In-Depth Assessment of Impact of Recharge Pits on Groundwater Resource in Nashik District by Software Analysis

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Abstract - *This research delves into an in-depth analysis of groundwater modeling and recharge pit assessment in Nashik district using MODELMUSE MODFLOW-6 simulations. Data from Survey of India, Open Topography, and India WRIS websites were processed to create Thiessen polygons around 18 observation wells, with two models per polygon developed to study the impact of recharge pits over a year. Various parameters including aquifer characteristics, EVT rates, recharge rates, hydraulic conductivities, sediment thickness, and drain conductance were considered. Different scenarios based on minimum, average, and maximum conditions were explored to evaluate groundwater dynamics. The introduction of recharge pits led to a notable increase in groundwater inflow, with 3248 strategically placed recharge pits influencing observation wells. Additionally, satellite imagery from the Bhuvan portal was utilized to derive a land use map for Nashik district, aiding in well placement in areas of low elevation and barren land. The research findings provide valuable insights for sustainable water resource management in Nashik district.*

Key Words: Groundwater, GIS, Shapefiles, DEM

1.INTRODUCTION *(Size 11 , cambria font)*

Nashik District, situated in Maharashtra, India, covers an expanse of 15,525 square kilometers and supports a population exceeding 6 million. Over the past 19 years, the region has witnessed a significant decline in groundwater levels, with 2023 marking a record low of 9.89 meters below ground level. Data from the India Water Resources Information System highlights the pressing need for sustainable groundwater management in Nashik District. In numerous villages, women endure long journeys to fetch water, underscoring the profound impact of dwindling groundwater resources on local communities.

Groundwater recharge structures play a vital role in replenishing aquifers and sustaining water resources in regions facing water scarcity. Among these structures, recharge pits stand out as a primary method for augmenting groundwater levels by facilitating the infiltration of surface water into the underlying aquifer. Recharge pits are strategically designed to capture and percolate water efficiently, aiding in maintaining the water table and mitigating the effects of excessive groundwater extraction.

Recharge pits are man-made structures strategically located in areas with favorable soil permeability to promote efficient water seepage into the ground. These pits serve as essential components of sustainable water management practices, enabling the gradual infiltration of collected water into the aquifer to replenish the groundwater table. By supporting natural groundwater recharge processes, recharge pits contribute significantly to water conservation efforts, water table stability, and mitigation of drought impacts.

