficient systems. This led me to the International Water Management Institute (IWMI)'s project on Underground Transfer of Floods for Irrigation (UTFI), which positions itself at the Water x Energy x Food nexus, i.e., how can we ensure water access for food production while simultaneously addressing groundwater depletion, floods, and droughts. Thus, this thesis explores how UTFI might prove an innovative solution to India's rising rural-urban groundwater demand while providing hydrological disaster resilience in the face of urbanization taking 2035 as the timeline. I focus my analysis around a study area in northern India in the state of Uttar Pradesh. I take the perspective of hydrosocial territories from water justice to holistically view the rural-urban interlinkages, rather than only centering urban nodes. This is a suitable lens as water management issues transgress boundaries of city vs. village and as I embark on a career in developmental planning, I hope such a study expands my perspective. Water being a fundamental resource has always been the linchpin of civilizations, and the poem below from the ancient Indian text of Thirukural in Tamil perfectly encompasses my motivations behind this thesis project.

Thirukural Kural 20:

நீர்இன்று அமையாது உலகெனின் யார்யார்க்கும்

வான்இன்று அமையாது ஒழுக்கு.

When water fails, functions of nature cease, you say. Thus, when rain fails, no men can walk in duty's ordered way (Tiruvalluvar, Penguin Classics, 2005).

The Thirukural is over 2000 years old and the above Kural 20 emphasizes that without rain the water cycle is in disarray, and without that nature and livelihoods are out of balance. In my context, I interpret this as the need to save rain and flood waters, which can serve as a foundation for society's growth.

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Abbreviations

AS pond scheme – Amrit Sarovar recharge ponds national scheme
BDO – Block Development Officer
CDO – Chief Development Officer
CGWB – Central Groundwater Board
GW – groundwater
IBF – Induced bank filtration
IGRAC - International Groundwater Resources Assessment Center
IWMI – International Water Management Institute
IWRIS – Indian Water Resources Information System
KLD – kilo liters per day
LPCD – Liter per capita per day
MDA – Moradabad Development Authority
MGNREGA – Mahatma Gandhi National Rural Employment Guarantee Act 2005
MLD - millions of liters per day/megaliters per day
MLY – millions of liters per year
NBS – Nature-based solutions
NCR – National Capital Region
NIUA – National Institute of Urban Affairs
NOC – no-objection document
R-U – rural-urban
RWH – rainwater harvesting.
SMEs – Small-to-medium enterprises
SW – surface water
UP – Uttar Pradesh state
URMP – Urban River Management Plan
UTFI – Underground Transfer of Floods for Irrigation
WWF – World Wildlife Fund

1 Introduction

Chapter preface

This research studies groundwater sustainability and hydrological disasters (floods and droughts) in growing regions of northern India by taking a solutions-perspective. It evaluates the landscape of co-management solutions known as Managed Aquifer Recharge (MAR) by testing one example intervention known as Underground Transfer of Floods for Irrigation (UTFI) proposed by the International Water Management Institute (IWMI). Opportunities and barriers for scale-up of UTFI within a study-region are evaluated by uncovering specific rural-urban linkages of the study region. This introductory chapter sets the context, highlights the urgency for such solutions, establishes the research aim & scope, and finally introduces the research questions.

1.1 Background

1.1.1 Groundwater as a limited resource

Groundwater is the most critical source of freshwater on earth, accounting for 99% of all liquid freshwater(UN IGRAC, 2018a). Dialogue around climate change concerns is increasing globally, with topics around solar and wind energy scale-up to green hydrogen generation being center stage. However, given its critical importance, further emphasis on groundwater sustainability is urgently needed. Globally, groundwater overuse and the risk of aquifer depletion are a mounting concern; regions experiencing recurrent water stress are the Sahel, South Africa, the central U.S., Australia, India, Pakistan, and North-East China (Wada et al., 2010). At least 2 billion people in the world use groundwater as their primary source of water, and India and China are the largest consumers (Hackley, 2018). Further, the theme of 2022's UN World Water Day was "Groundwater: Making the Invisible Visible" serving as a testament to the rising emphasis on groundwater sustainability. While groundwater is not an explicit Sustainable Development Goal and only target 6.6 addresses it, the UN World Water Development Report emphasizes that close to 53 other developmental targets are interlinked with groundwater (UN IGRAC, 2018b).

1.1.2 State of groundwater issues in India

India is a vital country when studying groundwater both because it is a large consumer and because the sub-continent is naturally endowed with fertile soils, a favorable climate, and an abundant supply of water. The Indo-Gangetic plains of north India are a critical rice basket for the world (Aggarwal et al., 2004), producing food not just for India but for the global food trade. Further, the Ganga (Ganges) basin in North India, which is part of the larger Ganga-Brahmaputra river basin, covers vast regions across Tibet, Nepal, India, and Bangladesh, making it one of the most populated river basins in the world with a population density of 550 people / square kilometer (Natarajan, 2013).

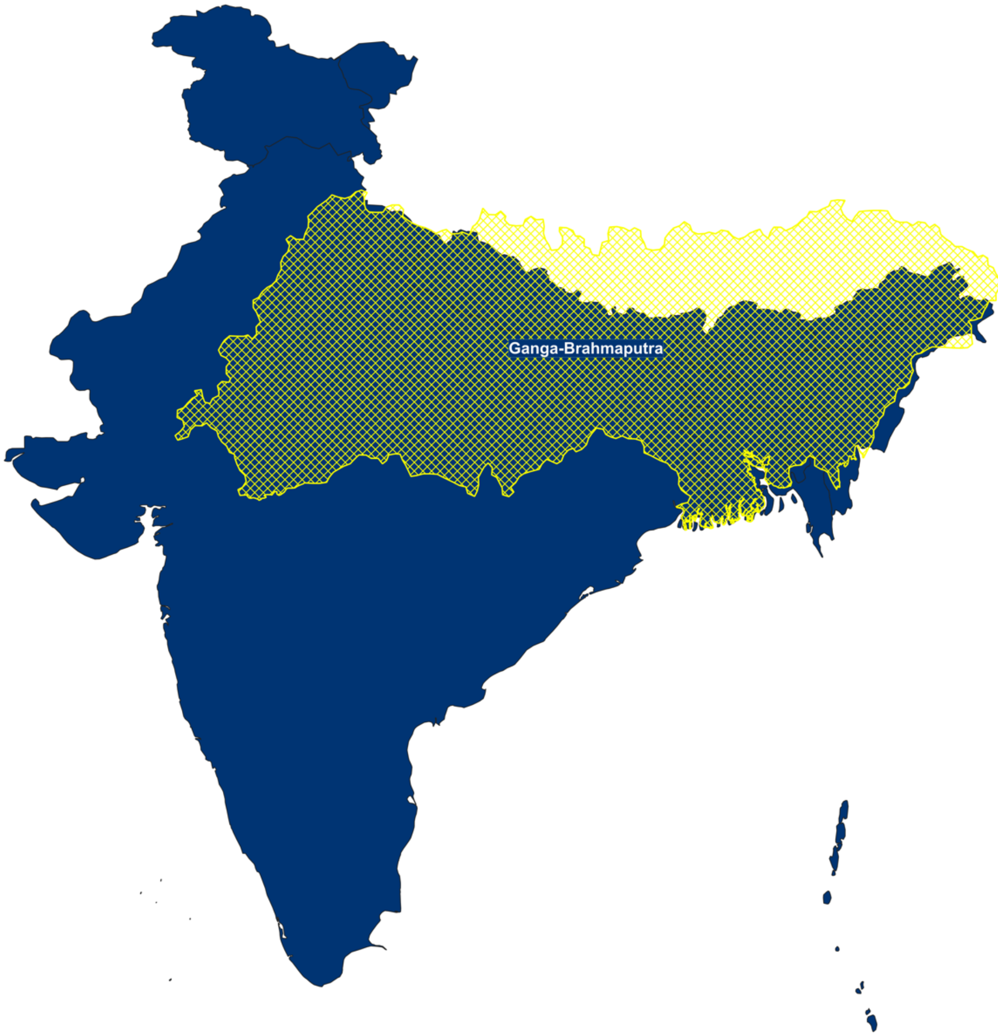


Figure 1-1: This map demonstrates the extent of the Ganga-Brahmaputra River basin across South Asia, generated using World Bank World Basins dataset.

In recent years, India has also been straining its aquifers. A Reuters Graphics report from 2019 extensively studied every Indian district and presented an online dashboard from safe, to semi-critical, critical, and overexploited districts (Bhatia, 2019). Some of India's megacities and economic centers like Delhi (north India, Ganga River basin), Chennai, and Bangalore (south Indian basins) are overexploited. Looking further at the Ganga River basin, second-tier cities like Varanasi or Moradabad located in the basin's fertile plains are rated as critical or semi-critical respectively. Lastly, when it comes to demand drivers for India, it is a direct function of irrigation requirements for the global food trade (Dalin et al., 2017) and strains from rapid Indian urbanization (Bhatia, 2019). I.e., both local and global dynamics dictate how the local resource of groundwater is consumed.

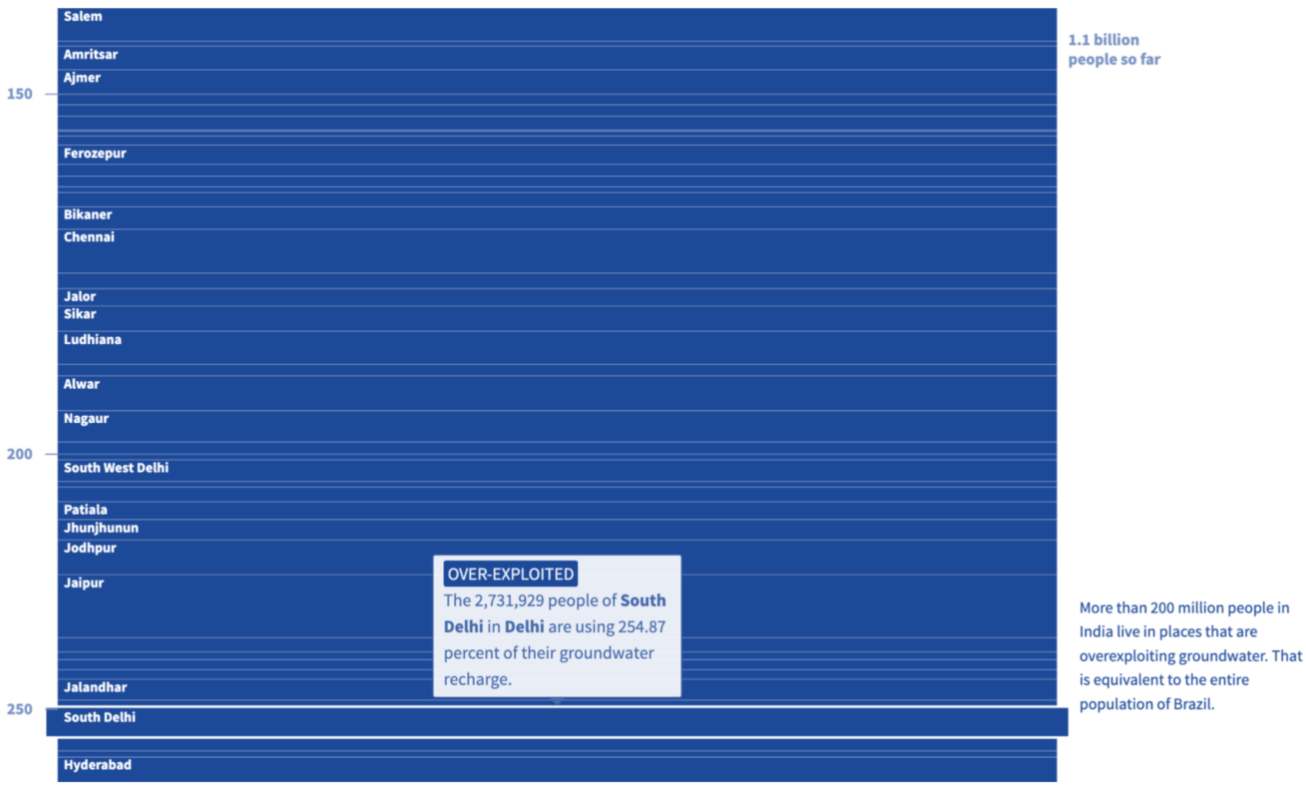


Figure 1-2: This figure depicts an excerpt from Reuter's dashboard visualizing Indian cities & their state of GW use. Notable cities like Delhi, Hyderabad & Chennai are all over-exploited (Bhatia, 2019).

1.1.3 Coupled phenomena of water-related disasters

In addition to groundwater overexploitation, regions in the Ganga basin also face increasing occurrences of water-related disasters like floods and droughts. With climate change, wet seasons are becoming wetter, and dry seasons drier (Padma, 2020). On the surface, the issues of floods, droughts and groundwater depletion might seem disconnected, but these are intrinsically linked through the earth's biophysical conditions, human-induced growth aspects, and climate change (Das et al., 2007). A recent study from a team of IIT Roorkee researchers & the National Centre for Ocean and Polar Research, Goa used satellite data to show that the Indus-Ganga-Brahmaputra basins are experiencing less rain and warmer weather, which is further depleting already overexploited groundwater reserves (Patel et al., 2021). For this research on the flooding side, for rural and urban contexts I will study fluvial or river flooding of my case-study area. Pluvial or flash flooding is relevant only to the extent to which these floodwaters are drained through streams from inner-city regions to neighboring rivers. And for the drought side, my focus is on agricultural drought since that is interconnected with groundwater i.e., lack of access to or the decline of the water table used for irrigation needs.

1.1.4 Indian Urbanization

When addressing water-related issues in the Ganga basin, it is also important to study urbanization and growth – i.e., the backdrop against which groundwater demands are shaped and the level of impact disasters might have on growing regions. India is a rapidly urbanizing country and home to some of the world's megacities. As of 2021, India's urbanization rate was 1.34%; a positive urbanization rate means the urban population is growing at a rate faster than the total population (India's Rate of Urbanization (2010 - 2021, %), 2023). India's growth is still trending upward rather than tapering down.

Here it should be underscored that urbanization is a complex process involving socioeconomic development, shifts in GDP proportions towards more tertiary sectors, and the general influx of people into cities seeking their right to opportunity (US EPA, 2015). It is not a mere reflection of population growth, which is a necessary caveat as overpopulation is often blamed for an increase in demand for critical resources like water, energy, and food. It is vital to call out the notion of overpopulation especially when working in the Global South context as it comes with many implicit biases and connotations that I hope to avoid in this research. Research by some UN bodies like the UN Population Fund highlights that the problem at hand is more nuanced – it is about equitable resource distribution & management, and governance & power structures, rather than the simple number of people (UNFPA, 2022). Therefore, this perspective of equitable management for the case of groundwater will form the philosophy of my research.

Next, the Ganga River basin is a massive breadbasket, and many large cities are located along this floodplain. Indian states along the basin derive a sizable portion of their GDP from agriculture. An example is the state of Uttar Pradesh (UP) in the Ganga basin – with large cities like Varanasi and Lucknow to the east and Moradabad and Bareilly to the west. In the case of Uttar Pradesh, it derives 27.46% of GDP from agriculture i.e., primary sector, compared to the national case of 20.19%, (India GDP Sector-Wise 2021 - StatisticsTimes.Com, 2021) demonstrating the importance of agriculture and irrigation in the state. And lastly, on population, 77.7% of UP's demographic is rural, compared to the national case of 68.84% (Shalu, 2020). This shows that UP is not the most urbanized state, but given that some key cities, both first and second tier, are present, it makes an interesting case to understand groundwater use between agricultural needs and growing urban needs. It is also important to take a holistic approach to incorporate both the urban and rural to achieve equitable management of groundwater. This is because of the nature of development trajectories i.e., how cities form & sustain. As such, this thesis will develop a case-study approach in selecting a region of interest in the state of UP, which includes a core city and its surrounding villages to analyze rural-urban linkages & dependencies in groundwater sustainability especially when considering the growth trajectory & future demand of this region. In doing so, the hope is to develop recommendations for holistic groundwater recharge planning.

In summary, all the above underscores a critical issue for India, and specifically the Ganga River basin. Urban and rural demand for groundwater is increasing in an already overexploited region, and climate change is bringing other coupled disasters. But the region is one of the most well-endowed aquifers of the world and there is room for better management. So, what are some current solutions for groundwater recharge?

1.1.5 Current Solutions - Managed Aquifer Recharge (MAR)

One suite of civil engineering solutions that targets many of these hydrological phenomena at once is known as Managed Aquifer Recharge (MAR). It is a series of water management methods that recharge an aquifer using either surface or underground recharging methods, and this stored water can later be retrieved in dry months (Luxem, 2017) thus alleviating groundwater overextraction & agricultural drought. There are many types of MAR including percolation ponds, check-dams, reverse drainage, borehole or shaft drainage, sub-surface dams etc. (DEMEAU, 2015). One simplified setup is visualized in the below Figure 1-3 showing a recharge pond (labeled infiltration structure) and nearby injection wells and abstraction wells, which call all collectively be deployed under MAR.

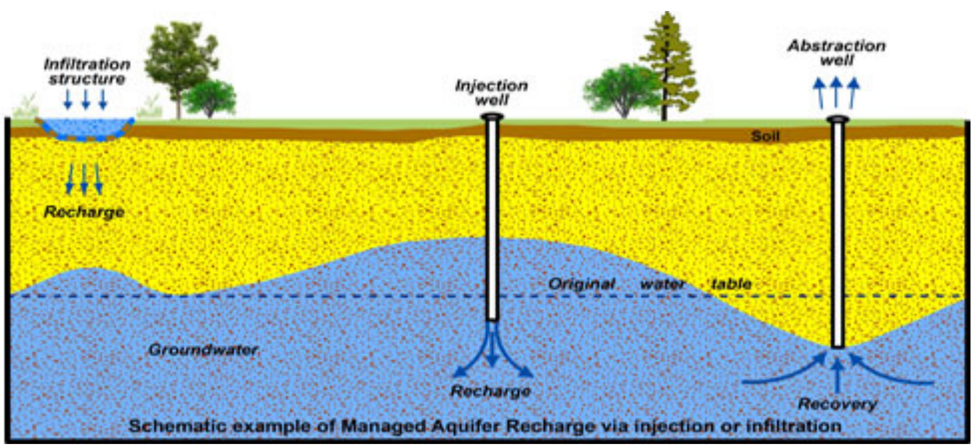


Figure 1-3: This schematic visualizes the different MAR modalities like a separate recharging pond, injection, and abstraction wells (Frost, 2016).

For the Ganga River basin there are some MAR approaches being implemented like the Ganges water machine (GWM), pumping along canals (PAC) and distributed pumping and recharge (DPR) (Ratna Reddy et al., 2020a). A modified version of MAR proposed by the International Water Management Institute (IWMI) is known as Underground Transfer of Floods for Irrigation (UTFI.) This technology works on the same principles as recharge ponds but proposes to recharge using flood waters that stagnate as surface water during flooding months. Therefore, UTFI attempts to address the trifecta of groundwater overextraction, excess flooding during wet seasons, and scarcity of drought in dry seasons (Ratna Reddy et al., 2020a). The below Figure 1-4 demonstrates UTFI on a conceptual level (Pavelic & Alam, 2020).

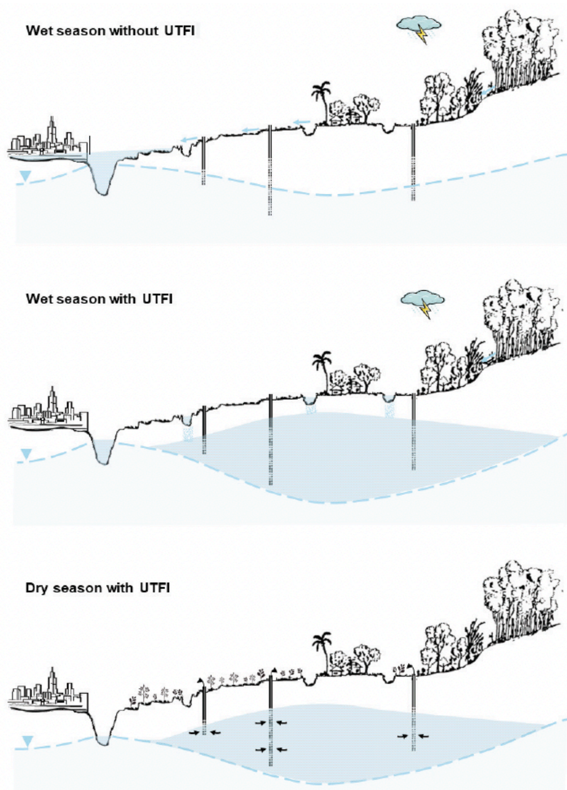


Figure 1-4: This graphic shows IWMI's conceptual explanation of UTFI's impact during dry and wet seasons (Pavelic et. al, 2020).

While MAR is an interesting technical solution, it does face barriers both in its Indian context, and from cases around the world. A literature review revealed that MAR is also widely explored in Mexico City and California (both rural and urban), and challenges experienced in these contexts are relevant to other contexts as well. For instance, one paper examining MAR for Mexico City concluded that while technical and economic challenges prevail, regulatory frameworks, water governance & maintenance responsibility are also a challenge (Palma Nava et al., 2022). A similar interdisciplinary study in California highlights that while geological and infrastructure-related considerations are well-explored, critical evaluations of land-use planning for implementation are limited (Ulibarri et al., 2021). And finally for the case of UTFI, IWMI has long been researching the technology with extensive hydrological modeling & technical feasibility already demonstrated. But key papers published by IWMI also highlight the governance challenge and propose required frameworks for scaling up UTFI in the Ganga River Basin context (Ratna Reddy et al., 2020a). I.e., there is a research gap land-use planning strategies and institutional frameworks for MAR implementation.

Globally, existing work in MAR either heavily focuses on the rural or urban contexts. Work is yet to be covered for addressing rural and urban applications cohesively. Examples on rural work include UTFI from above; IWMI's work has focused on rural piloting in a pilot area of the Ganga River basin. The pilot area was specifically a sub-basin of the river Ganga's first distributary – the Ramganga, which will also become the focal sub-basin of this research. And looking to the future, IWMI has outlined ambitions to explore urban & peri-urban implementation (Pavelic & Alam, 2020). Next on the urban side, examples of MAR for cities include a research case in South London proposed by the Urban Flood Resilience consortium at Cambridge University, where MAR is coupled with urban runoff from rainfall events and urban flooding (Kapetas, 2018). Therefore, work is needed in understanding land-use planning, institutional frameworks, and the sociotechnical connections that underpin rural & urban groundwater sustainability.

1.2 Problem Statement

So far, I have discussed some key water-related concerns for the Ganga River basin and India at large – from groundwater over-extraction, coupled phenomena of water-related disasters and state of Indian urbanization. These facets when triangulated form the problem field and larger context behind this thesis as illustrated in the below Figure 1-5. I have also highlighted the current solutions landscape which includes MAR, and the challenges MAR faces. I also introduced an example MAR technology of UTFI recharge ponds, which is relevant for the Ganga River basin and this research.

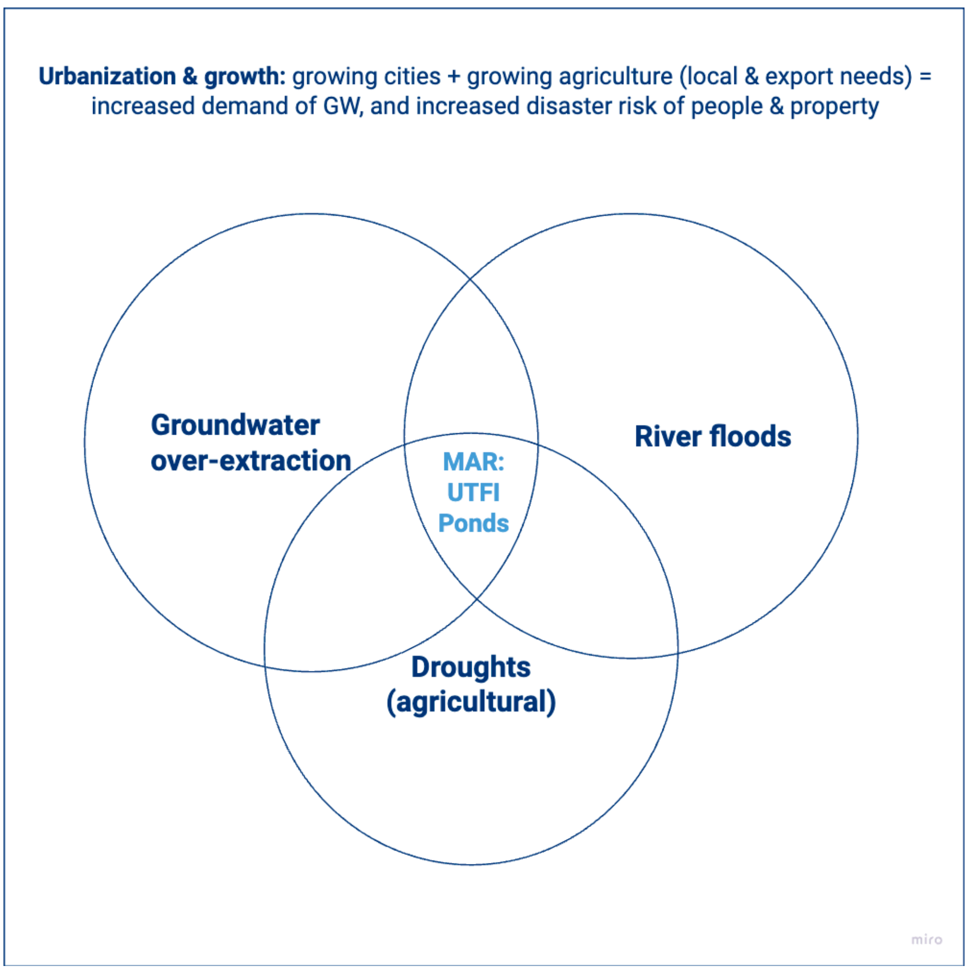


Figure 1-5: This graphic shows the problem triangulation and context for this research.

Therefore, the larger problem statement to address is: There is an acute urgency to at once plan for growing demand in cities & rural irrigation, recharge groundwater resources, and at the same time alleviate water-related disasters like droughts & floods which negatively impact these growing regions. This problem statement will be honed into a sociotechnical & land-use planning analysis for a study region encompassing rural and urban, to holistically assess the opportunities and barriers for UTFI ponds as the example solution technology.

1.3 Research Aim

1.3.1 Research approach & aim

Here I outline the main research question along with the sub-questions that will help in answering it. This is done through a case-study approach where the spatial aspect is choosing a specific study region, and the intervention aspect is choosing a specific MAR intervention i.e., UTFI recharge ponds. Given the case approach, a field trip to the location is also a part of this study. The research questions are also categorized by their phase pre-, during, and post-field trip. The overarching aim of this research is uncovering opportunities and barriers to UTFI's scale-up to then develop recommendations.

Table 1-1: List of research questions

What are the opportunities and barriers of UTFI recharge pond technologies in developing rural-urban regions of the Ramganga Basin when used for improving groundwater sustainability & hydrological disaster resilience?			
Phase	*#*	*Sub- research question*	*Objective*
Pre field work	SQ1	What is the current state of groundwater management & what technologies are available to address the drought-flood-groundwater nexus?	Review current literature, challenges and lessons learned from similar projects globally, help narrow down on core research gap surrounding MAR & UTFI.
Pre field work + during	SQ2	Where can UTFI technology be potentially tested in the Ramganga Basin and to what capacity can it address the drought-flood-groundwater nexus?	Select a study region encompassing rural and urban. Allow of mixed methods between GIS mapping and developing a criteria list based on various aspects like urbanization trends, village distances to focus river, recent flood events etc.
Field work	SQ3	What rural-urban linkages pose opportunities and barriers for UTFI recharge ponds?	Allow for fieldwork approaches, observations, and learnings; assess opportunities and barriers through the specific lens of rural-urban linkages which also serves as a larger umbrella for institutional frameworks, i.e., one type of linkage
Post field work	SQ4	What locations & recommendations can be identified for future implementation of UTFI recharge ponds?	Develop recommendations using fieldwork data and post-fieldwork analysis. Help in developing 3 final products: 1. land-use recommendations across rural + urban 2. mixed-interventions recommendations across rural + urban 3. UTFI urban scale-up locations using Moradabad city masterplan2031.

1.4 Scope

It is important to highlight the complexity & large-scale nature of groundwater sustainability in a region like North India where the issue undercuts several disciplines from hydrology to policy & governance. Therefore, for this MSc. thesis, certain aspects will be out of scop while others will be emphasized further to align with the program requirements. These are:

1. Groundwater quality will not be considered in-depth but is recognized as a critical piece. The focus will lean on groundwater quantities, and the source water for recharge will be narrowed to clean run-off and rainwaters, rather than greywater.
2. The importance of food production in connection to groundwater demand is recognized but not delved into. A more extensive study will also account for quantitative food footprints in relation to groundwater footprint, i.e., where the agricultural output from rural regions travels to. For this research, the scope stops at briefly highlighting a few crops entering the focus city of Moradabad from the focus villages as discovered during fieldwork to demonstrate one rural-urban linkage.
3. This research studies one MAR modality of UTFI recharge ponds to refine fieldwork and data collection within a 7-month period but recognizes the many typologies under MAR.
4. Land-use laws are recognized as relevant but out of scope for this study. However, the spatial side of locations and required land percentages for land-use planning is relevant.

1.4.1 Thesis partner organization – International Water Management Institute (IWMI)

The above section briefly introduced one MAR technology of UTFI proposed by IWMI. For this research over a 7-month period from March – September 2023, I worked in partnership with IWMI to evaluate rural-urban linkages in groundwater sustainability using UTFI's implementation as an example. For IWMI and its larger parent organization CGIAR, UTFI is an intersectional proposal and falls under their *Water x Food x Energy* nexus body of research ("NEXUS Gains," n.d.). IWMI operates in the larger scope of development challenges for entire countries, but for the purposes of my research I will be evaluating UTFI for a specific metropolitan region in the Ramganga basin and its connection to the surrounding villages. UTFI's positioning within the Water x Energy x Food nexus emphasizes the impact & interconnectivity of groundwater issues. My research is primarily independent, with periodic check-ins and contextual insight from IWMI. For the month of May-June 2023, I conducted fieldwork in my case region later described, and during this period I had increased collaboration with IWMI's Delhi office.

Chapter summary

This introductory chapter established the context, partner organization, the interdisciplinary sustainability problem at hand and the set of research questions needed in unpacking it. Critical takeaways are the holistic lens of rural plus urban that I will adopt, studying UTFI's relevance for urbanization needs & co-phenomena of hydrological disasters, and realizing the institutional & land-use planning gap MAR faces currently.

2 Theoretical Framework

Chapter preface

This chapter outlines concepts and existing theories that are relevant to this research, and as defined by the University of Southern California, it serves as the conceptual basis for understanding, analyzing, and designing ways to investigate relationships between social systems (Labaree, 2023). For this research, a theoretical framework is vital given the topic's interdisciplinarity, thus forming the backbone of the upcoming chapters.

2.1 Hydrosocial territories

This theory is the main philosophy behind why my research encompasses both the rural and urban. There is a growing body of theory to understand interactions between humans, their hydrological landscapes, institutions, and other aspects of society as it becomes more evident that water-related issues are seldom purely technical. One such theory is that of hydrosocial territories, which is defined by Boelens et. al as "spatial configurations of people, institutions, water flows, hydraulic technology and the biophysical environment that revolve around the control of water" (Boelens et al., 2016a). Hydrosocial territories offers a spatial dimension while also encompassing hydraulic technology in studying human-water relationships and this holistic lens is relevant. Here, the spatial will include rural and urban study regions and resulting land-use planning recommendations, the hydraulic technology is UTFI, and human-water relationships addressed is the dimension of stakeholders & institutions.

2.1.1 Rural-urban connections within hydrosocial territories

Rural and urban regions interact through sharing resources, people flows, economic flows and many other dependencies. A pertinent paper discussing this is "Evolving connections, discourses, and identities in rural-urban water struggles" where the authors emphasize the need to look beyond the urban and equally study rural and peri-urban territories while unpacking water governance for rapidly urbanizing regions (Hommes et al., 2019). The paper can be viewed as a set of recommendations from the academic world, speaking to policy makers and planners thus serving as a valuable set of philosophies for my research. Two recommendations are specifically relevant to this work, namely:

1. The importance of links between rural areas and middle-sized or small cities rather than megacities, and emphasis on the peri-urban and growing 'spaces of in-between' (Hommes et al., 2019) – this forms the foundation for selecting my mid-tier city of interest (Moradabad, later discussed) and final peri-urban recommendations.
2. The emphasis on what urban development truly means; the authors warn that urbanization and development reports typically assume a linear and 'natural' shift from agriculture to industry, when the reality of urbanization is not this simplistic (Hommes et al., 2019). This caveat serves as a critical point as the study region here is not experiencing a rural-to-urban exodus, but rather a parallel growth in both rural and urban development.

Therefore, keeping in line with this, the methodology to answer sub-questions 2 & 3 on case-study location and rural-urban linkages include data & field observations from both rural and urban stakeholders and waterscapes.

2.2 The Urban Continuum: Indian urbanization & water systems

Next, this work requires a theory to contextualize urbanization and its impact to water systems for India. A critical paper titled 'Urban water systems in India: Typologies and hypotheses' by authors M. Shah and H. Kulkarni classifies the process of rural to urban development for the Indian context. Specifically, their paper defines growth scenarios through the lens of its impact on water systems i.e., groundwater and sewage (Shah & Kulkarni, 2015). The authors outline 4 stages of the urban continuum as pictured below in Figure 2-1:

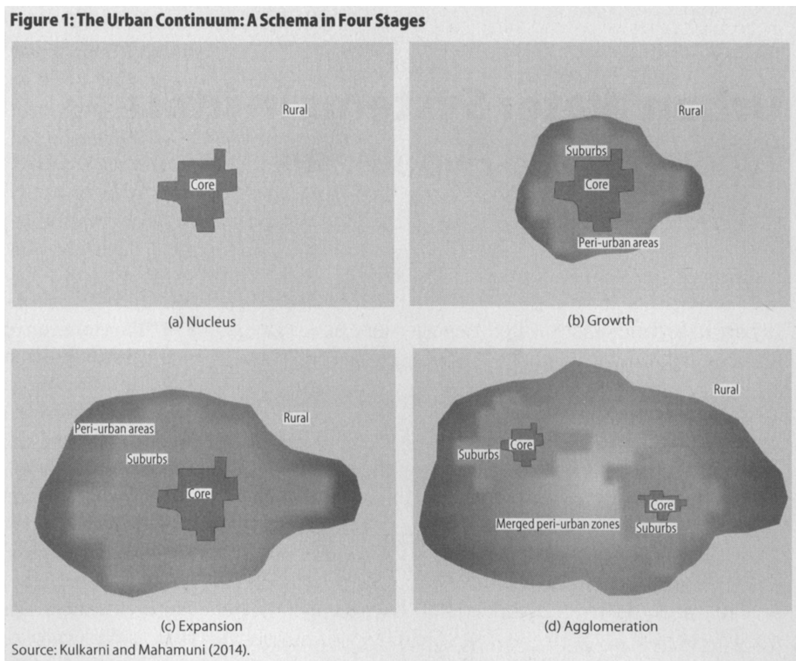


Figure 2-1: An excerpt showing growth trajectories in the Indian context (Shah & Kulkarni, 2015).

Shah & Kulkarni theorize 4 stages to urbanization for India, with stages 2 and 3 being relevant here. Characteristic of stage 2 and 3 is concerns around groundwater over-extraction. Further, remedies like rooftop rainwater harvesting are typically taken on by cities in this growth phase albeit with poor implementation. Ultimately these in-between stages of 2 and 3 offer opportunities to implement sustainable solutions before the problems propagate further as they agglomerate into stage 1 mega-cities (Shah & Kulkarni, 2015). I take this perspective of mitigating groundwater issues at middle-stages of urban development as a theoretical backing in selecting my city of interest discussed later.

2.3 Hydrological cycle

The main biophysical theory relevant to my research is the hydrological cycle. This is the fundamental understanding behind how groundwater comes to be, how sources of water are all connected to the regenerative cycle of precipitation, evaporation, and transpiration. These processes occur above-ground, and through infiltration generates groundwater and subsurface flows. Interesting aspects to note here are:

1. the connection between groundwater and surface water bodies like rivers, which can flood during heavy rain events thereby demonstrating the physical interconnectivity of these issues and
2. these physical processes occur and impact rural, urban and wilderness landscapes all the same which in-itself serves as a global rural-urban linkage.

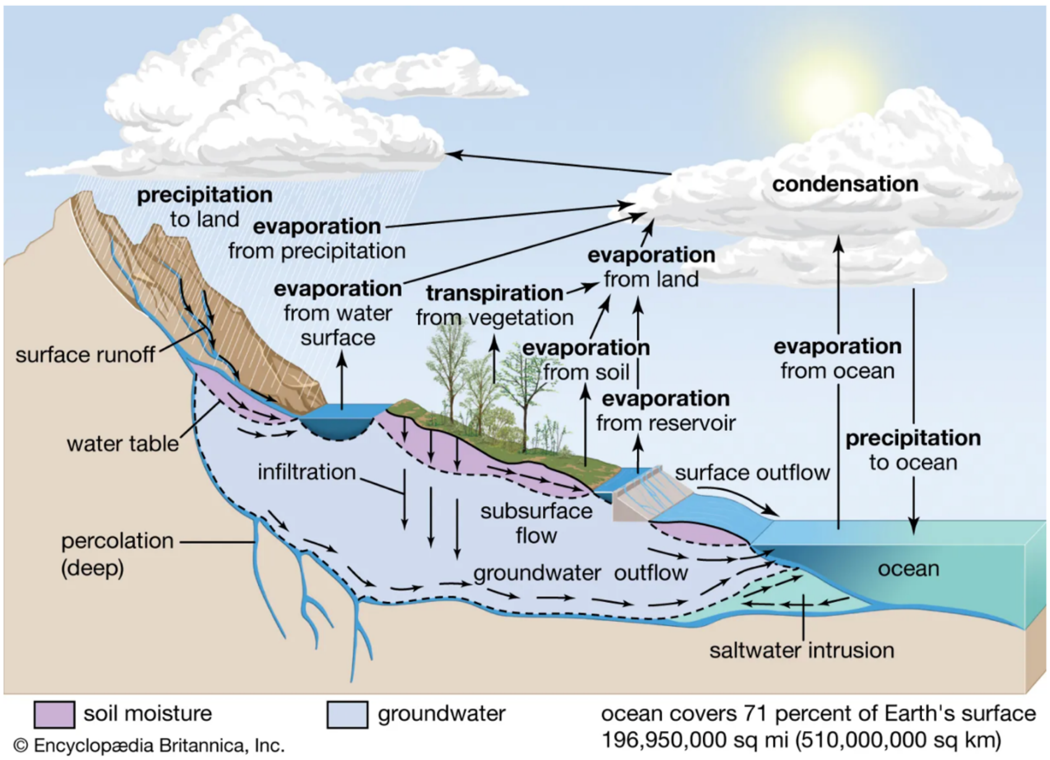


Figure 2-2: A schematic of the hydrological cycle (Britannica, 2023).

Chapter summary

Three theories are relevant to this research and are present as background context in subsequent chapters. The first is that of Hydrosocial Territories, the second is the fundamental scientific concept of the Hydrological Cycle, and the last of the Urban Continuum to contextualize Indian urbanization.

3 Methodology

Chapter preface

In this chapter I outline the qualitative and quantitative mixed-methods associated with each sub-question and brief reasoning behind its suitability. The research is conducted in phases centered on a 1-month long fieldtrip as the middle-phase. Overarchingly, I conduct a transdisciplinary literature review, semi-structured stakeholder interviews, field observations, GIS mapping, and python data analysis for results generation.

Given the intersecting topics of rural & urban links, urbanization, groundwater & disaster management, and stakeholder frameworks, a pluralistic approach was necessary. This combination of rural and urban water management can be viewed as a sociotechnical regional planning study involving a host of actors, making it a 'Wicked Problem' known in the planning sphere. Wicked problems in policy & planning cannot be solved by a purely technical, scientific approach and necessitate a mixed approach as argued by Rittel and Webber in their 1973 paper 'Dilemmas in a General Theory of Planning.' (Rittel & Webber, 1973) (Head, 2022). Thus, Table 3-1 below outlines the mixed-methods adopted for various stages of data handling and the tools I used to do so.

Table 3-1: An overview of mixed-methods and associated tools used for data handling in this study.

Type of data handling	*Purpose / method*	*Tools used*
Data collection	Transdisciplinary literature review on broader academia and IWMI work, policy reviews, semi-structured interviews, informal interviews, ethnographic field observations, and technology scoping i.e., fieldtrips to observe existing infrastructure	Scopus literature searches, fieldwork
Data analysis	Qualitative text coding, water budget calculations, demographic data handling for census information, GIS mapping & visualizations	ATLAS.ti AI coding, Python and Excel, QGIS
Data visualization	Maps, infographics, diagrams	QGIS, Adobe Illustrator, Miro

I now outline in further detail the phases of research, the associated sub-questions, and methods used in answering them.

