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INVESTIGATION OF GEOTHERMAL ENERGY POTENTIAL USING ELECTRICAL RESISTIVITY SURVEY AND CHEMICAL GEOTHERMOMETERS: A STUDY OF THE MANGHOPIR HOT SPRING KARACHI, SINDH PAKISTAN

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ABSTRACT

Electrical resistivity survey and chemical geothermometers methods were used to find the geothermal gradient energy potential of the Manghopir hot spring which is located in Karachi, Sindh. Schlumberger electrode configurations were used to demarcate the two shallow potential subsurface aquifers. At various depths, three lithological units were encountered: alluvium, sandstone, and shale. The first thermal water aquifer lies below at the average depth of 10m and average thickness of 9 m lies in sandstone lithology of Nari Formation of Oligocene age. The second thermal water aquifer encountered at the average depth of 68 m and the average thickness of aquifer was 40.5m in sandstone lithology of Nari Formation. The surface water temperature was calculated with digital thermometer which shows the range in between 48 °C to 50 °C and subsurface temperature was calculated with the help of chemical geothermometers. The Na–K geothermometers indicate the subsurface equilibrium reservoir temperature in the range of 135.52 °C,125.54 °C, 172.964 °C and 184.08°C and the Na-K-Ca chemical geothermometers indicate the subsurface reservoir temperature 148.493°C. The Na-K-Ca geothermometers show a high temperature, but the reservoir temperature appears to be lower due to the mixing of sea water with the chemical composition of hot spring water within the subsurface aquifers.

KEYWORDS: Hot springs, Apparent resistivity, Geothermometers, Manghopir, Karachi, Sindh

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1. INTRODUCTION

The increased consumption of fossil fuels as an energy resource is leading to their rapid depletion as they are non-renewable. Fossil fuel usage has increased due to economic growth in the modern world. Fossil fuels are limited resources that are quickly diminishing and also contribute to environmental deterioration and heavy pollution (1,2). Consequently, we require a clean source of energy (3). Geothermal energy is a sustainable energy source that is receiving more and more attention on a global scale.(4). The geothermal resources are more superior than traditional fossil fuel resources, because they are environment friendly and possess large reserves (5,6,7). Geothermal energy is relatively greener and more sustainable form of energy as compared to energy from traditional energy sources including hydrocarbons, which can be used for range of purposes including power generation. It is a cleaner source of energy and have average capacity factor of 74.5 that can be increased up to 90% in the ideal conditions (8). By offering sustainable energy and heat sources that are friendly to the environment, geothermal energy may play a significant role. [9] Many countries in the world such as China, Iran, Turkey and USA have put efforts in geothermal assisted plants in an attempt to advance their energy capacities. International energy agency estimates 30% increase in consumption of electricity by the year 2040 (10).

It is the time now that like the other countries leading in geothermal energy Pakistan also explore new means of energy providing higher sustainability and lower environmental impacts.

Pakistan also faces energy shortfall off 5500 Mega Watt (MW) with the total requirement of 19000MW with generation capacity of only 13500MW, with the increase in demand of 9% per annum (11).

At the same time, Although Pakistan is rich in both non-renewable and renewable resources. Despite huge energy resources, Pakistan falls under energy deficient countries due to increased population and energy management crisis. Geothermal energy is yet unexplored resource for power generation. Pakistan can counter energy shortage by harnessing non-conventional energy resources, i.e., geothermal energy. Pakistan has many mud volcanoes and hot springs along seismic belt. Pakistan has a practical geothermal energy manifestation southern part of Pakistan (Sindh) shows a large number of hot springs with high subsurface temperature due to active faults (12,13). Some of the hot springs of southern Pakistan (Sindh province).

