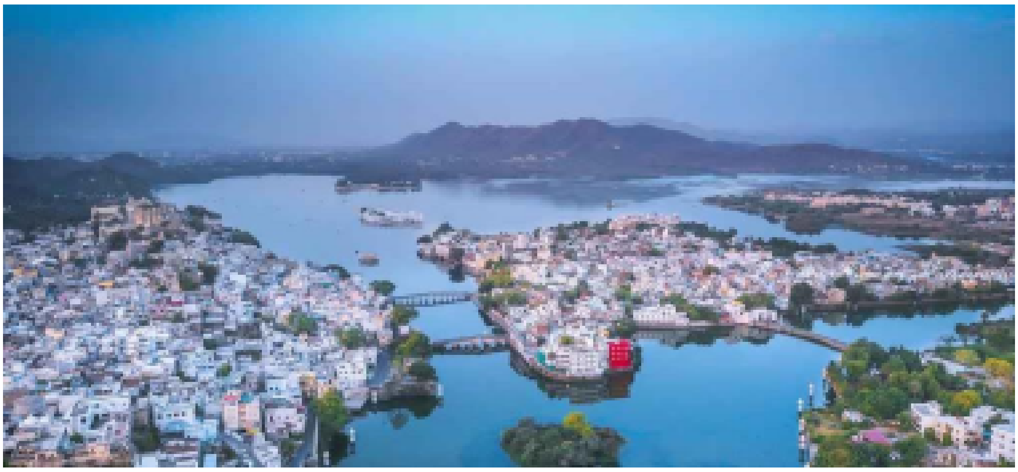
Sponsored Thesis Project Competition on

“RE-IMAGINING URBAN RIVERS” Season- 3



Project Title : Udaipur, the City of Lakes: Traversing through City’s Titular Sobriquet to Anthology of Lakes and People Creator : Yash Rajesh Dhawade, Department of Architecture and Regional Planning. IIT Kharagpur

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Preface

Very few urban settlements in India are left with urban identities very specific and unique to them. The urban identities may be a result of the settlement's geographic, topographic, climatic, historic, socio-cultural, political or functional aspects, to name a few. But, the number of such settlements are only decreasing with time due to the pressure of globalisation and urbanisation. Udaipur, the City of Lakes, is one such example, with its identity of unique topographic conditions, under great threat. The city, though known to be the city of lakes, has acute water shortage, that indicates a need for deeper research and planning intervention.

The entire city of Udaipur was planned keeping the terrain and hydrology as the key aspect and using it to the best of the advantage to tackle the acute water shortage the region faced. For this an integrated hydrological network of lakes, streams, Ayad river, aquifer and stepwells was conceived, well integrated with the then urban fabric. But today, only a couple of lakes remain prominent to the urban identity of the city and the entire lake system is getting disrupted due to human interventions.

With this thesis, it is this problem of water shortage and urban identity that is intended to be tackled using Urban Planning and Urban Design. For this, firstly the ancient lake system which was unique to Udaipur was understood, and is explained in this book. Next, identification, understanding and enlisting of the various reasons resulting in the problems of the water system of the city was done.

Finally, appropriate proposals relating to urban planning and urban design, using suitable analysis was done using modern tools and techniques in GIS to restore Udaipur's urban problem of water systema and reinforce its identity as the 'City of Lakes'.

Key words: water sensitive planning, sponge approach, decentralised water system.

1. Introduction

The medieval city of Udaipur is nestled in a saucer formed terrain, surrounded by minerals rich hills that are cladded with trees. In the olden days, after the inception of the city 500 years before till the early 20th century, the city was surrounded with an interconnected cascaded system of lakes. But, due to anthropogenic activities the system has got disrupted from its roots.

In the olden days, the ground water was the root and soul of the water system of the city of Udaipur, while the environmental, geographic and topographic conditions helped in nurturing it. The tree cladded hills, the forests, the many lakes surrounding the city and their interconnecting streams and river Ayad (or Ahar) kept the aquifer recharged throughout the year for the population of Udaipur use it for many purposes using the baories. Interconnected waterbodies like lakes via natural drainage and interlinks made sure that water was circulated throughout the region, making ground water even more rich. As a result, at intermediate levels of the terrain, a cascaded system of lakes was formed. Eventually, as the water table rose in the urban areas, that made the baories even more accessible for the masses to fetch water for domestic and agricultural uses.

Figure 1: Graphical Representation of Traditional Water System in Udaipur, 500 years ago *Source: Author*

In modern terminology, this system could be called a decentralised supply of water, where the main source of water were local baories as the source of water, that were distributed amidst the population throughout the city, in contrast to modern system that is centralised in nature. In modern system, water is extracted from a distant source and ultimately distributed in a tree-branch linear network of layout of pipelines.

