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Water Harvesting through Inter-basin Transfer Technique for part of Visakhapatnam Urban Area using Geo-Spatial Technology

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Abstract

The increasing demand of the water resources in urban environment requires the formulation of scientific methods to augment them. In this paper a methodology has been demonstrated for the development of these valuable water resources in the urban watershed of Visakhapatnam, the second largest metropolitan city in Andhra Pradesh using geospatial technology. This methodology is based on a detailed examination of the existing tanks in the study area using both spatial technology and ground based observations. Total Station survey for the existing surface tanks in the study area along with Geophysical investigations are carried out to identify the thicknesses of top soil, weathered rock, fractured rock and hard rock formations, to assess the volume of the groundwater that can be stored in the aquifer system and accordingly rainwater harvesting structures are suggested, which collects the runoff and recharges the aquifer zone. Inter-basin transfer technique is suggested to recharge the tank catchments having high aquifer storage capacity and low surface area from neighboring tank catchments having more surface area and rainfall runoff.

Introduction

Utilizing and recharging the storm water created by urban runoff to avoid inundation/flooding best achieve the development of groundwater. Depending upon the topographic, geological conditions and infiltration capabilities of the area under consideration, suitable recharging techniques like contour trenches, recharge pits, recharge wells, retention ponds etc. are useful (Singh et al., 2017; Albert et al., 2002; Roy et al., 2017). The soils existing in the study area are below 5m in thickness, 5m deep recharge well (Breusse, 1963; Jacob et al., 1999) is suggested as the rainwater harvesting structure for the study. The lithological data clearly indicate an alternating sequence of clay and sand in which deep aquifers made up of coarse sand would be best suited for adequate water supply and good groundwater quality (Krishnamurthy et al., 1996; Musa et al., 2014). Land Cover is defined as observed physical features on the Earth's Surface (Kanga et al., 2017; Tomar et al., 2017; Singh and Kanga, 2017; Sadhu et al., 2017). When an economic function is added to it, it becomes Land Use (Singh, 2016; Obi et al., 2000). Roads in the residential colonies vary between 10 m to 25 m wide and nearly the road network occupies 25 to 30% of the colony area. There are open lined drains on either side of the roads which carries the storm water generated from the houses, roads and the daily used sullage / sewage water. If underground drainage system is adopted in the colony, the contribution of storm water to these drains is only from the houses and roads. The authorities must bring the awareness in the public regarding the storm water utilization program as the road runoff gets polluted by the oil spills from the automobiles, pet waste etc. that require some treatment before reaching into any of the storage or ground water recharge structures. Controlling of floods and waterlogging hazards in highly flood-prone regions of India, including Bihar state has been largely response oriented with little or no attention to mitigation and preparedness (Pratap et al., 2000; Venkateswaran and Jayapal, 2013). Land use change dynamic and water quality assessment techniques were estimated to examine the impact of urbanization on the river and its water quality especially as along the river the urban encroachment has developed haphazardly and in unplanned way in recent years (Saraf and Choudhary, 1998).

The sending out zone can encounter lessened streams, changed regular hydrology, or diminished weakening, all of which can adversely effect on the riverine natural assets that give immediate and aberrant advantages to populaces living in the territory (Shahid and Nath, 1999). For instance, diminished weakening can contrarily effect on the nature of water and in this manner the soundness of individuals and creatures utilizing the water (Srinivasa and Jugran, 2003). The bringing in zone can encounter flooding of streams; changed water temperature, science and quality; and water logging, which may affect contrarily on sea-going environments (Subba et al., 2001). Imported water can likewise worsen scouring and disintegration in the accepting streams. The disintegration may adjust the streams important to immerse floodplains/wetlands and effect adversely on rural efficiency and floodplain/wetlands biological communities. Water exchange plans have apparent advantages in water insufficient regions, yet in the event that not painstakingly evaluated, instream biological impacts of such exchanges can have genuine financial and ecological effects on downstream riparians1 in both the sending out and bringing in regions (Rao et al., 2009). For example, an excessive amount of water than ideal, could be exchanged to the bringing in territory at a high open door cost for lost biological asset/biodiversity esteems and thus decreased social welfare (Rao., 2004). It is, along these lines, imperative to coordinate instream environmental contemplations into sectoral administration of water assets with a specific end goal to amplify the immediate and backhanded social advantages of water asset utilize. In numerous nations strategies used to oversee between bowl waters are typically in view of sector by-division advancement approaches went for meeting monetary segment's shortfalls. These methodologies don't coordinate riverine biological contemplations into water administration programs and subsequently, regularly prompt fracture as opposed to incorporation looked for by socially and earth feasible improvement.

