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Research Article

Effect of Faults and Fractures on Springwater Quality and Discharge of West Phaileng, Mizoram

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ABSTRACT

The North Eastern part of India comprise of hilly slopes and ridges, where the main water sources are rivers, streams and springs. Many springwater sources have been reported drying up recently. A lithology shows the area to consist of clay, silt, shale, siltstone and sandstone where porosity is limited. The hydrochemistry suggested immature and relatively young with weathering of phyllosilicate mineral governing them. Dual flow hydrodynamic of govern the recharge hydrograph with initial rapid recharge through conduit flow followed by slower diffused flow through pores. The conservation measures by recharge pit, bunds and checkdams is the most viable option.

Keywords: Geochemical modelling, Water Quality Index, Mountain Front Recharge, Principal Component Analysis, Spring Hydrograph Analysis.

1. Introduction

The rapid increase in population and urbanization aided by the ever increasing rate of climate change has led to the rapid escalation of demand on fresh water for consumption, sanitary use, domestic use and agricultural use (Filippini et al., 2024; Pandit et al., 2024; Daniel et al., 2021; Bhat et al., 2022; Laskar et al., 2022; WWAP, 2019) An alarming water scarcity problem affects Northeast India including Mizoram state and is a more significant especially during lean seasons i.e. November to March even though the state has one of the highest rainfall rate, accumulating to over 2500 mm annually (EFCC-GoM 2020; SAPCC, 2017). From time immemorial, the people of Mizoram depend on groundwater that emerges at certain point creating a visible flow of water known as spring or "Tuikhur" in local language (SAPCC, 2017; DRDA, 2009; Thasangzuala and Mishra, 2014). This generate the main source of water for consumption and domestic use in the hilly rural and remote areas of urban settlement in the North Eastern region of India such as West Phaileng where there is limited distribution of treated water.

The acute shortage in water supply and rise in demand is a problem generated by the recent reports of decrease in water discharge and drying up of these springs (Filippini et al., 2024; Pandit et al., 2024; Bhat et al., 2022; EFCC-GoM, 2020; Sailo et al., 2022). The water shortage may be caused by a number of factors such as rapid urbanization, agricultural practices, localised development of infrastructures and climate change (Daniel et al., 2021; Biswas et al., 2023; Ghimire et al., 2019; Chitsazan et al., 2017; Ozdemir, 2011). The relation between the water sources and aquifers and its recharge system is an important factor and must be understood for the management and preservation of these springs and streams.

The complexity of hillslope hydrology and movement of water through the hillslopes affects the depth of percolation and flow rate of water through fractures, faults that may cause catchment stream flow, spring discharge (Filippini et al., 2024; Segadelli et al., 2021; Buttle and McDonnell, 2002; Markovich et al., 2019). Many studies have been conducted on hillslope runoff (Martin-Rodriguez et al., 2023;

Wilson and Guan, 2004; Kresic, 2007; Tao et al., 2021; Segadelli et al., 2021; Filippini et al., 2024), or the hydrological process of water storage and evapotranspiration on the soil of hillslopes (Lee and Kim, 2019; Markovich et al., 2019; Buttle and McDonald 2002).

The estimation of recharge of unsaturated soil is typically done on a flat study area, where runoff is considered to be negligible (Markovich et al., 2019; Tao et al., 2019). The higher angle of slope converts a higher percentage of total recharge to lateral flow thus reducing the volume of vertical flow and thereby reducing the volume of groundwater and groundwater recharge (Rusjan et al., 2023; Tao et al., 2021; Ghimire et al., 2019; Buttle and McDonald 2002). The lithological construct of hilly areas such as Mizoram consist of a thin layer of soil covered with thick vegetation and has a low water yielding capacity overlying a rocky strata (SAPCC,, 2017) (Fig. 1). This stratum consists of sedimentary rocks such as shales, limestone with numerous faults and fractures (Rao, 2018).

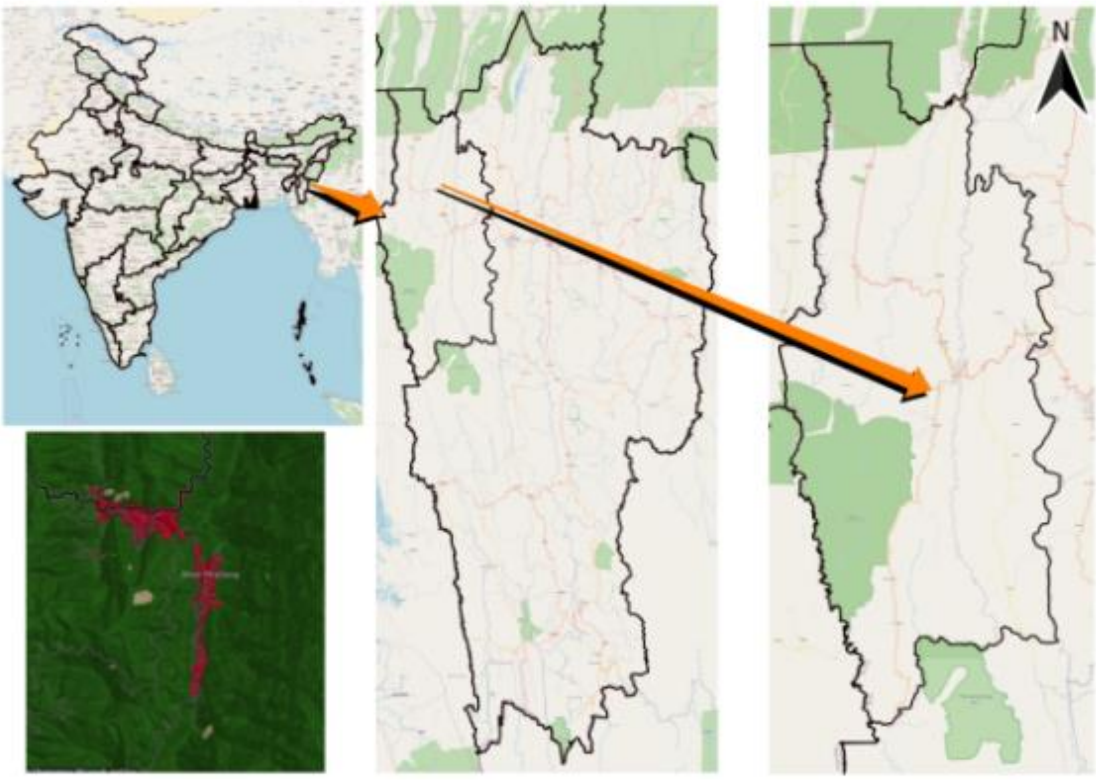

Fig.1 Study Area - West Phaileng, North East India illustrate the hilly terrain with red marking the habitations and spring water sample collection area