Constant deforestation around the city has caused land degradation and soil erosion causing hindrance to rain water to seep. Water is directly being used from the lakes (in contrast to baories which was only source of water) for drinking and domestic purposes along with ground water which is being pumped from the aquifer for irrigation and domestic purposes. Blockages at intermediate streams and interlinks due to construction debris and solid waste has furthermore disrupted the network. All these activities have caused the ground water table decrease considerably, resulting in drying of 70% of the baories and disrupting the entire traditional water system of the city.

Figure 2: Graphical Representation of Various Problems in Water System in Udaipur Faced Today
Source: Author

As a result, the spiritual, communal and social connection between people and water has dissolved to remaining with only the physical and requirement level on bondages.

1.1 The Identified Problems

For the purpose of this thesis project, there are three core problems identified in the water system of Udaipur and are explained below in the following text. By the virtue of resolving these issues shall consequently trigger the other smaller aspects of the problem in water system to resolve. By trying to resolving the following problems, the identity of the city as the 'City of Lakes' shall also be reinforced, which is currently under increasing threat.

1.1.1. Water Demand- Supply Gap

As per PHED, the total water demand of the city of Udaipur is 140 MLD, whereas, 103 MLD is supplied by the Udaipur Municipal Corporation (UMC). This accounts for a gap of 37 MLD that comes out to be around 26%.

Of the 103 MLD supply, 20% of the water that is extracted from lakes gets lost due to leakages, and what is finally reached to the users is supply with 40% gap.

Figure 3: Water Demand-supply Gap in Udaipur
Source: Author

1.1.2. Water Allocation and Distribution Problem

As per PHED, the total water demand of the city of Udaipur is 140 MLD, whereas, 103 MLD is supplied by the Udaipur Municipal Corporation (UMC). This accounts for a gap of 37 MLD that comes out to be around 26%.

Figure 4: Water Demand-supply Gap in Udaipur
Source: Author

It is clear from the below table that 40% of the water extracted come from more than 50 km away from the city.

Table 1: Changing and Supposed Future Roles of various Stakeholders
Source: PHED

The core reason for this problem of water allocation and distribution is that the system is centralised in nature. Meaning, the water is distributed and disseminated from source to the users in a linear tree-branch distribution system.

1.1.3. Administrative Problems

The present centralised water system of the city of Udaipur shares major administrative power over the resource of water by government agencies like PHED, Irrigation Department and Udaipur Municipal Corporation. As a result, the entire responsibility over water's use, misuse and handling is owed by the government agencies, and people as a stakeholder rest at the foot of the power pyramid.

The role of community has been changing since India's pre-independence times, when the system of water was decentralised in nature. The communities used to draw water from baories and local wells, which were the only sources of urban water. As a result, the community then had a sense of conservation and maintenance. Post independence, when centralised water system, i.e., the piped supply of urban water, was introduced, gradually, the baories and the wells started to become obsolete, and so did the communities' sense of conservation of water resources. The relation between the community and water has eventually become mechanical and therefore we see increasing levels of pollution in Udaipur's water resources.

Pre-independence, the role of the sovereign or the governments was limited to inception and construction of water resources like baories and lakes. Eventually when piped system was introduced, their roles expanded further to door to door supplying of water and even maintaining the system, which was earlier the role of the community. The people were supposed to pay a reasonable charge for the services. Today with increasing tourism and the city's economy majorly dependent on it, the role of the government has further increased to beautifying the water resources like lakes and stepwells. However, the

The private sector, majorly the industrial and the hospitality sector, were and are engaged in construction of hotels and buildings, excavation for projects, and pollution of the water bodies due to tourism and draining of sewage into the water resources.

Table 2: Changing and Supposed Future Roles of various Stakeholders
Source: Author

When it comes to water supply, then it is mainly the Public Health Engineering Department that majorly manages and controls it. From planning and designing, construction and implementation, organisation and management to regulating it, it is the PHED that carries out the role. When it comes to policy making pertaining to water supply, the Government of Rajasthan plays the main role in doing so.

Table 3: Departments Involved and their Roles in Urban Water Management of Udaipur
Source: Author

	PHED	UIT/ UMC/ PHED
	PHED	UIT/ PHED
	PHED	UIT/ UMC
	GoR	GoR
	PHED	UIT

2. Aim and Objectives

The aim of this thesis is to understand and tackle the problem in water system of Udaipur using water sensitive urban planning approach and integration of the traditional decentralised water system of Udaipur.

Following are the objectives derived for the thesis:

Objective 1: Planning conservation of water to bridge the water demand supply gap.

Objective 2: Targeting water allocation and distribution by incorporating a decentralised system of water to achieve self-sufficiency in water.

Objective 3: Introduction of administrative alterations by laying new roles and responsibility over communities to inject shift in power over water in the system.

3. Literature Review

Based on the identified problems and formulated objectives, various theories and content related to water sensitive planning and decentralised system of water supply was studies in the literature survey. Topics like relation of ground water and interconnection of water bodies, Sponge city approach, relation of afforestation to water sensitive planning, etc. was studied and has been explained below.

