Water Scarcity in Jaipur, Rajasthan, India

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Research in Jaipur in Summer 2013 | Document completed in Fall 2013

Executive Summary

Jaipur, the capital and largest city of the state of Rajasthan, India, is currently experiencing severe water scarcity that threatens drinking water sources. While Jaipur receives only an average of 600 millimeters of precipitation per year, mostly in the monsoon months of June-September, we believe that management issues exacerbate Jaipur's water scarcity issues. Problems such as poor water quality, a lack of adequate infrastructure (for example in sewage systems, water piping, drainage systems, and water metering), rapid population and area growth, and a lack of unified government are just a few of the issues that play important roles in the complex interactions surrounding Jaipur's current water scarcity condition.

Two engineering students from Northwestern University, Kathleen Roberts and Michael Reiner, traveled to Jaipur in the summer of 2013 to study the water and sanitation system. The conditions of Jaipur's water resources were investigated by touring various critical sites, conducting literature searches regarding water resources in Jaipur at sites such as Rajasthan University and the Institute for Development Studies, and meeting with professionals in the field of water issues in Jaipur. We were assisted in this assessment by our colleagues at the Jal Bhagirathi Foundation, an organization based in Jaipur and Jodhpur, which "strives to provide an enabling environment in which communities can access adequate drinking water with a vision of water security leading to sustainable development through responsive governance and inclusive growth."

This document looks at the history of Jaipur, specifically focusing on the links between its history, growth, and its water supply system. We attempt to view the water supply system history as a whole, in order to determine where the water scarcity issues originated and what the contributing factors are. We then discuss the general urbanization of Jaipur, and what impacts urbanization has had on the water system, with special attention to the urban impacts on hydrology, surface waters, groundwaters, natural gradients, and the flood plain. We then delve into the current water supply scheme and management structure looking at the role of the government and its policies, estimates of water supply and demand, surface water and groundwater treatment and distribution, drinking water quality, the sewerage and waste system, and the potential impacts that climate change may have on water in Jaipur. Lastly, we make general recommendations and policy recommendations in order to ensure a sustainable water future in Jaipur.

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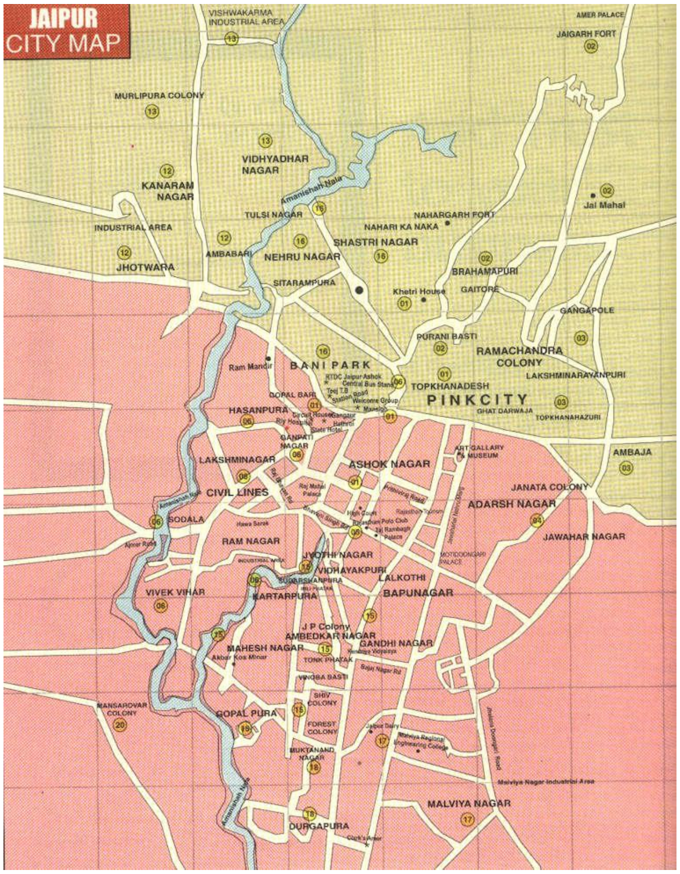
I. Introduction

Jaipur is the capital and largest city of the state of Rajasthan, India. As the only million plus city in Rajasthan, it is fast growing: Jaipur ranks 10th in the list of Indian megacities with an annual growth rate of 4.94% between 2001 and 2011, and a population of 3.1 million. Population and municipal area growth has been greatly increasing, most notably since Jaipur became the capital of Rajasthan after Independence in 1956. The city's economy is primarily based on trading, administration, tourism activities, and local handicrafts industries. Trade and commerce account for the largest percentage of the workforce at 24%, followed by household industries at 22% of the workforce. With an influx of over 2 lakh between 1991-2001, Jaipur attracts migration from all parts of Rajasthan (with 70% of migrants coming from within the state). Jaipur has become a popular tourist destination, with about 3000 tourists visiting the city everyday[1].

Jaipur is currently experiencing growing water scarcity and diminishing drinking water sources, relying extensively on groundwater and a single surface water source, the Bisalpur Dam, which is shared with Ajmer and villages in the Tonk District and located 120 kilometers southwest of Jaipur. There appears to be little awareness by the public of the city's water issues as well as a lack of serious participation by Government agencies. Jaipur, the first planned city of India, was originally designed with water supply in mind. However, as a result of rapid urbanization, population growth, the expansion of the city limits since Independence, and Jaipur's change in status to the capital of Rajasthan, serious considerations of water management have fallen by the wayside. Jaipur depended extensively on the Ramgarh Dam as its surface water source throughout the 1900s, but it became a non-viable source in the late-1980s/early-1990s, leading to a shift to complete dependence on groundwater. This transition has led to a rapidly depleting groundwater table and overexploitation of the aquifer that Jaipur relies upon. Today, the Bisalpur Dam contributes water to the system; however, the population is still primarily dependent on groundwater as its primary water source. In addition to the water supplied by the Public Health and Engineering Department, there are tens of thousands of unaccounted for wells throughout Jaipur, since tapping of groundwater is still a landowner's right. There appears to be a lack of adequate water supply and demand accounting, both in terms of government water supply and private water supply.

Jaipur has a semiarid climate, receiving about 600 millimeters of rainfall annually, mostly between the monsoon months of June to September. Many other cities around the world receive similar or less precipitation. Thus, scarcity of rainfall is not the sole problem contributing to Jaipur's water scarcity - Jaipur's water scarcity is mostly related to water resource management issues. In addition to water scarcity, degradation in quality of both surface and groundwater sources is of great concern. This highlights the need for a greater focus on expanding and thoroughly implementing sanitation and waste management throughout Jaipur, as well as a need for regulations and restrictions on waste produced by industries. This paper aims to connect Jaipur's history and growth trajectory to its current state of water supply in order to identify what had worked in the past and where conditions changed leading to the water scarcity issues at hand today. Based on this evaluation, recommendations are suggested to promote a more sustainable water future for Jaipur.

Figure 1: Map of Jaipur



Source: 2

II. Physical Geography of Jaipur

A. Climate

1. Temperature

Jaipur is located in the semi-arid zone of India, which is characterized by high temperatures, low rainfall, and a mild winter. The mean temperature of Jaipur is 36 °C, varying from about 18 °C in January to about 40 °C in June, the hottest and coldest months respectively. However, the full temperature range of Jaipur is 45 °C to 1 °C. Jaipur's winter season begins in November and temperature decreases until January (generally with a minimum temperature of 8 °C). The monsoon season decreases temperature in late June or July[3]. The average maximum and minimum monthly temperatures in Jaipur are found in Table 1.

Table 1: Average Maximum and Minimum Monthly Temperatures in Jaipur

Month	Average Temperature	
	Maximum	Minimum
January	22.2	8.4
February	24.5	10.7
March	31.6	16.6
April	37.3	20.5
May	41.1	26.3
June	39.5	27.5
July	33.0	29.9
August	31.6	24.3
September	32.6	23.0
October	33.6	17.9
November	29.5	11.7
December	25.1	8.5

Source: 3

2. Precipitation

The average annual rainfall of Jaipur is slightly less than 600 millimeters. Ninety percent of the rainfall in Jaipur occurs during the summer monsoon season, which lasts from June to September. Ten percent of the rainfall of Jaipur is a result of winter cyclones. Overall, rainfall in Jaipur is highly variable from year to year. It has been calculated that there is a 25% probability that annual rainfall of Jaipur will exceed the average, and a 19.7% probability that Jaipur will encounter a drought season[4]. August is the rainiest month for Jaipur, as well as for the state of Rajasthan, with a relative humidity of 84% for Jaipur. The higher rainfall, which occurs during July and August, occurs in downpours that cause excessive runoff and are not too useful in recharging groundwater aquifers[3]. The monthly average rainy days, relative humidity, and annual rainfall can be seen in Table 2.

Table 2: Annual Rainfall in Jaipur

Year	Rainfall (millimeters)	Year	Rainfall (millimeters)	Year	Rainfall (millimeters)	Year	Rainfall (millimeters)
1969	388	1982	620	1995	755	2008	572
1970	709	1983	681	1996	887	2009	306
1971	1018	1984	85	1997	715	2010	659
1972	330	1985	689	1998	696	2011	660
1973	983	1986	531	1999	397	2012	1084
1974	564	1987	406	2000	404		
1975	1091	1988	410	2001	451		
1976	653	1989	315	2002	230		
1977	1161	1990	694	2003	641		
1978	925	1991	561	2004	677		
1979	546	1992	742	2005	529		
1980	595	1993	493	2006	345		
1981	736	1994	713	2007	508		

Source: 3; 4

Figure 2: Annual Rainfall

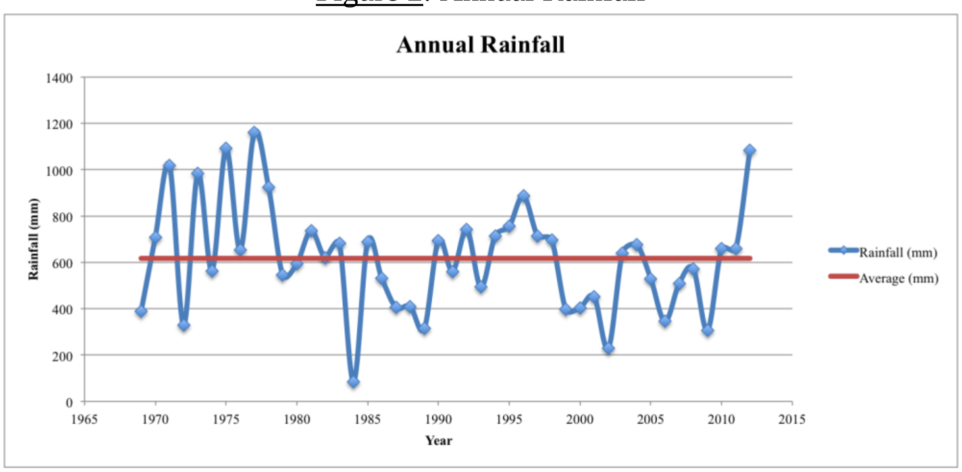
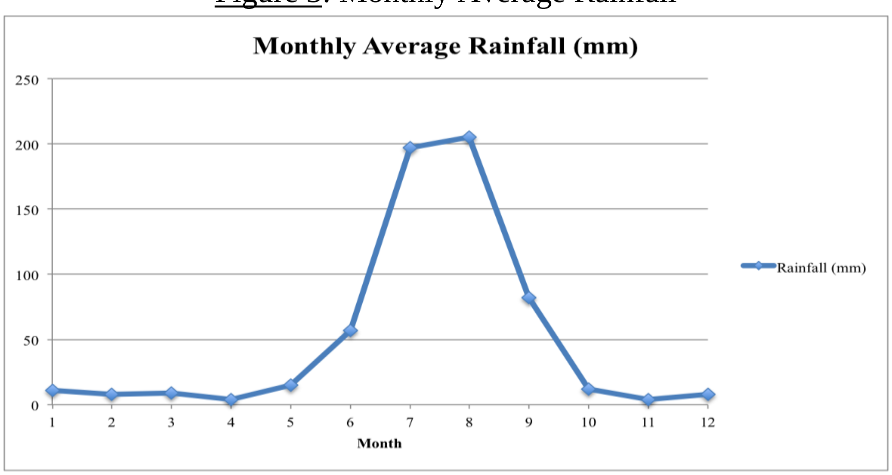


Table 3: Monthly Average Rainfall, Rainy Days, and Relative Humidity in Jaipur

Months	Rainfall (millimeters)	No. of Rainy Days	Relative Humidity
January	11	0.9	58.0
February	8	1.0	57.5
March	9	0.8	41.5
April	4	0.5	34.2
May	15	1.5	30.1
June	57	3.7	51.1
July	197	10.2	67.2
August	205	10.0	87.4
September	82	5.0	73.6
October	12	0.7	41.1
November	4	0.3	56.2
December	8	0.7	57.2
Annual	612	35.3	

Source: 3

Figure 3: Monthly Average Rainfall



B. Topography and Drainage of Jaipur

Jaipur is located of 26° 55’ north latitude and 75° 49’ east longitude. Its urban boundary extends from 26° 38’ and 13” north latitude to 27° 11’ north latitude and 75° 27’ and 12” east longitude to 76° 58’ and 21” east longitude. Jaipur is surrounded by the Nahargarh hills in the north and Jhalana hills in the east, which is a part of the Aravalli hills. The higher elevations in the north of the city are the low, flat-topped hills of Nahargarh, Jaigarh, Amber, and Amargarh, which are now extremely dissected and eroded. The range of the Aravalli hills continues farther north, towards Alwar and Kotpuli, and finally disappears near Delhi. To the south and west of Jaipur are prevailing hills, but they are isolated and discontinuous. The southern end of the city is open to plains. The slopes of the south are in general gentle. The hills surrounding the city do not run in a single range, but are traversed by passes and depressions. Three passes exist-one in the east, one in the north, and one in the west. The eastern hills run from its southern end to the Purana ghat pass as a single block known as the Jhalana hill, with another block starting at Purana ghat and known as Gulta hill. At Surajpol Gate there is a passage leading to the holy tank of Galta, with Gulta hill continuing to the north. Further northward there is another depression, which was blocked by Maharaja Man Singh I to create Man Sagar Lake. The Jaipur-Jamwa Ramgarh road cuts through this pass, as well. At the junction of the eastern and western hills in the north, an area formerly known as Govind Ghati, is a pass through which the Jaipur-Delhi road traverses. The western hill is punctuated by one pass, which starts from Gaitor in between the Nahargarh hill and Ganeshgarh. The southern part of this western hill is known as Nahargarh hill, and the northern portion of this western hill is known as the Amber hills. There is a small colonial mount known as Moti Doongari in the southern part of the triangular plain, and another small mount in the south on which stands the fortress of Hathroi. One more hillock lies on the Amber road[3].