During sedimentation process, these rocks acquire different bedding planes or lamination and the study area is located in active zone of earthquake which further increases the formation of fractures in the hydrogeology (SAPCC, 2017; Rao, 2018; Hauhnar et al., 2021). The properties and the dip orientation of theses laminations have a significant effect on the properties of the rock in terms of stability and strength (Hauhnar et al., 2021; Biswas et al., 2023). They are greatly affected by motion of water in the presence of abrasive objects such as clay and sand. This forms cracks, fault lines and voids in this layer reducing the strength in terms of shear strength by a considerable amount. These faults and fractures may reduce evapotranspiration and may provide the route and opening of water as springs (SAPCC, 2017; CGWB,2013a; CGWB 2013b).

Groundwater hydrochemical composition are affected by the long-term actions of the surrounding environment and continuous interaction of the surrounding medium during the flow process, which would result in a series of change in both physical and chemical properties of the water (Daniel et al., 2021; Bhat et al., 2022; Chitsazan et al., 2017). These properties provide data that can represent information such as climate change and the origin of the water (Yu et al., 2024). Depending on the surrounding hydrogeological conditions and human activities the hydro-geochemical composition of water varies. Analysing such characteristics provides important information such as chemical behaviour of various elements and intensity of chemical weathering by groundwater (Yu et al., 2024; Chitzasan et al., 2019; Bhat et al., 2022).

Spring hydrograph represents a sum of individual block discharge that originates from infiltration of water in the form of diffusion and conduit discharge from concentrated recharge (Filipinni et al. 2024; Rusjan et al., 2023; Kovacs and Perrochet, 2008). The recession flow curve was analysed using Maillet's equation (Maillet, 1905) i.e. late stage of spring hydrograph where the springwater is fed from groundwater flow without the intervention of recharge processes (Abirifard et al., 2022; Segadelli et al., 2021). The recession curve of hydrograph is generally more stable and is assumed to express the geometrical and hydraulic characteristics of aquifers (Filippini et al., 2024; Abirifard et al., 2022; Segadelli et al. 2021; Fiorillo, 2014). The hypotheses of the study include, that in absence of groundwater abstraction with tubewells in the springshed area, the recharge and discharge are least affected by it, and hydro-geochemical composition is mainly rock-water interaction and precipitation is the only recharge mechanisms. The systematic study on the springwater discharge characteristics is not carried out so far in the area. Indeed, the aquifers have long been of vital importance due to their socio-economic significance and unfortunate associated vulnerability due to climate change and pollution. The aim of this paper is to analyse the hydro-geochmical composition of spring water, identify the mechanism of its recharge, and formulate the conceptual recharge process and finally analysing the springwater hydrograph to obtain the hydraulic behaviour of the aquifers and its origin.

2. Material and methods

2.1 Study Area

West Phaileng is a village located at the intersection of 23°42'34" N latitude and 92°29'05" E longitude in West Phaileng sub division of Mamit district in Mizoram. Even though the region receives an annual rainfall of 2587.8 mm according to District Rural Development Agency, Mamit District (EFCC-GoM, 2020; DRDA, 2009), 78 % of rainfall gets concentrated during monsoon season and flows as runoff as a result of geological features such as its slope and soil type (DRDA, 2009). West Phaileng is situated in an area where the inhabitants are heavily dependent on agricultural practices. The practice of jhum cultivation has exposed the area to more erosion and increases the runoff characteristics of the mountain which is the main source of groundwater recharge (EFCC-GoM, 2020; SAPCC). The area consists of a shallow layer of soil underlined by a layer of rock strata consisting of rocks such as shale, sandstone (CGWB, 2013b) which has faults and fracture (Rao, 2018). It potentially provides a path for underground water and emerge as spring on the surface as observed from cutting via road network.

2.1.1 Hydrogeology

The hydrogeology of West Phaileng is controlled by the lithology of the area where terrain is considered to be tectonically immature and young. The study area lies on a hill slope which mainly consist of shale, siltstone and mudstone, fine grained and compact sandstone covered by a thin layer of dark brown clayey soil, where porosity is very limited (Fig. 2). The study area physiography is mostly parallel anticlinal hills and synclinal valleys with deep gorge in north south direction (Rao, 2018). The geology mostly composed of Miocene gray sand silt, shale and mud of Surma formation, Barail group (sandstone, siltstone, shale), Tipam formation (ferruginous sandstone with siltstone and clays) are also common (SAPCC, 2017; CGWB, 2013b). As a result of low porosity of rocks, the yielding capacity of aquifers significantly decreases. A number of springs occur from weak areas such as cracks and fractures in the layer of rocks underlain by a thin layer of clayey soil (CGWB, 2013b). They are observed to be perennial and are one of the main sources of water for domestic use. However due to low yielding capacity, infiltration and permeability properties of the area, majority of source of recharge converts to runoff causing water discharge to reduce significantly from the month of December or January (CGWB, 2013a).

Fig. 2 Springwater from fractured sedimentary rocks and water seepage through fractures during dry period during March 2021, the sedimentary rocks such as shales from outcrop/cutting slopes is the sources springwater

2.2 Collection of Data

A total of 10 samples were collected during the years 2020-2022 for pre-monsoon, monsoon and post-monsoon. Out of the samples collected, 8 samples were spring water samples and the other 2 were of that of tube-wells having depth of 60m – 70m. Handheld Global Positioning System (GPS), Garmin-Etrex10 was used to determine the geographical position of each source. Two samples, one acidified sample using H_2SO_4 and another non-acidified sample were collected from each source in a 250 ml plastic sampling bottle.

