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PRE-MONSOON GROUNDWATER LEVEL DYNAMICS IN SOLAPUR DISTRICT, MAHARASHTRA: A COMPARATIVE ASSESSMENT OF MARCH 2026 STATIC WATER LEVELS AGAINST THE 2021–2025 BASELINE IN DECCAN BASALT AQUIFERS

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ABSTRACT

Groundwater in the Deccan Basalt terrain of semi-arid Maharashtra sustains millions of rural livelihoods, yet systematic pre-monsoon assessments remain scarce. This study analyzes March 2026 Static Water Level (SWL) observations from 156 Observation Dugwell Wells distributed across eleven talukas of Solapur District and compares them against the five-year baseline mean (2021–2025) derived from GSDA's 156-well monitoring network. The primary objectives are to quantify inter-annual groundwater fluctuations at the well, taluka, and watershed scales; identify stress zones; and evaluate spatially differentiated recharge–depletion dynamics before the arrival of the 2026 Southwest Monsoon.

The dataset spans wells with dug well depths ranging from 5.20 m to 27.60 m below ground level (bgl), distributed across 64 sub-watersheds in the Bhima and Sina river basins. District-wide mean pre-monsoon SWL in March 2026 stands at 6.12 m bgl, which is 0.64 m shallower than the 2021–2025 baseline mean of 6.76 m bgl. Of the 156 monitored wells, 92.9% record a positive fluctuation – meaning the water table in 2026 is higher than the five-year average – while only 4.5% show a decline. Thirteen wells record SWLs exceeding 10 m bgl, constituting critical stress nodes concentrated in Karmala, Madha, Mohol, Sangole, Solapur North, and Solapur South talukas. Barshi and Madha talukas register the largest mean improvements (0.93 m and 0.83 m, respectively), whereas Mangalvedhe shows the most muted response (0.28 m).

These findings indicate that cumulative recharge from the 2025 monsoon season more than compensated for extraction-driven depletion across most of the district. The results carry direct implications for pre-monsoon water supply planning, artificial recharge site prioritization, and groundwater conservation under the Atal Bhujal Yojana, Jalyukt Shivar Abhiyan, Jal Jeevan Mission and other artificial recharge government schemes. The study demonstrates the value of systematic, multi-year observation networks in hard-rock aquifer management.

KEYWORDS: *Static Water Level; Deccan Basalt; pre-monsoon groundwater; Solapur District; aquifer dynamics; groundwater fluctuation*

1. INTRODUCTION

Groundwater is the world's most extracted natural resource, with global abstraction exceeding 1,000 km³ per year (Loáiciga, H., & Doh, R., 2023). In data-scarce, semi-arid hard-rock terrains, groundwater monitoring assumes heightened strategic importance because aquifer storage is thin, transmissivities are low, and communities carry little hydrological buffer against sequential drought years. The Intergovernmental Panel on Climate Change (Mukharjee el. Al., 2015) flags South Asian aquifer systems as acutely vulnerable to increasing precipitation variability and rising irrigation demand, a projection that carries direct operational weight for the basaltic uplands of peninsular India.

India extracts approximately 249 km³ of groundwater annually—the highest in the world—with agriculture accounting for around 89% of total withdrawal (Kishore., et., al., 2021). Maharashtra contributes disproportionately to this pressure: the state's 36 districts collectively depend on Deccan Basalt aquifers for drinking water supply to roughly 40,000 villages and for supplemental irrigation to the rain-fed agriculture that defines its semi-arid hinterland (Shaikh and Birajdar, 2025). Solapur District, located in the southeastern corner of Maharashtra, exemplifies this tension. Annual rainfall averages 575–700 mm across the district, most of it concentrated in the June–September monsoon window (Shaikh and Birajdar, 2024). Hard-rock aquifers—principally weathered and fractured Deccan Trap basalts—have limited storativity, and pre-monsoon water levels fall sharply as extraction for rabi crop irrigation and domestic supply continues through the January–May dry season (Jasechko., et., al., 2024, Foster Stephen., 2012).

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Pre-monsoon Static Water Level measurements, recorded just before the onset of the Southwest Monsoon, represent the annual minimum groundwater storage condition. Tracking SWLs against a multi-year baseline reveals whether cumulative recharge is keeping pace with extraction (Singh et., al., 2020, Ghosh and Bera., 2023). Where it is not, early warning is essential for intervention before rural water supply systems fail. The Groundwater Survey and Development Agency (GSDA) has maintained a 156 Observation Dugwell Well (OBW) network in Solapur, generating quarterly SWL readings since the 1972 (Shaikh, 2025).

The Atal Bhujal Yojana (ABY), Jalyukt Shivar Abhiyan a flagship programme of Government of Maharashtra, launched as a community-led groundwater management programme, mandates Water Security Plans for participating Gram Panchayats and relies on OBW network data to trigger conservation interventions (Srivastava and Chinnasamy., 2023, Shaikh and Birajdar 2024a, 2025b, 2024f). Rigorous pre-monsoon analysis is therefore not merely academic; it is an operational requirement of the programme. Birajdar and Shaikh (2024) and Shaikh and Birajdar (2024b, 2024e) have documented the hydrogeological context of Solapur's hard-rock aquifers and the institutional architecture of GSDA's monitoring programme. The present study builds on that baseline, focusing specifically on the March 2026 pre-monsoon SWL dataset across 156 wells and eleven talukas.

1.1 Research Gap

While district-level groundwater assessments are published periodically by state hydrogeological surveys, comparative well-scale analyses that place current measurements against verified multi-year baselines—disaggregated by taluka, watershed, and well depth class—are largely absent from the indexed scientific literature. Most published studies in the Deccan Basalt region rely on post-monsoon data, which reflects recharge but masks the acute pre-monsoon stress that drives drinking water scarcity (Shaikh and Birajdar 2015,2015a, 2025d). This study addresses that gap.

1.2 Objectives

- To quantify district-wide and taluka-specific pre-monsoon SWL conditions in March 2026 relative to the 2021–2025 five-year baseline.
- To identify critical groundwater stress zones (SWL > 10 m bgl) requiring priority intervention.
- To examine spatially differentiated fluctuation patterns across 64 sub-watersheds.
- To assess correlation between dugwell depth, historical SWL, and current water-level status.
- To translate findings into groundwater management recommendations aligned with difference government schemes for implementation.

2. STUDY AREA

2.1 Geographic Setting

Solapur District (17°40’ to 18°30’ N; 74°42’ to 76°18’ E) covers approximately 14,845 km² in the southeastern fringe of Maharashtra. It is one of the most water-stressed districts in the state, consistently featuring in Maharashtra's Drought Prone Area Programme (Shaikh and Birajdar 2025a). The terrain is gently undulating plateau topography at elevations between 400 m and 700 m above mean sea level, draining primarily into the Bhima River and its tributaries (Sina, Man, Nira, and Bhogavati rivers). Administrative units relevant to this study span eleven talukas: Akkalkot, Barshi, Karmala, Madha, Malshiras, Mangalvedhe, Mohol, Pandharpur, Sangole, Solapur North, and Solapur South.

2.2 Climate

The district has a semi-arid tropical climate (BSh under Köppen classification). Annual rainfall ranges from 400 mm in the leeward south (Pandharpur, Sangole) to 700 mm in the north (Karmala, Barshi). Rainfall is strongly monsoonal, with the July–August period delivering 60–70% of the annual total. Potential evapotranspiration (PET) exceeds 1,800 mm year^{-1}, creating a persistent moisture deficit from October to May (Todmal., 2022). Mean maximum temperatures reach 40–43°C during April–May, when groundwater demand is highest and levels are at their annual minimum (Shaikh and Birajdar 2024g).