The slope of the city has an overall trend from the hills in the north to the plains in the south then to the southeast. Nearly all ephemeral streams in Jaipur flow in this same direction. The higher elevations in the north exist as the low, flat-topped hills of Nahargarh, Jaigarh, Amber, and Amargarh. These hills are extensions of the Aravallis and continue further northwards, but are now deeply dissected and eroded. The elevation of Jaipur ranges from 600 meters in the north to 300 meters in the south[3].

The walled city was originally located on a rocky street to provide an easy drainage system on either side of the city. However, city growth took place in the south and the west on the alluvial plains and in the confluence zones of the Amanishah Nala in the west and the Jawahar Nagar Nala in the east and beyond, disrupting these confluence zones[3]. The natural drainage of Jaipur is along the Amanishah Nala, which originates from the highest point of the Nahargarh hills, and flows in the west from the north to the south. The drainage first flows northwards in the upper reaches, turns south and southwest in the middle of its course, and then flows towards the east in a broad semi-circle until the drainage meets the Dhund River downstream[5]. The length of Amanishah Nala is about 48 kilometers, and flows sluggishly throughout the year. Many of the other nalas in the city, Nahri Ka Naka Nala, Ganda Nala, and Jawahar Nala, also merge with the Amanishah Nala. The Mazar Dam, Sikar Road Dam, Goolar Dam, and Shri Ramchandrapura Dam are constructed on the Amanishah Nala[6]. The Dhund River in the east is mainly ephemeral and flows straight from north to south for a considerable distance. The Dhund River and the Amanishah Nala form a fork-like drainage pattern in the confluence zone, on which the major part of Jaipur is situated[3]. Westerly flowing streams drain the western part of Jaipur, the Bandi River in the northwest and Sadruya Nadi in the west, as well as their lower order streamlets. There were four natural drainage patterns in Jaipur that are now ganda nalas, rivers of dirty water. Two of these ganda nalas flow to the southwest to meet the Amanishah Nala, and the other two ganda nalas flow to the northeast to meet Man Sagar Lake.

The Jaipur Development Authority divides Jaipur into five watershed/drainage zones:

1) Drainage to Amanishah Nala: This drainage zone controls the major drainage system in the western outskirts of Jaipur city. It originates from Amer Hill at an elevation of about 500 meters and after draining through the hilly tracts comes to a flat area at an elevation of 440 meters. It crosses National Highway 11 near Ambabary and then crosses the Jaipur-Phuera Railway track. Then sweeping through the western outskirts of Jaipur, it crosses National Highway 8, and after collecting the drainage of C-Scheme, it meets the Dhund River.
2) Drainage of Nala through C-Scheme: This forms the major internal drainage system of the city. This drainage passes through C-Scheme, collecting water of half of the old city, and crosses Jaipur-Bandikui Railway track near Bais-Godam and meets the Amanishah Nala near the village Devri.
3) Drainage of Jawahar Nagar Nala: This Nala originates in the Jhalana Hills at an elevation of 425 meters in Jawahar Nagar. The drainage flows through the back of Rajasthan University and the Jhalana hills and crosses the Jawahar Lal Nehru Marg near O.T.S. and joins the Amanishah Nala downstream of Sanganer.
4) Drainage to Man Sagar Lake: Man Sagar Lake receives the water drained from the major part of the old city, from Chhoti Chaupar to Suraj Pole. Part of the Nahargarh hills also drains into Man Sagar Lake via many culverts on National Highway 8.
5) Drainage to Ambagarh and Jhalana Hills: This drainage flows from Ambagarh and Jhalana Hills and turns towards Gulta and Highway 11 between Kor to Nasian[3].

III. Linking Jaipur's History to its Water Management

A. Overview

Jaipur, as a planned city, was developed to utilize the mountains and natural slope of the land for water supply. The Old City (now the area considered the Pink City or Walled City) continued to benefit from the original natural water systems in place until the 1930s when the population of Jaipur exceeded the capacity of the Old City. The city soon had to turn to reservoirs located outside the immediate reaches of the city. Compounded by a lack of infrastructure, such as sewage systems, water piping, or drainage systems, and rapid growth, which defied any unified government planning, Jaipur's water security and supply began to deteriorate. Given the water resources, the city cannot meet demand. Jaipur relies on a single, unreliable surface water source, the Bisalpur Dam, as well as a rapidly diminishing groundwater supply. The Bisalpur Dam is also utilized by Ajmer and the Tonk districts, and is highly dependent on yearly rainfall, which is extremely variable. The inability to meet demand and the general inadequacy of water supply is evident in calculations of a deficit in water supply through supply and demand estimates from the Public Health Engineering Department, the limited duration of government water supply, high unaccounted for water losses, drops in supply pressure due to large quantities of water released in short durations or the depleting groundwater table affecting tube wells, and the tens of thousands of unaccounted for tube wells throughout the city to supplement government water supply or lack thereof[7,8,9].

A look at Jaipur's water resources throughout its existence reveals how the recent lack of sufficient planning has disrupted and damaged previous systems and structures that allowed the city to have adequate water supplies. Certain specific historical events and movements help demonstrate the transition of Jaipur's water supply from adequate supply to all citizens based on demand and coverage of the municipal area to inadequate supply today. There are various things that have contributed to this situation including Jaipur's rapid population and urbanized area growth, a reliance on government supply and thus declining reliance in traditional water harvesting measures, and the tendency of the government to invoke emergency measures for water supply instead of planning measures that account for future water supply demand and issues. This section will look at the history of Jaipur's water management practices, and how water management has evolved in recent years.

B. Jaipur's Early History of Water Management

Before the founding of Jaipur in 1727, Amber, located 9 kilometers north of Jaipur, was the capital of the then state of Kachwahas (often cited as Jaipur State, as well). Amber did not have enough space for growth and was dealing with water scarcity. Therefore, Maharaja Sawai Jai Singh II decided to build a new capital. The location decided for this new capital, the Old City of Jaipur today and the nearby surrounding areas, had been mostly covered with lush forest and had served as hunting grounds for the royal family. Maharaja Sawai Jai Singh II also is credited with the construction of Jal Mahal Palace, located in the middle of Man Sagar Lake, in the 1730s. Man Sagar Lake was created by the damming of the river Darbhawati between the Khilagarh hills and the hilly areas of Nahargarh in the late 1500s by Raja Man Singh, the ruler of Amber at the time. The purpose of this artificial lake was to preserve water for use in the time of water shortage in response to famine that was occurring at that time. In addition to the construction of Jal Mahal, Maharaja Jai Singh II updated the damming structure of Man Sagar, which converted the dam from earth and quartzite materials to a stone masonry structure. The

Maharaja would visit Jal Mahal for game and for hunting tigers and leopards. Maharaja Jai Singh II was a scholar of astronomy, mathematics, and town planning. Thus, he consulted Greek treatises and Arabic and European architecture in order to establish a well-planned new capital for his state. Maharaja Jai Singh II commissioned town planner, Vidyadhar Bhattacharya, and they began the work for the foundation of Jaipur on November 29, 1728.

Vidyadhar Bhattacharya put great thought into the layout of this new city, Jaipur. He adopted a gridiron plan, with a main road running almost east-west along a ridge in the center, and placing the palace at the core of the city, which occupied about one-seventh the area of the city. The new buildings were also strictly built according to a city plan. Jaipur was laid out in rectangular blocks, and divided by primary cross streets 111 feet in width, secondary cross streets at 55 feet, and smaller cross streets at 27.6 feet. To the north of the palace in the center, Tal Katora Tank was placed and enclosed by a masonry wall. Behind Tal Katora Tank was the Raja Mal-Ka-Talao. Jaipur was planned to support a population of 150,000 people and had a size of 1658 acres (or 6.7 square kilometers). Nine sectors of the city, known as mohallas or chowkries, were built for different castes of people and different professions. A masonry wall 20 feet high and 6 feet wide protected Jaipur, as it would often be attacked as a result of internal feuds[3].

Within six years of the laying of the foundation of Jaipur, Maharaja Jai Singh II had completed the main portion of the city, and its population and prosperity were growing rapidly. Maharaja Jai Singh II died on September 21, 1743, and Shri Ishwari Singh became the ruler of Jaipur State. In the seven years of his rule (1743-1750), he only built the seven-storied Isar Lat Tower on the southern wall of the city palace. The next two rulers, Madho Singh I (1751-1768) and Prithvi Singh (1768-1778), made no new additions to Jaipur City. The next ruler, Pratap Singh (1778-1803) made a few additions, such as building the Hawa Mahal, many roads, and many temples. However, expansion still did not occur outside the city wall during Maharaja Pratap Singh’s rule.

Local wells met water demand in the 1700s, and citizens would draw water from open wells or baories/stepwells. As well, a moat wall was constructed along the foothills of Nahargarh both for keeping wild animals away from the city and diverting rainwater to Man Sagar Lake. This served as a source of groundwater recharge and allowed the water in the hills to percolate into the wells. As well, a tank known as Raj Jaimal’s Tank was situated within the four walls of the city, and provided recharge for those in the northern part of the city. The first water supply involved big public wells constructed in the different sectors of the city. As well, some 100 open wells were constructed from time to time to address the growing population. The first water supply system involving the transportation of water was initiated for the City Palace and involved lifting water by oxen at a well near Balandji’s Temple and transporting it to the City Palace through a canal. The first public water supply involving transportation of water was built in the mid-1700s for those who could not afford their own wells and consisted of a canal supplied with water from the Amanishah Nala that was built from Surajpole Gate to Chandpole Gate with three reservoirs known as Chhoti Chauper, Bari Chauper, and Ramganj Chauper. The water was lifted manually and collected in kunds, underground water tanks, where people could fetch the water from[3]. Maharaja Sawai Jai Singh II had also attempted to ensure an abundance of drinking water, initially attempting to supply water through a 16-mile long canal from the River Bandi. While water did reach Jaipur, a sustained supply was not possible due to the elevated nature of Jaipur.

Water needs were a great concern when the city of Jaipur was planned and constructed. The city was planned to take advantage of the topographic features that allow natural drainage and storm water runoff through soils with high percolation rates. Natural drainage of the topography was utilized, as evident through the dividing line of Jaipur, with Surajpole Gate on the east to Chandpole Gate on the west--in which the side north of this dividing line would have drainage to the north and the side south of this line would have drainage to the south.

Prior to 1874, water was obtained through public wells, open wells, and channels from which water was collected in kunds, and the city maintained a relatively sufficient water supply. However, with growth of Jaipur through the 1700s and 1800s, augmentation of the water supply scheme to ensure a sustained water supply was required. In 1844 a dam was constructed across Amanishah Nala, but it was breached in 1853. Colonel Jacob, whom became the Executive Engineer of the State in 1867, was tasked with the construction of two service reservoirs in 1874 that utilized steam engines to pump water to a height of 110 feet into these reservoirs, known as the Amanishah water supply. Both reservoirs were 150 feet by 100 feet and 15 feet deep[10]. In 1874, piped water supply to Jaipur began through a 12-inch iron pipe connected to branch pipelines in all of the principal streets with stand posts installed at every street corner from one of the reservoirs. The other reservoir supplied water to Hathroi Fort through 6-inch delivery lines. In 1884-85, an 800-foot long and 61-foot high dam was constructed across the Amanishah Nala, accompanied by a steam engine pumping station[11]. At the time of the dam construction, Amanishah Nala was a perennial nala. However, after some years, the inflow of water into the Amanishah Nala became depleted in hot seasons. Heavy silting of the dam also contributed to a reduction in the capacity of Amanishah Nala. Open wells and tube wells were subsequently sunk into this reservoir, and water was pumped from these wells to maintain water supply. This Amanishah water system did away with the earlier system of water canals and the collection of water in kunds[3].

