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# Preference Selection Index and Geospatial Technique for Groundwater Potentiality Zonation in Aizawl district, Mizoram, India

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**Abstract**

*In hilly topography, groundwater mapping is crucial owing to maximum precipitation washout through surface runoff. Keeping this in mind, Groundwater Potential Zonation (GPZ) was done in the capital district of the state of Mizoram-Aizawl, using the preference selection index (PSI), a multi-criteria decision-making tool that takes eleven criteria into account: slope, aspect, elevation, rainfall distribution, distance to the river, precipitation concentration index, topographic wetness index, Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI), geology, and land use land cover. An Inverse Distance Weighting (IDW) technique was adopted for GPZ based on the PSI value of 19,916 random alternative points. Further, GPZ was classified as having very high potential, high potential, moderate potential, low potential, and very low potential based on the natural breaking classification system. The study highlighted that 5.16 percent of the total area falls under very high potential, followed by 16.02 percent in high potential, 27.76 percent in moderate potential, 31 percent in low potential, and 19.46 percent in very low potential, respectively.*

**Keywords:** *MCDM, Groundwater, Preference Selection Index (PSI), Aizawl*

## Introduction

One of the most crucial resources for maintaining life is water. Of all the sources of freshwater resources, groundwater is one of the most critical sources for drinking and irrigation. Only a fraction of the precipitation seeps into the ground and is stored and contributes around 30 percent of the world's constituting the largest source of non-frozen freshwater (Wada, 2016). The most important criterion for the occurrence of groundwater and its flow are that the lithological horizon is porous and permeable, thereby allowing water movement with ease (Nagabhushaniah, 2001). Remote sensing has been a very useful and efficient tool for groundwater exploration for targeting water resources for local supply. This technique can provide key data that can be corroborated by other field techniques (Gupta, 2003). GIS lays out a number of tools for extracting information on the groundwater prospect of a region from the remotely sensed images by combining information in relation to land use, vegetation, lithology, geomorphology, etc. (Rawal *et al.*, 2016). Different bivariate and multivariate techniques have been previously used, namely frequency ratio (Razandi *et al.*, 2015, Guru *et al.*, 2017); maximum entropy (Rahmati *et* *al.*, 2016); logistic regression (Nguyen *et al.*, 2020); support vector machine (Naghibi *et al.*, 2017, Miraki *et al.*, 2019) in groundwater potentiality zonation.

Multi-criteria decision-making (MCDM) methods are increasingly being used in different streams of the sciences and social sciences. The advantage of the PSI multi-criteria method is it does not incorporate criteria weightage for decision-making, while most of the MCDMs need relative weightage for the criteria, which is always time-consuming and problematic. The state of Mizoram as a whole consists of rugged mountains. Although the region receives a good amount of rainfall annually, shortage of water nevertheless is a serious problem in Mizoram. The steep slopes lead to excessive runoff during the monsoon without much availability of storage, resulting in scarcity of water during other seasons (Barman & Biswas, 2022). The shortage of water is more acutely felt as Mizoram's population is hugely invested in farming. Scientific insight with the proper management of groundwater is much needed for sustainable usage of the same. The present study is carried out on the preference selection index (PSI) for groundwater index. Aizawl, one of the most populous districts of Mizoram regularly faces water shortages owing to insufficient water supply, mismanagement of the natural springs, and high population density. A sustainable method for accessing groundwater is needed.

## Materials and methodology

### *Study area*

The Purvanchal range is the eastern extension of the Himalayan mountains, which is made of fragile tertiary deposition. Rough and deep valleys are common geomorphological features. The district extends from 23º19'40"N to 24º 29'N latitude and 92º 40'E to 93º10'E longitude and is bounded by Champhai district in the east, Mamit district in the west, Lunglei district in the south-west, Kolasib district in the north-west, Serchip district in the south, Assam and Manipur in the north and north-east respectively (Fig. 1). Physiographically, the district is characterized by anticlines and synclines. The southwest monsoon directly controls the annual precipitation, which is approximately 2500 mm (Barman and Das, 2023). The district of Aizawl is known as the heart of Mizoram which includes a number of small rural settlements and Aizawl city. Owing to the dearth of potable water in the villages of the Aizawl district, springs (locally called *Tuikhurs*) become the backbone of water supply in the villages of the district (Biswas *et al.*, 2021). Though rainfall is sufficient during the monsoon, the post-monsoon period suffers from a shortage of water. By tradition, Mizo people have been practising *Jhum* (shifting) cultivation for a long. Due to rugged topography, maximum precipitation goes down as surface runoff. Major rivers of the district such as Tlawng, Turial, Tuivawl, and Chite are perennial, and other small streams play an important role in the daily life of the local population.