2.3 Geology and Hydrogeology

Solapur District is underlain almost entirely by Deccan Trap basalts of Late Cretaceous to Early Eocene age (65 Ma). The basalts are arranged in sub-horizontal lava flows, each 5–30 m thick, comprising vesicular/amygdaloidal zones at flow tops and compact, massive interiors (Shaikh and Birajdar 2025c). Productive aquifers occur in three settings: (i) the shallow weathered regolith (lateritic and red bole zones) extending 5–15 m bgl; (ii) vesicular flow-top zones at 15–30 m depth; and (iii) jointed and fractured compact basalt where tectonic discontinuities provide secondary permeability. Hydraulic conductivity typically ranges from 0.1 to 5 m day^{-1}, and specific yield values of 0.01–0.03 characterize these phreatic to semi-confined systems (Deolankar, 1980) (Fig.1). Recharge is almost exclusively precipitation-dependent, with negligible contribution from alluvial channels except along the Bhima and Sina floodplains (Shaikh et., al., 2019).

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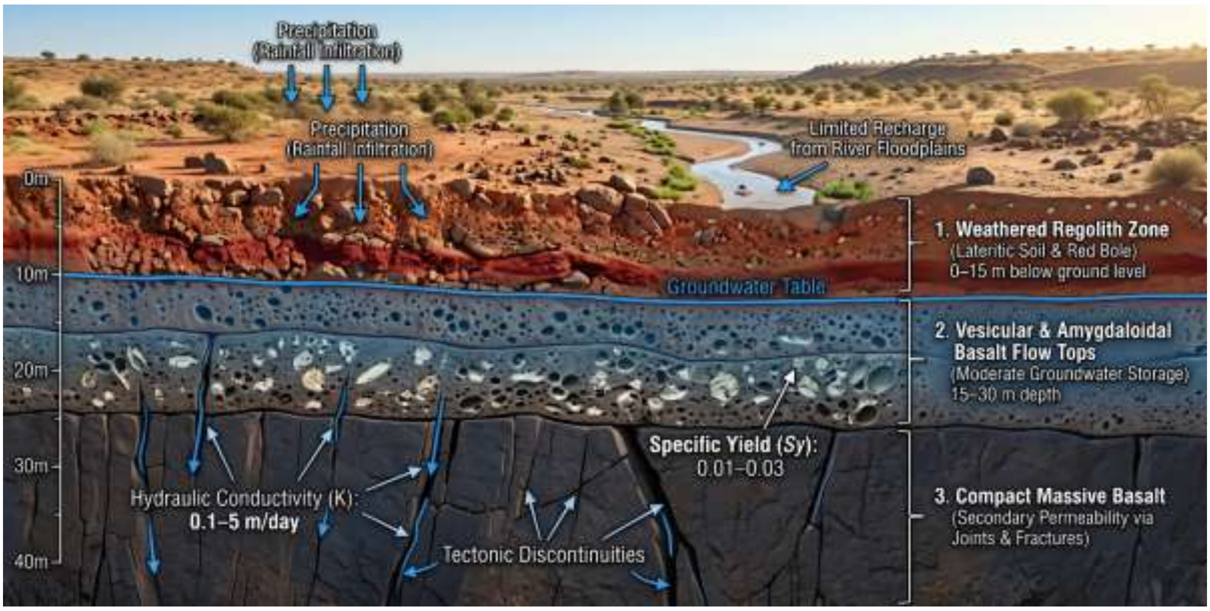

Figure 1. Geology and Hydrogeology of the Study Area.

2.4 Land Use and Irrigation
Agriculture dominates the land use matrix, with net sown area covering approximately 70% of the district. Principal crops include sugarcane (irrigated, Madha and Malshiras), jowar (Sorghum bicolor), bajra, and soybean (Shaikh and Birajdar, 2023). Groundwater irrigates roughly 55% of the irrigated area, predominantly through open dug wells and shallow dugwell wells. Sugarcane cultivation in the eastern belt around Pandharpur and Madha imposes perennial groundwater abstraction pressure, a factor that shapes the observed SWL patterns in this study (Raheem et., al., 2023).

3. DATA AND METHODOLOGY
3.1 Dataset Description
The dataset comprises March 2026 pre-monsoon SWL observations from 156 Observation Dugwell Wells (OBWs) managed by GSDA Solapur Division. For each well, the dataset records: Site ID (unique 18-character alphanumeric code), District, Taluka, Village, Sub-watershed (using GSDA basin nomenclature: BM- prefix for Bhima basin; SA- prefix for Sina basin), dugwell depth (m bgl), five-year average SWL for March (2021–2025 baseline), March 2026 SWL reading, and the calculated SWL fluctuation (Avg 2021–25 minus 2026 reading; positive values indicate a shallower water table in 2026, i.e. improvement) (Table 1 and Fig. 2).

All SWL measurements are recorded in meters below ground level (m bgl), with lower numerical values indicating shallower (better) groundwater conditions. The 156 wells span 64 named sub-watersheds and are distributed across eleven talukas. Well depths range from 3.5 m to 27.6 m bgl, with 44.2% of wells in the 0–10 m depth class, 42.3% in the 10–15 m class, 11.5% in the 15–20 m class, and 1.9% exceeding 20 m.

Table 1 Groundwater Level Dynamics and Fluctuation Patterns in Solapur

Taluka	Village	Watershed	Depth	Avg.21-25 SWLs	Mar 26 SWLs	Fluctuation
Akkalkot	Kurnur	BM-129	14.50	3.97	3.30	0.67
Akkalkot	Satan Dudhani	BM-137	9.35	4.19	3.50	0.69
Akkalkot	Udagi	BM-137	10.40	4.41	4.20	0.21
Akkalkot	Wagdari	BM-134	9.35	4.84	4.50	0.34
Akkalkot	Gogaon	BM-135	8.85	5.17	5.00	0.17
Akkalkot	Sultanpur	BM-130	7.50	5.90	5.10	0.80
Akkalkot	Hannur	BM-133	11.20	5.17	5.10	0.07
Akkalkot	BaSAlegaon	BM-137	10.10	6.68	5.50	1.18
Akkalkot	Tadwal	BM-139	9.65	5.40	5.60	-0.20
Akkalkot	Karjal	BM-138	13.20	6.23	6.20	0.03
Akkalkot	Arali	BM-131	10.00	6.57	6.40	0.17
Akkalkot	Chungi	BM-130	10.60	6.23	6.40	-0.17
Akkalkot	Chikkahalli	BM-136	10.60	7.44	6.90	0.54
Akkalkot	Kajikanbas	BM-129	9.75	6.77	7.00	-0.23
Akkalkot	Chapalgaon	BM-133	11.35	7.51	7.20	0.31

Akkalkot	Borgaon	BM-134	8.40	8.18	8.20	-0.03
Akkalkot	Jeur	BM-138	11.50	9.03	8.20	0.83
Akkalkot	Binjger	BM-136	11.75	8.73	8.50	0.23
Akkalkot	Dudhani (Rural))	BM-136	15.90	9.18	8.60	0.58
Akkalkot	Kini	BM-129	11.40	9.22	8.70	0.52
Barshi	Kari	SA-33	9.00	2.57	2.30	0.27
Barshi	Chare	SA-26	7.56	3.82	3.10	0.72
Barshi	Raleras	SA-34	7.85	5.60	4.50	1.10
Barshi	Gaudgaon	SA-34	10.00	5.30	4.60	0.70
Barshi	Nandani	SA-33	8.10	5.69	4.70	0.99
Barshi	Agalgaon	SA-26	13.15	5.57	4.80	0.77
Barshi	Pangaon	SA-31	9.35	6.08	5.10	0.98
Barshi	Kalambawadi (A)	SA-26	9.00	5.70	5.20	0.50
Barshi	Jamgaon	SA-33	12.65	6.14	5.40	0.74
Barshi	Kuslamb	SA-27	12.00	6.27	5.70	0.57
Barshi	Alipur	SA-27	15.65	6.92	5.70	1.22
Barshi	Malwandi	SA-30	10.85	7.65	5.90	1.75
Barshi	Vairag	SA-34	18.90	7.75	6.40	1.35
Barshi	Chikharde	SA-32	9.90	7.92	7.20	0.72
Barshi	Shendri	SA-27	18.25	10.02	8.50	1.52
Karmala	Kavitgaon	BM-65	5.50	2.26	1.95	0.31
Karmala	Karmala	SA-16	9.00	4.08	2.90	1.18
Karmala	Jinti	BM-47	7.95	4.22	3.20	1.02
Karmala	Bhalavni	BM-65	16.40	3.94	3.20	0.74
Karmala	Kedagaon	BM-63	9.65	4.88	3.50	1.38
Karmala	Ghargaon	SA-21	7.35	4.42	3.60	0.82
Karmala	Arjunnagar	SA-20	7.15	4.42	3.70	0.72
Karmala	Ketur	BM-62	8.45	4.30	3.80	0.50
Karmala	Jategaon	SA-15	13.50	5.58	3.80	1.78
Karmala	Kem	BM-65	9.35	5.95	4.10	1.85
Karmala	Shelgaon (Wangi)	BM-64	12.00	4.80	4.20	0.60
Karmala	Pophalaj	BM-63	13.00	4.78	4.40	0.38
Karmala	Warkute	SA-22	7.70	5.10	4.50	0.60
Karmala	SArapdoh	BM-64	9.85	5.49	5.00	0.49
Karmala	SAvadi	BM-62	12.00	6.22	5.40	0.82
Karmala	Mangi	SA-16	7.90	7.47	7.40	0.07
Karmala	Rajuri	BM-62	9.00	7.88	7.80	0.08
Karmala	Khadaki	SA-15	13.61	10.28	9.20	1.08
Karmala	Bhose	SA-16	12.00	11.73	10.20	1.53
Karmala	Padali	SA-21	16.36	11.03	10.20	0.83
Karmala	Borgaon	SA-21	12.75	10.78	10.30	0.48
Karmala	Pande	SA-20	10.50	10.50	10.50	0.00
Karmala	Bhilarwadi	BM-47	19.40	11.60	10.50	1.10
Madha	Palwan	BM-80	12.00	4.00	3.50	0.50
Madha	Adhegaon	BM-79	8.40	4.57	4.00	0.57