2.3 Analysis of Data

On site analysis were conducted on the spots using YSI Pro Plus Multiparameter and YSI pHotoFlex STD. The tube-wells were purged for 5-10 minutes before conducting analysis and sample collection so as to avoid contaminations caused by stagnant water. APHA (CGWB, 2013, 2) recommended standard methods were used for the measurement of dissolved ion concentration in the samples. Major anions viz. Alkalinity was measured using titration method, Chloride (Cl^-) using argentometric method, Sulphate (SO_4^{2-}) using turbidimetric method, Phosphate (PO_4^{3-}) using Spectrophotometer – Shimadzu UV1800.

2.4 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a method of analysis of components and constructing the basis of the components using data collected. It is dimension-reduction process where a large dataset with high number of dimensions is reduced by reducing the size of the set of variables without significant change in information within the set of variables (Zeinalzadeh and Rezaei, 2017). This reduction decreases the interpretation of data in exchange for accuracy. However, exploration, visualization and analysis of data are performed at a higher speed and ease. To perform a principal component analysis on the samples collected, a statistical analysis programme called SPSS developed by IBM was used. Using this programme, data collected were used to run a multivariate analysis for multiple parameters.

2.5 Geochemical Modelling

PHREEQC Version 3.7.3, developed by United States Geological Survey and released on December of 2021, a computer program written in the C++ programming language that is designed to perform a wide variety of aqueous geochemical calculations was used to prepare speciation model.

Geochemical speciation model determines the saturation status of minerals which may be reacting within various solutions and mixtures. The saturation status of a mineral in a solution can be represented using a saturation index. A saturation index can be defined as an index expressing the tendency of solution to dissolve or precipitate a particular mineral. The saturation index (SI) is calculated by comparing the chemical activities of the dissolved ions of the mineral (ion activity product, IAP) with their solubility product (K_{sp}) (Chitsazan et al., 2017; Sailo et al., 2022) and can be represented by the following equation:

$$SI = \log (IAP/K_{sp}) \quad (1)$$

The saturation index provides an accurate concentration level of different minerals dissolved within the solution. This data provides information on the type of minerals dissolved during the interaction period of the solution with the soil present in the path followed by groundwater.

2.6 Water Quality Index

A Water Quality Index (WQI) is a numerical summarization of water quality data in a simple and consistent manner so as to be understandable and useable by the general public (Adelagun et al., 2021; Bhat et al., 2022). Suitable parameters were used to compare the water quality to WHO and Indian standard values (Kizar, 2018; BIS, 2012) to construct the water quality index using a slightly modified version of Weighted Arithmetic Index method (Table 1) (Deshpande et al., 2021). Modification made to the method consist of the unit weight calculated from a constant being changed in favour of relative weight calculated from assigned weights obtained from studies conducted. The water quality observed is then classified into five groups (Table 2). The following steps are used to calculate Water Quality Index (Chandra et al, 2017):

Calculation of unit weight/relative weight (Wn) using the formula

$$Wn = AW/\Sigma AW \quad (2)$$

Where, AW =Assigned weight of a parameter, ΣAW = Sum of assigned weight of all parameters

Calculation of quality rating for nth parameter (Qn).

$$Qn = 100\{(Vn-Vo)/(Sn)\}. \quad (3)$$

Where, Vn=Value of the nth parameter of the given sample, Vo = Ideal value of nth parameter in pure water, Sn = Standard permissible value of the nth parameter.

Calculation of Water Quality Index (WQI)

$$WQI = ((\Sigma Wn x Qn)/\Sigma Wn). \quad (4)$$

Table 1: Standard and weight of various parameters for WQI

Parameter	Assigned Weight	Relative Weight	Standard
pH	2.57	0.08	8.50
DO	4.09	0.12	5.00
EC (µs/cm)	3.22	0.10	300.00
TDS	2.75	0.08	1000.00
Sodium (Na)	2.00	0.06	200.00
Calcium (Ca)	2.00	0.06	75.00
Magnesium (Mg)	2.00	0.06	30.00
Alkalinity (HCO3-)	2.00	0.06	200.00

Sulfate (SO4-2)	3.00	0.09	250.00
Nitrate (NO3-)	2.21	0.07	50.00
Chloride (Cl)	3.00	0.09	250.00
Hardness	1.40	0.04	200.00
Phosphate (PO4-3)	3.00	0.09	12.00
Summation(∑)	33.25	1.00	

Table 2: Water Quality Index Classification

Water Quality Index	Water Status
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unsuitable for consumption

2.7 Spring Hydrograph

A spring hydrograph is a graphical representation of discharge of spring over a specified course of time. The hydrograph of spring may vary according to various factors such as precipitation, topographical characteristics and flow path (Filippini et al., 2024; Kogovsek et al., 2023; Kovacs and Perrochet, 2008; Russo et al., 2015). In many cases, hydrograph may fluctuate within a short observation period in accordance to input of water. These fluctuations may be caused by a number of factors such as short travel distance, intensity of precipitation/recharge, high porosity of soil and drainage systems such as cracks, fractures and karst systems (Martin-Rodriguez et al., 2023; Kogovsek et al., 2023; Abirifard et al., 2022; Daniel et al., 2021; Kresic, 2007; Kovacs and Perrochet, 2008; Manna et a., 2017) In many cases such as unconfined aquifers, changes in discharge may be rapid and occur in a varied magnitude (Rusjan et al., 2023; Russo et al., 2015). In other cases, changes may occur over a prolonged period or even delayed by days or even months depending on the characteristics of aquifer and other factors.

The receding and base flow of the spring is then studied using a mathematical formula proposed by Boussinesq (1904) and Maillet (1905). The equation is dependent on the flow Q_t and Q_o which represents flow at a specific time 't' and the initial flow at recession.