3.1. Interconnection of Waterbodies

The phenomenon of ground water recharge happens in two ways depending on the nature of soil, namely its hydraulic conductivity (Winter et al., 2003).

Figure 5: Ground water flow applicable primarily to terrain having low-hydraulic conductivity (generally less than ~0.3 m/day)
Source: (Winter et al., 2003)

Figure 6: Ground water flow systems in porous media having greater hydraulic conductivity: the water table is more likely to be a continuously sloping surface from one surface water body to the next. *Source: (Winter et al., 2003)*

The areas near to water streams have considerably higher levels of water recharge. Thus, the disconnection of lakes in Udaipur has contributed to lower levels of water tables in areas where connections used to exist before.

3.2. Sponge Approach in Urban Planning

The concept of sponge approach of planning cities happens in four conceptual stages: firstly, protection of city's blue-green systems. Secondly, delaying of stormwater from reaching drains/ canals/ rivers for more seepage of rainwater in the ground. Thirdly, storage of rainwater in reservoirs and, finally, release of the stored rainwater into the aquifer from where water can be exploited for future use.

Figure 7: Steps Involved in Sponge Approach of Planning Cities
Source: (Sponge Collaborative, 2019, Sponge Handbook-Chennai)

There are various ways and various infrastructural technology in which a city can be planned as a Sponge city. These involve interventions on streets, open spaces and buildings as represented in the figure below.

Figure 8: Types of Intervention involved in Sponge Approach
Source: (Sponge Collaborative, 2019, Sponge Handbook-Chennai)

These interventions and infrastructures are spatially appropriated and proposed using Land Suitability Analysis using AHP on GIS.

Figure 9: Spatial Data needed to Identify Suitable Areas for Sponge Infrastructure
Source: (Sponge Collaborative, 2019, Sponge Handbook-Chennai)

Various layers or components like existing natural drain, soil data, groundwater level, topography data, land cover and land use, that aggregate together to decide on the exact location where the various Sponge Infrastructure shall be located.

3.2.1. Chennai Sponge City Proposal Case Study

The city of Chennai has Buckingham canal that runs N-S, collecting the storm water of the entire city along the coastal edge, finally draining the stormwater into the Bay of Bengal.

Figure 10: Hydrology and Blue-Green Areas of Chennai
Source: (Sponge Collaborative, 2019, Sponge Handbook-Chennai)

After land suitability analysis was done and areas viable for sponge infrastructure were identified, physical interventions were proposed as per the nature of the area.

Figure 11: Areas of different types of Physical Interventions done along and around Buckingham canal
Source: (Sponge Collaborative, 2019, Sponge Handbook-Chennai)

3.3. Afforestation

In semi-arid areas, there is little groundwater recharge through the soil matrix, and most of the soil water returns to the atmosphere by evapotranspiration. Under such conditions, macropores provide the only plausible recharge mechanism. Macropores are present in forest soils but are lost after deforestation and land degradation.

Land degradation typically leads to surface sealing, reduced infiltration capacity, and a loss of water via overland flow. (Sandstrom, 1995)

Figure 12: Where does water go after rain falls over land?
Source: (*Sandstrom, (1995), Differences in Groundwater Response to Deforestation*)

Forested-Nondegraded soil characteristics in semi-arid tropical areas:

- Surface evaporation is moderate, since the ground is covered by with humus & the forest canopy lowers ground temperatures and wind speeds.
- Infiltration rates are generally high due to the presence of humus, and thus little splash erosion and negligible surface crusting.
- Soils are generally well structured, implying that macropores may play a significant role in the recharge of groundwater.
- Surface roughness is greater than on eroded open land.

Figure 13: Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics
Source: (*Sandstrom, (1995), Differences in Groundwater Response to Deforestation*)

3.4. Centralised System of Water Supply

Udaipur presently has a centralised supply of water, where water is supplied from distant lakes and then branched out in smaller sections of pipes. If the demand of the city increases in future, the authorities will have to increase the supply and thus the cross section of the main pipes.

Figure 14: Schematic Sankey Diagram of Centralised Water Supply
Source:Author

3.5. Decentralised System of Water Supply

Typically, in a decentralised system of water supply, the rain water is collected for the terraces of the buildings in a neighbourhood, or other sources of storm water. The storm water is then collected in an open tank or a community pond.

Post this stage there are two methods of supplying water back to the users. Firstly, the water can then be allowed to settle, post which the water is filtered and supplied back to the users of the neighbourhood. Another method is to allow the collected rainwater to seep through the bed of the pond and extract ground water using pumps and then store it in an elevated reservoir, form where

it can be supplied to the users. For the latter method, a centralised monitoring agency, with adequate facility to collect and monitor data is required.

Excess water is then channelised through an overflow connection into a larger waterbody like river or lake.