3.1 Phase 1: Pre-field work

Phase 1 encapsulates desk research that occurred prior to fieldwork with the primary objective of problem triangulation and understanding the current state of research for SQ1. For my work, it is important to note the delineation between the overarching research in the wider field of groundwater management, and research specifically published by IWMI. This results in two bodies of literature, both having its corresponding reviews and research gaps. The bulk of work for SQ2 also occurred before the trip, wherein the study region was selected with a city of interest and its surrounding villages to represent the rural and urban focal zone. Various selection criteria were considered when selecting the city and villages, and this is also a sub-result for SQ2. SQ2 also continues during fieldwork to verify initial village selections. This was done during my first week in the IWMI Delhi office prior to heading into the study region of Moradabad and corresponding villages for the next two weeks. Overall, the methods and output for this phase are summarized in the below Table 3-2.

Table 3-2: A sub-chapter summary table for Phase 1 methods.

Sub-Question	Methods	Output
SQ1: *What is the current state of groundwater management & what technologies are available to address the drought-flood-groundwater nexus?*	- General Literature review - Policy review - IWMI meetings	Overview of MAR technologies, introducing UTFI, research gap identification
SQ2 Where can UTFI technology be potentially tested in the Ramganga Basin and to what capacity can it address the drought-flood-groundwater nexus?	- IWMI Literature review - policy review - IWMI meetings - GIS mapping	Overview of current UTFI work, initial selection & corresponding criteria of rural and urban locations for fieldtrip, GIS maps of city and village blocks, collating relevant policy and master plans for case region.

3.2 Phase 2: Fieldwork

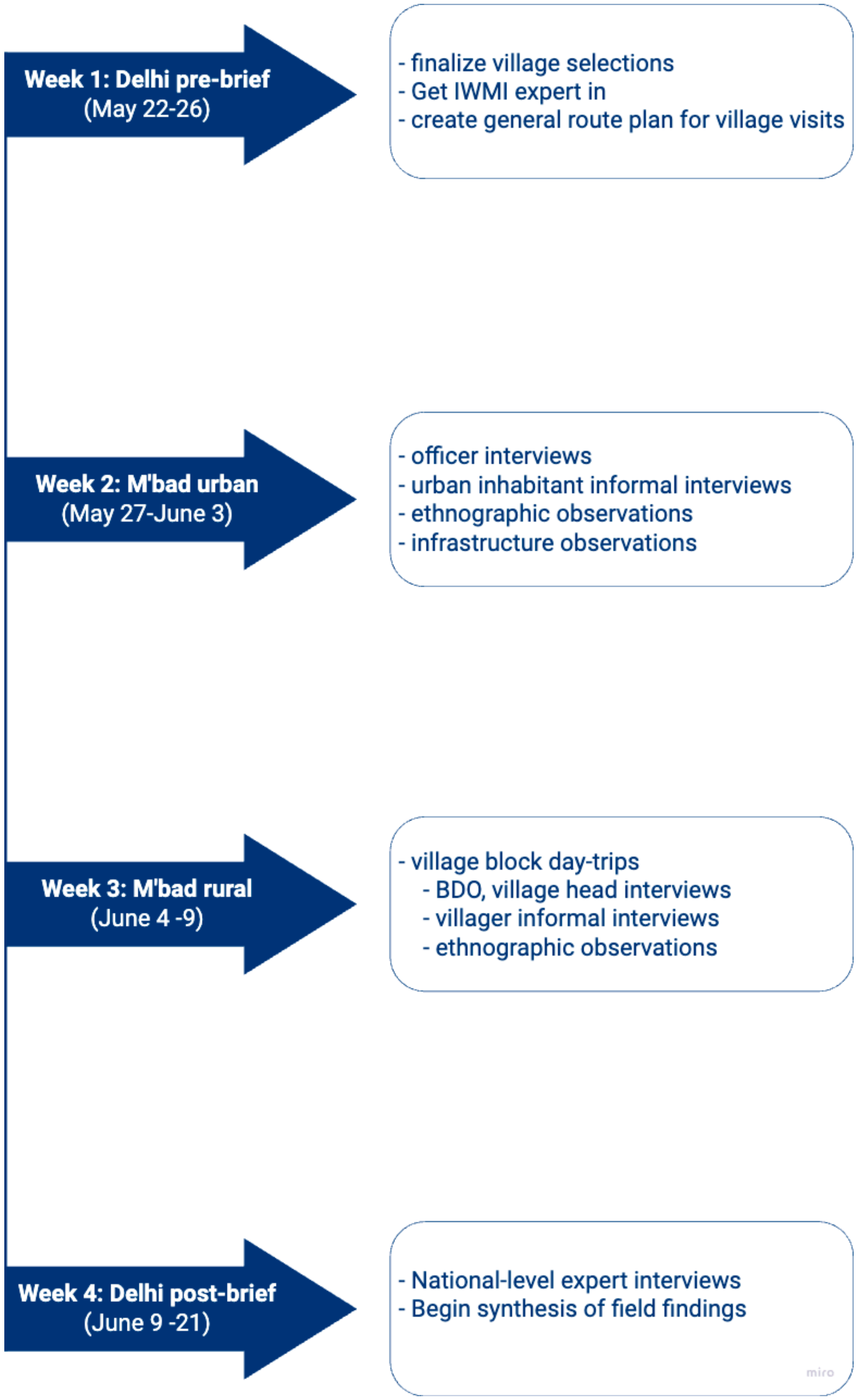


Figure 3-1: The timeline of fieldwork efforts between time in Delhi & study region of Moradabad.

Phase 2 was between May 22 – June 21 when I split my time between the IWMI Delhi office and the study location 4hrs away in Moradabad and corresponding villages. The field trip was the main window of data collection. Figure 3-1's timeline depicts how I planned my time to optimize findings both from the study region and experts and organizations in Delhi. Next, SQ3's methodology relies on semi-structured interviewing and ethnographic observations and these methods were selected given the nature of multi-stakeholder interviewing and fieldwork in a dynamic and new location.

3.2.1 Semi-structured interviews

Semi-structured interviews allow for open-ended discussion while still providing overarching questions to guide the flow, as explained by Alan Bryman in 'Social Research Methods' (Bryman, 2016). I chose this method to allow for a conversational style with district officials, engineers, expert consultants, and village leaders. Semi-structured interviews have also been used in similar sociotechnical research in India as seen in T. Kumar's work on hydrosocial territories in Ladakh, North India. (Kumar & Saizen, 2023) As for urban residents and villagers, I adopted a completely informal conversational style to relate better with them. All interview questions were along key themes for specific demographics as seen in, Appendix 3.

3.2.2 Ethnographic observations

Finally, I borrowed from the method of ethnographic observations which is common in social geography. My application of it over 1 month and various locations is not in-depth as would be typical for extensive anthropological work; for my purposes ethnographic observations also known as participant-observations is a means to record my experiences and observations while exploring a site and/or partaking in activities. It allows for informal discussions, videography, observational notes, and photos while being on the go (Barone, 2020), to later be summarized as needed.

Table 3-3: A sub-chapter summary table for Phase 2 methods.

Sub-Question	Methods	Output
SQ2 Where can UTFI technology be potentially tested in the Ramganga Basin and to what capacity can it address the drought-flood-groundwater nexus?	- GIS - news on flooded & groundwater stressed areas, - IWMI in-field expert recommendations	further detailed GIS maps: listing villages from phase 1's village blocks, and amendments to initial location choices if needed.
SQ3: What rural-urban linkages pose opportunities and barriers for UTFI recharge ponds?	- semi-structured interviews with officials - informal resident interviews - ethnographic observations	interview summaries, list of opportunities and barriers, institutional & community implementation for urban and rural sides.

3.3 Phase 3: Post-field work

The period after the field-trip was primarily data analysis and synthesis, with a few validation interviews and IWMI check-ins. The end goal in answering the main research question was providing a comprehensive list of recommendations for UTFI scale-up & land-use planning arising from opportunities and barriers uncovered. Further, a water budgeting calculation was done to understand 2035 groundwater demand due to urbanization to assess UTFI's scalability for future implementation. Final recommendations are related to land-use planning, policy, and institutional proposals on the rural and urban sides. The spatial planning recommendations are developed to an initial concept stage and visualized on GIS maps; these include suggestions for UTFI implementation in urban areas, along the Ramganga flood plains, and other rural possibilities. Looking to future work, a zoom-out approach will be taken to understand replicability and shortcomings of this research. Next, as time permits during the final weeks in September, I will also develop a 1-2 pager meant for IWMI, my partner organization highlighting new findings especially on the urban side as their past work has been focused only on the rural. This way, my research will be synthesized into something concrete for IWMI's future efforts as they see fit. Lastly, the below graphic in Figure 3-2 summarizes how each research question, associated mixed-methods, and theory from Chapter 2's theoretical framework all come together.

Table 3-4: A sub-chapter summary table for Phase 3 methodology.

Sub-Question	Methods	Output
SQ4: What locations & recommendations can be identified for future implementation of UTFI recharge ponds?	- qualitative text classifications of interview summaries water budget calculations - design thinking, GIS maps - semi-structured validation interviews	list of recommendations from opportunities & barriers – rural & urban, recharge potential needed for future demand, GIS map concept recommendation of area needed for UTFI locations, especially urban

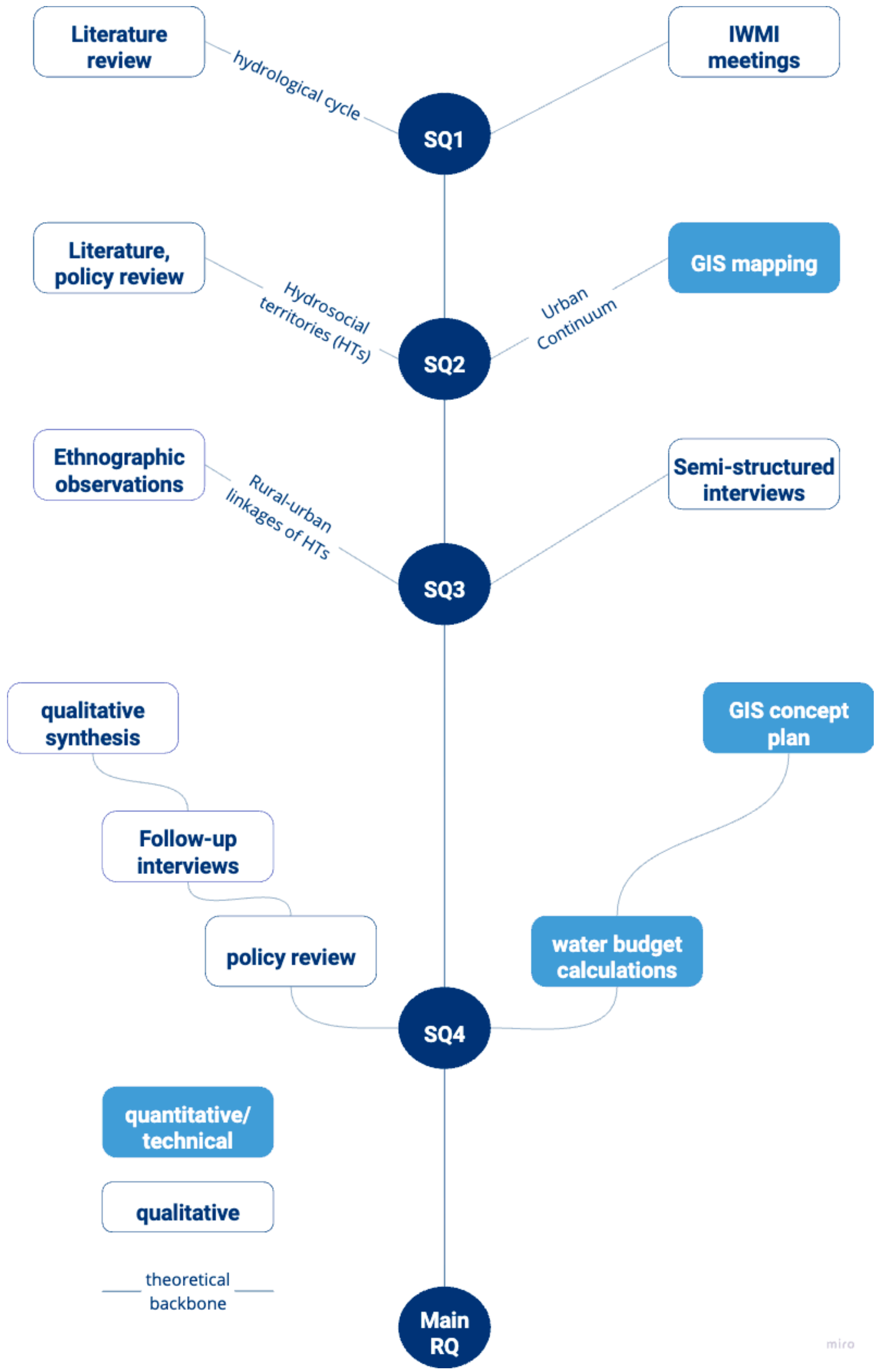


Figure 3-2: A schematic summary of research questions, methods, and theoretical framework.

Chapter summary

This chapter outlined the key methods used in answering each sub question. Key takeaways include the mixed-methods adopted given that this study is interdisciplinary, and the phasal approach centered around a fieldtrip in the middle. Further, the theories outlined in Chapter 2 are also tied into the methodology framework. This sets the tone for the next three chapters on results, recommendations, and discussions.

4 Results & Analysis

Chapter preface

This chapter presents key results to answer each of the sub-questions under Phases 1, 2 and 3 and is the central body of work for this thesis. The chapter is structured along pre-fieldwork, fieldwork, and post-fieldwork. Analysis of results is done following the qualitative or quantitative methods listed in the Methodology chapter. The transdisciplinary results presented here form the basis of recommendations in the next chapter.

4.1 Phase 1: Pre-field work

Phase 1 primarily involved desk research and preparatory work to understand the context prior to my field-trip; this is now discussed in the below sections.

4.1.1 SQ1 Results: current state of groundwater management & the gaps

SQ1: *What is the current state of groundwater management & what technologies are available to address the drought-flood-groundwater nexus?*

This sub-question relies on a transdisciplinary literature review to identify state-of-research, current recommendations, and key research gaps. Next, I also summarize key findings from initial rounds of IWMI meetings to understand their on-going work. For this thesis, it is important to note the divide between bodies of literature studied; these break down into 1. broader academic research and 2. IWMI-published research and are summarized below.

4.1.1.1 Broader academic state-of-research

Scopus searches were conducted to understand the current state of groundwater management which covers hydrology, policy, civil engineering, and stakeholder participation (ScienceDirect, 2015). Groundwater management is critical when working towards its sustainability and there are various emerging technologies. Therefore, I narrowed down my literature review to focus on one type of groundwater management., i.e., managed aquifer recharge (MAR). The Scopus search for MAR yielded 1212 papers, and this was manually filtered to 175 papers of interest based on title. Results also yielded papers on water quality, groundwater chemistry and bio-pollution, which were out of scope. I further filtered the selected 175 papers by topics on 1. sociotechnical approaches, 2. institutional, legal, governance aspects,3. community management or co-ownership, 4. case studies relating to the following countries leading in MAR: India, Mexico, Australia, Bangladesh, USA (California), 5. spatial planning and land-use, 6. urbanization, 7. urban stormwater management, 8. rural-urban links, and 9. rainwater harvesting systems. From this list of 175 papers, I reviewed the top-5 most cited on Scopus, followed by 3 papers chosen based of topical relevance.

Table 4-1: A literature synthesis of broader state-of-research; top-5 Scopus most cited papers and further 3 selected for topical relevance.

Scopus rank	*Paper*	*Region*	*Paper focus*	*Takeaways for this work*
1	*Climate change and groundwater: India's opportunities for mitigation & adaptation.* Tushaar Shah, 2009	India	Energy-irrigation nexus, groundwater depletion from pumped irrigation, need for integrated groundwater governance.	Establishes India's critical state with groundwater, importance of multi-actor governance analyses, MAR relevance.
2	*Enhancing drought resilience with conjunctive use and MAR in California and Arizona.* Bridget R Scanlon et. al, 2016	USA	Managing climate extremes, drought-floods connection California and Arizona. MAR and Conjunctive use (CU) of surface and groundwater.	Establishes interplay of climate extremes, feasibility of MAR and using floodwaters to recharge groundwater.
3	*Inventory of MAR sites in Europe: historical development, current situation, and perspectives.* C. Sprenger et. al, 2017	Europe	Catalogs 224 active sites across 23 European countries. Highlights MAR's relevance for water (re)use and storage, highlights MAR using stormwater and wastewater for natural filtration properties. Top MAR countries are Germany and Netherlands, with Induced Bank Filtration (IBF) as the primary MAR modality.	IBF method a possible recommendation for my study area given river and aquifer adjacency. Proves MAR as a valid solution to rising demand from urbanization, potentially offers cross-continent learnings between Germany/Netherlands to this research's Indian context.
4	*Groundwater – a global focus on the local resource.* Stephen Foster et. al, 2013	Global	Overarching sociotechnical and hydrological recommendations for groundwater management, critical areas globally from sub-Saharan Africa to India. Emphasizes need for more integrated institutions going from national to basin,	Further backing on critical need for groundwater planning in urban areas, especially those 100% reliant on groundwater; emphasizes need for spatial & institutional planning and planning for urbanization trends.

			district, rural and municipal levels.	
5	*Urban recharge beneath low impact development and effects of climate variability and change.* Michelle E. Newcomer et. al, 2014	USA	Low Impact Development (LID) and Best Management Practices (BMPs) that help reduce stormwater runoff. LID BMPs are microscale and decentralized, like infiltration trenches and pervious pavement. two case-studies in El Nino to compare recharge capacities of an infiltration trench vs. irrigated lawn. The former performs better.	Infiltration trenches could be viewed as like ponds on a smaller scale, have some proven performance capabilities.
NA (topical)	*Understanding and quantifying water balance for sustainable city and agriculture of Yogyakarta Province.* Oki Setyandito et. al, 2018	Indonesia	Studies Yogyakarta province in Indonesia which faces rising groundwater demand for irrigation and urban needs. Proposes groundwater planning up to 2030 by studying demand trends from 2017-2030. The study area includes a focal city and 3 surrounding provinces, and the paper concludes for 2030, if 65% of excess surface runoff is recharged, the city and 2 provinces will overcome its groundwater deficit. recommends MAR generally without typology or location suggestions	This paper is most close to this thesis. The water balance method to evaluate future demand in 2030 for the Yogyakarta province is relevant. The difference is this paper doesn't delve into institutional and community arrangements required to enact this. further, my work will also address spatial land-use planning for required recharge rates using the water balance calculations.
	Managing stormwater in South African neighborhoods: When engineers and scientists need social science	South Africa	Emphasizes the need for hydrologists and civil engineers working in MAR for urban stormwater harvesting, to look beyond	Importance of interdisciplinary sociohydrological approaches

	skills to get their jobs done. C.T. Tanyanyiwa et. al, 2023		the technical. i.e., a better understanding of socioeconomic and historic contexts is required	
	Issues of governance, policy, and law in managing urban-rural and groundwater-surface water connections. Rebecca Nelson et. al, 2015	Global	Textbook chapter from: Understanding & managing urban water in transition. Highlights two critical system interactions: rural-urban, and groundwater-surface water. Discusses cases in Australia and the USA, recommends MAR for urban and rural applications.	Rural-urban linkages: water law to support connections between urban-rural water trading, source swapping and agricultural use of urban wastewater. All could be viable considerations for this thesis' recommendations

Table 4-1 above synthesized key gaps from the state of research on MAR and these are: the need for land-use planning, a need for a combined rural-urban perspective, a better understanding of institutional & community aspects, and push for mixed-interventions & conjunctive use of groundwater and surface water. These are all gaps I address through my results & recommendations. Next, I synthesize key literature from IWMI-specific research.

4.1.1.2 IWMI-published research on UTFI

IWMI has been working on UTFI since 2015 with two key project reports released in 2020 and 2021(Alam & Pavelic, 2020) Both these reports are overarching summaries on global scalability and reporting on successes & failures from the first pilot site (Pavelic et al., 2021). Foundational to these project reports are 5 papers I reference below and highlight research gaps that my work will contribute towards.

1. *"Modeling the potential for floodwater recharge to offset groundwater depletion: a case study from the Ramganga basin, India" – Pennan Chinnasamy, et. al.*

   In this paper, Chinnaswamy et. al outline the key findings of their hydrological modeling study, taking a technical approach for evaluating the Ramganga basin. The team undertook a semi-coupled hydrological modeling approach to test scenarios where 3 models were built. A hydrological model (SWAT), groundwater model (MODFLOW) and flood inundation model (HEC-RAS) was applied to the entire Ramganga basin of about 19,000 square km. The paper concludes that distributed Managed Aquifer Recharge (MAR) can be effective in improving groundwater levels and reducing impact of floods, their results showed 10% drop in inundation area and 7m improvement in the groundwater levels within 5 years of implementation (Chinnasamy et al., 2018) Thus, I take this paper as a technical proof-of-concept that demonstrates MAR's hydrological relevance in the basin. As the authors outline, future work is needed to investigate land availability, community interest, aquifer capacity and the nature of hydraulic connections between the aquifer and river (Chinnasamy et al., 2018). Especially the and availability, institutional and community gaps mentioned will be taken up in this research.

Key research gap: land availability, social & institutional analyses in implementing MAR
Paper's relevance to this work: taking the hydrological proof-of-concept and efficacy of overarching MAR technology for Ramganga, wherein UTFI is one modality of MAR, as fact

2. *"Identifying priority watersheds to mitigate flood and drought impacts by novel conjunctive water use management" – K. Brindha, Paul Pavelic*

The result from this paper was a basin-level suitability map based on GIS methods to identify suitable locations for UTFI's implementation across the larger Ganga River basin, of which the Ramganga basin is a sub-basin. This paper develops a multi-criteria methodology considering drainage density, flood frequency, flood mortality and distribution, extreme rainfall events, land use, population density, geology, slope, soil, groundwater level, aquifer transmissivity and economic loss due to floods. The paper concludes that within the 43% of the ganga that is routinely subject to floods, 68% of the area has either high or very high suitability conditions for UTFI implementation, and this methodology for evaluating basins for UTFI or other types of MAR, is transferable globally (Brindha & Pavelic, 2016). This is a critical input for my research as the UTFI suitability map serves in defining my study area. However, this study leans more spatial and hydrological in approach thus allowing for future work in social & institutional studies for UTFI scale-up. Also noteworthy is that this is at the entire Ganga basin scale, where distinction between urban and rural pockets was not necessary. This then provides further scope for my work around rural & urban differences.

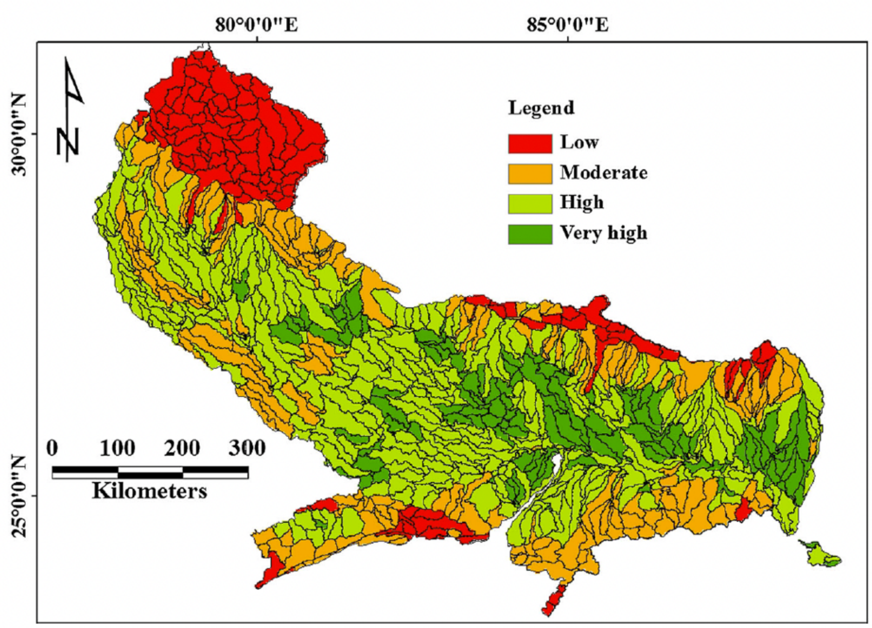


Figure 4-1: The UTFI suitability map for entire Ganga river basin (Brindha & Pavelic, 2016).

Key research gap: social & institutional indicators for suitability of a location beyond population density or economic loss from floods.
Paper's relevance to this work: Suitability map incorporated into my GIS work for SQ2 later as it is a foundational spatial layer which already accounts for biophysical suitability; from here social, land-use & institutional aspects can be built upon.

3. *"Managed Aquifer Recharge of monsoon runoff using village ponds: Performance assessment of a pilot trial in the Ramganga basin, India" – Mohammad Alam, et. al*

    This paper evaluates the performance of the first UTFI pilot site in a village located in the Rampur district within the Ramganga basin. The pilot consisted of 10 recharge wells installed in a formerly unused village pond located near a canal that provided the input of floodwaters. The site was monitored & tested over 3 years and it recharged 26,000 to 62,000m^3 of water each year over windows of 62-85 days. This recharge is equivalent to 1.3-3.6% of total recharge in the village, and the yearly average recharge rates were 580m^3 / day (Alam et al., 2020).

Key research gap: rural pilot, success defined through technical performance & efficiency although later papers account for villager perception (GRIPP, 2021).
Paper's relevance to this work: the demonstrated recharge rate will be input into my water budget calculations in SQ4, however the limitation is this being a technical result from one closely monitored pilot site with its specific biophysical conditions.

4. *"Managing underground transfer of floods for irrigation: A case study from Ramganga basin, India" – V. Ratna Reddy, et. al.*

    This is a critical paper from IWMI researchers that emphasizes socio-economic and institutional contexts using Rampur pilot for a case-study approach. The paper proposes 3 potential routes to institutionalize UTFI and provides insights for scaling up the interventions in the Ganga and other river basins. It establishes that managing the interventions involves community participation in regular operations & maintenance tasks. It also highlights the need for involvement from district administration for both funding and maintenance and proposes a longer-term governance & funding structure for wider UTFI replication pictured below.(Ratna Reddy et al., 2020b.) Worth noting here is that the proposed institutional & funding structures lean towards rural development with less emphasis on urban governance of UTFI.

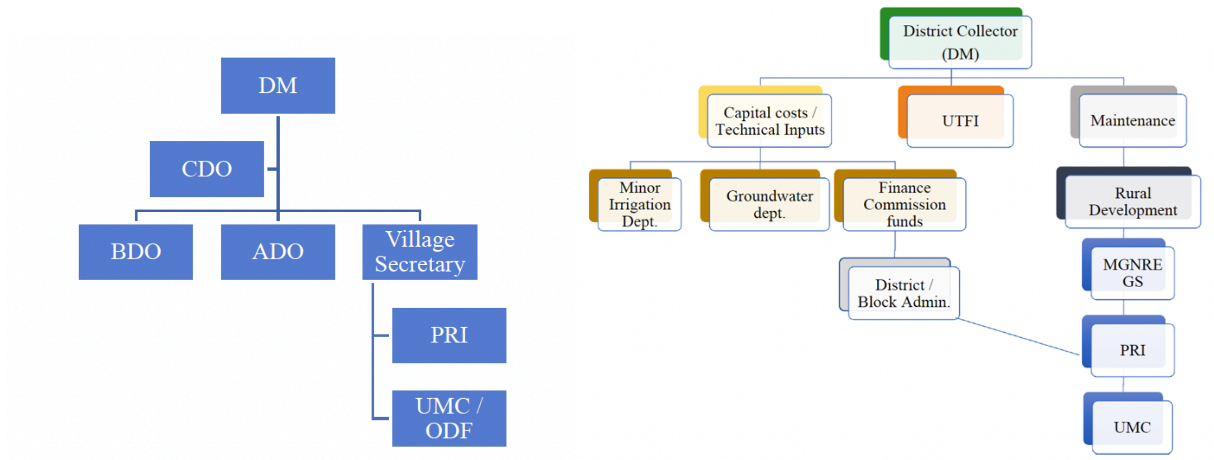


Figure 4-2: The institutional and funding structures proposed. (DM: District Magistrate, CDO: Chief District Officer, BDO: Block Development Officer, ADO: Assistant Development Officer, UMC: new UTFI Management Committee, PRI: Panchayat Raj Institution, an Indian rural institutional structure, ODFs: Open Defecation Free Committees. MGNREGS: Mahatma Gandhi National Rural Employment Guarantee Scheme) (Ratna Reddy et al., 2020b.)

Key research gap: rural case-study, little distinction on urban institutions and land-use planning when considering future scale-up
Paper's relevance to this work: I use rural findings to validate my rural fieldwork in Phase 2 and assess how urban institutions & community engagement modalities might differ from rural. further this paper proposes a specific UTFI committee, and I avoid this recommendation in my work to reduce institutional complexity.

5. *"UTFI in the river basins of South Asia: institutionalizing approaches and policies for sustainable water management and livelihood enhancement." – V. Ratna Reddy, et. al.*

This paper further establishes the need for institutional arrangements for scale-up. It emphasizes that to achieve more substantial positive benefits it promises i.e., flood reduction & groundwater table improvement, it needs to be scaled to the level of meso-watersheds (10s of km^2) or sub-basin level (100-1,000s of km^2) (Reddy et al., 2017).

Key research gap: urban/peri-urban institutions & funding not emphasized as much since institutional arrangements are discussed at the overarching district level. It provides a starting-point framework for visualizing institutional arrangements, which can be further formalized especially on the urban side.
Paper's relevance to this work: further validation for relevance of institutional approach and I will build on this for urban governance. On the spatial side it highlights the need for meso-watershed level implementation rather than individual village pilots; this recommendation will form the backbone for selecting my study area in that area range.

To summarize, when studying the current state of groundwater management & what technologies exist in addressing the drought-flood-groundwater nexus, IWMI's UTFI is a typified example. Therefore, key takeaways from reviewing foundational IWMI papers and project reports are: IWMI has extensively researched hydrological & economic modeling for proof-of-concept, with institutional and governance analyses as those done by Reddy focusing more on rural or overarching district-level implementation of UTFI. This provides scope for urban & peri-urban explorations of UTFI scale-up along two key trajectories:

1. spatial planning side of where to situate UTFI ponds within a meso-watershed, and
2. researching the institutional plus community-based governance modalities needed to accomplish it.

The literature review across broader academia and IWMI work – 13 papers in total – helped in answering SQ1 by providing an overview of MAR technologies' current state of development. It elucidated the need for further work in understanding institutional frameworks, urban scale-up & wider-scale spatial planning for MAR & UTFI implementation in meso-watersheds. Finally, other key themes extracted from the literature review that prove relevant for subsequent sections are rural-urban linkages and sociotechnical approaches.

4.1.1.3 IWMI meeting takeaways

I had several check-in meetings, email exchanges, and consultations with IWMI's Paul Pavelic & Faiz Alam, who provided consistent feedback on my proposals & research direction through the course of February – October 2023. The initial meetings helped in identifying aspects that would prove new to IWMI's current body of work. Recommendations from their side included a focus on institutional frameworks, cooperation modalities when maintaining UTFI ponds, rural-urban linkages, and an exploration of urban scale-up for UTFI beyond current rural pilot work. These recommendations were in-line with literature review gaps mentioned in the previous section. Through the course of working with Paul and Faiz, they also provided specific resources like reference papers – both IWMI and general academia work, which are all also public and found on Scopus.

4.1.1.4 Research gap synthesis

When synthesized, core research gaps that my thesis will contribute towards become evident. From the broader literature, gaps lie in studying the rural and urban conjunctively with more focus on land-use planning & institutional frameworks of MAR, i.e., planning for urbanization in a holistic manner. From IWMI work, areas for new contribution include the meso-watershed level of scaling up, urban applications, and a deeper understanding of urban institutions. This is synthesized in Figure 4-3.

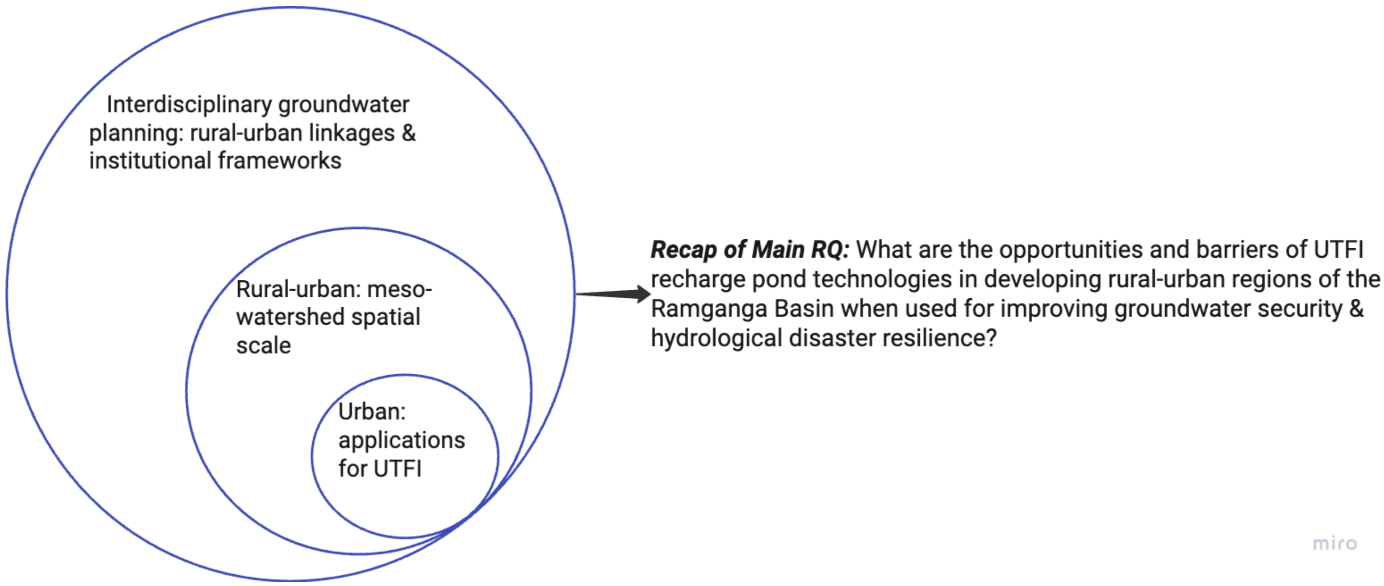


Figure 4-3: A schematic to visualize key research gaps and connection to the main research question.

4.1.2 SQ2 Results: identifying the study region.

SQ2 Where can UTFI technology be potentially tested in the Ramganga Basin and to what capacity can it address the drought-flood-groundwater nexus?

The goal of this sub-question is to identify the main study area using GIS analyses, policy recommendations and literature. Further, UTFI technology's specifications needed in identifying its applicability for the region is also outlined.

4.1.2.1 Location to test UTFI: The study area

To take a holistic view of groundwater planning and keep in line with the theory of hydrosocial territories, both the rural and urban were considered together. Therefore, selecting the study area within the Ramganga basin entailed choosing a focal city and surrounding villages based on a set of criteria. The rural plus urban zone selected was at the meso-watershed to the sub-basin level recommended by abovementioned IWMI literature, i.e., in the 100s – 1000s of square kilometers to ensure UTFI's benefits are realized at scale. The considerations for the city and villages were as follows:

Focal city: Moradabad

Within the upper Ramganga basin, there are two major cities of Moradabad and Bareilly. Moradabad is more north-west and became the city of choice for 3 critical reasons listed below.

1. Urbanization and the National Capital Region (NCR): For the state of Uttar Pradesh, the western part is most urbanized, industrialized and developed (Singh, 2020) and western UP cities are near the National Capital Region (NCR). The NCR in north-central India triangulates the three states of Uttar Pradesh, Haryana and Delhi and includes major cities like New Delhi, Noida, and Ghaziabad (NCR Planning Board, 2017). This area is a crucible of economic activity and pulls urbanization of Uttar Pradesh westward. Moradabad is one such growing city in western UP.

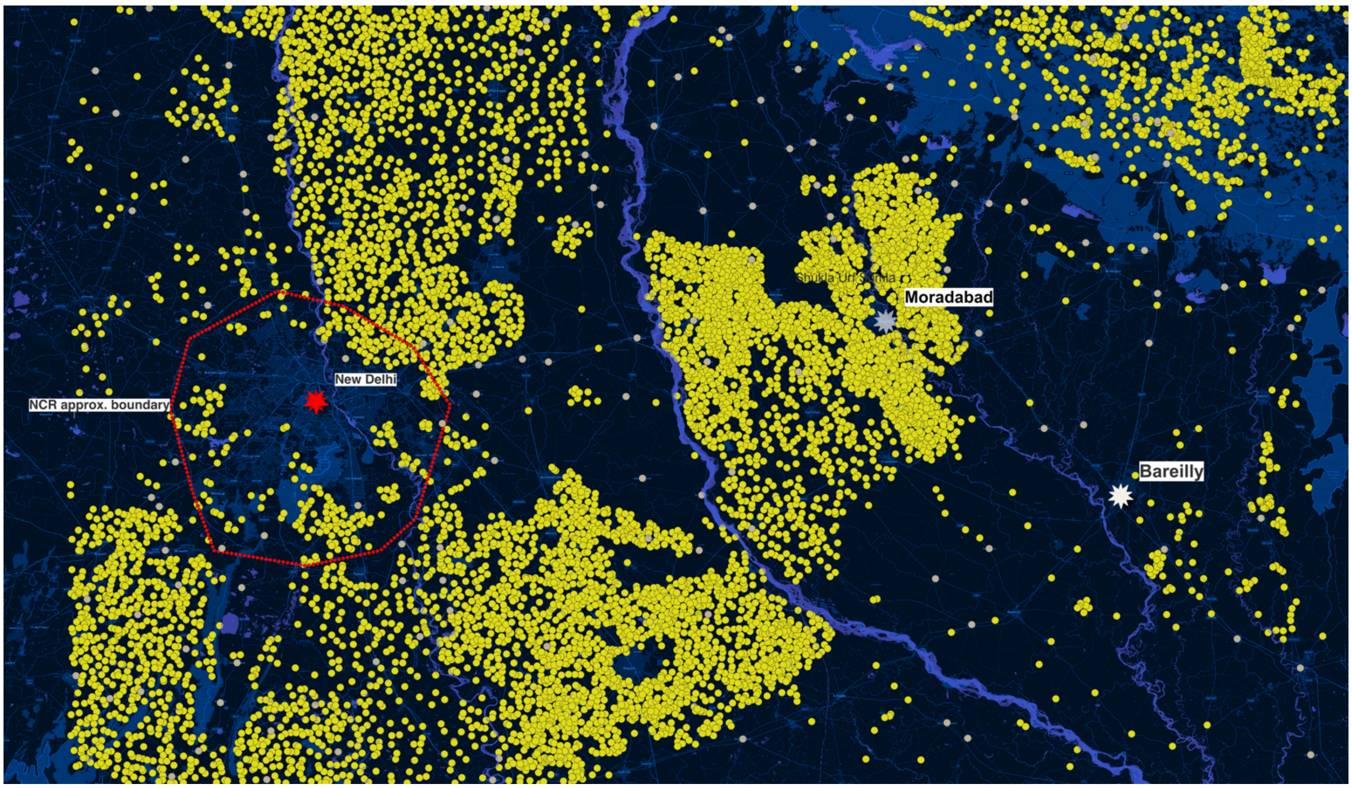


Figure 4-4: A map of Moradabad vs. Bareilly's surrounding settlements and proximity to NCR region around New Delhi. Settlement data from OpenStreetMap query on villages & towns.

2. Indian urbanization patterns & classifications: In section 2.2 I outline the urban continuum theory proposed by Shah & Kulkarni, outlining stage 2 and 3 cities for the Indian context. Going by this classification Moradabad and Bareilly with populations between 1-5 Million, are seen as expansion cities (Shah & Kulkarni, 2015). Specifically with Moradabad, in census 2011 it had a population of 887.871 (Census India, 2021). While conducting fieldwork for this research, I received data from the city's municipal office that reports 2022's urban population as 1,086,755 seen in Appendix 3. This population change shows that Moradabad has gone from stage 2 to

stage 3 along the authors' metrics, likely experiencing quicker urbanization than Bareilly especially when also considering its proximity to NCR.

3. Groundwater stress percentages & water table measurements: Since this research focuses on groundwater sustainability, I chose the city that is relatively worse off with its current extraction rates. While both Moradabad and Bareilly are extracting at unsustainable rates, data from the Central Ground Water Board (CGWB) shows Bareilly is at 66.95% extraction of current resources and Moradabad at 89.34% (Sinha, 2021), making Moradabad more critical.

Village block selection

Next a set of rural blocks and corresponding villages within each block were selected to define the study area. Within the Moradabad district, there are 4 Tehsils i.e., sub-districts, and 8 blocks. All blocks are rural and fall under the rural development authority, and the district of Moradabad has one city i.e., Moradabad city. The city falls under its own municipal corporation known as Nagar Nigam and urban development authority Moradabad Development Authority (MDA). (UP State Government, 2023).

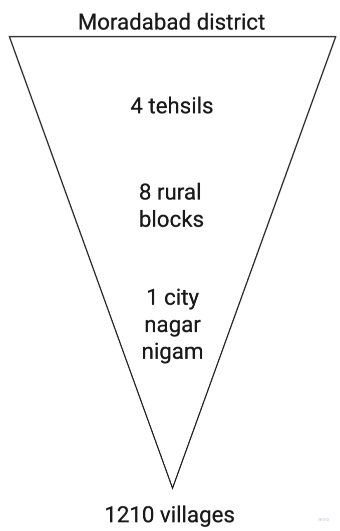


Figure 4-5: A graphic of Moradabad district breakdown, where Nagar Nigam means city municipality.