- Manghopir Hot spring
- Laki Shah Saddar Hot spring
- Lal Bagh Hot spring
- Kai Hot spring
- Naing Hot spring
- Ghaji Shah Hot spring

The surface temperature of Manghopir is 48°C-50°C (14).A proper study of the area for identification and exploration of these hidden energy resources, which can help to benefit country in social and economic development. Present research is carried on the hot springs of Manghopir area which is famous for the hot water springs from many decades (15). The hot water from Manghopir hot springs seeps out as transparent, colorless and order less. The Manghopir spring may be classified Euthermal spring (16). A leper Asylum is present at Manghopir hot spring, and people come here form different areas of country for skin cure. Researchers found that the skin curative in water is because of the arsenic concentration in it (17).

The western margin of the Indian Plate has clear signs of its presence in Pakistan. As we observe from the Arabian Sea, we will find the first important geothermal region in the Karachi which is surrounded by coast and the upper belt has the Indus Delta. The Karachi is surround by 3 Faults and hosts two Hot-Water Springs with low to medium enthalpy brines. the Manghopir Spring and the Drig Road Karsaz Spring (18). An integrated approach of electrical resistivity sounding and chemical geothermometers was used which helped in the exploration of subsurface aquifer properties and geometry of thermal aquifer.Prospecting for geothermal resources typically instead relies on indirect investigation through geological and geophysical examinations, which give a generalised perspective of the subsurface conditions. Direct investigation and exploitation of geothermal resources involve potentially enormous costs due to the expense of drilling [19] by applying different techniques, the subsurface mapping was made by distinguishing subsurface geology, host rock lithology, depth, tectonic feature and reservoir extension of potential reservoir. With the help of chemical Geothermometers an estimate of the subsurface reservoir temperature was carried.

1.1 Study Area

The hot spring in study area is located at the base of Hallar mountainous range (13km North West of Karachi). This region is present in the survey of Pakistan Toposheet no 35 P/11, the Latitude 24° 59' 16.5" and Longitude 67° 02' 34.4" and elevation above sea level is 60 feet. (fig.1), which is present in the southern Kirthar fold belt (20) (Fig. 2). At the north of Manghopir, all structures are oriented north to south. They swing to the SW because it is located at the southern end of the Karachi Arc.

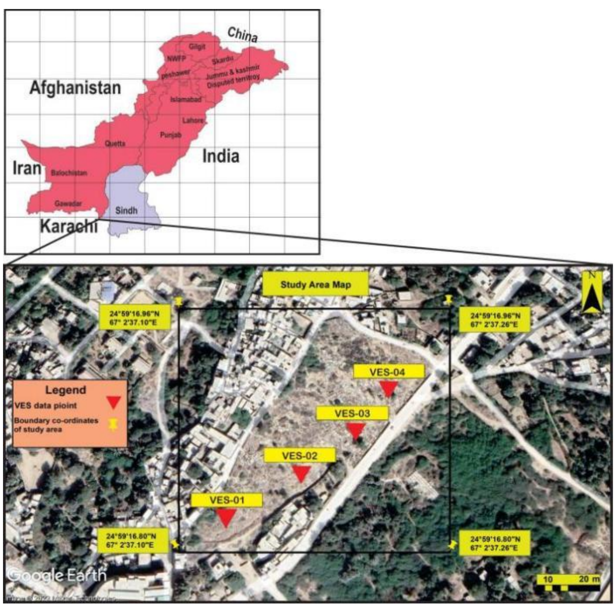

Figure 1. Satellite image map showing location of VES in study area.

2. GEOLOGY OF STUDY AREA

The exposed rocks units in the study area are the Nari Formation (Oligocene age) and the Gaj Formation (Miocene age), which are deposited in the Karachi Trough. Karachi Trough is triangular depositional basin opening southwards towards Arabian Sea. During the Himalayan Orogeny this basin was formed by the uplifting of the Southern Kirthar Fold Belt (21). Presence of fault bend folds is indicated by the structural geometries and the absence of the exhumed and emergent thrust which suggests that blind thrust is present in subsurface. The Hanging wall climbed upon the frontal ramp (present in subsurface parallel to the NE/SW structural trend) and partially climbed on oblique ramp oriented at a high angle, as the result the Manghopir domal structure has formed. The formed structures indicate the east-southeast tectonic transport of covered rocks. This region was active till Miocene, which is observed by the Miocene rock deformation.