Study Area

The study area lies between 17^0 47' 02" N to 17^0 48' 38" N latitudes and 83^0 11' 51" E to 83^0 14' 45" E longitudes, covering an aerial extent of 9.18 km^2 covering under part of Survey of India (SOI) Toposheet – 65 O/1 SE (Figure 2a) of 1:25,000 scale and the study area falls within the administrative boundaries of Greater Visakhapatnam Municipal Corporation (GVMC) of Visakhapatnam, Andhra Pradesh (Figure 1). Three major tanks existing at Sujathanagar, Laxmipuram and Chinamushidiwada drain the study area. Because of rapid urbanization there is an urgent need to protect these valuable water resources. Catchment boundaries for these tanks are shown in Figure 2b.

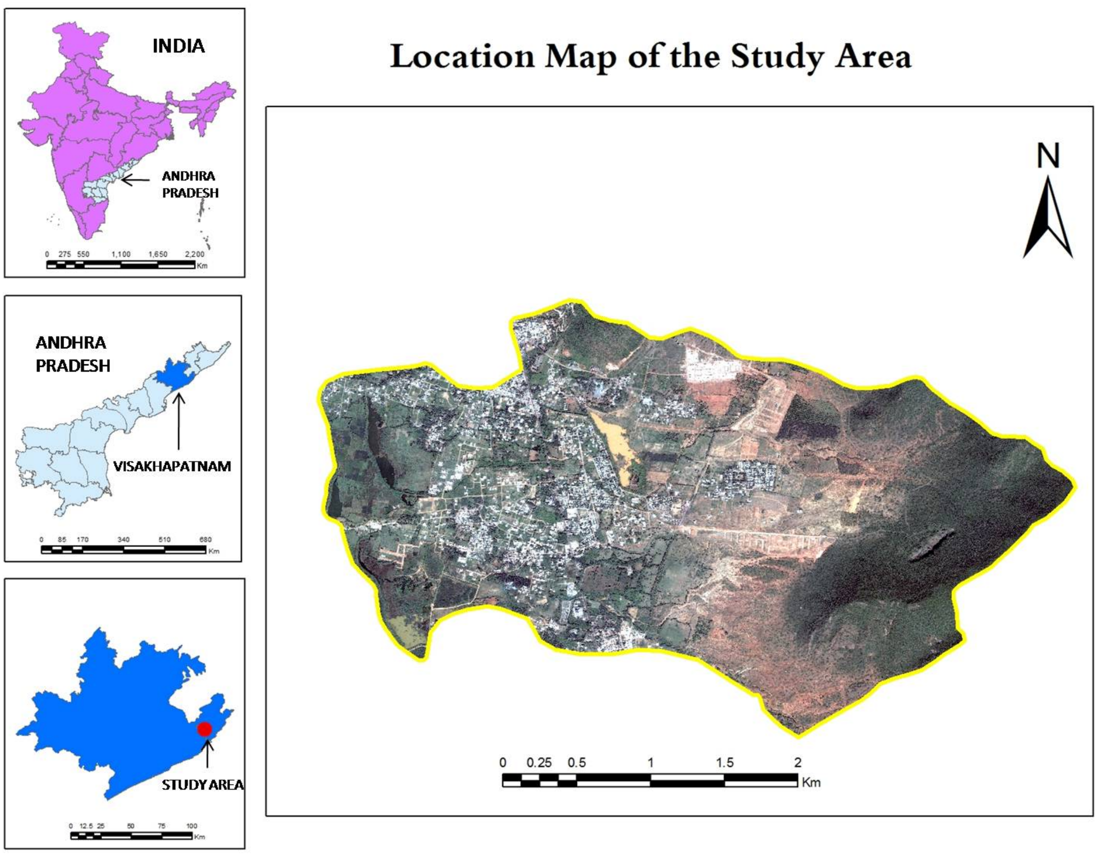
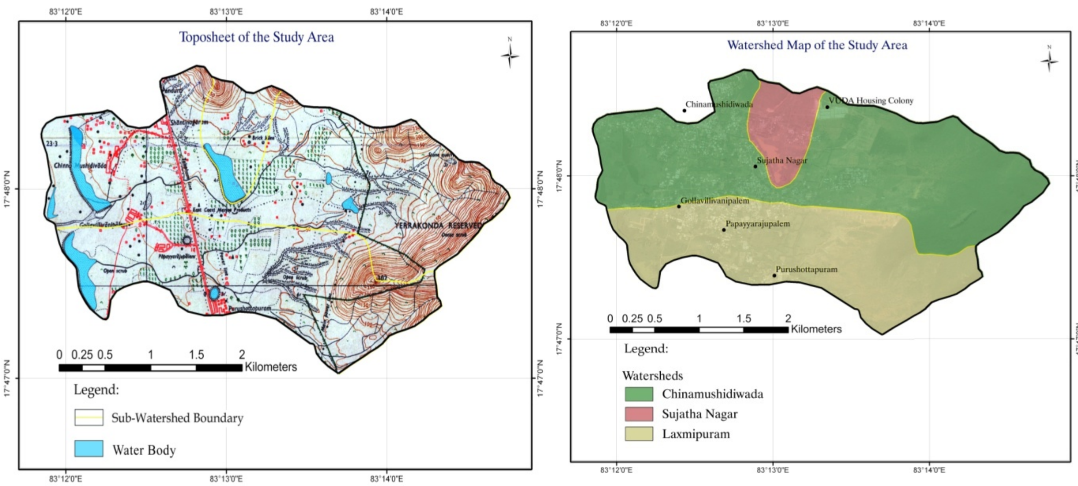