The early water supply system of Jaipur initially relied upon groundwater, but the topography of Jaipur was considered and thus the drainage patterns allowed for recharge of groundwater. Amanishah Nala later provided a surface water source involving the transportation of water through a canal and the collection of this water into kunds, though groundwater supplied the majority of water supply. The Amanishah Nala was further tapped in 1874 and utilized steam engines to pump water and supply Jaipur through a pipeline network. Soon after the damming of the Amanishah Nala, low inflow and silting of the dam lead to a reduction in its capacity. Availability and sustained water supply was of great concern to the planners of Jaipur and recharge to the highly depended upon groundwater was considered during the initial planning of Jaipur. Additional supply was needed to keep pace with the growth of Jaipur and technological advances allowed for the use of steam engines for water pumping and a piped water supply by the late-1800s, meeting water demand, although these innovations did away with the more traditional methods of the earlier water supply scheme, such as the use of canals and collection in kunds.

C. Growth and Urbanization Pre-Independence

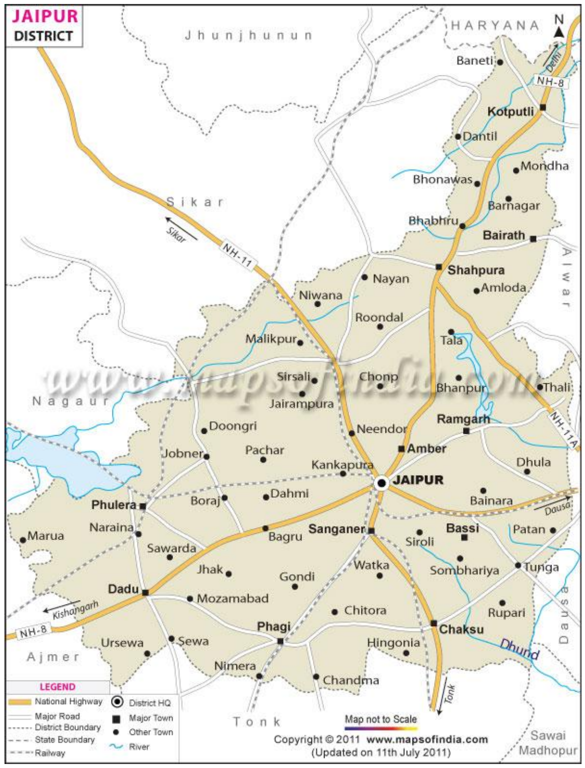
The water system described above was able to meet the water demand of the city until the first quarter of the 20th century. The population was exceeding a lakh, and with increasing dependence on the water supply scheme, the existing system needed to be augmented and expanded. Compounding the increasing water demand, the Amanishah Nala was considered inefficient for further tapping due to recurring droughts. In 1896 the rainfall partially failed, followed by succeeding years of rainfall deficiencies until complete rainfall failure in 1899. Rainfall was heavy in 1900, but this lead to floods that brought down a large amount of silt and silted up the Amanishah reservoir by 15 feet. By February 1902 the reservoir dried up, but due to a supplementary dam below the main dam, one-quarter to one-third of normal supply to the city was achieved. In 1905 rainfall completely failed again, which led to no water entering the reservoir. As an emergency measure two wells at the reservoir were sunk deeper in addition to the sinking of eight new wells, which were completed by February 1908 and became the sole water source for Jaipur until the monsoon rains came that year. Five additional wells were sanctioned within the reservoir, but due to floods in 1912, these wells were not completed until 1914. At this time all wells were raised so as to be carried above the highest flood level in the reservoir. Five more wells were sanctioned in 1916 due to another monsoon failure in 1915[10]. Due to the series of droughts in the first two decades of the 1900s and the gradual silting of reservoirs and wells, by the 1920s the water supply scheme was estimated to have a reduced capacity that was 1/5th of the original water supply scheme capacity[11] and new sources of water supply to expand the water supply scheme were investigated.

In 1903, a large reservoir and dam, named Ramgarh Dam, was constructed 30 kilometers northeast of the Jaipur, which depended on water inflow from the Banganga River. The water from Ramgarh Dam was initially used for irrigation purposes in the surrounding villages. With the advent of power generation, which started in 1925 in Jaipur, a scheme was developed to actually bring this water to Jaipur. The scheme consisted of 28 kilometers of pipelines that fed water to a filtration site called Laxman Doongri in the hills northeast of Jaipur, which was connected with a pipeline to existing pipelines already present in Jaipur. Thus, by the time Ramgarh Dam supplied water to Jaipur in 1931, the city had two water sources: the Amanishah Nala system and the Ramgarh Dam/Laxman Doongri system[3]. At this time, household piped water supply was not common and was only available to well-to-do families. Many localities did not have a public distribution system, and thus reliance on wells was still extremely common[12].

The walled city became very congested in the early 1900s and the expansion of a modern Jaipur outside of the walled city became the dream of Maharaja Sawai Man Singh II (1922-1969).

During his period of rule, Jaipur grew from an area of 6.7 square kilometers to 64 square kilometers. Buildings such as the Maharaja's college, S.M.S. Medical College and Hospital, Sawai Man Guards, the present secretariat building, Rajasthan University, Maharani's college, and Maharani Gayatri Devi School were erected during Sawai Man Singh II's time. As well, 5 residential colonies, recognized as the first residential development outside of the Walled City, were also planned: Adarsh Nagar, Banipark, C-Scheme, New Colony, Fetah Tibba. Development efforts were made in the 1940s to make Jaipur a center of industry and trade.

Figure 4: Map of Jaipur District (View of Ramgarh in relation to Jaipur)



Source: 13

D. Growth and Urbanization Post-Independence

During the 1940s the population of Jaipur began a rapid increase due to the partition of India in 1947, which lead to the immigration of refugees from Pakistan, and the declaration of Jaipur as the capital of the newly merged Rajasthan State in 1949. Population increased from 175,810 to 291,130 between 1941 and 1951, a percentage growth of 6.55%[3]. Sawai Man Singh II was declared the governor of Jaipur. With a government eager to satisfy the immediate needs of its residents, city planning and infrastructure were neglected. Jaipur's expansion during this time did not follow the traditional architectural and civic designs present in the Old City. The symmetry, order, and design of the city were compromised in order to allow for the rapid influx of people. Many new residential colonies were built around this time, such as Bapu Nagar, Napunagar, and Moti Doongri.

In 1953, capacity of pumpage from Ramgarh Lake was increased from 9 million liters per day to 27 million liters per day by installation of pumping stations, distribution mains, etc[3]. The capacity of Ramgarh Dam was increased again in 1963 from 27 million liters per to 54 million liters per day, with the addition of a new filter plant, three additional filters, and a new reservoir of 10 lakh gallons at Laxman Doongri, and additional distribution lines. Population pressure necessitated an augmentation scheme for water supply in 1971-72, in which groundwater was taken as a source. The city was divided into fourteen zones, and tube wells were bored and commissioned in each zone. Before this scheme the capacity of groundwater in Jaipur was 63 million liters per day. The augmentation scheme increased this value to 99 million liters per day in 1973-74, and further increased this value to 129 million liters per day in 1976-77 with the addition of wells. Another water scheme was implemented between 1980 and 1985 to increase Jaipur's water supply capacity by 72 million liters per day. The capacity of Ramgarh Lake was increased by 18 million liters per day at this time, and the groundwater scheme was enhanced to add 54 million liters per day from 120 wells. After this scheme, the capacity of the Jaipur water supply was 234 million liters per day.

During its rapid, pre- and post-independence urbanization, Ramgarh Lake was the main source of water for Jaipur. Ramgarh Lake only had overflows, resulting in flooding, three times during the period after its construction. Issues with Ramgarh Lake started to become evident in the 1980s, and Ramgarh started to show signs of excessive drawdown, and in fact, completely dried up occasionally. After 1983-84 the water level of Ramgarh Lake never went above 54 ft. The Ramgarh reservoir became silted up to 14 ft., which greatly reduced its storage capacity. Anicuts, barriers constructed across a waterway, were also being built in the catchment area of Ramgarh Lake, resulting in interception of the water coming into the lake. There were years starting in the late 1980s/early 1990s in which Ramgarh remained dry (anonymous source), and it quickly lost its potential for providing additional water supply. By 1999, water was no longer reaching Ramgarh Dam at all. The government attempted to find another source of water supply in 1989 by sanctioning a water supply scheme to bring 18 million liters per day from the Bandi basin 20 kilometers away from Jaipur. However, due to resistance from local people, this scheme could not be implemented.

E. The 1990s to Today

As discussed above, Ramgarh Lake was rapidly depleted in the 1980s and 1990s and could no longer be used as a main source of water for Jaipur. This led to a shift to and a heavy dependence on groundwater sources. Emergency measures were sanctioned in 1989-90, which resulted in the installation of 202 hand pumps and 31 tube wells. Many of these hand pumps quickly became abandoned or dried up. Throughout the 1990s, emergency plans were implemented to replace failed tube wells and replace operationally inefficient pumping sets.

A new source of water needed to be found because the in-place system was inefficient and Jaipur continued to grow. The Bisalpur Dam was commissioned by the Rajasthan government in the mid-1990s after other investigated sources were found to be inefficient. Bisalpur Dam is located in the Tonk District of Rajasthan, over 150 kilometers from the center of Jaipur, and provides water to Tonk, Ajmer, and Jaipur. The transmission of water from Bisalpur Dam to Jaipur began in 2009. The capacity of Bisalpur Dam is 1,095 million cubic meters, however the amount of water in the dam is highly dependent on yearly precipitation patterns. The Bisalpur System consists of two parts: a transmission system and a transfer system. The raw water from Bisalpur Dam is pumped to a filter plant at Surajpura and undergoes filtration and chlorination. This treated water is than transferred to rural areas and Jaipur City up to the Balawala pumping station. The pipeline system of Bisalpur Dam water in Jaipur consists of a central feeder from Balawala to Jawahar Circle, Ramniwas Bagh, Amanishah, Shastri Nagar, Vidhyadhar Nagar, and VKI area. The water from the central feeder then extends from Jawahar Circle to Mahesh Nagar, Triveni Nagar, and Barkat Nagar and from Rambagh to Jypti Nagar, Civil Lines, and Shanti Nagar. The pipeline system also consists of a western feeder from Balawala to Mansarovar, Shyam Nagar, Vidhyut Nagar, Khatipura, and Jhotwara.

Figure 5: Map Containing Jaipur and Bisalpur Reservoir

Source: 14

Another common source of water is from tanker transportation of water in both areas connected and unconnected to the piped water supply. It is reported that tanker transportation of water is done in slum areas, areas where Public Health Engineering Department piped water supply does not exist, and areas where water pressures are less and water supply is inadequate. Until 2012, the number of tanker trips during summers was about 2,800, and has decreased to 1000 trips. It is likely that as distribution system improvements progress, tanker trips may further reduce[15, 16].

The increased dependence on groundwater throughout the 1990s and 2000s has led to overexploitation of groundwater and a rapidly declining water table. The recharge to groundwater has also been diminishing as Jaipur continues to grow and green space (recharge) area decreases. It has been estimated that the excessive withdrawal of groundwater is at 600% in Jaipur City and groundwater supplies in areas such as Jhotwara, Murlipura, Jagatpura, Malviya Nagar, part of Mansarovar, Bapu Nagar, C Scheme, Jawahar Nagar etc. are almost dry.

