HYDROGEOLOGICAL INVESTIGATION AND GROUNDWATER RESOURCE ESTIMATION OF AYAD RIVER BASIN, UDAIPUR (INDIA)

Kuldeep Pareta
DHI (India) Water & Environment Pvt. Ltd.
815, DLF Prime Tower, Okhla Phase-I, New Delhi - 110020 India

Abstract:

Water scarcity has been a long-lasting problem in Udaipur despite the several man-made lakes. Due to excessive usage, the stage of groundwater development in the Ayad river basin, Udaipur has reached 101.88%. The study has focused on hydrological and hydrogeological investigations to estimate and project the groundwater resources using data collected from various sources. Rainfall (1901-2021), land use land cover, and geology have been analyzed based on satellite imagery, digital elevation model, toposheet, and other secondary data. The area has a good aquifer inside the hard rock formations phyllite, schist, gneiss, and quartzite which is predominantly formed in weathered, fractured, and jointed rocks. The average depth of groundwater in various rock formations ranged from 3.9 m to 16.3 m. Based on behaviour of groundwater flow recharge and discharge zones have been identified. Rama and Iswal situated in north-east of basin are the best recharge zones, while Amberi, Bedla, Badgaon, Sukher, Dhinkli, and Udaipur situated in the central basin are discharge zones. The average annual groundwater resource (2011-2020) was estimated based on the GEC-97 (Groundwater Resource Estimation Committee-97) method, which is 127.81 Mm^3. Based on mini-max rainfall data and deficit / surplus reserves, a mathematical relationship has been established, and the same has been used to project the availability of groundwater. Large RHS, water conservation, reuse-recycle measures have been recommended for sustainable management of groundwater reserves. Awareness campaigns and training on these measures may be helpful to stop decline in water level and justified use.

Keywords: hydrology, hydrogeology, groundwater resource, Ayad River, remote sensing and GIS

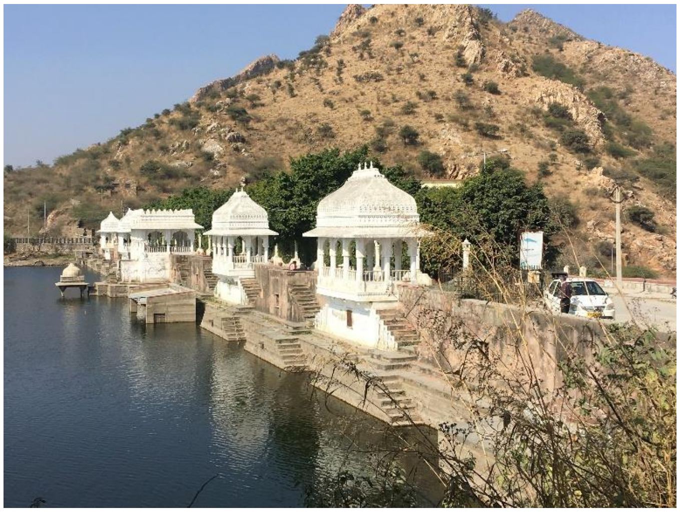
About the Author:

Dr Kuldeep Pareta

Dr Kuldeep Pareta obtained his M.Sc. degree in Geography from Dr Hari Singh Gour University, Sagar (MP) in 2001, and Ph.D. in Geomorphology, Hydrogeology and Remote Sensing from the same university in 2005. Presently, he is working in DHI (India) Water & Environment Pvt. Ltd., New Delhi, India as a RS/GIS Expert and Hydrodynamics Modeller. Dr Pareta has expertise in fluvial geomorphology, hydrogeology, hydrodynamic modelling, floodplain modelling and stochastic hydrology. He has more than 21 years' experience in the field of RS/GIS and water resources. He has been involved in research and consultancy in projects, varying from basin to reach scale. He is well-versed in associated modelling tools such as MIKE HYDRO River, MIKE 21 C, MIKE FLOOD, MIKE SHE, ERDAS Imagine, and ArcGIS. He has published over 93 research papers in referred national and international journals and 7 international books. He has conducted several training courses on relevant subjects targeting officials and professionals at prestigious organisations such as MCD Delhi, CWC Delhi, FMISC Lucknow, FREMAA Guwahati and NDRMP-CPO, MARD, Hanoi Vietnam. He was awarded a University Gold Medal in 2001 in first class-first in Geography and received the MP Young Scientist award in 2004.