Figure 1 Location map of Study Area



(a) (b)

Figure 2 Toposheet of Study Area (a) and Tank Catchment boundaries (b).

Materials and Methods

Total station survey has been carried out in the study area and Subsurface lithology is identified using Schlumberger method of resistivity survey at thirty locations in and around the study area (Figure 3) and accordingly the corresponding thicknesses for weathered, fractured, hard fractured and hard rock surfaces are determined, which are tabulated in Table 1.

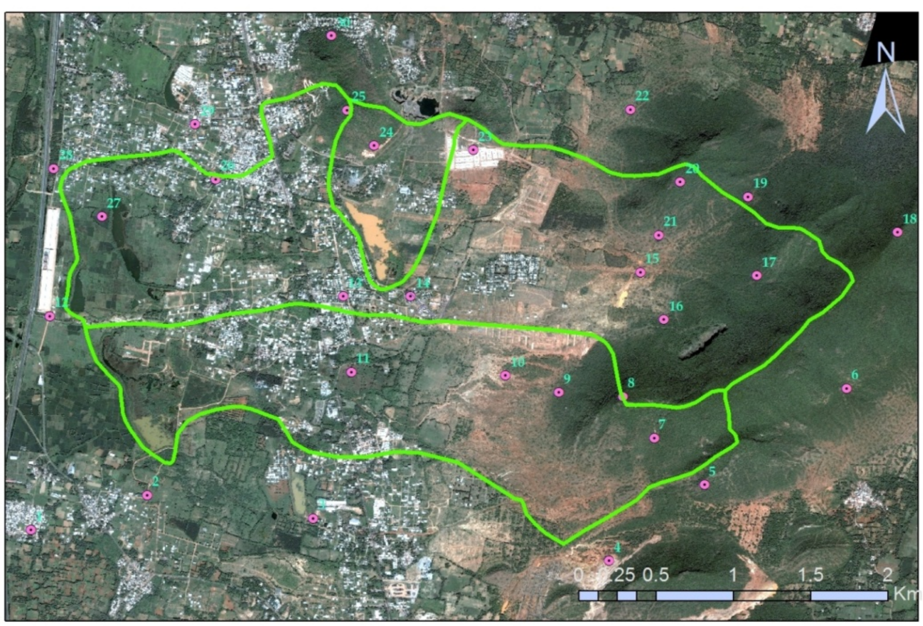


Figure 3 Locations of 30 VES data sampling stations

The Isopach map (Figure 4) generated represents equal thickness of the different units used generally to represent the subsurface layers indicates that the thickness of the water yielding zone is within 20 meters range in the hilly and pediment zones whereas the maximum thickness of more than 60 meters is in the central parts of the study area.