Maillets equation,

$$Q_t = Q_o e^{-\alpha(t-t_o)} \quad (5)$$

Where:

$Q_t$is flow at specific time t, Q_o is flow at beginning of recission, α coefficient of discharge/flow, t_o initial time. The coefficient of discharge is dependent on the aquifers transmissivity and specific yield and is represented by the equation

$$\alpha = \frac{logQ_o - logQ_t}{0.4343(t-t_o)} \quad (6)$$

Where Q_t = flow at specific time t, Q_o= flow at beginning of recission, t = specific point in time, t_o= initial time. Using the coefficient and discharge interpreted as Maillet (1905) the volume of liquid accumulated in the aquifer can be calculate using the formula

$$V = \frac{Q}{\alpha} \quad (7)$$

Where, Q is the discharge and α is the coefficient of discharge.

The volume of liquid accumulated in the aquifer at the initial stage of the recession period was calculated as the sum of the volume of the three regimes the recession period was divided into given by the following formula

$$V_o = \frac{Q_1}{\alpha_1} + \frac{Q_2}{\alpha_2} + \frac{Q_3}{\alpha_3} \text{ x } 86400 \text{ s } [m^3] \quad (8)$$

Where, Q_1, Q_2& Q_3 = the difference of final and initial discharge in each regime, α_1, α_2& α_3 = coefficient of discharge of each regime

The volume of liquid remaining in the aquifer after the third regime was further calculated as $V^*=Q^*/\alpha_3$, where * represents a point in time after the third regime. The difference between V^* and V_o gives the volume of all the liquid stored during the time (t^*-t_o).

3.0 Results and Discussion

3.1 Hydrogeochemical Composition

The hydro-geochemistry of the West Phaileng suggested the water is relatively young and immature due to its low electrical conductivity values (Table 3 with p-value - 0.05). The pH values of the samples range between 6.62 – 8.32. It was observed that the cations were dominated by Na^+ ions and anions by HCO_3^-. Average abundance of cations was observed to be in the order: $Na^+>Mg^{2+}>Ca^{2+}>Mn^{2+}>Fe>K^+$ and anoins in the order: $HCO_3^->Cl^->SO_4^{2-}>NO_3^->PO_4^{3-}$. Since the springwater samples are immature the cations concentration are also found to be low. The dominant cations Na^+ may be attributed to weathering of rocks and minerals such as plagioclase and feldspar. The abundance of significant Mg^{2+} and Ca^{2+} ions suggested the presence of calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and vivianite. The springwater dissolved oxygen (DO mg/l) were observed in the range of 4.5-7 mg/l, which might have led to the oxidation of Fe^{2+} ions and Mn^{2+}, thus lower its concentration. The overall appearance of the springwater was aesthetically appealing and colourless.

Table 3: Mean and Standard Deviation of Springwater samples of West Phaileng

	pH	EC (µs/cm)	Na^{2+}	Ca^{2+}	Mg^{2+}	Fe	Mn^{2+}	HCO_3^-	SO_4^{-2}	NO_3^-	PO_4^{-3}	K^+	Cl^-
Max	8.32	458.40	25.00	22.00	31.34	3.55	2.80	202.00	14.31	3.20	2.46	14.00	19.99
Min	6.62	84.30	12.00	1.00	4.98	0.02	0.30	42.00	1.65	0.10	0.07	0.00	4.00
Avg	7.22	193.29	18.20	6.20	13.34	0.84	0.83	88.20	6.47	2.20	0.62	1.90	9.20
SD	0.45	109.72	4.42	7.49	7.33	1.37	0.71	49.63	3.44	0.85	0.79	4.11	4.75

The anions parts were significantly dominated by HCO_3^- ions which accounts to 80% of total anions, suggesting the presence of carbonates aquifer minerals presence in the area. The other cations SO_4^{2-}, NO_3^-, PO_4^{3-} were observed to be present in lower concentration in all the samples. The people in the area are well aware of the catchment area protection measures and have proper sanitation (septic tanks) and drainage systems. This lead to lowering of anthropogenic sources directly discharging near thespringwater sources.

To evaluate the relation of composition of water and the petrologic properties, a diagram named Gibbs Diagram was used. The diagram is divided into three major categories according to their dominant fields namely, precipitation dominance, rock-water interaction dominance and evaporation dominance which relates to post evaporation (Gibbs, 1970; Chitsazan et al., 2017). The samples fall within rock-water interaction dominant region and show relations close to precipitation dominant (Fig. 3). The rock-water interaction dominance indicates that there is interaction between the solution and the lithological construct (Yu et al., 2024; Kumar et al., 2015). Results show that the source of ions to be from the dissolution of minerals and of rock weathering.

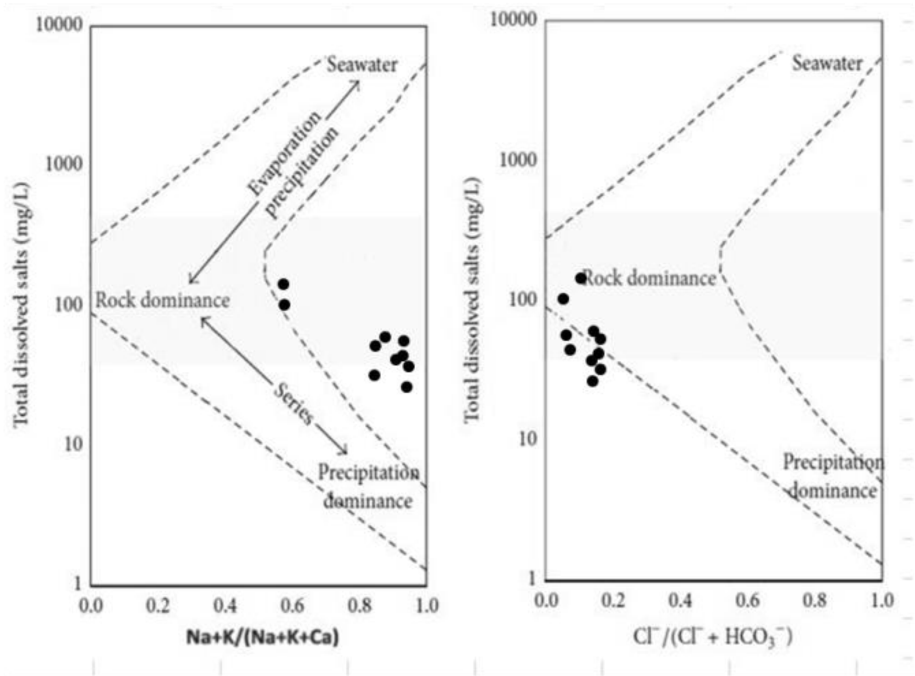

Fig. 3 Gibbs diagram of springwater samples showing rock dominance,(a) lower TDS due to low residence time the dominance of Na^{+} ions from weathering of silicate minerals (b) the dominance of HCO_3^- in the samples in the suggested the dissolution of carbonate minerals and silicates.