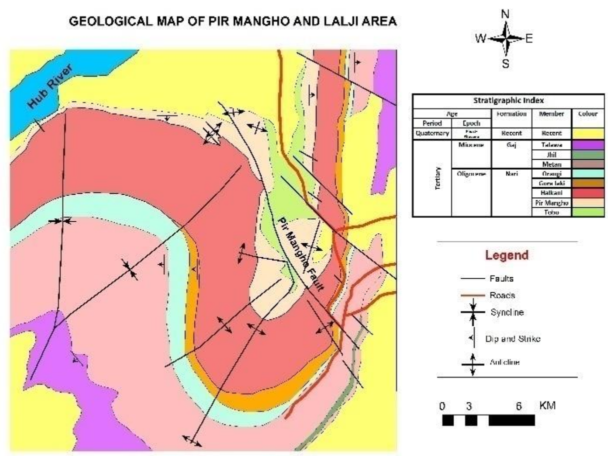

Figure 2. Geological map of study area (modified and reproduced after HSC,1960 (22)

3. METHODOLOGY

3.1 Electrical Resistivity Survey

In geophysical techniques the vertical electrical sounding (VES) resistivity method is a technique, which is used for the exploration of geothermal energy (21). To estimate the geothermal reservoir prior to exploitation, this survey is generally known to be the most important geophysical survey. As the temperature increases the electrical conductivity of electrolytes also increases. In the comparison of meteoric fluid, the more saline fluids are more conductive. In the association with geothermal fluids, hydrothermally altered rocks have lower resistivity. The values of water-dominated geothermal energy reservoir are usually below than 5 Ohm meters (22). lithological knowledge can be acquired from the apparent resistivity distribution by the geological structural changes in the subsurface (23).

In Manghopir hot spring SAS4000 ABEM Terrameter was used to calculate the subsurface potential of thermal aquifer and for the compiling of resistivity data of subsurface geology in the form of geoelectric section, which helped in the investigation of geothermal energy reservoir in study area. The calculation of electrical potential difference of subsurface materials is calculated by the measurement of potential difference and by the function of the electric current to the material.

Equations

$$\rho a = k\,(V/I) \quad (1)$$

$$\rho a = 2\pi a \times V/I \quad (2)$$

k is a geometric factor, and depends on the configuration of electrode rods. Resistance value given by Terrameter have to be changed to apparent resistivity value (24).

$$(\rho a = k * R) \quad (3)$$

Schlumberger electrode configuration was used for the collection of data in Manghopir hot spring for geothermal exploration. In Schlumberger electrode configuration the current induce in the earth through the current (outer) electrodes and the potential difference is measured by the potential (Inner) electrodes. The distance between outer electrodes is gradually increased after taking individual reading, and the inner electrodes are kept closely to the center, and all electrodes were aligned in straight line (25). The collected data of VES was processed on IPi2win software to interpret the depth, relevant resistivity and the thickness of each layer.

3.2 Geochemistry of Hot Spring

Water samples were collected from Manghopir hot spring for analyzing the physiochemical characters of hot spring and estimation of subsurface temperature of geothermal reservoir by using chemical geothermometers. The representative sample of hot spring w collected from Manghopir hot spring in a new unused cleaned plastic container, which was rinsed more than 3 times with the sampling water (26). Alcohol thermometer was used to measure the air temperature 1m above the surface of hot spring water, and the temperature of hot spring water was measured by mercury thermometer. The physical parameters of water were measured by specific devices in the field (Orion 115 conductivity meter was used to measure the conductivity, salinity and TDS of water). The pH of water was measured by Orion 420A pH meter in laboratory. After collection the samples rapidly, they were sealed and stored in cool box, then transported to laboratory and was filtered by 45m membrane and by following the standard methods, analyzed immediately (27).