Table 1 Elevation data of surface and subsurface layers

VES No	Type of Curve	Resistivity Ω-m	Thickness (Meter)	Depth (meter)	Lithological Units
1	H	38	1.19	1.19	Red Loamy Soil
		13.2	12	13.20	Weathered Rock
		220	-	-	Fractured Rock
2	QH	35.4	0.5	0.50	Red Loamy Soil
		18.7	2.46	2.96	Gravel
		8.01	16.9	19.90	Weathered Rock
		2219	-	-	Hard Rock
3	H	37.1	2	2.00	Red Loamy Soil
		14.7	19.4	21.40	Weathered Rock
		3804	-	-	Hard Rock
4	HA	137	1.34	1.34	Gravel & Boulder
		41.2	2.23	3.57	Weathered Rock
		181	23.5	27.07	Fractured Rock
		269	-	-	Hard Fractured Rock
5	H	1436	0.5	0.50	Gravel & Boulder
		244	12	12.50	Fractured Rock
		486	-	-	Hard Fractured Rock
6	H	247	1.92	1.92	Gravel & Boulder
		123	10.6	12.52	Weathered Rock
		357	-	-	Hard Fractured Rock
7	QH	563	0.524	0.52	Gravel & Builder
		236	5.92	6.44	Gravel
		47.2	8.14	14.58	Weathered Rock
		364	-	-	Hard Fractured Rock
8	HA	1872	0.8629	0.86	Gravel & Boulder
		75.159	0.9943	1.86	Gravel
		558.21	49.121	50.98	Hard Fractured Rock
		1071	-	-	Hard Rock
9	H	355	1.29	1.29	Gravel & Boulder
		88.4	9.38	10.67	Weathered Rock
		327	-	-	Hard Fractured Rock
10	QH	122	0.672	0.67	Gravel & Boulder
		54.9	1.84	2.51	Gravel
		29.9	14.1	16.61	Weathered Rock
		148	-	-	Fractured Rock

Table 1 continued…

VES No	Type of Curve	Resistivity Ω-m	Thickness (Meter)	Depth (meter)	Lithological Units
11	HA	28.9	1.34	1.34	Red Loamy Soil
		9.69	2.23	3.57	Clay
		21	22.2	25.77	Weathered Rock
		3070	∞	-	Hard Rock
12	QHK	27.7	0.91	0.91	Red Loamy Soil
		895	7.89	8.6	Weathered Rock
		2926	∞	-	Hard Rock
13	H	48.9	1.01	1.01	Red Loamy Soil
		20.2	18.1	19.11	Weathered Rock
		382	∞	-	Fractured Rock
14	HA	128	0.5	0.50	Gravel & Boulder
		17.9	4.54	5.04	Weathered Rock
		47.9	61.7	66.74	Fractured Rock
		6480	∞	-	Hard Rock
15	H	85.1	2.59	2.59	Gravel & Boulder
		14.7	3.13	5.72	Weathered Rock
		146	∞	-	Fractured Rock
16	HA	191	1.7	1.70	Gravel & Boulder
		28.9	3.7	5.40	Weathered Rock
		89.9	43.8	49.20	Fractured Rock
		4663	∞	-	Hard Rock
17	HKH	816	1.02	1.02	Gravel & Boulder
		44.4	1.25	2.27	Weathered Rock
		1280	2.3	4.57	Boulder
		119	7.68	12.25	Fractured Rock
		722	∞	-	Hard Fractured Rock
18	HK	1677	1.81	1.81	Gravel & Boulder
		661	11.5	13.3	Fractured Rock
		1356	∞	-	Hard Fractured Rock
19	H	468	1.99	1.99	Gravel & Boulder
		53.7	2.38	4.37	Fractured Rock
		1168	∞	-	Hard Fractured Rock
20	H	2138	0.961	0.96	Gravel & Boulder
		436	7.84	8.80	Fractured Rock
		1442	∞	-	Hard Fractured Rock