### *Database*

Groundwater is not randomly distributed all over the world. The storage of groundwater depends on specific geo-environmental conditions. For the current study, daily rainfall data from 1990 to 2020 was downloaded from IMD, Pune to prepare long-term average rainfall and precipitation concentration index factors. Likewise, morphometric indices like slope, aspect, elevation, and TWI, have been prepared from the ASTER 30m digital elevation model. Good groundwater storage directly depends on the nature of rock beds.

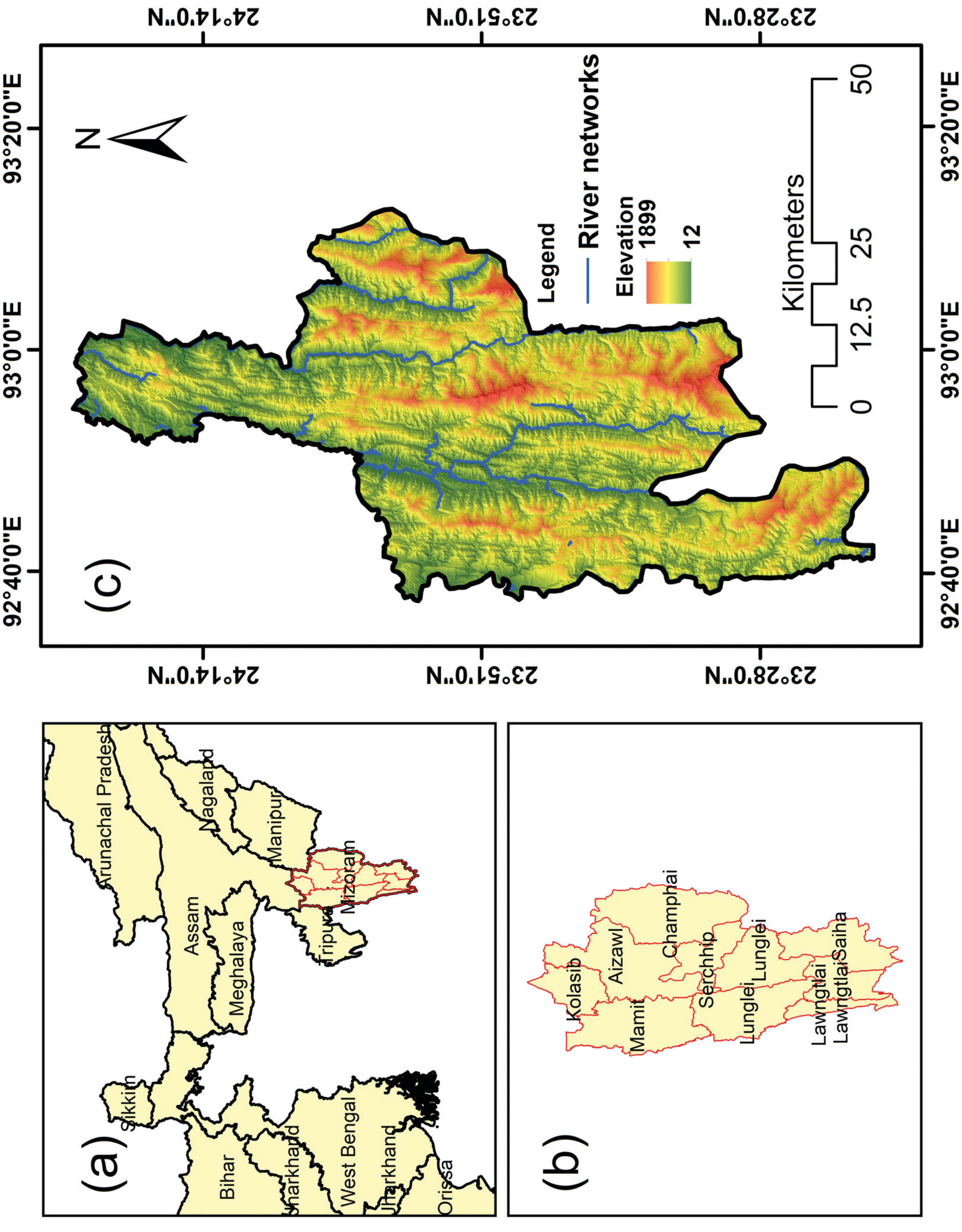


Fig. 1: Location of the study area. (a) Mizoram in NE India, (b) Aizawl district in Mizoram, (c) Elevation distribution in Aizawl district.