Figure 15: Schematic Representation of Decentralised Water Supply System in a Neighbourhood
Source: Author

Advantages of this system include:

1. Irrespective of the city's population size, the system that is designed for a neighbourhood with a fixed maximum population shall still work without any augmentation in terms of water requirement.
2. The system is self-sufficient in nature. No external input of water is required from distant sources of water.
3. The system revokes a sense of community and helps in creating a socially active and healthy neighbourhood.
4. The system in the context of Udaipur shall help the city in reinforcing its identity as the 'City of Lakes'.

3.6. Urbanization in Udaipur

Udaipur presently classifies as a tier-1 city as per the norms set by census of India, and is growth at a fast rate, both in terms of sprawl and population.

Figure 16: Growth of Udaipur in the Past Years
Source: (Mondal et al., 2020)

Figure 17: Population Projection of Udaipur
Source: MCP batch 2021-23 (2022), CDP of Udaipur Report, IIT Kharagpur

For the above graph, it can be understood that the city of Udaipur shall have a population of around 5.5 lakhs in the year 2031 as compared to around 5 lakhs in 2021.

Table 4: Water Demand-supply Gap of Udaipur City
(Source: Feasibility Report for Rehabilitation Augmentation and Operation of Water Supply and Sewerage System in Udaipur Town through Public Private Participation (2014), p.89)

From the above table it can be comprehended that the water demand-supply gap has been increasing in the past years and is projected to increase consequently.

3.7. Hydro-social Contract

The first three aspects were relating to the biophysical or infrastructural aspect of water, but to tackle Udaipur's problem from the root, the other two dimensions become critical to study (*Source: Neha Singh, D. Parthasarathy and N.C. Narayanan (2018). Chapter 16: Contested Urban Waterscape of Udaipur, Sustainable Urbanization in India Challenges and Opportunities)*.

Figure 18: A Sustainable Hydro-social Contract Flowchart
Source: Author

Figure 19: The Time-line of Water Allocation in Udaipur
(*Source: Singh, Parthasarathy & Narayanan (2018) Sustainable Urbanization in India)*.

Figure 20: Water Transfer Scheme Map of Udaipur
Source: Dewas Stage I - IV Project (2010), Project Report, Udaipur

Even after existence of the transfer schemes, there prevails the problem of water shortage in the city of Udaipur as the water demand supply gap prevails. This indicates some planning issue in the system.

There emerges a need for a more sustainable approach towards supplying water to the users of the city.

4. Objectives, Scope and Limitations

From the problems identified and the appropriate literature survey done, following objectives and their corresponding scope was formulated as mentioned below.

4.1. Objectives and their Scope

Objective 1: Bridging the water demand supply gap by conserving water.

Scope: Land suitability using AHP and NDVI analysis to propose new water bodies and areas of afforestation to eventually come up with water conservation master plan.

Objective 2: Targeting water allocation and distribution by incorporating a decentralised system of water to achieve self-sufficiency in water.

Scope: Prototyping a decentralised model of water in a neighbourhood like an action area plan incorporating nature-based solutions like Sponge city approach and appropriately changing LU as per suitability from the Land Suitability Analysis.

Objective 3: Handling administrative problems by altering administrative roles and powers with incorporation or community involving in the system. Scope: Decentralised administrative structure and policy interventions using primary surveys and experts' interviews.

Figure 21: Overall Thesis Approach
Source: Author

4.2. Limitations

Urban planning and strategizing using calculations and comprehensive approach by bring multiple aspects of the problems is the overarching scope of the thesis. Any kind of simulation, ground water or storm water, is out of the scope of this thesis due to limitation in correct data availability pertaining to the respective software simulation parameters and requirements.

5. Existing Condition of Water Network

The rich and crucial network of waters in Udaipur can be attributed to its unique topographic conditions. However, when the topographic conditions are hampered due to construction and other anthropogenic activities, the entire system gets disrupted, which can result in multiple consequences.

Figure 22: Condition of Water Network of Udaipur
Source: Author

Figure 23: Condition of Water Network of Udaipur
Source: Author

From the Madar lakes, the water is diverted through canal system with retaining walls on either side. The water that was supposed to be naturally drained through Ayad river, is now diverted through concretised canal. This has two impacts. Firstly, the concretised bed doesn't allow water to seep through to recharge water. Secondly, the retaining walls with manicured conditions hampers the ecological condition of the region.

Moreover, the basin of Ayad river carries sewage of the residential colonies on either side of the river via constructed open drains along the edges inside the river basin. The limited amount of fresh water drains along a concrete bed along the centre of the basin which is normally polluted by aquatic weeds or solid waste and sometimes blocked by cattle.

Figure 24: Condition of Water Network of Udaipur
Source: Author

The overflow from both, the Fatehsagar and the Pichola Lake drain together at a junction with concretised bed and retaining walls on either side. This further hamper the ecology in terms of ground water, vegetation and fauna, whereas drainage junctions like this act as very important in terms of ecology. Minimum construction and anthropogenic activities at spots like these help in thriving the regional ecology and maintaining the water system of the region.