E-mail ID: kupa@dhigroup.com, kpareta13@gmail.com
Contact: +91-9871924338

1. Introduction



Water resources are essential for human survival on the Earth and the functioning of nature since the beginning of time (Priscoli, 2000). Though water is the main source of life on earth it is challenging to obtain this resource in sufficient amounts, and its quantity, as well as quality, are dwindling quickly (Sirhan et al. 2011). One of the major challenges of the 21st century is maintaining good quality, and enough water in urban and peri-urban areas to meet the needs of communities and ecosystems with unregulated urbanization fueled by internal migration and population expansion (Anomohanran, 2015). Many people depend on groundwater exploitation for sufficient, and good-quality water, and that has increased extensively due to awareness and technology. Though groundwater is a resource that is replenished, its availability is not constant in time and space (CGWB, 2006). With time, the rapid urbanization and the expanding population have greatly strained surface water resources and deteriorated the quality of groundwater (Carpenter et al. 1998). Udaipur city is a growing urban area, which now is the sixth largest city in Rajasthan. During the last decade, groundwater has been depleted in Udaipur city, particularly in the valley fills near Ayad river around Kanpur, and most wells run dry throughout the summer (CGWB, 2013).

2. About the Study Area

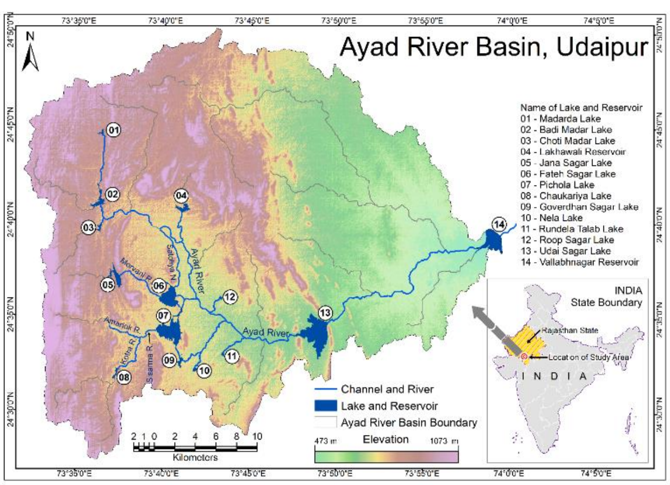


Figure 1. Location Map of Ayad River Basin, Udaipur

The Ayad river basin extends from 24° 50' 16" N to 24° 27' 46" N and 73° 31' 44" E to 73° 59' 44" E covering an area of 1206.75 Km^2. Administratively, the Ayad river basin falls into 4 tehsils (Girwa - 58.48%, Mavli - 19.85%, Vallabh Nagar - 6.97%, Gogunda - 5.94%) of Udaipur district and 1 tehsil (Nathdwara - 8.76%) of Rajsamand district. The Ayad river originates from the hills of Gogunda in the north-west of Udaipur and travels through for 68.45 Km before joining the Vallabh Nagar lake in the eastern part of Udaipur (Figure 1). The Ayad river is the major river flowing through Udaipur, it is seasonal, and discharge is peaking during Monsoons. The Ayad river is a tributary of the Berach river, which is itself a tributary of Chambal River of Yamuna basin.

3. Data Used and their Sources

The present study is based on a comprehensive data base including rainfall, topography, digital elevation data, land use land cover, geology, groundwater level, and groundwater draft which have been compiled from different sources e.g., Water Resource Department (WRD) Rajasthan, United States Geological Survey (USGS), Geological Survey of India (GSI), Ground Water Department Rajasthan, Central Ground Water Board (CGWB). The list of data used, and their sources are given in Table 1.

Table 1. List of Data Used and Sources

S. No.	Data Type	Period	Sources
1	Landsat-7 ETM+, and Landsat-9 OLI-2 Satellite Imageries with 30 m Spatial Resolution	2011, 2021	USGS Earth Explorer Source: http://earthexplorer.usgs.gov
2	Topography / Digital Elevation Data (DEM) Data with 30 m Spatial Resolution	2014	Shuttle Radar Topography Mission (SRTM), USGS Earth Explorer Source: http://earthexplorer.usgs.gov
3	Geological Data at 1:50,000 Scale	1999-2001	Geological Survey of India (GSI) Source: http://www.portal.gsi.gov.in
4	Depth to Water Level (DTWL) Data (Pre-Post Monsoon)	2011-2020	Ground Water Department, Jodhpur (Rajasthan) Source: https://phedwater.rajasthan.gov.in