Table 1: Database

| Products | Sources | Types | Resolution |
|---|---|---|---|
| Rainfall | Climate Monitoring and Prediction Group (imdpune.gov.in) | Grided | 0.25 |
| Digital elevation model | Earthdata \| Earthdata (nasa.gov) | Raster | 30m |
| OSM | BBBike extracts OpenStreetMap | Vector | NA |
| Landsat8 OLI | EarthExplorer (usgs.gov) | Raster | 30m |

The geology map was digitized from Barman and Rao (2021) paper.

Subsequently, the river networks were extracted from OSM (Open Street Map) and the Euclidean distance technique was used for preparing the distance to the rivers. The land use land cover and the other two vegetation indices, namely NDVI and NDWI were prepared from Landsat 8 OLI access from USGS. A brief description of all the thematic layers is tabulated in Table 1.

### *Preference selection index (PSI)*

The model PSI was developed by Maniya and Bhatt in 2010 for a materials selection problem (Emovon *et al.*, 2020). Eswaran *et al.*, in 2018 carried out spectrum moderator using PSI for fog-assisted internet of things. Jha *et al.*, 2018 used PSI to decide the optimum phase combination of biodegradable composites. Similar to the Entropy and CRITIC objective weighting systems, PSI can also itself determine the criteria weight. The model has several steps as follows:

(a) Selection of relevant groundwater conditioning factors.

(b) Decision matrix: A decision matrix is used for holding all the information as criteria and alternatives. Each of the rows and columns represents criteria and alternative criteria, respectively. Therefore, Yij of the Y decision matrix gives the non-normalized real value of the Jth alternative and units for the ith alternative. If a decision matrix has c alternative and d criteria, c*d matrix mathematically can be formulated as Eq. 1.

$$Y_{ij} = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1C} \\ Y_{21} & Y_{22} & \cdots & Y_{2C} \\ \cdots & \cdots & \cdots & \cdots \\ Y_{D1} & Y_{D2} & \cdots & Y_{CD} \end{bmatrix} \quad (1)$$

(c) Normalization of decision matrix: a decision matrix needs to normalized for making the decision values dimensionless. For this intention, the attribute values are converted into 0 and 1. For the beneficial criteria, the maximum value is the desired value and the minimum is the desired value for non-beneficial criteria.

Eq. 2 and 3 were used for normalization based on the nature of the criteria.

$$N_{ij} = \frac{Y_{ij}}{Y_j^{max}} \text{ (For beneficiary criteria)} \quad (2)$$

$$N_{ij} = \frac{Y_j^{min}}{Y_{ij}} \text{ (For non-beneficiary criteria)} \quad (3)$$

(d) Mean values of normalized performances in relation to each criterion have been done using Eq. 4.

$$\mathcal{M} = \frac{1}{n}\sum_{i=1}^{n} N_{ij} \quad (4)$$

(e) Preference variation values of every criterion have been calculated using Eq. 5.

$$\phi_j = \sum_{i-1}^{n}(N_{ij} - \mathcal{M}) \quad (5)$$

(f) Deviation in the preference values for every attribute has been computed using Eq. 6.

$$\Omega = (\phi_j - 1) \quad (6)$$

(g) Eq.7 was used to measure each criteria weight.

$$W_{ij} = \frac{\Omega_j}{\sum_{j=1}^{m}\Omega_j} \quad (7)$$

(h) In the final stage, the preference selection index value of alternatives was used to determine the groundwater potentiality using Eq. 8.

$$\theta_i = \frac{1}{n}\sum_{i=1}^{n} Y_{ij} * W_{ij} \quad (8)$$

The largest preference selection index value denotes more groundwater potentiality.

## Groundwater conditioning factors

**Slope** is an inclined ground surface that can either be natural or man-made greatly impacting the groundwater condition such as speed and retention of runoff as well as infiltration of rainwater into the ground. Topographically Aizawl district is characterized by a steep slope ranging between 0 and 720. Flat areas, unlike steeper slopes, have good infiltration capability due to a slower rate of runoff, permitting greater water retention and infiltration. Thus, slope gradient directly affects infiltration, thereby leaving the area as a less potential recharge point.

**Aspect** is the compass direction that a topographic slope faces, usually measured in degrees from north. Aspect can be generated from continuous elevation surfaces. Aspect gives slope directions that influence the amount of rainfall, wind speed, and land cover which directly affect the amount of rainwater infiltrating the soil and hence, influencing groundwater occurrence (Moghaddam *et al.*, 2020).

**Elevation** of a geographic location is its height above or below a fixed reference point, most commonly a reference geoid. It is a mathematical model of the earth's sea level as an equipotential gravitational surface. The elevation is considered because the altitude of topography controls the speed of surface runoff and its direction on ground level; thereby, influencing water permeability (Zhang & Li, 2009). The elevation in the study area ranges between 12m and 1899m.