Some portion (50ml) of sample was preserved by adding 2ml of 10% HCL and analysis of Na, K, Ca and Mg was carried out within 30 days with the help AAS (atomic absorption spectrometer) at 589, 766.5 422.7 and 285.2 nm respectively, the conditions was according to the recommendations of manufacturer (Varian spectr AA-20, Australia). With the integration time 3s and the delay time 3s the analysis was carried out in triplicate (n=3). The standard salts and earlier of this standardized with primary salts the calibration curve was establish by using five different concentrations of elemental solution. The collection of valid data all the standard methods (titrimetric, AAS and spectrophotometric) were applied and standardized. With the titration of ethylene diamine tetra acetic acid disodium salt the total hardness was determined (using eriochrome black T as indicator at pH 10. Total alkalinity was determining with the titration of HCL (Methyl Orange as endpoint indicator). And for chloride analysis AgNO3 (Silver Nitrate) titration was used with Potassium Chromate (K2CrO4) as an indicator. At acidic pH the Sulphate was determined spectrophotometrically using Barium Sulphateturbiditimetric method.

5. RESULTS

Integrated results of geophysical and geochemical are given below.

5.1 Geo-Electrical Sections

Total 100m depth was investigated through the VES. The data of total 100m was processed and the Geo-electrical section developed through the IPi2win software which helped to identify subsurface lithology with thickness of each layer. Each Geo-electrical section has same lithological properties which consist of sandstone, shale and alluvium. Each section of VES curve is produced and generated by IPi2win software. The sections are piled up along lithological sections (based on the resistivity contrast of aquifer in different lithology (fig 3)) and the thickness of the subsurface lithology by the resistivity of each layer.

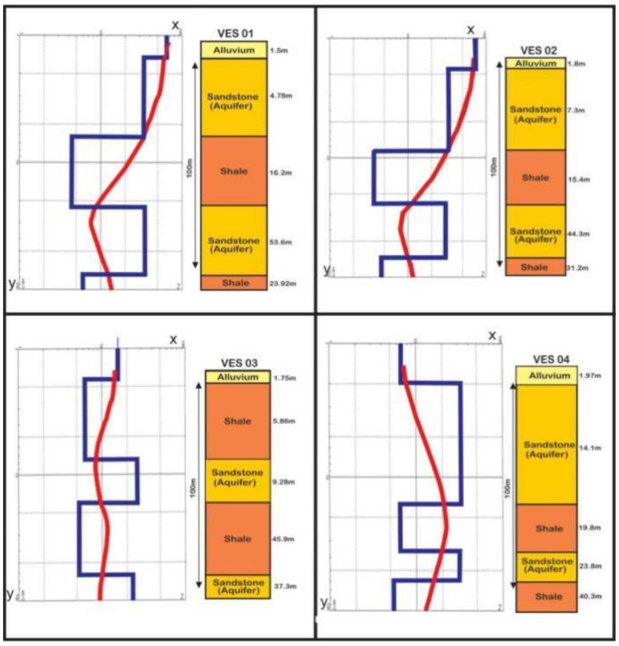

Figure 3. Stacked lithological logs of subsurface resistivity sections of Manghopir area.

5.2 Geochemical Results

The geochemical studies pertaining to interpret the temperature of the hot spring using geochemical thermometers were carried. The analysis primarily of the determination of physiochemical properties of hot spring water conducted through techniques satisfied earlier. The results of the physiochemical diagnosis are given in Table 02.

Table 1. Computed resistivity, Thickness and depth of VES data from Manghopir area.