A graphical representation of the characteristics/contents of the solutions was created in the form of a piper diagram (Fig. 4). The samples solutions could be magnesium type bicarbonates to mixed type bicarbonates. These results show the presence of dolomite, limestones and other magnesium carbonates.

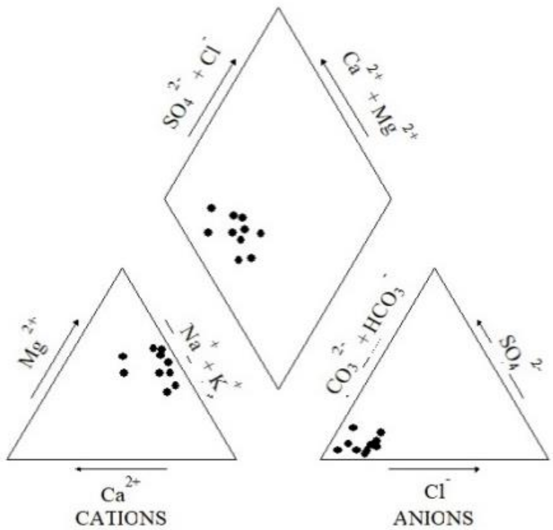

Fig. 4 Piper diagram showing the geochemical composition suggesting Na^{+} and HCO_3^- dominance the geochemistry of the springwater classified as Mixed Ca^{2+} Mg^{2+} HCO_3^- and Na^{+} HCO_3^- types

3.2 Saturation Index

Geochemical speciation model constructed using Phreeqcshowed the saturation status of minerals. The model show the presence of minerals such as dolomite, calcite and vivianite as the dominant minerals (Table 4). These minerals show similar properties like composition. Dolomite is a rich source of calcium and magnesium carbonate and also contain small amount of other minerals. Calcite is a widely distributed mineral and is one of the most common sources of calcium carbonate. Vivianite and other minerals present in higher saturation are at least a small source of magnesium and calcium carbonates.

Table 4: Saturation Index of minerals

	Calcite	**Dolomite**	**Gypsum**	**Halite**	**Siderite**	**Vivianite**
Max	2.230	4.620	-0.610	-5.170	2.980	6.220
Min	-0.140	0.710	-2.190	-5.950	0.160	-0.820
Average	0.966	2.754	-1.321	-5.666	1.363	1.456

3.3 Principal Component Analysis

Principal component analysis (PCA) plots were used to infer the relationship between various springwater samples in the study areas in a single plot. From the scree plots (Fig. 5) showing the graph between Component number vs eigen values, the three principal component with eigen-values >1 is considered (Zeinalzadeh and Rezaei, 2017) and the variance explained by each component is PC1 – 50%, PC2 – 23% and PC3 – 13% with total variation extracted 86% . The contribution of each principal component was extracted using correlation matrix with varimax rotation to reveal the processes of evolution of geochemistry of springwater.

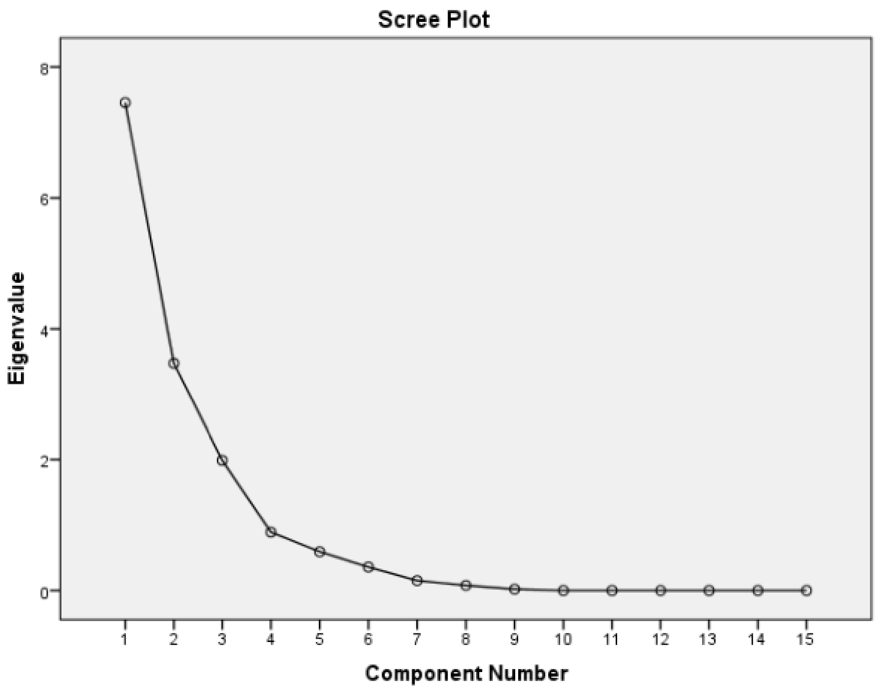

Fig. 5 Scree plots of PCA suggesting that 3 PC with variance (PC1 – 50%, PC2 – 23% and PC3 – 13%)

The PCA plot (Fig 6) show significant correlation between alkalinity, Ca^{2+} and Mg^{2+} which are lying near each other. The suggestion of mineral phase saturation indices (section 3.2) suggested the dissolution of minerals dolomite, vivianite and calcite. A bivariate plot of (Ca^{2+}+Mg^{2+}) were also found to be highly correlated to SO_4^{2-} + HCO_3^- (Fig. 6). This may indicate the presence of minerals such as calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$(Marandi and Shand, 2018). The Na^+ ion corresponds well with increase in electrical conductivity and alkalinity from the PCA plot (Fig. 6). This has been attributed to the weathering of locally available like Na-Feldspar and Na^{+} silicate minerals along the subsurface flow path. Hardness was found to be in high relation with Ca^{2+} and Mg^{2+} which infer that would create/cause a temporary hardness of the water. With moderate relation between iron and chloride, presence of compounds such as ferric chloride is possible. Similarly, silica may react with ironto forms iron oxides.