4. Methodology

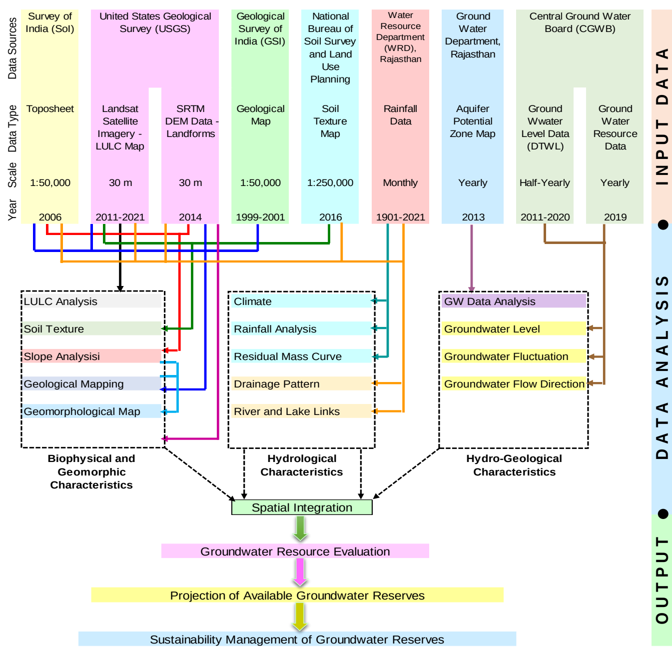


Figure 2. Overall Methodology of the Present Study

Landsat satellite imageries were used in this study to prepare land use and cover (LULC) maps, and geology data. Rainfall data from 1901 to 2021 (121 years in total) was collected from WRD Rajasthan which was further analyzed with mean, standard deviation (SD), coefficient of variation (CV), and Mann-Kendall's test was performed for rainfall trend analysis. A residual mass curve was prepared to analyze the annual groundwater increment condition. Depth-to-water-level (DTWL) data from 45 water monitoring stations from 2011 to 2020 (pre and post-monsoon) was acquired from Central Ground Water Board (CGWB). I estimated the groundwater resource by using Watertable Fluctuation (WTF) and specific yield method, and rainfall infiltration factor method recommended by GEC-97. Additionally, the annual groundwater draft, the overall stage of groundwater development, and projected groundwater reserves were analyzed. A flow diagram of the overall methodology is shown in Figure 2.

4.1. Geology

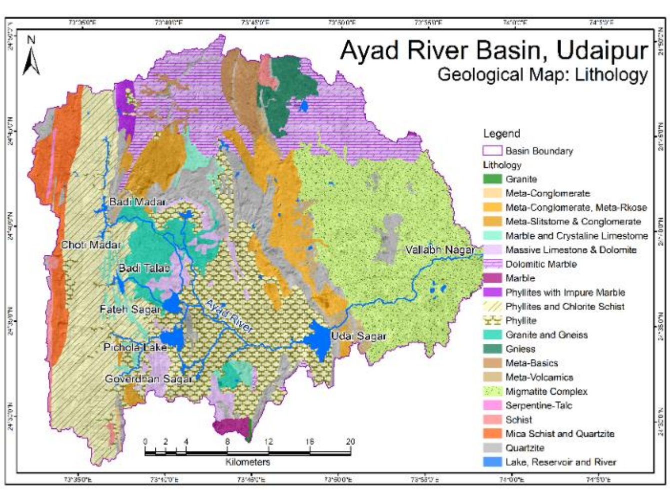


Figure 3. Geological Map of Ayad river basin, Udaipur

Geological maps based on satellite remote sensing imageries often yield information such as (i) distribution of the rock type and lithological of the area; (ii) an indication of the dips of the strata, (iii) faults and unconformities can also be picked up on satellite imagery. The general geology of the area was mapped by the GSI. Several geologists have contributed to the study area, among them are Sahu et al. 1995; Sinha-Roy et al. 1998; Aggarwal et al. 2011; Pareta et al., 2013, etc. They described various geological aspects of the study area and recorded the principal rock formations. A geological map of the Ayad river basin was prepared using a published geological map of GSI at 1:250,000 scale, Landsat-9 OLI-2 satellite imagery (30 m spatial resolution), SRTM DEM data (30 m spatial resolution), and Survey of India (SoI) topographical map at 1:50,000 scale with limited field check. A geological map of the Ayad river basin is shown in Figure 3.

4.2. Rainfall Analysis

The monthly rainfall data of the Ayad river basin was downloaded from the Water Resource Department, Rajasthan between 1901 and 2021 (121 years in total). For detecting the trends, time series graphs were plotted, and Mann-Kendall's test was used for the selected variables. Annual rainfall variability shows that the average annual rainfall of the Ayad river basin is 640 mm with CV of 32.82% (Figure 4). The 1st highest (1222.8 mm), and 2nd highest (1184 mm) rainfall were realized during the year 1917, and 2019 respectively, while the lowest (127.8 mm) during 1938. The annual rainfall during 1917 was about 91% more than the long period average (LPA-640 mm).