Madha	Dhanore	SA-31	10.50	5.15	4.10	1.05
Madha	Loni	SA-22	6.70	5.45	4.20	1.25
Madha	Tembhurni	BM-79	9.00	4.98	4.30	0.68
Madha	Kanhergaon	BM-79	8.70	5.65	4.60	1.05
Madha	Barloni	SA-28	7.65	5.30	4.70	0.60
Madha	Ambad	SA-28	9.65	5.40	4.90	0.50
Madha	Warawade	BM-80	8.50	6.43	5.00	1.43
Madha	Parite	BM-80	12.20	7.82	5.50	2.32
Madha	Kewad	SA-30	15.50	8.50	7.50	1.00
Madha	Upalai Bk	SA-29	16.65	9.05	8.30	0.75
Madha	Tulshi	BM-91	12.30	9.46	8.70	0.76
Madha	Manegaon	SA-30	19.20	9.37	9.20	0.17
Madha	Madha	SA-28	17.25	11.25	10.50	0.75
Madha	Bhend	BM-93	10.70	10.70	10.70	0.00
Madha	Aran	BM-93	18.00	14.75	14.10	0.65
Madha	Modnimb	BM-93	27.60	15.12	14.20	0.92
Malshiras	Malkhambi	BM-99	11.00	4.35	3.50	0.85
Malshiras	Bacheri	BM-98	9.00	3.33	4.00	-0.67
Malshiras	Tandulwadi	BM-98	7.20	4.43	4.10	0.33
Malshiras	Tarangfal	BM-99	8.20	5.00	4.10	0.90
Malshiras	Malshiras	BM-89	10.10	4.48	4.10	0.38
Malshiras	Khudus	BM-90	5.20	4.38	4.20	0.18
Malshiras	Jalbhavi	BM-89	8.70	5.30	4.80	0.50
Malshiras	GurSAle	BM-87	8.20	5.22	5.10	0.12
Malshiras	Piliv	BM-99	10.10	5.98	5.20	0.78
Malshiras	Dharmpuri	BM-87	7.95	5.68	5.50	0.18
Malshiras	Foundshiras	BM-88	10.80	6.74	6.50	0.24
Malshiras	Karunde	BM-88	10.85	8.08	7.10	0.98
Malshiras	Kothale	BM-87	10.60	8.68	8.00	0.68
Malshiras	Lawang	BM-90	12.80	9.40	8.50	0.90
Mangalvedhe	Borale	BM-108	14.00	3.99	3.00	0.99
Mangalvedhe	DikSAl	BM-108	8.00	5.86	6.00	-0.14
Mangalvedhe	Pout	BM-111	8.00	7.00	7.00	0.00
Mangalvedhe	Barmhapuri	BM-108	8.00	7.72	7.40	0.32
Mangalvedhe	Siddhankeri	BM-119	8.35	7.98	7.50	0.48
Mangalvedhe	Kagasht	BM-111	9.00	8.63	8.60	0.03
Mohol	Bhoire	SA-35	14.90	3.55	3.00	0.55
Mohol	Ichgaon	BM-95	8.20	5.18	4.40	0.78
Mohol	Wagholi	BM-109	9.80	5.98	5.30	0.68
Mohol	Narkhed	SA-31	10.85	5.73	5.40	0.33
Mohol	Arjunsond	SA-37	13.00	5.98	5.50	0.48
Mohol	Patkul	BM-94	11.35	6.52	5.60	0.92
Mohol	Warkute	BM-95	10.90	7.12	6.20	0.92
Mohol	Adhegaon	BM-94	9.40	8.18	6.90	1.28
Mohol	Kamthi Kh	SA-39	12.10	7.80	6.90	0.90

Mohol	Kurul	SA-39	21.90	8.25	7.00	1.25
Mohol	Pokharapur	SA-36	14.10	7.87	7.20	0.67
Mohol	Yawali	SA-36	14.10	11.40	10.90	0.50
Pandharpur	Gurasale	BM-92	17.00	2.50	2.50	0.00
Pandharpur	Karkamb	BM-91	14.00	3.81	3.10	0.71
Pandharpur	Shirgaon	BM-107	6.85	4.43	4.00	0.43
Pandharpur	Jaloli	BM-91	8.35	5.45	5.00	0.45
Pandharpur	Anawali	BM-96	9.65	6.35	5.10	1.25
Pandharpur	Eklaspur	BM-107	10.60	5.92	5.60	0.32
Pandharpur	Kharsoli	BM-94	25.10	6.75	5.80	0.95
Pandharpur	Gardi	BM-97	13.20	6.52	6.00	0.52
Pandharpur	Bhose	BM-92	10.20	6.85	6.20	0.65
Pandharpur	Bhalawani	BM-98	12.50	6.53	6.30	0.23
Pandharpur	Bhandi Shegaon	BM-97	13.20	7.17	6.40	0.77
Pandharpur	Sangavi	BM-91	10.60	7.58	7.00	0.58
Pandharpur	Wakhari	BM-96	8.00	7.75	7.40	0.35
Pandharpur	Bardi	BM-92	9.70	9.51	9.50	0.01
Sangole	Wadegaon	BM-112	14.40	5.88	4.50	1.38
Sangole	Junoni	BM-115	14.00	5.36	5.00	0.36
Sangole	Bamani	BM-106	7.00	5.28	5.10	0.18
Sangole	Pare	BM-112	14.00	6.06	5.40	0.66
Sangole	Dongargaon	BM-117	8.60	5.83	5.50	0.33
Sangole	Rajapur	BM-112	12.65	6.90	5.50	1.40
Sangole	Pachegaon Kh	BM-116	6.00	5.86	5.70	0.16
Sangole	Javala	BM-117	10.00	6.82	6.50	0.32
Sangole	Ajanale-Ligadewadi	BM-105	7.85	7.32	7.10	0.22
Sangole	Sonand	BM-117	12.20	7.82	7.10	0.72
Sangole	Achakadani	BM-106	12.90	8.40	7.20	1.20
Sangole	Pachegaon Bk	BM-115	10.80	9.30	9.00	0.30
Sangole	Hangirage	BM-119	16.40	9.53	9.00	0.53
Sangole	Tippehali	BM-115	16.30	11.08	10.50	0.58
N. Solapur	Akolekati	SA-37	8.90	5.28	4.60	0.68
N. Solapur	Kalman	SA-35	9.65	5.64	5.30	0.34
N. Solapur	Karamba	SA-38	16.50	6.37	5.40	0.97
N. Solapur	Mardi	SA-38	14.50	7.20	6.50	0.70
N. Solapur	Wadala	SA-37	13.90	10.78	10.10	0.68
S. Solapur	Takali	BM-110	14.50	1.22	1.90	-0.68
S. Solapur	Kandalgaon	SA-40	6.70	3.36	3.10	0.26
S. Solapur	Yelegaon	SA-40	7.10	4.52	3.90	0.62
S. Solapur	Dhotri	BM-139	9.00	5.00	4.40	0.60
S. Solapur	Dindur	BM-138	11.90	4.89	4.60	0.29
S. Solapur	Nandani	BM-110	15.70	7.42	6.10	1.32
S. Solapur	Hotgi	SA-41	12.00	7.22	6.30	0.92
S. Solapur	Tandulwadi	BM-133	11.50	7.20	6.50	0.70
S. Solapur	Mandrup	BM-110	9.50	7.55	6.70	0.85

