Exploration of Groundwater Potential Zones: A Case Study In Phuentsholing

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Abstract

In places where surface water sources are insufficient for drinking purpose, groundwater serves as an alternative source. This report highlights all the different methods that can be used for exploration of the groundwater and to analyse this different exploration methods considering various parameters such as economy, suitability, accuracy, etc, hence providing an individual with various choices regarding the selection of particular method during the exploration of groundwater potential zone. Considering the availability of the instrument in Department of Geology and Mines (DGM) and the economic factor in our project, seismic refraction Tomography (SRT) and Geographical Information System (GIS) was used todelineate the potential zones of groundwater in Phuentsholing, Bhutan. GIS focuses on the surface features for groundwater indicator while SRT identify the subsurface layers and the depth of groundwater. The various information regarding existing bore well in the study area were also collected to validate the potential zones developed both by surface and subsurface method.

Keywords– *Seismic Refraction Tomography, Geographical Information System,Groundwater Exploration, Drinking water, Water management.*

Introduction

Water is the mankind's most important resources and an adequate supply of water is one of the essential factors for development and industrial growth. The shortage on water resources started due to exploding domestic and industrial demands and many more. The finite water resources available should be explored to satisfy the thirst of populations. Therefore, in areas where surface water is not available, ground water constitutes important part of fresh water resources around the world.

Due to climate change many water sources are drying up causing local and seasonal drinking water scarcity. Growing cities like Thimphu and Phuentsholing are running short of water (Kuensel, 2018). Despite Bhutan being one of the most water abundant country in south Asia, there are water shortages because of poor water management and accessibility. According to the survey carried out by the Ministry of Health in 2014 found out that 13,372 rural households across the county faced drinking water problems. Bhutan 12th five-year plan GNH, (2018) highlighted that there is now growing concern on water availability for drinking supply and for agriculture as many spring water sources are drying up.

Study Area

The selected study area for this research is in Phuentsholing gewog as shown in figure 1. It lies in the southern part of the Himalayan country Bhutan situated at a latitude of 26°50'N to 26°59'N and Longitude of 89°15'E to 89°28'E where a maximum annual rainfall of about 3000 mm is estimated. The total area of 133.6 km^2 with a population of 33,444 people and major part of the human settlement are situated at the southern portion of area of study that is in Dzongkhag

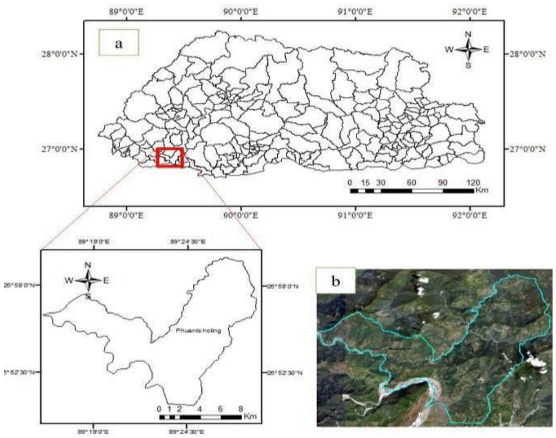


Fig.1 (a) Study area (b) Satellite image of the study area

Methodology

The project was carried out in three phases. In first phase, works related to site selection was, second phase exploration with SRT and final phase generation of ground water potential mapand its verification through validation was completed as highlighted in figure