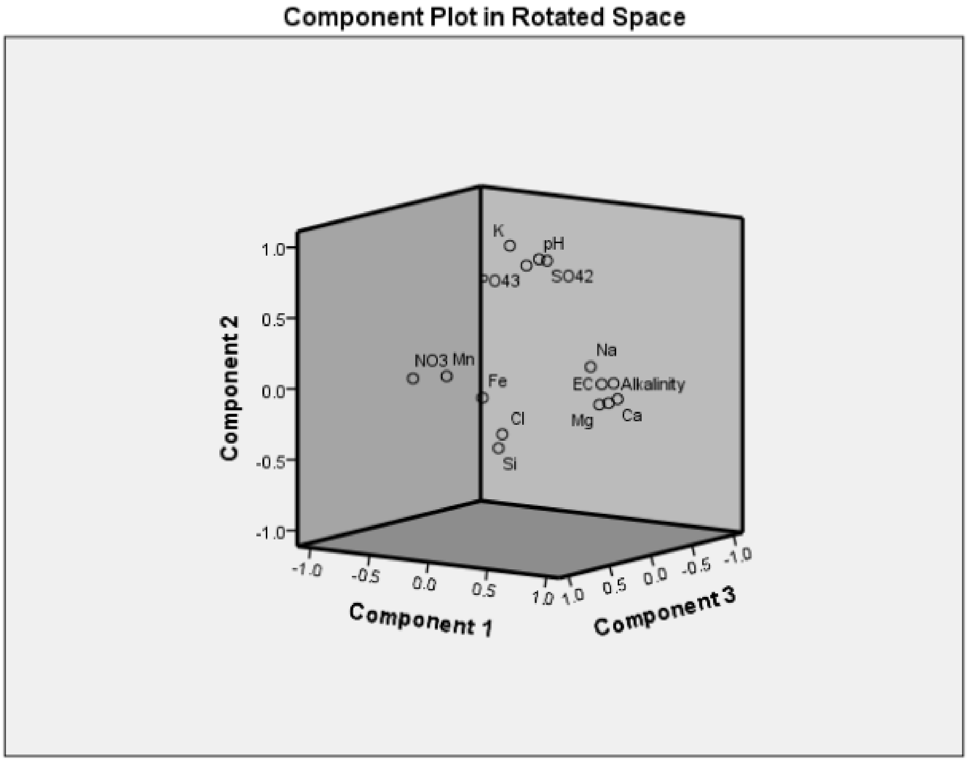

Fig. 6 PCA plots of three components (PC1, PC2 and PC3) for water quality parameters

3.4 Water Quality Index

The water quality index (WQI) from various sites of West Phaileng (Table 5) have either Good or Excellent water quality with the exception of site 6 which has a poor quality. Site 6 was observed to have a WQI value of 56.96 (Table 5) which is considerably close to being classified as good in quality. Site 6 was observed to have high concentration of cations Na^{+}, Ca^{2+} and Mg^{2+} as compared to other sites. It was also observed that the water was higher mineralized with high EC, alkalinity and hardness than water from other sites. The water sample was observed to have low DO which is 2.2 mg/l. This low DO may be due to the anthropogenic pollution as site 6 was located within the village with possible pollutant sources such as drainage systems in its proximity. Overall, the village is located in a well forested area with a substantial land with low pollution. The village is free of industrial, agricultural and horticultural activities as the water sources are protected and lies in the uphills of settlement. But the site 6 is located near a natural drainage along the road so possible pollution might have occurred from the wastewater discharge. Thus, the water of all sites is in good condition and fall within safe for consumption category with an exception of site 6, according to WHO and Indian standards (Table 2) (Kizar, 2018; BIS 2012).

Table 5: Water Quality Index

Site	Overall WnQn	Water Quality Status
1	27.28	Good
2	21.51	Excellent
3	31.06	Good
4	19.12	Excellent
5	18.69	Excellent
6	56.96	Poor
7	41.51	Good
8	28.65	Good
9	34.26	Good
10	17.12	Excellent

3.5 Conceptual Recharge Mechanism:

The geological formationof the area being clayey soil, silt and fine sand combined with its underlying bedrock material with partial alluvial characteristics, the area is subjected to a series of forms of recharges, among which is Mountain Front Recharge (MFR). MFR is the recharge of an aquifer by and adjacent/parallel mountain and intermontane recharge are least quantified and challenging to distinguish subsurface inflow from adjacent mountains (Dar et al., 2022). Observation made on ionic concentration (EC) and analysis of data collected implicates that the flow path of the water is short and near the surface or has high conductance of water. It was also observed that majority of springs in the area were found on exposed bedrock located at slopes. The water was found to be seeping through weak spots in the bedrock charged by the adjacent hillside (fig 2). Observations made correspond to MFR and are speculated to be the main recharge format in action.

A Digital Elevation Map was constructed using computer programs such as Google Earth, QGIS and Modelmuse (Fig 7). The elevation was taken from handheld GPS and digital map was used to construct the elevation profile showing the topographical construct of the study area. The map shows the highest point in terms of elevation to be located on the north eastern section situated around 930m represented by the red which gradually changes to a dark blue colour through the scale with the decrease in altitude on the south western section at around 380m. The eastern ridge of the study area shows a higher elevation with the area sloping down towards the west.