Table 1 continued…

VES No	Type of Curve	Resistivity Ω-m	Thickness (Meter)	Depth (meter)	Lithological Units
21	HA	249	1.34	1.34	Gravel & Boulder
		71.1	2.23	3.57	Fractured Rock
		363	21.9	25.47	Hard Fractured Rock
		629	-	-	Hard Rock
22	HA	203	1.58	1.58	Gravel & Boulder
		47.9	2.29	3.87	Weathered Rock
		216	35.5	39.37	Fractured Rock
		24848	-	-	Hard Rock
23	QH	203	0.744	0.74	Gravel & Boulder
		136	4.41	5.15	Hard Fractured Rock
		28.8	8.81	13.96	Fractured Rock
		318	-	-	Hard Fractured Rock
24	HA	162	1.34	1.34	Gravel & Boulder
		30.3	2.23	3.57	Weathered Rock
		117	22.2	25.77	Fractured Rock
		435	-	-	Hard Fractured Rock
25	H	1046	1.11	1.11	Boulder
		162	6.07	7.18	Fractured Rock
		498	-	-	Hard Fractured Rock
26	HA	12.3	0.938	0.94	Red Loamy Soil
		2.93	1.36	2.30	Clay
		27.1	63.6	65.90	Weathered Rock
		1164	-	-	Hard Fractured Rock
27	H	3.01	2.04	2.04	Clay
		7.82	15.2	17.24	Weathered Rock
		11377	-	-	Hard Rock
28	H	47.9	1.2	1.20	Gravel
		13.4	4.46	5.66	Weathered Rock
		229	-	-	Fractured Rock
29	QHA	46.3	0.5	0.50	Red Loamy Soil
		23.6	1.53	2.03	Gravel
		4.1	2.2	4.23	Clay
		25.3	16.1	20.33	Weathered Rock
		14887	-	-	Hard Rock
30	H	370	1.26	1.26	Gravel & Weathered
		161	6.38	7.64	Fractured Rock
		608	-	-	Hard Fractured rock

From all the vertical cross sections, it is clear that the thickness of the water bearing formations i.e., weathered and fractured rock zones has increased from the foot hill regions to the low lying areas of the study area. Over the hill slopes and hill ridges, hard rock is present immediately below the top soil. Even though there is some fractured rock zones noticed over the hill slopes, these may not contain aquifer system but may guide the rainwater to percolate from the top soils into the aquifer system down below.

However, the hill slopes are useful to retain rainwater for some time and release it into the aquifer system existing down below the foot hill region. Therefore this zone is considered to be suitable for constructing harvesting structures, like contour trenches. Apart from rainwater harvesting structures, inter-basin transfer technique, a method to transport rainwater between two tank catchments, is suggested.

Inter-basin transfer method

The process of rainwater harvesting is catchment based and can be recharged in a particular tank catchment only. Sometimes we may come across situations where there will be lager catchment area and less potential aquifer system. In contrast, there might be a tank catchment, adjacent to the previous one, having aquifer with large storage volume but with lesser catchment area. To benefit this kind of situations, the study suggested a method, inter-basin transfer technique, in which the rainwater will be collected from the rainwater harvesting structures and transferred to the adjacent tank catchment at suitable location through subsurface.