**Long term average rainfall (R)** is the average rainfall recorded during the last 30 years (IMD, 2020) from 1990 to 2020. The recharge of groundwater, estimated from long-term piezometric records, is observed to be directly connected to annual rainfall when referred to in previous studies. Reduced but heavier rainfall may result in an increase in groundwater recharge (Kotchoni *et al.*, 2018). The average annual rainfall of the study area ranges between 2266.56 mm and 2623.29 mm, mainly distributed in the northern and western parts of the study area.

**Distance to river (DTR):** Lithology and river networks are related to each other and play a significant role in the occurrence and availability of groundwater. Thus, groundwater recharge has been found to be greatly influenced by river flow leading to fluctuation in groundwater levels. Hence, distance from the river is considered for delineating groundwater potential zones (Mohammad *et al.*, 2020). The distance to river map for the current study was prepared from the open street map using the Euclidean distance method in the ArcGIS environment.

**Precipitation Concentration Index (PCI)** is a powerful indicator for temporal precipitation changes and is also very useful for the assessment of seasonal precipitation changes (Zhang *et al.*, 2019). PCI is one of the important climatic variables due to the intensity and amount of rainfall. The PCI allows quantifying the relative distribution of precipitation patterns. When information on long-term total variability in the recorded precipitation amount is generated, it can be used as an indicator of a particular region or area that falls in the potential zone for groundwater recharge and storage (Gocic *et al.*, 2016).

$$PCI = \frac{\sum_{i=1}^{12} pi^2}{(\sum_{i=1}^{12} pi)^2} * 100 \quad (9)$$

The PCI value of the study area ranges between 16.73 and 17.54, denoting irregular precipitation distribution in the district.

**Topographic wetness index (TWI)** quantifies the influence of topography on hydrological processes and can be used to characterise biological processes such as forest site quality, vegetation patterns, and so on (Beven & Kirby, 1979, Sorenson *et al.*, 2006). TWI is often used for describing spatial moisture patterns to illustrate the influence of topographic conditions on groundwater. It plays an important role in effecting the movement and accumulation of runoff at the surface of the soil which in turn influences the efficiency of recharge points of groundwater (Benjmel *et al.*, 2020).

$$TWI = In(\frac{\alpha}{tan\beta}) \quad (10)$$

where $\alpha$ represents scaled flow accumulation and tan $\beta$ represents the slope.

**Normalized Difference Vegetation Index (NDVI)** is used for observing any particular area to determine whether the selected zone hosts healthy vegetation or not. When the NDVI value is high, it suggests a healthy and thick type of vegetation, and a value on the lower side suggests not-so-healthy vegetation that is sparse in distribution (Taloor, 2021). NDVI is calculated as:

$$NDVI = (NIR - Red) / (NIR + Red) \quad (11)$$

where *Red* and *NIR* stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. In Landsat 8 OLI bands 5 and 4 represent the near-infrared and red respectively.

**Normalized Difference Water Index (NDWI)** is a satellite-derived index from the near-infrared (NIR) and short-wave infrared (SWIR) channels (Gao, 1996). It is used for monitoring changes related to water content in water bodies. A high NDWI value corresponds to high plant water content and high density of vegetation while a low NDWI value corresponds to low vegetation content and low vegetation cover. The NDWI ratio is calculated as:

$$NDWI = (NIR - SWIR)/(NIR + SWIR) \quad (12)$$

Where $NIR$ and $SWIR$ are bands 5 and 6 of Landsat 8 satellite images represented near infrared and short wave near infrared.

**Geology** plays an important role in the accumulation, occurrence, and distribution of groundwater in any terrain (Chen *et al.*, 2022). The availability of groundwater