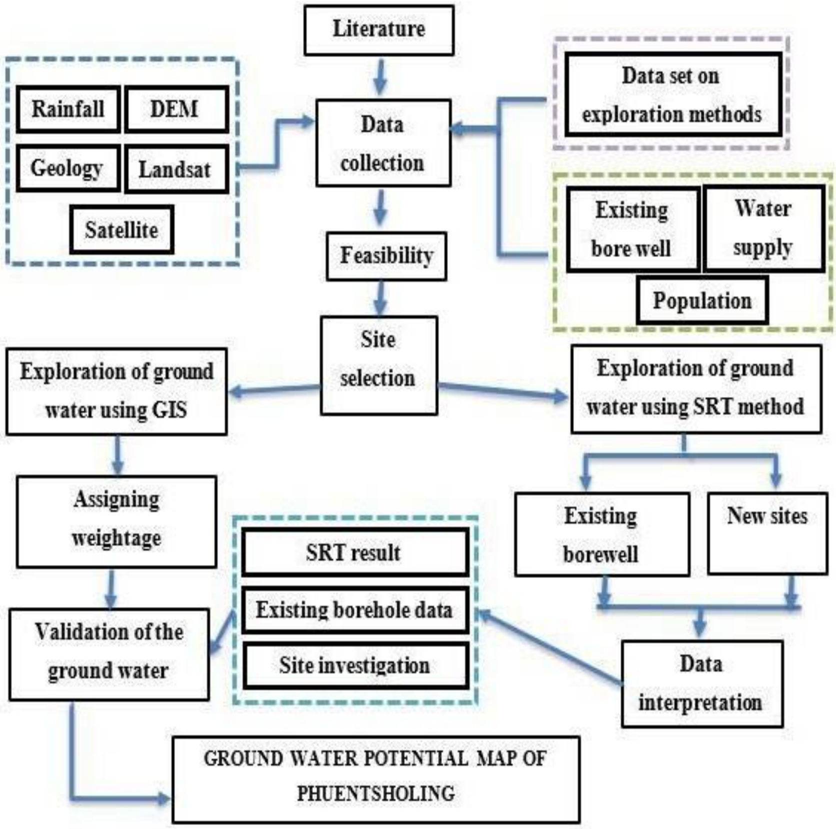


Fig.2 Methodology

Water Supply

The water supply scheme model generated signifies the places with more water demand corresponding to the population density and places that needed improvement in the water supply. The water supply for seven different places namely Damdara, Phuentsholing towncore 1, Phuentsholing town core 2, Rinchending, Pekarzhing, Pasakha and Kabraytar that lie under Dzongkhag Thomde was studied, as it is the most populated area in Phuentsholing with a population of 27650 people. Red zoned place includes Phuentsholing core town 1 and 2, Kabraytar and Rinchending have the lowest supply of water at present according to supply data i.e. 0-750 litres/day/household as shown in figure 4.

Fig.3 Satellite image for water supply survey Area

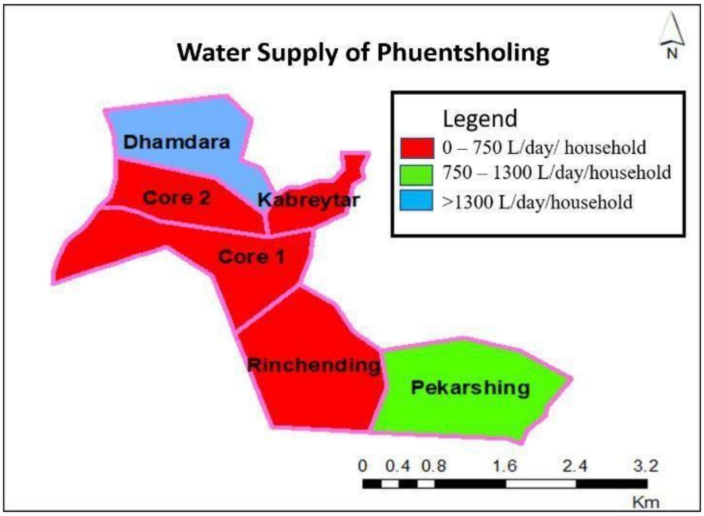


Fig.4 Water supply in Phuentsholing (Dzongkhag Thomde)

Seismic Refraction Tomography

Principle and Method

It depends on the principle that time taken by seismic waves to travel which is refracted or reflected at the interfaces amid the subsurface layers of different velocities.

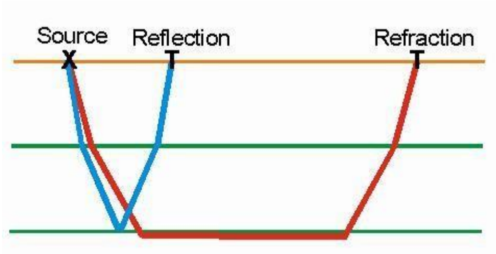


Fig.5 Principal of Seismic Refraction/Reflection

Seismic wave is provided to the system by striking a metal plate kept on the earth surface. This refracted energy is then detected by the geophones deployed, separated at regularintervals on earth's surface which is connected to DAQ Link III through which data are transferred to the computer. Keeping record of the refracted waves as travel-time, the information on depth of refractor profile can be determined. First arrival time of each waves is generated on graph using Pickwin Software. This software generates a Travel-Time Graph. Thereafter, tomography image of the profile can be produced showing a number of lithological layers and primary wave velocities of each layer using Plotfera software (Figure 6). This velocity is then compared with the standard velocity of natural soils and rocks provided in the standard guide of the instrument shown in Table 1 to identify the layers below the surface.