III. Urbanization of Jaipur

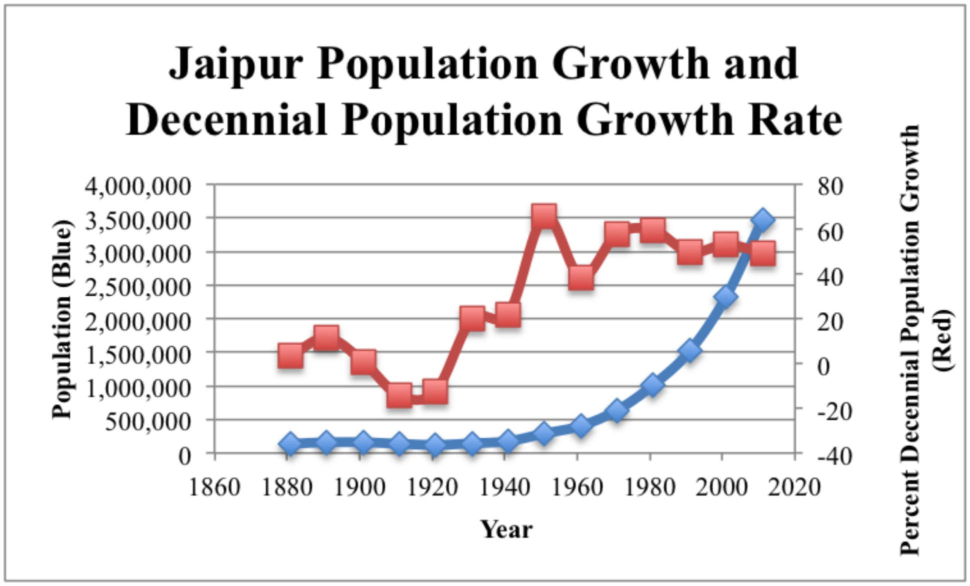
A. Population Growth

Table 4: Jaipur City- Decadal Population Growth (1871-2011)

Years	Population	Variation	Decennial Growth in Percentage	Percentage Growth per Annum
1871	137,887	-	-	-
1881	142,578	+4,691	+3.40	0.34
1891	158,905	+16,327	+11.45	1.14
1901	160,167	+1,262	+0.79	0.79
1911	137,098	+23,069	-14.40	-1.44
1921	120,207	+16,891	-12.32	-1.23
1931	144,179	+23,972	+19.94	+1.99
1941	175,810	+31,631	+21.93	+2.19
1951	291,130	+115,320	+65.59	+6.55
1961	403,444	+112,314	+38.58	+3.85
1971	636,768	+233,324	+57.83	+5.78
1981	1,015,160	+378,392	+59.42	+5.94
1991	1,518,235	+503,075	+49.55	+4.95
2001	2,324,319	+806,084	+53.09	+5.30
2011	3,471,847	+1,147,528	+49.37	+4.94

Source: 3, 17

Figure 6: Jaipur City- Decadal Population Growth (1871-2011)



Jaipur has experienced rapid population growth, especially since post-independence, which resulted in a vast expansion of the city limits. Decadal population growth since 1871, when the first census estimate was taken, is analyzed. Table 4 below shows decadal population growth in Jaipur City since 1871. The first official census for Jaipur city was conducted in 1881, and after 1891 regular decadal censuses have been conducted. In Table 4, there are specific time periods that show population trends that must be discussed. Population increased from 1870 to 1901, but at an uneven rate. A sharp decline in population growth occurred from 1911-1921 (as well as in Rajasthan as a whole), due to large-scale famines and epidemics, which were occurring throughout the country. The city experienced plague, malaria, and cholera outbreaks throughout this time. Population began to increase after 1931. As a result of the Partition of India in 1947, there was an upward growth in population due to the influx of migrants from Western Pakistan (as can be seen in the 1951 census). During 1951-1961, percent population increase slowed down due to a change in the definition of urban centers. Since 1961, the population growth rate has been great and stable. As has been shown, population can greatly be influenced by external factors[3].

B. Urban Impact on Hydrology

In the early stages of Jaipur, city expansion was restricted to the foothills and thus surface water drainage patterns were not disturbed. As expansion took place, people began to fill, divert, and block the streams of Jaipur. There are as many as 518 rivulets originating from the Aravalli Hills[5]: 398 1st order streams, 92 2nd order stream, 25 3rd order streams, and 3 4th order streams (*stream order is a hierarchy to classify streams, running from 1st order, the smallest streams, to

12th order, the largest streams). Many natural streams began to be used for dumping garbage. Due to expansion, 150 streams with 113 of 1st order, 37 of 2nd order, and 10 of 3rd order are blocked or have been filled for construction purposes. Consequently, this greatly influences the availability of clean surface water and groundwater recharge[5].

C. Urban Impacts on Surface Waters

1. Degradation in Water Quality

Industrial processes in and around the city have greatly and negatively affected the quality of surface waters in Jaipur. Amanishah Nala has become unsightly and foul smelling due to the discharge of industrial wastewater to its storm water drainage network. These conditions encourage insect breeding, most notably mosquitos, which creates health risks and increases spending on health care. Spending is also increased for repairing the surface of roads when garbage blocks the drains, causing spillage of wastewater. There are also health risks linked to downstream usage of wastewater for domestic purposes or agricultural use. These conditions also allow for an increased risk of pollution of groundwater by direct seepage to the aquifer. Relatively shallow aquifers are present, and thus pollution can quickly seep down into these aquifers. In addition to industrial wastewater, hotels have also contributed to this wastewater issue as in most cases their wastewater is let out in a drain connecting to the sewerage network[3].

2. Depletion of Surface Water: A Look at Land Use Change in the Ramgarh Dam Catchment Area

The Technical Committee of the Government of Rajasthan analyzed land use change through remote sensing through the years around the catchment area of Ramgarh Dam, the previous main water source for Jaipur, in their report “Report on less/no inflow in Ramgarh Dam district despite average and above average rainfall and remedial measures to restore[18].”

One can see that agricultural land area greatly increased and water bodies greatly decreased from 1985 to 2012. The Ramgarh Dam was completely dry in 2012. The significant increase in agricultural activity obstructed the flow into the reservoir. Upstream of the dam, diversions for water use in agriculture have resulted in depletion of surface water sources. As well, with an increase in farmers taking double and even triple crops annually, there is more withdrawal from groundwater and depletion of the water table, thereby increasing the unsaturated thickness of the soil and absorption of the surface flow. As well, when farmers engage in leveling their fields, water tends to pond longer, increasing infiltration and percolation to the subsurface and reducing water flow to surface waters. The use of contour bunding,

Table 5: Land Use Change

Land Use	1985-86 (Hectares)	1996-97 (Hectares)	2006-07 (Hectares)	2011-12 (Hectares)
Kharif Crop	0	958.06	1,551.74	4,103.02
Rabi Crop	13,183.30	12,692.79	15,367.22	15,633.50
Double Cropped (Kharif & Rabi)	0	472.84	2,056.15	2,145.40
Fallow Land	25,841.89	267,748.92	25,100.24	22,146.74
Gullied/Ravnious Land	14,731.63	14,337.91	13,146.39	13,034.76
Scrub Land	6,897.05	5,165.63	4,845.60	4,607.77
Stony Waste Area	18,251.57	17,896.15	17,820.69	17,779.05
Water Bodies	1,146.57	1,817.97	113.64	128.91
River	2,082.80	1,349.05	2,082.99	1,957.82
River Water Channel Area	245.98	894.12	0	0
River Bed Cultivation	73.48	21.02	62.84	198.32
Mines/Quarries	10.11	78.39	223.03	343.35
Settlement	726.02	756.75	818.44	841.77
Total Area	83,190.41	83,190.41	83,190.41	83,190.41

Source: 18

plowing and planting across a slope following its elevation contour lines, has also decreased surface flow by harvesting water flow during rain spells. About 70% of the cultivated area around Ramgarh use contour bunding. In addition, cultivation in the riverbed and submergence area of the dam has increased, reducing runoff and increasing percolation and evaporation losses. Furthermore, increases in the construction of mines and quarries restrict runoff to surface water due to storage in the depressions. Some government works in recent years have also negatively affected runoff. The Forest Department has constructed 11 anicuts in the Ramgarh area, and has dug trenches at the foot hills/boundary or reserve forest. These trenches collect runoff from the hills first before the runoff is able to join the main stream. Moreover, during the construction of a link highway connecting NH 8 to NH 11, lateral trench excavations were made in patches along the highway, which now contribute to inadequate drainage when runoff gets collected in these trenches[18]. This water either evaporated or seeps down into the soil. Due to an alteration of catchment area characteristics in general, the silt content in runoff has increased over the years and deposited sandy material in riverbeds and water bodies.

D. Urban Impact on Groundwater

1. Overview

Originally Jaipur' groundwater resources exhibited a high water table and good quality. Today, however, Jaipur's groundwater has been overexploited and its quality degraded. Jaipur's groundwater supply has diminished to a critical limit, with more than 500% overexploitation in some areas and severe degradation of groundwater quality. Urbanization and industrialization have led to much of the overexploitation, but the lack of regulation of tube wells has also compounded the problem. With an estimated 20,000 private tube wells within the city, compared to approximately 2,000 Public Health Engineering Department controlled tube wells, the regulation and monitoring of groundwater extraction are nearly unachievable. The overexploitation of groundwater concentrates the inherent salts, fluorides, chlorides, and other chemicals already found in the water[3]. The seepage of sewage water into surface water sources has further degraded the water. While the depth to water table is dynamic in nature, the variability is great throughout Jaipur, with depth to the water table ranging from 10.3 meters to 70.2 meters[20]. In some areas, communities are forced to drill tube wells adjacent to ponds that are fed by sewage steams to create water reuse systems. Additionally, natural groundwater recharge has been obstructed, further intensifying the depletion of groundwater quantity and the deterioration of quality. Jaipur city's groundwater is currently caught in a vicious cycle where the lack of supplied surface water has led to the further exploitation and degradation of quality of an already overexploited groundwater source.

2. Destruction of Ground Water Recharge System

Groundwater recharge is an important process in the Earth's hydrological cycle, in which water moves downward from surface water to groundwater. When rain falls or snow melts, a part of that water infiltrates the soil, while the remainder evaporates or runs off into surface water bodies. Tree roots increase water percolation into groundwater--infiltrating the water more deeply, which will eventually accumulate above impermeable strata while saturating all available pore space and forming an underground reservoir. Some proportion of the moisture in plant roots will be lost through transpiration and put back into the atmosphere.

Groundwater recharge can be greatly impeded due to anthropogenic activities, such as deforestation, destruction of local water systems, stoppage of river flows, and paving/concretization. Deforestation results in the loss of topsoil and thus reduced water infiltration. Increased surface runoff and changes in river flow regimes, also affecting recharge in a given area, are additional results of deforestation. Urbanization and development greatly affects groundwater recharge, as impervious land does not allow water to permeate. As built up area increases and there is more developed land in the form or houses, roads, etc., there is less area available for groundwater recharge. This also results in local flooding, as water collects on the surface of concretized land[3].

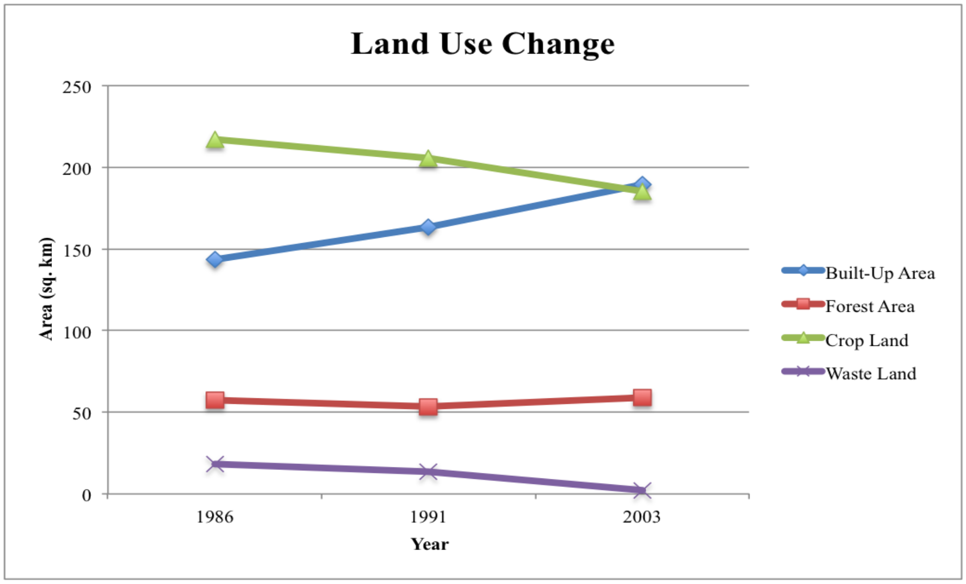
Land use change has a great influence on groundwater recharge, and land use change in Jaipur recently shows a trend with a negative impact on groundwater. Compared to built-up land, alluvial plain (crop, waste land, and forest) is good for water percolation and thus, groundwater recharge. As one can see in Table 6 below, from 1986 to 2003 alluvial areas were reduced by 48 square kilometers in the Jaipur region, while the built-up area increased.

Table 6: Major Land Use Change in the Jaipur Region

	Major Land Use Category	Area (Square Kilometers) Year 1986	Area (Square Kilometers) Year 1991	Area (Square Kilometers) Year 2003
1	Built-up Area	143.40	163.32	189.70
2	Forest Area	57.45	53.52	59.01
3	Crop Land	217.03	205.80	185.05
4	Waste Land	18.30	13.63	2.24
5	Total	436.00	436.00	436.00

Source: 5

Figure 7: Major Land Use Change in the Jaipur Region



3. Depletion of Groundwater

Rapid encroachment upon forest lands, agricultural fields, pasturelands, and open wasteland due to urbanization, building of roads, houses, and commercial complexes has reduced the open areas of Jaipur to a great extent. As open areas are useful places for rainwater to soak into the soil and percolate to groundwater aquifers, the reduction in open areas has had an affect on the lowering of the water table. In "Shrinking of Water Resource," Joshi claims that from 2005-2010, the water table had declined one meter per year on average in Jaipur[5]. Advances in the technology of extraction have also contributed to a lowering of the water table, as this improved technology is able to provide high pump rates, leading to large scale groundwater development, but ultimately to overextraction, lowering of the water table, and decreases in the yields of wells. Most of the Jaipur urban area is now categorized as over-exploited in terms of groundwater.