S. Solapur	Aurad	SA-40	9.00	8.08	7.10	0.98
S. Solapur	Kumbhari	SA-41	11.40	8.46	7.60	0.86
S. Solapur	Vinchur	BM-109	10.00	8.33	7.90	0.43
S. Solapur	Vadapur	BM-109	12.35	11.13	9.00	2.13
S. Solapur	Musti	BM-132	9.90	9.87	9.70	0.17
S. Solapur	Bankalgi	SA-41	19.60	12.70	11.80	0.90
				6.76	6.12	0.64

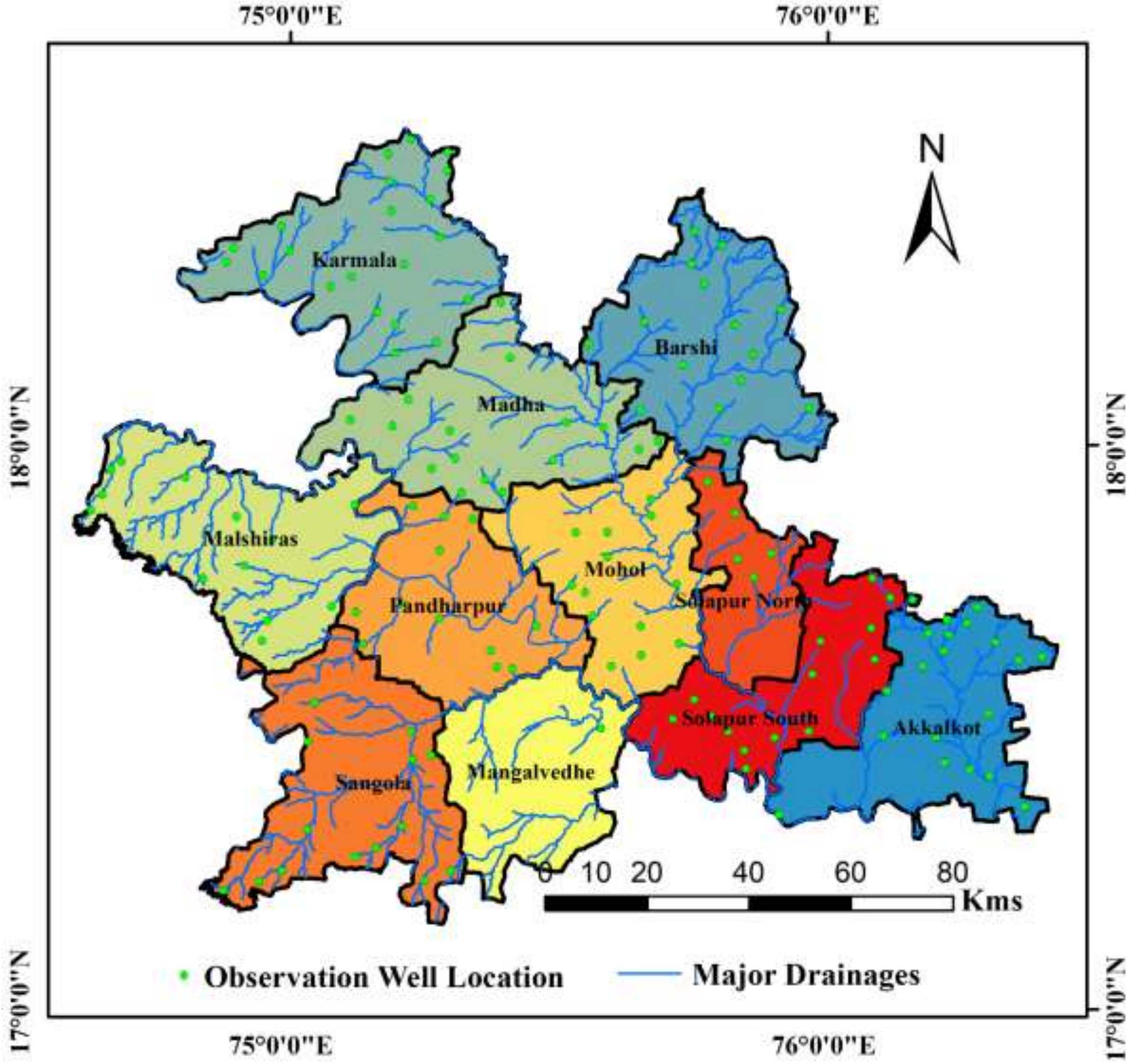

Figure 2. Observation Well Network of Study Area

3.2 Data Preprocessing

The raw dataset was imported from the GSDA district register and standardized. Numeric conversions were applied to depth, SWL, and fluctuation fields. No outlier removal was applied; extreme values were retained and examined contextually because they reflect genuine hydrogeological conditions rather than measurement artefacts. The five-year baseline (2021–2025) was computed as the arithmetic mean of March readings for each well from GSDA archives.

3.3 Analytical Framework

The following analytical procedures were applied:

- Descriptive statistics (mean, standard deviation, minimum, maximum, interquartile range, coefficient of variation) were computed at district, taluka, and watershed scales for both the historical baseline and the 2026 observation.
- SWL fluctuation analysis: fluctuation = Avg(2021–25) - SWL(Mar 2026). A positive fluctuation indicates the 2026 water table is shallower than the baseline; a negative fluctuation indicates deepening relative to the baseline.
- Critical stress classification: wells with March 2026 SWL > 10 m bgl were classified as critical stress nodes,

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consistent with GSDA operational thresholds for drought intervention.

- Pearson correlation coefficients were computed between: (i) dugwell depth and March 2026 SWL; and (ii) the historical baseline SWL and March 2026 SWL.
- Coefficient of Variation (CV) was computed per taluka to assess spatial heterogeneity in water-level distribution.
- Watershed-scale analysis: mean March 2026 SWL was computed for all 64 sub-watersheds and ranked to identify extreme conditions.

4. RESULTS

4.1 District-Wide SWL Status: March 2026 versus Baseline

Table 1 presents the district-level descriptive statistics for OBW. The mean March 2026 SWL across 156 wells is 6.12 m bgl, compared to the five-year baseline mean of 6.76 m bgl. This represents a district-wide mean improvement of 0.64 m—the water table in March 2026 sits, on average, 0.64 m shallower than expected based on the 2021–2025 pattern. The standard deviation in 2026 (2.30 m) is marginally lower than in the baseline (2.35 m), suggesting that the spatial dispersion of water levels has narrowed slightly, consistent with a relatively uniform monsoon recharge distribution in 2025 (Table 2 and Fig. 3).

Table 2 District-level descriptive statistics for Solapur OBW network, March 2026 (n=156). Positive fluctuation denotes shallower 2026 water table relative to baseline.

Parameter	N	Mean (m bgl)	SD (m)	Range (m)
Dugwell Depth	156	10.72	3.94	5.2 – 27.6
SWL Avg 2021–25 (baseline)	156	6.76	2.35	1.22 – 15.12
SWL March 2026	156	6.12	2.30	1.90 – 14.20
SWL Fluctuation (2026 vs baseline)	156	+0.64	0.48	-0.68 – +2.32

SWL = Static Water Level; bgl = below ground level.

