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Experimental Investigation on Hard Rock Strata for the purpose of Ground Water Improvement with the inclusion of Bore Blasting Technique

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ABSTRACT

Due to yearly uneven rainfall distribution, exsiccation of water availability, specifically during the summer in the agricultural field in Saurashtra, is a usual scenario. Saurashtra region's land formation contains Basalt rock. The area is categorized under the semi-arid region. Hence, the Groundwater condition was observed to be poor as the self-characteristic of land for water-storage capacity for the Basalt is negligible within its strata. Mining Engineering and Groundwater Improvement Techniques were incorporated to find a way out of water stress conditions. An experimental study was carried out for mass blasting with the permission of the Government body and an expert team of mining explosions at the study area within the catchment of check dams and river beds. A group containing five borewells was blasted at a 27, 18, and 9 m depth, respectively. In each borehole, 15 blasts of 2.76 unit explosion were exploded together by sealing a cover of sand over it. The impact assessment of 30 wells was monitored Post-blast within the range of 400m of the Bore Blasting Technique (BBT) performed. As a result, a rise in water level up to 19m has been recorded near the streamline of BBT performed. In addition, the movement of the water was diverted from its parental aquifer to the observed dug wells. Hence, it is concluded that channelizing the groundwater can be possible by incorporating BBT in the basalt region, and identical improvement can also possible interms of fractured basalt rock and availability of water in the basalt region.

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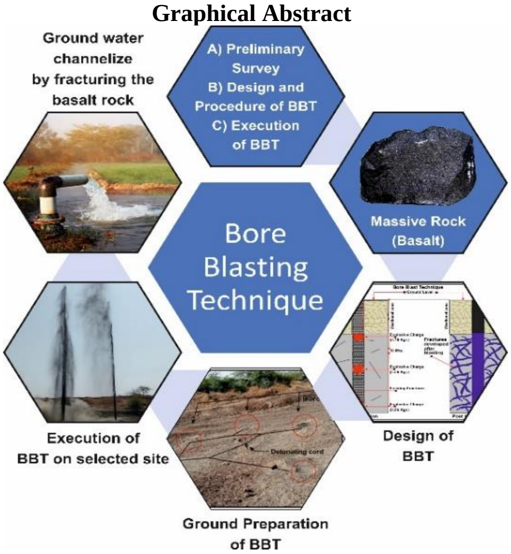
Graphical Abstract



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1. INTRODUCTION

Groundwater is a valued resource, especially in the agricultural field. Day by day quantity and quality of groundwater are decreasing due to groundwater extraction at its never-ending demand. It is an alarming situation for the human being for the optimum use of natural resources, specifically water. Right now, water extraction from the ground is higher than the infiltration rate due to global population growth. The situation becomes more critical when the lithological background is not capable of storing/holding the quantity of groundwater (1). Generally, the scarcity of water is faced by people in the summer season due to the less avaibility of groundwater. In addition, the groundwater depends on the percolation capacity of the topsoil of the particular region during the monsoon season. In the case of basalt rock, the percolation of the infiltrated water can not pass to the basalt formation due to its impermeable properties. The recharging capacity of the basalt rock depends on the quality and the thickness of the rock formation (2, 3), i.e., overlaying thickness, the texture of the formation, and the formation of soil structure according to geomorphology and topography (4). The groundwater recharge also depends on the amalgamation of parameters like hydrological conditions, topographic conditions, hydraulic conductivity of layers, water table level and its placation, thickness of strata, infiltration rate, and rate of recharge (5). Hence, a comprehensive examination of the characteristics, dynamics, and distribution of groundwater is imperative prior to formulating the research methodology.

Fractures and joints have been identified as pathways for quick movement of water recharged (6). This study aimed to explore and analyze the characteristics of strong lineaments that exhibit quick recharge movement. The study investigates the various aspects of these contours, including their strength and the speed at which they recharge. By examining existing literature and conducting a comparative analysis, the findings of the study conducted on the Hard Rock (Basalt) region. Li (7) have determined that the water content within the strata does not possess any capacity for storativity. The presence of lineaments is a characteristic feature observed within the weathered zone. The presence of water connections and joints in massive rock is significantly lower compared to that in weathered rock (8). The yield in wells is contingent upon the interplay between the connection and permeability of the given area.