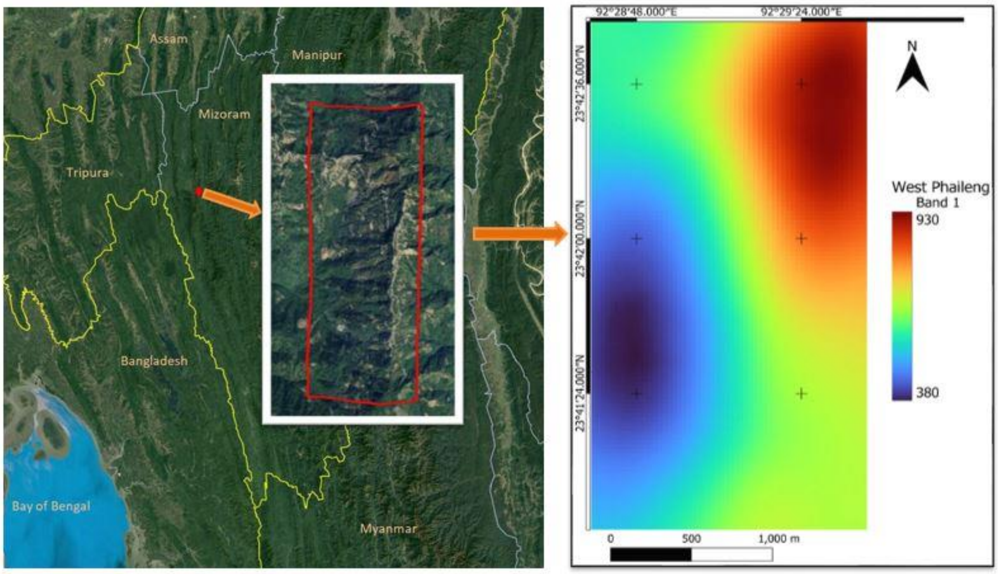

Fig. 7 Digital Elevation Model map of West Phaileng (SW part with low relief observed higher springwater discharge)

In Mizoram, most of the the hills runs in the North-South direction with its slope facing western direction. The study ~~of~~ which was performed at hillslopes scale observed that the top permeable and hydrologically active layer thickness is quite low which varies between 1 m to 3 m but the presence of fractured bedrock is also hydrologically active. At the roots of trees fractures were found at a depth of about 4 m, tapping rock moisture. Holbrook et al. (2014) observed rock moisture zone as primary conduit for lateral groundwater as mountain front recharge draining to valleys that sustain stream base flow. Various researchers also have reported the role of geographical settings on spring distribution and recharges, influencing parameters viz. gentle slope, low relative relief, high flow accumulation, denser lineament, high vegetation density along with precipitation (Ghimire et al., 2019; Ozdemir, 2011; Tao et al., 2021). There is progressive lowering of elevation in western direction, the occurrence of spring water along the faults and natural drainage also increases. The discharge of springwater in the western direction is also higher comparatively which may be due to the larger and more numbers of faults densities as we move down the elevation of West Phaileng. This kind of pattern is found in most places of the North east India.

3.6 Spring Hydrograph

Observations were made within 24 hours of rainfall where significant changes in discharge occur within a few hours of rainfall. After a period of rapid increase in discharge, a rapid decline in discharge rate occurs during recession period as shown in Fig. 8. Discharge rate was observed (Fig. 9) to be stabilized within 9 hours of recession period. Using a well-known mathematical formula proposed by Boussinesq and Maillet, a study was conducted on the receding flow and base flow of the spring (Filippini et al., 2024; Abirifard et al., 2022; Kersic, 2007).

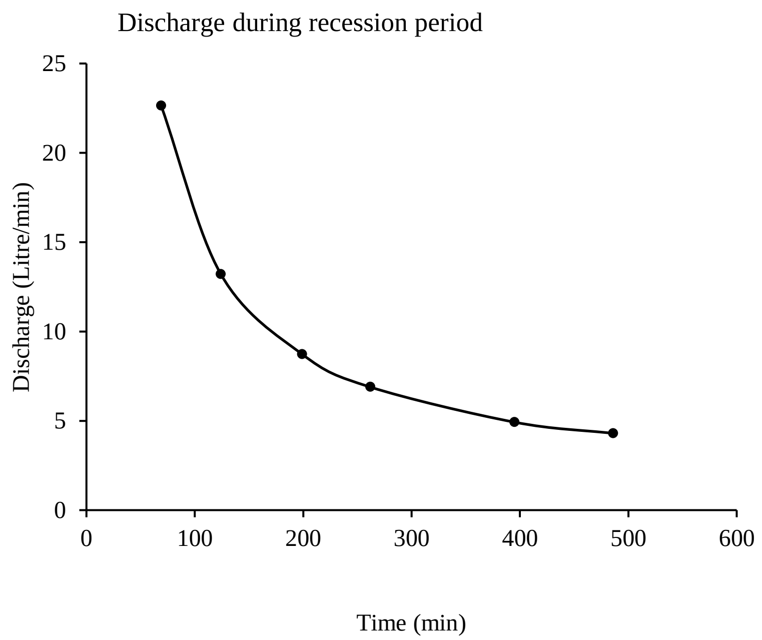

Fig. 8 Recession curve of springwater discharge showing rapid decline in discharge after recession due to conduit flow followed by slower diffuse/matrix flow

The coefficients of discharge were also observed to be in the order of 10^{-2} (Table 6) which explains the rapid decrease of discharge during initial recession period (Fig. 8). The coefficients of discharge of the recession period with mild slopes were observed to be in the order of 10^{-3} (Table 6) which mainly represents voids which are smaller in size and porosity of the aquifers (Abirifard et al., 2022; Segadelli et al., 2021; Kersic, 2007). The study area being located in the Himalayan range is considered to be in a region of fault line and fractures (Rao, 2018). The hypothetical conclusion of the presence of an intricate system of faults and fractures within the topography is explained by the rapid increase in discharge of a spring within a few hours of recharge in the form of rainfall and a sharp decrease in discharge during the initial stages of recession period followed by a low but steady discharge after the recession period.