The block-level focus is relevant to my work as there is state-provided data on blocks that are at risk for floods and groundwater stress (UP Disaster Management Cell, 2021), (Sinha, 2021). A Venn diagram of flood and groundwater-stressed blocks is shown in Figure 4-6. These two criteria when overlayed with the UTFI suitability map provided the final selected 5 blocks for this study, depicted below in Figure 4-7. Appendix 1 shows the entire Moradabad district with 8 blocks against the UTFI suitability map prior to selecting the final 5 blocks. It should be noted that Munda Pande, while both at risk for floods and droughts, was not selected since its location was not in a high UTFI suitability segment of the basin. Similarly, Bilari was chosen to have one extreme case of groundwater stress which also has high UTFI suitability even if its flood risk is low.

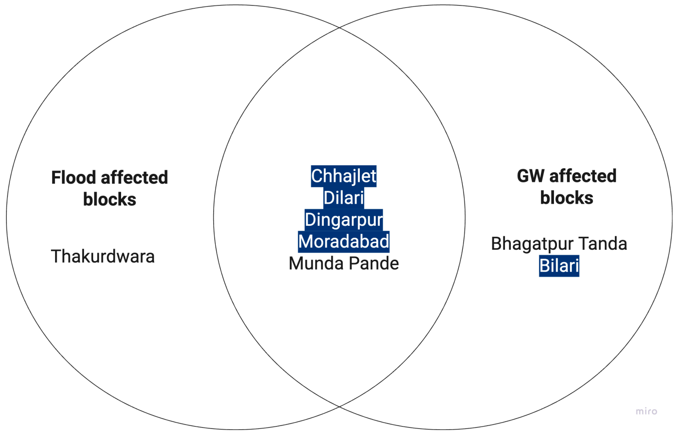


Figure 4-6: A Venn diagram of flood vs. groundwater-affected blocks, with selected blocks in blue.

Figure 4-7: The study area of selected blocks in relation to location in UP state, northern India.

After the blocks were selected, the final step was selecting sample villages in each block to visit during fieldwork. I started with an initial list of flood-affected villages in groundwater-stressed blocks within the study region. This is plotted in Appendix 2 and comes from state-generated datasets on flood and groundwater risk. Overarchingly, by selecting an urban city and 5 blocks the total area of the study region notwithstanding final village selections within each block, comes to 1400 sqkm. This is in the range of 100s-1000s of sqkm i.e., meso-watershed to sub-basin level resolution that was recommended by Ratna Reddy in previous IWMI research (Reddy et al., 2017).   From here, I needed on-field input from IWMI Delhi experts and government official interviews to filter down to ~2 villages per block to later visit. This will be discussed in the next section phase 2: fieldwork and the summary to this phase 1's findings are tabulated in the following Table 4-2.

Table 4-2: A sub-chapter summary table for Phase 1 results.

Sub-Question	Methods	Result
SQ1: *What is the current state of groundwater management & what technologies are available to address the drought-flood-groundwater nexus?*	- Literature review, - IWMI meetings	Scopus-based literature review on MAR technologies (8 papers), introducing UTFI (5 papers), key research gaps identified, key takeaways for use in later SQs listed.
SQ2 Where can UTFI technology be potentially tested in the Ramganga Basin and to what capacity can it address the drought-flood-groundwater nexus?	- Literature review - policy review, - IWMI meetings, - GIS mapping	Initial selection of city and village blocks as pre-work for fieldtrip, UTFI's capacity to address drought-flood-groundwater nexus answered through its suitability map, 1400sqkm total study area, relevant policy, and master plans for case region identified.

4.2 Phase 2: Fieldwork

This phase encompasses one month on the field between mid-May to mid-June. I conducted work in Delhi and my study area of Moradabad and its surrounding villages according to the timeline in Figure 3-1. In that time, I conducted a total of 26 semi-structured or informal interviews amongst all relevant stakeholders and a flowchart mapping stakeholders and number of interviews is presented in Appendix 3. Now I summarize key findings from the field to help answer SQ2 and SQ3.

4.2.1 SQ2 results: study area refinement in-field

SQ2 Where can UTFI technology be potentially tested in the Ramganga Basin and to what capacity can it address the drought-flood-groundwater nexus?

Prior to arrival, I had selected the 5 blocks of interest (figure 4-7) with an initial list of villages to choose from (Appendix 2). The first step on arrival was to refine this village list with expert input from IWMI researcher Dr. Navneet Sharma and other field insights during the first and second weeks. One such new insight I learned after arrival was the Amrit Sarovar (AS) scheme which was rapidly scaled up in the last year. The scheme aims at constructing or rejuvenating at least 75 ponds per district all over India. The scheme runs for one year between 24th April 2022 to 15th August 2023, (PIB Delhi, 2022) but it is unclear how the scheme might continue. Further, it was also unclear during field visits if permanent maintenance of the ponds over the years would fall under this scheme or an extension of it. Due to this scheme, several ponds have already been built in Moradabad district, so we decided to visit villages with AS ponds to understand how communities and local officials implemented them. This would then serve as a proxy to understanding opportunities and barriers for UTFI scale-up in the future given that they are similar pond recharging methods. The below Figure 4-8 shows the final selection of villages visited per block and Table 4-3 lists the criteria I considered in selecting them. Appendix 7 further lists any additional data sources I used for each criterion.

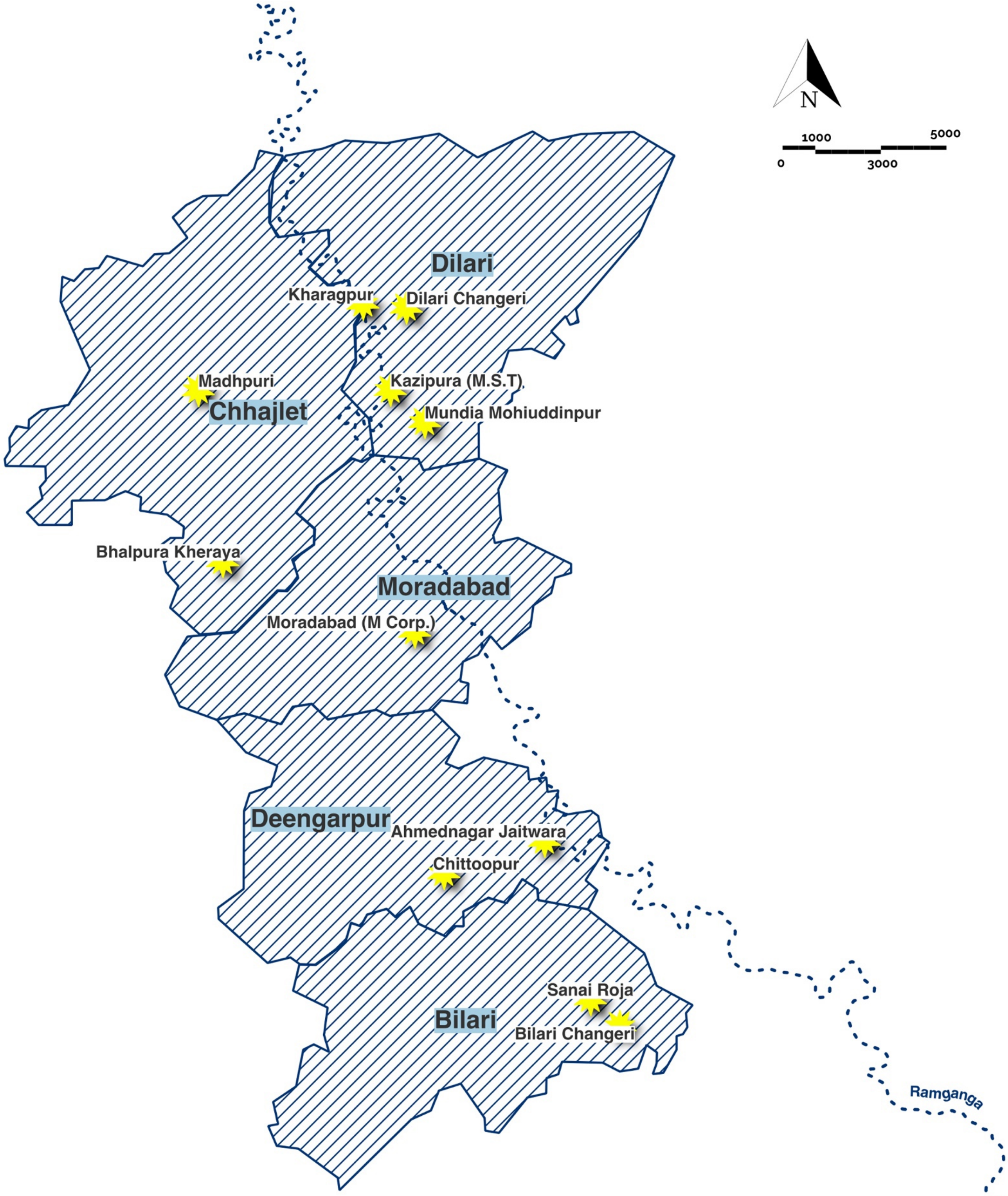


Figure 4-8: This map depicts the final list of villages in yellow per block that the team visited during field visits in June 2023. It also outlines Ramganga's main river path through the study area.

Table 4-3: This table lists the criteria considered while qualitatively choosing between villages per block to later visit on the field.

Village criteria	*Explanation*
Flood risk	Historically flooded villages likely to flood again, and communities already impacted.
Drought risk	Drought was primarily taken as agricultural drought, i.e., if groundwater risk exists then agricultural drought risk also does.
Groundwater critical classification	This dataset is critical in understanding which blocks within the Moradabad district are lists as critical or semi-critical for their groundwater extraction rates.
Distance to Ramganga	Villages closest to the river are most affected by the river overflowing in both up and downstream cases. It is also the case that downstream villages face more severe flooding as uncovered during community interviews of downstream villages.
flood-drought pair	Distance from the river will cause communities to have different perceptions of risk to either floods or droughts. nearer communities might fear floods more than droughts and vice versa.
Population of village census 2011	Villages with higher populations have more to lose during times of disaster.
Presence of Amrit Sarovar Pond	Serves as a proxy in understanding community & governance perceptions to recharging ponds and therefore a parallel for UTFI.

4.2.2 SQ3 results: rural-urban linkages uncovered on the field.

SQ3: What rural-urban linkages pose opportunities and barriers for UTFI recharge ponds?

SQ3 encompasses all fieldwork efforts and outcomes. The methods used were primarily semi-structured stakeholder interviews and ethnographic observations. The main objective here was to uncover rural-urban linkages. The urban and rural are connected through various means when viewed cohesively as one hydrosocial territory. As the theory dictates, within a hydrosocial territory spatial regions can be connected via people, institutions, water flows, hydraulic technology, and the biophysical environment (Boelens et al., 2016b). For the purposes of this research, these dynamic linkages are distilled into 4 main pathways of community, spatial planning, biophysical environment, and institutional frameworks that were analyzed during fieldwork. Figure 4-9 serves as a conceptual visualization of these pathways to show how rural blocks interact with the urban center, along with independent pathways within each block and city. It was important to understand these (de)linkages as that forms the foundation for listing specific opportunities and barriers for UTFI's scaleup. Findings for each pathway are reported in the next sections.

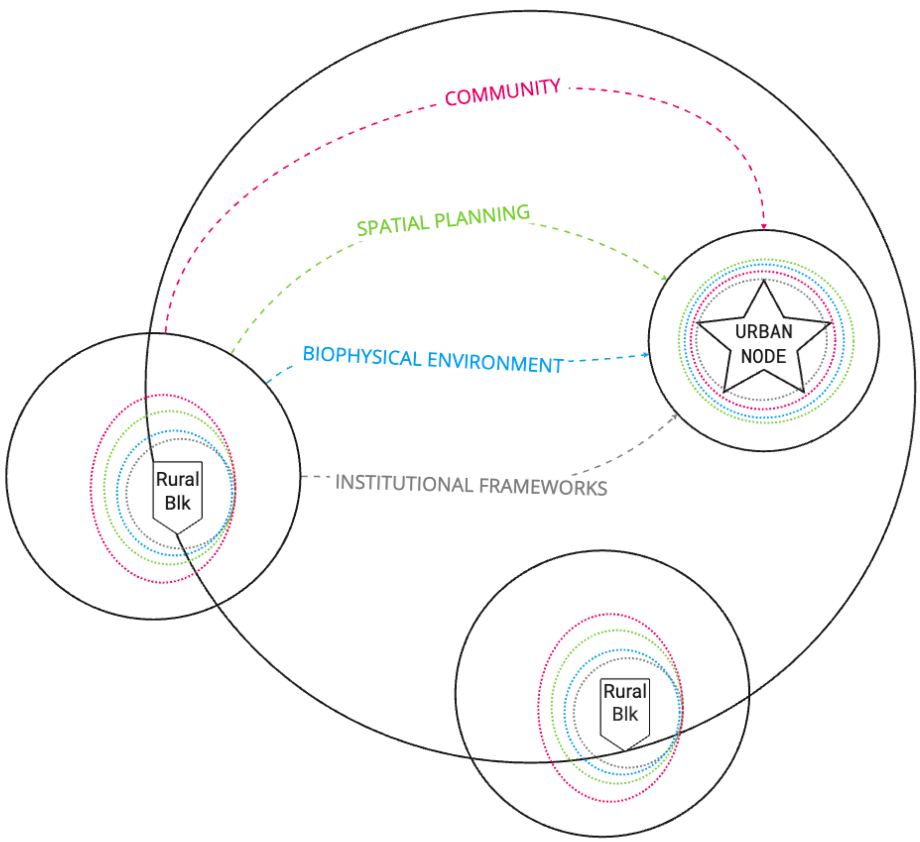


Figure 4-9: This schematic visualizes how the rural and urban are connected along 4 pathways which will now be unpacked in sections 4.2.2.1 to 4.2.2.4.

4.2.2.1 Community findings

Rural and urban communities are connected to each other, and independently also to their hydrological environment. The findings along the community pathway are twofold; the first is a sense of water ownership, and the second of rural-urban people flows. Firstly depending on which side you engage with; rural or urban groups feel different degrees of ownership of their water landscapes. This (dis)connection to water in their daily lives influences groups' perception of hydrological problems like floods, droughts, and groundwater, and therefore if they perceive UTFI as necessary or would partake in the co-management of it. I.e., if rural agriculture is affected by groundwater droughts, or villages flood frequently, the problem is closer to home and the urgency for a solution is higher. This could perhaps explain the case of a Ladies' Self Help group in Sanai Roja village, Bilari block where women actively engaged in both the construction and continued maintenance of the recently built Amrit Sarovar Pond (Figure 4-10.) These women are farmers and interact with groundwater daily on their farms; therefore, they viewed recharge ponds as useful for both surface water needs and longer-term percolation. This offers an opportunity for co-management through community ownership for UTFI.

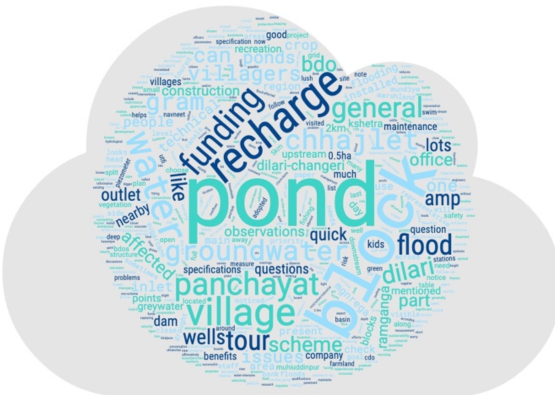
Figure 4-10: Going clockwise from top-left, first is the Amrit Sarovar Pond in Sanai Roja, Bilari block. The second is an image of a lady washing her cattle at the groundwater handpump, and the last of my meeting with the Sanai Roja Ladies' Self-Help group.

On the urban side in Moradabad city, this was less the case. There in the bustle of a dense city, inhabitants are one degree removed and rely on municipal water supply to their homes or have private borewells with so-far reliable supply. An informal chat with three urban inhabitants highlighted that they were satisfied with the municipal supply and floods occurred only close to the Ramganga. This then demonstrates that for urban UTFI scale-up and management, cooperation with urban governance bodies (Moradabad Development Authority or the Nagar Nigam city municipality) will be more necessary than direct community engagement.

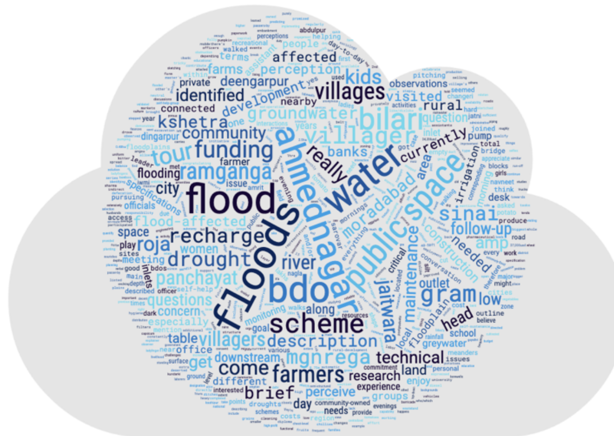
Secondly, the rural and urban communities also interact with each other through people flows for economic trade and migration during crises like floods. Trade flows include key produce like sugarcane, mangoes, Indian peaches, and other produce like those in Figure 4-11.

Figure 4-11: Fresh fruit is brought into Moradabad city by farmers from neighboring village blocks to access the urban market.

Beyond economic activity, rural and urban are also connected through people flows during times of disaster. As one village head mentioned, his community in Ahmednagar Jaitwara and the surrounding 15 villages downstream of Moradabad city annually experience severe flooding during monsoons. This causes them to flee to Moradabad city for refuge as their farms and homes get inundated. They have long been requesting officials to implement flood protective pitches for the Ramganga, and they do not perceive recharge ponds as an immediate solution to flooding or groundwater improvements. This is the case for villages close to the Ramganga floodplains and the converse is true for settlements further away with only cropland bordering the river. For the latter, village respondents in Dilari block upstream of Moradabad perceived ponds as useful in both groundwater recharge and flood prevention since their homes were further away and putting a pond along the floodplain would help 'catch' flood waters before it flows into their homes further inland. They already experienced this positive impact from the recently implemented Amrit Sarovar Pond in the village of Dilari Changeri. These takeaways are reflected in Figure 4-12 and 4-13. Ultimately, the opportunity here is to strategize which communities would immediately adopt ponds over others while coupling pond interventions with more direct flood-protection measures like pitching the Ramganga.



Rural, upstream: *word cloud from synthesis of upstream interviews & researcher observation notes; strong emphasis of pond recharge modes. and funding & governance issues (panchayat) raised*



Rural, downstream: *word cloud from synthesis of downstream interviews & researcher observation notes; highlights flood-risk fears of Ahmednagar community and emphasis on public space benefit from ponds highlighted by Dingarpur BDO.*

Figure 4-12: Word clouds that show differences in priority of upstream and downstream communities.

Figure 4-13: Two pictures from the field; top from the downstream Ahmednagar where communities get flooded along these Ramganga banks and don't perceive ponds as helpful with river pitching being the urgent need. And the bottom of an existing pond in upstream Dilari Changeri village where ponds are perceived as useful.

4.2.2.2 Spatial planning findings

Next, the rural and urban are linked spatially and these (de)linkages manifest through two key aspects. The first is groundwater infrastructure that typifies both the urban and rural built environments. The second de(linkage) manifests in larger-scale landscape elements like floodplains, urban parks, and other public space aspects. These are discussed as they pose certain barriers and opportunities for UTFI scale-up.

On the infrastructure front, one linkage is the ubiquitous presence of groundwater handpumps across both rural and urban. These pumps as seen in Figure 4-14 are present at regular intervals every few hundred meters and were noticeable during my urban rickshaw ride observations and while driving to rural village blocks. These pumps are also frequently used by locals to grab a quick drink on a hot day or wash their cattle. This exemplifies India's intricate dependence on groundwater as it is day-to-day and part of the urban & rural fabrics. In later conversations with IWMI researcher Dr. Navneet Sharma who was helping me on the field, I learned about a decades-old national water planning policy focused on implementing handpumps in every district for improved water access.

Figure 4-14: These photos show rural & urban water infrastructure. The left shows a rural setting where a woman washes her cattle, the middle of an urban handpump along a sidewalk, and the right of a large city overhead water tank. Author generated.

There are also infrastructure delinkages with certain infrastructure approaches present only in rural or urban. Examples include rooftop rainwater harvesting coupled with underground recharge tanks more common in Moradabad city given space constraints in the urban footprint. As part of fieldwork, we toured the rainwater system of Moradabad Polytechnic, and notes from this are found in Appendix 3. Further, the city also relies on large overhead water tanks connected to piping systems for distributing groundwater and these tanks are visible across the city (Figure 4-14.) Conversely, rural farmlands possess other groundwater infrastructure like deep groundwater pumps and larger open farm wells for agriculture. Infrastructure (de)linkages like these reveal the collective awareness & means of daily interaction with groundwater along with differing approaches in rural or urban regions; understanding this could help in more strategic implementation of groundwater interventions like recharge ponds.

Next on the landscape side, the most obvious continuum connecting rural and urban is the floodplains of Ramganga. Fieldwork showed that these riverbanks present opportunities for waterfront recharge ponds provided free pockets are accurately identified. The Ramganga floodplains are largely cultivated and rural interviews with village heads and inhabitants showed that farmers sometimes prefer cultivating as close to the riverbank as possible. This is because the soil is fertile from sediments and some farmers also do not mind their croplands getting inundated as it enriches the land. Interestingly, this trend continues into the urban pockets as well. The floodplains bordering Moradabad city can be considered the urban fringe or parts of peri-urban areas, and a short walking tour around these zones revealed the land to be either empty or already being used for agriculture (Figure 4-15.) i.e., the trend of floodplains being exploited for agriculture is not only restricted to rural blocks but is evident right outside the city as well. Regardless of if we were in rural or urban zones, it was clear that the floodplains are active and everchanging, but not yet completely exploited or encroached upon. Lastly, another noticeable landscape element in both rural and urban was small existing ponds currently likely neglected. This is also evident from satellite images and offers opportunities to rejuvenate existing ponds with recharging structures like the current UTFI pilot in the neighboring Rampur district. Thus, now is the opportune moment in Moradabad's development trajectory to accomplish rezoning, bank protection, and re-allocation of certain pockets of the riverbank for recharge structures. This will require a combination of spatial planning and policy shifts and will be discussed further in the Recommendations chapter.

Figure 4-15: Photos of the floodplain right outside Moradabad city, concrete walls show where development stops. There is lots of activity and cultivated land along the banks. However, some open plots are noticeable where ponds could be proposed.

Finally, landscape disconnects include perceptions and availability of public space in rural vs. urban. One common sentiment echoed during rural interviews with officials and inhabitants was that while land availability is plentiful in rural blocks, there are seldom communal places for villagers to partake in social activities. While touring the Amrit Sarovar Pond in the downstream Dingarpur block, it was immediately evident how children and adults alike enjoyed the space. The block development officer (BDO) of Dingarpur took pride in developing Amrit Sarovar ponds with sidewalks and benches for his constituents to enjoy, and villagers were appreciative of his leadership. This highlights the dual function of recharge ponds as meaningful public spaces, especially in rural areas where such spaces are sparse. However, on the urban side, one critical issue is land availability due to the dense urban fabric. As was highlighted during an officer interview in the Moradabad Smart City Office, land availability and ownership are complex. Any recharge efforts are limited to rooftop rainwater harvesting or initiatives restricted to government-owned land and property rather than private property. Given the land ownership issue, more immediate opportunities for recharge lie in government-owned land and public space. Along these lines, an interesting suggestion arose during an expert interview with a representative from the National Institute of Urban Affairs (NIUA.) He highlighted that the Indian Railways is both a large consumer of groundwater and occupies plenty of urban land within Moradabad city; thus, providing another opportunity for recharge efforts on government land. As for urban public space, creating new pockets might be tough but existing open parks in the city will be the easiest entry point. To this end, several urban parks are identified in Moradabad city under the Recommendations chapter. Thus, for the rural side implementing ponds with public facilities creates much-needed public space, whereas for the urban, the use of already existing public space might be the way forward.

Figure 4-16: The above photos show a contrast between rural and urban public space; the above was taken at an Amrit Sarovar Pond in Dingarpur block where kids appreciated the public area. The below picture depicts a busy intersection in Moradabad city. Author generated.

4.2.2.3 Biophysical environment findings

This rural-urban linkage is closely connected to the spatial pathway. The floodplain and Ramganga River themselves are obvious hydrological features part of the natural environment that permeates rural and urban. These have been discussed in the context of landscape planning under the spatial sub-chapter above. For this section on biophysical linkages, I now highlight another two features relevant to this study. The first is the aquifer underground, and the second is the atmosphere linkage of precipitation across rural and urban land. Both these features and processes are much larger than manmade demarcations of rural and urban, but human activity and climate change in rural or urban impact them in particular ways. Further, since this study looks ahead into 2035 for analyzing urbanization impact, it is important to note current and projected patterns of extreme hydro-meteorological events in this region.

Firstly, on precipitation, while on the field in IWMI Delhi's office, I had the chance to discuss more of my study with IWMI Delhi experts Faiz Alam and Navneet Sharma. They had many context-specific insights thanks to their extensive work on UTFI and other IWMI agriculture-related research projects. One point to note from these informal meetings includes the academic consensus that the Gangetic plain is set to see more extreme rainfall coupled with hot days in the coming decades, i.e., wet seasons will get wetter, and dry seasons drier. This trend is also corroborated in a recent paper by H.V Singh et.al, where the research team projected climate extremes over agro-climatic zones of the Ganga River basin under 1.5, 2, and 3°C global warming levels. They found that Consecutive dry days (CDD) and Consecutive Wet Days (CWD) both show a significant increasing trend. While 2035 is closer than these longer-term projections, it's critical to note that this region stands to experience more hydrological extremes. Thus, co-management solutions like UTFI for capturing wet-season excess to recharge depleting aquifers would have long-term benefits down the line.

Lastly, on the aquifer, the study region is located atop a deep alluvial aquifer, i.e., underlain by thick alluvial sediments like clay and silt (INRM Consultants & Tahal Consulting Engineers, 2020). It is also rich in groundwater and regularly being tapped for agriculture and urban needs. This was evident during fieldwork through the many rural pumps we noticed, the handpumps discussed in Figure 4-14, and in the urban scenario where according to data provided by the Moradabad municipal Nagar Nigam, the city is 100% dependent on groundwater (Appendix 3.) The below schematic Figure 4-17 demonstrates that while rural and urban blocks have distinct boundaries, the alluvial aquifer beneath is impacted regardless. Thus, this rural-urban linkage is critical in emphasizing a cohesive planning approach encompassing rural and urban for groundwater sustainability.

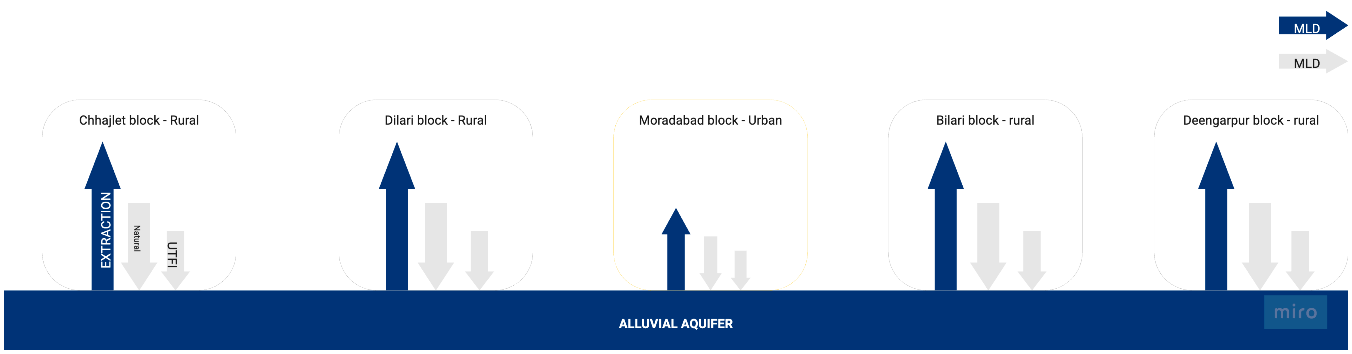


Figure 4-17: This is a conceptual diagram to visualize how rural and urban are connected beneath the surface through the aquifer.

4.2.2.4 Institutional framework & urban governance findings

The Ramganga basin is also a teeming policy environment. Many layers of governance overlap and dictate the development of the entire basin. One key finding is that at the basin level, rural and urban policy agendas are connected. But they get delinked and fall under separate governance bodies beyond the district level. This was informed by field findings and desk research, and for example, Appendix 3 interview summaries with the District's Chief Development Officer and Assistant town planner echo this disconnect beyond the basin scale. Figure 4-18 illustrates these governance strata and the delink beyond the district level.

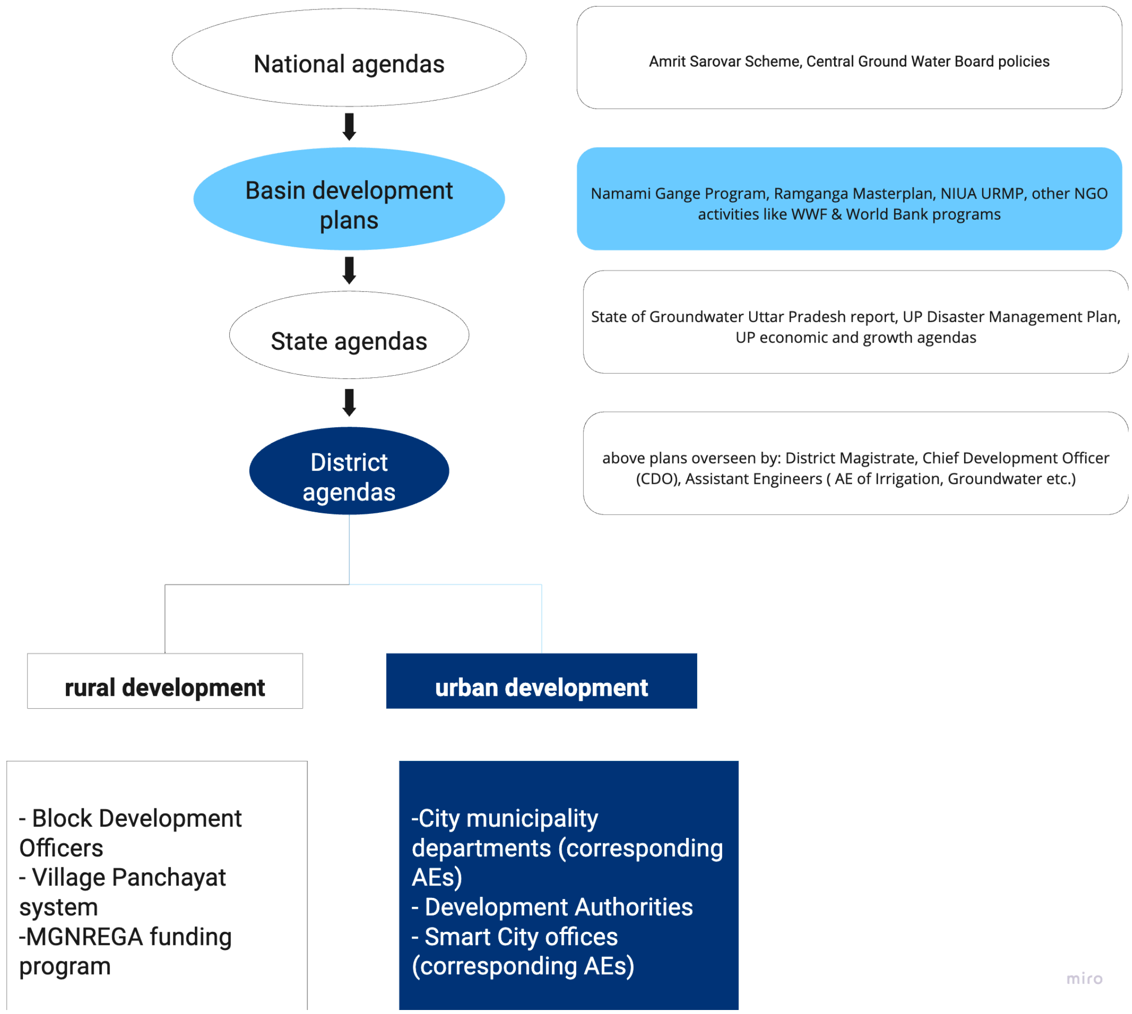


Figure 4-18: Part 1: This is an overview of Indian water governance as discovered during fieldwork & desk research. Dark & light blue segments are expanded upon in Figure 4-19 and 4-20.

As far as rural & urban linkages go, they are connected only at the basin level. I now highlight two key private and public entities contributing to Ramganga's master planning. First is the Urban River Management Plan (URMP) under NIUA, and second is the Ramganga Basin plan developed by the private consultants, INRM Consultants, and Tahal Group for the State of Uttar Pradesh. Basin plans are long-term; the Ramganga plan looks ahead to 2045 (INRM Consultants & Tahal Consulting Engineers, 2020). I extensively reference this plan in my water balance calculations of the upcoming Phase 3 sub-chapter. These plans set agendas that go beyond state borders but result in coalition building between various governance bodies. For example, during an interview with a representative from NIUA who leads the (URMP) Urban River Management Plan, he discussed that part of his work entails coalition building with different city departments and officers from urban sewage departments to town planning officers. INRM's Ms. Puja echoed the same sentiment on transboundary coalitions across rural & urban during her interview. Past the basin scale, rural and urban get disconnected. Rural areas fall under the Rural Development Board and India's complex and indigenous mode of village governance known as the

Panchayat system. All infrastructure, social programs, and funding pertaining to rural areas fall here. In past years, IWMI has done extensive work analyzing rural institutions as seen in Ratna Reddy's paper reviewed under the Phase 1 Literature review section 4.1.1.2. Thus, my new contribution towards policy and institutional frameworks for UTFI focuses on urban governance and the landscape of basin-level master plans. This cross-section of policy reveals urban departments IWMI will have to collaborate with to scale up UTFI (Figure 4-19) and potential partnership opportunities with other research organizations or NGOs like WWF & World Bank programs active in the basin (Figure 4-20).

The urban region is governed by city corporations or municipalities called Nagar Nigams, Development Authorities like the Moradabad Development Authority (MDA), town planning departments, and the more recent Smart City Initiative offices. All infrastructural affairs relevant to groundwater sustainability like waterworks, sewage, and disaster management are broken down by department and led by an Assistant Engineer for each under the city municipality. The below chart in Figure 4-19 highlights the different governing bodies for the city of Moradabad to complement previous IWMI work on rural governance frameworks.

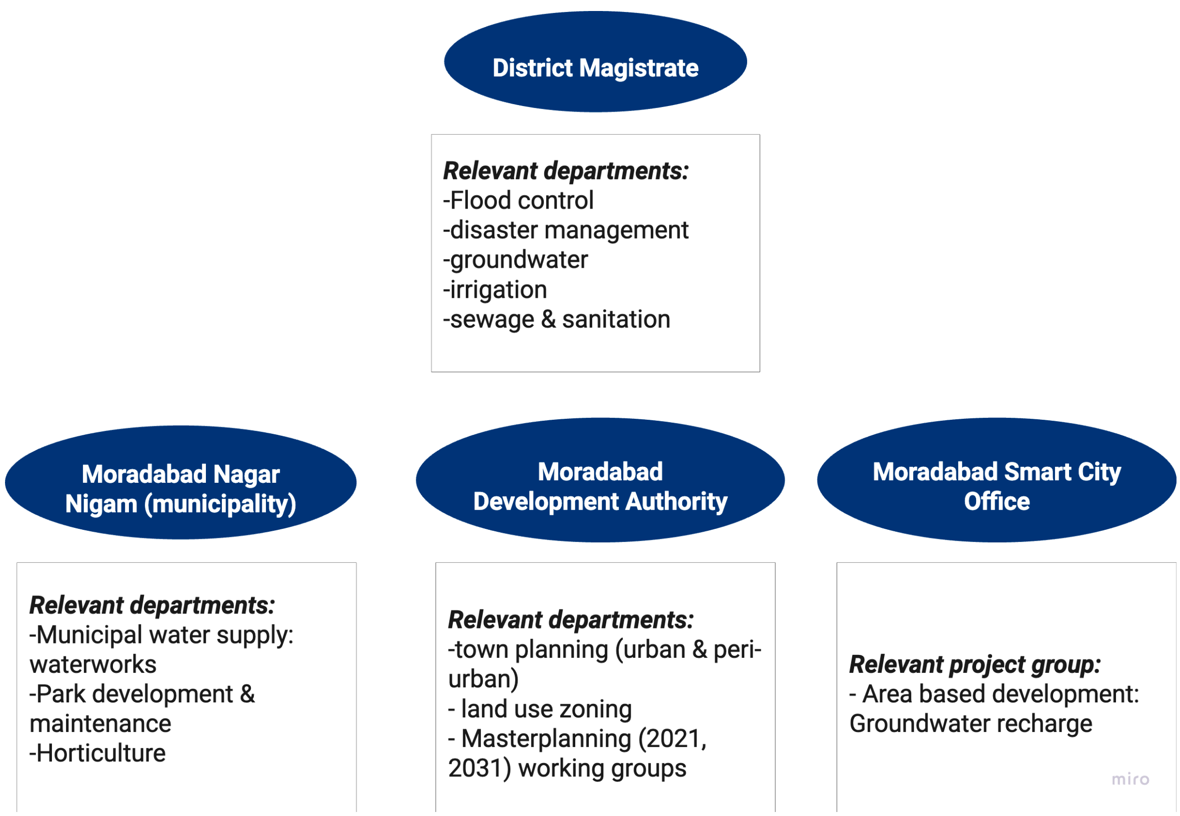


Figure 4-19: Part 2: A schematic of urban groundwater governance and relevant institutions for IWMI to engage with to scale up UTFI. This is summarized from fieldwork & desk research findings.

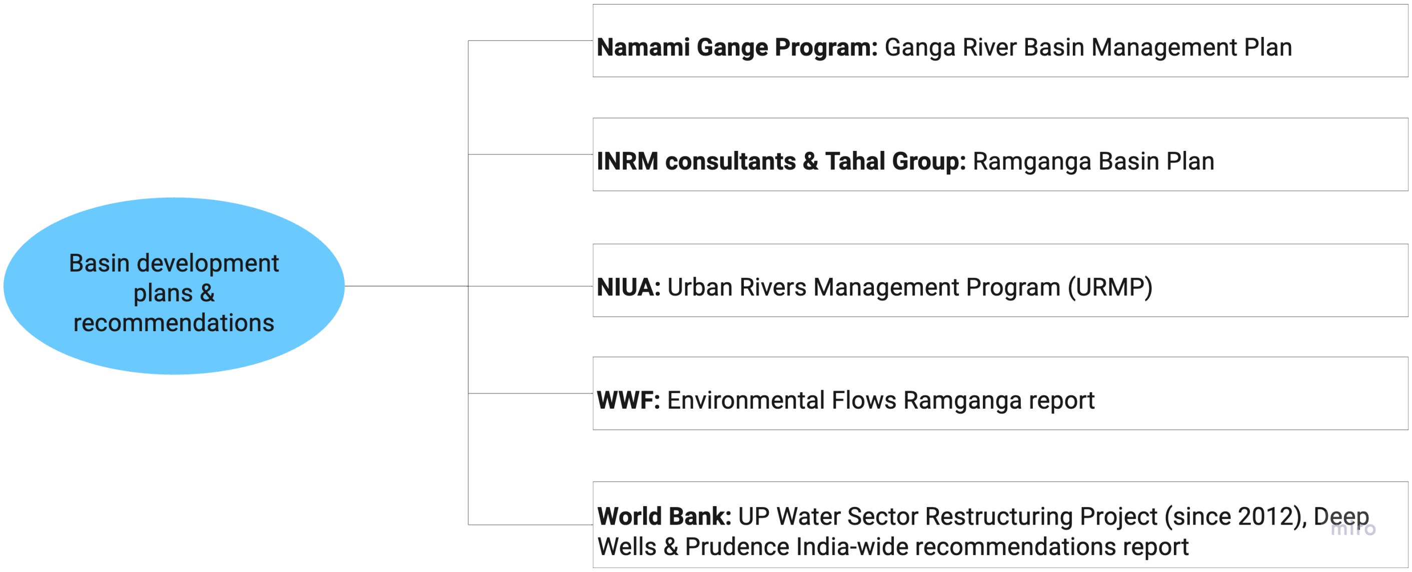
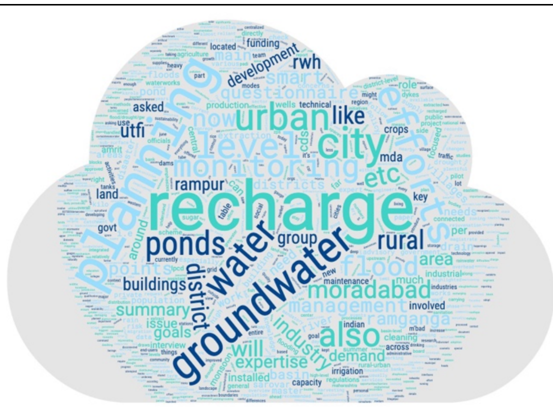
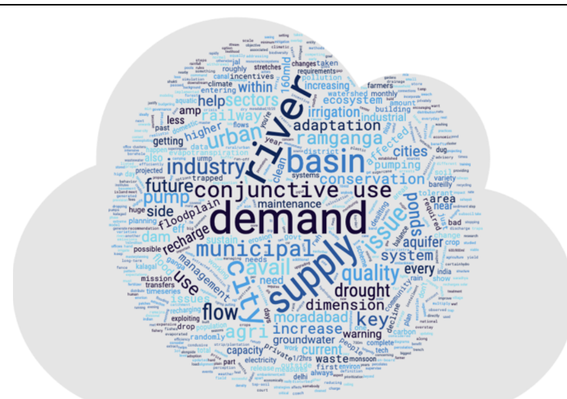


Figure 4-20: Part 3: A schematic of basin-level development plans that offer opportunities for partnership as UTFI aims towards scale-up.