Furthermore, the basin of the Ayad river has blockages due to construction debris and other pollutants at multiple spots throughout along its basin. This creates stagnation of water that becomes a breeding ground for pests. Significance of continuous and gradual flow of water in river basin is critical in maintenance of water system.

Figure 25: Location of Various Protected Forest Lands Falling in Ayad Drainage Basin
Source: Forest Department of India, Udaipur Division

If lakes are the storage organs of water, then forests are their protectors and healers. Without forests lakes would eventually get dried up as forests attract rains, help in seepage of rain water into the ground that enables lakes flourish during the dry months. As a result, documenting the lands as protected lands by the Forest Department becomes an essential step of the thesis.

6. Existing Condition of Baories

The semi- arid city of Udaipur was conceived with around 121 baories spread throughout the urban built where most of the population resided. Due to anthropogenic activities, the ground water levels in certain regions have reduced to such levels that the wells became defunct, consequently resulting in burying and extinction of around 73% of the ancient baories. Today, of the 121 baories, 32 exist, and are known to the Archaeological Survey of India. Of these 32, 21 have been documented for the understanding and purpose of this thesis project. Spatial and visual data of the same has been documented below in this report.

Figure 26: Location of Various Existing Baories of Udaipur
Source: Author

Table 5: Documentation of Baories 1 to 7
Source: Author

Figure 27: Condition of Baories 1 to 6
Source: Author

Table 6: Documentation of Baories 8 to 15
Source: Author

Figure 28: Condition of Baories 8 to 14
Source: Author

Table 7: Documentation of Baories 16 to 21
Source: Author

Figure 29: Condition of Baories 16 to 21
Source: Author

It is observed that the location of baories was incepted around waterbodies where the level of ground water has been higher than other regions. They were not just a part of the city's physical infrastructure as the source of water, but also acted as a key source of the city's social infrastructure where communal, cultural, recreational and social activities used to take place.

Today around 5-6% of the water administered by the PHED accounts for ground water supplied and pumped from few of the baories of Udaipur. Although there is no monitoring of ground water by any central governing agency that administer or regulates the supply of ground water inside private plots.

It has been observed that traces of a religious centre have always been linked with location of baories. Multiple religious activities with supporting infrastructure like gathering platforms, steps culminating into water, chhatris is also observed.

Recreational or leisurely activities and land use like gardens, parks, open spaces or play grounds are observed adjacent to some of the baories.

Social activities like gathering of elderly, children, ladies in the morning and evening for casual congregation or administration of the temples is observed where the baories are surrounded by residential land use.

Cultural activities like traditional ceremonies with community level gathering for festivals are also observed near certain baories.

7. Objective 1: Demand-Supply Gap

As per PHED, the total water demand of the city of Udaipur is 140 MLD, whereas, 103 MLD is supplied by the Udaipur Municipal Corporation (UMC). This accounts for a gap of 37 MLD that comes out to be around 26%.

Of the 103 MLD supply, 20% of the water that is extracted from lakes gets lost due to leakages, and what is finally reached to the users is supply with 40% gap.

Figure 30: Water Demand-supply Gap in Udaipur
Source: Data collected from PHED

To solve this issue, water conservation is intended to be used, so that regional level self sufficiency in water is achieved and minimum or no water is required to be pumped or drawn from outside the Udaipur's catchment area. To execute this process, some technical analysis like Land suitability analysis for water conservation and NDVI analysis for afforestation strategies shall be required. Eventually a water conservation master plan would be needed to be proposed to tackle the situation.

From the land suitability analysis, locations and areas for proposal of new water bodies and water conservation sites, based on various factors, using AHP (Analytical Hierarchical Processing) shall be used on GIS. NDVI (Normalised Difference Vegetation Index) analysis for the delineated catchment area or the study area shall be used to understand the change in vegetation over years and where all extension of protected forests can be done or conservation be applied, or rejuvenation be proposed to them. A difference between the older generated map of NDVI analysis and latest one shall give the required understanding of the same. This along with land suitability analysis, reserved forests map and other environmental considerations shall help cohesively to finally prepare a comprehensive water conservation master plan for the study area.

Figure 31: Schematic Representation of Methodology used for Objective 1
Source: Author

7.1. Land Suitability Analysis for Water Conservation in Study Area Using various previously done studies and research, the multiple layers and their respective weights to do the AHP for resultant map of land suitability was done.

7.1.1 DEM Data

From the USGS Earth Explorer, DEM data for the grids as per toposheet of GSI (Geological Survey of India) was collected. Grid number 45H/17, 45H/9, 45H/7, 45H/13 and 45H/10 were identified and data accordingly was retrieved.

Figure 32: DEM Data of the City of Udaipur, from 45H Series of Toposheet from GSI
Data Source: USGC Earth Explorer

Figure 33: Pour Points used for Watershed Analysis for the Selected Grids
Data Source: USGC Earth Explorer

After retrieving the DEM data, pour points were selected on GIS software on the basis of which the further watershed analysis shall be carried out. Typically pour points are intersecting points between streams where the stream order changes and thus the catchment boundary.