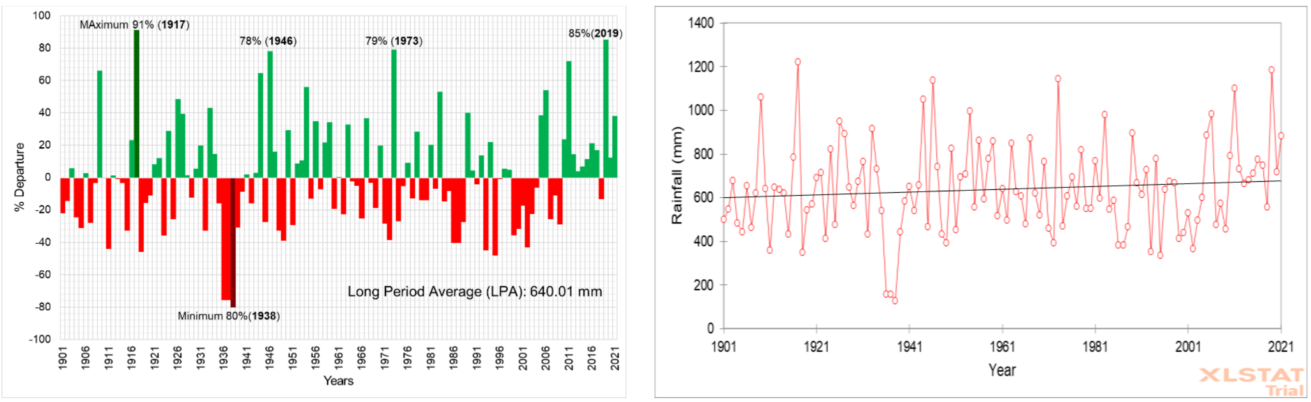


Figure 4. Percentage departure of annual rainfall from LPA: 640 mm and trend analysis of rainfall in the Ayad River Basin, Udaipur

4.3. Residual Mass Curve

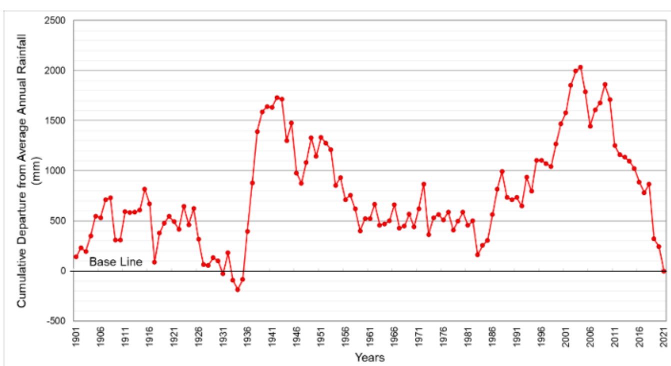


Figure 5. Annual Residual Mass curve of Ayad River Basin, Udaipur

The residual mass curve is the deviation from mean monthly rainfall plotted against time. Positive slopes on the residual mass curve indicate periods of above average rainfall whereas negative slopes indicate periods of below average rainfall. In developing the residual mass curve for the Ayad river basin, the annual rainfall for 121 years (1901-2021) was considered. The annual rainfall was prepared by taking the cumulative departure from the average annual rainfall against the number of years and divided into different cycles based on the departure from the average annual rainfall (Figure 5). The parts of the curves, which are above the baseline, (representing the average annual rainfall for the number of years under consideration) indicate a better period of recharge and filtration conditions for the groundwater. The residual mass curve can be divided into three cycles: 1901-1930, 1931-1935, and 1936-2021. The second cycle (1931-1935) lies below the baseline and indicates negative values of cumulative departure, which indicate the drought condition of the Ayad river basin. The other two cycles lie above the baseline and indicate positive values of cumulative departure, which indicates a better condition for annual groundwater increment from 1901 to 1930 and 1936-2021.

4.4. Groundwater Level

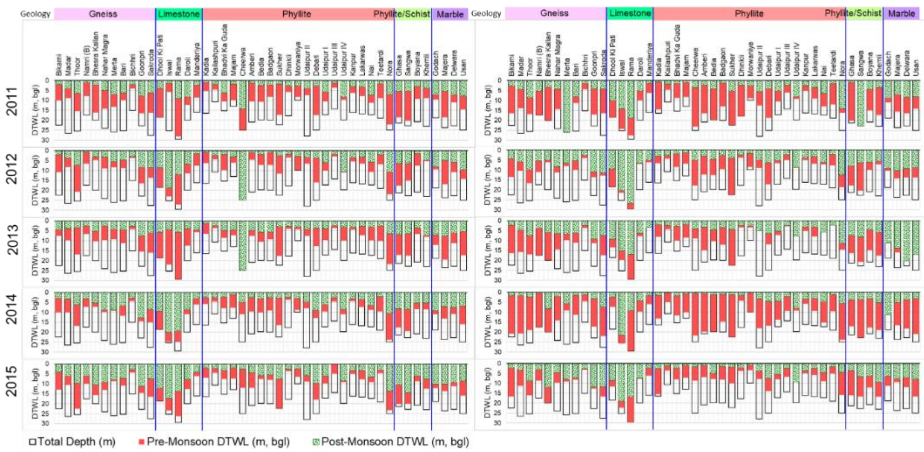


Figure 6. Pre-and-Post-Monsoon Depth-to-Water-Level Data from 2011 to 2020 in Ayad River Basin, Udaipur