Another global finding across institutional interviews revealed an across-the-board prioritization for groundwater recharge. I.e., basin-level planners down to district and urban officials all recognize the urgency of groundwater sustainability. This can be seen in the below word clouds from various officials' interview summaries in Figure 4-21. The main reason for this is the 2022 national Amrit Sarovar Scheme to rejuvenate 75 ponds per district across India; this has meant officials across governance levels are busy with the scheme.



Word cloud from interviews with different levels of government officials (x8 interviews), highlights policy priority across-the-board on groundwater recharge efforts.



Basin-level interviews with INRM Consultants Delhi, and National Institute of Urban Affairs (NIUA) representative for River Cities Program; highlights their expert emphasis on both demand-supply management, conjunctive use of GW and SW recommendation, and basin-level linkages.

Figure 4-21: The above are word cloud summaries from officer and expert interviews.

Finally, for urban planning policies, a key document is the Moradabad city master plan with a 2021 version and 2031 update (MDA, 2021a). The 2031 draft master plan in Appendix 5 depicts land use and allocation; some takeaways include riverbank development, a green belt, various levels of district or zonal parks, and locations of existing ponds. These offer opportunities for urban scale-up for UTFI. When comparing the 2021 (Appendix 4) and 2031 documents, most urban green, riverbank development, and ponds remain. One shift is an increase in area for small-scale & service industries. This is in the south of the city where some planned residential areas in the 2021 document are being switched to small-scale industries for 2031. This increase in emphasis on industry corroborates Moradabad's identity as the "Brass city" with a notable industrial segment; perhaps growth objectives also include the expansion of industry. This might increase groundwater demand thus calling for further recharge efforts. Ultimately, these findings form the basis for urban planning recommendations for UTFI's implementation & basin-level partnerships in the upcoming chapter.

Table 4-4: A synthesis of all fieldwork findings along rural-urban linkage pathways, summarizing answers to sub-question 3 and the second half of Phase 2.

R-U pathway	*Opportunity*
Community	- community co-management of ponds especially in rural blocks - coupling ponds with direct flood interventions for communities more directly affected by flooding
Spatial planning	- optimizing existing public space & government land in urban Moradabad - rejuvenating existing ponds that might be neglected, - near main city canal to connect & divert floodwaters during storms - development timeline wise, better to implement floodplain measures now before further encroachment & agricultural exploitation. - proposing ponds with a dual function of recharge and creating meaningful public space, especially for rural areas - existing urban parks as the entry point for UTFI in urban Moradabad - rural communities with more flood risk require coupled interventions of ponds with more direct flood-protection measures
Biophysical environment	- region set to experience more extremes, opportunity to capitalize in increasing rainfall for capture and recharge. - aquifer common to rural & urban, therefore needs to be planned for collectively
Institutions & governance	- urban side master plan document: areas to highlight UTFI implementation include riverbank development, green belt, district and zonal parks, and existing ponds. - urban governance: 3 main bodies identified where IWMI will need to collaborate with for urban UTFI scale-up – Moradabad development authority, Moradabad Nagar Nigam, and Moradabad Smart City Office. - basin-level masterplanning should incorporate R-U perspective for land use planning and allocate land to recharge infrastructures. - Amrit Sarovar scheme's current success is also an opportune point of entry.

Table 4-5: Sub-chapter summary table for all Phase 2 results.

Sub-Question	Methods	Results summary
SQ2: Where can UTFI technology be potentially tested in the Ramganga Basin and to what capacity can it address the drought-flood-groundwater nexus?	- GIS - news on flooded & groundwater stressed areas, - IWMI in-field expert recommendations (Navneet Sharma)	Final map of chosen villages in 4 rural blocks + Moradabad city (Figure 4-7).
SQ3: What rural-urban linkages pose opportunities and barriers for UTFI recharge ponds?	Extensive fieldwork: - semi-structured interviews with officials - informal urban resident & villager interviews - ethnographic researcher observations	Findings per rural-urban pathway, special note on spatial and institutional findings that will be developed in next chapter. R-U pathway summaries above in Table 4-4.

4.3 Phase 3: Post-field work

SQ4: What recommendations & urban locations can be identified for future implementation of UTFI recharge ponds?

This phase encompasses analysis and post-processing work I conducted after fieldwork. Outcomes from Phase 3 will be presented both in section 4.3 and the next Chapter 5 on final recommendations. Here in section 4.3, I set up the quantitative analyses required for the upcoming Chapter 5. I present results from the quantitative water balance calculation to identify levels of recharge required on both rural and urban sides in the current state and 2035 needs. This forms an input for Chapter 5, where a conceptual spatial plan is proposed to accomplish the required recharge. Finally, this is paired with the institutional and community actors who will become relevant when aiming for UTFI scale-up. One point to note here is the final recommendations for the percentage of land required will be presented on both rural and urban sides, along with overarching intervention suggestions across the whole study area. But the next step of potential locations for UTFI pond implementation will be restricted to the urban side. This is due to the time limitations of this study combined with the aim of providing new urban scope towards IWMI's existing rural work. Thus, a deeper dive into master planning documents and developing selection considerations for suitable land will be narrowed down for Moradabad city only, with an initial list of considerations also presented on the rural side. This process for sections 4.3 and chapter 5 is visualized below in Figure 4-22.

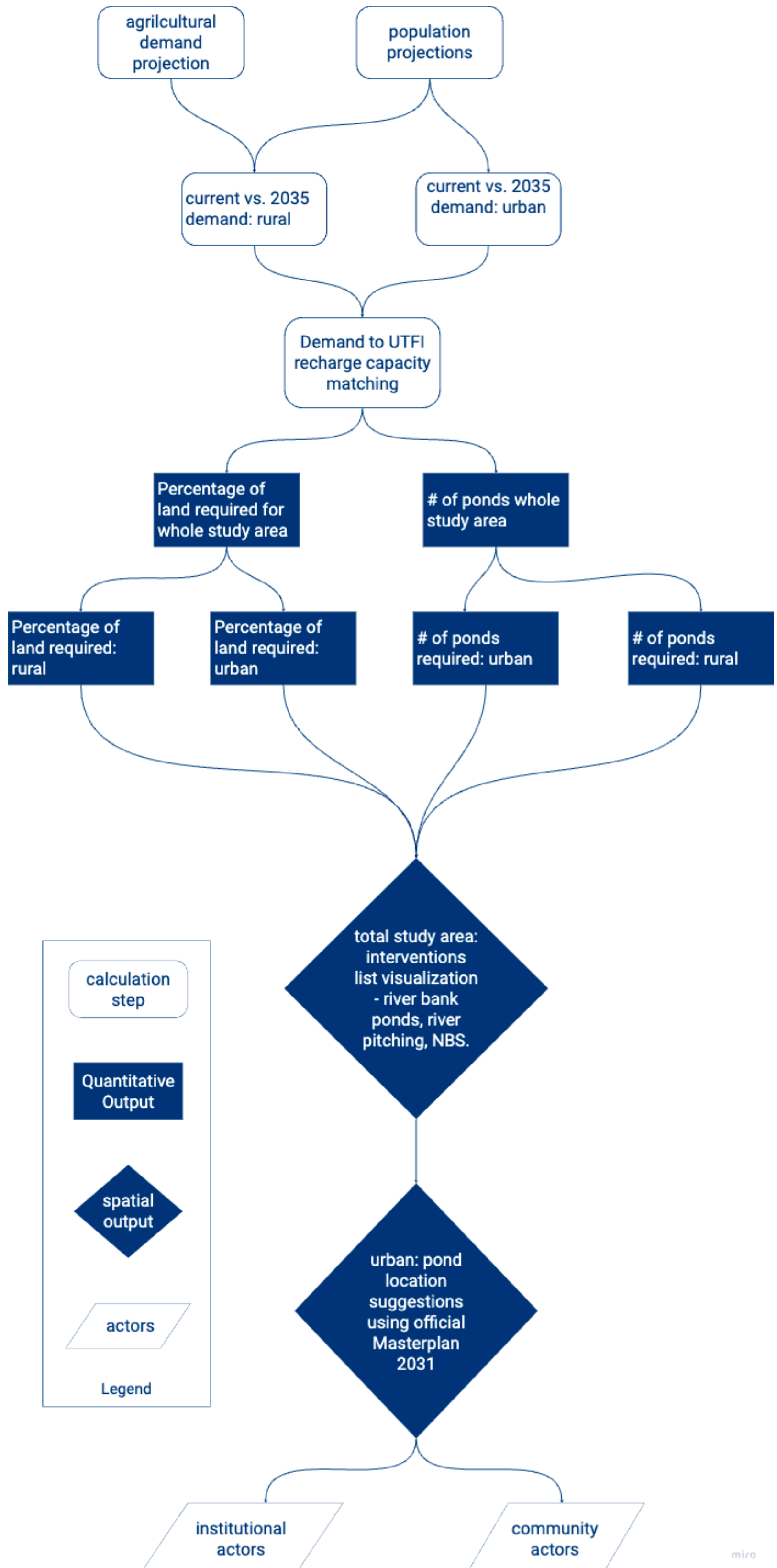


Figure 4-22: The above process chart describes the steps relevant to section 4.3 and chapter 5, both of which demonstrate the post-field work analysis of this research.

Section 4.3 comprises two key results, first a comparison of the current vs. 2035 number of recharge UTFI ponds required to meet demand, followed by the total percentage of areas required for recharge in Moradabad city and rural blocks of the study region. I chose to represent both number of ponds and normalize it to percentage areas because from the policy perspective, national schemes like the Amrit Sarovar adopt language of number of ponds per district.

For this analysis, the pilot UTFI pond from the neighboring Rampur district is used as the baseline. Key metrics relevant for the below calculations are the pilot pond's area which is 2625 sqm (75 x 25m) and average recharge rate of 580 m^3 per day (Alam et al., 2020). All the calculations for this section were conducted on Python and the code for the rural and urban sides are presented in Appendix 6.

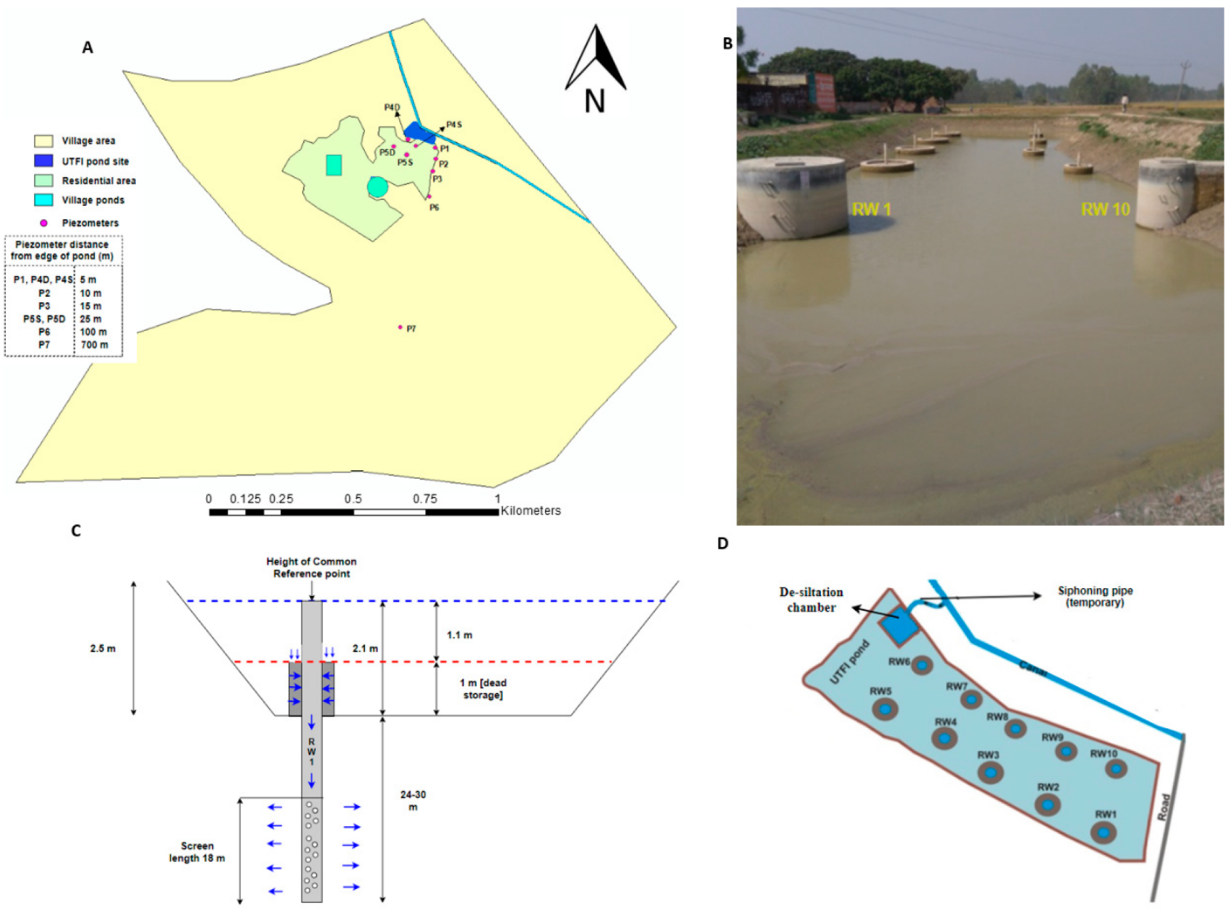


Figure 4-23: The above figures depict dimensions & site images from the first UTFI pilot in Rampur district Uttar Pradesh, nearby Moradabad district (Alam & Pavelic, 2020).

Overarchingly these calculations depend on a few critical inputs:

- per person demand in liters per person per day (LPCD), rural (55 LPCD), and urban (135 LPCD) (PIB Delhi, 2020).
- per day urban extraction in Million Liters per day (MLD), provided by the Moradabad waterworks department (181.92MLD).
- agricultural demand estimate extrapolated as 255.93 MLD for all rural blocks: current rural demand estimated as a percentage of urban demand from district-level data provided during interviews. We know for the whole district, agricultural demand is ~90% of total groundwater demand and urban is ~8%. Future projections extrapolated from INRM Ramganga master plan numbers of Upper Ramganga region in 2035 (INRM Consultants & Tahal Consulting Engineers, 2020).
- population of rural or urban areas: census 2011 for current populations, and future projections extrapolated from INRM Ramganga master plan projections of Upper Ramganga region in 2035 (INRM Consultants & Tahal Consulting Engineers, 2020)
- area of rural or urban study regions, extracted from QGIS.
- annual rainfall and rate of natural recharge 22% from the Central Groundwater Board (CGWB) (CGWB, 2018).

I now explain the calculation process for three key outputs, by first presenting some equations:

1. *OP*, Overshoot percentage that shows what percentage over natural recharge is consumption i.e., demand (present-day and 2035),
2. *NP*, Number of UTFI ponds required to meet different degrees of demand (present-day and 2035),
3. *PA*, Percentage of land area required to implement recharge ponds if we are to meet 50% of demand (present-day and 2035).

Table 4-6: The below is a list of key variables for calculations.

Variable	*Abbreviation*	*Unit*	*Constant value?*
Per person demand	P	Liter per capita per day, LPCD	Rural = 55, urban = 135
Per day population demand	PD	Million liter per day, MLD	-
Per year demand	PY	MLD	-
Annual rainfall	R	Meters, m	0.99
Block or city area	A	Square meters, sqm	-
Annual rainfall volume	RV	MLY	-
Natural recharge	NR	MLY	-
Overshoot percentage	OP		-
UTFI pond average recharge	UR	MLY	42.63
UTFI pond area	UA	sqm	2625

Intermediary calculations:

$$PD = P \times Population$$

$$PY = PD \times 365$$

$$RV = R \times A$$

$$NR = RV \times 0.22$$

Demand breakdowns in MLY:

Level of artificial recharge required to meet 50% of demand, AR5:

$$AR5 = (PY - NR) \times 0.5$$

Final outputs:

1. Overshoot percentage, OP:

$$OP = \left[\frac{(PY - NR)}{NR}\right] \times 100\%$$

2. Number of ponds required to meet demand, for e.g., 50% demand, NP:

$$NP5 = \frac{AR5}{UR}$$

3. Percentage of city or rural block area required, for e.g., 50% demand, PA:

$$A5 = NP5 \times UA$$

$$PA5 = \left(\frac{A5}{A}\right) \times 100\%$$

These equations are the same for rural and urban with few context-specific variables and remain the same for current and 2035 calculations. With these equations known, I now delve into these specific steps on the rural and urban sides for current and 2035 numbers.

4.3.1 Number of UTFI recharge ponds required to meet current and 2035 projected demand.

4.3.1.1 Current state recharge numbers, urban:

Demand is taken as 181.92 MLD according to data provided by the Moradabad Waterworks department. This is planned at 135 LPCD (Liters per capita per day) for a population of 887.871 from the census 2011, which yields 119.86MLD but the city extracts 181.92MLD showing a 52% extraction buffer. i.e., they are extracting 52% more than what is needed of 119.86MLD. However, it is likely that this buffer also accounts for more end-users than residential, like industries that are hard to profile in this study. Further, there might be infrastructure loss considerations this buffer also accounts for. For instance, losses within the city piping network & storage facilities, such that it requires the municipality to extract at a certain percentage higher than precise end-user demand. Nonetheless, this buffer is likely too large and can be reduced to improve savings by considering infrastructure upgrades and a better accounting of end-user needs beyond population & industry use numbers.

4.3.1.2 Future state 2035 recharge numbers, urban:

For the 2035 scenario, I increased the population to expected future numbers to then evaluate changes in demand. I also propose dropping the extraction buffer by half to 26% to increase savings.

4.3.1.3 Current state recharge numbers, rural:

Next on the rural side, it was critical to account for both irrigation and domestic groundwater demand. This is because, for the Moradabad district, irrigation demand is much higher than urban and rural domestic needs. It was highlighted during the interview with Moradabad district's Assistant Engineer for Groundwater that agricultural demand is around 90% of total district groundwater demand; refer to interview summary Appendix 3 section 9.3.3. This number was later corroborated with the Ramganga Master plan developed by INRM consultants, where for the entire Ramganga basin, agricultural demand accounts of 94% of all groundwater demand (INRM Consultants & Tahal Consulting Engineers, 2020). For this section, I used two primary data sources to estimate agricultural MLD since this was not directly available per block. For current state MLD, I had the raw data of urban extraction at 181.92MLD, and this accounts for 8% of district demand. This information was provided during the interview with Moradabad district's Assistant Engineer of Groundwater. From here I extrapolated what 90% would be for district-wide irrigation to then arrive at 255.93MLD per block. Next, for rural domestic demand, the national ministry of Jal Shakti recommends 55LPCD for rural use (PIB Delhi, 2020). This was multiplied by block population to get domestic demand. Block-wise population was also not readily available, and the census 2011 village population dataset was transformed using Python to abstract up the village populations per block, code for these population calculations can be found in Appendix 6.

4.3.1.4 Future state 2035 recharge numbers, rural:

Finally, for the future MLDs, the population was projected using the INRM Consultants Ramganga Master plan's growth rates for the Upper Ramganga region master plan (INRM Consultants & Tahal Consulting Engineers, 2020). The master plan also modeled a slight drop in irrigation demand between 2015 to 2045 due to improving irrigation practices and cropping techniques. I, therefore, take this percentage drop in demand to project block-wise agricultural MLD in 2035 from my baseline of

255.93MLD currently. As the master plan states, for the upper Ramganga irrigation demand in 2015 is 2028.24MCM, in 2025 it is 1928.94MCM, and in 2035 stands at 1827.01 MCM. This shows a 4.9% drop between 2015 to 2025 and a 5.3% drop between 2025 and 2035. This averages to a 5.2% drop in irrigation demand as modeled in the Ramganga master plan. For my calculations, I take this 5.2% as the drop from the initial agricultural demand of 255.93MLD to arrive at 247.75MLD in 2035 per block. Considering future population numbers, the block-wise results for recharge numbers in 2035 are presented below.

4.3.1.5 Assumptions and caveats of the above calculations

This calculation is a simplistic model that was built on a set of assumptions which are also limitations of this research. These are listed below and further discussed in the Chapter 6 Discussions.

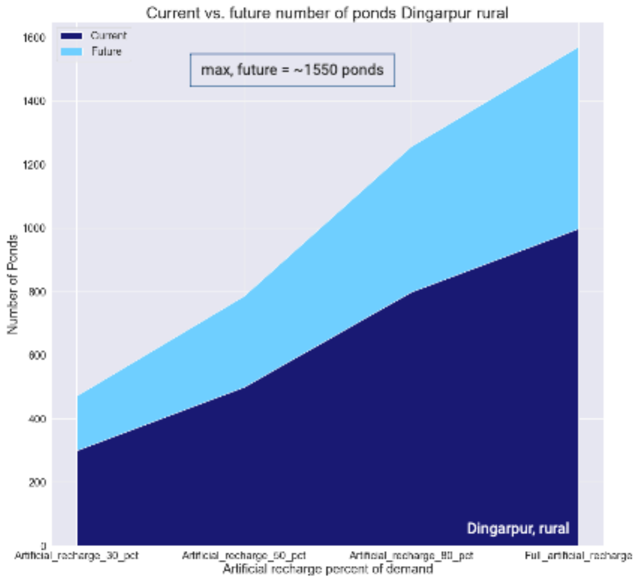
1. *Daily extraction rates*: For daily extraction in MLD, I only take the data provided by the city waterworks department (181.92MLD) and I further estimate agricultural MLD from here. There are two caveats here, first using only the 181.92MLD on the urban side and using this as the baseline to extrapolate agricultural MLD. 181.92MLD only accounts for the official extraction pumps monitored and accounted for by the city. There is a whole private sector of informal groundwater extraction in India, from individual extraction pumps installed in households and shophouses, to other unaccounted-for agricultural extraction. This informal sector is common knowledge amongst all stakeholders and daily practice, but very difficult to quantify. Therefore, the real extraction rates i.e., demand per day might be much higher. This assumption & difficulty in estimating a number was confirmed during interviews with INRM consultants. Thus, it was hard to determine a rule-of-thumb or correction factor to estimate this unaccounted extraction and was left out in the above results. The second assumption follows from this, as there was no ready block-wise data on agricultural MLDs, it came from the 181.92MLD since I at least know percentage breakdowns between urban vs. agricultural from district officials. Overall, future in-depth work is required on both fronts.
2. *Agricultural block demand:* I assume all rural blocks to have the same demand of ~255MLD and this is a simplification. Deeper calculations will account for specific crop types grown in each block to arrive at block-wise MLDs, but this level of crop irrigation modeling was out of my scope. To keep the calculations high-level and accomplish the purpose of elucidating the thinking process, I went with 255MLD.
3. *Sectoral demand*: The urban calculation ignores industrial extraction as I assume the 181.92MLD of municipal supply also accounts for piped supply to factories and other commercial parties. Another key point brought up during an expert interview with INRM consultants is that the main industrial sectors of Moradabad, i.e., brass and leather manufacturing, are extremely fragmented. There are innumerous small-to-medium enterprises (SMEs) operating out of people's homes and small shophouses, therefore any estimation of industrial consumption will require a deep in-field study to catalog all these SMEs.
4. *Site characteristics & infiltration rates*: I am assuming uniform recharge rates across all ponds in the entire study region. This ignores the soil and site-specific conditions of different locations as

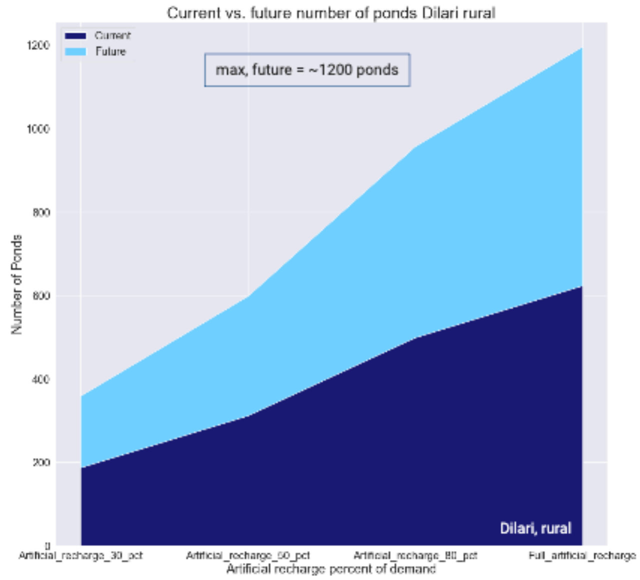
this would affect natural infiltration rates. To simplify the study, I went with the CGWB recommendation of assuming a 22% infiltration rate in Indo-Gangetic alluvial aquifers. Along these lines, for the urban side, I also did not estimate paved surfaces and their impact to either run-off or infiltration rates. i.e., both rural and urban infiltration rates are taken as 22%. Future work to build a more sophisticated model will require a correction factor to represent urban paved surfaces.

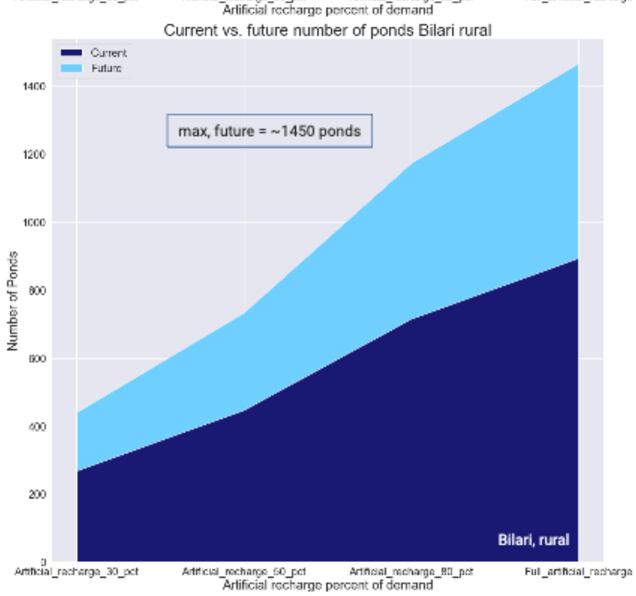
5. *Per pond recharge rates*: The pilot UTFI used as a baseline pond is a best-case scenario. It had 10 recharge wells in one pond and was closely monitored over three years. 10 recharge wells are an optimistic scenario from a cost perspective, and as the District's Assistant Engineer for Irrigation mentioned in his interview, 4 wells would be more realistic. Thus, the realistic recharge rate per pond might be lower than assumed in these calculations.
6. *Out of scope:* Finally, many other critical aspects were out of scope for this study including water quality, surface-groundwater tradeoffs, and inter-basin transfers but these still impact daily demand and the region's water use. For instance, one critical recommendation from experts for Indian cities like Moradabad is to move towards conjunctive use. I.e., to use a mix of ground and surface water sources. This future scenario was not represented in my calculations for 2035.

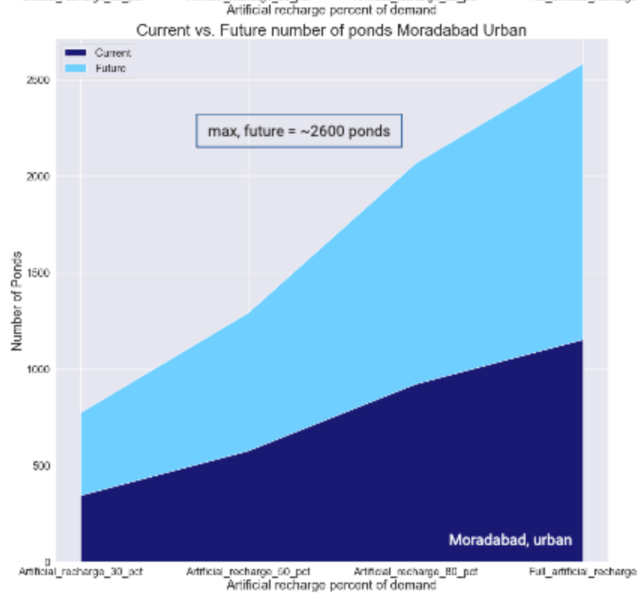
4.3.1.6 Current vs. 2035 number of ponds required – plots & infographic.

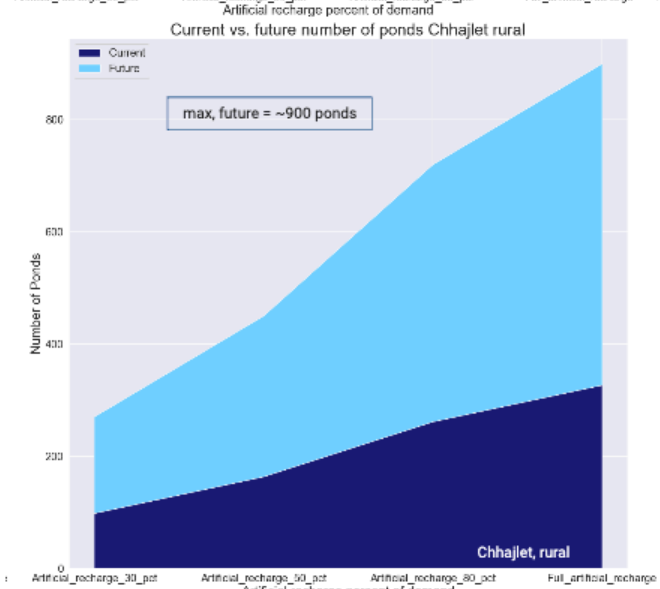
The charts derived from the above calculations are now presented below. These are based on Python calculations for Overshoot percentages, number of ponds, and percentages of block areas required according to equations presented in section 4.3's preamble. The plots in Figure 4-24 below demonstrate that no matter urban or rural, the number of ponds needed to meet future demand is rapidly increasing. Critically, even when considering the assumptions behind these simplistic calculations, we see that the number of ponds required just for this study region is in the 1000-2000s per rural block and city boundary. Whereas schemes like the recent Amrit Sarovar, while well-intentioned, only call for a blanket 75 ponds per district which would be insufficient. Next, there is a critical overshoot percentage in all cases seen in Figure 4-25, which highlights the percentage by which consumption exceeds natural rates of recharge for today and 2035's scenarios. All this considered, the urgency for implementing rechange modes like ponds is high and a concerted effort to plan & allocate land for recharge infrastructures is required.











Number of ponds required to meet demand

These say: To meet 30 percentage of demand, we will need X ponds today and Y ponds in 2035. To meet 50% of demand, we will need A ponds today and B ponds in 2035; etc.

artificial recharge required to meet differing levels of demand: meeting 30 percentage, 50, 80% and 100%

Figure 4-24: This shows plots for all 4 rural blocks and Moradabad urban. It demonstrates the number of recharge ponds that will be needed to meet different percentages of demand (30,50,80,100%), today and in 2035. The max number of ponds for the 2035 scenario is highlighted per block.

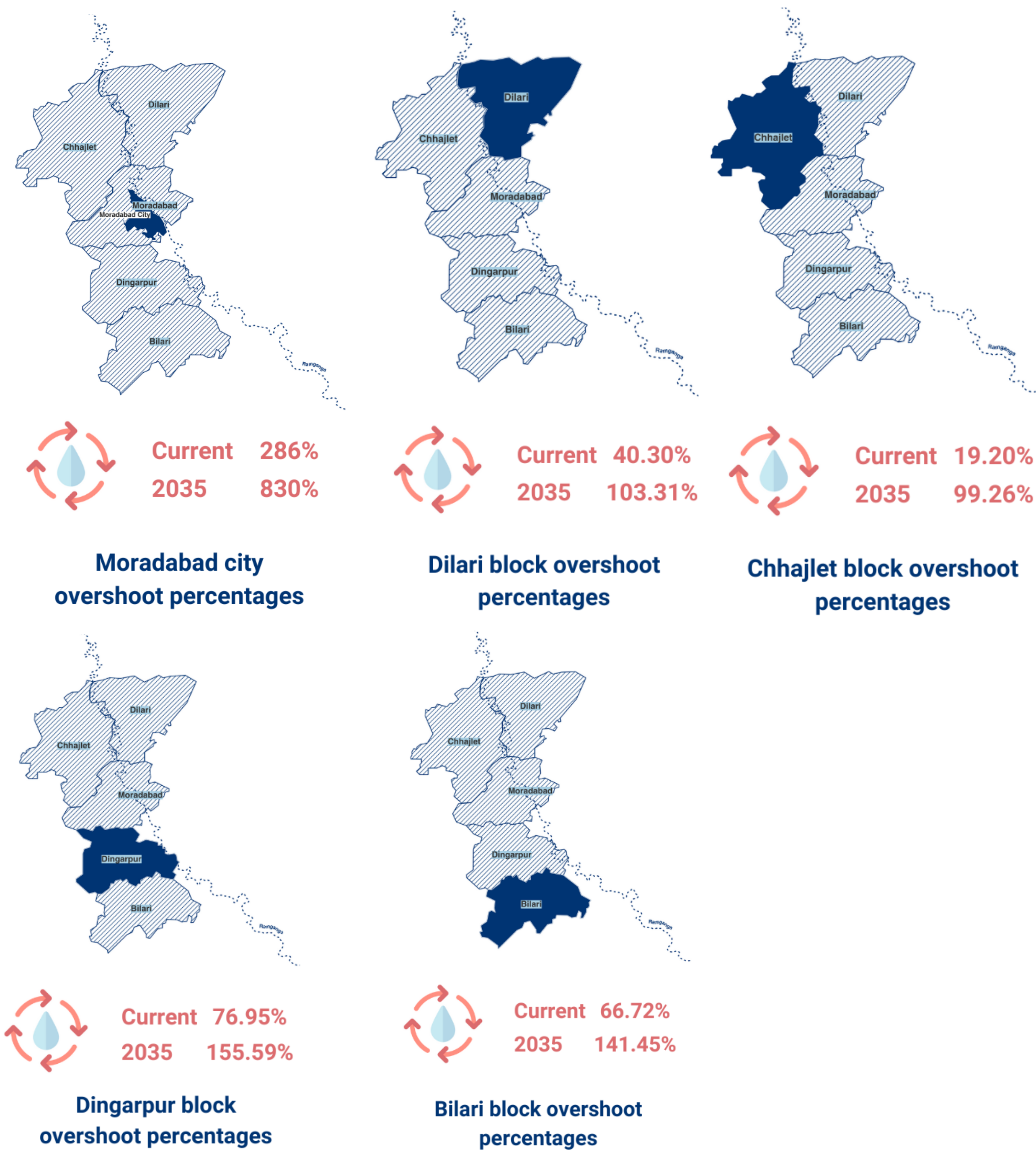


Figure 4-25: An infographic to highlight overshoot percentages of current vs. 2035 for all rural blocks and urban regions of the study area. Overshoot percentage here means how much current and projected 2035 groundwater demands are over the rates of natural recharge.

4.3.2 Percentage of land area required to a maximum of 50% demand in 2035.

Next, the above data on the number of ponds can be expressed as percentages of area per rural block and for the city. Here I take the middle case of meeting 50% of groundwater demand through artificial recharge for current and 2035 needs. These numbers will finally be used as a rough guide to identify locations that could be suitable for recharge ponds, with more detailed analysis on the urban side.

Table 4-7: Summary table of percentage area calculations for the whole study region.

Block / region	*Percentage of area to meet 50% demand - current*	*Percentage of area to meet 50% of demand - 2035*	*Future 2035 area required in sqkm*
Moradabad City	1.92	4.29	3.39
Rural Dingarpur	0.49	0.77	2.16
Rural Dilari	0.25	0.48	1.76
Rural Chhajlet	0.11	0.31	1.46
Rural Bilari	0.42	0.69	2.04
Total Area			10.81

4.3.3 Result validation: follow-up interview outcomes with INRM Consultants.

As I developed my results above and formulated initial recommendations, I was in touch with my IWMI external supervisors Paul Pavelic and Faiz Alam. Their inputs on my calculations, assumptions, and areas of improvement have been incorporated to the best of my abilities during the last weeks of this project. Finally, I was also able to host one penultimate validation interview with INRM consultants' Ms. Puja Singh. She spearheaded the efforts behind developing the Ramganga Basin plan and provided a valuable first round of feedback during Phase 2 interviews on the field. As for the validation of my calculation assumptions and results, some key takeaways included:

1. Representing recharge needs as a percentage of area from a land-use perspective will be a very useful tool for policymakers.
2. These area numbers can be used as an initial starting point while planning land on both urban and rural sides and are a useful tool for communication. This helps set a framework that can later be refined with in-depth calculations.
3. It is important to caveat all assumptions of the calculations – per my calculations a range of 25-50% of demand could be met, rather than stating precisely 50% of demand will be met.
4. Informal extraction rates are difficult to estimate but their occurrence is widely known.
5. Sectoral MLD for specific industries like leather and brass manufacturing is difficult to estimate given these industries are very fragmented. A detailed field study to document individual actors will be needed.
6. When asked if urban and agricultural MLDs used in my calculation seem reasonable, she commented they are a reasonable starting point that will require further refinement. INRM's

approach is far more detailed with hydrological modeling based on the crop types for the agricultural side.

7. On the urban side, proposing areas on existing parks and government land makes the most sense. Creating new spaces in already dense urban areas is unrealistic & will have opposition.
8. On both rural and urban sides, highlighting the public space benefits of recharge ponds will be a good argument.

I now take all the above into consideration for the upcoming chapter on final recommendations.

Table 4-8: Sub-chapter summary of all Phase 3 results.

Sub-Question	Methods	Results summary
SQ4: What locations & recommendations can be identified for future implementation of UTFI recharge ponds?	- quantitative water budget calculations - semi-structured validation interviews	Set-up for next chapter of final recommendations on land-use planning: overshoot percentages per block, area required for recharge to meet 50% future demand, number of ponds required per block.

<u>*Chapter summary*</u>

Chapter 4 was an extensive interdisciplinary presentation of all results across the three phases of 1,2 and 3 pre, post and during fieldwork. Each section of this chapter centered around answering one of the sub-questions which all provide takeaways to synthesize my final set of recommendations in the next Chapter 5. Chapter 4 Phase 1: Pre fieldwork began with an extensive literature review to identify research gaps and defined a rural-urban study-region with Moradabad city and 4 rural blocks. Phase 2: Fieldwork outlined all my field findings along 4 rural-urban linkage pathways of *community, institutions, spatial planning, and biophysical environment*. And finally Phase 3: Post fieldwork dove into quantitative analyses on number of UTFI ponds and percentage of land that will be required to meet current, and 2035 groundwater demands. All this primes the next chapter on multi-disciplinary recommendations.

5 Recommendations

All desk research and fieldwork culminate in this chapter where I synthesize three key recommendations and propose the institutional and community cooperation modalities needed to realize them. I break these down by looking at the entire study area of rural+urban and then zooming into only the urban. The first two sub-chapters can be seen as general recommendations speaking to policy-makers in this field, and the last recommendation is specifically for IWMI to dialogue with city-officials in helping meet its goal of urban scale-up for UTFI. Therefore, this chapter is structured as seen below in Figure 5-1.