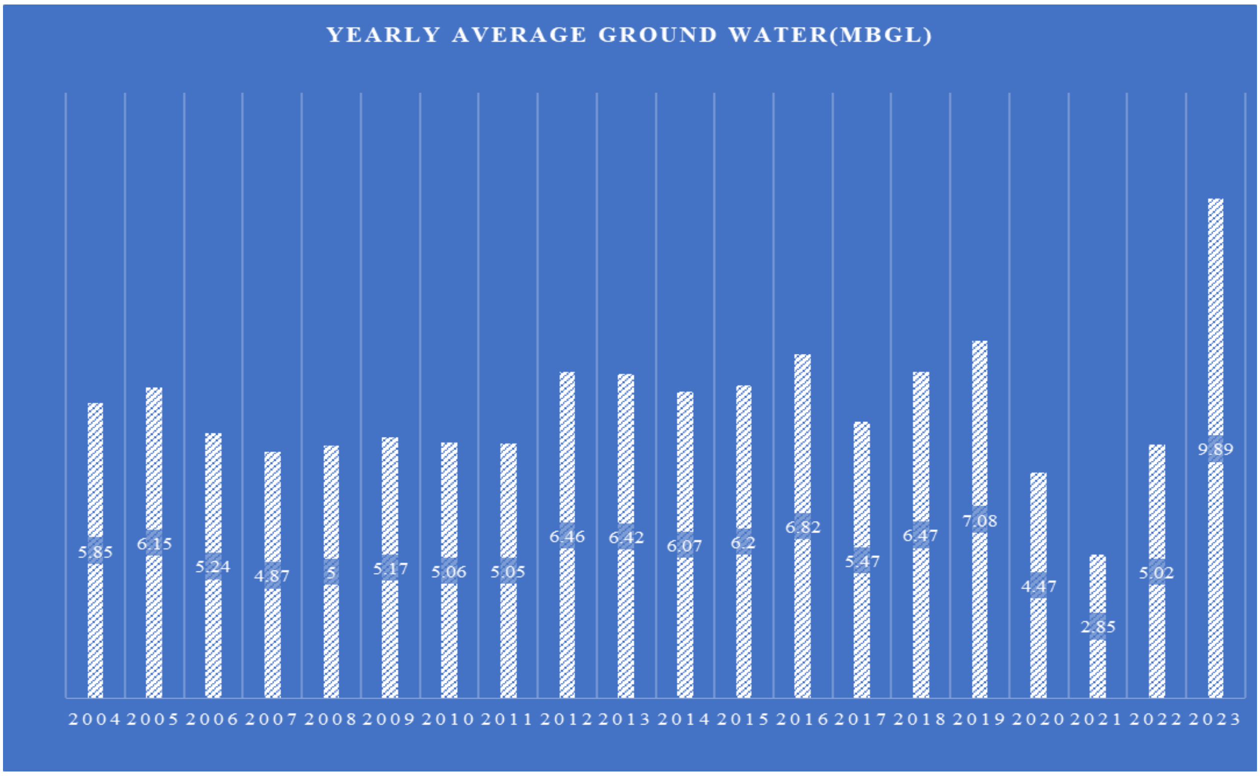

Chart -1: Yearly Average Ground Water Level of Nashik District from 2004 to 2023 in mbgl (source : India WRIS)

2. LITERATURE REVIEW

Various research endeavours have been undertaken to comprehensively analyse groundwater dynamics in diverse regions, offering distinct insights. In the Chikkodi region of Belagavi District, Anusha Honnannanavar, Nagraj Patil, and Vivet Patil utilized MODFLOW for groundwater analysis, prioritizing parameters like evapotranspiration, temperature, and hydraulic conductivity. Their study, inclusive of lithology considerations using SURFER software, aims to elucidate the intricate interplay of these factors within the Chikkodi region's groundwater system.

Researchers like Souvik Chakraborty have utilized tools like Visual MODFLOW. This tool simplifies complex aquifer behaviours and was used in Chakraborty's study of East Midnapur, India. Using data from 2002 and 2012, the tool predicted groundwater levels for 2017. The predictions were validated against observed 2012 data. The study also considered potential sea water ingression from the Bay of Bengal. This research highlights the importance of such tools in understanding hydrogeology across diverse regions.

In Iran's arid and semi-arid landscapes, Farzaneh Soltani, Saman Javadi, Abbas Roozbahani, and Alireza Massah investigated escalating water dependency due to population growth. Their scrutiny of river-groundwater recharge interactions concluded that rivers may not be substantial contributors to groundwater recharge, emphasizing the need for alternative water resource management strategies.

Dr Sajeena Shaharudeen and others have used Visual MODFLOW, integrated with MT3D software, to simulate this phenomenon in the Kadalundi river basin. Their study utilized water level and quality data, along with secondary hydrogeological parameters and aquifer properties. The findings suggest potential saline water intrusion extending 0.5 km to 1.9 km from the coast. Activities like coconut retting, lime shelling, and sand mining, along with increased groundwater pumping due to development, contribute to this issue. The study emphasizes the importance of groundwater replenishment and sustainable development as countermeasures.

Dr. Chaitanya Pande and Sudhir Kumar Singh developed a groundwater flow model for the Akola and Buldhana regions, incorporating data from 9 test wells. Utilizing MODFLOW, their model provides a comprehensive understanding of groundwater flow dynamics in the specified area. Collectively, these studies paint a nuanced picture of groundwater systems across diverse geographies, underscoring the pivotal role of MODFLOW in advancing hydrogeological understanding.[6-15]

3. MATERIALS AND METHODS

This study employed an exhaustive and intricate approach to investigate groundwater levels using the Geographic Information System (GIS) and MODFLOW. The focus was on the areas influenced by 18 observation wells located in various villages within the Nashik district. These observation wells include Belgaon Dhaga, Devlane, Dongargoan, Matane, Nandgaon(MCL), Nimbole, Phule Nagar, Pimpalgaon, Satvaichiwadi, Sawatamalinagar(Nv), Varhale, Vighanwadi(Bharatpur), Warshi, Kanchangaon, Kapashi, Khuntewadi, Kumbharde, and Malegaon_3 stations. The research commenced with the careful acquisition of essential data. The Administrative Boundary Shapefile, which delineates the geographical boundaries of all the Talukas in India, was sourced from the Survey of India Website.