Pialdara, two sites at Kabraytar and Damdara under Phuentsholing gewog was selected for conducting the SRT experiment with the aim to explore groundwater and one site beside YDF Hostel which is one of the main sources of water supply in Phuentsholing was selected to conduct a study on existing bore well.

There are 11 bore wells at YDF site out of which two bore well have stopped yielding. Asingle bore well yields about 30 m^3/hour for about 8 hours a day. The drilling of bore well was carried out without any scientific studies and details about the bore wells were missing.

Table 1 P-Wave Velocity of Different Rocks

SI No.	Material	Veolcity (m/s)
1	Surface Weathered material	240-610
2	Gravel/ dry sand	460-915
3	Clay (saturated)	915-2750
4	Water	1430-1665
5	Sand (Saturated)	1220-1830
6	Sandstone	1830-3960

SRT Result:

YDF Area

A total of 12 geophones were aligned at the site with a spacing of 2.5m. Sledge hammer (10 kg) and steel plate were the materials used for seismic source.

The results obtained from the topographic section after conducting seismic refraction tomography in the study area was correlated with table 1 to reveal the possible water table depths. Presence of subsurface water table can be indicated at depth where wave travelled at the velocity of 1430 m/s to 1665 m/s. Due to limitation of the instrument and test area, the depth of the tomography generated was 16.37m only and the velocity of wave reached 856m/s as shown in figure 6(a). Therefore, water table was not detected within 16.37m and can be concluded that water table is below 16.37 m.

Damdara Site

In Figure 6(b) the blue layer corresponds to the velocity ranging from 1367 m/s to 1671 m/s and mean velocity of 1519 m/s. This layer clearly indicates the presence of water tableat a depth of 8.49 m from the topmost soil level. Usually the main water table is proportional to the surface of the landscape, which contradicts with profile. Thus, profile depicts Perched water table which is an accumulation of groundwater that lies above the main water table in the unsaturated zone.

Kabraytar (Site 1)

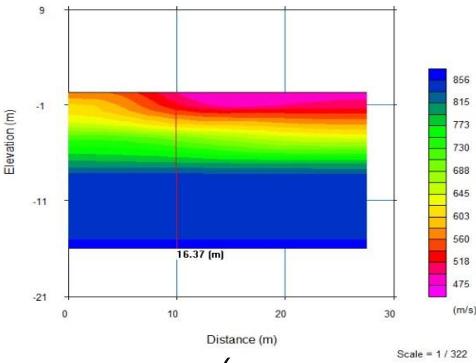
The blue layer corresponds to the velocity ranging from 946 m/s to 1129 m/s and an average velocity of 1037.5 m/s as shown in Figure 6(d). Again, at this site due to the limitation of the instrument water table depth was not identified and can be concluded that it lies below 13.06 m from the surface.

Kabreytar (Site II)

The last layer (blue layer) corresponds to the velocity ranging from 1371 m/s to 1675 m/s andthe mean velocity of 1523 m/s as highlighted in Figure 6(c). This layer clearly indicates the presence of perched water table at a depth of 6.83 m from the top most soil level.

Pialdhara

According to Figure 6(e) the blue layer corresponds to the velocity ranging from 622 m/s to 713 m/s and the mean velocity of 677.5 m/s. Water table depth could not be determined bythe instrument and can be concluded that water table is below 16.13m.



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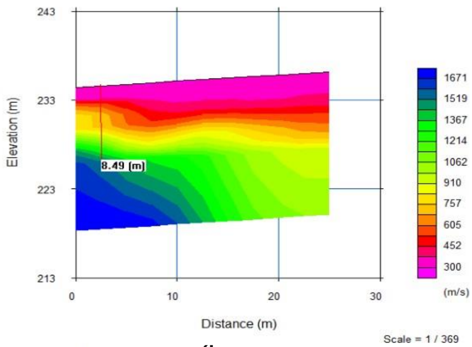

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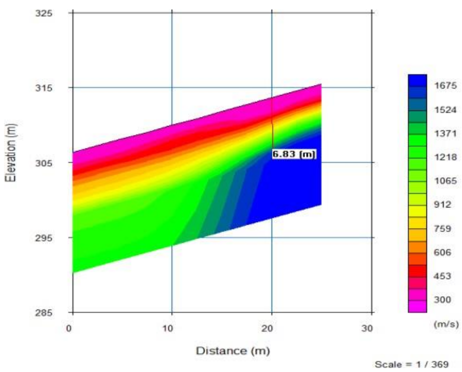