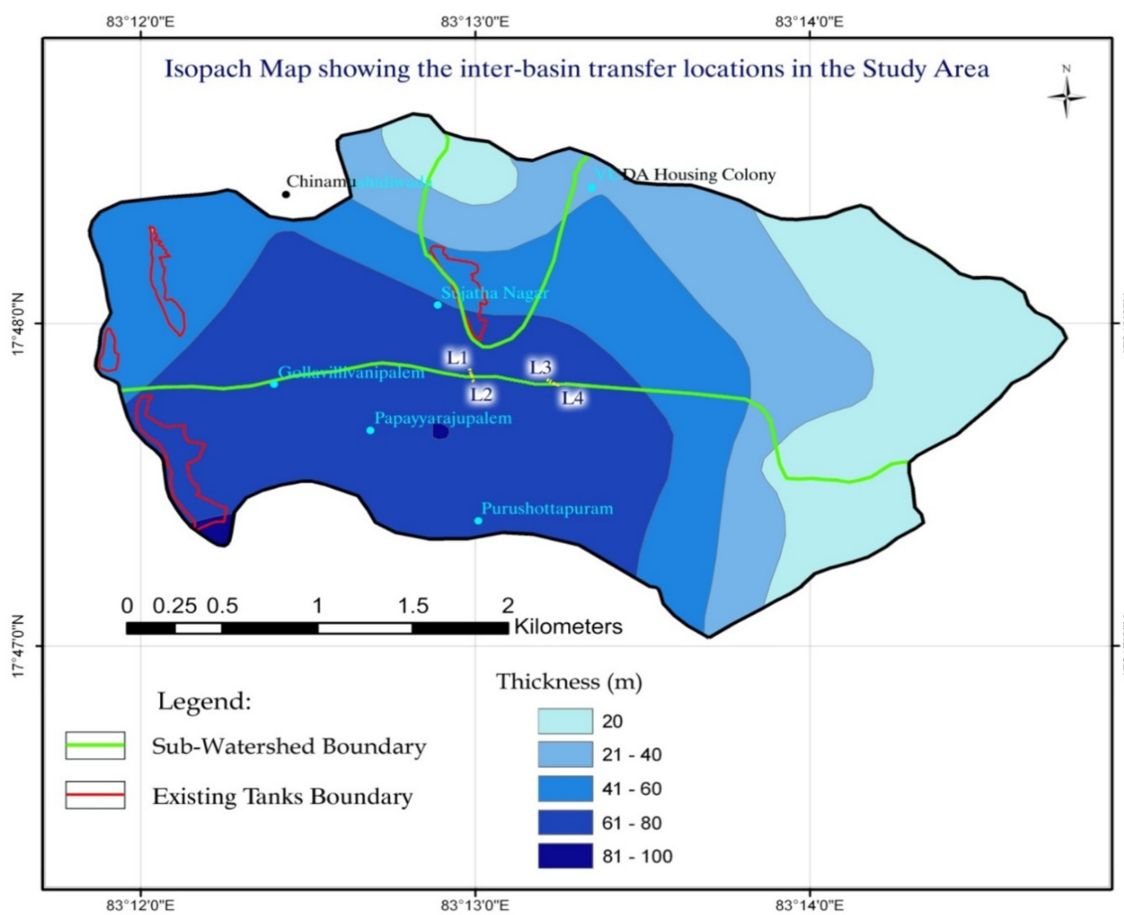


Figure 4 Isopach map showing inter-basin transfer locations (L1, L2, L3 and L4)

RESULTS AND DISCUSSIONS

The soils existing in the study area are below 5m in thickness, 5m deep recharge well (Venkateswara Rao et.al, 2009) is suggested as the rainwater harvesting structure for the study, which is described briefly below:

Recharge well

It is like an open well of ~ 4′ (1.2 m) diameters with variable depth of 4 to 8 meters and lined with concrete rings. There will not be any filter media filling and the soil at the bottom of the well acts as filter. The top surface of the well is covered with perforated RCC slab after connecting the rooftop pipe through underground. The wells are lined with concrete rings to avoid the collapsible nature of the soil structure and the gap between the concrete rings is filled with cement concrete to stop the lateral flow towards the building foundations and the percolation is only through the bottom of the well (Figure 5).