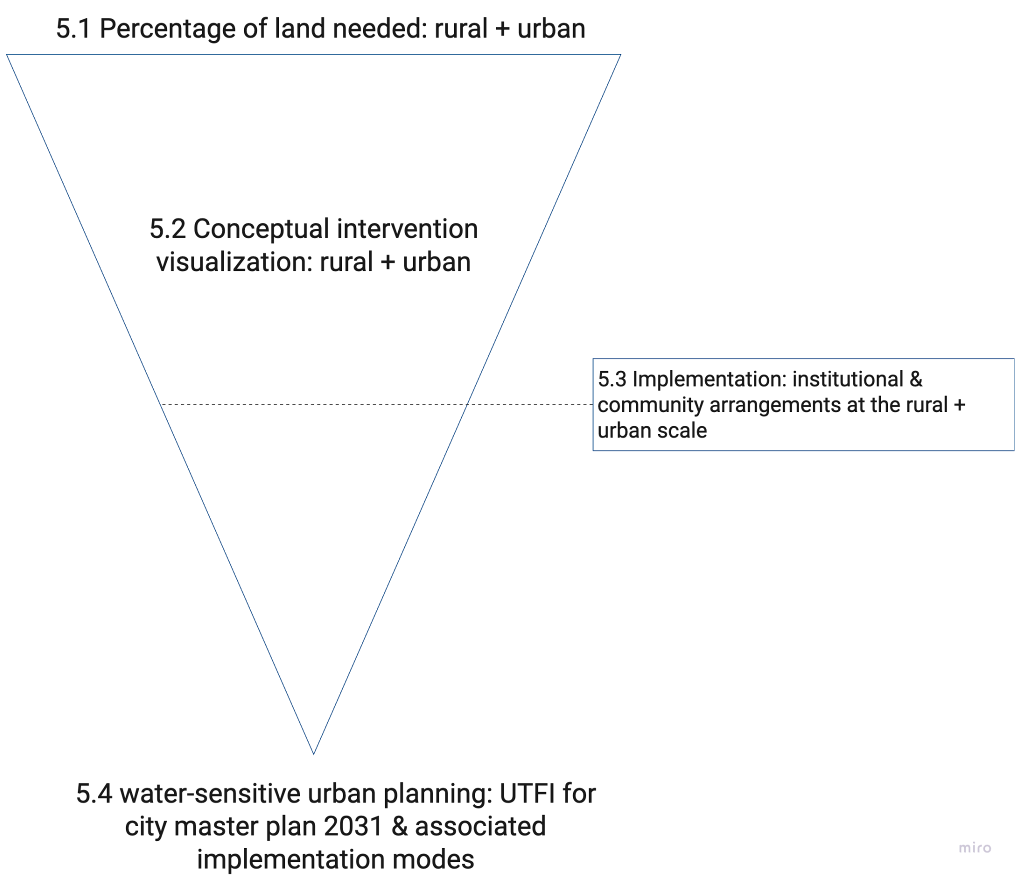


Figure 5-1: This image outlines the structure of recommendations from this research.

5.1 Required recharge area for meeting up to 50% of demand in 2035.

5.1.1 The recommendation: land area budgeting.

This recommendation is to understand how much land would be required for recharge structures like UTFI. These numbers were developed in section 4.3.2 and vary for the rural and urban sides. Given that the calculations behind it are simplistic, this is just an initial rule-of-thumb to guide policymakers. Further detailed calculations are needed to sharpen these findings and is discussed in Chapter 6. In Figure 5-3 an inverse relationship is noticed; urban areas with the smallest land require the highest percentage ~4.29% to be set aside for meeting up to 50% of groundwater demand. This makes sense as firstly, urban areas are densely populated i.e., higher demand for domestic needs, and secondly, a smaller city footprint means lower area for natural recharge. Thus, it requires further efforts to artificially recharge. As part of my recommendation, I urge policymakers to include recharge infrastructure in their land-use planning. Calculations from this research paint a picture for budgeting land for various needs between water infrastructure & other land-use like residential, agricultural, and industrial land-use. From my calculations and its associated caveats, a starting point is: 10.81 sqkm across both rural and urban to satisfy up to a maximum of 50% groundwater demand in 2035 for the combined study region. Similarly with a lower bound, to meet a maximum of 30% of groundwater demand in 2035, around 6.48 sqkm would be required.

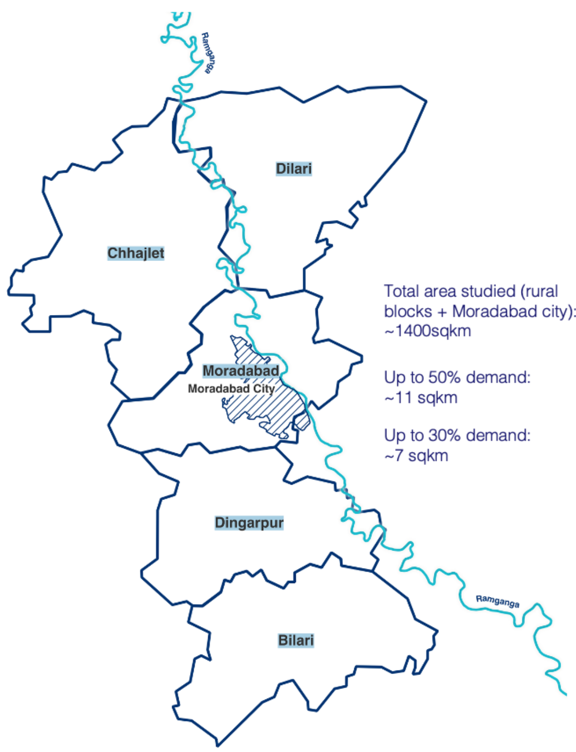


Figure 5-2: This map summarizes sqkm needed to meet different levels of demand for the study area.

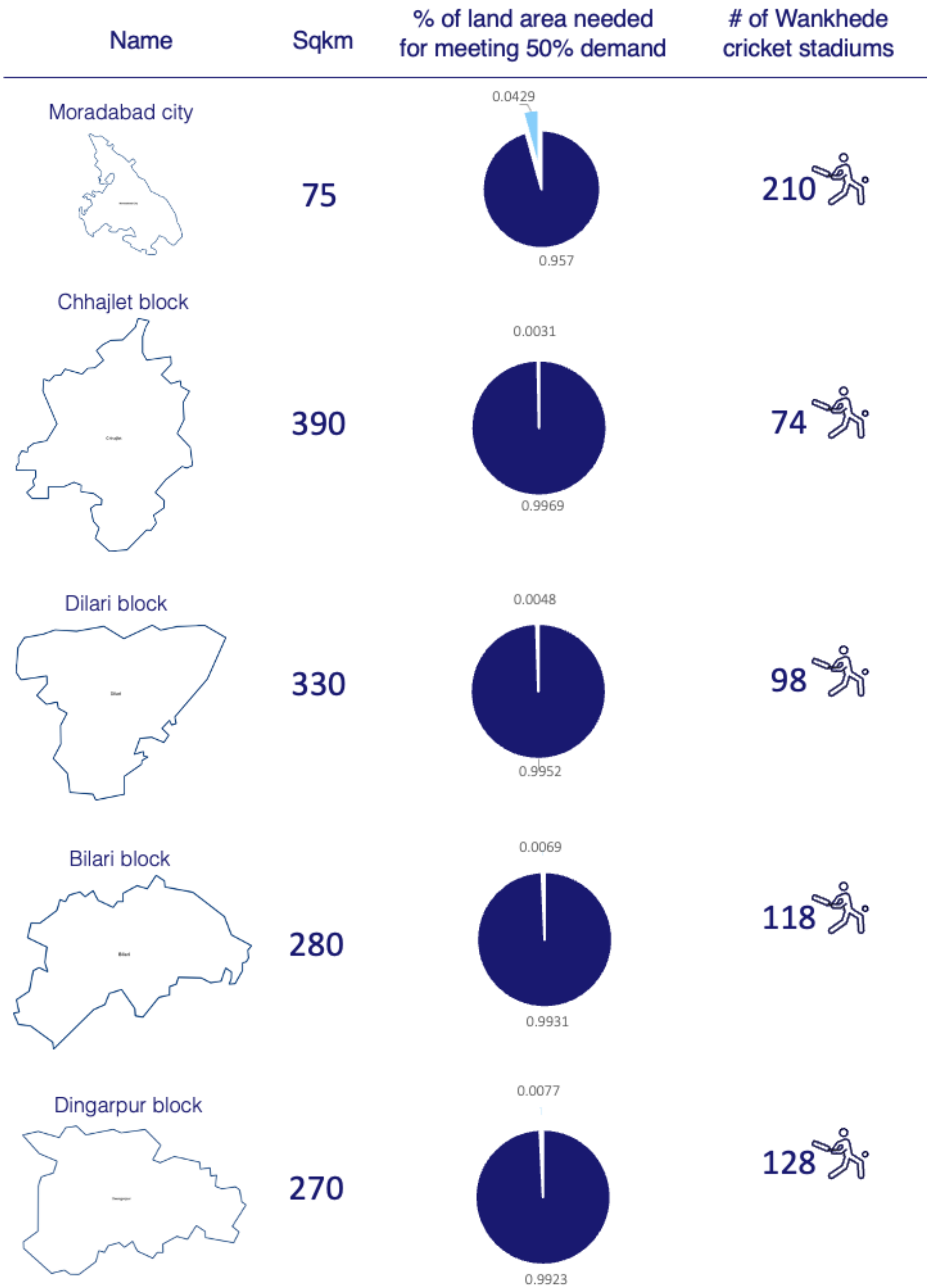


Figure 5-3: This infographic summarizes the percentage of land required for Moradabad city and the rural blocks to meet 50% of demand in 2035; it uses India's most played sport, cricket to illustrate relative areas to Mumbai's Wankhede stadium.

5.2 Conceptual visualization of interventions: rural + urban

5.2.1 The recommendation: sustainable adaptation of existing infrastructure & landscapes

Now that the overarching areas required are known, the next step is spatially identifying locations to help accomplish this. While considering this aspect of spatial planning, I am also including findings from the field that arose in discussions with community members and officials.

Spatially, the easiest point of entry for UTFI is existing ponds. Rejuvenating existing ponds with recharge wells will be a worthwhile first approach, and Figure 5-4 visualizes all existing ponds in the study region. Based on a QGIS zonal statistics analysis of a global surface water dataset, all available ponds in the study region account for ~4.6 sqkm. From previous analyses in Figure 5-2, to meet a maximum of 50% demand or a maximum of 30% demand in 2035, ~11 sqkm and ~7 sqkm will be required respectively. Therefore, even if all existing ponds were rejuvenated successfully, the required recharge rates won't be met. Further, recommending a blanket approach of rejuvenating all ponds would overlook land ownership and private-public classifications of these ponds, thus requiring a mixed approach. Finally, this number is based on many assumptions & simplifications of this research, but nonetheless, some of these mixed approaches are now discussed. Some key recommendations visualized in Figure 5-4 are as follows:

1. *Pond zones*: Upstream communities like villages visited in Dilari were more readily receptive of pond modalities because they perceived ponds close by the river as 'catchment zones' that could catch floods before overflowing into the village.
2. *River training & Nature-based solutions (NBS)*: Downstream communities in Dingarpur are most severely affected by floods each year, for example, the 15 villages surrounding Ahmednagar. These groups perceive ponds as secondary solutions and more urgently need river pitching as the village head emphasized. There are many methods to do this under the umbrella of river training, including hard-engineering methods to hold back the riverbanks with caged stone groynes, or creating embankments to hold back flood waters (EOPCW, 2023). Other river training methods include check-dams which also have a dual function of groundwater recharge and are currently being researched by IWMI. Soft-engineering methods include a suite of nature-based options, and a recent UN Environment report lists a few. Some of these are restoring wetlands and reconnecting rivers to floodplains (UN Environment - DHI and IUCN, 2018), which can be coupled with the abovementioned river training mechanisms. This way, groundwater infiltration is more directly improved along with flood-protection measures and water quality improvements thus combining a suite of river training, NBS, and MAR.
3. *Urban waterfront development:* Fieldwork showed that floodplains right outside the city offer interesting zones for recharge since these areas are not yet completely exploited for agriculture or urban encroachment. NBS will also be applicable in these areas but special considerations for urban water quality and stormwater run-offs will be needed. Therefore, floodplain urban UTFI

coupled with NBS would be one way forward. Two key policy briefs become relevant for river city water management – NIUA's Urban River Management Plan and the UN Environment's policy primer section on NBS for growing cities. For the former, I conducted an interview with NIUA's representative (Appendix 3) and summarized key findings in the previous chapter. Some key takeaways from his interview included using existing government land like the Indian Railways corridor for recharge infrastructure and considering the tradeoff between groundwater recharge vs. adding more water to river baseflows when working close to the river on its floodplains. Next, the UN Environment's document also recommends urban ponds, validating UTFI's relevance for growing cities. The document also suggests permeable pavements, rooftop rainwater harvesting, urban catchments & uplands, and bioretention (UN Environment - DHI and IUCN, 2018). These could form compatible pairings for UTFI to offer a mixed-suite of solutions on the urban waterfront.

Figure 5-4 visualizes these recommendations that when combined, help go beyond only relying on existing ponds. To summarize, when taking a holistic perspective, sections 5.1 and 5.2 have covered some bigger-picture recommendations across both rural and urban. Recommendations include land-use allocation for recharge and initial spatial suggestions for where to situate UTFI. All of this serves as a starting point but to realize them, key institutional and community engagement arrangements will be needed. These are now discussed in section 5.3. Following this, I take a final zoom-in into the urban scope for the city of Moradabad and its Masterplan 2031 in section 5.4.

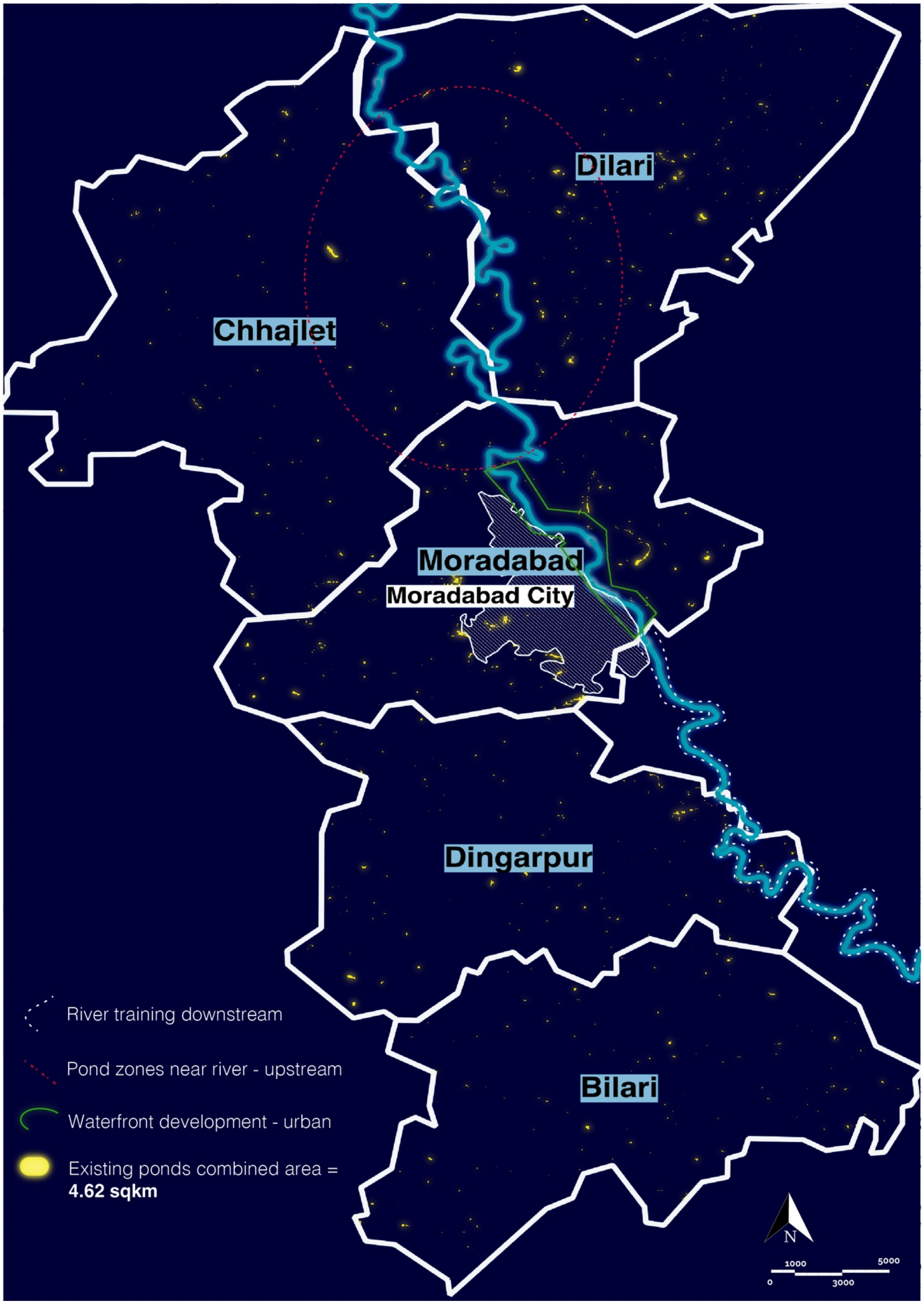


Figure 5-4: This is a conceptual map of interventions for the entire study region.

5.3 Implementing R-U recommendations 5.1 and 5.2: institutions & policy

For recommendations across rural and urban, a higher-level basin planning approach is needed. The mode of implementation here is for basin planning to take a holistic R-U perspective and allocate land for recharge structures. This will require basin and district-level planning actors mentioned previously in Chapter 4 Figure 4-23.

Fieldwork showed that at this level, the decision-making landscape and institutional structures are complex. Indian governance is multifaceted between its administrative wing of appointed officials, versus its electoral wing of elected representatives. District, rural, and urban departments all have a mix of these representatives. District officials set district-wide agendas that then get implemented by rural and urban development departments below. However, these district officials are also motivated by national agendas they need to report progress on. This was evident in the case of the recent Amrit Sarovar national scheme of implementing 75 ponds per district. This national agenda acted as a great push for district goals, eventually trickling down to rural and urban implementation.

Then there is the parallel ecosystem of international research organizations and NGOs working on basin planning. Examples include IWMI, WWF, World Bank programs, and inter-country partnerships for example the India-Australia coalition, operating in this sphere. These actors serve as the backbone of empirical research to bring about needed policy shifts. This is already the current landscape, but lobbying for basin-level land-use planning to include recharge infrastructure would be a new angle for IWMI specifically and a worthwhile recommendation for the organization to pursue.

Ultimately, Indian governance is top-down and institutionally complex, with a host of departments, governance bodies, and private-public collaborators juggling national and local agendas. A larger conversation on horizontal governance and transparency will always be relevant, but for the purposes of this thesis, I focus on working with the current system. As it is now, this complexity might hinder the scale-up of UTFI ponds if IWMI's proposals lack larger-picture incentives for implementation bodies to adopt these recharge structures.

Therefore, any proposal to sway groundwater policy from IWMI or otherwise will need to be convincing to a host of actors and accomplish many goals at once. I.e., recommending mixed interventions that help accomplish a suite of goals for the basin will make a stronger argument than proposing recharge ponds in isolation. In this vein, I see three key opportunities for successful UTFI scale-up at the R-U basin scale:

1. Now is an opportune time to tag onto the ubiquitous prevalence of the Amrit Sarovar scheme. Every official we interviewed at the district, rural, and urban governance levels was currently working with the scheme to some capacity. Seeing as this scheme is temporary, the momentum from it will still be alive for further conversations around recharge in the coming years. I.e., UTFI

and MAR scale-up can build off the initial efforts from Amrit Sarovar. The scheme has created valuable awareness and political will; this can be capitalized on further.

1. UTFI and other MAR modes will have more success when proposed in conjunction with other basin masterplans rather than as standalone interventions – there is an opportunity to collaborate more with basin masterplanning entities to enhance current documentation with the rural-urban perspective on land-use planning for recharge structures. The Ramganga Masterplan by INRM and NIUA's Urban River Management Plan will likely both have upcoming updates and IWMI could lobby for these additions. Finally, the national coalition known as Namami Gange which aims at restoring the river Ganga, of which Ramganga is a tributary, can be an interesting avenue of collaboration. Currently, Namami Gange's pillars are the following: Sewage treatment, riverfront development, river surface cleaning, biodiversity, afforestation, public awareness, industrial effluent monitoring, and Ganga Gram focused on constructing toilets (NMCG, 2016). There is room here to argue that groundwater recharge touches many of these pillars.
2. The institutional web is already complex, so working with existing structures could prove more successful than proposing further new departments or governance bodies. Prior IWMI work recommended the establishment of a UTFI Management Committee (UMC) within the rural governance structure (Ratna Reddy et al., 2020c), and this might run the risk of adding further redundancy to the system.

This wraps the policy considerations at the basin level; the core proposal here is for basin-level actors to consider an R-U perspective on land-use planning to then allocate land to recharge structures; and for groups like IWMI to continue the momentum of the Amrit Sarovar scheme.

5.4 An urban zoom-in: Water-sensitive urban planning for master plan 2031

Now for the final recommendation, I zoom into the urban segment of Moradabad city to propose water-sensitive additions to their recently released 2031 Master plan.

5.4.1 The recommendation: inclusive water planning through pond & park interventions

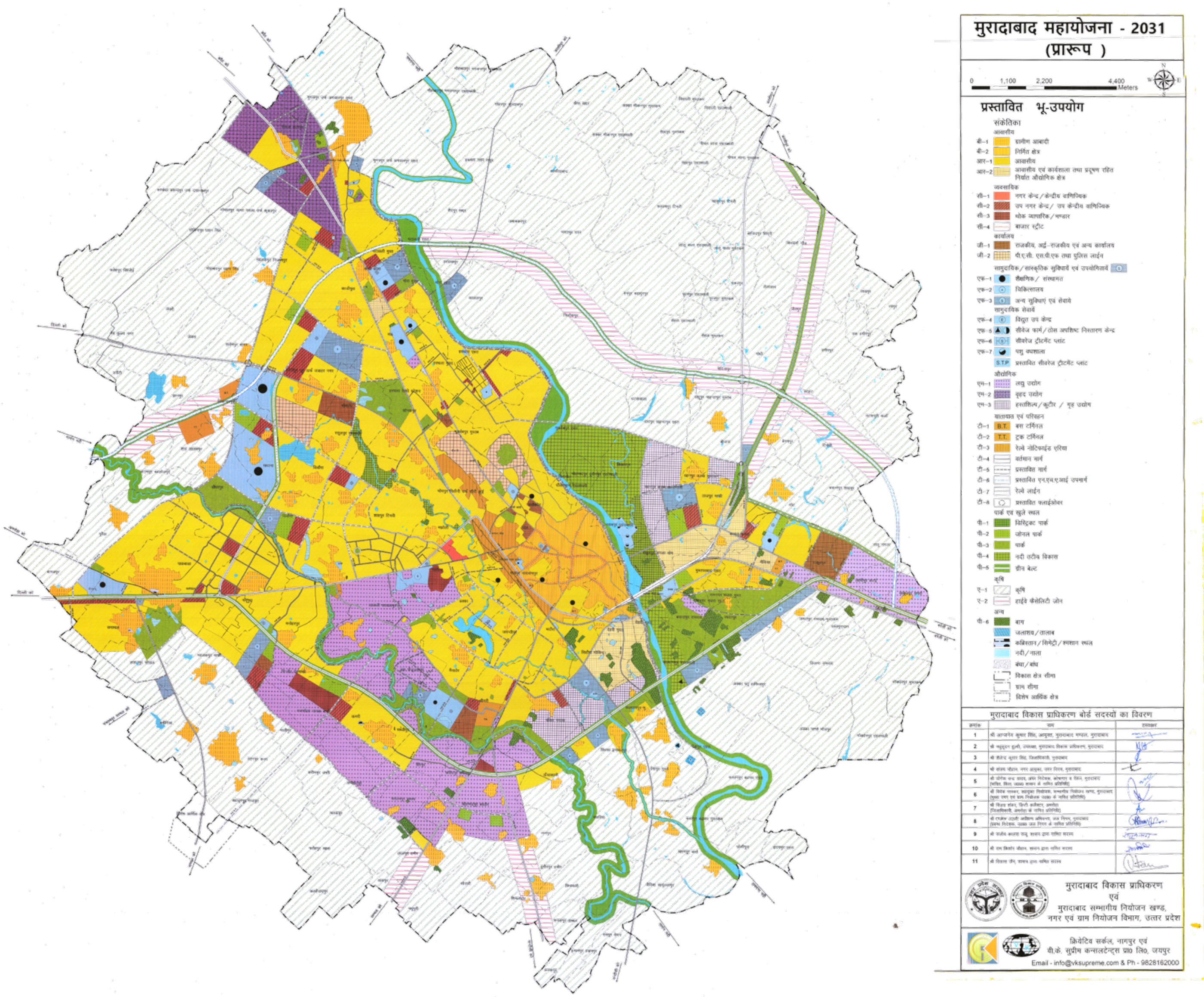


Figure 5-5: This is the draft 2031 master plan by the MDA. (MDA, 2021b).

The Moradabad Development Authority recently released its draft masterplan for 2031 pictured in Figure 5-5. It allocates land for different functions between residential (yellow), industrial (purple), and other uses. A new initiative for 2031 includes the green belt in the bottom right corner of the above plan surrounding the Main Ramganga and its tributary river. Further, the checkered green indicates areas for riverbank development. Parks are broken down into various categories, the ones relevant for this research are existing district and zonal parks as these are public. I ignore the classification of just 'parks' since these might mean private parks in residential colonies or apartment complexes. The last relevant classification is the light blue without any symbols indicating existing ponds and lakes. Based on these, I now propose opportunities for UTFI recharge ponds in the urban context while also considering findings from fieldwork and interviews. These are as follows:

1. *Existing stand-alone and park ponds*: One key finding from interviews across stakeholders was that land is already tight in the city so any recommendation will have to work with existing space rather than demanding new space. Thus, in the below in Figure 5-6 I indicate existing stand-alone ponds and ponds located in parks. When rejuvenated, these will also serve an important recreational and public-space function as we already noted positive responses to Amrit Sarovar ponds on the rural side during village fieldwork.
2. *Development area limit*: I intentionally also highlight ponds outside the direct city boundaries and within the peri-urban zones as these regions offer more space than dense inner-city blocks. One secondary benefit to developing ponds & NBS along peri-urban zones could be their role in reducing rapid urban sprawl and encroachment. Peri-urban regions in countries like India are especially tricky because they suffer from downsides of rapid urbanization for example pollution, industrial waste disposal issues, trash, and sewage mismanagement, etc. Perhaps if UTFI ponds coupled with NBS are developed and maintained in these areas, they will act as defined public spaces with more regulation and maintenance thus disincentivizing unchecked urban sprawl.
3. *Green belt buffer areas*: While parts of the proposed green belt might be too narrow for UTFI ponds specifically, they offer opportunities for coupled interventions to incorporate some of the NBS suggestions from the previous recommendation in section 5.2.
4. *Riverbank development:* These are larger pockets of green zones along the floodplains where new UTFI ponds and NBS can be developed as part of the riverbank planning.
5. *Existing stream diversion:* Fieldwork and Google satellite images uncovered many small streams within the city and right outside city limits. These are natural streams that flow through the city and then join the main Ramganga; they carry stormwater during rain events. One possibility could include diverting stormwater from these pre-existing streams and creating trenches or UTFI ponds adjacent to them capturing and recharging run-off flood waters. This will also more directly address the flooding side of co-management.
6. *Government-owned property:* Fieldwork uncovered that efforts for roof-top rainwater harvesting are currently prioritized for the government-owned property as officials have more say over this. I.e., issues of land ownership are less complex when government and/or public land is targeted first. Therefore, I highlight some opportunities with the Civic Lines area housing most government offices, the police training campus, and the Indian Railways quarter which was also mentioned during the NIUA interview.
7. *Roof-top interventions in dense urban areas:* the final recommendation is to consider all the rooftop areas across private and public buildings to incorporate rainwater harvesting. Since this leads to concerns about property ownership, I have not visualized this potential area available in Figure 5-5 and I'm proposing public & government land as the first points of entry. However, it is still worth noting that any mixed-intervention recommendation for dense urban regions will have to also include rooftop RWH after understanding the jurisdiction on property ownership.

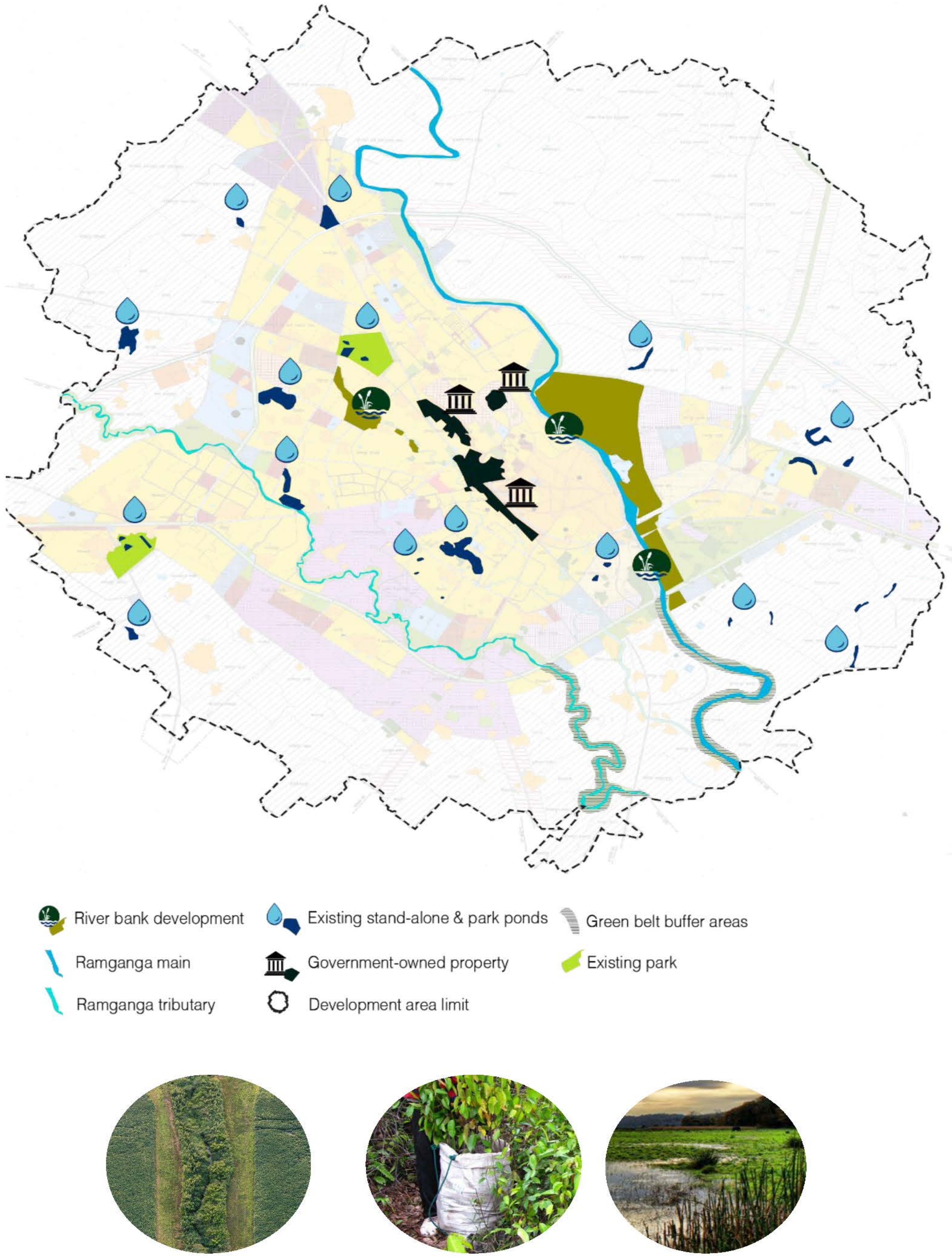


Figure 5-6: This is a schematic map of recommendations for the 2031 draft master plan. Below it is examples of NBS like wetland rejuvenation and floodplain restoration recommended by UNEP. These can be applied in masterplan areas designated for riverbank and green belt development.

5.4.2 Implementing the recommendation: urban institutions & community

Implementing the above measures will require institutional and community cooperation & engagement. I intend this recommendation for IWMI to have a starting point in understanding the urban landscape, to then advocate for UTFI ponds in cohesion with NBS at the abovementioned locations. Institutionally, there is already an awareness of groundwater urgency as seen in officer interviews. Further, the interview with the city's assistant town planner highlighted his awareness of community co-creation & buy-in when proposing interventions in public spaces.

However, the institutional complexities and top-down governance discussed in Section 5.3 also hold true in the urban realm. Several entities preside over urban planning & its implementation, including the Moradabad Development Authority (MDA), the city municipality called Nagar Nigam, the Smart City Office, and other departments like sewage and disaster management. This complexity can again be a barrier to implementation if IWMI's proposals are too singular, i.e., advocating for recharge wells in urban locations alone might not suffice. But lobbying for recharge through partnerships on the riverfront development projects, rooftop RWH, combined NBS modalities, and other mixed approaches will make for better arguments. Ultimately, UTFI cannot be proposed in isolation but in concert with key priorities of the city like riverfront and green belt development. Another strong argument is the creation of public space through recharge ponds and park interventions. All these arguments will make the case for UTFI stronger in the urban & peri-urban context. Key groups for IWMI to pitch such proposals to would be the following:

1. Moradabad Development Authority (MDA)'s masterplanning team & town planning department
2. Nagar Nigam waterworks & public parks departments
3. Community groups when considering community co-management for maintenance.

Next, it is also critical to engage with urban residents & communities because these interventions shape the experience of public space and involve land & property ownership. Further, UTFI ponds and other MAR modes require frequent maintenance to de-silt & remove accumulated sediments. This responsibility could lie between both government and community actors and this arrangement will require prior community engagement. My brief time in Moradabad city allowed for a few informal interviews, but extensive community engagement will be required to understand citizen perspectives. These can also serve as valuable inputs when pitching to urban governance bodies. To summarize, scale-up into the urban realm will be new for IWMI given its longstanding focus on the rural. To enter the urban space, understanding the urban planning sphere is required, and there are many windows of opportunity for IWMI when they adopt mixed interventions and partnerships while engaging with urban governance bodies & communities.

Chapter summary

Chapter 5 synthesizes key recommendations from this research along 3 layers; two recommendations lie at the rural + urban scale, and the final one takes a zoom-in into Moradabad city's urban master plan for 2031. Ultimately, I propose mixed-interventions and the need to take a holistic rural+urban perspective to land-use planning & allocation for recharge infrastructures.

6 Discussion & Reflection

I split this chapter of Discussion & Reflection between content matter and personal experience of the research process. I will critically discuss limitations and future work along key content themes. I then share personal reflections given that this research was international in nature, and while I am Indian, I was still foreign to this northern Indian context.

6.1 Research reflection, limitations, and future work

This is an interdisciplinary thesis project where I tie quantitative and qualitative methods & findings across various disciplines. Therefore, while synthesizing my results and recommendations, key points of discussion arose along different themes: the rural-urban approach, assumptions of my quantitative analyses, institutional and community scope, and the technical side of hydrology & civil engineering. I now outline research limitations and resulting future work connected to these themes.

6.1.1 The R-U cohesive approach & growth studies

The backbone of this study is taking a cohesive rural plus urban lens to groundwater sustainability and think beyond just the urban. This is because natural phenomena like the hydrological cycle transcend these human boundaries but human activities within these boundaries impact our biophysical world. Further, I sought to study this impact against the background of growth and urbanization in the context of a developing country. It was critical to study both rural and urban because developing regions have much more interplay between R-U. To do so, I needed a theory to ground my perspective and chose that of rural-urban linkages within hydrosocial territories. Hydrosocial territories is an emerging discussion in the world of interdisciplinary water management and advocates for a dynamic perspective on how rural and urban interact. In the way I adopted it here, I chose a meso-watershed (~1000s sqkm) study area encompassing rural and urban and studied 4 pathways along it: *biophysical environment, spatial planning, institutions, and community*. However, this still makes static, something that is more dynamic. Within the scope of this 7-month research, I could not realistically develop a way to work with dynamic spatial boundaries or model a regularly changing socioeconomic and hydrologically diverse region. However, findings from my work indicate that a dynamic understanding of evolving hydrosocial communities is needed to properly research groundwater extraction and urbanization impacts. Secondly, I also study growth and urbanization. Growth in the Indian context is growth in the agricultural sector and not just population growth. Critically for the former, our agricultural sector is also export-facing with the state of UP promoting higher export ambitions (Agriculture Export Nodal Agency, 2022). Therefore, it is imperative to discuss that there is not a direct connection between growth in the Indian population to immediate growth in food production to support the local population. Certainly, local population growth will increase food & domestic water demand, especially in a state like UP with high birthrates, but the full picture is more complex given the global food trade (Dalin et al., 2017). I believe this caveat is needed to stay away from Malthusian implications of over-population which has been debunked many times (Sconfienza, 2020) and unfortunately puts undue blame on Global South countries.

6.1.2 Calculation assumptions & spatial planning

The calculations I proposed in Chapter 4 are only a starting point and I listed the assumptions made in developing them. However, I believe this approach of water balance calculations to inform land-use budgeting for rural & urban can serve as a skeleton to then be filled in with detailed calculations. i.e., the process and interdisciplinarity of this research are more valuable contributions than the details of the calculations themselves. Nonetheless, section 4.3.1.6 lists all my quantitative assumptions and how they impact my results & recommendations. As complex calculations and more MAR modes beyond UTFI are modeled together, the recommendation of land-use percentages required for recharge will change, but the process steps remain.

In this study, I connected quantitative calculations to spatial planning by highlighting regions for water-sensitive urban planning & meso-watershed land-use planning. One spatial area for improvement is how I chose villages to visit for fieldwork. This scientific part of this was based on flood and groundwater data, and population data. But I followed this up in-field with more manual and anecdotal input, i.e., by manually selecting final villages based on the distance to Ramganga, taking expert insight from IWMI researchers working in the area, along with considering villages that already have Amrit Sarovar ponds. Thus, the process was partly scientific and partly impromptu and can be more streamlined. Next, I also recommended mixed interventions especially coupling NBS and UTFI, along with more waterfront and floodplain techniques. This was again done at a conceptual level, and there is plenty of room for in-depth planning studies or urban design especially when taking a landscape architecture approach.

6.1.3 Institutions & community engagement

For this study, I sincerely attempted to take in community input and holistically tie it into the final recommendations. As a researcher, I was consciously trying to avoid merely consulting groups for the sake of checking off a participatory planning approach without meaningfully using their input. Some ways I hope I brought this in is through the concepts of river training requested by downstream village heads in Ahmednagar, highlighting optimism towards ponds by upstream communities, emphasizing the value of public space echoed by all village residents up & downstream, and demonstrating that mixed-intervention approaches are preferred. Further work in this realm is especially required on the urban side; I managed to conduct 5 urban resident interviews between street vendors, our fieldwork driver, and two residents at the Nagar Nigam office. But as IWMI hopes to scale up further in the urban context, more community engagement in Moradabad city will be required. On the institutional and policy side, navigating a more top-down governance structure was challenging at first but overall, I was met with many officials willing to share their time and insight. However, with my research timeline, it took some time to understand the complex web of Indian governance. There is plenty of room here for closer policy studies, and one tool could be Elinor Ostrom's Institutional Analysis and Development Framework. This will especially be critical at later stages when getting into land ownership & rights issues under spatial planning.

6.1.4 Hydrology, UTFI specifics, & civil engineering scope

Some other research limitations concern the hydrology and civil engineering scope which was new to me given my background in a different engineering discipline & now in urban studies. As such, I did not take a critical hydrological modeling approach & adopted more interdisciplinary methods and analysis to stay in line with my master's program. This meant a few technical details became out-of-scope, but I nevertheless learned about these concepts thanks to this thesis, and it can be scope for future research. Some of these include:

1. *Groundwater aquifer fence diagrams:* these were mentioned by NIUA' representative during our interview as a technical tool to understand the actual shape of the water table close to river and how recharge will impact it. I could not pursue it for my study, but this could be another technical calculation to refine my findings.
2. *One modality of recharge:* I refined my study to only UTFI pond modalities, but more complex calculations could account for recharge rates across different technologies and simulate what the net recharge-to-demand ratios would be. I began this process only to the extent of recommending mixed interventions, and such quantification can be valuable next steps.
3. *UTFI suitability map:* I rely on the UTFI suitability map to gather ideal locations for recharge, other MAR technologies would need their own suitability or the UTFI SI map will need to be studied further for its transferability to other MAR modes.
4. *Implementation timelines*: it is critical to recognize that these processes are slow; intended recharge rates will not be met the instant UTFI ponds are installed. Most engineering interventions come with buffer periods until they reach their peak capacity. They also require regular maintenance over time given their risk of silting and clogging. But within the scope of this research, I did not account for these buffer windows before which peak efficiencies are achieved or later proceed to decline.

6.1.5 Adaptability and Impact of research findings

Here I discuss the adaptability of this research to other contexts. Parts of my approach & recommendations are relevant to other study areas within & outside India that face similar challenges of groundwater over-extraction and hydrological disasters coupled with urbanization. Here, I am careful not to propose exact replicability since every case is different with its set of unique sociotechnical & biophysical preconditions. Therefore, in Table 6-1, I highlight transferrable and context-specific elements that will need to be acknowledged for any other study region.

Firstly, it is worth reiterating the problem prevalence, i.e., other Indian and global regions facing similar challenges. Groundwater continues to be the world's most extracted raw material and India is the biggest consumer. Within India, some of its biggest economic hubs are already past critical points e.g., New Delhi, Bangalore, and Chennai (Bhatia, 2019). Other countries overexploiting the resource include China, the United States, Pakistan, Iran, Bangladesh, Mexico, Saudi Arabia, Indonesia, and Turkey all in the top 10 biggest consumers (NGWA, 2023). And parallelly, floods and droughts everywhere from California to Pakistan are worsening with climate change (O'Malley, 2023). Thus, the urgency is high for co-management solutions and holistic approaches in deploying them. Next, the International Groundwater Resources Assessment Centre (IGRAC)'s global portal for MAR is a useful resource in understanding both the extent of the problem and the relevance of MAR as a solution for different regions. The below visualization in Figure 6-1 from IGRAC highlights places around the world that are suitable for MAR; many locations are viable for maximizing natural recharge shaded in yellow.