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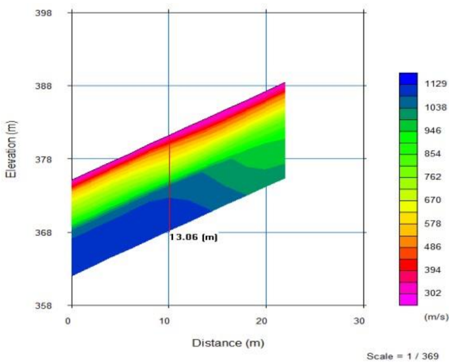

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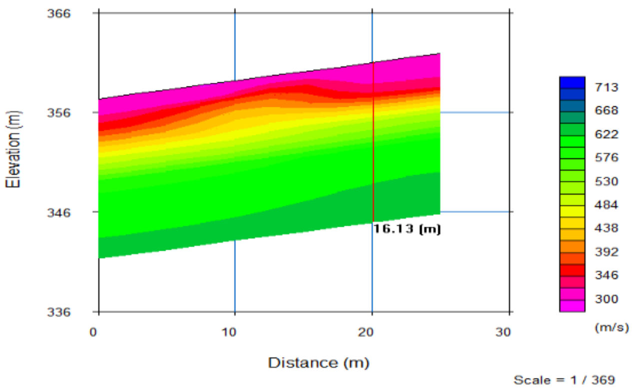


(e)

Fig.6 SRT result at different study locations (a)YDF, (b)Damdara, (c)Kabreytar II,(d)Kabreytar I and (e)Pialdara.

Groundwater Exploration Using Gis Technique

The remote sensing data which includes Shuttle Radar Topography Mission (SRTM – 30m resolution), Landsat 8 and satellite image was used to create the thematic layer of Slope map, Vegetation map, Terrain map, Drainage map and Lineament Map. The DEM data and the study area shape files were extracted from the archive of Ministry of Work and Human Settlements (MoWHS).

The Landsat 8 map was downloaded from United State Geological Survey (USGS) of January 15, 2019 which was used to generate Lineament map using PCI Geomatica Software.Finally, the satellite image was used to tabulate Normalised difference Vegetative Index (NDVI) for Vegetation map. The Geology of the area was digitized from soft copy of the geological map of Bhutan; Journal of Maps published on 2011 of given scale 1:50K. The thematic layer used in this present study are lineament, slope, geology, rainfall, elevation, vegetation and drainage density. The weightage of each thematic layer was determined from various literature of nearby Himalayan country and weighted overlay tool in ArcGIS software was used to generate groundwater potential map as shown in figure 7(h).

Result and Discussion

Geology

Groundwater occurs under the water table conditions in weathered, jointed and fractured formations (Sethupathi A.S et.al, 2012). The area of the study is in Baxa Group, Lesser Himalayan Zone, Structurally Lower Greater Himalayan section and Daling Shumar group.

Table 2 Geology Units

Geology Unit	Characteristics
Baxa Group	Highly fractured schists, slates, and phyllites
Lesser Himalayan Zone	Biotite rich, garnet bearing schist and quartzite
Structurally Lower Greater Himalayan	Massive weathering, granite composition orthogenesis and abundant feldspar
Daling Shumar group	Tan weathering, very fine-grained quartzite.

With reference to Table 2, higher weightage was assigned to Baxa group and structurally lower Greater Himalayan Zone. Geology map of Phuentsholing is presented in figure 7(a).

Slope

Usually, flat and gentle slope encourage infiltration and groundwater recharge but steep slope promotes run-off and less infiltration for the rain water. Therefore, the potential of groundwater is expected to be higher in the gentle and flat sloping ground. For Mountainous zone the slope was classified into three classes such as flat and gentle (0-10 degree), steep (10-35 degree) and very steep (35 degree) (Pathak and Shrestha,2016). The higher weight is assigned for gentle and flat slope and vice versa. Slope map of Phuentsholing is presented in figure 7(b)

Vegetation

If there is presence of green vegetation in dry season it is a good indicator for groundwater at shallow depth (Khodaei and Nassery, 2013). The vegetation map was classified into vegetated and non-vegetated area. High weight is assigned to the Vegetated zone as it is considered to have more potential for groundwater. Low weight is assigned to Non-Vegetatedzone. Vegetation map of Phuentsholing is presented in figure 7(c).