Site	VES Number	Identified Lithology	Apparent Resistivity(Ωm)	Thickness (m)	Depth (m)
Manghopir	VES-01	Alluvium	64.7	1.5	1.5
		Aquifer in Sandstone	33.5	4.78	6.28
		Shale	4.41	16.2	22.5
		Aquifer in Sandstone	35.1	53.6	76.1
		Shale	6.05	23.9	100
	VES-02	Alluvium	77.18	1.8	1.8
		Aquifer in Sandstone	34.5	7.0	8.8
		Shale	3.86	15.4	24.2
		Aquifer in Sandstone	31.8	44.4	68.6
		Shale	4.78	31.4	100
	VES-03	Alluvium	15.7	1.7	1.7
		Shale	6.28	5.91	7.61
		Aquifer in Sandstone	26.7	9.29	16.9
		Shale	5.34	45.9	62.8
		Aquifer in Sandstone	23.4	37.2	100
	VES-04	Alluvium	6.81	1.9	1.9
		Aquifer in Sandstone	32.8	14.1	16
		Shale	6.52	19.9	35.9
		Aquifer in Sandstone	31.2	23.8	59.7
		Shale	5.46	40.3	100

Table 2. Showing the Physio chemical properties of Manghopir hot spring water.

S.no	Water Quality parameters	Units	Permissible Limits (WHO)	Results
01	Electrical Conductivity	Us/cm	1000	2710
02	PH	…..	6.5 to 8.5	7.45
03	TDS	Ppm	750	2021
04	Calcium	Ppm	75	92
05	Sodium	Ppm	200	410
06	Potassium	Ppm	12	21
07	Magnesium	Ppm	……	48
08	Chloride	Ppm	250	426
09	Sulphate	Ppm	250	278
10	Bicarbonate	Ppm		165

6. DISCUSSION

6.1. Interpretation of VES data

TheVES-01 demarcated a total of five layers up to the depth of 100 m and data interpreted as first layer showing the apparent resistivity of 64.7 Ωm with layer thickness of 1.5 m is the topmost alluvium lithology. Second layer showing the apparent resistivity of 33.5 Ωm with layer thickness of 4.78m at the depth of 6.28m interpreted as a thermal water aquifer in sandstone lithology of Nari Formation. Third layer showing apparent resistivity of 4.41 Ωm with layer thickness of 16.2 m at the depth of 22.5m interpreted as shale lithology of Nari Formation. Fourth layer showing apparent resistivity of 35.1 Ωm with layer thickness of 53.6 at the depth of 76.1m interpreted as an aquifer in the sandstone lithology of Nari Formation of Oligocene age. Fifth layer showing apparent resistivity of 6.05 Ωm with layer thickness of 23.9m at the depth of 100 m interpreted as shale lithology of Nari Formation (Table 1, Fig.3).

The VES-02 demarcated five lithological layers and data interpreted as first layer showing the apparent resistivity of 77.18 Ωm with layer thickness of 1.8 m is the as a topmost alluvium lithology. Second layer showing the apparent resistivity of 34.5 Ωm with layer thickness of 7.0m at the depth of 8.8m interpreted as a thermal water aquifer in the sandstone lithology of Nari Formation. Third layer showing the apparent resistivity of 3.86 Ωm with layer thickness of 15.4 m at the depth of 24.2m interpreted as shale lithology of Nari Formation. Fourth layer showing apparent resistivity of 31.8 Ωm with layer thickness of 44.4 m at the depth of 68.8m interpreted as an aquifer in the sandstone lithology of Nari Formation of Oligocene age. Fifth layer showing apparent resistivity of 4.78 Ωm with layer thickness of 31.4 m at the depth of 100 m interpreted as shale lithology of Nari Formation (Table 1, Fig.3).

The VES-03 demarcated total five lithological layers and data interpreted as first layer showing the apparent resistivity of 15.7 Ωm with layer thickness of 1.7 m is the topmost alluvium lithology. Second layer showing the apparent resistivity of 6.28 Ωm with layer thickness of 5.