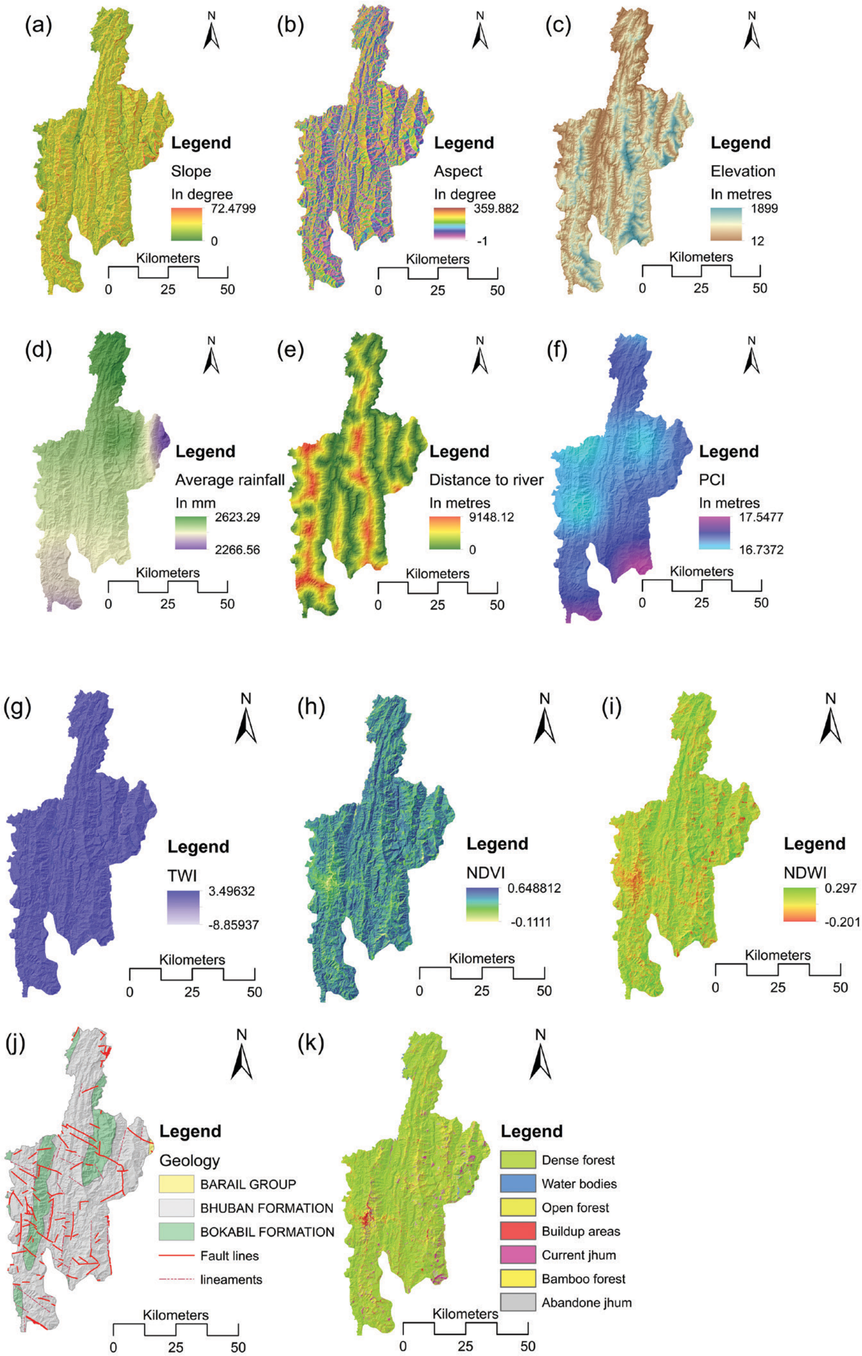


Fig. 2: Groundwater potentiality conditioning factors. (a) Slope, (b) Aspect, (c) Elevation, (d) Average rainfall, (e) Distance to river, (f) Precipitation concentration index (PCI), (g) Topographic wetness index (TWI), (h) Normalized difference vegetation index (NDVI), (i) Normalized difference water index (NDWI), (j) Geology, and (k) Land use land cover (LULC).

Table 2: Decision matrix

| SL.No. | Slope | Aspect | Elevation | R | DTR | PCI | TWI | NDVI | NDWI | Geology | LULC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40.45 | 125.15 | 90 | 2610.18 | 1897.6 | 16.93 | 3.5 | 0.34 | 0.1 | 2 | 1 |
| 2 | 4.68 | 229.09 | 249 | 2623.29 | 150 | 16.87 | -3.47 | 0.32 | 0.16 | 2 | 1 |
| 3 | 19.03 | 206.26 | 137 | 2610.27 | 169.71 | 16.93 | 3.5 | 0.37 | 0.15 | 2 | 1 |
| 4 | 18.47 | 179.29 | 140 | 2610.34 | 234.31 | 16.92 | 3.5 | 0.39 | 0.16 | 2 | 1 |
| 5 | 26.82 | 123.69 | 92 | 2610.55 | 90 | 16.92 | -3.63 | 0.27 | 0.16 | 2 | 1 |
| | …..... | ……..... | ……..... | ……... | ……... | ……..... | ……..... | …….. | …….. | …….. | ……..... |
| 19912 | 21.2 | 212.85 | 452 | 2403.85 | 750.6 | 17.36 | 3.5 | 0.31 | 0.11 | 2 | 1 |
| 19913 | 33.2 | 188.33 | 926 | 2406.04 | 67.08 | 17.37 | 3.5 | 0.38 | 0.18 | 3 | 3 |
| 19914 | 20.57 | 236.66 | 576 | 2407.3 | 276.59 | 17.37 | -4.06 | 0.32 | 0.17 | 2 | 3 |
| 19915 | 22.24 | 131.73 | 1116 | 2402.24 | 212.13 | 17.38 | -3.31 | 0.36 | 0.2 | 2 | 1 |
| 19916 | 21.02 | 75.07 | 712 | 2411.62 | 42.43 | 17.35 | 3.5 | 0.37 | 0.18 | 3 | 1 |