4. Degradation in Groundwater Quality

A. Overview

Urbanization and industrialization have had a negative impact on groundwater quality in and around Jaipur. Degradation in groundwater quality is very much linked to the degradation in surface water quality as discussed in the sections above. Groundwater can be easily polluted from waste generated from domestic, industrial, and agricultural sources. Wastewater generation from industry, as well as hotels, can negatively affect groundwater through direct seepage into the aquifer below. The sedimentary formation from which groundwater is tapped can also affect water quality depending on the types of adjacent rock types and the mineral composition of these rocks. Overexploitation of groundwater concentrates inherent salts found in these rock compositions and influences such factors of water quality as total dissolved solids, fluorides, chlorides, etc. The pollution created by nearby industries has had a noticeable effect on the quality of hand pump water in various areas of Jaipur.

B. Fluoride Pollution and Impacts from Textile Industrialization

Use of chemical dyes in the place of vegetable dyes, caused by the expanding of the cloth printing industry, has caused high levels of fluoride in the groundwater of Sanganer, a village located 16 kilometers south of Jaipur, famous around the world for the fabrics printed there. A high level of fluoride in drinking water causes dental caries (tooth decay), hardness in the bones, and deformation of the human skeletal system known as skeletal fluorosis The Sanganer area is known for having many cases of fluorosis in its residents. There are about 500 small scale dying and printing units that discharge their effluents in the Amanishah nala and this polluted effluent seeps into the groundwater of Sanganer[3]. Fluoride pollution can also be a result of the overexploitation of groundwater magnifying the inherent fluoride concentrations from fluoride-bearing minerals.

C. Nitrate Pollution

High nitrate groundwater pollution has been observed in Jaipur and is caused by the increase in population, a lack of a properly designed sewerage system, and groundwater drawdown. Nitrates are found dissolved in water, mainly as the salts of calcium, magnesium, and sodium. As groundwater levels decrease, these salts are magnified in the water. If this water is used for consumption stomach disorders, such as constipation, stomach ulcers, and erosion of the mucous membranes of the intestines, and the disease methemoglobinemia or blue-baby syndrome, which has been linked to infant mortality (infant mortality is high in Rajasthan), can occur[3]. As well, repeated heavy doses of nitrates may cause carcinogenic disease. Methemoglobinemia primarily affects bottle-fed infants. The stomach acid of an infant is not as strong as in older children and adults, which allows for increased bacteria that convert nitrate to nitrite. Nitrite is absorbed in the blood, and hemoglobin (the oxygen-carrying component of the blood) is then converted to methemoglobin, which cannot carry oxygen efficiently. This results in reduced oxygen supply to vital organs. While adults are often able to change methemoglobin back to hemoglobin, infants cannot. Methemoglobinemia can result in brain damage or death.

D. Salinity

High levels of salinity in groundwater have been observed in Jaipur, specifically in the Old City. High salinity in groundwater, similar to high nitrate in groundwater, is attributed to increased population, a poor sewerage network, and shallow water levels. High salinity has rendered this water non-potable.

ds **E.** Heavy Metals

Contaminations of groundwater by heavy metals is of great concern as these elements can be toxic, exhibit accumulative behavior, are not biodegradable, and undergo a global ecobiological cycle in which natural waters are the main pathways. While many heavy metals, such as copper and cobalt, are essential to humans, large quantities can cause physiological disorders. Other heavy metals, such as cadmium, chromium, and lead are highly toxic to humans even at low concentrations[19].

E. Urban Impact on Natural Gradient and Flood Area

Fast urbanization of Jaipur and its resulting increase in paved area and decrease in agricultural land, which acted as percolation or recharge zones, has resulted in an increase in local urban flooding. Urbanization and construction disrupt the natural gradient of lands and in turn disrupt the natural drainage patterns of the area. The catchment area around the Amanishah drain has shown increased water flow during the rainy season due to construction and paving around it. Amanishah Nala, Gandh Nala, Jawahar Nagar Nala, and Jagatpura Nala carry most of the drainage out of the city. During rapid urbanization, the drainage system of Jaipur was not given much attention. New development and residential colonies developed over the bed of the drainage patterns. As well, construction often involves flattening of the land, which disrupts the natural topography and thus drainage of the area. The Jawahar Nala is virtually non-existent due to development around it. Unauthorized colonies or informal settlements in the Jaipur area have also increased flooding, as these colonies have been developed by local colonizers without consideration of city plans, drainage, sewage, etc. Encroachments along water drains causes the obstruction of water flow to the drains, which in turn increases flooding. Areas, which act as buffers of flooding, such as water retaining plains, are gradually being filled up and built upon[3].

IV. Current Supply Scheme and Management

A. Overview

Jaipur's current water supply system is primarily dependent on tube wells, but estimates of government water supply vary greatly from source to source. There are great distribution losses within the system and water metering is either absent or broken at water receivers. Many of these tube wells are fitted with power pumps, which supply water to clear water reservoirs and then to elevated storage reservoirs for distribution to the system. In the Walled City there are 5 clear water reservoirs and 5 elevated storage reservoirs. In the northern part of the city there are about 31 service reservoirs to supply water to distribution zones. In the southern part of the city there are about 64 service reservoirs to supply water to distribution zones[6]. According to the Public Health and Engineering Department there are a total of 390,893 water connections with

352,393 working connections, 384,058 metered connections, 6,835 flat rate connections, 329,093 domestic connections, 51,246 non-domestic connections, 3,719 industrial connections, and 1,170 public stand posts. According to a survey by the Public Health and Engineering Department, there are about 1,340 tube wells scattered throughout the city, in addition to about 1,845 hand pumps[15]. However, there are many unaccounted for wells, as people are free to drill their own wells on their property. There have been estimates of greater than 20,000-30,000 unaccounted for tube wells throughout Jaipur. At this time, then, drinking/domestic water supplies for Jaipur are essentially dependent on groundwater[3]. The water supply from the government is intermittent and the average duration of running water is 90-120 minutes per day. General inadequacy in water availability can be found in calculations of supply and demand that reveal deficits in government water supply, high unaccounted for water losses, drops in supply pressure due to large quantities of water released in short durations or the depletion of groundwater affecting pressure in tube wells, and issues with water metering and fees[7, 8, 9].

Jaipur has been receiving water from Bisalpur Dam since 2009. Bisalpur also supplies water to the Tonk District of Rajasthan and Ajmer, and is dependent on rainfall, which is highly variable from year to year. Estimates from the Public Health and Engineering Department claim that Bisalpur is currently supplying about 320 million liters per day of water. In general, estimates of water supply and demand are extremely variable amongst different sources of data. A contributing factor to these uncertain estimates may be the large distribution losses in Jaipur’s water supply system.

Water quality in Jaipur is unreliable and uncertain. High nitrate, fluoride, total dissolved solids, and other compounds of concern have been found in areas of Jaipur’s groundwater[19, 20]. A recent study of drinking water quality in Jaipur concluded that while the water quality in most of Jaipur is acceptable, however high fluoride and nitrate levels are a concern in some areas[19]. According to the Public Health Engineering Department, Jaipur does have 100 online chlorination plants on direct supply tube wells and 12 electro-chlorinators are pump stations to purify water from Bisalpur[9]. There are various pumping stations that provide chlorination for the overall water supply. The primary means of chlorination in Jaipur is through the use of bleaching powder and the Public Health Engineering Department claims to take daily water samplings for residual chlorine and for bacteriological examination[9]. Many homes of those that can afford it also have reverse osmosis systems to treat their groundwater or the water they store in their own underground tanks.

B. Role of the Government and Policy

1. Governmental Water Agencies

It appears that there is no single government entity that controls or manages the urban water supply; the organization of Jaipur’s water supply is divided amongst several different sectors of government. The Public Health Engineering Department is mainly in charge of water and waste treatment within Jaipur, however the Jaipur Municipal Corporation, Rajasthan Water Resources Department, the State Water Resources Planning Department, and others may also be involved water planning schemes in Jaipur. It has been said that due to competing interests it is difficult to have one umbrella organization to oversee and coordinate all water management in Jaipur.

2. The Master Plans

The rapid growth after Independence led to issues such as shortages of living accommodations, traffic congestion, lack of sanitation, etc. and thus the Rajasthan Urban Improvement Act with passed in 1959. There was a need for a master plan for growth, and thus in 1965 a Master Plan was prepared (with 1961 as the base), with what the Government believed included projections of the city's needs up to 1991. Due to even more rapid expansion, a new modified and updated Master Plan was prepared using 1971 as the base year. Another master plan was prepared in 1998 with targeting the needs of Jaipur up to 2011. A fourth master plan was completed in 2011 with projections of the city's needs up to 2025. The most recent master plan provides an existing profile of the Jaipur District, Jaipur Region, and Jaipur City. The existing profile covers subjects such as climate and physical characteristics, the physical infrastructure, land utilization, and the social infrastructure. The most recent plan also provides a development plan for the Jaipur Region and Jaipur City and presents projections and proposals covering the topics of demography, the demarcation of the development area, land utilization, transportation, economy & infrastructure, environment, urban design, recreation, and disaster management[6]. The proposals present in the development plan provide ideas for future development in Jaipur, however, these concepts are not set in stone and there is nothing in place to enforce these development plans. Often, many of these ideas for the future are not implemented.

3. Water Metering

The Public Health Engineering Department admits that there is much to be done concerning water metering and tariffing. The future of water metering is very important to ensure collection of revenue to manage the upkeep of the water supply system, in addition to allowing for more precise measurements of Jaipur's water supply and demand. According to the Public Health Engineering Department, there are 384,058 metered connections in the Jaipur water supply scheme[15]. However, about 60% of meters are not functional[9]. Lack of adequate replacements of water meters is attributed to a shortage of staff and a low meter repair rate.

There are many issues with the tariff system for water consumption. The tariff system is not well defined and charges are generally not based on actual consumption in the majority of the houses, but based on an average consumption value in the household based on past readings. The timing of water readings is inconsistent, as often the time between on site water reading can be weeks to months. Revenue collection is not systematized and long queues can be found at payment sites. In addition to these issues, the charges for water consumption are very nominal (generally ranging from 50-100 rupees/month), leading to low revenue for the water supply department[8]. Even more troubling than these issues is public awareness about the water tariff system - some citizens of Jaipur say they have a regular bill for water, while others claim to never have seen a water bill during their time in Jaipur.

C. Estimates of Water Supply and Demand

Recent water supply and demand estimates have been calculated by the Public Health and Engineering Department. Satish Jain, an executive engineer at the Public Health and Engineering Department, estimates that Jaipur's total water demand is 462 million liters per day, water supply from the government is 374 million liters per day, and thus, there is a water supply deficit of 90 million liters per day[15]. These estimates are based on the population and number of water connections present in the city, discussed in the introduction of this section above, and completed in 2012 for 2011. Jain claims that 275 million liters per day is supplied by the Bisalpur system, 87 million liters per day is supplied from tube wells, and 2 million liters per day is supplied by single point tube wells combining to make a total supply of 374 million liters per day. In an October 2012 report prepared by SMEC, an Australia-based infrastructure consulting company, for the Public Health Engineer Department it was estimated that water demand in Jaipur in 2011 was 174.16 million cubic meters/year, while production was 140.56 million cubic meters/year[22]. Amit, Dass et. al. claim that according to the Public Health Engineering Department there was an average water supply system production in 2010 of 401 million liters per day. Of the 401 million liters per day, 368.32 million liters per day came from tube wells while 32.64 million liters per day came from Bisalpur Dam. Amit, Dass et. al. claims that in Jaipur, in 2011, with a population of 31.12 lakhs and a population of 27.98 lakhs connected to the water system there was a demand for 4197 lakhs liters, a water supply of 3400 lakhs liters, and a deficit of 797 lakhs liters[7]. It is difficult to make accurate estimates for water demand due to the presence of many tourists, large migration fluxes, high unaccounted for distribution losses, and inadequate water metering for customers. However, it is clear that water supply does not meet demand.

D. Surface Water Treatment and Distribution

Surface water treatment is currently operated by a series of filtration and purification stations that treat incoming water from Bisalpur Dam. Raw water from Bisalpur Dam is pumped to a 400 million liters per day filter plant at Surajpura, in the southern edge of Jaipur. The raw water goes through filtration and chlorination before it is then transferred to Balawala pumping station, where it is piped to the city via various, smaller distribution systems.

E. Groundwater Treatment and Distribution

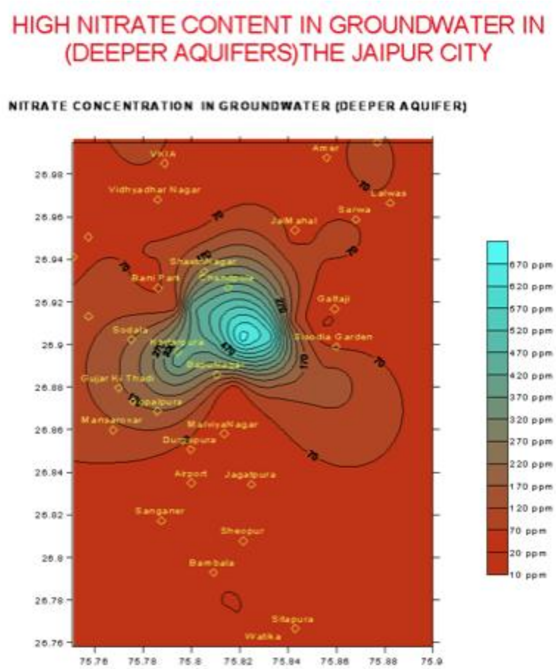
Groundwater in Jaipur is treated and then distributed on a localized level based on zones. City tube wells transfer water to different pumping stations where the groundwater is chlorinated before distribution to city pipelines. However, with such a large amount of tube wells operated by private users, it is impossible to identify whether or not private sources of groundwater receive any form of treatment. Many of those that can afford it have reverse osmosis systems in their homes that will purify their private tube well water.