Moreover, it is imperative to acknowledge that the weathered zone plays a crucial role in facilitating the movement of water from infiltration areas to the underlying hard rock stratum (9). Henceforth, it is imperative to establish a connection between the weathered zone and the hard rock due to the inadequacy of the disturbance caused within the fractured zone (9). Therefore, it is evident that the weathered zone holds significant importance in the process of groundwater circulation and recharge (10). The influence of the weathered zone on groundwater resources, runoff, and base flow has been widely acknowledged in scientific literature. The weathered zone plays a crucial role in regulating these dynamic hydrological processes. According to previous research findings, it has been observed that the primary occurrence of water level fluctuation is predominantly confined to the weathered zone (11).

The role of groundwater flow in the implementation and design of water recharge systems is of utmost importance (11). The lithological network, which includes dykes and outcrop ridges, poses a significant challenge to the implementation of conventional recharging techniques. In order to implement effective remedial measures for recharging techniques, it is imperative to conduct a thorough analysis of the subsurface conditions, including the origin, formation, and mineral composition of the strata. This preliminary assessment is crucial for the successful design and implementation of any recharging measure. In the land of assessing the potential zones for groundwater, it has been observed that the utilization of Geographic Information Systems (GIS) and Remote Sensing (RS) data has yielded results that are closer to accuracy (12). The assessment of geomorphological mapping provides a comprehensive analysis of the distinct geological zones, offering a detailed delineation of their bifurcation. The analysis and characterization of fracture and lineament features offer valuable insights into the presence and nature of open and closed fractures. The analysis of a drainage network provides valuable insights into the patterns and characteristics of water flow within a given area. By examining the arrangement and configuration of drainage channels, a comprehensive understanding of the flow trills can be obtained. The cartographic representation of dyke rock formations provides insights into the presence of vertical barriers and the degree of permeability within a given area.

Previous studies have demonstrated the application of the blasting technique in various construction projects, particularly in the development of hydroelectric facilities and the extraction of iron ores from mines. Notably, the utilization of split blasting and mass blasting methods has been observed as an effective means to excavate metallic materials from the earth's interior (13-15). Simultaneously, existing literature substantiates the efficacy of the control blasting technique in enhancing rock permeability and hydraulic conductivity (16). According to previous research findings, it has been observed that sandy soil exhibits superior performance compared to clayey soil when subjected to blast loading (17). The current investigation focuses on the utilization of the Mining Engineering concept to facilitate groundwater recharge. The implementation of the bore blasting technique was devised in accordance with a cluster system in order to enhance the channeling and transmissibility of the designated area.

Executing the technical survey before the BBT performance is essential to achieve the desired results. In the present study, consideration of a special survey for the area of GIS/RS data was analyzed, a Technical on-site survey, of Geological and lithological survey, a Pump test for the well, and a resistivity survey were analyzed for the best consideration of applying BBT technique and get the maximum channeling zone. Generation of cracks is mainly dependent on two stages; stage 1 is a shock wave that primarily effect generates radial cracks within the surrounding area, and stage 2 gases penetration stage, which creates a secondary effect to widen and expand the existing cracks (18, 19). For a generation of crack, few methods were experimented like explosion blasting, hydrofracturing, gas fracturing (16, 20), by injecting CO_2 gas (rock fragmentation) (21), air deck method for rock fragmentation (22, 23), etc. with the purpose of mining or tunnel construction. After experimentation, an Artificial Neural Network (ANN) was used for rock fragmentation (16). Riedel-Hiermaier-Thoma (RHT) model was observed within LS-DYNA software and was used to find rock fracturing uncertainty as far as rock cracking is concerned (16, 21). The conceptual model in the groundwater modeling system was designed and analyzed by the software MODEFLOW, and results were found positive for the Artificial Recharging concept by injection well (24). However, all these experiments were designed for either mining or tunnel construction. Few researchers worked on predicting the crack length developed by the blasting effect under a rock (25); fragmentation and fracture mechanics deal with models like mathematical and ultrasound models, considering parameters like wave propagation (25-27).

To achieve the targeted goal, designed boreholes were drilled in specific patterns up to the hard rock as per the pre-decided depth. The mass blast of the bore was carried out so that the rock region gets fractured, and the water can get channelized in the aquifer. A detailed description of BBT is in a subsequent section.