Drainage Density

Where there is high drainage density there will be low infiltration rate and has less groundwater potential whereas a low drainage density indicates a high infiltration rate and hence favours the potential of groundwater (Khodai K. et al, 2011). By taking equal interval the drainage density was classified as low (0-2.49 km/km^2), Moderate (2.49-4.99 km/km^2) and high (4.99-7.49 km/km^2). The high weights are given for low density and low weightsare given for high density. Drainage density map of Phuentsholing is presented in figure 7(d).

Elevation

The Terrain height affects the distribution of underground water as groundwater flows from high elevation to low elevation. The terrain height is divided into 5 clas n bbb srxfyjstaeaw23wqr gefwgAGed\ n bbb ssrfegr ses with an equal interval of 500 m each. Higher weights were assigned to lower elevation and vice versa. Terrian elevation map of Phuentsholing is presented in figure 7(e).

Rainfall

Where the rainfall intensity is higher the potential zone for groundwater will be higher. Based on highest and lowest value the rainfall is classified into four Classes namely Low (2655 – 2835 mm), Moderate (2835 – 3015 mm), High (3015- 3196 mm) and Very High (3196 –

3377 mm) of equal interval. Higher weightage is assigned to Very High rainfall and vice versa. Rainfall map of Phuentsholing is presented in figure 7(f).

Lineament density

In a landscape a linear characteristic which is an expression of underlying geological structures is called lineament. It could be thrusts, faults, joints or fold axes. Therefore, areas with lineament are very good areas for the groundwater recharge and are given the highest weightage. The lineament density was divided into three classes namely low (0 to 2 km/km^2), moderate (2 to 4 km/km^2) and high lineament density (4 to 6 km/km^2). High weightage is given for high lineament density and low weightage is given for low lineament density. Lineament density map of Phuentsholing is presented in figure 7(g).

Analytical Hierical Process

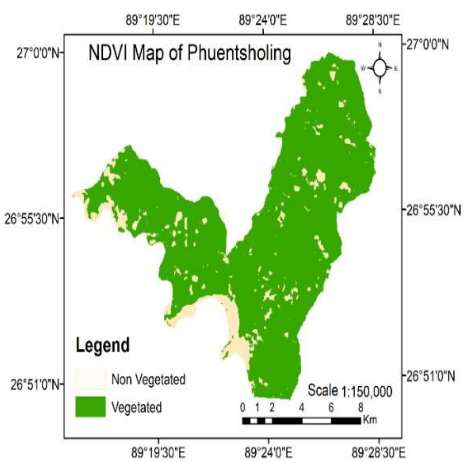
Multi criteria decision analysis using Analytical Hierarchical Process (AHP) is the most common and well-known GIS based technique for indicating groundwater potential zones. (Arulbalaji et al, 2019). As per the amount of important considered for each thematic layer the weightage is assign in Saaty’s scale which has range from one to nine (1-9) and the weightage of the thematic layer was developed in the matrix. The rank of each sub-classes present in different thematic layer is given in Saaty’s with regard to their amount of influence for development of groundwater.

Table 3 Weightage of Parameters

Parameter	Classification	Weightage	Ranking
Lineament	Low Moderate High	28	1 3 5
Slope	0-5 degree 5-35 degree >35 degree	28	5 3 1
Rainfall	2655-2835mm 2835-3015mm 3015-3196mm 3196-3377mm	18	1 3 5 7
Drainage Density	Low (0-2 km/km^2) Moderate (2-4 km/km^2) High (4-6 km/km^2)	5	5 3 1
Geology	Baxa formation Structurally greater Himalayan zone Structurally Lesser Himalayan zone Daling Shumar Group	11	3 5 1 1
Elevation	187-587m 587-994m 994-1499m 1499-2437m	7	7 5 3 1
Vegetation	Vegetated Non-Vegetated	3	3 1

Groundwater Potential Map

The groundwater potential map is prepared taking into consideration the Slope, lineament, geology, elevation, rainfall, drainage and vegetation in the area. By taking the weightage of parameters, four zones (i) High (ii) Moderate (iii) Low and (iv) Very Low have been prepared which is shown in figure 7(h). From the area statistics of different ground water potential about 6.6 % covering an area of km^2 falls under High potential zone, 48.2 % (64.4 Km^2) falls under moderate potential zone, 39.6 % (52.8 Km^2) falls under low potential zone and 5.6 % (7.5 Km^2) falls under very low potential zone. Similarly, the high potential zone was maximum at Dzongkhag Thromde with 63.57 % (4.17 Km^2) of total high potential area whereas very low potential was maximum at Chong Geykha Dophulakha with 82.2 % (6.4 Km^2) of total low potential area.