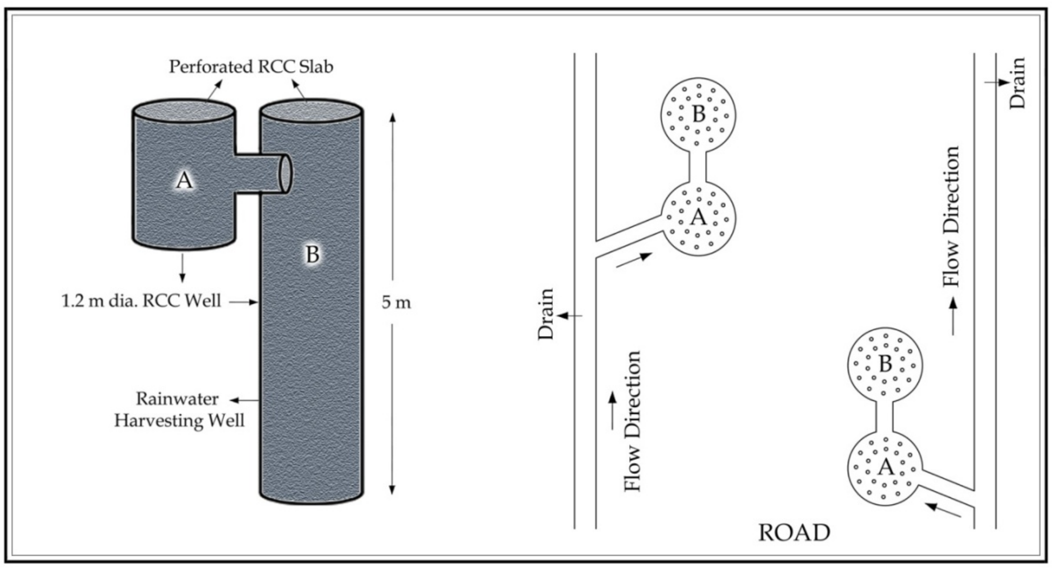


Figure 5 Schematic diagram of Rainwater Harvesting Well

The advantage of recharge well is that; it can hold high quantity of water instantaneously during high intensity rainfall, high amount of infiltration due to high head, the water is allowed only through the bottom of the well at 5 m depth, and there will not be any effect on the foundations and there will not be any movement restriction in the residential area as the surface is covered with concrete slab. The recharge well structures are suitable in the aquifer zones ranging 5 to 20 m depths and are found to be more effective in conservation and charging the shallow aquifer system. These recharge wells are normally laid along the roads and all the runoff water from storm water drains located on either side of the roads are connected with these recharge wells, and each recharge well is inter connected for flowing excess water one to another recharge well.

L1 and L3 are the locations in the Chinamushidiwada tank's catchment, where rainwater from the recharge structures will be transferred to L2 and L4, which are the locations in the Laxmipuram tank's catchment, where the rainwater comes out and enters into its recharging system. ArcGIS 3-D Analyst module is used to map the topographic surface profile along the transfer locations, shown in Figure 6.

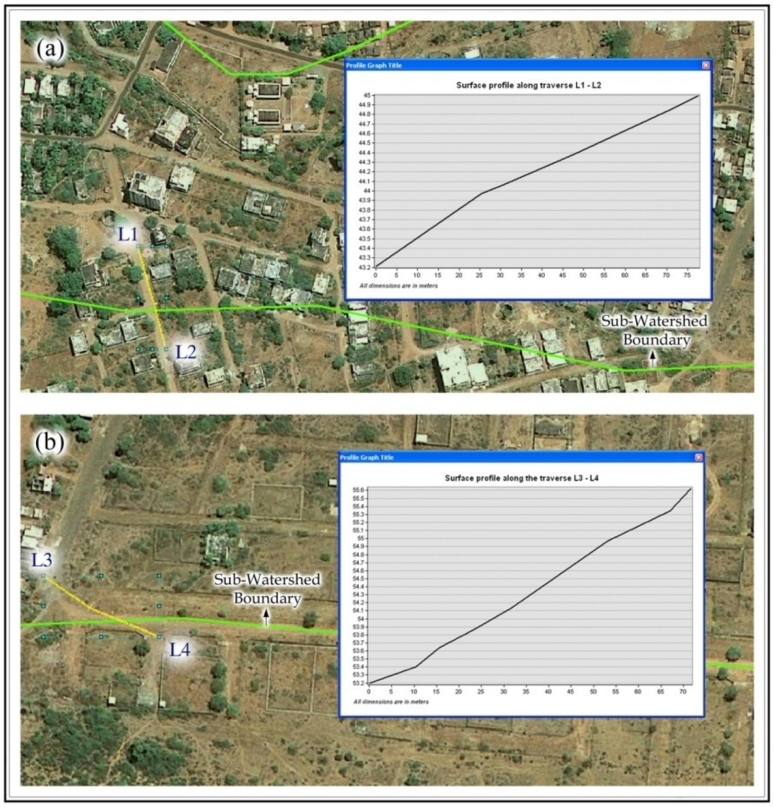


Figure 6 Topographic surface profiles at transfer locations (a) Chinamushidiwada tank's catchment (L1and L2) and (b) Laxmipuram tank's catchment (L3 and L4)

This technique can be used to recharge the aquifer systems which are rich in storage capacity, but lack of catchment area. Not only for adjacent catchments is this technique applied but also to catchments far from the high potential ones, simply by extending the subsurface transfer pipe. A schematic diagram of this technique is shown in Figure 7. At L1 and L3 the water collected from the recharge structures enters in to the pipe in a considerable amount and flows out of L2 and L4 by gravitational flow. When there is no flow through L1 and L3 there will be water at the same elevation in L1/L3 and L2/L4 because of capillary action, the collected water from different recharge structures at L1/L3 are more in quantity, which create pressure at L1 and L3. The pressure is useful to lift the water and flows out at L2 and L4. The distance, water to be transferred is shorter, it is not necessary to place any pumps to lift water. If the water has to be transferred to a considerable distance, suitable pumps/motors must be equipped. All the recharge wells are interconnected through subsurface and the excess water from all the recharge wells will reach L1/L3, if properly interconnected using 6″ (150 mm) pipes, will result more water which can be transferred through inter-basin connections to the nearest catchment basin having less water. These sub surface pipes connecting two basins are similar to recharge wells in terms of diameter say ~ 2′ (600 mm) along with bends having similar diameter.