Many models were analyzed post-blasting, like the integrated scheduling model, transition model even 3D analysis for blasting overview (2, 3). Still, uncertainties were observed threw out the process, whether that was a purpose of mining activity or tunneling purpose (2, 3). Post effect of blasting was observed in different rock types in Sweden and Norway for the different rock formations while executing the tunnel project for La Estrella-Los Valles (28). It was observed that the magnitude and the effect of blasting differ by changing for each rock formation (28). From the literature, it was found that the effect may be different for the formation of rock, but the method works effectively for the tunneling preview (5). Therefore, the probability of groundwater can be estimated auspiciously with a numerical solution post-blasting (21).

1. 1. Research Significance

The investigation of porosity and permeability in hard rock formations, specifically basalt, reveals that these properties exhibit significantly lower values when compared to sandstone. The groundwater storativity or holding capacity of basalt rock is comparatively low when compared to other geological strata. This study aims to propose a method for improving groundwater availability in the basalt rock region, which experiences a significant shortage of groundwater during the pre-monsoon period. The objective of this study is to investigate the phenomenon of groundwater level upliftment and its impact on the generation of secondary porosity in Basalt Rock. This research focuses on the process of blasting Rock strata and the subsequent linkage between them as the primary mechanisms for creating secondary porosity. The desired outcome of this research is to gain a deeper understanding of the factors contributing to groundwater level upliftment and the resulting generation of secondary porosity in Basalt Rock.

Furthermore, it is an advantage of the experimented land was selected as the agricultural land for this research. In addition, it is worth noting that a significant proportion, approximately 72%, of the land area under consideration faces the constraint of being unsuitable for cultivation during the summer season. This limitation arises primarily from the issue of water scarcity, which hampers agricultural activities in these regions. The provision of essential services is of paramount importance for the inhabitants residing in these rural communities. With the consideration of the aforementioned parameters, the selaction of the site was made in order to serve the benefit of the research outcomes.

2. EXPERIMENTAL METHODOLOGY

The experimental methodology was divided into three phases: phase 1: lithological survey, phase 2: design and procedure of BBT, and phase 3: execution of BBT at selected site. The detailed schematic diagram is depicted in Figure 1.

2. 1. Preliminary Survey

In this study, the location of the cluster was selected not only in the river bed or water-accumulated catchment where ground conditions are suitable (probability to connect water and get connections within aquifer) but also for technical tests, such as Geophysical, Electric Resistivity Survey, and Pump test considered within the study area was performed.

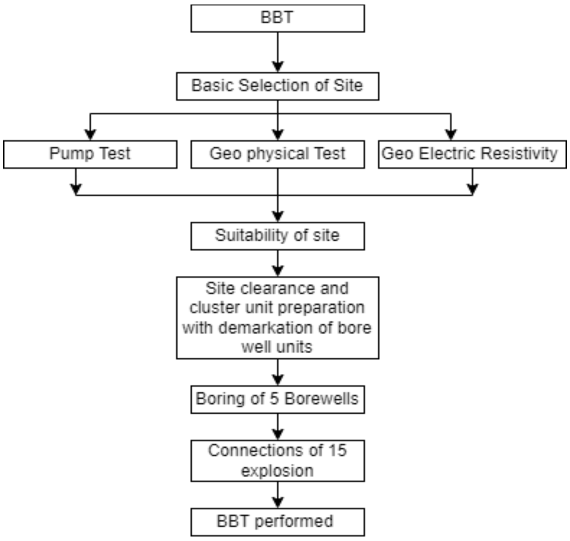

Figure 1. The flowchart of BBT

The preliminary survey (geological and lithological) of the below-ground level strata was carried out in order to investigate the type and quality of the lithological strata. Table 1 represents the geological survey of the selected site. It is noted that the average trap rock is between 5 to 20 m below ground level. Therefore, it is considered as basaltic region.

The site was selected at Talaja (Bhavnagar, Gujarat, India), as shown in the index map in Figure 2. The geology of the considered area falls under the upper Cretaceous to Pleistocene age and is covered by a layer of black cotton soil.

A detailed investigation found a weathered zone formation as a successive layer. A Deccan trap formation is found after the weathered zone, representing a basalt region area. It was observed that the major surveyed area and the selected site location is being used for cultivation purpose.

2. 2. Design and Procedure of BBT After the lithological survey is carried out, as described in the previous section, a suitable grid pattern for boreholes should be selected. The grid patterns depend upon the geological condition and the basalt strata, ranging into the selected site location. In general, 100 to 150 mm diameter and approximately 30 m depth of the boreholes are preferable, and they must be near the shallow aquifer. The BBT technique is divided into three parts: i) the position of boreholes, ii) the drilling of boreholes, and iii) the blast preparation.