6.2. Pseudo Section and Resistivity Section

In Manghopir profile VES 1 to 4, resistivity data were processed for producing the pseudo-section. The total length of profile is 150 m and the distance between each VES is 50m. In general low, moderate, high resistivity zones were delineated on the basis of lithological variation. Two major lithology were interpreted as shale and sandstone there is a major discontinuity in lithology in VES-03 indicates presence of faulting and giving path to hot water plumes. Two major aquifer zones were demarcated in sandstone lithology of Nari Formation of Oligocene age. First shallow water aquifer zone presents at the average depth of 8m and second aquifer zone present at the average depth of 40m. Due to structural contrast in VES -3 to VES -4 aquifer depth varies in VES-4 and also vary in subsurface (Fig. 4).

The resistivity section of Manghopir profile is described by topmost high resistivity zone value lies in the range of (50 to 63 Ωm) up to a depth of 2 m which indicates the alluvium lithology below the alluvium layer resistivity values are falling at the range of (25 to 35 Ωm) in the (VES-1,2 and 4) up to depth of 16m indicating the thermal aquifer present in sandstone lithology of Nari Formation but in VES-3 abrupt change in lithology showing low resistivity values in profile and interpreted and sandwich like intrusion of shale lithology may be presence of fault which could have given path to hot water plumes in study area (Fig.05). The third low zone showing resistivity of (4 to 8 Ωm) interpreted shale lithology of Nari Formation of Oligocene age.

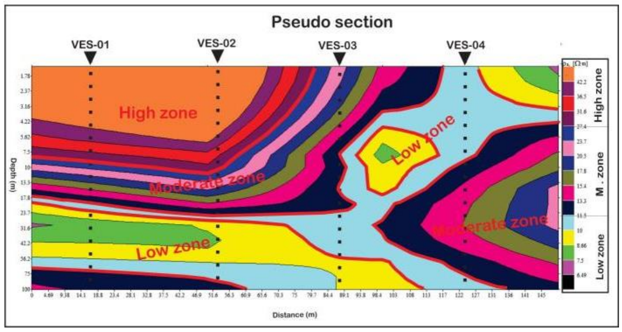

Figure 4. Pseudo section of resistivity profile at Manghopir area.

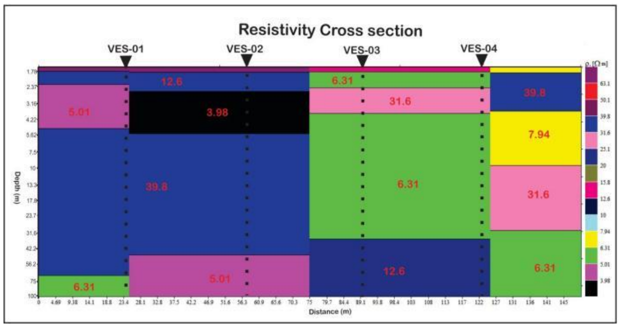

Figure 5. resistivity cross section of profile at Manghopir area.

6.3. Interpretation of Geothermometers

The surface temperature of hot spring was calculated with the help of digital thermometer and showing the maximum temperature is 50 °C respectively. The pH values of hot spring are 7.45 and electrical conductivity of thermal water showing EC 2710 uS/cm. The total dissolved salts TDS of thermal water analyzed is 2021 ppm). Different chemical geothermometers were used to calculate the subsurface reservoir temperature of hot spring such as (30,31,32,33,34) The Na–K geothermometers indicate the subsurface equilibrium reservoir temperature in the range of 135.52 °C,125.54 °C, 172.964 °C and 184.08°C (Table 3). the Na-K subsurface reservoir temperature laying in the range of standards recommended by different scientists(Fig.6) The Na-K-Ca chemical geothermometers indicate the subsurface reservoir temperature 148.493°C respectively. The Na–K–Ca geothermometers shows higher temperature but the geothermal energy reservoir temperature is low because of the influence of the sea water intrusion with the chemical composition of the aquifer. The hot spring water have high percentage % of Na and Cl because of the mixing of the Arabian Sea water with source of the hot spring.