Digital Elevation Models (DEM), crucial for providing topographical details, were obtained from the Open Topography Website. These models present a 3D depiction of a terrain's surface, which is critical for comprehending the physical attributes of the study area. Groundwater Level Data for the dates 21st and 22nd November 2023 was gathered from the India WRIS website. This data, which includes the names of the stations (i.e., village names) and the groundwater levels in terms of mbgl, provides a baseline for the study. It is essential for understanding the present state of groundwater levels and serves as a reference point for future projections. The groundwater level data was extracted from the downloaded excel sheet and prepared for further analysis. This involved isolating the stations situated in Nashik District approximately, by noting their coordinates from Google Maps and preparing another excel sheet containing the Name of Station, X- Coordinate, Y-Coordinate, and Water level. The sheet was then saved in ".csv" format. This excel file was imported into QGIS as Delimited Text Layer. By sampling the elevations at those coordinates and substracting it from the groundwater readings, the groundwater level is converted from mbgl to meters above mean sea level. These values were then interpolated using the "IDW Interpolation" tool from the "Processing Toolbox".

Once the data was secured, it was processed using QGIS, a powerful open-source GIS software. The boundary shapefile was prepared by selecting the required talukas of Nashik District and merging them into a single shapefile. based on the locations of observation wells, the polygon of Nashik district was segregated into a number of influence areas for the observation wells.

The DEM was then clipped and converted to the appropriate format, which was ASCII raster format with the .asc extension for each polygon. This process ensured that the topographical data matched the geographical boundaries of the study area.

The next phase of the research involved creating a model in MODFLOW, a popular software used for simulating and predicting groundwater levels and flow. The model grid was set up, and the aquifer layers were defined based on the report titled "AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES BAGLAN, CHANDWAD, DEOLA, MALEGAON, NIPHAD, SINNAR BLOCKS, NASHIK DISTRICT, MAHARASHTRA" by the Central Ground Water Board(CGWB). The layers were provided as follows :

Table -1: Ground Layers created within simulations

Layer No.	1	2	3	4
Description	Model_Top	Aquifer-I (Hard rock)	Aquifer-I (Alluvium)	Aquifer-II (Hard Rock)
Range	-	8 to 32	10 to 40	30 to 200
Model Formula	Model_Top = DEM	Model_Top - 20	Model_Top -25	Model_Top - 200

The data for the Evapotranspiration rate and depth on 21st November 2023 was sourced from the India WRIS website. The dimensions of the recharge pits were presumed to be 1.5 m x 1.5 m x 3 m. The recharge rate of these pits was determined using the equation(1)[4]:

Q = A x R x C….. (1)

Here,

Q represents the Recharge rate,

A signifies the Area = 4.5 x 10-6 mm^2 ,

R is the mean Quantum of Rainfall, calculated as the total actual rainfall divided by the number of years = 1010.697 mm/year as per data from IWRIS (India – Water Resources Information System), C is the Runoff Coefficient, C = 0.479….. [3].

The quantum of rainfall was calculated by using the rainfall data from 1993 to 2023. The value of recharge rate of one recharge pit is worked out to be 0.96798 m/year. The natural recharge rates were selected from the range specified in the "Annex 2 Infiltration rate and infiltration test" by the Food and Agriculture Organization. The hydraulic conductivity, as found in literature, was used to compute the drain conductance using the formula given on the MODFLOW Guide website, as shown in equations (2)[7] and (3)[7].