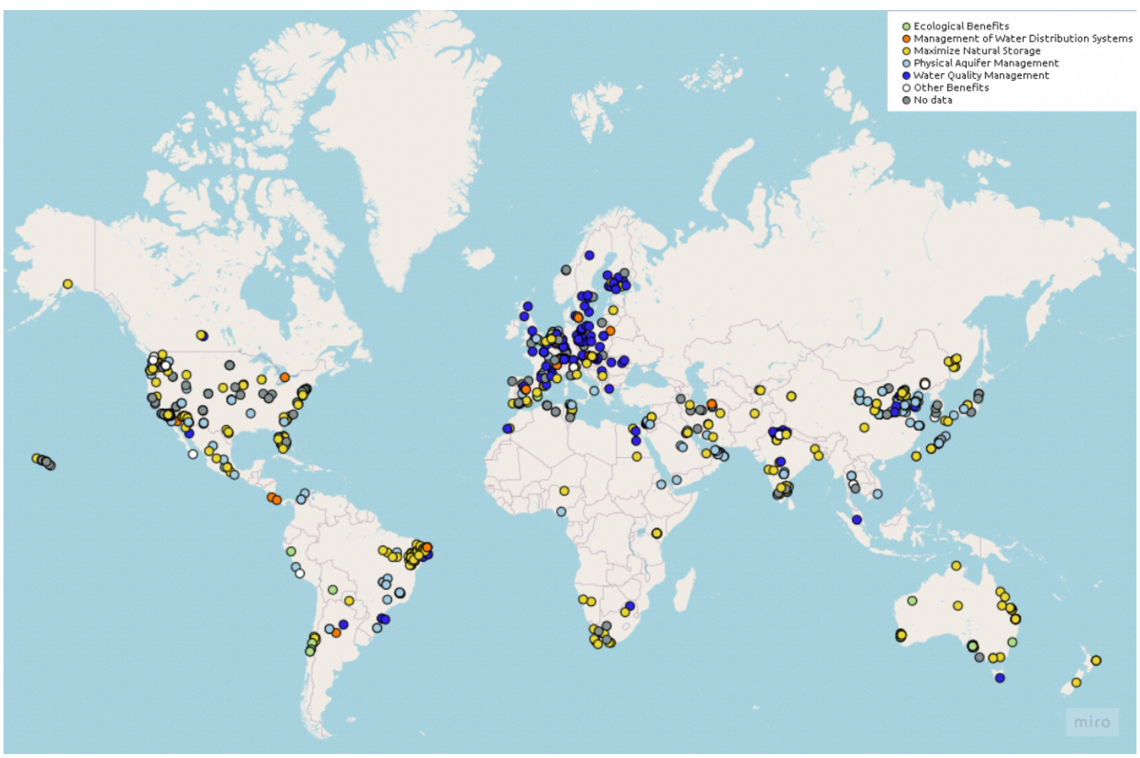


Figure 6-1: A visualization from IGRAC's global MAR catalogue portal (IGRAC, 2023). Yellow indicates places that can adopt MAR to maximize natural recharge.

Finally worth noting is UTFI's specific global applicability. IWMI's report from 2020 presented a suitability map for UTFI seen below; this combined with the more general MAR applicability of Figure 6-1 highlights the wide-scale relevance of groundwater recharge & impact to be had with sound deployment.

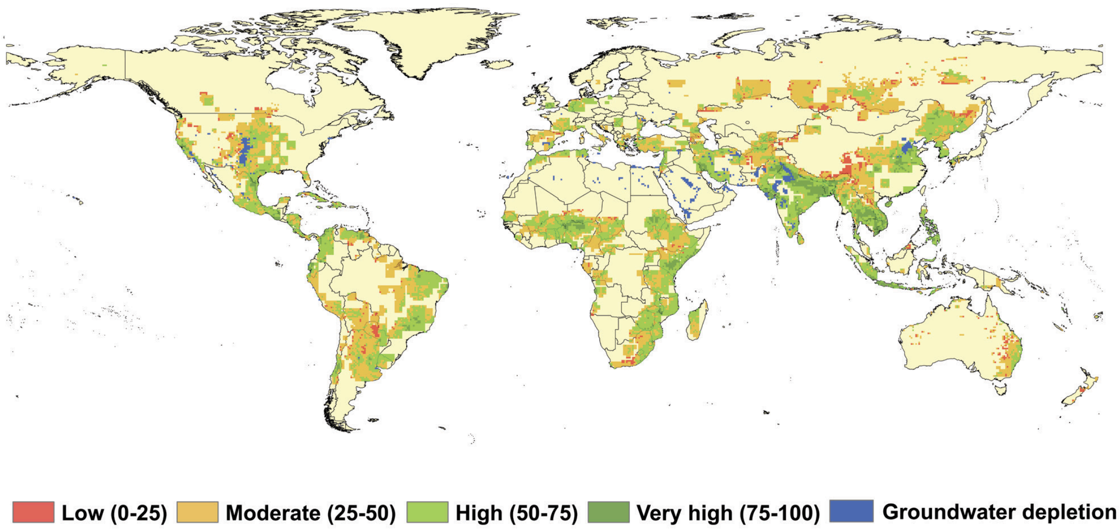


Figure 6-2: Global map of UTFI suitability from IWMI's report "exploring potential at the global scale" (Pavelic & Alam, 2020)

6.1.5.1 Transferability of recommendations

Now knowing that the problem is far-reaching, and MAR solutions have far-reaching potential, I briefly discuss the applicability of my research to different contexts and give two specific examples. My work focused on the follow-up stages that come after the technical feasibility and civil engineering design of MAR. I studied land-use planning and institutional structures for the subsequent deployment of MAR by taking the example of UTFI and transposing it to a rural-urban study region. Further, I contextualized this planning for the future scenario of 2035 in the selected study region.

The main contribution of this thesis is: How to take a holistic R+U approach for land-use allocation to incorporate recharge planning and in so doing, identify implementation zones for mixed interventions. Parts of how I arrived at this recommendation are transferrable, and parts of it are necessarily context-specific. I now summarize these in Table 6-1 according to core areas of research contribution.

Table 6-1: The below table summarizes the adaptability of this research.

Research aspect	*Needed improvements*	*Context-specific element*	*Transferrable element*
Interdisciplinary methodology	Deeper technical validation, institutional analysis & community engagement. Ideally these steps will also be iterative & co-creative rather than linear.	Inputs of the various quantitative and qualitative steps.	Quantitative and qualitative methods between spatial planning, water budget calculations, and stakeholder engagement.
Hydrosocial R-U perspective	Adoption of hydrosocial territories theory needs to be more dynamic.; i.e., somehow capture evolving nature of these human-water-institutional boundaries.	Economic, biophysical, social & cultural characteristics of rural and urban regions. Definitions of rural and urban might also differ from country to country.	Collectivistic approach of rural + urban after contextual definitions are applied.
Urbanization backdrop while choosing a relevant R-U region	Better defining of growth contributors – cities and agriculture in developing countries are growing, but there are many global dynamics at play. For example, the global food trade which dictates that these economies are producing food not just for their local needs, but global exports while using their local resource of groundwater.	Growth drivers, historic urbanization trends and trajectory definitions, rural-to-urban transfers.	Selection of "middle-cities", areas in the middle of their growth phases prior to becoming megacities. Selection to be made after context-specific growth trajectories are studied; for this research I borrowed from the Urban Continuum theory that highlights stage 2 & 3 'middle cities' before they agglomerate to stage 4 megacities. Similar classifications for other contexts will be needed.
R-U pathways analysis	Only four pathways considered: spatial, biophysical, community, institutional. Further socio-	Pathways – community, institutional, spatial, and biophysical environments will all be	Approach of studying pathways through which rural and urban are (de)linked.

	technical, ecosystems & spatial justice pathways can be added.	different for different R-U study regions.	
R-U scale land-use planning: tying quantitative with spatial.	I proposed an initial approach to tying water budget calculations with land-use allocation, more detail needed on MLDs, R-U area demarcations and quantifying natural recharge.	Soil characteristics dictating natural recharge, metrological and hydrological differences. Land availability, ecosystems considerations. Subsequent community & institutional strategies towards implementation.	Water budget calculations to then match to recharge rates of specific MAR modalities. Subsequently, using these demand-to-recharge ratios to plan land allocation. On the institutional side, recommendation of more horizontal governance & creating R-U governance linkages. Community engagement & co-management.
Water-sensitive urban planning	Spatial planning suggestions only developed to the concept stage, i.e., waterfront development, green belt zones, etc. need further design.	City-specific masterplans and development timelines (2031, 2035 etc.) Subsequent community & institutional strategies towards implementation.	Existing public space (e.g. parks), landownership considerations, riverfront approaches all common considerations for dense river cities.

Now I propose two examples to highlight transferability. During the literature review and fieldwork, I uncovered many parts of India and Southeast Asia that could be potential study regions. The core feature of these areas is growing cities with surrounding rural agriculture that currently experience groundwater stress & hydrological disasters. My research focuses on 'middle tier' cities, i.e., cities in their urbanization trajectory such that they have not become megacity agglomerations yet. I went with this scope as these middle-tier cities offer more room for corrective measures. However, this is not to say that megacities are far gone in their crises; just that they will require more concerted efforts across socio-technical & political realms to address these issues. Nonetheless, for the purposes of elucidating another rural-urban pair, I take the example of Northeast Delhi. Here rather than looking at the entirety of New Delhi which has 11 districts, one might consider the district of Northeast Delhi its own urban node that is growing with a population of 2.2 million within 56 square kilometers (NIROL, 1997). Northeast Delhi also borders the river Yamuna, is at the heart of the National Capital Region (NCR), has agricultural land to its north, and Reuters reports it is over-exploited for groundwater (Bhatia, 2019). Northeast Delhi is also routinely affected by flooding of the river Yamuna, with the most recent incident from July 2023 (Bureau, 2023). These combined make northeast Delhi and its surrounding rural blocks a viable option for holistic groundwater recharge planning. Finally outside India, a possible case study could be Yogyakarta, Indonesia previously reviewed as part of my literature review. The paper titled "*Understanding and quantifying water balance for sustainable city and agriculture of Yogyakarta Province"* explores rural-urban linkages around Yogyakarta province along with a water budget calculation (Setyandito et al., 2018). These can feed as inputs into the next steps of land-use planning as I proposed in this thesis.

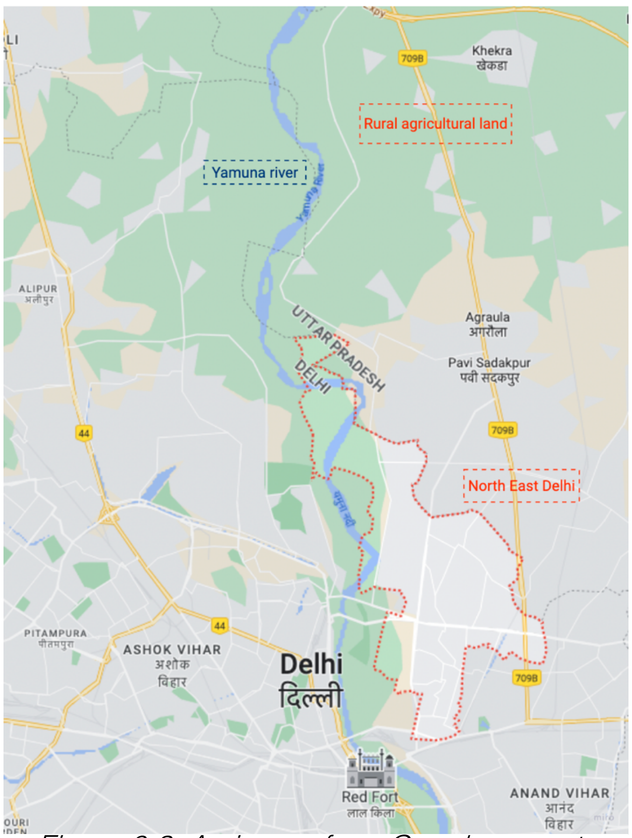


Figure 6-3: An image from Google maps to show North East Delhi in relation to the Yamuna river and agricultural land.

These are two initial suggestions to highlight the impact of the potential transferability of my research. After further tweaking to overcome limitations & future work discussed in Chapter 6, recommendations from this research could hopefully serve as meaningful contributions to the planning and policy sphere.

6.1.6 Replicability of the research process

The data collection and analysis process included geodata visualization, literature reviews, stakeholder interviews, and Python calculations. All datasets used were from public domains or Scopus peer-reviewed papers. Data received during fieldwork is all compiled in the Appendix section, and interview summaries – while anonymous in some cases, all outline fieldwork data that formed the basis of my recommendations. Tools used for each data handling step were recorded in Table 3-1 of the Methodology chapter and datasets accessed for various calculations are tabulated in Appendix 7. The Methodology and Results chapters also outline specific intermediary steps and assumptions behind calculations such that the entire process is replicable. Further, the Python code used to generate the charts in section 4.3.1 is presented in Appendix 6. The policy and masterplanning documents referenced are all also public information found through various government websites or published online on the website of Moradabad Development Authority (MDA).

6.2 Personal Reflection

My greatest takeaway from this 7-month process as I embark on a career in urban planning, is that urban planning is much more than just the city. It helped me realize that we need to think holistically as planners, i.e., beyond the spatial and policy boundaries of rural-urban especially when it comes to critical resource distribution like water and energy. I got into urban studies for my master's because of an intrinsic interest in cities and how they come to be; they act as crucibles of socioeconomic opportunity and there is a tendency in my field to romanticize the idea of great human agglomerations. The flip side of this is negative externalities like resource over-extraction and unequal distribution to keep our cities running. However, therein lies the biggest opportunity for course correction. Cities can be both drivers of the problem and solution, and through this thesis, I reckon that will happen when we take holistic approaches to think beyond traditional definitions of the city. These 7 months served as a learning opportunity and avenue for personal growth; I learned a lot in terms of content matter in a field I was initially unfamiliar with, and I also challenged myself to step outside my comfort zone, especially during fieldwork. I now reflect on a few product and process-related learnings that will stay with me for years to come.

6.2.1 Product

The entire process was complex to navigate as I moved between the bigger picture and drilled down to one piece of the puzzle. Therefore, studying groundwater sustainability through the context of one intervention i.e., UTFI helped in grounding my work. Some challenges I faced in relation to my final product are as follows:

1. Cohesively synthesizing an interdisciplinary project with interdisciplinary findings. Findings along different disciplines and methods were each critical, and understanding how to piece it all together into useful recommendations was at first difficult. I eventually got around this by picking a focus on land-use planning, which as an umbrella helped capture many findings.

2. Positioning an engineering-leaning intervention under the larger spatial, social, and policy contexts.
3. Genuinely studying rural and urban together rather than separating them myself; and realizing there is a balance to be met. Beyond a certain level of detail i.e., at stages of implementation & respecting differing community needs; studying them separately is still needed. This was tricky to grasp and carefully approach during the recommendations chapter.
4. Seeing the entire web of complexity on groundwater issues but choosing to focus on one corner of the web – scoping down meant I first needed a sense of all the interconnecting topics & systems. Groundwater sustainability touches food systems, water quality & pollution, surface water – groundwater tradeoffs, environmental flows, ecosystems & biodiversity, and many more aspects. Rightfully, organizations like IWMI position groundwater research under the Water x Food x Energy nexus, and while it was inspiring to work under such an impactful umbrella, it was also a learning curve to scope down and deliver meaningful research.

Ultimately, I hope I successfully overcame some of the above challenges and sufficiently highlighted areas of future work. I believe I opened new doors while exploring this topic regarding connecting water budgeting and land-use planning, along with taking an R+U approach using the theory of hydrosocial territories. I hope this will serve as a starting point in the greater groundwater policy sector and offer kernels for further research.

6.2.2 Personal research process

This thesis was a challenging and therefore deeply rewarding experience in my academic career. While this was a 7-month long process officially, my search for a thesis topic began a year ago in September 2022. I was sincerely motivated to pursue a thesis topic in India because throughout the MSc. MADE I have felt a strong pull to apply some of my learnings in the developing world. More crucially, I felt the need to expand my worldview beyond the Amsterdam and Dutch context. This might be partly rooted in my personal upbringing having lived in India, Singapore, and the US prior to my move to the Netherlands; but I firmly believe for me to become a sound urban planner, I need personal exposure to various urban contexts and issues. This diversity in experience and learning will help me develop compelling solutions and build more cross-cutting partnerships as I embark on this career path. Therefore, this drive led to me searching for case studies all over India. Since September 2022 I have been taking either in-person meetings while home in India, or cold-emailing & hoping on various calls with private and public entities who might have a project for me to work on. I searched for opportunities in my hometown Coimbatore, in many pockets of Chennai's water planning ecosystem, and reached out to contacts in Mumbai and Delhi. I am grateful that I was able to finally land this project through my supervisor, Dr. Pande's ongoing work with IWMI.

The 7 months of working on this, and especially the fieldwork time, was transformational for me. I am Indian but south Indian, and this study is based in northern India. I am ethnically Tamil and speak the language Tamil, while this case region is predominantly Hindi speaking. While I understand Hindi well, I do not speak it fluently and thus there was a language barrier to navigate. On this front, IWMI researcher

Dr. Navneet Sharma was of great help in translating discussions when needed and after the initial days, I picked up enough Hindi to hold informal interviews myself. Further, I am also a woman in a predominantly male-dominated civil engineering-leaning space. This combined with my South Indian identity meant stepping out of my comfort zone and confronting intrinsic personal biases, culture shocks, and external perceptions. It was difficult at times during interactions to communicate my positioning; some stakeholders in viewing me as a South Indian, wondered what my reason was for studying a North Indian case. It was also interesting for me to ponder how a researcher from a different background might be perceived since it is also common for Westerners from European & American institutions to research the Ganga basin. Nonetheless, these interactions did not prove as a barrier and served more as interesting observations. On being a woman in these contexts, I am familiar with this tension given that I come from a mechanical engineering education in the US, but with time I am learning to build a confident yet respectful personal approach to effectively communicate my reasons for being in these rooms and to carry out meaningful work. In this sense, finding my footing as a minority in these spaces was a great opportunity for personal growth. Of course, a larger conversation about creating room for women in science and engineering is always needed be that in India or any other traditionally technical space globally.

Another bias I had to overcome was my personal comfort levels having always lived in cities, and especially developed western cities. The Delhi portion of my fieldwork was extremely manageable and familiar, but spending weeks at a time in a second-tier growing city like Moradabad was difficult, with everything from adjusting to food options to modes of transport. Interestingly, however, the days doing rural fieldwork left me feeling energized perhaps because it was a completely new setting. Driving or walking through farmland to visit Amrit Sarovar ponds, interacting with villagers, or striking conversations with kids playing near mango plantations all felt rejuvenating and expanded my worldview, and on some level perhaps helped calibrate any sub-conscious superiority I might have as a city dweller.

Lastly, I want to highlight one interaction that will stick with me for years to come. While spending time in the downstream village of Sinai Roja, I had the opportunity to sit in on a meeting with rural officials and a women's self-help group. The group was led by a woman who, in the short time she had allocated, had to communicate her community's needs to higher officials and petition for requests ranging from funding resources to more administrative help. Worth noting also, is this part of rural India is still in its developmental phase when considering gender equality and literacy rates. No matter the rural context women in these areas face, this leader spoke with such poise and exercised her voice for her community. She was steadfast in her advocacy and left me thoroughly inspired to find my voice as a woman in all the contexts that will call for my advocacy.

I've learned that all of this is about communities; we plan cities & rural blocks for communities, we strive towards equitable distribution of resources so more communities can thrive, and we care about sustainability to safeguard that sense of community over time.

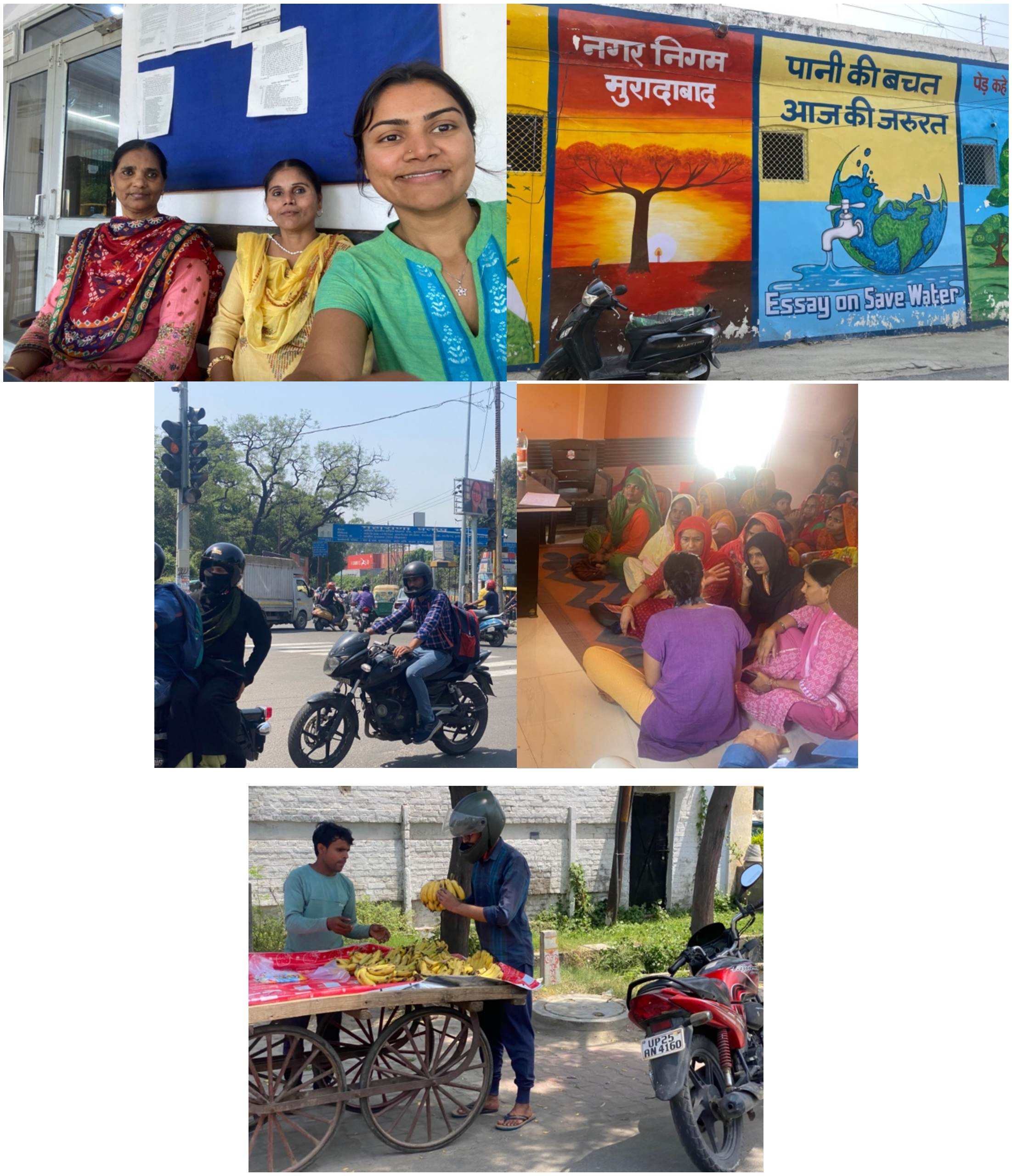


Figure 6-4: A series of images from rural and urban interactions during fieldwork.

<u>*Chapter summary*</u>

Chapter 6 encompasses discussion & reflection for content matter and personal introspection on the process. I also discuss transferability of this research in table 6-1 by highlighting context-specific versus transferrable elements. The main contribution of this work is: How to take a holistic R+U approach for land-use budgeting to incorporate recharge planning and in so doing, identify implementation zones for mixed interventions.

7 Conclusion

This thesis tackled the main question of opportunities and barriers for the scale-up of UTFI recharge pond technologies in developing rural-urban regions of northern India's Ramganga river basin. UTFI proposed by IWMI, is a co-management solution to recharge groundwater using floodwaters in wet seasons, thereby improving drought scenarios during dry seasons. Overarchingly, this study evaluates groundwater sustainability and hydrological disaster resilience in the study region and proposes recommendations for land-use planning by quantifying current and future groundwater demand in 2035.

The main research question was answered with 4 sub-questions starting from establishing the current state of groundwater management, choosing rural-urban locations within the Ramganga basin to test UTFI, and then uncovering rural-urban linkages that pose opportunities or barriers for UTFI. These three sub-questions combined formed the foundation for recommendations in sub-question 4 and Chapter 5. These questions were answered by adopting Chapter 3's mixed methods of combining quantitative and qualitative approaches during desk research and fieldwork. It also required a sound theoretical framework from Chapter 2 where three key theories employed were rural-urban linkages within Hydrosocial Territories, the hydrological cycle, and the Urban Continuum to contextualize Indian urbanization. Figure 3-2 is a summary of how the methods, theories, and sub-questions come together.

The novel contribution of this work was in recommending a holistic R+U approach for land-use planning to incorporate recharge infrastructures and in so doing, identify rural & urban implementation zones like existing ponds and parks for mixed interventions. Noteworthy qualitative findings were those from the field that unpacked rural-urban linkages along four pathways of *institutions, community, spatial planning, and biophysical environment*. These are summarized in Table 4-4. Noteworthy quantitative results to back land-use recommendations were 1. number of UTFI ponds that would be needed to meet current and 2035 demand (Figure 4-24), and 2. percentage of land area needed to implement recharge structures such that a maximum of 50% of 2035 demand might be met (Figure 5-3). These calculations were nonetheless based on many assumptions and caveats outlined in section 4.3.1.5. Finally, a key policy finding from the field was the ongoing national efforts under the Amrit Sarovar Scheme to rejuvenate 75 ponds in every district. The momentum of this scheme as well as its brief shortcomings were discussed in Chapters 4 and 5. In Chapter 5, I end with recommendations for the larger planning & policy world and specific recommendations to IWMI. Institutional complexities and areas for partnership are also discussed within these segments. Finally, there is always extensive room for improvement, and these were discussed in Chapter 6 along with the transferability of my findings. This 7-month experience also offered many personal insights which are explored in the Reflection section of Chapter 6.

My greatest takeaway has been that sustainable planning is for and about communities, and city planning is far more than just the city.

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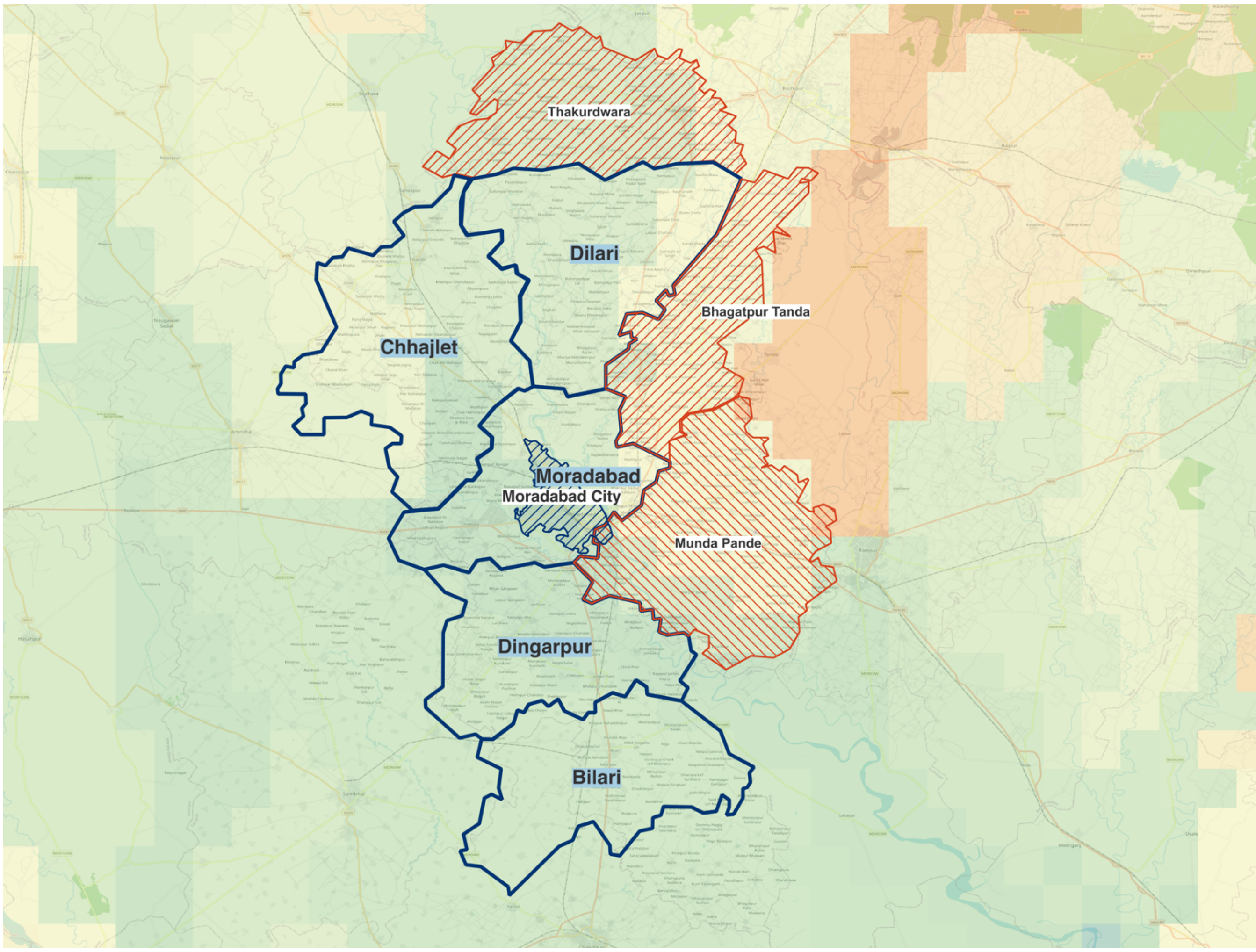
9 Appendix

9.1 Appendix 1: All 8 blocks of Moradabad district against UTFI suitability map

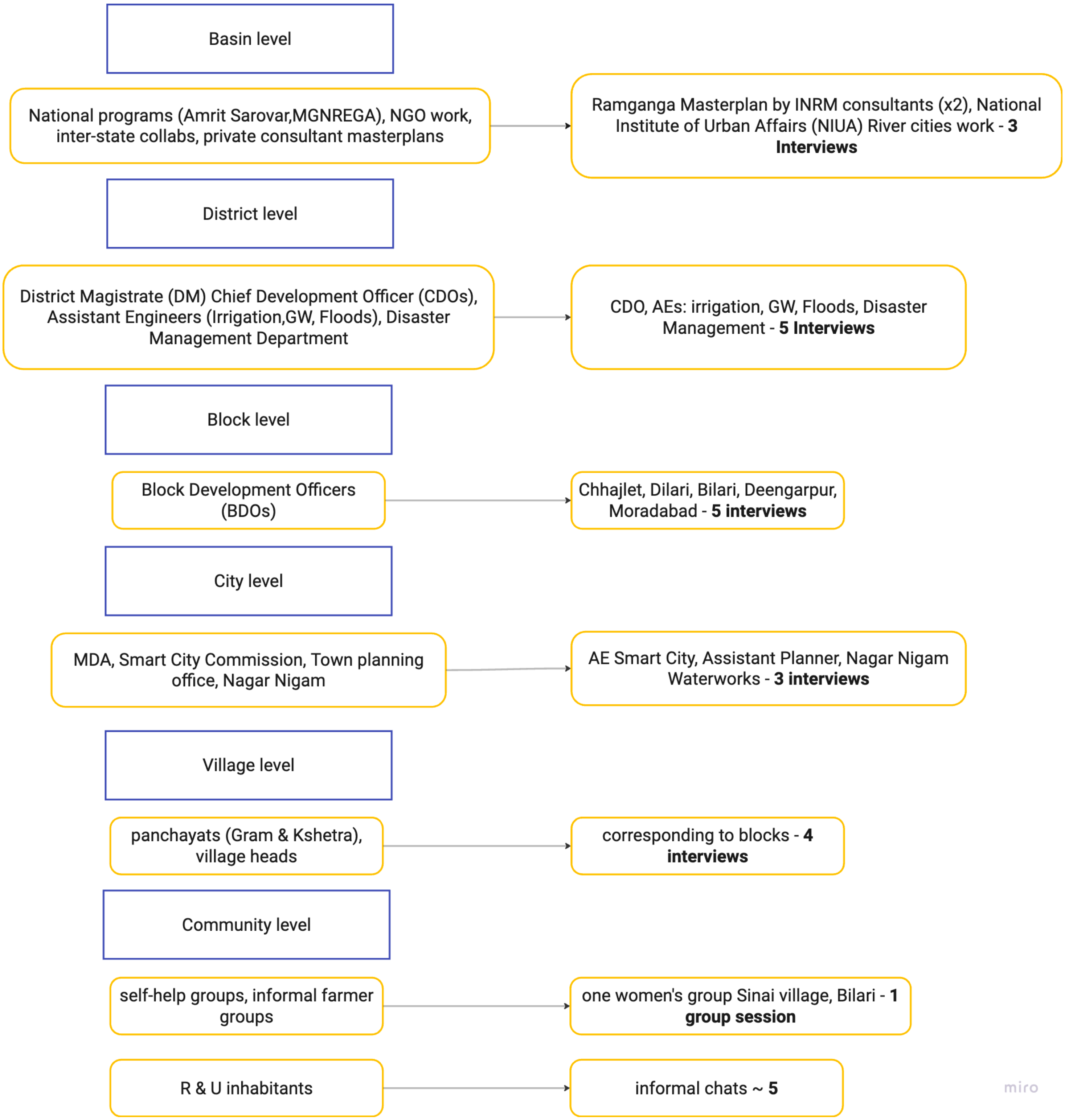


This map was an intermediary step in selecting the final 5 blocks Chhajlet, Moradabad, Dingarpur, Bilari and Dilari. Thakurdwara, Bhagatpur Tanda and Munda Pande were not selected given their location in yellow or red areas against the UTFI suitability map seen above.

9.2 Appendix 2: flood plus groundwater affected villages in study region.

9.3 Appendix 3: Fieldwork interview summaries and observation notes

9.3.1 Stakeholder map & corresponding interviews



9.3.2 Semi-Structured Interview Questionnaire (questions used as a rough guide):

Group 1: Moradabad Disaster Management Department

What are the top urban and rural disasters the department is addressing?

What is the protocol on flood and drought mitigation and do they view them as linked?

What are the department's priorities between urban and rural areas?

Might they be interested in solutions like UTFI? [provide short introduction and technical specs]

What are some initial impressions of the technology?

Where might they foresee implementation barriers?

Do they perceive floods or GW as the more pressing issue i.e., if they view it separately will such co-management solutions be attractive?

Group 2: Moradabad Development Authority

What is the typical master planning approach for urban infrastructure?

How do they currently plan for population density increases, and how far ahead do they plan?

Do you interface with the Rural Development Board and if so on what topics?

What are the main concerns when it comes to water security for the district?

Looking at the Groundwater scarcity report, what work is currently being done to improve access and quality?

Are there private actors or organizations involved in groundwater management?

Might they be interested in solutions like UTFI? [provide short introduction and technical specs]

What are some initial impressions of the technology?

Where might they foresee implementation barriers?

Group 3: Village panchayat / block leaders

What are their experiences from recent floods and droughts?

What are their experiences with water security, groundwater, and surface water?

Do they receive enough support (financial or otherwise) from higher-up governance bodies?

Do they feel prioritized especially in relation to the urban areas?

Briefly introducing UTFI, do they believe they have the capacity to take up maintenance of such structures?

And if not, what resources or incentives might need to be implemented?

Group 4: Village residents

What are their experiences, concerns, complaints from recent floods and droughts and its management?

What is their occupation, do they or members of their village rely extensively on agriculture?

What are their experiences, concerns, complaints with surface and groundwater access?

Do they face any ownership or maintenance issues with community ponds?

Are there any unofficial rules-in-use or socially agreed-upon ways of groundwater extraction or make-shift approaches they currently follow?

Are there any unofficial rules-in-use or socially agreed-upon ways or make-shift approaches of flood and drought mitigation they currently follow?

How do they view their relationship to and with the city nearby i.e., Moradabad?
How often do they travel to and for what purpose?
Do they perceive their rural area as being connected to the urban and vice versa?
Briefly introduce UTFI and what are their initial perceptions?
Would they be willing to co-manage this locally with neighbors or prefer formal institutions involved?
What would be key incentives that might persuade adoption of the technology?

Group 5: City dwellers

What are their experiences, concerns, complaints from recent floods and its management?
What is their occupation?
What are their experiences, concerns, complaints with surface and groundwater access? Do they have private borewells where they live, a utilities connection, or how do they receive water supplies?
Are there any unofficial rules-in-use or socially agreed-upon ways or make-shift approaches of groundwater extraction they currently follow?
Are there any unofficial rules-in-use or socially agreed-upon ways of flood and drought mitigation they currently follow?
How do they view their relationship to and with the rural areas nearby?
How often do they travel to villages surrounding them and for what purpose?
Do they perceive their city as being connected to the rural areas nearby and vice versa?

9.3.3 Semi-structured stakeholder interview summaries (officials and residents):

Date: May 29th, 2023
Interviewee: Anonymous
Designation: Assistant Town Planner
Department or office: Moradabad Town Planning Office & Moradabad Smart City Board
Interviewers *(* Navneet was on-field IWMI co-researcher helping my work):* Gayathri Angou, Navneet Sharma
Consent type: Anonymous, verbal.

Expertise	Master planning, town planning, city planning, zoning, land use, encroachment, boundaries, and general urban planning advisory Moradabad Development Authority (MDA)
Questionnaire group	District-level planning - advisory to MDA and on board of Moradabad Smart City Commission
Summary points	• Outlined his role as a town planner, and advisory position to MDA who demarcates city borders within with planners work o Everything from planning for road widths in anticipation of expansion, to land use zoning. I.e., this area will be industrial, this will be residential etc. o Addresses sprawl and its effects - positive and negative o Also concerned with social side: social fabric, housing, access to social services like education and healthcare o Shared his collaboration with private consultancies for GIS efforts and deeper research work o Currently working on a 2031 Master Plan which is not public yet ▪ (follow up) is the 2030s a good enough window for planning ahead, or needs to be 2050 etc.? recommended for this context 2030 is enough as land-use changes is far too dynamic in indian cities ▪ Key point on land-use: ▪ In most Indian contexts, land is privately owned, when the state/govt. Owns majority, planning is a significantly easier job o (follow up) what are some issues in planning today? ▪ Needs to be further integrated - waterworks, infrastructure development etc. works separately and might step on each other's toes.

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MDA’s main role: regulate, permit and/or restrict development

MDA gets approval from its own board
Urban dev is separate from rural dev and there is not much interface
MDA mainly focuses on urban + peri urban

Provided high-level overview of the planning landscape, the different offices and Assistant Engineers involved in water management on both rural and urban sides to follow up with

Irrigation
Groundwater
Waterworks
Nagar Nigam (municipal council)

Offered further contacts for river-level master planning of the Ramganga

Ramganga Master planning team at Center for Science and Environment
Namami Gange project - ganga cleaning efforts

Offered general opinions and perceptions of the role of urban planning.

Highlighted need for participation and stakeholder input, especially of community as they are the end-users.
Highlighted importance of planning for and around water in the river basin context. Coalition building needed

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Date: May 30th, 2023
Interviewee: Jitendra Sajni
Designation: Assistant Engineer
Department or office: Minor Irrigation department - Rampur and Moradabad districts, Uttar Pradesh
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: open, with designation mention

Expertise	Irrigation planning, rural and urban groundwater management, recharge, amrit sarovar ponds, civil interventions, and various recharge modes (dykes, check dams, etc.)
Questionnaire group	District-level planning - technical expert interview

Summary points	- Goals of interview: - technical understanding of co-managing GW recharge and floods, current AS pond efforts, - introduce UTFI, understand opportunities/barriers for UTFI, - learn about happenings in nearby districts like Rampur, - lay of land with other recharge modes - technology types, organizations involved, maintenance - Perception of flood/drought/GW risks and rural + urban links - Started off with briefly discussing check dams (CDs) - Helps with 2 things: - Recharge - Flood mitigation downstream - Can think of CDs as longitudinal ponds (Navneet qn) - specs to implement CDs: streams need to be at least 2km apart, and catchment area / CD assumed as 25Ha. But generally this catchment area is hard to calculate. Assume outlet of CD is the crest, and inlet is right after - All CDs so far only in community i.e., government land ponds - Some fears include upstream farmers worry when water is kept at bay, it might cause flooding upstream - Also need to work more closely with farmers to construct the CDs especially if it means giving up agricultural land → inflow [evap up] [recharge down] → outflow - He oversees both Rampur and Moradabad districts, - Rampur nationally recognized for water efforts - AS ponds have had extensive implementation in Rampur - Also already looking into pond + recharge shafts - what UTFI is about - He views UTFI as a collab opportunity, it's proven Rampur pilot will help with more funding for AS and other initiatives in Rampur and beyond - Other technologies: - Sub-surface dykes - an underground barrier and no pollution concerns - Surface flow is handled by check dams, and subsurface base flows can be handled with things like sub-surface dykes. Will percolate downwards and to the sides - With AS Ponds + recharge, or UTFI the main bens are:

- Improved GW table
- Flood protection secondary - so validates UTFI's claims
- And we often ignore a 3rd benefit - water for animals and birds with ponds and CDs

- When asked about UTFI pilot pond response - in Rampur pilot is 10 recharge wells per pond
  - He thinks not being cost effective, 3 to 4 recharge wells are more effective.
  - It is a balance of flood vs. recharge goals - as 10 by IWMI for UTFI is with flood prevention goal
- Asking about challenges with recharge:
  - With most modalities, must be careful with greywater. Now working on greywater ponds
- Asking about funding, maintenance, and other orgs invovled:
  - Funding from national MGNREGA scheme, and different levels of panchayat funding
  - Maintenance funding also from MGNREGA but co-maintenance modes evolving
  - Example - Art of Living NGO projects in Maharashtra, they are seeing more farmer participation in maintenance a 4 x 4 x 6 boulder pit technology
  - Orgs like Art of Living operate as NGOs and help other corporations fulfill their CSR goals
  - Other states also involved in knowledge sharing like Maharashtra and Karnataka
- When asked about flood/drought/GW:
  - Emphasizes all these efforts are about future planning/sustainability of GW. no current issue as the river basin is well endowed. I.e., it is about GW Over. extraction.
  - Floods and droughts again not massive concerns
- Brief note on water-intensive crops / popular crops of the region (Rampur and Moradabad districts):
  - Sugar cane - further processed for sugar, ethanol and waste for paper industry.
  - Mentha for menthol oil
    - Medical, cosmetic industries are major players here.