F. Drinking Water Quality

While drinking water is generally cited as adequate in most parts of the city, there are definitely some concerns regarding drinking water quality. In a 2007-2008 groundwater quality testing report conducted by the Central Pollution Control Board of India's Ministry of the Environment regarding 25 groundwater samples taken in 2004 during pre- and post-monsoon season, various concerns over drinking water guideline levels described by the Bureau of Indian Standards and the World Health Organization were identified. It was found that more than 50% of the samples had total dissolved solids above the desirable limit but within the maximum permissible limit in both pre- and post-monsoon seasons, making the water undesirable for drinking water due to gastrointestinal irritation. About 36% of the samples exceeded the desirable bicarbonate limit during the pre-monsoon season. For calcium and magnesium concentrations in the samples, about 48% of the samples fell within the desirable limit, while 28% passed the desirable limit but were permissible, and 24% of the samples were about the permissible limit during the pre-monsoon season. A few of the samples exceeded European Economic Community drinking water standards for potassium, indicative of groundwater pollution. It was found that 80% of the samples had chloride levels within the desirable limit, while no samples exceeded the maximum permissible limit. All samples fell within the desirable limit for sulfate. Regarding nitrate content, 40% of the samples fell within the desirable limit, while 40% of the samples exceeded the maximum permissible limit. Fluoride content is also of concern, with 40% of the samples exceeding the maximum permissible limit during the pre-monsoon season. Overall, this specific study did not find that the content of total dissolved solids or alkalinity were of concern in Jaipur's drinking water. Of concern however, was that 20% of samples exceeded the maximum permissible limit for calcium and magnesium and 40% of samples exceeded the maximum permissible limit for nitrate and fluoride[19]. The researchers also examined heavy metal contamination in Jaipur's groundwater. It was found that 90% of the samples fell within the desirable limit for manganese, however one sample did exceed the maximum permissible limit. Regarding copper levels, 96% of the samples fell within the desirable limits during both pre- and post-monsoon seasons. All samples fell well below the permissible limit for chromium. More than 80% of the samples fell within the permissible limit during per- and post- monsoon seasons for lead. 88% of samples fell within the permissible limit for cadmium. All samples were found to be within the desirable limit for zinc. Water quality regarding heavy metals is of concern, as standards were violated for iron in 44% of samples, for manganese in 4% of samples, for nickel in 32% of samples, for lead in 8% of samples, and for cadmium in 12% of samples during the pre-monsoon season, and showed similar levels in the post-monsoon season[19].

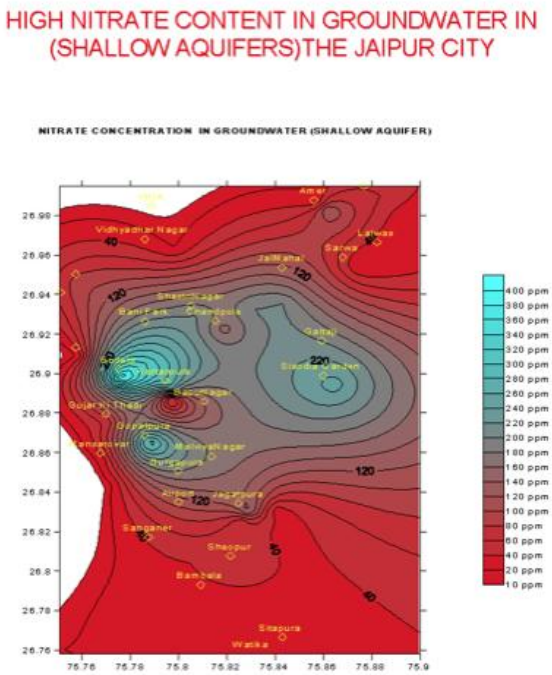
In another study of groundwater quality in Jaipur conducted by the Geological Survey of India, the researchers found high nitrate values ranging from 100 to 700 milligrams/liter in the walled city, Sodala, Banipark, C-Scheme, Maharaja College, Ghat gate, Brahampuri, Nahri ka Naka, Jagatpura, Gujar ki Thari, and Gopalpura. It is likely that soak pits percolating into the soil has polluted the aquifer with nitrate. The researchers also found high fluoride values of 3 milligrams/liter in Sarwa-Lalwas and Sitapura. High total dissolved solids level were found in shallow aquifers of the northeastern part of Jaipur near Lalwas and Amer, and in deeper aquifers near the walled city, Karthapura, north of Bapu nagar, Lalwas, and the southwestern part of Jaipur[20]. These high levels of nitrates, fluoride, and total dissolved solids are displayed in Figures 8-12 below.

Figure 8: High Nitrate Content in Groundwater (Deeper Aquifers)



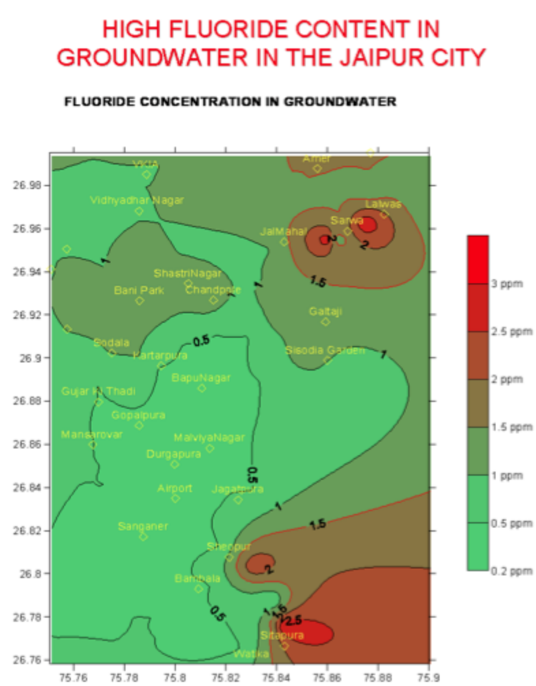
Source: 20

Figure 9: High Nitrate Content in Groundwater (Shallow Aquifers)



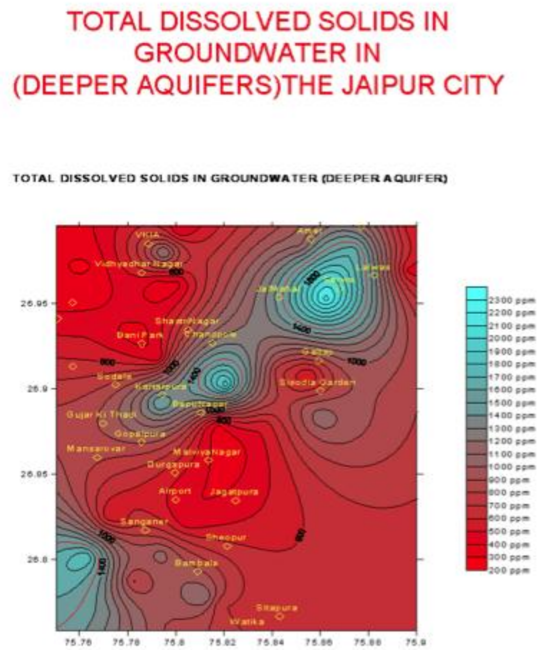
Source: 20

Figure 10: High Fluoride Content in Groundwater



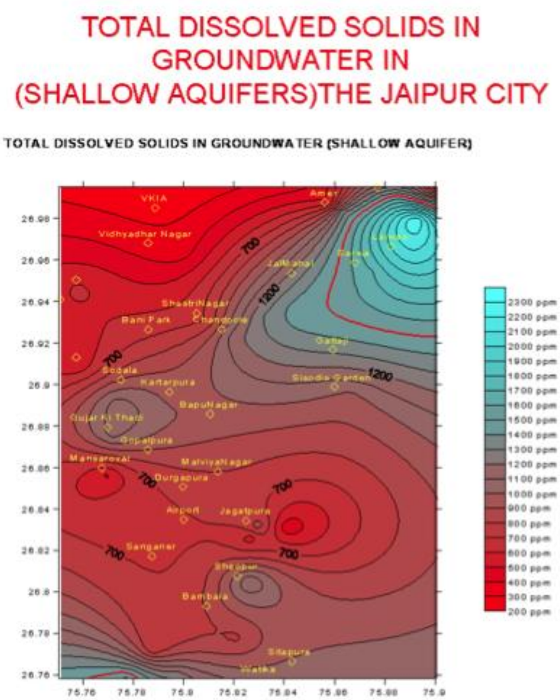
Source: 20

Figure 11: Total Dissolved Solids in Groundwater (Deeper Aquifers)



Source: 20

Figure 12: Total Dissolved Solids in Groundwater (Shallow Aquifers)



Source: 20

A 2010-2011 study conducted by Preeti Srivastava and Nisha Jain looked at various physiochemical parameters in household taps in Jaipur and also compared their findings to limits suggested by the Bureau of Indian Standards and the World Health Organization. The researchers found pH of the samples to be within permissible limits. Total dissolved solids in the Sanganer area were within limits, but towards the higher end of the maximum permissible limit. Alkalinity was above permissible limits in the Sanganer and Jhotwara areas. All samples were found to be within permissible limits for bicarbonate. Magnesium content, calcium content, sodium content, and potassium content varied greatly between samples, but were within the permissible limit in most of the samples. The researchers found high fluoride concentrations in the VKI and Jhotwara areas, but Sanganer town had alarmingly higher levels compared to all other areas. Concerning high nitrate levels, the Sanganer area again had alarmingly high levels, but was considered high in all areas[21].

Various studies regarding drinking water quality may have varying specific conclusions. However, it is quite evident that there are many concerns over the water quality in Jaipur specifically focusing on heavy metals, total dissolved solids, fluoride, and nitrate.

G. Sewerage and Waste Systems

1. Sewerage

Jaipur currently has a sewerage network that covers only 56% of the population[1]. Most of the remaining population relies on septic tanks, while the slum population resorts to open defecation. It has been estimated that the total sewerage generated in Jaipur is 200 million liters per day, which the wastewater treatment plants currently do not have the capacity to treat. The Jaipur municipal area is divided into 8 zones containing 77 wards for administrative purposes. The Jaipur Municipal Corporation, Rajasthan Urban Infrastructure Development Project, Jaipur Development Authority, and Rajasthan housing board are responsible for laying sewer lines, which the Jaipur Municipal Corporation is responsible for maintaining. According to a recent presentation by an Executive Engineer of the Public Health Engineering Department of Rajasthan, there are a few sewage treatment plants in Jaipur, which can be viewed in Table 7.

Table 7: Current Sewage Treatment Plants of Jaipur

Capacity, Location, and Process	Operational Status
27 million liters per day at Brahmpuri- Extended Aeration Process	Sewage treatment plant is in operation at full capacity. 8 million liters per day tertiary treatment & treated water in use for lake filling. Sludge is digested in anaerobic digesters.
2 units of 62.50 million liters per day at Delawas- Activated Sludge Process	Both Sewage treatment plants in operation at full capacity. Gas produced from Unit-I used for power generation. Gases produced from Unit-II are to be sold to generate a revenue. The treated water discharged in the nala is used by farmers for agriculture.
50 million liters per day STP (North Zone)- Activated Sludge Process	Sewage treatment plant is in operation at $1/6^{th}$ capacity. Methane gas is to be produced and sold. Treated water discharged in nearby area used by farmers (free of cost).
30 million liters per day South Zone (Ralawata Jagatpura area)- Activated Sludge Process	Under Construction (Jaipur Development Authority)
30 million liters per day North area (Gajadhar pura kalwar road)- Activated Sludge Process	Under Construction (Jaipur Development Authority)
1 million liters per day at Jawahar circle- Moving Bed Bioreactor Process	In operation from 2-3 years. Treated wastewater is being used for gardening.
1 million liters per day at Ramniwas Bagh- Moving Bed Bioreactor Process	In operation for 1 year. Treated wastewater is being used for gardening
1 million liters per day at Swarn jaynti garden Vidhyadhar nagar- process- Moving Bed Bioreactor Process	Under construction (Jaipur Development Authority)

Source: 15

While there appears to be quite a few sewage treatment plants in Jaipur, it is difficult to get the status on how the treatment plants are running. In our travel to the Delawas Sewage Treatment Plant, we were told the plant had not been up and running for an extended period of time. The low percentage of those covered by a sewerage network is of concern, as sewage presents a great risk of percolating into the soil and polluting groundwater. This leads, among other things, to high nitrate levels, which is already of concern in Jaipur.

2. Solid Waste

The types of solid waste that are generated in Jaipur can mostly be considered municipal solid wastes (from residential and commercial sources), biomedical wastes, industrial wastes, and construction and demolition wastes. There is collection of solid wastes, although sources have greatly varying number on the percentage of the population covered by collection services. As of 2011 Jaipur had two landfill sites, Sewapura in the north and Mathura Daspura in the east, and financing of another site at Lengriwasa in the east through the Rajasthan Urban Infrastructure Development Project was ongoing[1]. The Jaipur Municipal Corporation is responsible for waste collection.