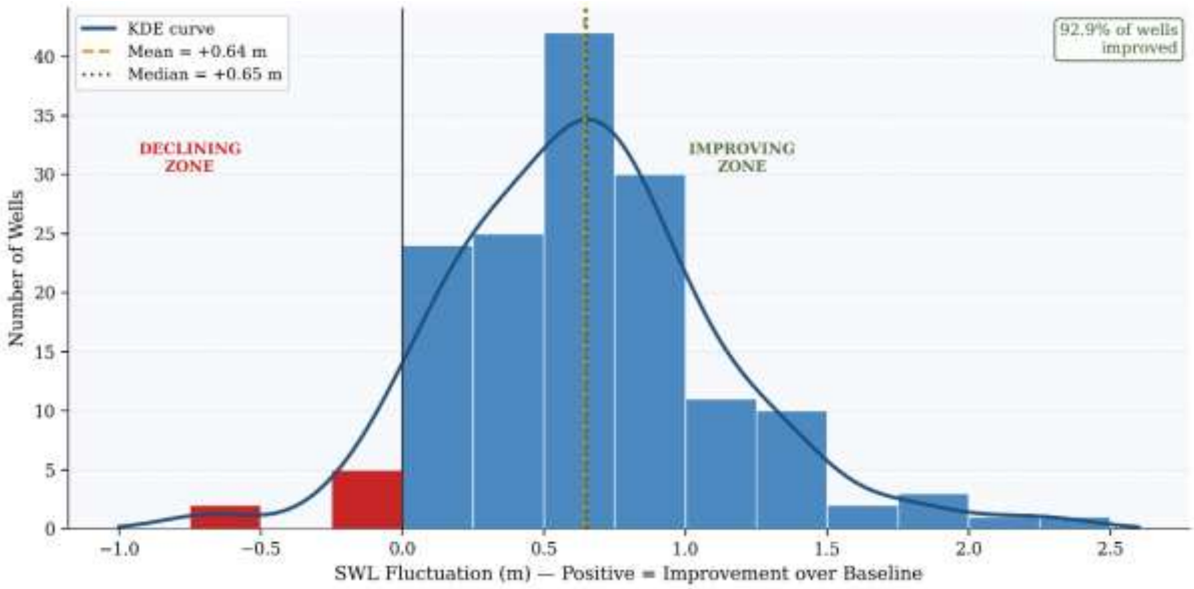

Figure 3. Frequency Distribution of pre monsoon SWL fluctuation March 2026 Vs 2021-25 Baseline (n=156 wells)

4.2 Taluka-Wise Analysis

Table 3 summarizes taluka-level statistics of OBW. Mean 2026 pre-monsoon SWL ranges from 5.27 m bgl in Barshi to 7.11 m bgl in Madha. The highest mean SWL improvement is recorded in Barshi (0.93 m) followed closely by Madha (0.83 m) and Karmala (0.80 m). Mangalvedhe shows the smallest improvement (0.28 m), and its negative minimum fluctuation (-0.14 m) indicates at least one well where the water table has deepened relative to the baseline (Fig. 4 and 5).

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Table 3 Taluka-wise SWL statistics, Solapur District, March 2026.

Taluka	n	Hist. Mean (m bgl)	2026 Mean (m bgl)	Mean Fluct. (m)	SD 2026 (m)	CV 2026 (%)
Akkalkot	20	6.54	6.2	+0.34	1.7	27.4
Barshi	15	6.2	5.27	+0.93	1.5	28.4
Karmala	23	6.6	5.8	+0.8	2.94	50.7
Madha	18	7.94	7.11	+0.83	3.47	48.7
Malshiras	14	5.79	5.34	+0.45	1.59	29.9
Mangalvedhe	6	6.86	6.58	+0.28	1.95	29.6
Mohol	12	6.96	6.19	+0.77	1.92	31
Pandharpur	14	6.22	5.71	+0.51	1.78	31.1
Sangole	14	7.25	6.65	+0.6	1.79	26.9
Solapur North	5	7.05	6.38	+0.67	2.19	34.3
Solapur South	15	7.13	6.44	+0.69	2.62	40.6

Hist. = Historical (2021–25); Fluct. = Fluctuation; CV = Coefficient of Variation.

Karmala and Madha talukas show the highest CV values (50.7% and 48.7%, respectively), reflecting wide intra-taluka heterogeneity in aquifer conditions. This is consistent with the geological transition zones within these talukas, where compact basalt interiors of limited permeability alternate with more productive vesicular zones. Conversely, Sangole and Akkalkot display relatively uniform water-level distributions (CV: 26.9% and 27.4%), suggesting more homogeneous aquifer behavior within the monitoring network.

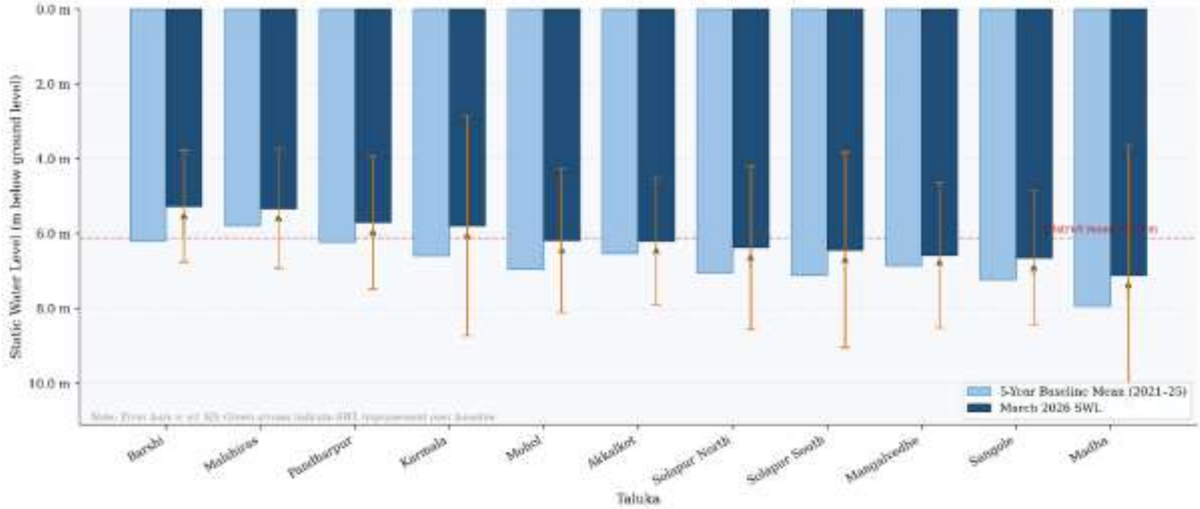

Figure 4. Talukawise Comparision of Pre Monsoon SWL

4.3 SWL Fluctuation: Spatial Pattern

4.4 Critical Stress Zones

Thirteen wells record March 2026 SWL exceeding 10 m bgl. These represent structurally deep aquifer conditions combined with intensive pre-monsoon abstraction and are classified as critical stress nodes (Table 4).

Table 4 Wells with critical pre-monsoon SWL (>10 m bgl), Solapur District, March 2026

Village	Taluka	Depth (m)	Baseline Mean (m bgl)	SWL Mar 2026 (m bgl)	Fluctuation (m)
Aran	Madha	16.12	14.75	14.1	+0.65
Modnimb	Madha	17.6	15.12	14.2	+0.92
Bhend	Madha	10.7	10.7	10.7	0.00
Madha	Madha	17.25	11.25	10.5	+0.75
Bhilarwadi	Karmala	19.4	11.6	10.5	+1.10
Pande	Karmala	10.5	10.5	10.5	0.00
Bhose	Karmala	12	11.73	10.2	+1.53
Borgaon	Karmala	12.75	10.78	10.3	+0.48
Padali	Karmala	16.36	11.03	10.2	+0.83
Yawali	Mohol	14.1	11.4	10.9	+0.50
Tippehali	Sangole	16.3	11.08	10.5	+0.58
Wadala	Solapur North	13.9	10.78	10.1	+0.68
Bankalgi	Solapur South	19.6	12.7	11.8	+0.90

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Modnimb (17.6 m dugwell depth, 14.2 m SWL) and Aran (16.12 m dugwell depth, 14.1 m SWL) represent the deepest stress conditions in the district. Karmala leads with five critical-stress wells, followed by Madha with four. Together, these two talukas account for 69% of all critical stress nodes. Madha's Modnimb village records the district's deepest March SWL at 14.2 m bgl, with an unusually deep dugwell of 27.6 m—evidence of longstanding intensive abstraction from deep fracture zones. Despite improvement relative to baseline at most of these wells, the absolute SWL remains dangerously low for pre-monsoon conditions.