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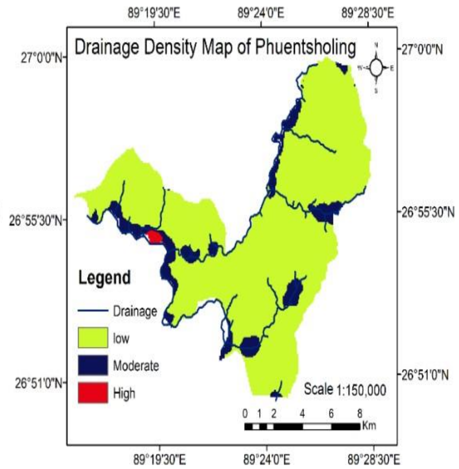

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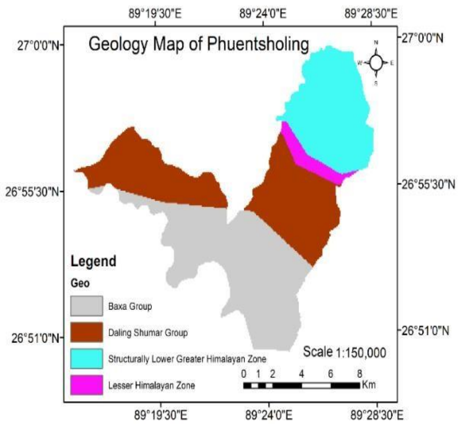

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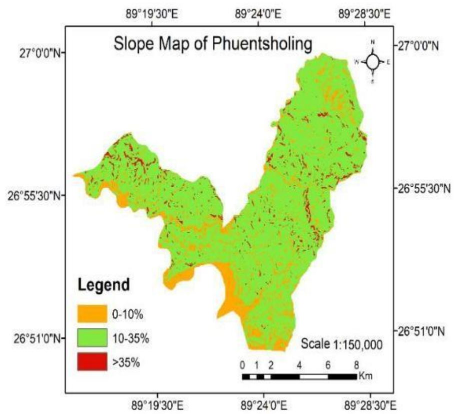

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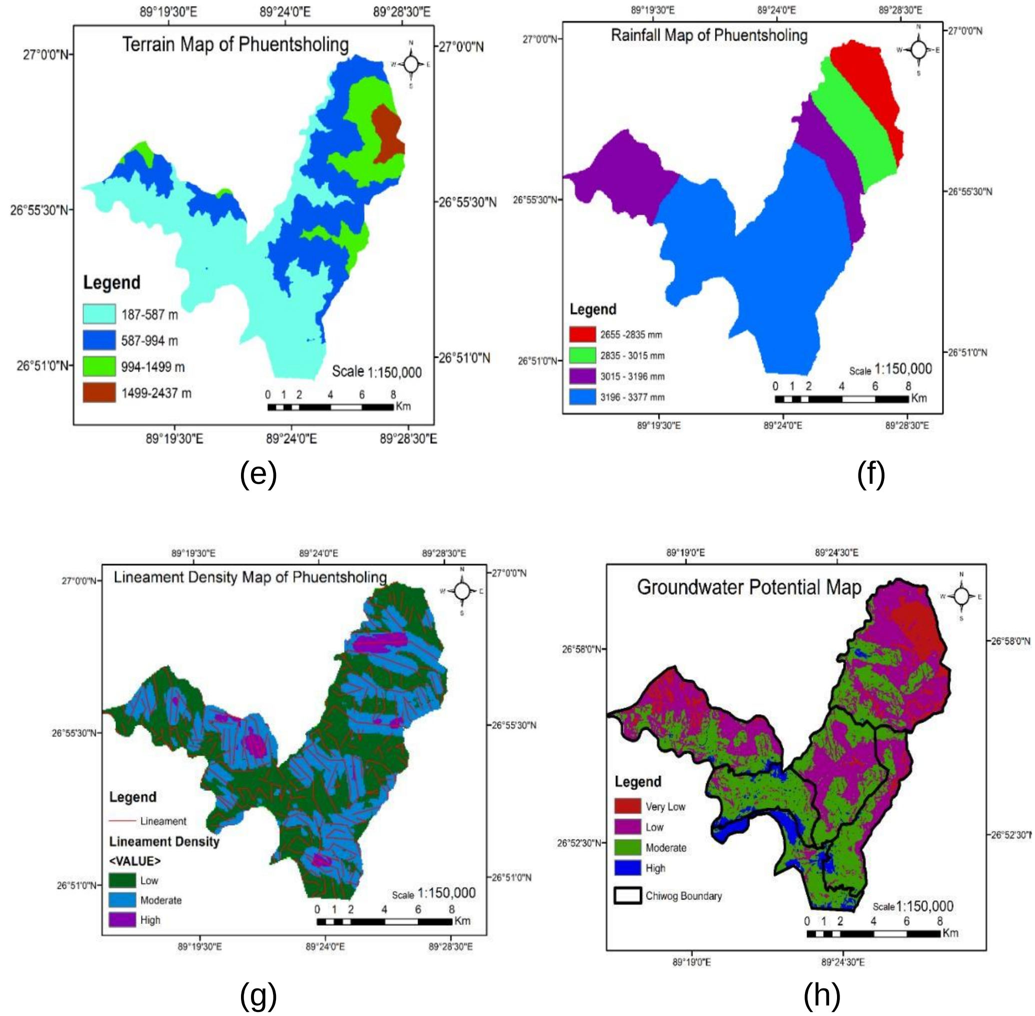