Date: June 1st, 2023
Interviewee: B.R. Ashok
Designation: Assistant Engineer - Waterworks, urban
Department or office: Nagar Nigam (Municipal council)
Interviewers: Gayathri Angou
Consent type: Can mention name, verbal

Expertise	Urban water distribution, waterworks, groundwater
Questionnaire group	City level - technical expert interview, short
Summary points	Currently Moradabad city is 100% reliant on groundwater for all water needs, no surface water involved. 24 x 7 supply Decentralized networks, set of large water tanks spread across the city with its GW source and end-users nearby. Speaks of groundwater in terms of production, storage, distribution and demand, production being supply / where and how much they extract .2 main zonal pumping stations (ZPS), 49 overhead tanks, 100+ (110) tube wells to extract from ground. Also worth mentioning people/homes/commercial shophouses etc. commonly also have their own private borewells Demand numbers: demand for civil uses is increasing, right now they plan around 135 LPCD (liters per capita per day) Hostels, colleges etc 70 LPCD, 40 LPCD Demand prediction is kept simple, only according to population Capacity of overhead storage tanks ~ 49 - 70,255 kilo L ZPS 9000 kilo L pumping capacity each For the entire city, water without revenue i.e., free supplies to public and religious spaces is 40% of total GW production When asked about centralization or joint utilities, centralized only in the sense of monitoring, and this project is in collab with Smart City office and currently underway Monitoring of tube wells will be automatic and connected to central monitoring systems Phase 1 done, 2nd phase to be completed somewhere in 2023 So will need to verify other policy briefs on future planning, will they move towards centralized grid/utilities supply etc.

Date: May 30, 2023
Interviewee: Anonymous
Designation: Executive Engineer - Flooding
Department or office: District Magistrate / Disaster Management Department
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: Anonymous, verbal

Expertise	Flood monitoring, gauging, basin level
Questionnaire group	District level - disaster management
Summary points	His role is more on flood monitoring, less around predictive studies. Manages team that tracks and records gauge status manually, these gauges are located at various locations along the lengths of the entire Ramganga. Monitors river levels after heavy rains, monitoring also involves barrage and dike monitoring. Gauge reading is on a daily, hourly basis and manual. They have records going back 10/15 years but not digitized. Most monitoring efforts also increased during monsoon times - 15 June through 30 October Emphasized the disconnect between desk studies/ mapping, to in-field realities and difficulties of monitoring

Date: May 31st, 2023
Interviewee: Anonymous
Designation: Executive Engineer Groundwater Department
Department or office: District Magistrate, Division - Moradabad, UP
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: Anonymous, signed consent form.

Expertise	Groundwater management, groundwater recharge methods, policies & regulations, groundwater monitoring, high level view of basin-level activities both rural and urban
Questionnaire group	District level - District Magistrate, technical expert interview

Summary points	Goals - issue now, efforts now, UTFI introduction, rural-urban differences, industry-residential differences in recharge Issue now: Moradabad district is over extracted, main goal is longer term groundwater sustainability even if the resource feels plentiful now Over extracted basically means we are taking more than is recharged Natural recharge from rain is around 100L per year 91 - 100% - over extracted, 71-91% - semi critical, <70% safe. Meaning that M'bad is taking out almost all of what is being naturally recharged Rural-urban dynamics: Main extraction sectors across rural and urban: agriculture, domestic industrial 88-90% used in agriculture 6-8% drinking and sanitation, leaning urban due to pop 1-3% industry, of which max 1.5% is heavy industry ~1% misc. Use So from this, the area for biggest change is agri demand. Pushing for crop use changes, more water-efficient crops, irrigation practices etc. cannot really touch drinking and sanitation needs, and is a lower share District is 100% reliant on GW Efforts now: Monitoring: 1hr data collection in M'bad of water table readings Jan, May + June [pre monsoon], August, Oct + Nov [post monsoon] Pre-monsoon - GW is low Also have piezometer monitoring stations across the district at low, medium and deep depths to study groundwater table - this is a World Bank funded project - the meters are located in 2 x 2 km2 grid areas in the city, and 5 x 5 km2 grid areas in villages. Every grid has low,medium,high monitoring On crops: summer padi is very intensive on GW table, need 43cm of GW compared to regular rice which draws 19cm. And the reason the summer padi draws more because the summer sees less rain Other key crops: sugarcane, rice (both intensive), wheat, mentha Recharge efforts: RWH in 1479 govt. Buildings planned, 840 installed. 639 left in 1-2 years. The RWH is connected to recharge well below that's how it's connected to GW. at about 60m deep silo About 20 big GW demand industries, usually in the outskirts of the city of village blocks (Bilari, Thakurdwara, Bhagatpur Tanda, M'bad villages) - sugar, distilleries,

	paper, export units, milk, heavy industry like clothes manufacturing. They consume 18071 KLD (kilo L per day) in the total industry sector of these 20. WWF works a lot in the industrial water quality monitoring segment of ramganga basin Other industry aspects, some can be 90% dry processes until the last stage which might involve painting/coating and there the GW demand spikes Industry regulation: required to recharge 100% if located in a non-notified area (outside MDA city boundaries) or 200% if within a notified area. methods: RWH Artificial - adoption of ponds under CSR, usually located outside the city. Kind of a GW extraction offset Doesn't always have to be Amrit Sarovar ponds but can be independent If you want an approved NOC (no-objection document) for any industrial construction, it requires mandatory RWH Also industry regulations around toxin level of the processes, slaughterhouse etc. cannot directly recharge as it will pollute On commercial side: If it's greater than 300 m2, RWH is mandatory Regardless of new sector, all new buildings approved now require RWH When asked on collaborations with other districts or international Western UP and a eastern UP districts India-israel partnership in Bundhelkhand region between UP & Madhya Pradesh Again emphasizes that the core issue is GW over extraction in the long term even if it's perceived as very available now Provided data on GW stressed blocks in moradabad district When asked on flood risk: Since the kalagarh dam was installed in upper ramganga at the mouth, that is the main controller. Some quick math: If building area = 100m2 → x Annual rain in moradabad = 950mm Aim to harvest 85% of that in rooftops =807.5mm avail for recharge Now multiply with building area = answer in m3 = 807500L recharge (but this likely ignores a lot of factors like evaporation, non-perfect RWH piping etc., my personal thought)

Date: May 30, 2023
Interviewee: Anonymous
Designation: District Disaster Expert
Department or office: District Magistrate - Disaster Management
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: Anonymous, signed consent form

Expertise	High level disaster planning - floods and droughts, state level reporting and documentation, policy setting
Questionnaire group	District level - disaster management department
Summary points	Operates more on the basin level. When asked about direct flood risk, nominal risk is not that high, a relatively normal region in the west. Eastern UP faces much more damaging and frequent flooding events When events do occur in western UP, losses are around agriculture production loss 2022 saw about 31 villages affected, 2021 saw 14 villages. They also monitor flood preparedness, things like availability of boats. more an adaptation measure

Date: May 30, 2023
Interviewee: Anonymous
Designation: Chief Development Officer
Department or office: District Magistrate
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: anonymous, by designation

Expertise	District-wide development officer for Moradabad, focused on rural development but has an overall view of urban, rural, and peri-urban activities. Involved with the Ramganga basin-level rejuvenation and planning activities. Policy high-level knowledge and interacts directly with the District Magistrate above him. Part of the central government as all Indian district officials are - IAS qualification (Indian Administrative Services)
Questionnaire group	District-level planning

Summary points	Goals of meeting: Administrative: get signatures for bottom officials to be interviewed later like Block Development Officers (BDO) who report to him, request for personal introductions to various Assistant Engineers, and introduce UTFI concept (IWMI side) Request for data on Amrit Sarovar ponds (national scheme on developing ponds for groundwater recharge) Research: understand rural-urban planning interfaces, ongoing work in flood, drought, and groundwater recharge efforts On his role: Focused on rural development. Recent work in Amrit Sarovar Pond scheme - which was launched in 2022 Goal is to have 75 water bodies restored as recharge ponds in every district. On the overall landscape of recharge and water management efforts: Rural and urban are largely disconnected with their planning agendas, but they do come together at the basin level master planning efforts They look at the entire spectrum from the river bank level down to the household level and AS ponds under this umbrella River level silt cleaning to increase carrying capacity especially during monsoon. 20-30-40km length cleaning efforts periodically Bamboo planting along banks for preventing erosion and flooding impact AS ponds distributed across districts to improve groundwater recharge Industry buildings have special regulations on how much they should be recharging groundwater based off how much they extract/use. And for toxic industries (eg. paper, distillery) that cannot directly recharge on-site, they can adopt AS ponds Rainwater harvesting on a building level - only have jurisdiction over government buildings not private Household level - improved tap connections in urban homes On general flood, drought and groundwater risks/concerns: None are too imminent an issue Drought almost nil Groundwater efforts a key concern: are more from sustainability perspective to preserve the plentiful resources available today - 100% of irrigation comes from groundwater Urban water supplies also 100% groundwater On population growth and urbanization concerns: Not too concerned about rural population growth, numbers stay relatively the same More noticeable is migration into cities like Moradabad from rural areas Recommended other key officials we should talk to:

	Groundwater Flood control Disaster management Wetland rejuvenation as WWF is very active in Ramganga - Mohammad Alam contact person WWF's efforts - 54 villages present on banks of ramganga. Meetings have been held with village heads. They are more focused on water quality to ensure drinkability. Also have attempted rejuvenating through fish species but running into issue of fish migration - they don't stay localized Planning timeline the WWF team will know more

Date: May 30, 2023
Interviewee: Anonymous
Designation: Assistant Engineer
Department or office: Moradabad Smart City Commission
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: verbal & anonymous with designation, at end of interview

Expertise	Engineering knowledge, overview of all Smart City initiatives and their progress
Questionnaire group	City-level planning, Moradabad Smart City
Summary points	On groundwater recharge as that is part of the smart city goals: Rainwater harvesting to recharge GW installed in govt. buildings, 15-20 so far All new upcoming buildings will need to be installed with RWH On urban floods, major effort is the Karola drain: Desilting, cleaning for this main drain in the city to increase its water carrying capacity On timelines, 2030, 2035 is a good benchmark, or no? Considers that to also be too far ahead as they are focused on a lot of execution efforts right now, like the Karola drain. Two largest water management efforts therefore: Stormwater drain mechanism in city. GW recharge / RWH in govt. Buildings On how recharge and drain needs are calculated, based of population etc. - those are details worked out by external consultants On how the Smart City Office works:

	It is part of the central govt. push to identify smart cities all over India, they have key goals and mandates from central bodies and report there. On other Smart City efforts: Facades in old market areas, developing new market public spaces. Smart roads and congestion Traffic regulation Solar panels in govt. Buildings ICCC - integrated control and command center - cameras to be installed all over city for tracking everything from traffic management, foot traffic etc.

Date: June 1st, 2023
Interviewee: Ms. Koosom and Ms. Sahana
Designation: Office maintenance / administrative staff
Department or office: Moradabad Nagar Nigam office
Interviewer: Gayathri Angou
Consent type: verbal

Expertise	Informal interview, spontaneous chat outside nagar nigam office
Questionnaire group	city/urban inhabitant

Summary points	Both live right outside the main city of Moradabad, considered a village but rapidly urbanizing given how close it is to the main city Koosom: Harthila village, Sahana: Divaan Bazar Both villages far from Ramganga Asked about perceptions on water in general Very satisfied and happy, plenty of water and piped into their homes No concerns with flooding or drought, especially since they perceive drought as connected to groundwater and there is plenty of that And no concerns on flooding as both are far from the main Ramganga When asked about urbanization Both their villages they basically consider mini-cities given how close it is to Moradabad They view Moradabad as a major city and smart city given its classification Followed-up on what they consider features of a city - paved roads, high population density, access to piped water, proper sewage systems and network (even if open ditches) When asked about people in their village, and what types of work they usually do: Some do labor Some agriculture some , like them, work various jobs in the main city Koosom started working here as her husband passed away some years ago, and the Nagar Nigam office offered his job to her for a revenue stream Koosom has 5 kids, all boys. Happy with access to schools and features like that too in the city Both really like their job at the Nagar Nigam, and say that’s why they keep coming in When asked on how they come into work, like most they take shared rickshaws or shared autos - there isn’t an extensive public transport network in Moradabad, so rickshaws and autos are the most common public transport. Both also briefly mentioned that Moradabad feels quite urban and industrial given that it is nicknamed Brass City

Date: June 2nd, 2023
Interviewee: Anonymous
Designation: Cab driver for field trip day
Department or office: -
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: Anonymous, verbal

Expertise	This was an informal interview with our driver, a conversation around his perceptions as a resident of Moradabad, on the Smart City initiatives
Questionnaire group	Urban inhabitant
Summary points	What is his perception of Smart City, and Moradabad being one? It will help with traffic regulation, law and order for example with wearing helmets Monitoring aspect present and being watched with cameras around the city Other aspects like roads will also be improved What is his perception on water issues, availability of groundwater? Water was never an issue, there is lot of access to groundwater too Individuals are also not too dependent on municipality; many people have their own wells or boreholes And as far as utilities go, he does not perceive an issue with electricity either, good access 24/7/365

Date: July 14th, 2023
Interviewee: Uday Bhonde
Designation: NIUA Researcher
Department or office: NIUA
Interviewers: Gayathri Angou, online.
Consent type: Ok, verbal.

- His background / work with URMP & NIUA: work w/ dif ministries, Jal Shakti, Forest Envrion climate change
- National mission for clean ganga, 2019 onwards - Urban River Management plan
- Planning part of cities - Ramganga
- 1st phase - river cities alliance
- Ramganga + WWF India - working since past 10 years, environ flows, biodiversity.
- managing rivers within urban stretches – Moradabad & Bareilly - working for the past year!
- → percolation ponds:
- dimension of the aquifer, how is it spread – objective of GW
- Aquifer dimension of the city - borehole

- subsoil GW monitoring
- Timeseries – multiply by 365 – rate of decline
- 160million L per day, only groundwater
- recharge strategy along floodplain - how can you show it benefits the city directly
- Fence diagrams? aquifer dimension - CGRMB but too big
- How is the aquifer dimension? if we know the density of the city, overexploiting areas in the city.
- There is a railway - divisional railway office, within the city there is a cluster covered by Railway offices - within 160MLD, 10MLD just for railways. – coach washing - irrigation and gardens - one entity is exploiting so much, but not really recharging – governance-wise, exploiting more and putting more less. And for a use – core area - river is quite far. We can propose ponds here! - so some combination of floodplain and inner-city ponds.
- Future goal: embankment 700m away from the center of river and will pass through the city. it's part of the masterplan. – alignment of embankment, will overlap.
- Floodplain area: how will it benefit city has to be established.
- Timeseries calculation 160MLD - India water information portal - groundwater data for Moradabad,10/20-year cities. 1 to 1.5m is the decline roughly.
- Water budgeting - 160MLD every day, rainfall is 600/800ml what is the balance that remains.
- floodplain interventions are useful.
- Expert interviews - consent is ok.

Date: September 8th, 2023

Interviewee: Puja Singh

Designation: INRM Researcher

Department or office: INRM Consultants

Interviewers: Gayathri Angou, online.

Consent type: Ok, verbal.

- Representing recharge needs as a percentage of area from a land-use perspective will be a very useful tool for policymakers.
- These area numbers can be used as an initial starting point while planning land on both urban and rural sides and are a useful tool for communication. This helps set a framework that can later be refined with in-depth calculations.
- It is important to caveat all assumptions of the calculations – per my calculations a range of 25-50% of demand could be met, rather than stating precisely 50% of demand will be met.
- Informal extraction rates are difficult to estimate but their occurrence is widely known.
- Sectoral MLD for specific industries like leather and brass manufacturing is difficult to estimate given these industries are very fragmented. A detailed field study to document individual actors will be needed.
- When asked if urban and agricultural MLDs used in my calculation seem reasonable, she commented they are a reasonable starting point that will require further refinement. INRM's

approach is far more detailed with hydrological modeling based on the crop types for the agricultural side.

- On the urban side, proposing areas on existing parks and government land makes the most sense. Creating new spaces in already dense urban areas is unrealistic & will have opposition.
- On both rural and urban sides, highlighting the public space benefits of recharge ponds will be a good argument.
- Very critical to mention desilting and maintenance issues for MAR.

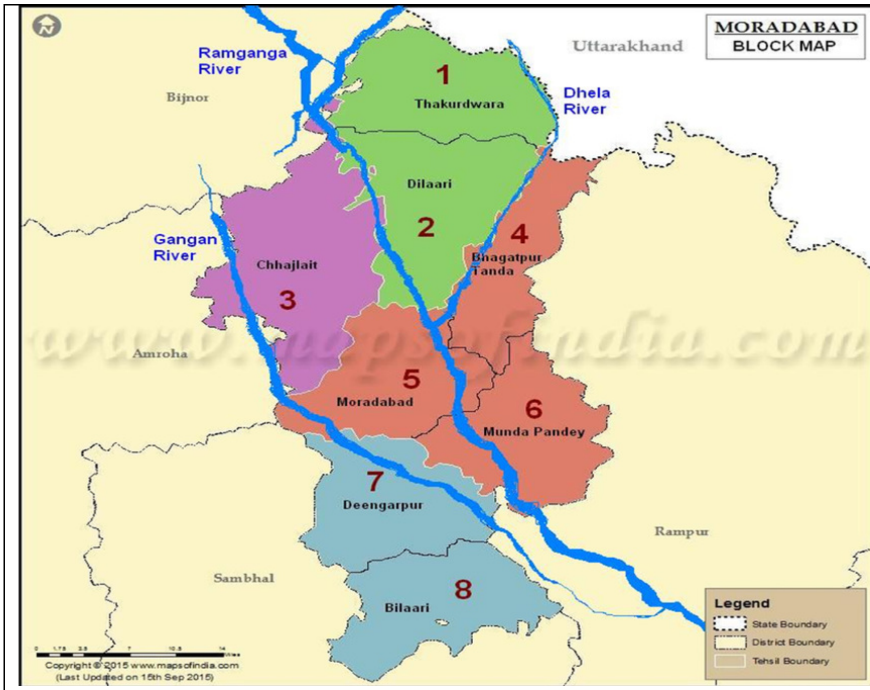
9.3.4 Fieldwork qualitative data collected – rural block field days.

Blocks visited: Field Day 1 - Downstream: June 2nd, 2023 Dingarpur, Bilari
Interviewee series: Block development officers (BDOs), Pond technical engineers, villagers, kids, passers-by present
Interviewers:* Gayathri Angou, Navneet Sharma
Consent type: verbal & anonymous with designation and/or description, at end of each interview

Day outline:
Part 1: Dingarpur Block (Flood & groundwater affected)
First met Block Development Officer (BDO) at BDO office block in Kundarki, Dingarpur block
Visited 2 AS ponds with corresponding villager interactions.
Got a brief explainer of floodplains on the way to Ahmednagar Jaitwara by village head
Visited my selection of flood-affected village Ahmednagar Jaitwara - tour by village head, 2 panchayat reps and also learned about other villages that were affected

Part 2: Bilari Block (only GW affected - decided to add because critical, and evolving increased research focus on GW)
First met Block Development Officer (BDO) at BDO office block and brief interview
Bilari AS pond 1 in Sinai Roja with corresponding villager interactions
Bilari Sinai Roja Villager Engagement - meeting with Ladies rural Self-Help Group

Part summaries:
Note: These were all group tours with BDOs, technical engineering assistants of the block, and villagers who joined the tour. Therefore discussions were semi-structured, with interview questions spread across general conversation.



<u>Part 1: Dingarpur Block</u>

<u>AS pond 1, Chittupur, Dingarpur block:</u>

[general points] - on pond specification, funding, AS scheme

4 inlets, 1 outlet (because of low rainfall), 1.3 Ha, depth ~2.5 - 3m

~30 Lakhs total cost (~37,000USD)

The pond is 'stepped' into 3 steps for different water level depths

Goal: clean water, recreation & recharge, people should be able to swim

Also no greywater, only run-off from nearby villages

Constructed in 2022 like most AS ponds from the 2022 scheme

Maintenance needed every 1-3 years to desilt, if no silt then 3 year window

Cleaning and/or construction needs done by gram panchayat and a few villagers, they get paid for this through various rural development and employment schemes ~230Rs a day (2.80 USD)

Community-owned

The AS scheme is that each district should incorporate 100 sites. Within this block, they've identified 31

Funding in this case = MGNREGA + Gram P + Kshetra P

Needs to be 1 Ha > greater for MGNREGA funds to be availed

[interview qn to BDO] - experience on floods, droughts, and groundwater issues

Floods not a concern, but further downstream Ahmednagar Jaitwara (validated as I identified this pre trip)

Drought not a concern, because water table is decent → they perceive drought as only connected to GW availability and not really lack-of rainfall.

GW also has no issue for now, water table available at 40-50ft (12-15m)
[interview qn on villager perception] - how do they experience (like / dislike) the recent Amrit Sarovar ponds?
2 years before this area was not functional. Now they can come enjoy the pond for morning and evening walks, and also take selfies
They mention they really appreciate this BDO and his commitment, he is on the ground a lot

[interview qn kids perception] - how do they like the pond?
Really love it, currently on summer break and come to play at 6/7am in the morning. Kids from other blocks also come over to play both in the mornings and evenings

[field observation qn] - the pond is full now, so is it infiltrating
This is the tradeoff, currently there is 0.75m silt layer to retain the water. Since current goal is to have Surface Water (SW) and pump (private diesel pumps) that when needed for irrigation, plus also provide recreational space
[follow-up qn] - are there challenges on who/which farmer gets to pump the SW and not? So far no issues, most farmers have sufficient GW on their own sites, and if needed as an additional the pond is there
If purely recharge is the goal, then will need a much more porous pond surface - to 'unclog' the tub. So its a balance

[interview qn on villager perception] - how do they perceive their connection to cities, especially nearby ones like Moradabad?
They are closely connected, especially for selling their produce.
High-profit vegetables all go into: Moradabad, Delhi, Kashipur
These include: potatoes, tomatoes, ladyfingers, pumpkin, bitter gourd, green chillies, eggplant, capsicum. Potato and tomato are the top
As for fruits: mangoes are the biggest - this region (downstream of Moradabad) and this block of Dingarpur is the capital of mango production
[follow-up question] - how do they transport into the cities?
This is by farmers' private vehicles like refrigerated trucks
Maiz, wheat, grains this is part of a national scheme where it goes to local 'mandis' or markets for village's own use, and extra is centralized then sent for distribution

<u>AS pond 2 - Kharagpur, Dingarpur block:</u>
[general points] - pond specifications, funding, AS scheme
3 inlets, 1 outlet, 0.63 Ha, depth ~3m
Inlets connected directly to farms, low land area
Only carries rainwater from farms but if there is some greywater, this inlet has filters

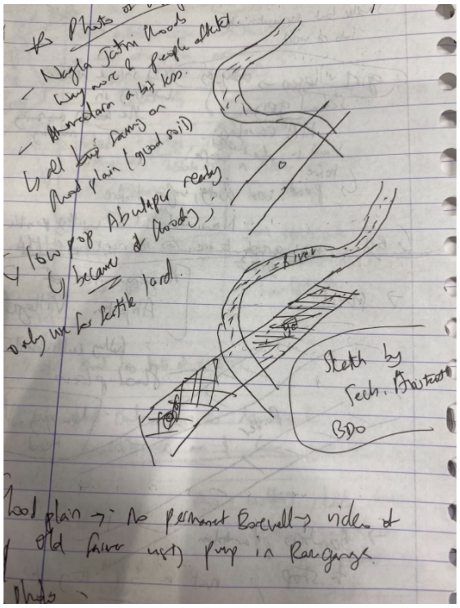
~28 Lakhs total cost (~34,200USD)
This pond is smaller than previous, but costs roughly similar due to higher excavation costs
Funding in this case = MGNREGA + Gram P + Kshetra P
Maintenance aspects same as pond above - community owned, gram panchayat responsibility, villagers can also contribute
[interview qn on villager perception] - how do they like/dislike the pond?
Really enjoy it, before this used to be a wasteland
Also before, this area was a place for open defecation, so with implementing the pond there's also indirect hygiene improvement
Now it's public space for morning and evening walks, kids come to play
They also mention they really appreciate this BDO and his commitment
[interview qn to passer-by girls] - two girls walked by in their uniform, we stopped them for a brief conversation
They are studying in the local rural university, and pursuing a Master's in MA sociology
They also really like the pond, used to be a dirty area before but now they can enjoy recreational space
BDO made a comment on congratulating their educational ambition, and that it is nice to see postgraduate education in women especially in the rural below

<u>Tour: on-route observations and flood-affected Ahmednagar Jaitwara identified during desk research:</u>

[general description] - structure of the tour ~1hrs, by road and then walking near ramganga of the flood-affected village Ahmednagar
The village head, Gram and Kshetra panchayat representatives, and one technical assistant joined us, BDO and his team left.
Group described the flood plains and dynamic shape-changing of the Ramganga river - they provided a brief sketch of this
then listed the 4 extremely-flood affected villages in their experience including Ahmednagar - Nagla Jatni, Govinpur, Abdulpur all near and one-after-another from Ahmednagar, downstream of Moradabad located along meanders of the Ramganga which overflow in heavy rains
[floodplain tour and observations] - describing and sketching the ramganga river shape and its banks aka floodplains
It's a fully cultivated floodplain
For this direct region, flooding is good because it nourishes the soil. A problem only when it enters the villages
In terms of these flood-affected villages, Nagla Jatni is the worst hit, then Abdulpur and then Ahmednagar (which was identified during desk research)
They are also planting Bamboo along the banks to help with erosion and flooding

Within the floodplain farmers cannot dig any permanent borewells, so for water for irrigation we even observed a mobile water pump brought along to the banks by a farmer who was pumping and piping water to his nearby farm

The village head and technical assistant then sketched (attached image) an outline of the river in relation to the bridge we were standing over, to demonstrate how the shape and meanders of the ramganga constantly changes. So when predicting or zoning flood extent, it can be tricky



[group interview & perceptions at flood village] - at edge of Ahmednagar Jaitwara, along another section of Ramgang

Group of: Gram and Kshetra Panchayat, and technical assistant of Panchayat who has long been working there

After the brief tour from the bridge, we drove to the village of Ahmednagar Jaitwara identified during desk research. We walked a bit past more farms and towards the banks of Ramganga

Here the group described frequent flooding

Mentions that these floods are a massive obstruction to livelihood, cannot celebrate marriages or community events and day-to-day activities all cut off

Group expressed frustrations around lack of resources and help

Not just this village, but in times of floods major roads (like the one we got off before walking to the river bank) all get flooded

This main road services 25 villages and all these people get cut off

Flood water levels can get as high as chest-level for the average male

They believe the best and only solution will be pitching of the river, some sort of barricade, stones or embankment, for eg. for about 2km length to hold back the river

[follow-up question] - do they believe recharge ponds will help in such cases?

They don’t think so, only pitching will help
Here ponds will also be difficult cause no community-owned ponds, all the land is private farmer land so they might have to do it on their own land privately
[follow-up question] - what do they do in times of floods, do they have to migrate?
Yes, they have to flee to Moradabad any time flooding happens
They do not like going into the city
[follow-up question] - why do they not like the city?
City life is chaotic, their culture, their families everything is in the village and they need to be promised resources and help so they can continue living in the villages of their comfort
<u>Part 2: Bilari Block</u>
<u>BDO office interview</u>
On drought perceptions:
Drought in general is not a concern, groundwater access is reliable. But the water table can go low, right now it is at 75ft
So drought is a concern on in terms of groundwater use/overuse, and Bilari is in the dark zone i.e. critical block
On the AS ponds:
There is low rain now, so ponds are empty
But recharge as a whole is a critical initiative and BDO sees it as important and it will help the farmers’ irrigation needs when groundwater table is improved
They currently have 4 completed AS ponds, identifying others
Hard to get every pond to qualify for the scheme, ~1Ha, no greywater at all
On funding here: MGNREGA + kshetra P, no Gram P _
Does he think there is enough support for these AS pond construction and maintenance?
There tends to be low budget
They view Sinai Roja pond (will be visiting next) as a successful effort
[On monitoring - Qn from navneet] - do they currently know or quantify the recharge capability of these ponds? Or will there be interest in doing so?
They would be interested if IWMI, orgs like IWMI help them with monitoring and will allow it in their ponds
Interested in automatic monitoring
<u>Bilari Pond 1, Sinai Roja, Bilari Block</u>

[general description] - pond specifications, funding, AS scheme
1 inlet, 1 outlet, 0.48Ha
Tubewells and ditches lining this pond extensively
Same maintenance / operation as other ponds: 1-3 years frequency depending on MGNREGA
[quick questions]
When asked about droughts, again, do not perceive drought as a major issue due to GW access

So GW dark zone is seen as main issue, recharge therefore needed
Farmers and villagers perceive this as good public space, come to exercise in mornings and evenings

Villager interaction - Sinai Roja women's group meeting sit-in

[General description]
The day we visited was a regularly scheduled monthly meeting with the different officials who were on tour with us, and a local community group.
In the village Sinai Roja, women have come together to form a self-help group.
I participated as a neutral observer and asked the women some general questions

[researcher observations]
One of the officials in our group was the head of rural-development, and part of his duty is attending meetings with community groups such as this.
He seemed to ask the women general questions about their day-to-day activities and provide tasks for the future
Overall, there seemed to be top-down governance between the different officials down to community groups such as this. Hard to say what level of autonomy such groups might have.

[Questions to group, directed to group leader]
What is this self-help-group meant for, what do the ladies help each other with?
Everything from planning personal finances, to helping on each other's farms, helping each other find work, filling out paperwork or administrative things for various schemes & subsidies, etc.
What are their personal backgrounds?
All are farmers, some go into the city to work as laborers (for example in construction.)
Most have kids, the group leader has a 23 year old son who is pursuing a diploma in Pharmaceutical studies
Do they engage with the AS pond?
Yes they help with its maintenance and also initially during construction, part of MGNREGA
What do their husbands do?
Most are farmers, some in labor
What do they grow?
Ladyfinger, tomato, potato, sugarcane
Where do they sell produce?
Most is for village self-sustenance.
What other amenities do they have in the village?
Government school, primary school
The bigger kids go into the city for school

AS Pond 2: Changeri, Bilari Block

[general description] - pond specifications, funding, AS scheme

1 inlet, 1 outlet, ~2.5Ha

This was emptier and more deserted, more water percolated to the ground because not as silted

Empty in terms of people activity because not close to villagers

Located in Changeri village, not on the CDO list of Bilari's Amrit Sarovar ponds.

Blocks visited: Field day 2 - Upstream: June 5th, 2023, Chhajlet, Dilari

Interviewee series: Block development officers (BDOs), Pond technical engineers, villagers, kids, passers-by present

Interviewers:* Gayathri Angou, Navneet Sharma

Consent type: verbal & anonymous with designation and/or description, at end of each interview

Day outline:

Part 1: Chhajlet Block (Flood & groundwater affected)

Toured 2 AS ponds, one had recharge wells (closest to UTFI)

Some brief on-the-drive observations

BDO and village head interview

Site tour of piezometers installed at BDO office block

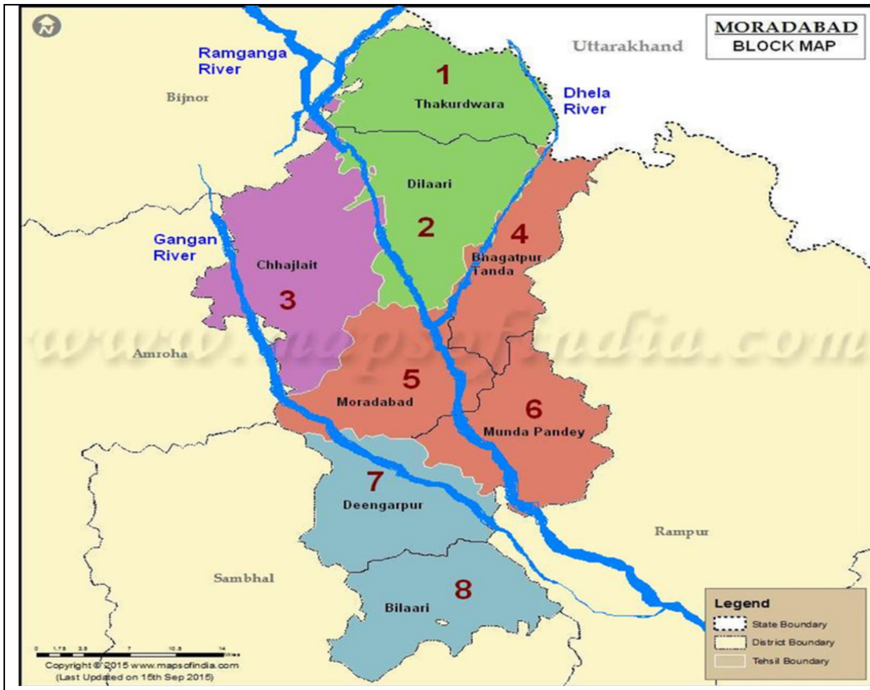
Part 2: Dilari Block (Flood & groundwater affected)

Toured 3 AS ponds, 2 in flood-affected villages one identified in desk GIS (Dilari-Changeri)

Visited 2 check-dams

Part summaries:

Note: These were all group tours with BDOs, technical engineering assistants of the block, and villagers who joined the tour. Therefore discussions were semi-structured, with interview questions spread across general conversation.



<u>Part 1: Chhajlet Block</u>

<u>*BDO and Village head interview in office*</u>

[general points]

CDO views Chhajlet as a successful block for AS pond installations

The block is high stress on groundwater issues so recharge efforts are again a priority for GW sustainability

[follow up question on flooding] - the ramganga basin is low-flow and especially upstream areas like this, they rely on Kalagarh dam way up north in Uttranchal. Since that was installed some decades ago, flooding is not much of a worry. Also mentioned a short comment on how the dam also helps with hydroelectricity.

They are facing some funding issues

When the pond is full it also serves as a source for fishing, this is an income for poor people

But leads to competing needs recharge vs recreation vs fishing - always keeping the pond full

[field drive observations]

Chhajlet has lots more canals by the farms, it's the block with the most extensive canal network. This has benefits:

Reduces flood risk

Also allows for more water access for water-intensive plants like sugarcane

Sugarcane is almost exclusively the only crop visible, according to Navneet it is about 94-95% of all crop yield in Chhajlet and this block is the main supplier of the crop

Generally looks lush and green, thanks to the many canals and small ditch systems, this was not the case in the other blocks

AS pond 1, Bhalpura Kheraya, Chhajlet block:

[general points & discussion] - on pond specification, funding, AS scheme
Pond under construction nearing completion
Recent build like all AS ponds
1 inlet, 1 outlet (outlet under construction), 0.4 Ha, depth ~2.5m
Here you can observe the pond being split into the 'AS' side and non-scheme side - the funds are limited and scheme has restrictions on pond qualifications
No greywater issues here
Goal: clean water, recreation & recharge, capturing rainwater
Funding: MGNREGA + Gram Panchayat, no Kshetra P
Little more deserted, not many villagers around
Water is recharging but as with all other AS ponds, they are not monitoring how much

AS pond 2, Madhpuri, Chhajlet block:

[general points] - on pond specification, funding, AS scheme
First pond to have recharge wells, this is closed to UTFI structure
Has 4 recharge wells, looks like ~ 0.5Ha. Each well has a 15ft borewell.
When water level goes above height of recharge well, it can enter and get recharged
Wells seem to be concrete structures on the outside, there's some filter inside
[follow-up question] - who maintains?
Recharge wells were installed by external org so does not fall under Gram Panchayat for maintenance
The pond is adopted by a company for them to off-set / meet out their recharge regulations. adopted by a paper company called Genus Paper & Boards Ltd.
This adoption plan falls under the larger Ganges Rejuvenation plan at the basin level
[post-field trip lookup] - this company is actually located in New Delhi, not even in Uttar Pradesh. So It shows inter-state rural/urban/industrial connections in groundwater management

Part 2: Dilari Block
BDO office interview
On flood problems:
Dilari-Changeri village and Mundiya Muhiuddinpur affected
Another village Gakharpur which is close to Dilari-Changeri village and about 2km from Ramganga also experiences floods

This village is populated too, >4000 people / ~800 households affected
On drought problems:
Not as significant, again because of good reliance on groundwater avail - so no issue of agricultural drought
On groundwater:
Recharge is again a priority because Dilari also has an over-extraction problem

BDO Office block - piezometer tour

[general description]
The office block of the BDO is also the site of a World Bank project to monitor the groundwater table across the state of UP
We noticed 3 piezometer stations, each at low, medium and deep levels to measure the changes in the water table year round
This project was also mentioned by the Moradabad AE Groundwater, the goal is to install these measurement stations for every 2 km x 2km grid of city blocks and 5km x 5km grid of rural areas.

AS Pond 1, Kasampur , Bilari Block (not on CDO List)

[general description and observations] - pond specifications, funding, AS scheme
1 inlet, 1 outlet, 0.5Ha, 3-4m deep
Villagers use the pond in the evening and mornings
Funding = MGNREGA + Gram panchayat, no Kshetra P
Maintenance by Gram Panchayat
There is lots of water
Biodiversity noted, saw one turtle and pond is known for turtles now
Villages right nearby, lots of homes visible and boarding 2 out of 4 sides of the pond

[quick questions to Gram Panchayat representative]
How did they choose pond sites? List came from Lucknow and this is the only pond in this village
No plans to include recharge wells
No greywater issues, village greywater has a separate sewer pipe system that leaves the village

[quick questions to kids nearby]
They like the pond, it's a good play area
But scared of safety issues, one child drowned last month while trying to swim, so now the kids don't swim
[follow up question to gram panchayat representative]
He mentioned the accident, said it occurred during the day without adult supervision
Hard to regulate who will enter/exit open water bodies and similar to risk with ramganga

[research note] - if we are however making this an open public space and inviting people over with park benches etc., maybe some small planning interventions like safety signs can be incorporated along with the existing 'CIB' - citizen information board

AS Pond 2, Dilari-Changeri, Dilari Block

[general description] - pond specifications, funding, AS scheme
Quick tour
1 outlet, 1 inlet, bigger around 1Ha
This village is also a flood affected area
No villagers in slight, located in a more secluded area
Not much farmland nearby, more of wilderness and the pond is present
Lots of wild marujana grows in this region and present along the edges of the pond - the main vegetation here

AS Pond 3, Mundiya Muhiuddinpur, Dilari Block

[general description and observations] - pond specifications, funding, AS scheme
Quick tour
1 inlet, 1 outlet ~0.5Ha
Can again notice the ponds split, one is AS the other is more marshland adjacent to it
This pond is also boarded by a large cow-shed, the the marshland pond is accessed by cattle for water
People also use the AS pond for recreation in the morning and evenings and villagers really appreciate this aspect
Funding = MGNREGA + Kshetra Panchayat, no Gram Panchayat
Also noticed some light construction activity of the pavement alongside the pond, and the workers went into the pond to scoop buckets of water to later use for their construction needs
[villager questions] - on flooding, pond perceptions
This region floods as it is close to Ramganga, which is about 2km away
Last big flood was in 2010, lots of crop and farmland losses
They affirmatively view the pond as a good flood protection measure, they believe it will catch flood waters before it overflows into the villages nearby - this perception makes sense here because the pond is closer to the river bank and further away from the village which is more inland

Check dams quick tour, Dilari Block

[Check dam 1], tour by technical staff:
In selecting CD location, need to choose a flat stream region
It helps with recharge because it collects / pools water upstream of it and this can be thought of as a long pond
Farmer cooperation can sometimes be tough because it takes up their land, and impact/ benefits are not equally distributed - they need to clearly be shown the benefits

[Check dam 2], tour by technical staff: Two main goals of CDs: recharge and drop in flow velocity to prevent downstream erosion Maintenance done by farmers who benefit from the CD and sometimes panchayat, but this governance and funding structure is not as clear as for AS Could also notice lush green aquatic vegetation (floating kind) in the slowed-down water downstream of CD

9.3.5 Fieldwork qualitative data collected – urban observations.

9.3.5.1 Urban Fabric Researcher Observations

Goal: understand GW infra through the city and how people interact with it Date: Sunday, June 2nd, 2023, ~1-3pm. ***Route and activities:*** Walked ~500 m down Delhi main road near the hotel to observe infrastructure, presence of water infra like overhead tanks, street vendors (fruits, vegetables, fried street food) and types of produce in this busy shophouse area during the Summer. Took a rickshaw from my Hotel (Mansarover Paradise) to Buddha Park ~6 km round trip Walked around Buddha Park for a bit, the park itself was closed and would open later in the evening. Again noticed series of street vendors lined up outside park entrance Headed back to hotel, dropped off ~500 m before to chat with street vendors Stopped for a fruit juice and chatted with storekeeper's perceptions of the city ***General observations***: Buddha Park has courtyard type thing out front, thru residential areas, groundwater pumps seen outside bldg blocks along streets, street vendors tend to rent up nearby Open sewage issues Notice GW hand pumps maybe once every 300m. All pumps look the same, which makes me think it's by the city and not private pumps that could all look different. Same gray pumps with circular platforms even in rural areas as it was observed during Downstream field day Above was later confirmed with Navneet, there has long been a nation-wide GW hand pump scheme Sometimes the GW pumps are more frequent, after every few buildings This route mostly seems like a residential area, but densely populated, lots of activity and people. Homes are close to each other There are also shop houses, carpenter stores, small light Industry Lots of street vendors with fruit stalls, all summer fruits: lychee, mango, sugarcane, pineapple, tomatoes - all are GW based irrigation and esp. Crops like sugarcane are GW intensive Vendors seem to congregate at cross road junctions

This region is biggest exporter of lychee as I overheard while stopped at a stoplight near a lychee vendor, when later looking this up the biggest exporting state is Bihar, which is near UP to the North East

[Fruitstall chat]: pineapple and butter fruit from Moradabad district outskirts

The sheer scale of things, the population, the number of individual actors in a system. I really am starting to feel like clean and pristine planning, "living labs" etc only work in Sim city type of places. Our greatest examples of planning - SG, NL or at best other small cities. It's easy, agent-based models model a cute lil number of agents.