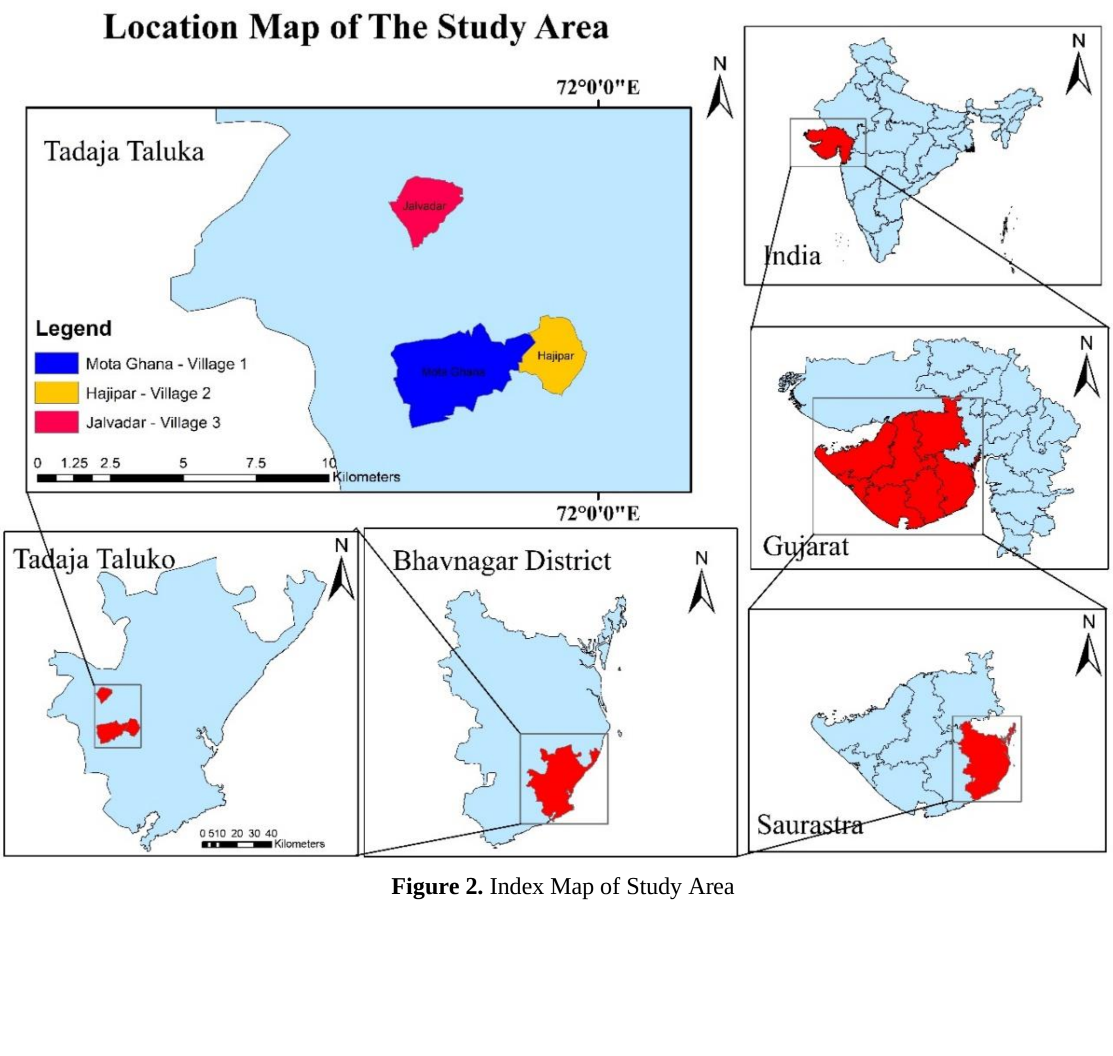

Figure 2. Index Map of Study Area

TABLE 1. Details of Geological data for different villages

	Village-wise data Recorded	Village 1	Village 2	Village 3
Geology with Stratigraphic Succession	Geology	From- To	From- To	From- To
	Cover soil (m)	0-(1.5-1.9)	0 to (1-1.5)	0 to (1-1.5)
	Weathered trap (m)	(1.5-1.9) -(9-19)	(1-1.5) -(8-14)	(1-1.5) -(5-15)
	Trap Rock (m)	(9-19) - Total Depth	(8-14)-Total Depth	(5-15)-Total Depth
the average total depth and water level	Max. Total depth (m)	37.5	45	40
	Min. Total Depth (m	23	20	25.5
	Max. Water level (m)	34	32	38
	Min. Water level (m)	22	18.5	20
The average seasonal fluctuation from water level	Max. Water level (m)	34	38	30.5
	Min. Water level (m)	10	18.5	20
Area related info	The total area of the Village (Hect.)	978.63	820	406.95
	Irrigated (Hect.)	696.27	600.4	289.48
	Non-Irrigated (Hect.)	201.18	29	61.62
Geological findings	Nature of Top Soil	Black cotton soil	Black cotton soil	Black cotton soil
	Topography	undulated	undulated	undulated
	Rock Exposures	available	available	Not prominent
	Geological Features	W/Trap rock, rock with few crack	W/Trap rock, rock with few crack	Massive rock with few cracks
	Drainage Pattern	Dendritic	Dendritic	Dendritic

Not more than 5 to 6 bores should be blasted at a time. Blasting should be carried out only in the hard rock portion, neither in a weathered zone nor in topsoil. The optimum quantity of class - 2 slurry explosives should be 0.15 to 0.20 kg/m^3 of covered grid volume. Charging and blasting must be carried out from the centered borehole and extended in radial directions. The depth of the boreholes is divided into three layers for each explosion, and the explosive materials should be penetrated from the bottom to the top.