The Ayad river basin has a well-distributed network of groundwater monitoring stations (45 in total, within the basin) owned by the Central Ground Water Board (CGWB). The available data of groundwater monitoring stations have total depth of well, pre-post depth-to-water-level from 2011 to 2020, and lithology / formation (Figure 6). Out of 45 groundwater monitoring stations, eleven locations are situated in Gneiss, five locations in limestone, twenty-one locations in phyllite, four locations in Phyllite/Schist, and only four locations in dolomitic marble formation. Ten years average water level of pre- and post-monsoon in gneiss, limestone, phyllite, phyllite/schist, and dolomitic-marble formation are 5.62-12.30 m below ground level (mbgl), 9.48-16.35 mbgl, 3.97-10.06 mbgl, 6.29-15.13 mbgl, and 8.38-13.64 mbgl, respectively. Depth-to-water-level (DTWL) represents the position of the water table with reference to ground surface, which is useful to delineate the areas of recharge, discharge, and water logging conditions.

4.5. Groundwater Fluctuation

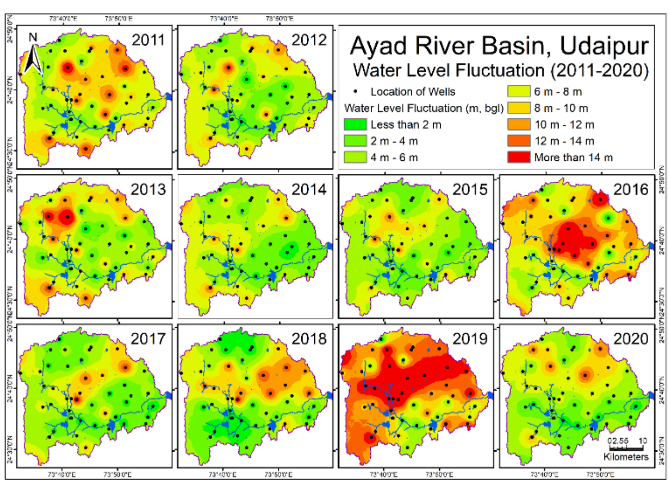


Figure 7. Water Level Fluctuation from 2011 to 2020 in Ayad River Basin, Udaipur

Water level fluctuation in the Ayad river basin ranges between 0 m and 21.2 m during 2011-2020. The low water level fluctuation from pre-monsoon to post-monsoon indicates overexploitation, which is represented by red color in Figure 7. The areas represented by green color have the highest deviation with dense drainage, higher hydraulic conductivity, and fertile soils. There are several factors involved in the difference in water level fluctuation in a distinct part of the Ayad river basin that may be natural over the time due to difference in seasonal variation, precipitation patterns, and streamflow. Artificial factors may also be affecting the water level fluctuation, these are mining activities, excess pumping out for different purposes, deforestation, and impervious surfaces on the landscape.

5. Results and Discussion

5.1. Groundwater Resource Estimation

Quantification of groundwater recharge is a basic prerequisite for efficient groundwater resource development, and this is particularly vital for Rajasthan with its widely prevalent semi-arid and arid climate. For the rapidly expanding urban, industrial, and agricultural water requirements of the study area, groundwater utilization is of fundamental importance. Quantification of groundwater resources is critical, and no single comprehensive technique is yet identified to estimate accurate groundwater assessment (Pareta et al., 2015). The methodologies adopted for computing groundwater resources have undergone a continuous change. The groundwater modeling methods have undergone gradual refinement with the generation of more and more data input and with a better understanding of the science of groundwater.

The Govt. of India established the Groundwater Estimation Committee (GEC) in 1982 and recommended two approaches for groundwater resource assessment: (i) watertable fluctuation and specific yield method and (ii) rainfall infiltration factor method. In the watertable fluctuation and specific yield ($GW_{LF}S_Y$) method, the change in storage (ΔS) is computed by multiplying water level fluctuation between pre- and post-monsoon seasons (h) with the area of assessment (A), and specific yield (Sy), and the formula is $\Delta S = h * Sy * A$.