We say encroachment, we call it uncouth and unclean - but this is almost the wild Wild West and collective psyche of millions which is very much still a system.

All this not to say that planning shouldn't happen, and govt isn't needed - but ALLLL the more reason it should be flat. Not top down. So, institutions can try their best to run parallel to the bullet trains of Indian societies.

Note on public Transportation, interesting dynamic. Few buses to speak off but almost all autos and rickshaws are shared, so still a form of public transport but operated by many private agents

Reflection & observations on what it means to be a Smart City:

so many murals and paintings on 'Moradabad Smart City' in public areas, a prominent Smart City Office

Most public artwork along parks or traffic circles allude to cleaner, maybe greener areas; keeping the city clean

Interestingly, India's Smart City website calls out European vs our definitions, but i sense that smart city can mean many things, and many agents of the city interpret it differently

A place is a city for as long as its inhabitants perceive it to be so. Sure, there are quantitative metrics like urban footprints of population density, indications of centralized resources and infrastructure or a means of distribution

And when discussing with the two ladies at the Nagar Nigam office, and our field day driver, they all consider Moradabad to be a congested and lively city, and for them smart city means aspects of law and order, cleaner streets etc.

9.3.5.2 Urban RWH & MAR example site observations

Location: Moradabad Polytechnic and hostels
Date: June 2, 2023
Goal: get visual idea of urban RWH equipment starting to be installed, also has MAR with recharge well tank, an urban example

General observations:

Just being installed, polytechnic professors on site mentioned they will observe how it performs in the upcoming monsoon season for the first time.

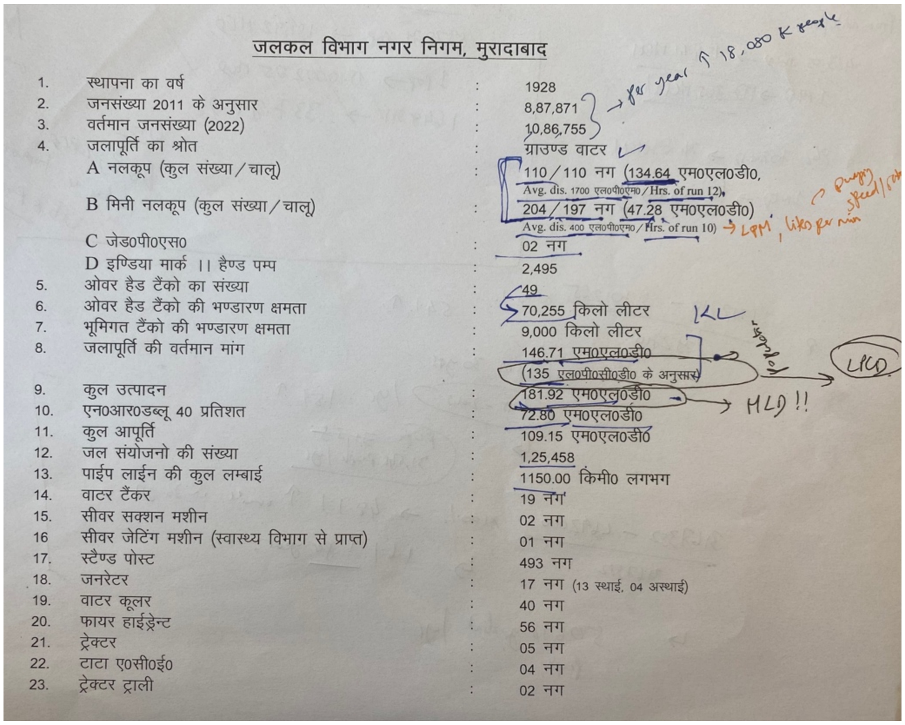
Low-cost, low-tech installations - PVC pipes that either drain directly to the ground outside or connected to recharge tanks underground and adjacent to tank.

Some MAR tanks were nearby the main buildings in open space areas, key issue with all MAR technology noticed - accumulation of silt, leaves and other flyaway trash/debris.



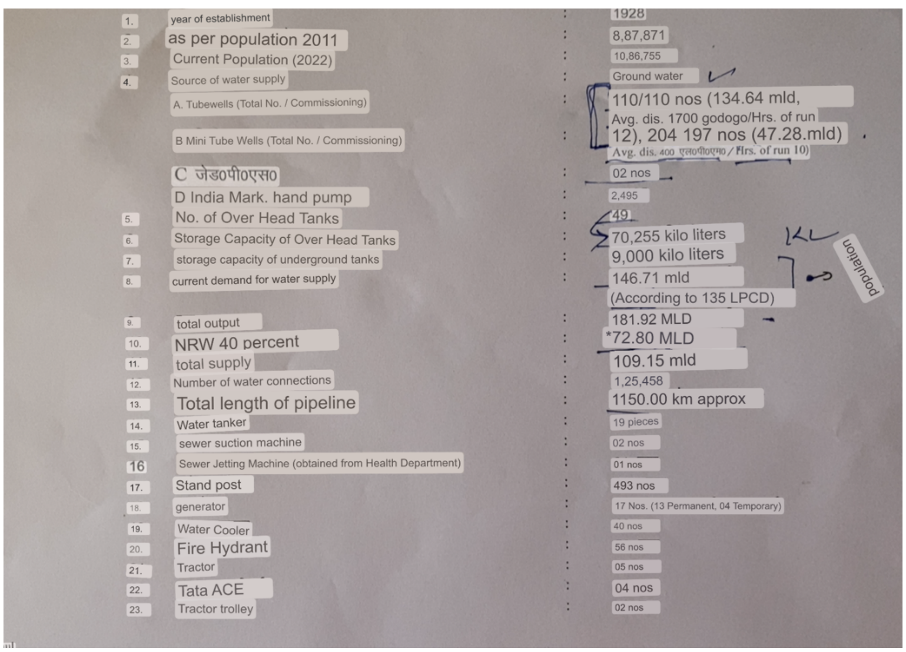


9.3.6 Fieldwork quantitative data collected.



जलकल विभाग नगर निगम, मुरादाबाद

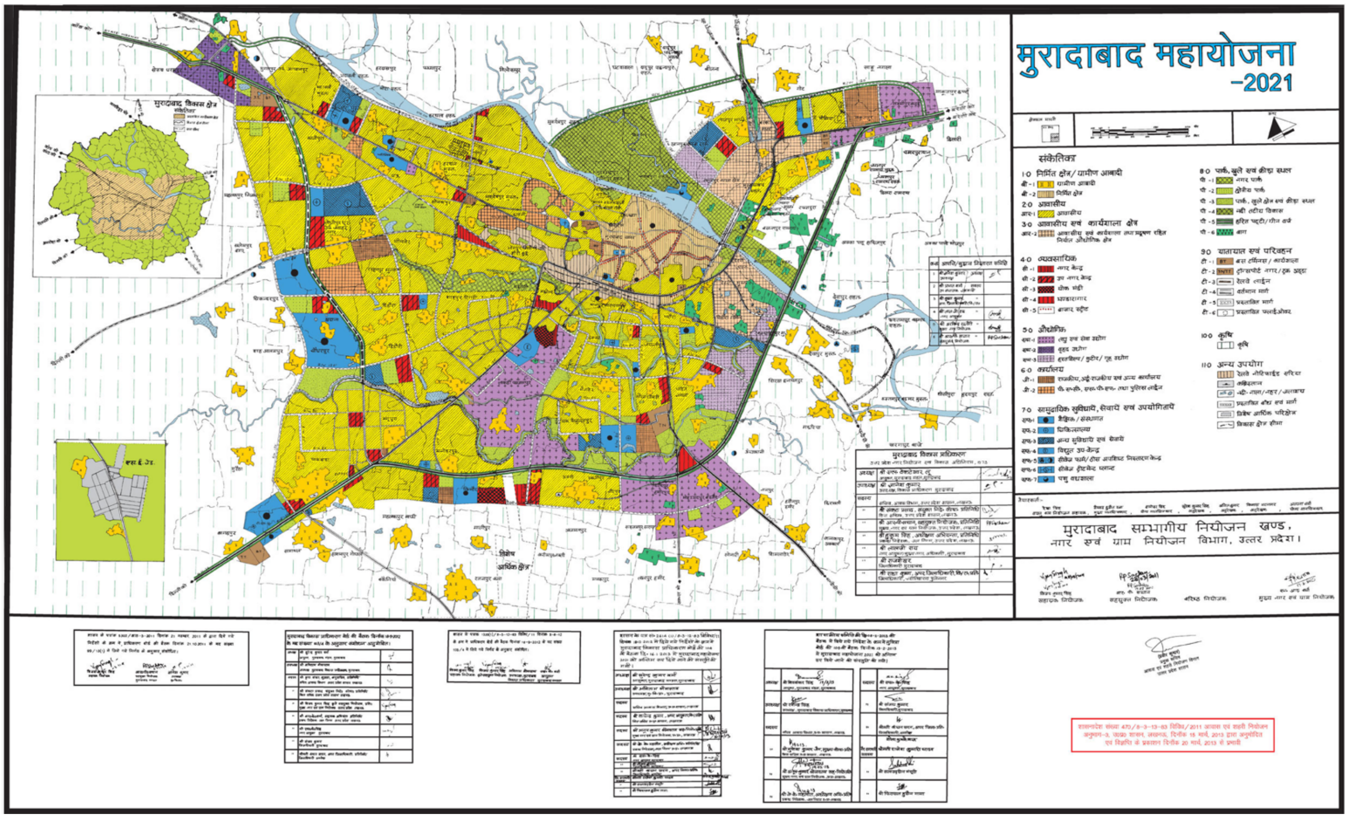
1.	स्थापना का वर्ष	:	1928
2.	जनसंख्या 2011 के अनुसार	:	8,87,871
3.	वर्तमान जनसंख्या (2022)	:	10,86,755
4.	जलापूर्ति का श्रोत	:	ग्राउण्ड वाटर
	A नलकूप (कुल संख्या/चालू)	:	110/110 नग (134.64 एम0एल0डी0, Avg. dis. 1700 एल0पी0एम0/Hrs. of run 12),
	B मिनी नलकूप (कुल संख्या/चालू)	:	204/197 नग (47.28 एम0एल0डी0) Avg. dis. 400 एल0पी0एम0/Hrs. of run 10)
	C जे0पी0एस0	:	02 नग
	D इण्डिया मार्क ।। हैण्ड पम्प	:	2,495
5.	ओवर हैड टैंको का संख्या	:	49
6.	ओवर हैड टैंको की भण्डारण क्षमता	:	70,255 किलो लीटर
7.	भूमिगत टैंको की भण्डारण क्षमता	:	9,000 किलो लीटर
8.	जलापूर्ति की वर्तमान मांग	:	146.71 एम0एल0डी0 (135 एल0पी0सी0डी0 के अनुसार)
9.	कुल उत्पादन	:	181.92 एम0एल0डी0
10.	एन0आर0डब्लू 40 प्रतिशत	:	72.80 एम0एल0डी0
11.	कुल आपूर्ति	:	109.15 एम0एल0डी0
12.	जल संयोजनो की संख्या	:	1,25,458
13.	पाईप लाईन की कुल लम्बाई	:	1150.00 किमी0 लगभग
14.	वाटर टैंकर	:	19 नग
15.	सीवर सक्शन मशीन	:	02 नग
16	सीवर जेटिंग मशीन (स्वास्थ्य विभाग से प्राप्त)	:	01 नग
17.	स्टैण्ड पोस्ट	:	493 नग
18.	जनरेटर	:	17 नग (13 स्थाई, 04 अस्थाई)
19.	वाटर कूलर	:	40 नग
20.	फायर हाईड्रेन्ट	:	56 नग
21.	ट्रेक्टर	:	05 नग
22.	टाटा ए0सी0ई0	:	04 नग
23.	ट्रेक्टर ट्राली	:	02 नग



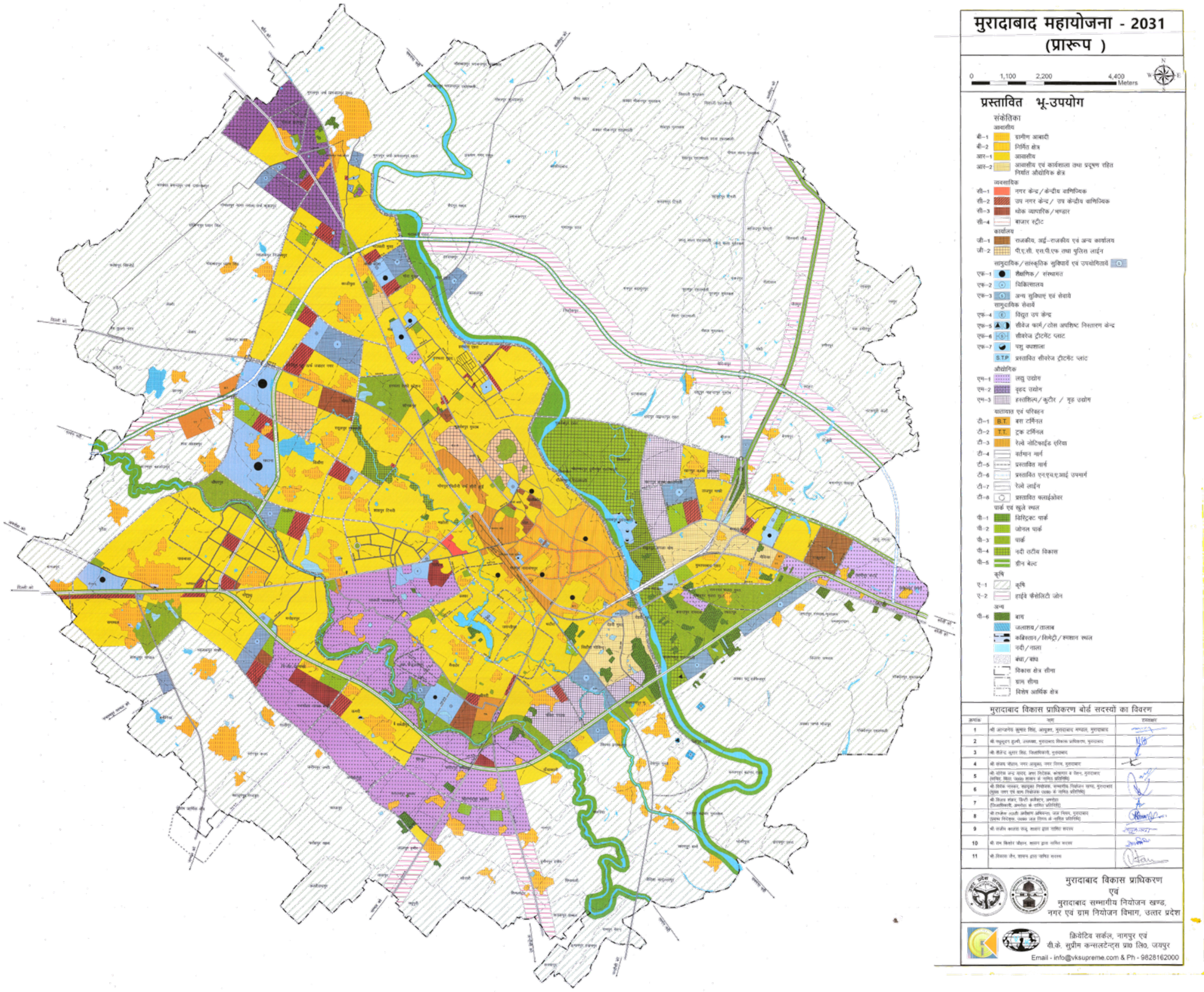
1.	year of establishment	:	1928
2.	as per population 2011	:	8,87,871
3.	Current Population (2022)	:	10,86,755
4.	Source of water supply	:	Ground water
	A. Tubewells (Total No. / Commissioning)	:	110/110 nos (134.64 mld, Avg. dis. 1700 godogo/Hrs. of run 12),
	B Mini Tube Wells (Total No. / Commissioning)	:	204 197 nos (47.28.mld) Avg. dis. 400 एल0पी0एम0/Hrs. of run 10)
	C जे0पी0एस0	:	02 nos
	D India Mark. hand pump	:	2,495
5.	No. of Over Head Tanks	:	49
6.	Storage Capacity of Over Head Tanks	:	70,255 kilo liters
7.	storage capacity of underground tanks	:	9,000 kilo liters
8.	current demand for water supply	:	146.71 mld (According to 135 LPCD)
9.	total output	:	181.92 MLD
10.	NRW 40 percent	:	*72.80 MLD
11.	total supply	:	109.15 mld
12.	Number of water connections	:	1,25,458
13.	Total length of pipeline	:	1150.00 km approx
14.	Water tanker	:	19 pieces
15.	sewer suction machine	:	02 nos
16	Sewer Jetting Machine (obtained from Health Department)	:	01 nos
17.	Stand post	:	493 nos
18.	generator	:	17 Nos. (13 Permanent, 04 Temporary)
19.	Water Cooler	:	40 nos
20.	Fire Hydrant	:	56 nos
21.	Tractor	:	05 nos
22.	Tata ACE	:	04 nos
23.	Tractor trolley	:	02 nos

Moradabad City Municipal (Nagar Nigam) Water Works Office - data received from Assistant Engineer in Hindi.

9.4 Appendix 4: Moradabad 2021 masterplan for reference.



9.5 Appendix 5: Moradabad 2031 draft masterplan for reference.



9.6 Appendix 6: Python functions

```
def Calculate_number_of_ponds_urban(path_name, sheet_name_in_spreadsheet):
    df = pd.read_excel(path_name, sheet_name = sheet_name_in_spreadsheet)
    "Per person demand"
    Per_person_demand = df[df['variable '].str.contains('Per person 
demand',na=False,case=False)]['value'].iloc[0]
    "Per day extraction"
    Per_day_extraction = df[df['variable '].str.contains('Per day 
extraction',na=False,case=False)]['value'].iloc[0]
    "Population"
    Population = df[df['variable 
'].str.contains('Population',na=False,case=False)]['value'].iloc[0]
  #"per day demand"
  #Per_day_demand = per_day_extraction #setting per day demand same as 
extraction because already in MLD
    Per_year_demand = Per_day_extraction * 365
    "Annual rainfall"
    Annual_rainfall = df[df['variable '].str.contains('Annual 
rainfall',na=False,case=False)]['value'].iloc[0]
    "Area"
    Area = df[df['variable 
'].str.contains('Area',na=False,case=False)]['value'].iloc[0]
    Volume_of_rainfall = Area * Annual_rainfall
    Volume_of_rainfall_MLY = (Volume_of_rainfall*1000)/10**6
    #Natural_recharge_CGWB = 0.1*Volume_of_rainfall_MLY
    #Chaturvedi_natural_recharge_constant = 1.35 * ((38.08-14)**0.5)
    "Inches to M precipitation"
    #Inches_to_M_precipitation = df[df['variable '].str.contains('Inches to 
M precipitation',na=False,case=False)]['value'].iloc[0]
    #Volume_of_rain_in_city = Inches_to_M_precipitation * Area
    #Liters_of_rainfall = Volume_of_rain_in_city * 1000
    Final_recharge_per_year = Volume_of_rainfall_MLY*.22 #From GEC 22% 
infiltration in indo-ganges areas
    Overshoot_percentage_demand = ((Per_year_demand -
```

```
Final_recharge_per_year)/Final_recharge_per_year) * 100
    print (Overshoot_percentage_demand)
    Full_demand = Per_year_demand - Final_recharge_per_year
    Demand_80_pct = Full_demand * 0.8
    Demand_50_pct = Full_demand * 0.5
    Demand_30_pct = Full_demand * 0.3
    Natural_recharge_amount_only_pct =
(Final_recharge_per_year/Per_year_demand)*100
    UTFI_constant = 580 * 73.5
    UTFI_recharge = (UTFI_constant*1000)/10**6
    UTFIPilot_area = 2625 #in sqm
    #no of ponds calc
    Full_artificial_recharge = Full_demand/UTFI_recharge
    Artificial_recharge_80_pct = Demand_80_pct/UTFI_recharge
    Artificial_recharge_50_pct = Demand_50_pct/UTFI_recharge
    Artificial_recharge_30_pct = Demand_30_pct/UTFI_recharge
    Artifical_recharge_equal_nat_recharge =
Final_recharge_per_year/UTFI_recharge
    #area calcs
    AreaofPonds_100PctDemand = Full_artificial_recharge*UTFIPilot_area
    AreaofPonds_80PctDemand = Artificial_recharge_80_pct*UTFIPilot_area
    AreaofPonds_50PctDemand = Artificial_recharge_50_pct*UTFIPilot_area
    AreaofPonds_30PctDemand = Artificial_recharge_30_pct*UTFIPilot_area
    AreaofPonds_NatRecharge =
Artifical_recharge_equal_nat_recharge*UTFIPilot_area
    #percent of city area required
    CityArea_100PctDemand = (AreaofPonds_100PctDemand/Area)*100
    CityArea_80PctDemand = (AreaofPonds_80PctDemand/Area)*100
    CiyArea_50PctDemand = (AreaofPonds_50PctDemand/Area)*100
    CityArea_30PctDemand = (AreaofPonds_30PctDemand/Area)*100
    CityArea_NatRecharge = (AreaofPonds_NatRecharge/Area)*100
    summary_df = pd.DataFrame()
    summary_df['Artificial_recharge'] =
['Artificial_recharge_30_pct','Artificial_recharge_50_pct','Artificial_recha
rge_80_pct','Full_artificial_recharge']
```

```
    summary_df['Number_of_ponds'] =
[Artificial_recharge_30_pct,Artificial_recharge_50_pct,Artificial_recharge_8
0_pct,Full_artificial_recharge]
    summary_df['Percentage_of_city_area'] =
[CityArea_30PctDemand,CiyArea_50PctDemand,CityArea_80PctDemand,CityArea_100P
ctDemand]
    return summary_df
```

Python function for future urban number of UTFI ponds:

```
def Calculate_number_of_future_ponds_urban(path_name,
sheet_name_in_spreadsheet, buffer_extraction, Per_person_demand):
    df = pd.read_excel(path_name, sheet_name = sheet_name_in_spreadsheet)
    "Per person demand"
    # Uncomment the line below if you want to read in the per person demand,
or just enter it as a function input above
    Per_person_demand = df[df['variable '].str.contains('Per person
demand',na=False,case=False)]['value'].iloc[0]
    #"Per day extraction"
    #Per_day_extraction = df[df['variable '].str.contains('Per day
extraction',na=False,case=False)]['value'].iloc[0]
    "Population"
    Population = df[df['variable
'].str.contains('Population',na=False,case=False)]['value'].iloc[0]
    Per_day_population_demand = (Per_person_demand * Population)/(10**6)
    Per_day_final_extraction = (buffer_extraction *
Per_day_population_demand) + Per_day_population_demand
    Per_year_demand = Per_day_final_extraction * 365
    "Annual rainfall"
    Annual_rainfall = df[df['variable '].str.contains('Annual
rainfall',na=False,case=False)]['value'].iloc[0]
    "Area"
    Area = df[df['variable
'].str.contains('Area',na=False,case=False)]['value'].iloc[0]
    Volume_of_rainfall = Area * Annual_rainfall
    Volume_of_rainfall_MLY = (Volume_of_rainfall*1000)/10**6
```

```
    Natural_recharge_CGWB = 0.1*Volume_of_rainfall_MLY
    Chaturvedi_natural_recharge_constant = 1.35 * ((38.08-14)**0.5)
    "Inches to M precipitation"
    Inches_to_M_precipitation = df[df['variable '].str.contains('Inches to M precipitation',na=False,case=False)]['value'].iloc[0]
    Volume_of_rain_in_city = Inches_to_M_precipitation * Area
    Liters_of_rainfall = Volume_of_rain_in_city * 1000
    Final_recharge_per_year = Liters_of_rainfall/10**6
    Overshoot_percentage_demand = ((Per_year_demand - Final_recharge_per_year)/Final_recharge_per_year) * 100
    print (Overshoot_percentage_demand)
    Full_demand = Per_year_demand - Final_recharge_per_year
    Demand_80_pct = Full_demand * 0.8
    Demand_50_pct = Full_demand * 0.5
    Demand_30_pct = Full_demand * 0.3
    Natural_recharge_amount_only_pct = (Final_recharge_per_year/Per_year_demand)*100
    UTFI_constant = 580 * 73.5
    UTFI_recharge = (UTFI_constant*1000)/10**6
    UTFIPilot_area = 2625 #in sqm
    Full_artificial_recharge = Full_demand/UTFI_recharge
    Artificial_recharge_80_pct = Demand_80_pct/UTFI_recharge
    Artificial_recharge_50_pct = Demand_50_pct/UTFI_recharge
    Artificial_recharge_30_pct = Demand_30_pct/UTFI_recharge
    Artifical_recharge_equal_nat_recharge = Final_recharge_per_year/UTFI_recharge
    #area calcs
    AreaofPonds_100PctDemand = Full_artificial_recharge*UTFIPilot_area
    AreaofPonds_80PctDemand = Artificial_recharge_80_pct*UTFIPilot_area
    AreaofPonds_50PctDemand = Artificial_recharge_50_pct*UTFIPilot_area
    AreaofPonds_30PctDemand = Artificial_recharge_30_pct*UTFIPilot_area
    AreaofPonds_NatRecharge = Artifical_recharge_equal_nat_recharge*UTFIPilot_area
    #percent of city area required
    CityArea_100PctDemand = (AreaofPonds_100PctDemand/Area)*100
```

```
    CityArea_80PctDemand = (AreaofPonds_80PctDemand/Area)*100
    CiyArea_50PctDemand = (AreaofPonds_50PctDemand/Area)*100
    CityArea_30PctDemand = (AreaofPonds_30PctDemand/Area)*100
    CityArea_NatRecharge = (AreaofPonds_NatRecharge/Area)*100
    summary_df = pd.DataFrame()
    summary_df['Artificial_recharge'] =
['Artificial_recharge_30_pct','Artificial_recharge_50_pct','Artificial_recha
rge_80_pct','Full_artificial_recharge']
    summary_df['Number_of_ponds'] =
[Artificial_recharge_30_pct,Artificial_recharge_50_pct,Artificial_recharge_8
0_pct,Full_artificial_recharge]
    summary_df['Percentage_of_city_area'] =
[CityArea_30PctDemand,CiyArea_50PctDemand,CityArea_80PctDemand,CityArea_100P
ctDemand]
    return summary_df
```

Merging current and future data frames and plotting urban scenario:

```
MbadCombined = pd.concat([MBadCurrentdf['Number_of_ponds'],
MBadFuturedf['Number_of_ponds']], axis=1, keys=['MBadCurrentdf',
'MBadFuturedf'])
MbadCombined
MbadCombined['Difference'] = MbadCombined['MBadFuturedf']-
MbadCombined['MBadCurrentdf']
MbadCombined['Difference + current'] = MbadCombined['Difference'] +
MbadCombined['MBadCurrentdf']
MbadCombined
color_map = ['midnightblue', 'lightskyblue','pink']
#sns.set_theme()
#hfont = {'fontname':'Helvetica'}
fig, ax = plt.subplots(figsize=(15,10))
plt.stackplot(MBadCurrentdf.Artificial_recharge,MbadCombined.MBadCurrentdf,M
badCombined.Difference,
              labels=['Current', 'Future'],
              colors=color_map)
plt.legend(loc='upper left',fontsize=20)
```

```
plt.title('Current vs. Future number of ponds Moradabad Urban',fontsize=25)
plt.xlabel('Artificial recharge percent of demand', fontsize=20)
plt.ylabel('Number of Ponds', fontsize=20)
```

Python code for current number of ponds, rural blocks:

```
def Calculate_number_of_ponds_rural(path_name, sheet_name_in_spreadsheet):
    df = pd.read_excel(path_name, sheet_name = sheet_name_in_spreadsheet)
    "Per person demand"
    Per_person_demand = df[df['variable '].str.contains('Per person 
demand',na=False,case=False)]['value'].iloc[0]
    "Population"
    Population = df[df['variable 
'].str.contains('Population',na=False,case=False)]['value'].iloc[0]
    "Per day population demand"
    Per_day_population_demand = (Per_person_demand * Population)/(10**6)
    "Per day agricultural demand"
    Per_day_agri_demand = 255.93
    "Per day agri + pop demand"
    Per_day_agriandpop_demand = Per_day_population_demand + 
Per_day_agri_demand
    "Per year total demand"
    Per_year_demand = Per_day_agriandpop_demand * 365
    "Annual rainfall"
    Annual_rainfall = df[df['variable '].str.contains('Annual 
rainfall',na=False,case=False)]['value'].iloc[0]
    "Area"
    Area = df[df['variable 
'].str.contains('Area',na=False,case=False)]['value'].iloc[0]

    Volume_of_rainfall = Area * Annual_rainfall
    Volume_of_rainfall_MLY = (Volume_of_rainfall*1000)/10**6
    #Natural_recharge_CGWB = 0.1*Volume_of_rainfall_MLY
    #Chaturvedi_natural_recharge_constant = 1.35 * ((38.08-14)**0.5)
    "Inches to M precipitation"
    #Inches_to_M_precipitation = df[df['variable '].str.contains('Inches to
```

```
M precipitation',na=False,case=False)]['value'].iloc[0]
    #Volume_of_rain_in_city = Inches_to_M_precipitation * Area
    #Liters_of_rainfall = Volume_of_rain_in_city * 1000
    Final_recharge_per_year = Volume_of_rainfall_MLY*0.22
    Overshoot_percentage_demand = ((Per_year_demand - 
Final_recharge_per_year)/Final_recharge_per_year) * 100
  #print (Overshoot_percentage_demand)
    Full_demand = Per_year_demand - Final_recharge_per_year
    Demand_80_pct = Full_demand * 0.8
    Demand_50_pct = Full_demand * 0.5
    Demand_30_pct = Full_demand * 0.3
    Natural_recharge_amount_only_pct = 
(Final_recharge_per_year/Per_year_demand)*100
    UTFI_constant = 580 * 73.5
    UTFI_recharge = (UTFI_constant*1000)/10**6
    UTFIPilot_area = 2625 #in sqm
    Full_artificial_recharge = Full_demand/UTFI_recharge
    Artificial_recharge_80_pct = Demand_80_pct/UTFI_recharge
    Artificial_recharge_50_pct = Demand_50_pct/UTFI_recharge
    Artificial_recharge_30_pct = Demand_30_pct/UTFI_recharge
    Artifical_recharge_equal_nat_recharge = 
Final_recharge_per_year/UTFI_recharge
    #area calcs
    AreaofPonds_100PctDemand = Full_artificial_recharge*UTFIPilot_area
    AreaofPonds_80PctDemand = Artificial_recharge_80_pct*UTFIPilot_area
    AreaofPonds_50PctDemand = Artificial_recharge_50_pct*UTFIPilot_area
    AreaofPonds_30PctDemand = Artificial_recharge_30_pct*UTFIPilot_area
    AreaofPonds_NatRecharge = 
Artifical_recharge_equal_nat_recharge*UTFIPilot_area
    #percent of rural area required
    RuralArea_100PctDemand = (AreaofPonds_100PctDemand/Area)*100
    RuralArea_80PctDemand = (AreaofPonds_80PctDemand/Area)*100
    RuralArea_50PctDemand = (AreaofPonds_50PctDemand/Area)*100
    RuralArea_30PctDemand = (AreaofPonds_30PctDemand/Area)*100
    RuralArea_NatRecharge = (AreaofPonds_NatRecharge/Area)*100
```

```
    summary_df = pd.DataFrame()
    summary_df = pd.DataFrame()
    summary_df['Artificial_recharge'] = 
['Artificial_recharge_30_pct','Artificial_recharge_50_pct','Artificial_recha
rge_80_pct','Full_artificial_recharge']
    summary_df['Number_of_ponds'] = 
[Artificial_recharge_30_pct,Artificial_recharge_50_pct,Artificial_recharge_8
0_pct,Full_artificial_recharge]
    summary_df['Percentage_of_rural_area'] = 
[RuralArea_30PctDemand,RuralArea_50PctDemand,RuralArea_80PctDemand,RuralArea
_100PctDemand]
    return summary_df
```

Python code for future number of ponds, rural blocks:

```
def Calculate_number_of_future_ponds_rural(path_name, 
sheet_name_in_spreadsheet):
    df = pd.read_excel(path_name, sheet_name = sheet_name_in_spreadsheet)
    "Per person demand"
    Per_person_demand = df[df['variable '].str.contains('Per person 
demand',na=False,case=False)]['value'].iloc[0]
    "Population"
    Population = df[df['variable 
'].str.contains('Population',na=False,case=False)]['value'].iloc[0]
    "Per day population demand"
    Per_day_population_demand = (Per_person_demand * Population)/(10**6)
    "Per day agricultural demand"
    Per_day_agri_demand = 255.93
    "Per day agri + pop demand"
    Per_day_agriandpop_demand = Per_day_population_demand + 
Per_day_agri_demand
    "Per year total demand"
    Per_year_demand = Per_day_agriandpop_demand * 365
    "Annual rainfall"
    Annual_rainfall = df[df['variable '].str.contains('Annual 
rainfall',na=False,case=False)]['value'].iloc[0]
```

```
    "Area"
    Area = df[df['variable
'].str.contains('Area',na=False,case=False)]['value'].iloc[0]
    Volume_of_rainfall = Area * Annual_rainfall
    Volume_of_rainfall_MLY = (Volume_of_rainfall*1000)/10**6
    #Natural_recharge_CGWB = 0.1*Volume_of_rainfall_MLY
    #Chaturvedi_natural_recharge_constant = 1.35 * ((38.08-14)**0.5)
    "Inches to M precipitation"
    #Inches_to_M_precipitation = df[df['variable '].str.contains('Inches to
M precipitation',na=False,case=False)]['value'].iloc[0]
    #Volume_of_rain_in_city = Inches_to_M_precipitation * Area
    #Liters_of_rainfall = Volume_of_rain_in_city * 1000
    Final_recharge_per_year = Volume_of_rainfall_MLY*0.22
    Overshoot_percentage_demand = ((Per_year_demand -
Final_recharge_per_year)/Final_recharge_per_year) * 100
  #print (Overshoot_percentage_demand)
    Full_demand = Per_year_demand - Final_recharge_per_year
    Demand_80_pct = Full_demand * 0.8
    Demand_50_pct = Full_demand * 0.5
    Demand_30_pct = Full_demand * 0.3
    Natural_recharge_amount_only_pct =
(Final_recharge_per_year/Per_year_demand)*100
    UTFI_constant = 580 * 73.5
    UTFI_recharge = (UTFI_constant*1000)/10**6
    UTFIPilot_area = 2625 #in sqm
    Full_artificial_recharge = Full_demand/UTFI_recharge
    Artificial_recharge_80_pct = Demand_80_pct/UTFI_recharge
    Artificial_recharge_50_pct = Demand_50_pct/UTFI_recharge
    Artificial_recharge_30_pct = Demand_30_pct/UTFI_recharge
    Artifical_recharge_equal_nat_recharge =
Final_recharge_per_year/UTFI_recharge
    #area calcs
    AreaofPonds_100PctDemand = Full_artificial_recharge*UTFIPilot_area
    AreaofPonds_80PctDemand = Artificial_recharge_80_pct*UTFIPilot_area
```

```
    AreaofPonds_50PctDemand = Artificial_recharge_50_pct*UTFIPilot_area
    AreaofPonds_30PctDemand = Artificial_recharge_30_pct*UTFIPilot_area
    AreaofPonds_NatRecharge = 
Artifical_recharge_equal_nat_recharge*UTFIPilot_area
    #percent of rural area required
    RuralArea_100PctDemand = (AreaofPonds_100PctDemand/Area)*100
    RuralArea_80PctDemand = (AreaofPonds_80PctDemand/Area)*100
    RuralArea_50PctDemand = (AreaofPonds_50PctDemand/Area)*100
    RuralArea_30PctDemand = (AreaofPonds_30PctDemand/Area)*100
    RuralArea_NatRecharge = (AreaofPonds_NatRecharge/Area)*100
    summary_df = pd.DataFrame()
    summary_df = pd.DataFrame()
    summary_df['Artificial_recharge'] = 
['Artificial_recharge_30_pct','Artificial_recharge_50_pct','Artificial_recha
rge_80_pct','Full_artificial_recharge']
    summary_df['Number_of_ponds'] = 
[Artificial_recharge_30_pct,Artificial_recharge_50_pct,Artificial_recharge_8
0_pct,Full_artificial_recharge]
    summary_df['Percentage_of_rural_area'] = 
[RuralArea_30PctDemand,RuralArea_50PctDemand,RuralArea_80PctDemand,RuralArea
_100PctDemand]
    return summary_df
```

Merging current and future data frames and plotting rural scenario, ran multiple times for each block, Dingarpur example below:

```
DingarpurCombined = pd.concat([DingarpurCurrentdf['Number_of_ponds'], 
DingarpurFuturedf['Number_of_ponds']], axis=1, keys=['DingarpurCurrentdf', 
'DingarpurFuturedf'])
DingarpurCombined
DingarpurCombined['Difference'] = DingarpurCombined['DingarpurFuturedf']-
DingarpurCombined['DingarpurCurrentdf']
DingarpurCombined
color_map = ['midnightblue', 'lightskyblue','pink']
```

```
#sns.set_theme()
#hfont = {'fontname':'Helvetica'}
fig, ax = plt.subplots(figsize=(15,10))
plt.stackplot(DingarpurCurrentdf.Artificial_recharge,DingarpurCurrentdf.Numb
er_of_ponds,DingarpurCombined.Difference,
              labels=['Current', 'Future'],
              colors=color_map)
plt.legend(loc='upper left',fontsize=20)
plt.title('Current vs. future number of ponds Dingarpur rural',fontsize=25)
plt.xlabel('Artificial recharge percent of demand', fontsize=20)
plt.ylabel('Number of Ponds', fontsize=20)
# Filtering by only villages after loading in census dataset
Census_2011_UP_village = Census_2011_UP[Census_2011_UP['Level'] =='VILLAGE']
Census_2011_UP_village
import difflib
# Columns to match on from df_left
left_on = 'Village_name'
# Columns to match on from df_right
right_on = 'Name'
def fuzzy_merge(df1, df2, left_on, right_on, how='inner', cutoff=0.95):
    df_other= df2.copy()
    df_other[left_on] = [get_closest_match(x, df1[left_on], cutoff)
                         for x in df_other[right_on]]
    return df1.merge(df_other, on=left_on, how=how)
def get_closest_match(x, other, cutoff):
    matches = difflib.get_close_matches(x, other, cutoff=cutoff)
    return matches[0] if matches else None
Census_block_villages_merged_95 = fuzzy_merge(VillageBlocks,
Census_2011_UP_village, left_on, right_on)
Census_block_villages_merged_95
Census_block_villages_merged_95.columns
Census_block_villages_merged_95['TOT_P'].sum()
Census_block_villages_merged_95.to_excel("Munda Pande Villages (DS) Census
Population.xlsx")
```

9.7 Appendix 7: Key datasets used.

Data	Data source / method	Explanation if needed
Flood risk	UP State 2021 flood-affected villages list	Historically flooded villages likely to flood again, and communities already impacted.
Groundwater critical classification	UP State document: state of groundwater	This dataset is critical in understanding which blocks within the Moradabad district are lists as critical or semi-critical for their groundwater extraction rates.
Population of village census 2011	Census India 2011 dataset	Villages with higher populations have more to lose during times of disaster.
GB Basin extent	World Bank dataset on major river basins of the world	-
Global surfacewater dataset	Maximum water extent	-