Street sweeping and door-to-door collection are the primary means of waste collection. This waste is then deposited in storage bins or at open storage points. However, while there are a few refuse vehicles, there are no specific waste collection norms in the city. Some places use a community bin system, in which residents and street sweepers can deposit their waste into the nearest community bins located at street corners and specific intervals. This system has created some issues, as an absence of adequate storage capacity leads to waste being dumped on the road. Some zones of Jaipur have private contractors for primary collection and waste disposal, with their own sweeping staff, waste collectors, and collection vehicles. Non-governmental organizations have also been contracted for house-to-house waste collection. There are only proper collection facilities in selected areas so it has been estimated that only 45% of waste is collected and 50% of the collection points are open storage points[1]. Remaining waste then goes into drains and open grounds are causing environmental problems. According to the 2025 Master Plan, "out of total waste generated only 40,000 MT/month waste is collected for processing/disposal, from which only 5,000 MT/month is sent for processing & recycling facilities and the remaining 35,000 MT/month of waste are disposed at disposal sites (274)."

The main concern regarding this lack of proper waste collection is that this solid waste can negatively affect storm water runoff, clog up water system canals and negatively impact treatment facilities, and just lead to general undesirable conditions in the streets.

H. The Impact of Climate Change on Jaipur

Some impacts of climate change have already been observed in Jaipur and climate change in the future will only exacerbate Jaipur's current water vulnerability. "The Uncomfortable Nexus: Water, Urbanization, and Climate Change in Jaipur, India" by Rathore et al. inspected evident climate change in Jaipur in recent years and projected the impacts of climate change on Jaipur in the future using four climate change scenario models[23]. The researchers did not find long-term decreasing trends in rainfall, but did observe that rainfall variability in general is high both on a year-to-year and seasonal basis. The researchers developed various climate change scenarios using output from two different global climate models each running two different emissions scenarios. All of the scenarios examined indicated the likelihood that the median annual rainfall is likely to decrease by 2040. Rainfall is expected to decrease in all seasons except the post-monsoon season, which includes October and November. The researchers believe that the changes in seasonal rainfall will have a greater impact on overall water supply management than changes in annual rainfall. Greater variability in annual rainfall and a higher possibility of more extreme years, both drier and wetter, are likely to occur. Overall, climate change, in addition to population increases and greater migration to Jaipur, will put more pressure on Jaipur's water supply vulnerability in the future.

V. Future Water Supply Scheme

A. Overview

There are various issues with the water supply in Jaipur, as discussed above. Jaipur was originally built with water management and traditional water conservation techniques incorporated into its urban plan. With the rapid urbanization of Jaipur after Independence, it appeared that people ignored the need to practice water conservation measures, likely because the government promised free water for all. Directly after Independence, per capita water use was still quite low and the population had much better health. With greater and greater urbanization, water use began to rapidly increase. In addition to increased water use due to population growth, as Jaipur became more modernized, people began to demand more water for daily needs. There are various strategies that can be employed at the household, municipal, and regional levels to mitigate Jaipur's water scarcity problems and create a more robust water management system. As one can see from the discussion thus far, there is a need for better water supply management.

B. Traditional Water Systems (A look at history, decline in use, and potential use for the future)

Historically, traditional technologies and systems could not meet the water demands due to the growth in population. The availability of modern and more convenient water supply through centralized storage systems such as reservoirs and canals became the official emphasis of the government, leading to the halt in expansion of traditional systems and disuse and deterioration of existing traditional systems. The government has developed a bias for large complex and costly systems with low capital efficiency, fostering a greater dependence on the state for all matters such as maintenance of existing systems. This has decreased community participation in maintenance and care of their water system. Communities have become disconnected from their water sources over time and are unaware of any water issues occurring. Traditional water systems were often kept small enough that they could be easily managed and controlled by the community by pooling together the needed capital, labor, and technical system. Economic independence and optimization of local resources operated at a micro-level. The community knew to take care of catchment areas and social prohibitions often curbed grazing in certain seasons, using catchment areas for toilet purposes, and dumping of animal carcasses. The modern systems that have replaced traditional systems depend on large-scale allocation of state funds and elaborate bureaucracy to manage them. These modern water technologies have mostly been imported from the West without regard to local conditions and features. All blame, however, cannot be put on the government for the decline in traditional water systems. Some water harvesting systems were caste-based, and British policies hardened caste hierarchies. Community-based systems were the antithesis to the British model of centralized rule[24], and after independence centralized rule and caste structures largely remained in place.

The forts built around Jaipur and the original layout of Jaipur exhibit traditional water harvesting techniques. However, these forts were not really incorporated in the construction of Jaipur and are located many miles outside the city. Maharaja Man Singh I built Amer Fort in 1592, Maharaja Jai Singh II built Jaigarh Fort in 1726 to protect Amber Fort, and Nahargarh Fort. Amber Fort was used as a palace for Maharajas and their families until the founding of Jaipur. Nahargarh Fort was constructed by Maharaja Sawai Jai Singh II was a place of retreat on the summit of the ridge above the city. One can view water drainage systems and water tanks at these forts, most notably at Jaigarh Fort. Jaigarh Fort has many wide water channels and three water tanks, with the largest tank having the capacity of storing 6,000,000 gallons of water. Water channels were built in the Aravalli catchment and conveyed water to Jaigarh Fort. Rainwater capture and storage systems are also present at Amer and Nahargarh Fort.

Recently, the government of Jaipur has looked to reemploy traditional water harvesting techniques. It is currently mandatory for all houses with more than 300 meters squared area to have rainwater harvesting structures[9]. The enforcement of this mandate is questionable, so the government will need to further invest in enforcement and other measures to make traditional rainwater harvesting techniques more widespread and a reliable strategy.

C. General Recommendations

1. Increasing Open Areas

As Jaipur has expanded, forestlands, agricultural fields, pasturelands, and open wasteland have decreased and paved area has increased. These open areas are important for soaking up rainwater and recharging the aquifers. Thus, the shrinking of vacant spaces has affected the rainwater supply to water-bearing rocks and has influenced the lowering of the water table in aquifers. As well, the increase in impervious areas not only inhibits the percolation of rainwater to recharge the aquifers, it also creates flooding issues, as the water has nowhere to go but follow the surface slope of the land. Recharge shafts/trenches could help alleviate the problems associated with storm water runoff.

2. Conservation of Surface Water

Surface water, in addition to being a source of water to the people of Jaipur, is important for recharging aquifers. Those water ponds that have not come under the influence of urbanization and pollution must be kept as pristine as possible for the sake of a clean water source and recharge of the aquifers with clean water. Water ponds that have come under the influence of urbanization and pollution should be restored, as this pollution may infiltrate and degrade the quality of groundwater (which is near-impossible to fix once it has been degraded). Unaccounted for settlements, agriculture, and industry around surface water sources must be restrained as much as possible. In addition, curtailment of construction that would cause diversions of water flow must be implemented so that these surface water sources have the opportunity to fill, as well as recharge groundwater sources. Coupled to the avoidance of water flow obstruction, pollution in the catchment area must be minimized so that surface water and groundwater quality does not become degraded.

3. Fluoride Pollution

Fluoride pollution as a result of textile dying, and industrial effluents discharge in general needs to be of concern, especially in the Sanganer area. While fluoride pollution may be a result of the lowering of the groundwater table thus magnifying the already present fluoride from fluoride bearing minerals, textile dying also contributes to high fluoride content in waters. The Sanganer area is home to many textile industries. Fluoride pollution greatly degrades both surface and groundwater sources. Industrial effluents must be treated before their disposal into the precious nalas of Jaipur. Deflouridation treatment must be required for these industries, and low-cost domestic defluoridation technologies are available. It would be even more beneficial if high fluoride rich dyes were banned, and only the use of organic dyes were allowed.

4. Pollution Prevention and Minimizing the Use of Fresh Water in Industrial Areas

Regulations should be put in place that effectively ban the discharge of industrial wastes into water bodies and require treatment of these effluents before release into water bodies. Arrangements should be made for effective collection of semi-solid and solid wastes from industries, as well as institutions such as area hospitals, so carcinogenic or infectious materials do not pollute water bodies or groundwater. Water-intensive industries and activities must not be further permitted in areas deemed over-exploited for groundwater and incentives for the adoption of recycling and reuse of wastewaters should be put in place to minimize unnecessary use of fresh water sources. Optimally the government must formulate a plan for the treatment of sewage and industrial wastewaters, and use this reclaimed water for activities that do not necessarily need potable water, such as the irrigation of crops and lawns, toilet flushing, and industrial cooling towers.

5. Curbing Nitrate Pollution

Nitrate pollution is also a large concern in many areas of Jaipur. Investment in sanitation and sewage disposal systems, especially in thickly populated areas such as the walled-city is the most appropriate and effective way to curb further nitrate pollution in these areas as nitrate pollution in Jaipur is largely a result of crowding, a shallow aquifer, and a lack of a proper sewerage system. A proper sewage disposal system must be employed and maintenance should be given a priority.

6. Educating the Public

Investment must be made in stronger waste collection systems for domestic wastes. Education and public awareness campaigns must be put in place to curb the pollution of water sources from domestic solid and sewage wastes and to promote the conservation of fresh water. The public must be made aware of the severity of water scarcity in Jaipur, and techniques to conserve water must be communicated to the public. Some of the technical techniques include incentives for installation of rainwater collection and storage technologies and the use of dual water supply systems (using water of inferior quality for purposes other than drinking). Some domestic water saving techniques that must be communicated to the public include using a container of water for shaving and teeth brushing instead of using flowing tap water, bathing using buckets instead of bathtubs or showers, and the use of a bucket for clothes washing instead of more water intensive techniques. If the public does not understand the severity of water issues in Jaipur, they will not voluntary chose to adopt these behaviors.

7. Groundwater Regulatory Measures and Conservation of Groundwater

Advances in technology and a lack of surface water sources after Ramgarh rapidly depleted in the 1980s and 1990s have resulted in an enormous increase in extraction of groundwater in the Jaipur region. As a result, some estimates place lowering of Jaipur’s water table at 1 meter per year with most of the Jaipur urban area groundwater system as over-exploited. A decrease in open areas has also affected the amount of land area available to serve as a source of recharge to groundwater. With Bisalpur as a new source of water for Jaipur, one would hope that the dependence on groundwater will decrease, but other techniques such as regulatory measures on groundwater extraction must occur as well. Regulatory measures on groundwater may encounter obstacles, especially since people have control over groundwater under their property, there are tens of thousands of unaccounted for wells in Jaipur, and government distribution of water does not reach all the population of the Jaipur region. There is no legislation currently in place to prohibit withdrawal of groundwater by any private agencies. Permitting for further construction of groundwater extraction structures and registration of drilling agencies should be made mandatory and enforced to the greatest extent possible. Metering of new wells should occur, and groundwater should only be mined in proportion to the possessed land area. As groundwater is used extensively for agricultural purposes, it should be required that large-scale agricultural programs employ drip agricultural methods if they are to use groundwater sources. The government should invest in recharge shafts/trenches in order to allow for protection against flooding and recharge to aquifers.

8. Development of Natural Resource and Land Use Monitoring System

It is necessary for the government to monitor land use through technology such as remote sensing. Unplanned expansion of the city and encroachments must be kept in check to alleviate problems to both the environment and people living in the area. Urban growth boundaries must be put in place so that further obstruction of natural water flow does not occur.

9. Rooftop Rainwater Harvesting

Recently rooftop rainwater harvesting, the accumulation and deposition of rainwater for reuse before it reaches the aquifer, has been made mandatory in state owned building of plot sizes more than 300 meters squared by the Central Ground Water Board of India. This rainwater can also be stored in a pit to percolate downward through a recharge tube well. All newly constructed government buildings are to have rooftop rainwater harvesting structures. This must be strictly enforced and incentives must be created to encourage the construction of domestic rooftop rainwater harvesting structures.

10. Investment in Update of Distribution Systems and Metering

Current distribution losses in Jaipur’s water system are estimated at about 40-50%. It has been estimated that 80% of the total water loss in the system is due to leaky service mains. These losses result in both loss of revenue to the water department and low pressure for customers. These service lines have an average life span of 10 years, and must be serviced regularly at 10-year periods[11]. A missed opportunity for revenue is also occurring because of an inadequate water metering and tariff system. There are varying degrees of knowledge when one asks Jaipur’s residents if their water supply is metered and priced. Many meters are not functioning or not checked on a regular basis and the tariff system is undefined. A system must be put in place for regular meter checks so that billing can be done fairly and uniformly (i.e. customer does not get overbilled or underbilled), and to keep track of the status of these meters so they may be repaired if need be. In some areas, supply is not metered and is limited to certain time periods.

Some residents claim to have never seen a water bill. Investment should be made in installing and updating water metering systems. While this may be a large initial cost, increased revenue to the water department will pay off these costs and allow for funds for other water projects. Water tariffs must be put in place at least to cover operation and maintenance charges so the water department does not incur a net loss in revenue.