To estimate the groundwater resource, the watertable fluctuation method was implemented by using the observation well data. Future, it is noted that the annual groundwater increment is not only due to rainfall but also the application of surface water for irrigation. To use this method, the area between two contours at 1 m intervals of watertable fluctuation was computed using observation well data and inverse distance weighting (IDW) interpolation method in the spatial analyst tool of ArcGIS software. Subsequently, the specific yield map of the Ayad river basin was multiplied by the groundwater fluctuation map for each year (from 2011 to 2020) using a raster calculator within the ArcGIS spatial analyst toolbox to estimate the groundwater resource from 2011 to 2020. This analysis provides the volume of saturated aquifer material occurring between contours. The saturated volume of aquifer material between successive contours was summed for all aquifers to get the total saturated volume of the aquifer materials, then this volume was multiplied by the specific yield to calculate the annual groundwater resources. The detailed logical calculation for the year 2011 of groundwater resources using the groundwater fluctuation method is given in Table 6, which is 152.63 Mm^3, and the same calculation has been done from 2012 to 2020. The estimated annual groundwater resource from 2011 to 2020 is given in column (11) of Table 2. The average annual groundwater resource (2011-2020) in the Ayad river basin is 127.81 Mm^3.

Table 2. Calculation of Annual Groundwater Resource for the year 2011 through Watertable Fluctuation (WTL) Method.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Groundwater Fluctuation (m) h	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-18	
Sy	Ave. Fluctuation (m)	1.0	3.0	5.0	7.0	9.0	11.0	13.0	16.0	
(%)	Area of Fluctuation (Km^2) in different Lithology and Formation (A)									Total
6.0	Clayey Alluvium, Alluvial Plain	0.0	1.7	23.9	39.2	6.4	3.2	1.2	0.1	75.6
2.0	Granite, Schist, Gneiss, Limestone	0.0	1.0	12.4	63.9	38.3	2.7	1.0	0.3	119.6
1.5	Marble, Phyllite, Quartzite	0.5	17.0	163.4	118.4	125.9	45.6	13.1	5.6	489.5
0.3	Migmatite Complex, and Meta-Basics	0.0	11.4	55.5	179.1	122.4	61.4	25.9	7.4	463.0
10	Valley Fill	0.3	6.8	24.6	14.3	5.9	2.8	2.8	1.5	59.0
	Total	0.8	37.9	279.8	414.8	298.9	115.6	44.0	15.0	**1206.8**
	The volume of Rock Material in which Fluctuation takes place (Km^3) in **2011**									
6.0	Clayey Alluvium, Alluvial Plain	0.000	0.005	0.119	0.275	0.058	0.035	0.016	0.001	0.508
2.0	Granite, Schist, Gneiss, Limestone	0.000	0.003	0.062	0.447	0.345	0.030	0.013	0.006	0.905
1.5	Marble, Phyllite, Quartzite	0.000	0.051	0.817	0.828	1.133	0.502	0.171	0.090	3.593
0.3	Migmatite Complex, and Meta-Basics	0.000	0.034	0.277	1.254	1.101	0.675	0.337	0.119	3.797
10	Valley Fill	0.000	0.020	0.123	0.100	0.053	0.030	0.036	0.024	0.388
	Total	0.001	0.114	1.399	2.904	2.690	1.272	0.572	0.240	**9.190**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Annual Groundwater Resource (Km³) (ΔS)									
6.0	Clayey Alluvium, Alluvial Plain	0.000	0.000	0.007	0.016	0.003	0.002	0.001	0.000	0.030
2.0	Granite, Schist, Gneiss, Limestone	0.000	0.000	0.001	0.009	0.007	0.001	0.000	0.000	0.018
1.5	Marble, Phyllite, Quartzite	0.000	0.001	0.012	0.012	0.017	0.008	0.003	0.001	0.054
0.3	Migmatite Complex, and Meta-Basics	0.000	0.000	0.001	0.004	0.003	0.002	0.001	0.000	0.011
10	Valley Fill	0.000	0.002	0.012	0.010	0.005	0.003	0.004	0.002	0.039
	Total	0.000	0.003	0.034	0.052	0.036	0.015	0.008	0.004	**0.152**
		Average Annual Groundwater Resource (Mm³)								**152.63**

Groundwater recharge may be estimated using rainfall infiltration factor method. In that method, the rechargeable area under different hydrogeological units (A_{HR}) is multiplied by relevant rainfall infiltration factors (R_{IF}), and normal rainfall (R_N), and the formula is Groundwater recharge (R_{GW}) = (A_{HR}) * (R_{IF}) * (R_N). GEC-15 (GEC-15, 2017) recommended the rainfall infiltration factors for different hydrogeological units, which is given in column (4) of Table 3. For the estimation of groundwater recharge from 2011 to 2020 through the rainfall infiltration method, all analyses were done by using ArcGIS software, and results are given in column (10) of Table 3.