Drain Conductance = Kz/(Drain Sediment Thickness) …..(2)

Where Kz = (Hydraulic Conductivity)/10 …..(3)

This drain conductance was applied to the imported drain shapefile in MODFLOW-6. These drain shapefiles were created by processing the DEMs in QGIS for all 18 influence areas. The evaporation rate was calculated based on the general weather data available from online resources for 21st November 2023. The following formula is as shown in equation (4)[6] :

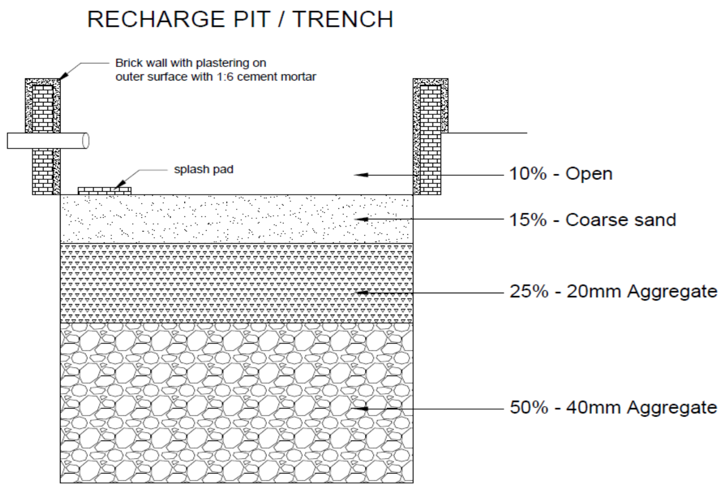

Fig -1: Section of Recharge Pit

Evaporation Rate (gh)= (25+19v) x A x (Xs−X) ….. (4)

Where v = Velocity of Air = 1.625 mph

A = Water Surface Area = 954933191.283 m^2

Xs = Maximum Humidity ratio of saturated air = 0.72

X = Current Humidity Ratio of Air = 0.5625

The Evaporation Rate for 21st November 2023 was found to be 53.655 m/year. a rectangular object was constructed over the entire area of interest to incorporate the evaporation, evapotranspiration, and recharge rate. Both evaporation and evapotranspiration were accounted for within the Evapotranspiration package. In addition to the infiltration rates, half of the simulations also included the cumulative recharge rate, which is the product of the recharge rate per pit and the total number of pits, within the Recharge Package. This approach assumes a uniform distribution of recharge from the pits across the entirety of the Theissen polygon.

The research involved creating 36 simulations using MODFLOW, each representing the 18 Theissen polygons. These simulations were designed to reflect the current situation and a proposed situation with the implementation of recharge pits. Each Thiessen polygon was simulated two times once with recharge pits and once without recharge pits. The 36 simulations provided results in the form of Water Budgets as shown in figure. Following Table shows the data used for the simulations :

Table -2: Parameters and their values for MODFLOW simulations

Parameter	Average	Source
Evapotranspiration Rate	0.32mm/day	IWRIS (India – Water Resources Information System)
Infiltration Rate	7.5 mm/hr	FAO (Food and Agriculture Organization of the United Nations)

Hydraulic Condictivity for Aquifer-I (Hard Rock) and Aquifer-II(Hard Rock)	4.2 × 10^{-7} m/s	[1]
Hydraulic Conductivity for Aquifer-I (Alluvium)	0.0023 m/s	[2]
Drain Sediment Thickness	2.32 km	[5]
Drain Conductance	0.00215 per day	

This study incorporated the use of satellite imagery obtained from the Bhuvan Landsat Data portal. These images underwent processing in QGIS to produce a Land cover map. The land cover map was then used to determine the area of the water surface, which was essential for calculating the model's evaporation rate. The recharge pits were strategically placed on barren land within the priority zone and at lower elevations, guided by the georeferenced Maharashtra Groundwater Recharge Priority Map. In total, 3248 recharge pits were identified and their locations were preserved in a shapefile.