7.1.2. Watershed Analysis and Catchment Area Delineation

Using the DEM data, watershed analysis was carried out on GIS software ArcMap and the resulting map has been show below.

Figure 34: Watershed Map for the selected Grid
Data Source: Analysis on ArcMap using DEM Data

Figure 35: Watershed Map with Study Area or Ayad Catchment Area Boundary
Data Source: Analysis on ArcMap using DEM Data

7.1.3. Stream Order Map

From the watershed analysis, the stream order map was generated using the same GIS software. Here the 1^{st} order streams are those streams which collect water from a catchment zone without the intervention of any other stream. 2^{nd} order streams are generated when two 1^{st} order streams intersect. Similarly, 3^{rd} order streams are created when two 2^{nd} order streams are intersected.

Figure 36: Stream Order Map for the Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

7.1.4. Parameter 1: Lineament Density Map

For the analysis of lineament density map, there are three prerequisite data sets or maps that are needed for its generation. They include elevation map, hill shade map and lineament map.

Figure 37: Elevation Map for the Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

Figure 38: Hill Shade Map for the Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

Figure 39: Lineament Map for the Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

Using the hill shade map, lineaments were drawn in GIS software and the above map was generated.

Figure 40: Parameter 1: Lineament Density Map for Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

Hence, the first map for the Analytical Hierarchical Processing for Land Suitability Analysis for water conservation, with a cell size of 10 m X 10 m, was generated, using the inputs as the lineament map and software tools from ArcMap. This data is important for generation of water conservation map because it spatially indicated the control on hydraulic conductivity in the catchment area. Areas with high lineament density have higher control over hydraulic conductivity and therefore most suitable for water conservation.

7.1.5. Parameter 2: Drainage Density Map

For the analysis of drainage density map, there are two prerequisite data sets or maps that are needed for its generation. They include contour map and elevation map.

Figure 41: Contour Map for Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

Figure 42: Elevation Map for Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

Figure 43: Parameter 2: Drainage Density Map for Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

The map on drainage density is important as it indicated the degree of control on the run-off distribution of the area. Areas with very dense drainage density are most suitable for conservation, pertaining to their proximity and availability of rain water.

7.1.6. Parameter 3: Slope Percentage Map

For the analysis of slope percentage map, there is one prerequisite data set or maps that is needed for its generation, that is the elevation map.

The slope percentage map is an important parameter for water conservation map as it indicates the driving water flow energy in terms of spatial data.

Very steep areas have very high slope percentages and therefore are least suitable for conservation due to the land's innate nature of not being able to hold water for longer durations.

Figure 44: Parameter 3: Slope % Map for Selected Study Area
Data Source: Analysis on ArcMap using DEM Data

7.1.7. Parameter 4: Lithology Map

From the data received from the geological Survey of India for the selected grid from toposheet of Udaipur, four classes of lithological layers were identified with decreasing order of levels of water infiltration, movement and ability to store water. The order is: Garnetiferous & Felspathic Mica Schist, then Phyllite, Chlorite Schist, Meta Conglomerate, then Granite, Quartzite, Dolomite, and finally Carbonaceous Phyllite, Meta Voalcanic layer.

Figure 45: Parameter 4: Lithology Map for Selected Study Area
Data Source: Geological Survey of India

7.1.8. Parameter 5: LULC Map

Using ESRI Sentinel Satellite image of 10 m X 10 m grid cell size, LULC map was generated. Five classes on the basis of their suitability for water conservation in terms of existing land use land cover was formulated. The increasing order of suitability that has been used in the analysis is water body, scrub land, tree cladded area, agricultural land, built area.

Figure 46: Parameter 5: Lithology Map for Selected Study Area
Data Source: Geological Survey of India

7.1.9. Parameter 6: Soil Texture Map

Using the data received from the National Bureau of Soil Survey & Land Use Planning, Regional Research Station, Udaipur office, different soil textures in the selected area of study was mapped in GIS with grid cell size of 10 m X 10 m. The increasing order of suitability of soil texture for water conservation is coarse loamy sand, skeletal fine loam, coarse to fine loam, fine loamy rock outcrop, fine loam.

Figure 47: Parameter 6: Soil Texture Map for Selected Study Area
Data Source: National Bureau of Soil Survey & Land Use Planning, Regional Research Station, Udaipur

7.1.10. Parameter 7: Transmissivity Map

From the transmissivity data from Deepesh Machiwal, 2015, transmissivity map of the selected study area was generated. Transmissivity affects infiltration rates. Greater its value, more suitable the soil is for water conservation.

Figure 48: Parameter 7: Transmissivity Map for Selected Study Area

Data Source: Pumping Test Data from Deepesh Machiwal, 2015

7.1.11. Resultant Land Suitability Map

From the various maps generated with grid cell size of 10 m X 10m, and on the basis of their importance, pairwise comparison was done. After its normalisation, weights of each parameter were determined and the final map was prepared that was useful for proposals and master plan for water conservation.