Table 3. Calculation of Annual Groundwater Recharge through Rainfall Infiltration Factor Method

(1)	(2)			(3)	(4)	(5)
S.No.	Hydrogeological Units			(A_{HR}) Km²	(R_{IF}) %	(A_{HR})*(R_{IF}) Km²
1	Clayey Alluvium, Alluvial Plain			75.77	24	18.18
2	Granite, Schist, Gneiss, Limestone			120.30	12	14.44
3	Marble, Phyllite, Quartzite			489.33	10	48.93
4	Migmatite Complex, and Meta-Basics			462.28	9	41.61
5	Valley Fill			59.06	25	14.77
			Total	1,206.75		137.93
(6)	(7)	(8)	(9)	(10)	(11)	(12)
Year	Normal Rainfall (R_N) mm	Normal Rainfall (R_N) m	(A_{HR})*(R_{IF})*(R_N) m³	Groundwater Recharge (R_{GW}) (Mm³) by RIF Method	Annual groundwater Resource (ΔS) (Mm³) by ($GW_{LF}S_Y$) Method	PD = ($GW_{LF}S_Y$-R_{IF}) / R_{IF} * 100 (%)
2011	1,100.40	1.100	151,772,866.29	151.77	152.63	0.56
2012	730.70	0.731	100,781,927.84	100.78	117.88	16.97
2013	663.50	0.664	91,513,355.86	91.51	117.54	28.44
2014	682.30	0.682	94,106,349.21	94.11	124.40	32.19
2015	711.50	0.712	98,133,764.42	98.13	106.98	9.01
2016	774.70	0.775	106,850,635.69	106.85	141.16	32.11
2017	747.40	0.747	103,085,278.32	103.09	104.83	1.69
2018	556.00	0.556	76,686,399.18	76.69	101.92	32.90
2019	1,184.00	1.184	163,303,411.20	163.30	206.01	26.15
2020	717.91	0.718	99,017,864.81	99.02	104.72	5.76
			Average	108.53	127.81	17.77

After the groundwater resource was estimated through watertable fluctuation and specific yield ($GW_{LF}S_Y$) method, results were compared with the rainfall infiltration factor method (R_{IF}) and calculated the percentage deviation (PD) using the standard formula: PD = ($GW_{LF}S_Y$-R_{IF})/R_{IF}*100, and results are given in column (12) of Table 7. As per the guideline suggested by GEC-97, if PD is greater than/less than/equal to ± 20%, the rainfall infiltration method should be considered. I adopted these suggestions and considered the data of groundwater resources obtained through watertable fluctuation methods.

5.2. Annual Groundwater Draft

The CGWB estimated groundwater resources in 2019 following the GEC-97-recommendations. Annual replenishable groundwater resources of the blocks under the Ayad river basin were estimated to be 139.24

Mm^3. Net annual groundwater availability is estimated as 129.02 Mm^3, which is matched with annual groundwater resource (127.81 Mm^3) estimated herein through the watertable fluctuation method. Annual groundwater withdrawal for all uses is 131.45 Mm^3. A summarized block wise estimate of dynamic groundwater resources is given in Table 4. The overall stage of groundwater development is 101.88%, which is larger than the Udaipur district average of 101.35% (CGWB, 2019).

Table 4. Annual Groundwater Resource and Groundwater Draft by CGWB

Block (district)	Annually replenishable groundwater resource (Mm^3)	Net annual groundwater availability (Mm^3)	Gross groundwater draft for irrigation (Mm^3)	Gross groundwater draft for domestic and industrial users (Mm^3)	Gross groundwater draft for all users (Mm^3)	Stage of groundwater development (%)	Category
Badgaon (Udaipur)	9.46	8.99	7.68	1.48	9.16	101.98	OE*
Girwa (Udaipur)	37.26	34.00	27.94	6.72	34.66	101.95	OE*
Mavli (Udaipur)	23.13	22.18	19.44	3.26	22.70	102.37	OE*
Gogunda (Udaipur)	23.94	22.02	21.18	1.08	22.26	101.10	OE*
Bhinder (Udaipur)	27.42	25.15	23.01	2.59	25.61	101.83	OE*
Khamnor (Rajsamand)	18.03	16.70	14.70	2.36	17.06	102.17	OE*
Total	139.24	129.02	113.96	17.49	131.45	101.88	OE*

**Over-Exploited. Source: Central Ground Water Board (CGWB), 2019.*

The dynamic groundwater resource estimation indicates that 101.88% of groundwater development in the Ayad river basin is below the over-exploited category. However, there are enough static reserves to sustain consumptive groundwater use during drought periods.