Each explosive must be connected to the other by a detonating cord in order to blast all the explosives together as a united effect the blast. Sand stemming must be carried out to create an airtight and confined condition for each borehole with the aim of the maximum pressure that should be spread within the selected layer of the rock. Detonating cords coming out of each borehole must be inter-connected in parallel connection. Finally, one electrical detonator has to be used to fire the shots instantaneously. Shot hole firing should be executed with the help of a shot-firing cable and an electrical exploder machine.

The schematic diagram of the proposed technique is depicted in Figure 3. Initially, five units of boreholes were employed in a pattern of the pentagon, scattered, zigzag, straight, or as per the suitable ground condition. Each borehole was divided into three different layers to the depth of 9, 18, and 27 m inside boreholes with blasting purposes with explosives charges 1, 2, and 3, as shown in Figure 4. Hence, the 15 blasts were connected, such as the 15 explosives blasted together, and the effect of the blasts spread uniformly.

Figure 4 illustrates the pre-blasting condition and expected post-blasting condition. It also represents the flowchart of the BBT technique proposed in the appended theory.

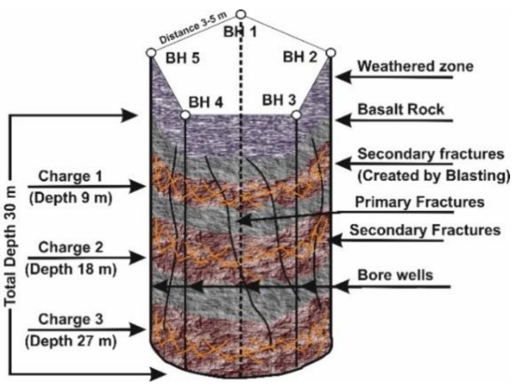

Figure 3. The 3-D schematic diagram of the secondary fracture created through BBT