Parameters and their weights derived from literature:

1. Yogesh P. Badhe, Ravindra S. Medhe, Tushar Shelar (2019), Site Suitability Analysis for Water Conservation Using AHP and GIS Techniques: A Case Study of Upper Sina River Catchment, Ahmednagar (India)
2. Deepesh Machiwal & P. K. Singh (2015), Comparing GIS-based multi-criteria decision making and Boolean logic modelling approaches for delineating groundwater recharge zones

Table 8: Data Retrieved and their Sources
Source: Author

1	DEM	USGC, Earth Explorer
2	Satellite Image for LULC	ESRI Sentinel
3	Lithology	Geological Survey of India
4	Soil Textures	National Bureau of Soil Survey
5	Transmissivity map	Deepesh Machiwal, 2015

Table 9: Pairwise Comparison Matrix and the Normalised Weights
Source: Author

Table 10: Parameters, their Weights used in AHP and their Roles in Water Conservation

Source: Deepesh Machiwal & P. K. Singh (2015)

Parameter	Weights %	Role
Lineament Density	27.9	Controls hydraulic conductivity
Drainage Density	28.9	Controls runoff distribution
Slope %	9.7	Drives water flow energy
Lithology	17.3	Controls infiltration, movement & storage of water
LULC	5.9	Affects recharge process
Soil Texture	5.1	Governs infiltration rate
Transmissivity	5.2	Affects infiltration rate

Figure 49: Resultant Land Suitability Analysis Map for Water Conservation in Study Area
Source: Analysis on ArcMap using AHP

7.2. NDVI Analysis for Delineated Catchment Area

Alongside, NDVI analysis was varied out to understand changing vegetation pattern- deforested land, protected forests, space vegetation, etc. Data source for satellite images was LandSat-8.

Figure 50: NDVI Analysis, Udaipur, 2013

Source: Analysis on ArcMap using LandSat-8 Satellite Image from USGS

Figure 51: NDVI Analysis, Udaipur, 2014

Source: Analysis on ArcMap using LandSat-8 Satellite Image from USGS

Figure 52: NDVI Analysis, Udaipur, 2016
Source: Analysis on ArcMap using LandSat-8 Satellite Image from USGS

Figure 53: NDVI Analysis, Udaipur, 2018

Source: Analysis on ArcMap using LandSat-8 Satellite Image from USGS

Figure 54: NDVI Analysis, Udaipur, 2020
Source: Analysis on ArcMap using LandSat-8 Satellite Image from USGS

Figure 55: NDVI Analysis, Udaipur, 2022
Source: Analysis on ArcMap using LandSat-8 Satellite Image from USGS

% Sparse Vegetation in Study Area

18

16

14

12

10

8

6

4

2

0

2013 2014 2016 2018 2020 2022 % Sparse Vegetation

Figure 56: Changing % of Sparse Vegetation from 2013 to 2022
Source: Author

The percentage of landcover with sparse vegetation is seen to be decreasing since 2013 to 2018 due to continuous deforestation for natural resources like wood, minerals and excavation for construction. However, a sudden spike is seen in the year 2020 due to stoppage in anthropogenic activities due to COVID-19 lockdown restrictions. The natural resilience and healing of the forests can be accounted to the lockdown. As the restrictions were loosened in 2021, again a considerable decrease in vegetation can be seen in the year 2022.

However, a spatial difference between the areas of sparse vegetation of 2013 and that of the year 2022 shall give areas and regions of deforestation. This would be helpful in identifying new areas for afforestation or extension of forest and old areas for rejuvenation or conservation or protection.

7.3.Reserved Forests

Figure 57: Reserved Forests Map of Ayad River Catchment Area
Source: Author

The city of Udaipur, that lies in the semi-arid region of Mewar, is surrounded by many deciduous forests with its characteristic sparse vegetation that is extremely helpful and crucial in terms of seepage of the limited rainfall that region receives. The reserved lands as protected forests are indicated in the map above along with other land uses that lies inside the regional catchment boundary.

7.4. Environmental Considerations

For a comprehensive master plan for water conservation, there are certain environmental considerations that are needed to applied while formulating a comprehensive water conservation master plan. The following environmental considerations are followed for the purpose of the master plan formulated in this thesis:

1. Forested buffer of minimum 50 m from all sides of streams, rivers, lakes, ponds, wetlands.
2. As the stream order increases, the depth of buffer forest should increase, typically by a difference of 50 m or on the basis of width of the stream.
3. New forests to be proposed with sparse vegetation density, depending upon the size of the trees used for afforestation. If the tree foliage size is 10 m, then sparse vegetation density of 25 trees per 100 sq. m, that roughly means planting trees at a centre-to-centre distance of around 10 m.
4. Extension of protected forest lands be done using similar vegetation and vegetation density to maintain the regional ecology.
5. Merging lakes with protected forests shall ensure greater rain water collection in the lakes.
6. New water bodies to be proposed seeing factors like terrain, land suitability, land availability and proximity with forested lands.