is largely influenced by the surface and subsurface geology of an area, as the porosity and permeability of a geologic formation control its ability to retain and transmit water. In geologic formations with well-connected pore spaces, faster water movement through the rock results in faster groundwater recharge, while geologic formations having lower permeability will have slower water movement through the rocks, resulting in slower groundwater recharge (Abdulrahman *et al.*, 2020). Aizawl district falls under the Surma group of rocks namely Bhuban, Bakabil, and and Barail formations (Fig. 2j) with lithology consisting of sandstone, shale, and their admixtures in various proportions. (Bharali *et al.*, 2017).

**Land Use/Land Cover (LULC):** To help understand the natural characteristics of any land surface, one of the most necessary thematic layers is LULC. Most of the changes in LULC are engendered by human action for development. A dense forest usually results in a lower groundwater volume since the vegetation draws a large volume of water, despite reducing the volume of surface runoff. When forest cover is decreased, it results in an increased flow of water into the river from groundwater (Ouyan *et al.*, 2019). In the present study land use land cover map was prepared by supervised technique using a support vector machine algorithm. All the groundwater conditioning factors for the present study are presented in Figure 2.

## Results

On the basis of different criteria, groundwater potential was studied in a similar condition. PSI was calculated using long-term average rainfall, precipitation concentration index, NDVI, NDWI, geology, elevation, aspect, slope, LULC, TWI, and distance to the river. As the current model is not pixel-based like the analytical hierarchy process (AHP) (Sari, 2021), 19,916 random points in the study area were chosen for the representation of criteria values (Table 2). Based on PSI values, the IDW interpolation technique was adopted for preparing the groundwater potentiality zones

Table 3: Distribution of PSI

| X | Y | PSI |
|---|---|---|
| 92.6799 | 23.7780043 | 2845.86 |
| 93.0093 | 24.2440386 | 2485.03 |
| 92.9068 | 23.9638831 | 696.968 |
| 92.9195 | 23.8527359 | 31.6843 |
| 92.913 | 24.2557076 | 2786.64 |
| ….. | ….. | …. |
| 92.94 | 24.2520049 | 1034.23 |
| 93.0389 | 24.0465266 | 159.787 |
| 93.1326 | 24.0402158 | 2992.42 |
| 93.0055 | 24.2807015 | 2026.3 |
| 93.012 | 23.9092752 | 9714.72 |

Table 4: Areal distribution of groundwater potentiality

| Groundwater potentiality zones | Area | Area (%) |
|---|---|---|
| Very high potentiality | 178.09 | 5.16 |
| High potentiality | 552.76 | 16.02 |
| Moderate potentiality | 957.74 | 27.76 |
| Low potentiality | 1090.41 | 31.60 |
| Very low potentiality | 671.39 | 19.46 |

(Table 3). The natural break classifier system is used to understand the potentiality level and has been classified into five potentiality classes, namely very low, low, moderate, high, and very high potentiality zones. The district as a whole is characterized by very low potential, with patches of very high, high, and moderate potential zones (Fig. 3). Only 5.16 percent of the total area covers very high potential, followed by high 16.02 percent, moderate 27.76 percent, low 31.60 percent and very low 19.46 percent of the total area (Fig. 4 and Table 4). For lack of groundwater information, accuracy tests for the present study have not been done. However, the previous study by Lalbiakmawia (2015) demarked low-lying areas, riverine valleys, and floodplain areas as highly potential for groundwater potential. PHED, Mizoram, 2020 reported groundwater depth (GWD) ranging from 8.80-1.25m below ground level in Mizoram. The GWD depletion during pre-monsoon and post-monsoon is 0.32m and 0.57m, respectively, about 0.50m on average. A field survey by CGWB revealed instances of small pond-like formations with relatively shallow water levels (2.0 m bgl). Dissected hills are characterized by high runoff and low water infiltration and permeability. Siltstone, hard compacted sandstone, shale, and their alternation in the Surma group in moderate linear ridges are extremely poor