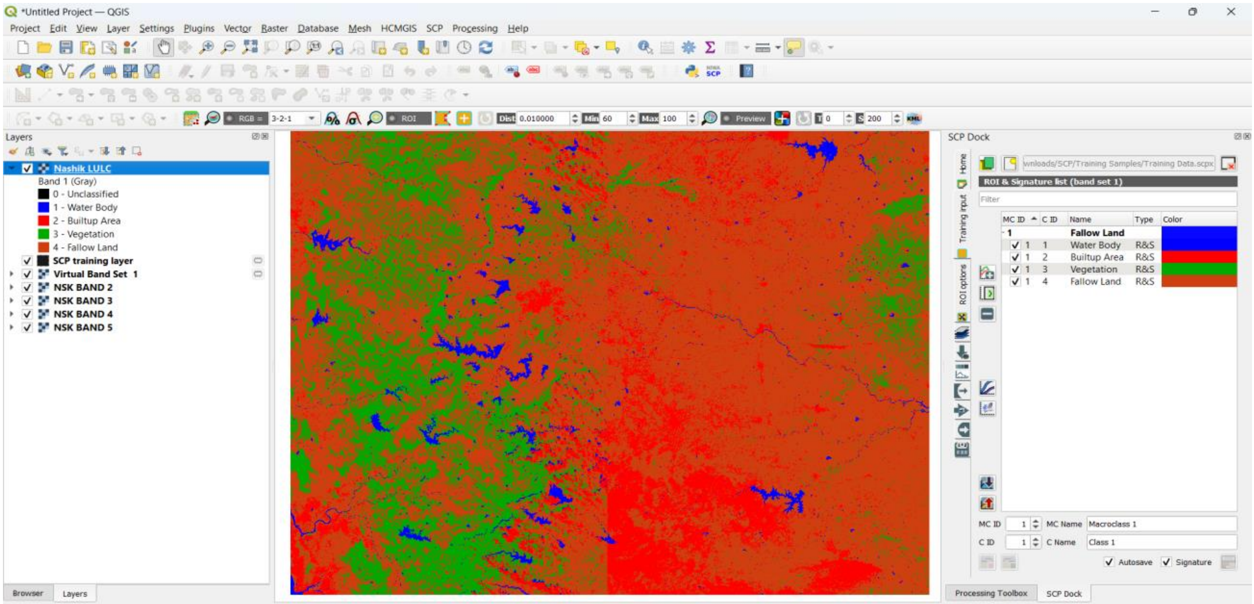

Fig -2: Land Use Map prepared from FCC image

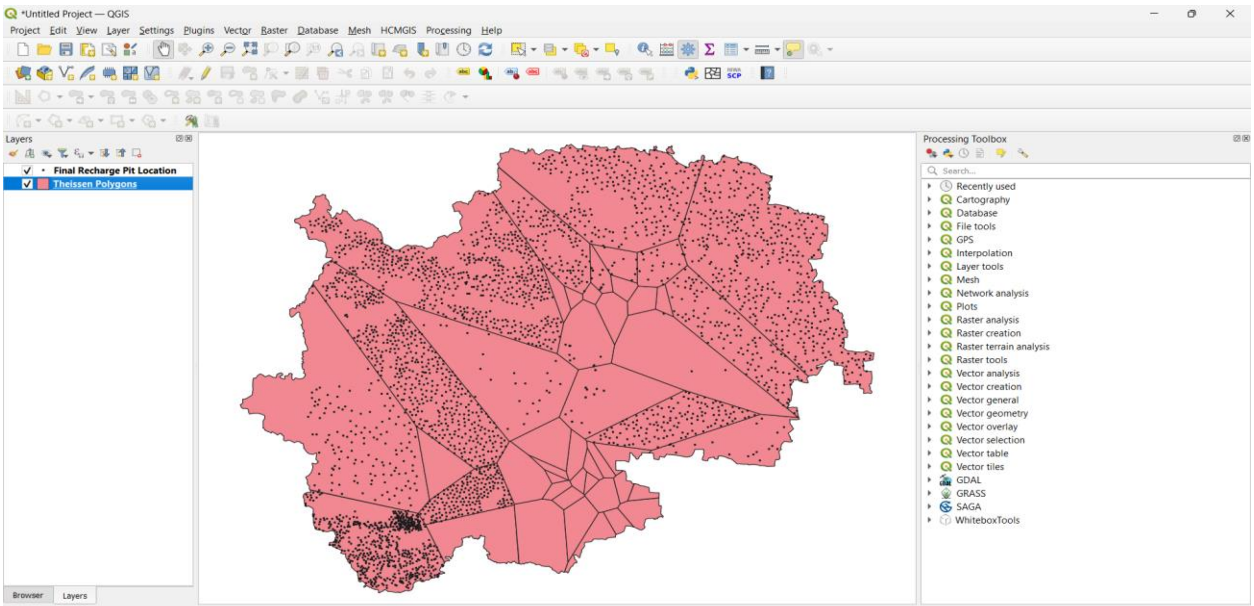

Fig -3: 3248 Recharge Pits located over 18 villages in villages Nashik District

4. RESULTS AND DISCUSSION

Table -3: Volume Budget obtained from MODFLOW-6 for 18 villages and its analysis

Station Name	Without Recharge Pits			% Discrepancy	With Recharge Pits			% Discrepancy	No. of Recharge Pits	Area (km^2)	Increase in Head	Relative Increase in Head
	IN(m^3)	OUT(m^3)	IN-OUT(m^3)		IN(m^3)	OUT(m^3)	IN-OUT(m^3)					
Belgaon Dhaga	10.2738	32.0591	-21.7853	-102.92	32.0708	32.0591	1.17E-02	0.04	144	1794.517	6.51E-12	1.21E-02
Devlane	7.2878	34.0826	-67.5901	-26.7948	34.1311	34.0826	4.85E-02	0.14	250	1273.118	3.81E-11	5.31E-02
Dongargoan	2.5574	0.9184	1.6389	94.3	3.3109	0.9184	2.3925	113.14	20	452.458	5.29E-09	-3.62E-03
Matane	2.4687	6.2656	-3.7969	-86.94	6.2877	6.2656	2.22E-02	0.35	105	429.048	5.17E-11	8.85E-03
Nandgaon(MCL)	2.513	7.675	-5.162	-101.33	7.6966	7.675	2.15E-02	0.28	140	433.719	4.97E-11	1.19E-02
Nimbole	0.9165	1.1713	-0.2548	-24.4	1.1731	1.1713	1.81E-03	0.15	19	151.745	1.19E-11	1.68E-03