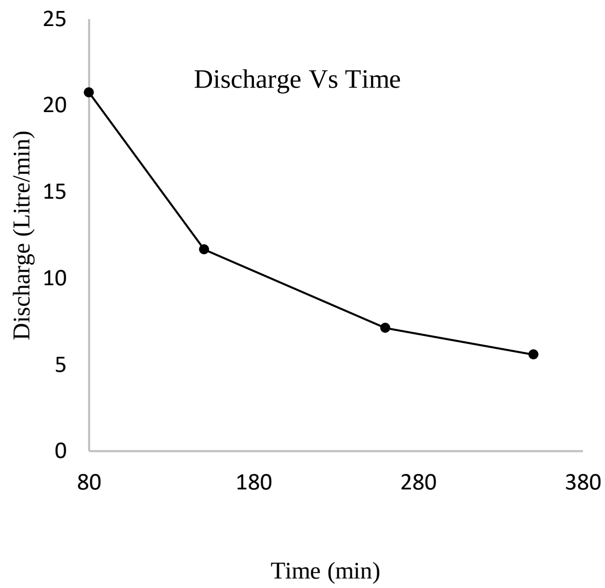

Fig. 9 Springwater hydrograph showing discharge versus time with 3 slopes

Table 6: Discharge and Coefficient of discharge of spring

Time(min)	Coefficient (α)	Discharge (Litre/s)
80	0.082	0.35
150	0.005	0.19
260	0.004	0.12
350	0.003	0.09

Using the coefficient and discharge interpreted as Maillet proposed, the volume of liquid accumulated in the aquifer was calculated. The initial volume of the liquid that had accumulated in the aquifer during this observation was calculated to be 3.97x10^6 litres and the volume of liquid remaining was 2.59x10^6 litres. Thus, the volume of liquid discharged during the 350 minutes of recession was 1.38x x10^6 litres. A comparable result was reported by Segadelli et al. (2021) on springwater recharge in sedimentary hard rocks with faults and fractured,composting of calcareous and siliciclastic in Italy. The Maillet's coefficient (α) ranges between 3 x 10^{-3} days^{-}to 8 x 10^{-2} days^{-} in the spring, and the coefficient showing good relationship with the slope of the recession plot (fig 8).

The observed fractures and faults in the study areas are small in size but in higher density. The analysis of observed springwater hydrograph and model calculations using Maillet's equation further support the hypothesis of the influence of fractures and faults to form springs commonly known as fault springs and fractures springs. These fractures with their higher porosity would allow liquid to permeate with higher intensity during recharge periods in the fault core. And allow the slow flow/seepage of water from nearby aquifers with lower intensity. When the hydraulic head falls during discharge the water flows out of the fault core into the damage zone. The initial higher discharge may be attributed to the conduit flow governing in fault core while precipitation event occurs due to higher head which leads to higher turbidity in the observed springwater. As time elapse the diffuse flow systems governs the discharge where there is a gradual discharge in the damaged zone due to lower permeability, the water during this discharge is found to be clear and turbid free. The whole recharge mechanisms provide higher volume of inflow and temporary storage for water beyond the surrounding aquifers with a higher discharge rate and a path for the water stored by aquifers to resurface in the form of fracture springs (Filippino et al., 2024; Fiorillo, 2014).

The co-existence of diffused and concentrated recharge occurs during infiltration in springwater discharge. It was conceptualized that a certain percentage of the recharge occurs in a diffusive method throughout the matrix block, while another part occurs as an action of direct infiltration taking places at fractures (Filippini et al., 2024; Segadelli et al., 2021; Russo et al., 2015; Manna et al., 2017; Kovacs and Perrochet, 2008; Kresic, 2007). A higher percentage of direct infiltration recharge compared to diffusion recharge procures a higher peak discharge with a lower base flow recession discharge. The recession coefficient, being exclusively dependent on block hydraulic characteristics and block geometry is not affected by a different proportion of direct infiltration and diffusion recharge (Abirifard et al., 2022; Segadelli et al., 2021; Kovacs and Perrochet, 2008).

3.7 Limitation of the work

The hydrological process in faults, fractures and heterogenous springwater catchments is highly complex and information of properties systems properties is extremely difficult to obtain (Rusjan et al., 2023: Filippini et al., 2024). Thus, applying available modeling tools and parameterization is highly ambiguous. The spring hydrograph recession dynamics was used to distinguished hydrogeology, geometric and hydraulic characteristics of karst springs (Fiorillo, 2014; segadelli et al., 2021; Rusjan et al., 2023). The major limitation of this work is relating the modeling parameters to physical characteristics of the karst catchment storage such as the volume of storage volume (Section 3.6) due topresence of an intricate system of faults and fractures. The distribution of faults and fractures (fig 2) showed no particular patterns and with numbers of isolated conduit observed. The spring hydrograph model conceptualized on the system properties inferred from the recession curve which is difficult to link to physical meaningful and measurable landscape properties in the mountainous terrain.

Conclusion:

The hydrogeochemistry of springwater from West Phaileng shows that the soil water interaction and dissolution of minerals is the controlling mechanisms influencing its composition. The abundance of cations was observed to be in the order: $Na^+ > Mg^{2+} > Ca^{2+} > Mn > Fe > K^+$ and anoins in the order: $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$. The saturation indices indicated over-saturated of minerals such as dolomite, vivianite, siderite and calcite. The water quality index also suggested good quality with the exception of a single site located near the natural drainage with inhabitant areas. The springwater was relatively young and immature with low residential time, relates to mountain front recharge (MFR) to be the major recharge mechanism. The orientation of the study area and its profile via a digital elevation map rendered the topography; it was observed that progressive increase in springwater sources and discharge in western areas as elevation decreases.

The springwater hydrograph modelled using Maillet equation support the presence and dominance faults and fractures on the springwater discharge. Two types of recharge influence the process firstly, the initial rapid recharge which is mostly conduit flow through fault core with higher turbidity. Secondly, the low discharge of diffuse flow in damage zone which extends for longer period. The hydrodynamic of springwater suggested dual porosity due to fractured sedimentary and hard-rock strata with limited storage capacity. The hydrograph decomposition method provides an insight into the hydraulic behaviour of the hydrogeological systems. This allowed us to understand the spring discharge response to recharge events (i.e. precipitation) and its hydrogeochemical composition as it moves along its flowpath. Thus, under various scenarios such as climate change, prolonging the source of recharge will increase the availability of spring water. Therainfall withhigh intensity for shorter duration being common phenomena which may be due to climate change effect. The reduction of runoff though various means viz. bunding, check-dams and recharge pit be the most viable option to increase the availability and sustainability of spring water in the area.

Ethics Declarations

Conflict of Interest: The authors declare no competing interests.

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