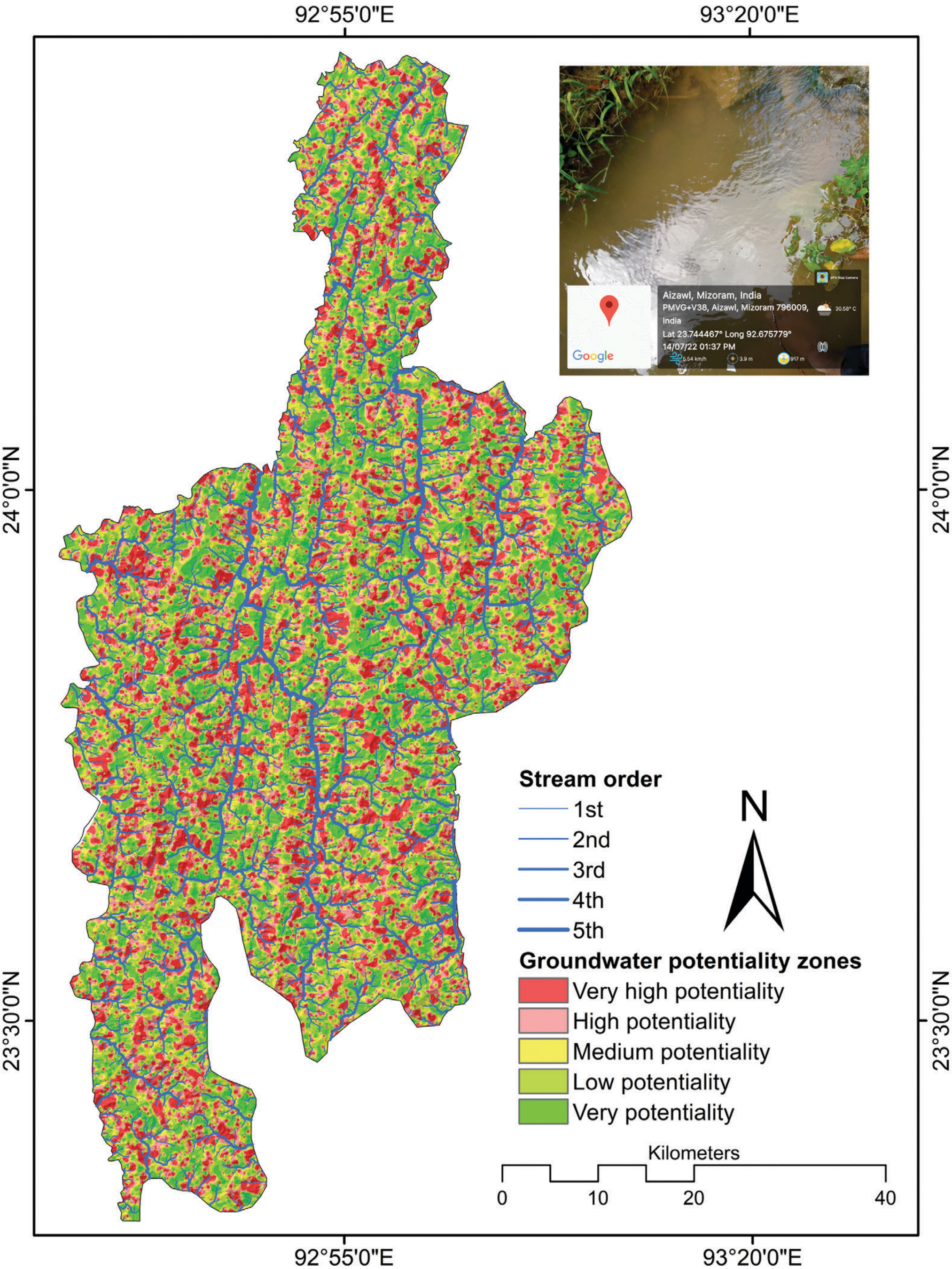


Fig. 3: Spatial distribution of groundwater potentiality zones.

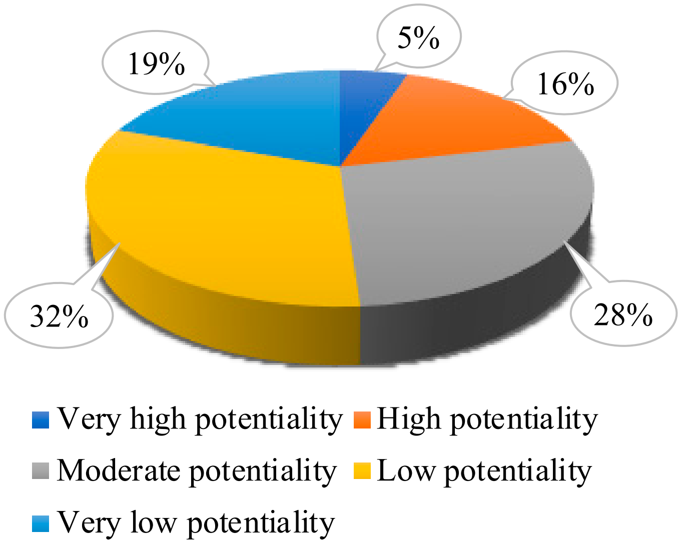


Fig. 4: Areal distribution of groundwater potentiality in percentage.

for infiltration and permeability capacity, and have a low groundwater potentiality and hence high runoff.