11. Conservation of Water in the Irrigation Sector

The government should initiate metering systems over wells so water charges for the intensive use of water in agriculture can be levied. Currently, this sector consumes 85% of the water supply. Incentives for growing low water requirement and salt tolerant crops in saline water areas and the installation of sprinkler and drip irrigation systems should also occur.

12. Artificial Recharge from Paved Areas

Paved areas inhibit recharge to groundwater; however, constructing recharge shafts/trenches, using pervious pavement, and improving existing storm water drain designs along roads, footpaths, etc. can initiate artificial recharge.

D. Policy Recommendations and Future Challenges

In order for the urban water supply and sanitation system to be fully successful, one must ensure that the government and policies are robust enough for the systems being proposed[11]. A shift in how the water supply sector is viewed must occur—the water supply and sanitation sector must be recognized as a utility service so that full cost recovery can be achieved. Adequate subsidies should be provided in a transparent manner to the poor in order to meet minimum water and sanitation requirements for all in Jaipur. Efforts must be made to achieve cost reduction in various areas such as manpower, energy consumption, reduction in the waste of water, and improvements in billing and collecting. The government and water supply agencies must be invested in maintenance of the system on a continuous basis, with comprehensive metering as a necessary policy. Greater inclusion of private companies in installation, operation, and management in the water supply and sanitation sector could also save the government money. These private water utilities would be required to maintain service connections at their own cost. The government and regional institutes could collaborate in order to provide training courses for those in or interested in the water supply and sanitation sector at different levels of education to both entice new workers in the field and ensure adequate educational preparedness. As discussed above, the government must pass and enforce legislation to curb overexploitation of groundwater, avoid deterioration of groundwater quality, and reduce the cost of pumping (incurred when pressures are low in the pumping system due to a lower water table). The government must also put in place legislation or incentives to promote the reclamation and reuse of sewage after an appropriate degree of treatment for uses such as horticulture, flushing sewers and toilets, air conditioning, cooling, and many other industrial uses in order to conserve fresh and potable water and reduce pollution load in receiving water body[11]. Lastly, the government should have an open dialogue with leaders of various communities or interested community groups to determine necessary allocation of water sources for various activities. It will be up to both the government and those involved to enforce this allocation of resources. There are various steps that the government must take to ensure an adequate water supply and sanitation system, as without policy measures passed by the government and enforcement of these policies, an inadequate system will surely persist.

VI. Conclusion

This document has addressed the need for a more robust water management system in order to combat the water scarcity issues in Jaipur. While Jaipur does only receive an average of 600 millimeters of precipitation per year, mostly in the monsoon months of June-September, we believe that Jaipur's water scarcity issues are mostly attributed to management issues. Jaipur is considered one of the first planned cities of India, and when founded in 1727, adequate water supply for its citizens was a major concern. As Jaipur grew in population many measures had to be taken to maintain an adequate water supply. It appears that the problems that have laid the foundation for Jaipur's water scarcity issues today can be attributed primarily to a great population boom and rapid expansion of the city in the mid-1900s without adequate consideration of issues around the city layout and water supply. A huge boom in population and rapid industrialization occurred when Jaipur became the capital of Rajasthan after Independence, which put a great strain on the water supply system. At that time, Jaipur was relying primarily on the Ramgarh reservoir, in addition to some tube wells. The increasing strain led to the drawdown and eventual complete drying of Ramgarh reservoir by the 1990s. Until 2009, when the Bisalpur Dam began supplying water to Jaipur, Jaipur was almost exclusively dependent on groundwater causing extreme overexploitation and lowering of the water table. While Bisalpur reservoir will allow for an alleviation on the pressures put on groundwater, estimates for how much water it is bringing to Jaipur appear to vary by source, Bisalpur is highly dependent on highly variable rainfall patterns, and water from Bisalpur is not exclusively used by Jaipur but shared with Ajmer and villages of the Tonk district. Calculations of water supply and demand consistently show a supply deficit. In addition to unreliable water sources for the future if the status quo continues, there are other problems compounding water issues in Jaipur. Drinking water quality is also a serious concern in some areas of Jaipur. Inadequate sewerage and waste disposal are having negative effects on water sources and the environment, in general. The potential effects of climate change could also exacerbate all these problems. Some measures must be taken to ensure the future of Jaipur.

The future picture of Jaipur's water supply is not completely bleak, however. With investment by the government to change the system in place now, Jaipur could have a sustainable water future. This will be difficult, but it is achievable. Measures such as increasing open areas in Jaipur, creation of artificial recharge zones, educating the public on water issues and conservation, reclamation and reuse of wastewater, rooftop rainwater harvesting, and investment in updating the water distribution and metering system could all help to improve the water supply system and Jaipur as a whole. Policy challenges must be overcome, but it is definitely possible to transform Jaipur from a city with extreme water scarcity issues to a city with a sustainable water supply for the future.

Works Cited

1. Joshi, K.N. Status Report on Urban Reform in Rajasthan for The Urban India Reforms Facility (UIRF) at Institute of Development Study Tata Institute of Social Sciences. Prepared by Institute for Development Studies, 8-B Jhalana Institutional Area, Jaipur, Rajasthan, India. June 2011. Working Paper.
2. *Jaipur City Map.* 2012. *Jaipur Maps, Jaipur Travel Guide, Jaipur Tourism Portal Jaipur Rajasthan.* Web JPEG. http://www.jaipurtravel.com/jaipur_maps.htm
3. Joshi, K.N., Vinod Agrawal, and Bhawna Chawla. Environmental Impact Study on Degradation of Natural Resources in Urban Area and Strategy for Sustainable Development. Prepared by Institute of Development Studies, 8-B Jhalana Institutional Area, Jaipur, Rajasthan, India. Sponsored by Indian Council of Social Science Research, New Delhi. 2009. Working Paper.
4. *Rainfall Data*. Government of Rajasthan Department of Water Resources. Web. < http://waterresources.rajasthan.gov.in/Daily_Rainfall_Data/Rainfall_Index.htm>
5. Joshi, KN. Shrinking of Water Resource Due to Anthropogenic Activities in Urban Area (A Case Study of Jaipur Using Remote Sensing and GIS). Prepared by Institute of Development Studies, 8-B Jhalana Institutional Area, Jaipur, Rajasthan, India. 2010. Working Paper.
6. "Master Development Plan-2025: Jaipur Region." Jaipur Development Authority. 2011. Web PDF.
7. Dass, Amit, A.S. Jethoo, and M.P. Poonia. "Impact of Drought on Urban Water Supply: A Case Study of Jaipur. *International Journal of Engineering and Innovative Technology*. 1.3 (2012): 170-174. Print.
8. Jethoo, A.S. and M.P. Poonia. "Sustainable Water Supply Policy for Jaipur City." *International Journal of Environmental Sciences*. 1.6 (2011): 1235-1240. Print.
9. Sharma, Dinesh. "Drinking Water Management of Jaipur City." Web Lecture. 11 Dec. 2013. http://jaipur.nic.in/pdf/phedcity.ppt
10. Nathawat, G.S. "Water Supply in Jaipur: Retrospect and Prospect." In Urban Water Management. Edited by Rathore, M.S. and Reddy, V. Ratna. Institute of Development Studies, Jaipur. Rawat Publications: Jaipur, 1996. 159-171. Book.
11. Bhargava, S.P. "Status of Jaipur Water Supply." In Urban Water Management. Edited by Rathore, M.S. and Reddy, V. Ratna. Institute of Development Studies, Jaipur. Rawat Publications: Jaipur, 1996. 172-195. Book.
12. Bhat, N.P. "Jaipur Water Supply." In Urban Water Management. Edited by Rathore, M.S. and Reddy, V. Ratna. Institute of Development Studies, Jaipur. Rawat Publications: Jaipur, 1996. 196-204. Book.
13. *Jaipur District Map.* 16 Jan. 2012. *MapsofIndia.com* Web JPEG. < http://www.mapsofindia.com/maps/rajasthan/districts/jaipur.htm>

14. *Jaipur, Rajasthan, India*. 21 Dec. 2013. *Google Maps*. 21 Dec. 2013. Web Map. < https://maps.google.com/>
15. Jain, Satish. "Drinking Water Management of Jaipur City: Issues & Challenges." Web Presentation.
16. "Benchmarking of Urban Water Supply Schemes of Rajasthan: Milestone #4: Problem Analysis and Remedial Measures- Jaipur City." Public Health Engineering Department Government of Rajasthan. Prepared by SMEC International PTY. LTD. Oct. 2012. PDF.
17. "Census of India-2011: 2011 Rajasthan." Directorate of Census Operations Rajasthan, Jaipur. CD.
18. "Report on Less/no inflow in Ramgarh Sam District Despite Average and Above Average Rainfall and Remedial Measures to Restore." Government of Rajasthan Technical Committee. 9 Jan. 2013. PDF.
19. "Status of Groundwater Quality in India- Part II." Central Pollution Control Board. Ministry of Environment and Forests. Government of India. April 2008. Web PDF. 23 Dec. 2013. <www.cpcb.nic.in/upload/NewItems/NewItem_50_notification.pdf>
20. "Groundwater Related Problems of Jaipur City and Suitable Water Harvesting Scheme." Geological Survey of India. Western Region. Web PDF. 23 Dec. 2013. www.portal.gsi.gov.in/gsiDoc/pub/cs_gw_jaipur.pdf
21. Srivastava, Preeti and Nisha Jain. "Assessment of Potable Water Quality of Jaipur and Its Impact on Public Health." *Journal of Chemical, Biological, and Physical Sciences*. 2.4 (2012): 2151-2157.
22. "Benchmarking of Urban Water Supply Schemes of Rajasthan: Conjunctive Use of Water- Jaipur District. Public Health Engineering Department Rajasthan. Prepared by SMEC International PTY. LTD. Oct. 2012. PDF.
23. "The Uncomfortable Nexus: Water, Urbanization, and Climate Change in Jaipur, India." Prepared by Centre for Environment and Development Studies, Jaipur and Institute for Social and Environmental Transition. Sponsored by United States National Oceanic and Atmospheric Administration. July 2011. Web PDF.
24. "Central Highlands." Dying Wisdom: Rise, fall and potential of India's traditional water harvesting systems. Ed. by Agarwal, Anil and Narain, Sunita. State of India's Environment: A Citizens' Report. Centre for Science and Environment. Thomson Press (India) Limited: Faridabad, 1997. 152-175. Book.
25. "Benchmarking of Urban Water Supply Schemes of Rajasthan: Milestone #2: Performance & Operational Status of Water Supply Schemes: Jaipur District." Public Health Engineering Department Government of Rajasthan. Prepared by SMEC International PTY. LTD. Dec. 2012. PDF.
26. "EC Technical Support and Facilitation Mission- Rajasthan, 2004: Focus on water." Prepared by Team of Consultants for the EC Technical Support and Facilitation Mission to Rajasthan, 2004. Final Draft Report. Jan. 19 2005. MS Word Document.
27. Joshi, K.N. Depleting Water Resource in Urban Area. Prepared by Institute for Development Studies, 8-B Jhalana Institutional Area, Jaipur, Rajasthan, India. July 2010. Pamphlet.
28. "Man Sagar Restoration Model…success through INNOVATION." Jal Mahal Resorts Pvt. Ltd. Jal Tarang Jal Mahal Valley. 4 March 2013. Web Presentation.
29. "Master Development Plan-2011: Jaipur Region." Jaipur Development Authority. 2009. Web PDF.

30. Mishra, Anupam. "The Radiant Raindrops of Rajasthan." PDF.
31. Purohit, Brijesh C. and Siddiqui, Tasleem A. "Urban Water Supply in Rajasthan: A Case Study of Jaipur City." In Urban Water Management. Edited by Rathore, M.S. and Reddy, V. Ratna. Institute of Development Studies, Jaipur. Rawat Publications: Jaipur, 1996. 132-158. Book.
32. "Rajasthan Water: Problems and Solutions." Prepared by Jal Bhagirathi Foundation. MS Word Document.
33. Rathore, M.S. "Bisalpur Water Panacea for Drinking Water Scarcity: Reality or Myth?" Centre for Environment and Development Studies Jaipur. MS Word Document.
34. "Water and Environment Sector Report: Annex 1: State Fiscals and Mid-term Expenditure Framework." Prepared by EC Technical Support and Facilitation Mission-Rajasthan. MS Word Document.
35. "Water and Environment Sector Report: Annex 7." Prepared by EC Technical Support and Facilitation Mission- Rajasthan. Dec. 2012. MS Word Document.
36. "Water and Environment Sector Report: Annex 11: Governance and Institutional Assessment." Prepared by EC Technical Support and Facilitation Mission- Rajasthan. MS Word Document.

Definitions/Terms

Nala: A stream or drain; A gully or ravine (Alternative spellings: nullah, nalla)
Talao: A water storage structure; A lake
Stepwell/Baorie: Wells or ponds in which the water may be reached by a descending set of steps; May be covered and protected, and often of architectural significance.
Tube well: A type of water well in which a long, wide stainless steel tube or pipe is bored into an underground aquifer
Mohalla/Chowkrie: An area of a town or village; A community; A subdivision or neighborhood
Kund: Underground water tank
Anicut: A barrier constructed across a waterway to control the follow or raise the level of water; A dam or mole made in the course of a stream