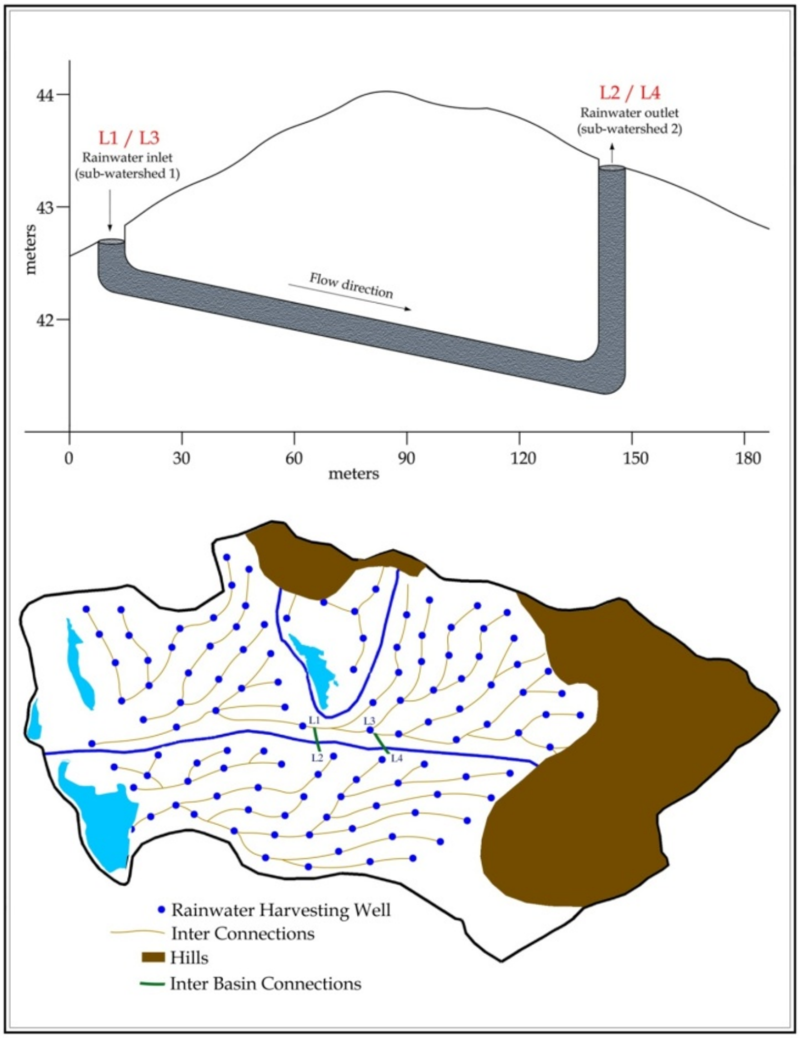


Figure 7 Schematic diagram of Inter-basin transfer method

Conclusions

The present study is limited to the development of groundwater scenario in the study area. In order to use land optimally, it is not only necessary to have the information on existing land use/cover but also the capability to monitor the dynamics of land use resulting out of both changing demands of increasing population and forces of nature acting to shape the landscape. Urban water systems must include not only the reservoirs, groundwater wells and aqueducts that are the sources of water supplies needed to meet the varied demands in an urban area, but also the water treatment plants, the water distribution systems that transport that water, together with the pressures required, to where the demands are located. Once used, the now wastewater needs to be collected and transported to where it can be treated and discharged back into the environment. Well-designed and operated urban water systems are critically important for maintaining public health as well as for controlling the quality of the waters into which urban runoff are discharged. In most urban areas in developed regions, government regulations require designers and operators of urban water systems to meet these sets of standards. Pressures must be adequate for fire protection, water quality must be adequate to protect public health, and urban drainage of waste and storm waters must meet effluent and receiving water body quality standards. This requires monitoring as well as the use of various models for detecting leaks and predicting the impacts of alternative urban water treatment and distribution, collection system designs and operating, maintenance and repair policies.

***Authors Contribution**: Kiran Jalem (Assistant Professor) performing the research work and data collection; Suraj K. Singh (Assistant Professor) is the main corresponding author of manuscript.*

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