Fig.7 GIS Maps of Phuentsholing (a) Geology Map (b) Slope Map (c) Vegetation Map (d) Drainage Density (e) Elevation Map (f) Rainfall Map (g) Lineament Density Map (h) Groundwater Potential Map

Validation Of Groundwater Potential Map

Validation of the groundwater potential map produced using GIS was done through field investigation and comparison of SRT result with GIS map generated.

Damdhara has been identified as high groundwater potential zone according to the groundwater potential map. As per our findings, this place has very rich vegetation from which some of them still flourish even during winter. It also has spring water which does not dry up during winter and it is located just above the investigated site.

Fig.8 Pictures of vegetation and spring water at Damdara

Toorsa falls under moderately potential zone. This place is found to be vegetated area withlow elevation having flat slope.

Fig.9 Vegetation and flat slope at Toorsa

Kabraytar has a gentle slope (0-23 degree) and the exposed rocks were highly fractured which permits easy seepage of the rain water (infiltration). Geologic structure such as foldson exposed rock.

Towards the base of Kabraytar, the area has highly weathered rocks whichis the best physiographic for high groundwater potential zone.


(a)


(b)

Fig.10 (a) Fracture and (b) Fold at Kabreytar

Table 4 SRT Result Correlation with GIS

Location	**Water table (1400-1600 m/s) SRT result**	**Ground water potential**
Kabraytar I	Below 13.06m	Low
Kabraytar II	At 6.83 m	High
Toorsa	Below 16.37m	Moderate
Pialdara	Below 16.13m	Low
Damdhara	At 8.49 m	High

Out of 23 bore wells identified in Phuentsholing, eleven bore wells are located near Youth Development Fund hostel, Toorsa. But nine of them are functional and each bore well yields 30 m^3/hr. The bore wells located at this site have average depth of 120 m and are drilled using casing pipes and column pipes with pumps.

At the Amochhu Land Development and Township Project by Construction Development Corporation Limited, Phuentsholing, two bore wells are currently under use which wasdrilled and water table was detected at 8-10 m. Thus, validates the high potentiality of the area as identified by GIS map generated.

At Pemaling where one functioning bore well is located is identified as moderate groundwater potential zone.

Conclusions

The main aim of the project is to assess and delineate potential zones for groundwater in Phuentsholing. About 6.6% of the overall area covering 8.8km^2 lies in high potential zone. Most of the area under research lies under moderate potential zone.

Data retrieved from the SRT detected Damdhara and Kabraytar (site II) with perched water table as per the figure 6 (b) and (c). There are only few numbers of bore wells present in the study area that were used to validate groundwater potential map from which all the bore well was located at the potential zones. Moreover, after correlating the SRT result with groundwater potential map, the area at Pialdara and Kabraytar (Site I) were found to haveless potential for groundwater.