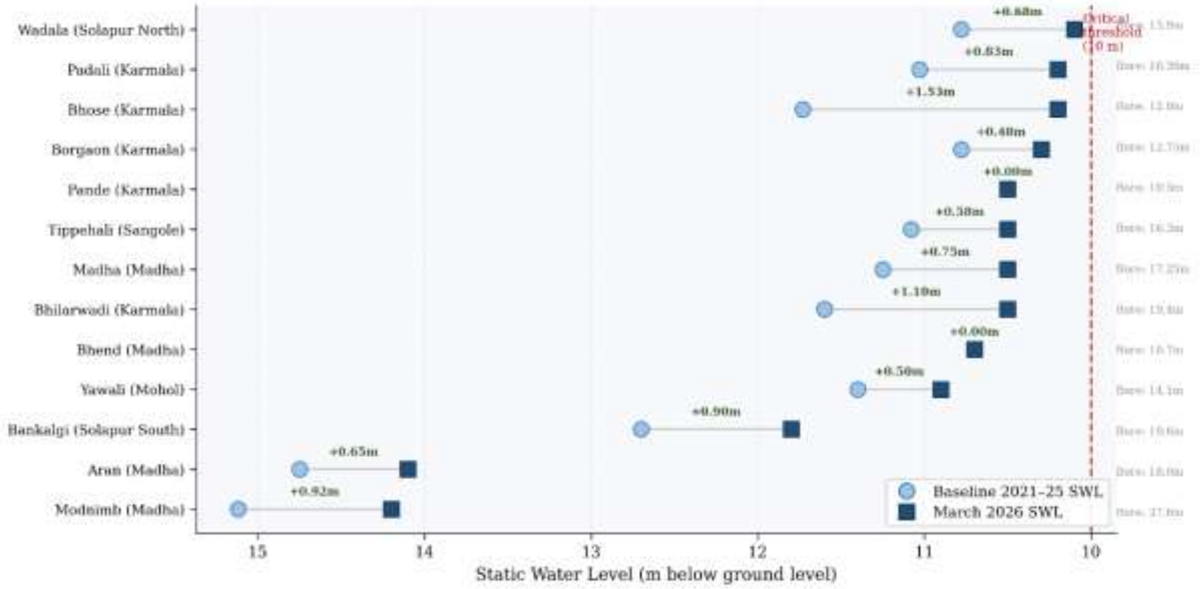

Figure 7 Critical Stress Wells

Figure 7 maps the 13 critical-stress wells (SWL > 10 m bgl) alongside a heatmap of taluka-wise mean SWL, clearly identifying Karmala and Madha as the primary stress clusters requiring priority intervention.

4.5 Watershed-Scale Patterns

Across the 64 sub-watersheds, mean March 2026 SWLs range from 3.08 m bgl (sub-watershed BM-65) to 13.00 m bgl (sub-watershed BM-93). The five shallowest-SWL watersheds—BM-65 (3.08 m), BM-63 (3.95 m), Sa-33 (4.13 m), SA-35 (4.15 m), and BM-99 (4.27 m)—indicate zones of relatively abundant shallow aquifer storage. In contrast, BM-93 (13.00 m), BM-132 (9.70 m), and Sa-36 (9.05 m) represent structurally deep stress zones. The prefix pattern—with BM-93 and BM-132 both in the Bhima basin—points to localized deep-fracture aquifer dependence in the eastern Solapur plateau, where surface-water irrigation infrastructure is less developed and groundwater bears the full burden of domestic and agricultural supply. This pattern, especially in parts of the eastern Solapur Plateau, shows that where surface irrigation is limited, communities rely heavily on groundwater—putting extra pressure on already fragile aquifers. To manage this effectively, a combined AI–GIS–IoT approach can be transformative. Real-time sensors (IoT), spatial mapping (GIS), and predictive analysis (AI) can work together to track water levels, identify stress zones early, and guide targeted actions like recharge and efficient water use (Shaikh and Birajdar 2025e, Shaikh., 2025f).

4.6 Correlation Analysis

Pearson correlation between dugwell depth and March 2026 SWL yields r = 0.448 (moderate positive). This confirms the intuitive expectation that deeper dugwells tend to tap deeper water levels, but the relationship is not deterministic—some deep dugwells access productive fracture zones with relatively shallow water tables, while some shallow dugwells in compact basalt yield high SWLs. The exceptionally high correlation between the 2021–2025 baseline mean and March 2026 SWL (r = 0.979) establishes that the inter-annual water-level pattern is spatially stable: wells that were historically stressed remain so, and wells in structurally favorable positions retain their relative advantage. This persistence is characteristic of hard-rock aquifer systems where structural geology, not episodic weather, determines long-run storage (Fig. 8 and 9).

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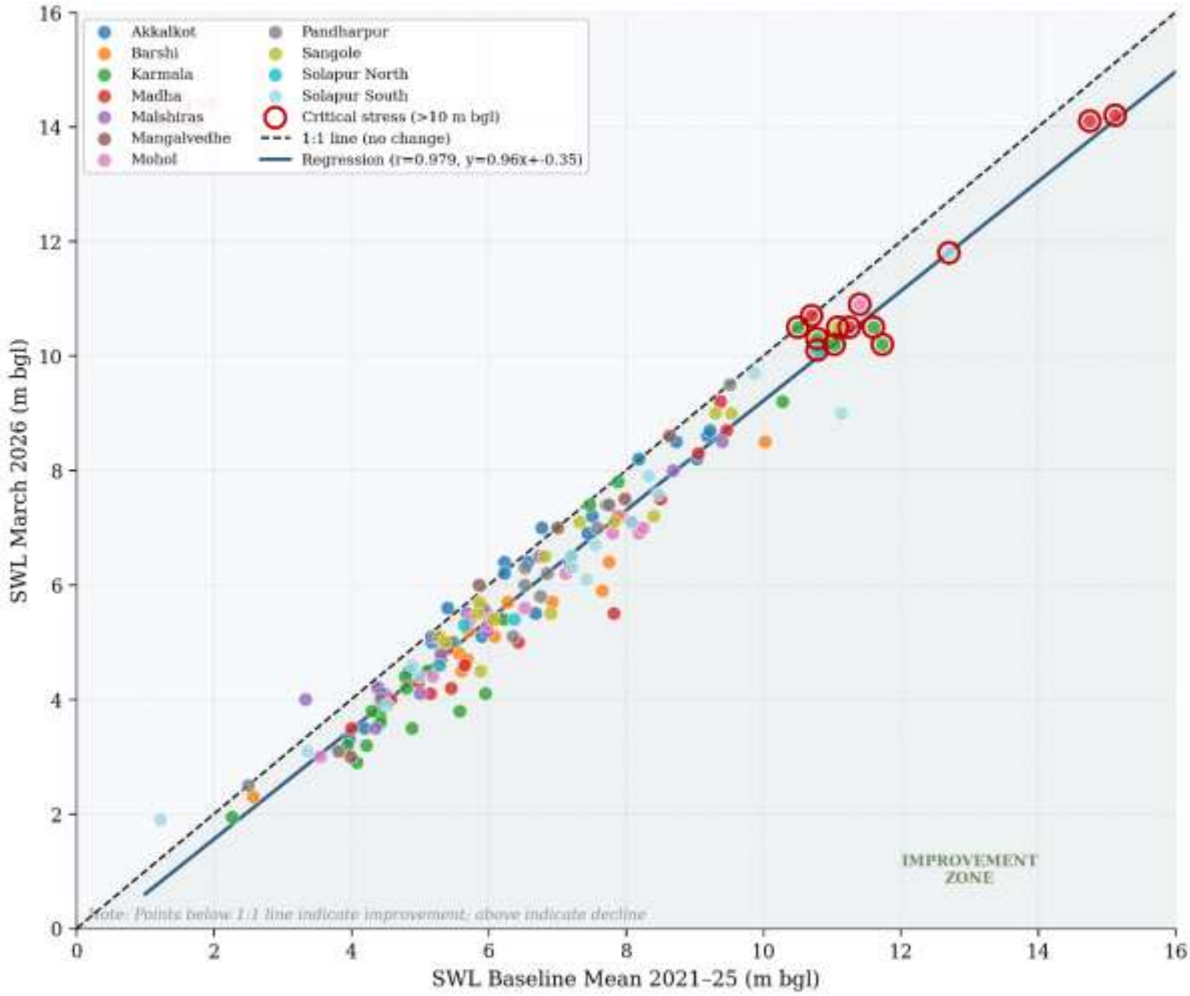

Figure 8 Scatter plot of Baseline Vs March 2026 SWL

Figure 8 presents two scatter plots: (a) dugwell depth vs. March 2026 SWL (r = 0.448), and (b) baseline mean SWL vs. March 2026 SWL (r = 0.979). The near-perfect correlation in panel (b) is the study's most diagnostically important finding.