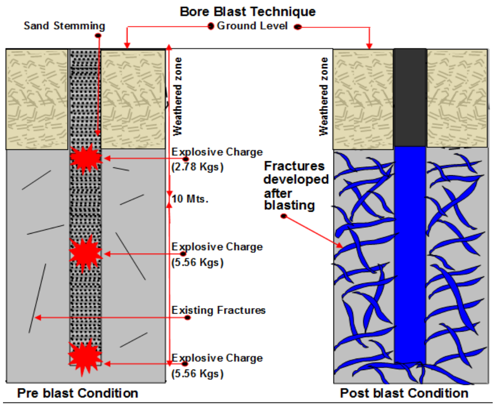

Figure 4. The Schematic Diagram of the Concept of BBT

2. 3. Execution of BBT on Selected Site According to described in section 2.1, the preliminary survey was conducted for three villages. Moreover, the design procedure of the BBT technique elaborated in section 2.2, a stipulated number of boreholes and the position of boreholes were decided, according to the site suitability. The site location was selected in such a way that the probability of water accumulation was maximum under natural conditions. Hence, during the peak season of inflow, the water may get infiltrated with the help of boreholes. Moreover, after performing, the infiltrated water entered the boreholes and uplifted the groundwater table. Simultaneously, a significant amount of water can get storage space within the bed of a vacant aquifer. Thus, the amount of runoff can be utilized adequately. The upstream area of the check dam or reservoir selected was in dried condition. A total of 32 cluster units of blasts were executed by different grid patterns, as described in Table 2. The grid patterns depended upon the geological conditions of the selected site. The pentagon-type grid pattern was used for all the locations, as shown in Figure 5, except locations 3 and 4, tabulated in Table 2. The staggered types of borehole positions were established for locations 3 and 4 due to their narrow catchment area.

Figure 6 illustrates the ongoing explosion of the boreholes. Water flowed upward side with the pressure from 1-2 boreholes as per Figure 6, and as per Figure 7, pressurized gases from 1-2 boreholes came up to release pressure among the network created (from the empty aquifer gallery).

3. RESULTS AND DISCUSSION

Post-blasting effects were observed immediately, and the sound of water flowing was clearly tuned into it. That is because water water-filled aquifer cracked, and that gets connectivity towards the blasting point. Out of all boreholes, 4 to 5 bore holes absorb pressure within it and widen the crack generated in the secondary effect of

TABLE 2. Number and location of BBT cluster details

Location No.	Type of catchment and identity	Year of Construction and village	Number of clusters
1	The upstream side of check dams 1	2022, Village 1	2
2	The upstream side of check dams 2	2022, Village 1	2
3	The upstream side of check dams 3	2022, Village 1	2
4	The upstream side of check dams 4	2022, Village 1	3
5	The upstream side of check dams 5	2022, Village 1	2
6	Lack catchment	The boundary of Village 1&2	10
7	The upstream side of check dams 6	2019, Village 2	4
8	The upstream side of check dams 7	2019, Village 3	4
9	The upstream side of check dams 8	2019, Village 3	4

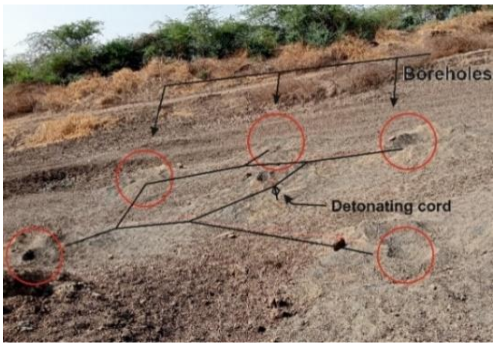

Figure 5. Preparation of BBT

Figure 6. Water upliftment due to explosion

Figure 7. Post-blasting effect on borehole

blasting; only 1-2 boreholes were found disturbed as united pressure of all boreholes was released from that borehole. The upliftment of water due to the explosion can be seen in post-blasting near the blast. No. 26, 6, 2, 1, and 7 were near streamlines. Therefore, the rise in water level was high, up to 19m. Previously, groundwater movement was governed by the amount of water extracted from the well. Now, the water movement is divergent and governed by the stream alignment from the BBT location performed. Thus, it was indicated that the improvement of the groundwater was identical to the BBT performed.