**Discussion**

Long-term average rainfall, precipitation concentration index, NDVI, NDWI, geology, elevation, aspect, slope, LULC, TWI, and distance to the river are important factors while determining a groundwater potential zone. Each factor performs differently for various criteria, and these performances occasionally contradict one another. It is exceedingly rare for any single factor to meet and satisfy all of the requirements. Problems involving the selection of contrasting and incompatible criteria fall under the category of multi-criteria decision-making (MCDM). Compared to other MCDM methods in the literature, namely WASPAS, SAW, TOPSIS, ARAS, and VIKOR, the PSI is a significant MCDM method having significant importance (Attri and Grover, 2013). It is simple to calculate and ignores the relative importance of the conditioning factors (Jha *et al.*, 2018). Initially, the decision matrix consists of alternatives in the column and criteria in the row arranged for the decision problem. Thereafter, the matrix is normalized, based on beneficial and non-beneficial criteria. Beneficial criteria are those that are directly proportional to groundwater potential.

The distribution of long-term average rainfall, river distance, TWI, NDVI, and NDWI are all considered useful criteria. Subsequently, slope, aspect, geology, and LULC are considered non-beneficial criteria. As mentioned above PSI itself determined objective weight for criteria. The aspect has the highest contribution in groundwater potentiality followed by slope and elevation, geology, LULC, long-term average annual rainfall, PCI, distance to river, TWI, NDVI and NDWI. As the area is located in the northern hemisphere, the south and south-east slopes receive huge rain during monsoon (Barman *et al.*, 2022). Slope is another groundwater-controlling factor in the district. It is found that very high groundwater potentiality is located between 0 and 170. Similar to the slope, the elevation of the district has a significant contribution to groundwater potentiality. Arabameri *et al.*, 2019 have noted elevation as the highest contributing factor to groundwater potentiality in the Damghan sedimentary plain, Iran. The result shows that most of the areas have very low potential for groundwater. Based on hydrogeological formation, two types of rocks, namely un-consolidated and semi-consolidated are the dominant types in Mizoram (PHE department, Govt. of Mizoram, 2020). Most of the area is covered by semi-consolidated rock formations, including sandstone, limestone, and shale characterized by low potential for groundwater and having secondary porosity (Singh *et al.*, 2013; Sharma & Kumar, 2008). Only the western part of the area has unconsolidated rock formations in flood plains and river valleys, primarily the Tlawng River valley region. The adjoining areas have high groundwater potential owing to the presence of sand, silt, gravel, etc., which are permeable in nature (Singha *et al.*, 2021; Thakur & Raghuwanshi, 2008).

The region is further helped by high rainfall thereby increasing the potentiality of groundwater. Mizoram is tectonically active and geologically immature. The occurrence of groundwater is further accentuated by the random distribution of faults, lineaments, and fractures. Most of the time, the groundwater is discharged as spring water. A survey conducted by CGWB in Guwahati mentioned that most of the springs are fracture-oriented and perennial in nature. They also reported during the dry season (January to March), between 3,000 and 20,000 litres of water are discharged daily from these springs.

## Conclusion

Groundwater assessment in hilly areas is not easy. While the physical investigation of groundwater is time-consuming, a multi-criteria decision-making method with the advancement of remote sensing and GIS has better potential in evolving zonation. Aizawl, the capital of Mizoram, faces extreme drinking water problems, especially during the winter months. The identification of groundwater potential zones in the Aizawl district through the MCDM technique of the Preference Selection Index was presented in this study. The results show that only 5.16 percent of the total area comes under the ambit of the "very high potential zone", followed by high (16.02%), moderate (27.76%), low (31.60%), and very low (19.46%) potential areas. The geological, slope morphology, and lithological setting enable high surface runoff, resulting in the bulk of the rainwater being washed out of the basin. The region is mainly dominated by shale, sandstone, and limestone, which have a low potential for groundwater storage/holding. In most cases, groundwater is discharged onto the surface through tectonically weak areas as spring water and for a long time, local people have conserved rainwater in a traditional way. A deficit of water has been observed in recent years due to overpopulation and an increase in built-up areas, mainly in urban areas. The future study will be directed toward groundwater inventory mapping. The region, blessed with ample rainfall and mountainous streams can overcome water scarcity/deficit issues to a great extent by applying the geo-spatial analysis for assessment and evaluation as suggested in this research.

## Competing interest

The authors declare that they have no conflict of interest.


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