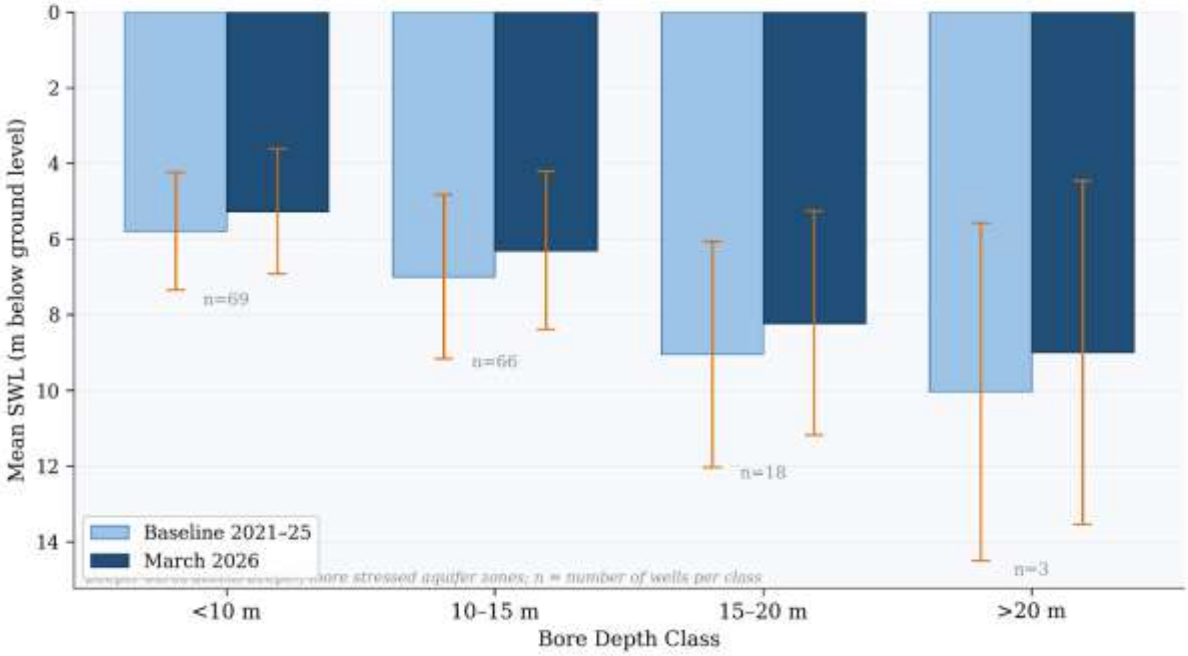

Figure 9 Mean Pre Monsoon SWL by Dug well Depth Class

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The figure 10 illustrates the spatial variability and distribution of March 2026 groundwater levels across talukas, showing that mean SWL generally ranges between ~5.5 and 7.0 m bgl with moderate to high heterogeneity (CV ≈ 25–50%), while box plot analysis indicates that most talukas remain above the 10 m stress threshold, with localized deeper water levels and outliers in areas such as Madha and Karmala reflecting emerging groundwater stress conditions.

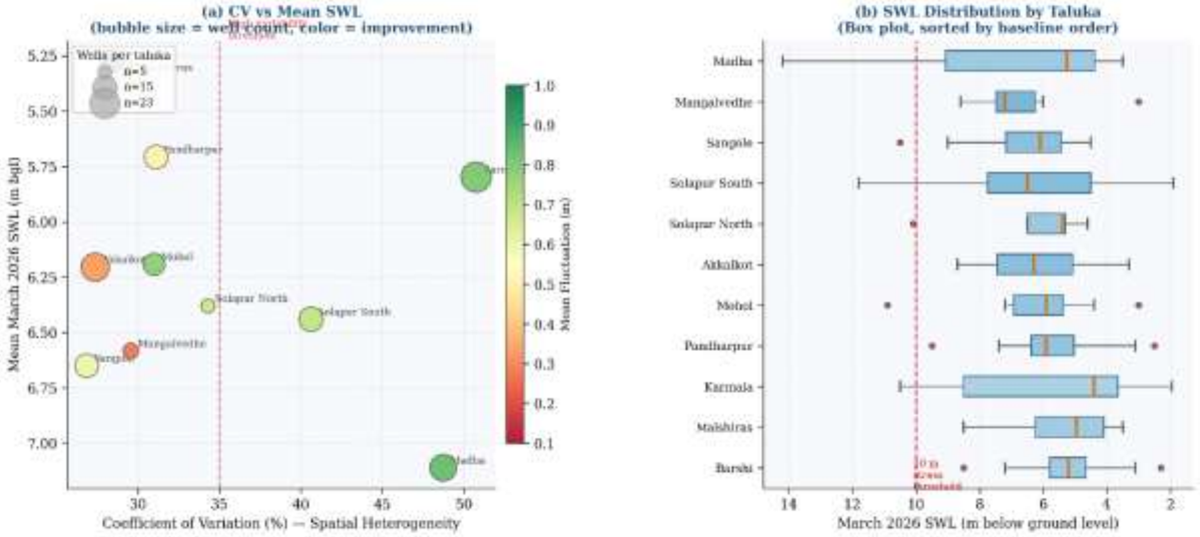

Figure 10 Spatial Heterogenity Analysis - Coefficient of Variation and SWL distribution

5. DISCUSSION

5.1 Interpreting the Generalized Improvement

The finding that 92.9% of monitored wells show a positive fluctuation in March 2026 relative to the five-year baseline is striking. Three interacting factors explain it. First, the 2025 Southwest Monsoon delivered above-normal rainfall over much of the Bhima basin; preliminary IMD data indicate that several Solapur talukas received 110–130% of long-period average rainfall during June–September 2025, enabling deep percolation into fractured basalt beyond the typical monsoon year. Second, the Government of Maharashtra's Jalyukt Shivar Abhiyan water conservation, District planning development committee fund, Jal Jeevan Mission, Atal Bhujal Yojana works—recharge shafts, farm ponds, check dams, nala bunding—have progressively increased local recharge in treated micro-watersheds, effects that accumulate over multiple seasons (Shaikh and Birajdar, 2024d). Third, GSDA's sub-watershed groundwater budgeting exercises under ABY have incentivized some Gram Panchayats to reduce dry-season groundwater extraction for non-essential irrigation, moderately lowering abstraction stress before the pre-monsoon measurement.

It would be premature, however, to interpret these results as evidence of aquifer recovery. The multi-year baseline (2021–2025) itself captures years of net depletion at many wells, so 'improvement over the baseline' may merely mean the water table is slightly less depleted than its recent depleted average. The thirteen critical-stress wells—where absolute SWLs exceed 10 m bgl despite positive fluctuations—reinforce this caution.