Phule Nagar	0.5174	0	0.5174	200	0.5936	0	0.5936	200	10	90.073	6.59E-09	-5.74E-03
Pimpalgaon	5.3956	7.3151	-1.9195	-30.2	7.383	7.3151	6.79E-02	0.92	25	933.845	7.27E-11	2.06E-03
Satvaichiwadi	6.6669	55.308	-48.6411	-156.97	55.3869	55.308	7.89E-02	0.14	496	1182.113	6.68E-11	4.11E-02
Sawatamalinagar(Nv)	1.5817	6.0703	-4.4885	-117.32	6.0794	6.0703	9.16E-03	0.15	193	274.286	3.34E-11	1.64E-02
Varhale	3.6365	10.1014	-6.4649	-94.12	10.1194	10.1014	1.80E-02	0.18	121	615.794	2.93E-11	1.05E-02
Vighanwadi(Bharatpur)	2.173	2.7011	-0.5281	-21.67	2.7173	2.7011	1.62E-02	0.6	17	386.613	4.18E-11	1.37E-03
Warshi	10.0817	98.262	-88.1803	-162.78	98.4609	98.262	0.1989	0.2	595	1773.712	1.12E-10	4.97E-02
Kanchangaon	4.1095	41.4796	-37.37	-163.94	41.5277	41.4796	4.81E-02	0.12	618	737.29	6.52E-11	5.07E-02
Kapashi	1.4043	0	1.4043	200	1.6112	0	1.6112	200	10	242.011	6.66E-09	-5.80E-03
Khuntewadi	0.3252	0.2739	5.13E-02	17.13	0.4019	2.74E-01	0.128	37.88	16	57.761	2.22E-09	-8.88E-04
Kumbharde	4.08	0.3095	3.7705	171.8	4.2603	0.3095	3.9508	172.91	3	724.689	5.45E-09	-5.20E-03
Malegaon_3	10.939	86.0355	-75.0965	-154.88	86.0437	86.0355	8.11E-03	0.01	466	1893.142	4.28E-12	3.97E-02
								Total	3248	13445.93	2.68E-08	2.78E-01