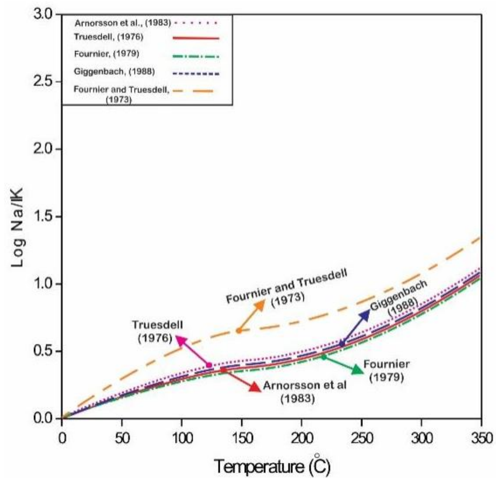

Figure 6. Subsurface temperature of Geothermometers.

Table 3. Shows the subsurface temperature calculation of Manghopir hot spring through chemical Geothermometers.

Geothermometers	Equations	Range (°C)	Source	Calculated Temperature of Manghopir hot spring
Na-K	$\frac{933}{0.933+\log(2343/316)}$ -273.15	25-250	Arnórsson et al. (1983b)	263.05 °C
Na-K	$\frac{856}{0.857+\log(2343/316)} - 273.15$	100-275	Truesdell (1976)	260.26°C
Na-K	$\frac{1217}{1.438+\log(2343/316)} - 273.15$	>150 °C	Fournier (1979)	272.58 °C
Na-K	$\frac{1390}{1.750+\log(2343/316)} - 273.15$	250-350 °C	Giggenbach (1988)	283 °C
Na-K-Ca	$\frac{1647}{\log(\frac{Na}{K}) + \beta[\log\sqrt{Ca}/Na] + 2.06 + 2.47} - 273.15$	250-350 °C	Fournier andTruesdell (1973)	154.23°C

CONCLUSION

It is concluded on the basis of electrical resistivity data that,

1) Two thermal water subsurface aquifers are present in the Manghopir hot spring area up to the depth of 100 m.

2) In resistivity profile lithological contrast in VES-3 to VES-4 indicate the hot spring laying on fault which gives paths to hot water plumes in pseudo section and resistivity section.

3) The first thermal water aquifer lies below at the average depth of 10 m and average thickness of 9 m present in sandstone lithology of Nari Formation of Oligocene age.

4) The second thermal water aquifer encountered at the average depth of 68 m and the average thickness of aquifer was 40.5m in sandstone lithology of Nari Formation.

5) The Na–K geothermometers indicate the subsurface equilibrium reservoir temperature in the range of 135.52 °C,125.54 °C, 172.964 °C and 184.08°C and the Na-K-Ca chemical geothermometers indicate the subsurface reservoir temperature of 148.493°C.

6)The Na–K–Ca geothermometers shows higher temperature but the geothermal energy reservoir temperature is lower because of the influence of the sea water intrusion with the chemical composition of the aquifer.

DECLARATIONS

Conflicts of interest/Competing interests:

The authors declare no any conflict of interest/competing interests.

Authors' contributions: **Muhammad Afzal Jamali:** Data Acquisition, sampling, data processing, **Muhammad Hassan Agheem**: map drawing and draft writing. **Rafique Ahmed Lashari**: Hands with software and curves generation **Akhtar Hussain Markhand**: Conceptualization, revision and editing. **AsfandYar Wali Arain**: Geochemical Analysis of water samples, Draft writing, **HasibAhmed:** Laboratory Analysis, Draft writing, Raw data acquisition and data processing. **Wahidbux alias Zain**: Field investigation and sampling, draft writing.

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