5.3. Status of Groundwater Development

Rainfall in the Ayad river basin is the main source of groundwater recharge. Due to less rainfall and increased groundwater withdrawals, groundwater levels are declining in some parts of the basin, particularly in the northern and central parts. Increasing urbanization and change in lifestyle have led to increased demand for water and leads to reduced recharge. Further groundwater is also an important source of irrigation in the basin. The stage of groundwater development for the Ayad river basin has reached around 102% and is thus over-exploited. There is practically no scope left for further groundwater development in the Ayad river basin.

6. Conclusions

The main purpose of this study is to investigate the biophysical-geomorphic, hydrological, and hydro-geological characteristics of the Ayad river basin to estimate and project the groundwater resource by using the innovative and extensive secondary source data collected from different agencies. LULC maps indicate the decreasing trends in forest area and agricultural areas and the increasing trend in urban and rural areas during the last decade. The geological map was updated using satellite images, toposheet, and DEM data. Geology and lithology found in the area are ranging in age from Archaean to Upper Proterozoic; and belong to three geological cycles - Bhilwara, Aravalli, and Delhi supergroups. Based on 121 years (1901-2021) rainfall data analysis, the average annual rainfall of the area is 640 mm, and a residual mass curve indications a better condition for annual groundwater increment.

The area has a good aquifer inside the hard rock materials such as phyllite, schist, gneiss, and quartzite, which are predominantly formed in weathered, fractured, and jointed rock formations. The average water level in gneiss, limestone, phyllite, phyllite/schist, and dolomitic-marble formation is 5.62-12.30 mbgl, 9.48-16.35 mbgl, 3.97-10.06 mbgl, 6.29-15.13 mbgl, and 8.38-13.64 mbgl, respectively. Water level fluctuation in the area is ranging between 0 and 21.2 m over the period (2011-2020). Based on the GEC-97 method, the average annual groundwater resource (2011-2020) of the area is 127.81 Mm^3. CGWB, 2019 has measured the annual groundwater withdrawal for all uses, which was 131.45 Mm^3. Overall stage of groundwater development is 101.88% and is over-exploited.

References

1. Aggarwal RK, Sharma A, Hussain, Kumar A and Pakshit P. 2011. Geology and mineral resources of Rajasthan. Geological Survey of India, Miscellaneous Publication (3rd Edition). No. 30(12), pp. 13-31.
2. Anomohanran O. 2015. Hydro-geophysical and hydro-geological investigations of groundwater resources in Delta Central, Nigeria. Journal of Taibah University for Science. Vol. 9(1), pp. 57-68.
3. Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN and Smith VH. 1998. Nonpoint of surface waters with phosphorous and nitrogen. Ecological Applications, Wiley. Vol. 8(3), pp. 559-568.
4. CGWB. 2006. Dynamic groundwater resources of India. Central Ground Water Board (CGWB), Ministry of Water Resources, Govt. of India.
5. CGWB. 2013. Groundwater scenario, Udaipur district, Rajasthan. Central Ground Water Board (CGWB), Ministry of Water Resources, Govt. of India. pp. 1-19.
6. CGWB. 2019. National compilation on dynamic groundwater resources of India-2017. Central Ground Water Board (CGWB), Ministry of Water Resources, RD & GR, Ministry of Jal Shakti, Govt. of India. pp. 1-329.
7. GEC-97. 1997. Report of the Groundwater Resource Estimation Committee (GEC), Ministry of Water Resources, Government of India, New Delhi. pp. 107.
8. Pareta K and Pareta U. 2015. Groundwater balance and resource estimation using geospatial technology. In: Esri International User Conference, San Diego, California. pp. 1-18.
9. Pareta K. 2013. Sustainable groundwater management in Kakund watershed of south Bharatpur district (Rajasthan) using remote sensing and GIS Techniques. In: 14th ESRI India User Conference, New Delhi. pp. 1-10.
10. Priscoli J. 2000. Water and civilization - using history to reframe water policy debates and to build a new ecological realism. Water Policy. Vol. 1, pp. 623-636.
11. Sahu RL. 1995. Final report on the geology of Vindhyan Supergroup of south-eastern Rajasthan. Geological Survey of India (GSI), FS. 1994.
12. Sinha-Roy S, Malhotra G and Mohanty M. 1998. Geology of Rajasthan. Journal of the Geological Society of India, Bangalore. pp. 278.
13. Sirhan A, Hamidi M and Andrieux P. 2011. Electrical resistivity tomography, an assessment tool for water resource: case study of Al-Aroub Basin, West Bank, Palestine. Asian Journal of Earth Sciences. Vol. 4(1), pp. 38-45.