High potential zones determined were verified with field investigation which was conducted in Damdhara, Kabraytar valley and Toorsa. The validations of groundwater parameter at these sites were documented by the existence of springs and rich vegetation even during offspring seasons. Geological formation like lineaments and perennial streams were observed as a positive result at sites. Thus, the current research and findings indicated that Phuentsholing Thromde has high potential for groundwater which can serve the increasing demand for dringking water supply.

References

Agbodike I.I., I. M. (2015). Use of seismic refraction tomography to obtain velocity and thickness of the weathered zone of Oru, in Imo State. *FUTO Journal Series (FUTOJNLS)*, 1-3.

Amin Shaban, M. R. (2006). Use of Remote Sensing and GIS to Determine REcharge POtential Zones: The Case Occidental Lebanon. *Hydrology Journal*, 1-11.

Azwina, I. N., Saadb, R., & Nordianac, M. (2013). *Applying the Seismic Refraction Tomography for Site Characterization.* Dubai, UAE: Elsevier B.V.

B.S. Manjare. (2014). Identification of Ground Water prospecting zones using Remote Sensing and GIS techniques in upper Vena River watershed Nagpur District, Maharastra,India. *Journal of Environmental Biology*, 1-14.

Badrinarayanan, T. S. (2000). *Groundwater Exploration - An Introduction.* Tamilnadu: BSquare Geo Tech Services.

Gelle, G., & Guadagno, F. (2009). Seismic Refraction Methodology for Groundwater Level Determination. *Journal of Applied Geophysics*, 1-7.

I.N. Azwina, R. S. (2013). *Applying the Seismic Refraction Tomography for Site Characterization.* Dubai, UAE: Elsevier B.V.

J. Krishnamurthy, N. V. (2007). An approach to demacrate ground water potential zones through remote sensing and a geographical system. *International Journal of Remote Sensing*, 1-20.

Jagadeshan G, G. B. (2018). Assessment of Groundwater Potential Using Seismic Refraction Method in Secha, Arba Minch, Ethiopia. *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 1.

Kamal khodaei, H. R. (2011). groundwater exploration using remote sensing and geographic information system in a semi-areid area (Southwest of Urmeieh,Northwest of Iran). *Arabian journal of Geosciences*, 1-13.

khodaei, K., & Nassery, H. R. (2011). groundwater exploration using remote sensing and geographic information system in a semi-areid area (Southwest of Urmeieh,Northwest of Iran). *Arabian journal of Geosciences*, 1-13.

Krishnamurthy, J., kumar, N. V., Jayaraman, V., & Manivel, M. (2007). An approach to demacrate ground water potential zones through remote sensing and a geographical system. *International Journal of Remote Sensing*, 1-20.

Manjare, B. S. (2014). Identification of Ground Water prospecting zones using RemoteSensing and GIS techniques in upper Vena River watershed Nagpur District, Maharastra,India. *Journal of Environmental Biology*, 1-14.

Medema, G. J., Shaw, S., Waite, M., Snozzi, M., Morraue, A., & Grabow, W. (2003). *Cacthment Characterisation And Source Water Quality, Chapter 4.* water publication CRC.

N Subba Rao. (2006). Ground water potential index in a crystalline terrian using remote sensing data. *Environmental Geology*, 1-11.

Pathak, & Dinesh. (2016). Delination of groundwater potential zones in rocky aquifer in themountainous area of Central Nepal. *Journal of Nepal Geological Society*, 1-10.

S. K. Nag, A. K. (2018). *Application of remote sensing, GIS and MCA techniques for delineating groundwater prospect zones in Kashipur block, Purulia district, West Bengal.* Kolkata: published online.

Shaban, A., Khawliel, M. R., & Abdallah, C. (2006). Use of Remote Sensing and GIS to Determine REcharge POtential Zones: The Case Occidental Lebanon. *HydrologyJournal*, 1-11.

Sharafeldin, M. S., Essa, K. S., Youssef, M. A., Karsli, H., Diab, Z. E., & Sayil, N. (2019).

Shallow Geophysical technique to investigate the groundwater table. *Research article*.

Thapa, R., Gupta, S., Guin, H., & Kaur, H. (2017). *Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: a case study from Birbhum district, West Bengal.* published onluine.

Vishwakarm, J., Sinha, M. K., Verma, D. M., & Amhad, I. (2014). Application of Remote Sensing and GIS in Groundwater Prospect Mapping. *International Journal of Engineering Research and Techonology*, 1-7.

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