5.2 Karmala and Madha: The Deep-Stress Cluster

The concentration of critical-stress wells in Karmala (23 monitored wells, CV 50.7%) and Madha (18 wells, CV 48.7%) reflects a convergence of unfavorable factors. Madha's geology transitions toward more compact, less vesicular basalt flows in its eastern zone, reducing primary porosity and effective recharge rates. Sugarcane cultivation—which requires year-round irrigation water—imposes perennial abstraction pressure that prevents seasonal aquifer recovery. Modnimb's dugwell depth of 27.6 m, the deepest in the monitoring network, illustrates the outcome: decades of intensive extraction have progressively lowered the productive zone, forcing progressively deeper dugwell drilling.

5.3 Mangalvedhe's Muted Response

Mangalvedhe Taluka, with only six monitored wells, shows the district's smallest mean improvement (0.28 m) and one negative fluctuation (Diksal village, -0.14 m). As the smallest and most southern taluka in the dataset, Mangalvedhe lies in the rain shadow of the Western Ghats, receiving lower monsoon rainfall than the northern talukas. Its limited recharge response to the 2025 monsoon—despite district-wide improvement—indicates that even an above-average monsoon year may deliver insufficient rainfall in this sub-region to generate meaningful aquifer recharge. This has direct implications for Mangalvedhe's drinking water supply planning, which cannot rely on monsoon-year recovery alone.

5.4 Comparison with Prior Work

GSDA datasets indicate that mean pre-monsoon groundwater levels in Solapur's Deccan Basalt aquifers historically ranged between 5 and 8 m bgl. This range is consistent with the present study, which estimates a district-wide mean SWL of 6.12 m bgl. However, it is important to note that the current assessment is based on an expanded monitoring network and reflects a more intensified groundwater extraction regime compared to the earlier benchmark conditions. (Shaikh and Birajdar 2024c). Deolankar (1980) noted specific yield values of 0.01–0.03 in Deccan Basalt, implying that even small SWL improvements represent substantial percentage changes in stored volume. Shaikh and Birajdar (2024a) reported that the GSDA 156-OBW

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network showed net pre-monsoon SWL improvement in 2024 relative to 2023 in roughly 78% of wells—the 2026 figure of 92.9% suggests a more pronounced monsoon recharge effect in 2025.

6. INNOVATIVE INSIGHTS AND HIDDEN PATTERNS

Three patterns emerge from the dataset that go beyond conventional descriptive analysis:
The near-perfect correlation between the 2021–2025 baseline and March 2026 readings means that the spatial map of groundwater stress is essentially fixed by sub-surface geology. This has a counter-intuitive implication: demand-side management (crop pattern change, micro-irrigation) at the village level has far greater leverage on aquifer stress than watershed-scale supply-side interventions such as check dams, because the supply response is geologically constrained. Artificial recharge works will be most effective when sited precisely at high-CV sub-watersheds (Karmala, Madha) where spatial heterogeneity indicates the presence of productive fracture zones capable of accepting and transmitting recharge.

The well at Takali (Solapur South) records the shallowest 2026 SWL in the district at 1.9 m bgl—yet it also records a negative fluctuation (-0.68 m). A water table at less than 2 m depth should not be declining unless localized abstraction is exceeding natural drainage. The most plausible explanation is intensive shallow pump extraction by a nearby community or livestock watering point, producing a cone of depression visible in the OBW record. This well warrants field investigation to determine whether a casing failure, local abstraction point, or surface drainage modification has altered its hydrological behavior.

Barshi Taluka records the highest mean improvement (0.93 m) despite having a historical baseline mean (6.20 m bgl) already close to the district average. This suggests that Barshi's aquifers respond more elastically to monsoon recharge than geology alone would predict—potentially because canal command area expansion in the Nira Right Bank Canal zone has reduced groundwater abstraction in parts of the taluka, allowing aquifer recovery.

7. GROUNDWATER MANAGEMENT IMPLICATIONS

7.1 Priority Intervention Zones

The thirteen wells with March 2026 SWL > 10 m bgl define a priority zone for pre-monsoon drinking water supply intervention. Village-level Water Security Plans under ABY for Modnimb, Aran, Londhewadi, Bhend, and Yeoti must include contingency supply provisions—tanker water or pipeline augmentation—for the April–June 2026 window before monsoon onset. These villages cannot draw on shallow groundwater when the water table is 10–14 m below surface.

7.2 Artificial Recharge

The high spatial variability in Karmala (CV 50.7%) and Madha (CV 48.7%) indicates that some sub-watersheds within these talukas have productive fracture zones capable of accepting recharge, while others are structurally unproductive. Recharge shaft technology—as deployed by GSDA Solapur in its existing network—should be targeted to the productive vesicular flow-top zones in the BM-131 through BM-139 watershed series within these talukas, where hydrogeological conditions favor infiltration of runoff into deeper fractures.

7.3 Crop Pattern Transition in Madha and Karmala

Sugarcane's year-round water demand makes it incompatible with the aquifer recharge cycle in hard-rock terrain. A phased transition from sugarcane to less water-intensive crops (jowar, pulses, drip-irrigated vegetables) in the eastern Madha belt—supported by state agricultural policy incentives—could reduce abstraction by an estimated 20–30%, allowing pre-monsoon SWLs to recover over 3–5 years. This recommendation aligns with the Maharashtra Water Resources Department's groundwater conservation directions under the Maharashtra Groundwater (Development and Management) Act, 2009.

7.4 Strengthening the Monitoring Network

The six wells in Mangalvedhe represent the thinnest taluka-level coverage in the dataset. Given Mangalvedhe's vulnerable rainfall regime and its single negative-fluctuation well (Diksal), the network should be expanded to at least 12–15 OBWs to capture spatial variability at the sub-watershed scale. Additionally, the anomalous behavior at Takali warrants immediate field inspection and possible installation of a continuous data logger to differentiate between aquifer-level trends and localized abstraction interference.

8. CONCLUSION

This study presents the first taluka-disaggregated, baseline-comparative analysis of March 2026 pre-monsoon SWLs across Solapur District's 156-well OBW network. The central finding is that district-wide water levels in March 2026 are, on average, 0.64 m shallower than the 2021–2025 mean—an improvement driven primarily by above-normal 2025 monsoon recharge. This finding, while encouraging, is qualified by three important observations: thirteen wells remain in critical stress (SWL > 10 m bgl); the spatial pattern of stress is structurally determined and will persist absent targeted structural intervention; and Mangalvedhe and parts of Akkalkot show negligible or negative response, indicating that the 2025 monsoon did not benefit all parts of the district equally.
The near-perfect correlation ($r = 0.979$) between historical baseline and current SWL confirms that aquifer vulnerability in Solapur's Deccan Basalt terrain is geologically fixed and not easily reversed by a single favorable monsoon year. The study identifies Karmala, Madha, Mohol, and Solapur South as talukas demanding sustained, multi-intervention attention, while Barshi and Madha (excluding its deep-stress villages) demonstrate the positive outcomes achievable when monsoon recharge is strong. These results have direct operational relevance for pre-monsoon water supply contingency planning, recharge work implementation, and state drought mitigation policy.

9. FUTURE SCOPE

Several methodological extensions would amplify the utility of this monitoring programme:

- Machine Learning applications: Long-run OBW time-series data (1990s–2026) across 156 wells provide a rich training dataset for LSTM (Long Short-Term Memory) neural network models capable of forecasting pre-monsoon SWL from preceding monsoon rainfall and abstraction indices, enabling predictive drought early warning rather than reactive assessment.
- Remote sensing integration: GRACE satellite data (Gravity Recovery and Climate Experiment) can validate district-scale groundwater storage trends derived from well networks. Integration of Sentinel-1 SAR data for land subsidence detection in deep-stress zones (Modnimb, Aran) would identify whether aquifer compaction is occurring alongside depletion.
- Rainfall-recharge modeling: A calibrated sub-watershed recharge model—linking monthly rainfall from IMD gridded datasets to observed SWL response—would quantify the non-linear threshold behavior typical of Deccan Basalt recharge, where little percolation occurs below approximately 400 mm annual rainfall.
- Groundwater Quality Co-monitoring: Future pre-monsoon campaigns should pair SWL measurements with EC (electrical conductivity) readings. In shallow aquifers approaching land surface, evaporative concentration of solutes during dry seasons elevates TDS—a quality risk that the current dataset does not capture.

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