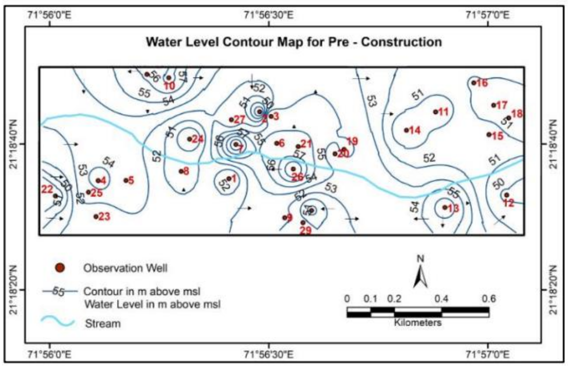

Figure 8. Water table of contour map (above mean sea level) Pre-BBT

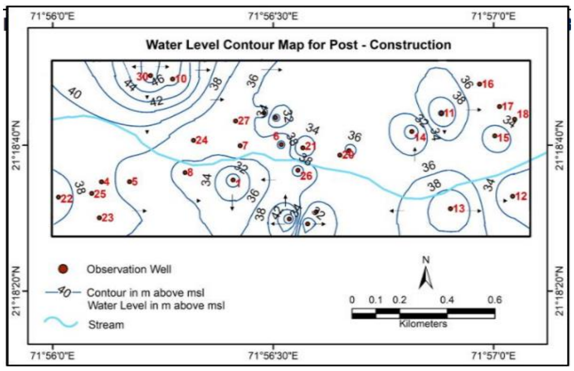

Figure 9. Water table of contour map (above mean sea level) Post-BBT

The BBT was performed in 32 different locations, as described in section 2.3. A total of 30 dug wells were monitored before and after explosions of the sites mentioned above within a range of 400 m from the stram line of BBT. Each dug well was identified by a unique number throughout the observation process. Figures 8 and 9 represent the pre and post-groundwater level with a contour map and the dug well's position, respectively. It was observed that a considerable amount of rise in all the dug well due to the fracture of the balastic region by BBT performed. It was also noted that the maximum enhancement of the water table level was increased up to 19m, near the 26th number of well. It was attributed that well was near to the streamline of the BBT performed.

4. CONCLUSIONS

This research is based on the Artificaial groundwater recharging technique with the help of the BBT technique. After the meticulous analysis of the obtined results found by the conducted experiment, the following conclusions are drawn.

1. The Basalt rock gets fractured due to the explosion. Hence, the secondary fractures were propagated in the basalt rock region, and the nearest aquifer was channelized to the nearer dug wells. Moreover, the infiltrated water can penetrate in the monsoon season from the boreholes, and the infiltrated water gets channelized from the secondary porosity propagated by BBT.
2. The fractured rock and the prepared boreholes for the BBT are not only used for recharging the groundwater from the earth, but also it can be helpful for rainwater harvesting. During monsoon season, the water gets penetrated threw the secondary fractured cracks created artificially. Therefore, the increase in the availability of water could be observed throughout the year.
3. The formation of basalt rock presents a significant obstacle to the natural movement of water. In order to overcome this challenge, the BBT technique was employed to facilitate the directed flow of groundwater within the aquifer system. This technique involved the construction of channels that effectively guided the water toward the dug wells located in the rocky region. Through the implementation of this network, an artificial recharging mechanism was established, allowing for the replacement of the aquifer.

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Persian Abstract

چکیده

با توجه به توزیع نابرابر بارندگی سالانه، تخلیه آب در دسترس، به ویژه در طول تابستان در مزارع کشاورزی در Saurashtra، یک سناریو معمول است. خشکی زمین های منطقه ساوراشترا شامل سنگ بازالت است. این منطقه در زیر منطقه نیمه خشک طبقه بندی می شود. از این رو، وضعیت آب زیرزمینی ضعیف مشاهده شد زیرا خود مشخصه زمین برای ظرفیت ذخیره آب برای بازالت در لایه های آن ناچیز است. تکنیک‌های مهندسی معدن و بهبود آب‌های زیرزمینی برای یافتن راهی برای خروج از شرایط تنش آبی گنجانده شده اند. یک مطالعه تجربی برای انفجار انبوه با مجوز ارگان دولتی و تیم کارشناسی انفجارهای معدنی در منطقه مورد مطالعه در حوضه آبریز سدهای چک و بستر رودخانه انجام شد. گروهی شامل پنج چاه به ترتیب در عمق های ۲۷، ۱۸ و ۹ متری منفجر شد. در هر گمانه، ۱۵ انفجار ۲/۷٦ واحدی با بستن پوششی از ماسه روی آن منفجر شد. ارزیابی تاثیر ۳۰ چاه پس از انفجار در محدوده ٤۰۰ متری تکنیک انفجار حفاری (BBT) انجام شد. در نتیجه، افزایش سطح آب تا ۱۹ متر در نزدیکی جریان BBT انجام شده ثبت شده است. علاوه بر این، حرکت آب از سفره اصلی آن به چاه های حفر شده مشاهده شده منحرف شد. از این رو، نتیجه‌گیری می‌شود که کانال‌سازی آب زیرزمینی می‌تواند با ترکیب BBT در منطقه بازالت امکان‌پذیر باشد، و بهبود یکسان می‌تواند بین سنگ بازالت شکسته و در دسترس بودن آب در منطقه بازالت نیز امکان‌پذیر باشد.