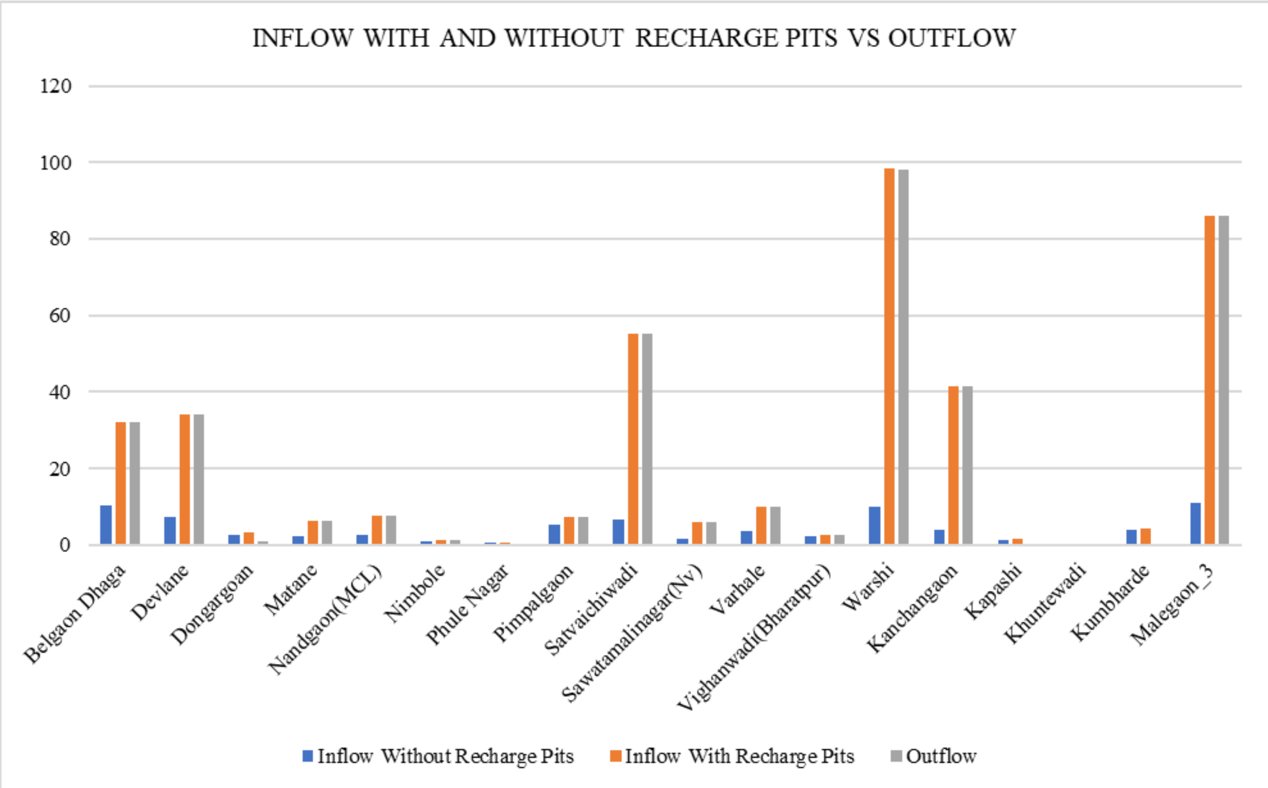

Chart -2: Chart of Inflow with and without recharge pits vs Outflow values for 1 year simulation

3. CONCLUSIONS

The Nashik District's abundant unused land offers an opportunity for installing groundwater recharge systems. Drain conductance, a major factor in groundwater loss, is inversely related to drain sediment thickness. This loss can be reduced by encouraging natural sediment formation in rivers with minimal human interference or by constructing structures like percolation tanks and check dams. Evaporation and evapotranspiration, while contributing to groundwater loss, are relatively minor compared to other factors. Given the disparity between natural groundwater recharge and depletion, artificial recharge structures are crucial for preventing groundwater scarcity. Recharge pits, small but effective, can be constructed in large numbers to improve groundwater conditions. These pits significantly increase groundwater inflow, with values increasing from 0.3252-10.939 m^3 without pits to 0.4019-86.0437 m^3 with recharge pits. This increase, coupled with a relative head increase of the order of 10^{-2} in one-year simulations, highlights the role of recharge pits in promoting groundwater conservation and sustainability.

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