7.5. Master Plan for Water Conservation for Udaipur

Figure 58: Water Conservation Master Plan based on Land Suitability and NDVI Analysis
Source: Author

A comprehensive approach for water conservation mater planning using land suitability and NDVI was used to come up with the final Master Plan for water conservation.

1. The 1st order steams that are most important in terms of collection of rain water from distant areas are protected with forested lands of 100 m on either side of the stream.
2. Hardier evergreen trees along with fruits and flower bearing trees proposed for afforestation.
3. Extension of protected forested lands done at two stretches. The northern stretch engulfing the Madar Lakes and connecting three scattered patches of forests along it.
   In the southern stretch, the extension of protected lands engulfs the southern network of lakes of Udaipur, that is otherwise extremely prone to effects of urbanisation and encroachment. This shall make sure water sufficiency from every direction of expansion of the city.

4. The eastern direction of the city has no lake. Although using land suitability study and

terrain study, two sites for new waterbodies have been proposed along with buffer forests and their linkages with 1st order streams that finally connects with the Ayad river.

Table 11: Areas of Different Interventions in Water Conservation Master Plan
Source: Author

Old Protected Land	31.5	Protected forest land	Protected forest land
Extended Protected Land	20.2	Encroachment, illegal construction, agriculture, vacant land	Protected forest land
Forest Proposed for Rejuvenation	8.4	Encroachment, illegal construction, agriculture, vacant land	Protected forest land
New Lakes	6.5	Agricultural	Water bodies

8. Objective 2: Allocation and Distribution

After accounting for the overall water conservation at regional level in the Ayad basin, the next step to tackle the problem of water system of the city becomes its sustainable and adequate allocation and distribution.

As per PHED, the total water demand of the city of Udaipur is 140 MLD, whereas, 103 MLD is supplied by the Udaipur Municipal Corporation (UMC). This accounts for a gap of 37 MLD that comes out to be around 26%. This clearly indicates a flaw in distribution part of the water system.

Figure 59: Water Demand-supply Gap in Udaipur
Source: Author

Furthermore, it is clear from the table below that 40% of the water extracted come from distant sources that are more than at least 50 km away from the city. This indicated a problem in water allocation in the water system.

Table 12: Various Primary Sources of Water in Udaipur
Source: PHED

The core reason for this problem of water allocation and distribution is that the water supply is centralised. If a decentralised water supply is used, where the surface water that falls over a particular neighbourhood is collected and distributed locally, the problem shall be resolved.

8.1. Decentralisation of Water System in the Context of Udaipur

To understand how a decentralised system of water supply would work in the context of Udaipur, it becomes important to understand the quantum of rain water the urban region receives on an average and whether or not that would be sufficient to meet the demand.

Table 13: Rainfall Data of Udaipur since 2017
Source: Indian Meteorological Department, Udaipur

Year	2017	2018	2019	2020	2021	Average
Rainfall (mm)	897.3	668.6	1063.3	910.22	511.65	810.22

The average rainfall in Udaipur, from the data collected from the year 2017- 2021 comes out to be around 810.2 mm.

Figure 60: Flow Chart to understand Overall Decentralised System in Udaipur
Source: Author

The city has approximately 100 sq. km of land from which it can collect rain water. Considering average rainfall to be around 800 mm for the purpose of the estimate calculation, the volume of water collected annually would be around 80,000 ML (million litres). Now, considering average water losses due to evaporation or drainage to be around 20%, the city can collect around 64,000 ML annually. As per present demand, that is 140 MLD, this could account for water collection with a surplus of around 92 days and considering demand for 2031, that is 180 MLD, that could account for no surplus.

Figure 61: Increasing Water Demand in Udaipur and its Connection with Water System Types

Source: Author

Water demand in Udaipur has been increasing with time. However, the city has resources for around 103 MLD, whereas, today, in the year 2023, the demand is slightly more than around 140 MLD. This extra water demand is sufficed by lakes from distant sources or ground water, which is not sustainable in nature. However, that can be fulfilled by rainwater collected at neighbourhood or local level using an integrated decentralised system of water supply.

But such broad scale water calculations can be said to be rudimentary and be helpful to only understand overall feasibility. An in-depth and neighbourhood level planning approach is important to be worked out for a system like this.

8.2. Delineating Catchment Area Boundaries

For the purpose of further study into decentralised system of water supply, a regional watershed map with delineated catchment area boundaries was generated in GIS using DEM data, with an overlayed Udaipur urban boundary map. Subsequent sub-catchment zones were delineated for further working of a prototype model to work out an action area plan for decentralised water supply.

Figure 62: Catchment Area Delineation in Udaipur at Regional Level in Ayad Basin *Source: Analysis done by author on ArcMap software, DEM Data from USGS Earth Explorer*