Geol. Bull. Univ. Peshawar, Vol. 25, pp. 23-37, 1992

Hydrochemical and hydrogeological studies of groundwater in Peshawar Valley, Pakistan

JOCHEN BUNDSCHUH

Institute of Geology, D-7400 Tübingen 1, Sigwartstr. 10, Germany

ABSTRACT: *In September 1988 a comprehensive three months programme for hydrogeochemical groundwater investigations in Peshawar Valley in the North West Frontier Province (NWFP) of Pakistan was carried out. Its main aim was to classify the groundwater chemically in order to limelight the regional differences and highlight problems related to drinking and irrigation water in the region. About 100 water samples were collected from wells and analyzed. The elevation of the groundwater table and the depth to the groundwater table were measured. These data show that the water table in Peshawar Valley is < 5m deep, except in areas near the mountains and in the southeast where it ranges from 5 to > 30m. There is a general groundwater flow towards the centre of the basin from where the discharge is towards the Indus Valley. It has been noticed that the electrical conductivity (EC-values) increases from < 800 S/cm near the mountains to a maximum of 7800 S/cm in the centre of the basin. Similar is the case of mineralization.*

The groundwater has been classified according to PIPER. In Peshawar Basin predominantly low mineralized groundwaters of the type "normal alkaline earth freshwater prevailing hydrogencarbonatic" and "normal alkaline earth freshwater with higher contents of alkalies prevailing hydrogencarbonatic" are present. These groundwaters are of good quality. Only in its central part highly mineralized groundwater of the type "alkaline freshwater either hydrogencarbonatic or sulfatic-chlorotic" are found. This high mineralization in combination with the low depth of the groundwater table causes salification of the soils in the centre of Peshawar Basin, i.e. Risalpur and its surroundings. It is concluded that the use of such highly mineralized drinking and irrigation water should be abandoned as soon as possible because of the expected hazards to human health and irrigation. It is highly recommended that deeper wells should be drilled to find low mineralized groundwater in this area.

INTRODUCTION

Purpose

Beneath air, water is the most important substance for the life of all organisms including human beings. As in many cases, water is present in more than sufficient amount in Peshawar Valley, the northwestern part of Pakistan. In this dry and hot region the ground and surface water, coming from the mountains in the north and west, is used for irrigation, drinking and industrial purposes. Generally hydrogeological explorations are carried out with emphasis on the quantity rather than quality (chemical composition) of groundwater. It is important to know the chemical composition of water from agricultural and health points of view. Water induced diseases may take years before they are recognized. The use of highly concentrated irrigation water, or water with a special chemical composition, causes salification of the soil which requires expensive and special treatment for productive agriculture. Therefore, a comprehensive three month hydrochemical study programme was initiated in September 1988 for groundwater investigations in Peshawar Valley. The main objective of these investigations was the chemical classification of the different types of groundwater, to interpret these results and to give some recommendations for the "right use of right water" in the area. The results of this work are a rough approximation for use as a base for detailed hydrochemical and hydrogeological investigations of the Peshawar Valley.

Methodology of investigations

Water samples were taken from 100 representative dug and tube wells. Electrical

conductivity, pH-value, oxygen content and the temperature of the samples were determined directly in the field. Additionally, the depth of the groundwater table was measured. The samples were analyzed for calcium, magnesium, sodium, potassium, hydrogencarbonate, sulphate, chloride and nitrate ions. The chemical types of groundwater were determined in order to estimate their local distribution in the project area. The direction of groundwater flow was found with the help of the groundwater elevation contours. Based on these investigations areas with suitable or unsuitable groundwater for irrigation and drinking purposes were identified.

GEOGRAPHY AND GEOLOGY OF THE AREA

Location and physiography

The Valley of Peshawar in the NW of Pakistan covers an area of approximately 8000 sq.km. It is surrounded by hilly and mountainous regions (Fig. 1), except at its southeast towards the Indus river where the intra-mountainous basin is open for discharge of water. The studied area is situated between the longitudes 71°15' and 72°45' E and latitudes 33° 45' and 34° 30'N. The Peshawar Valley consists of a sandy plain with undulating relief. In general, there are no major hills within the plain, except some isolated ones in the eastern part. The Kabul river, entering from Afghanistan, and the Swat river and the Kalpani Nala originating in the northern mountains flow through the area to drain into the Indus river. Additionally, there is a great number of channels for irrigation purposes. It has to be remarked, that there is no river coming from the southern mountains, which carries permanent water. To demarcate the Peshawar Valley from the surrounding hills and mountains the contour line 1500 feet (457m) above M.S.L. can be used (Fig.1). There is a gradual decrease to 900 feet (274m) towards the centre of the alluvial plain. In the central part of the basin a small rise to an altitude of 1000 feet (305 m) is recognizable.

Climate

The Valley of Peshawar has a dry and hot climate. The mean annual precipitation ranges from 33cm in the west to 60cm in the eastern part of the plain. There are two wet seasons: winter rains from January to April and summer rains from July to September. The mean average annual air temperature in Peshawar is 23°C with mean minimum temperatures of 4.7°C in January and mean maximum temperatures of 41°C in June.

Bedrock outcrops

In the surrounding of Peshawar Valley, a structural depression filled with alluvial sediments, a great number of strata of different age and lithological composition appears in the outcrops. According to the intensive tectonic movement the strata have steep dips. In the northern and western vicinity the rocks are predominantly metamorphic while in the south sedimentary rocks are found.

Alluvial sediments

The Peshawar Basin is filled with several hundred meters thick alluvial sediments of Quaternary age. Piedmont deposits are present near the mountains. These weathered rocks were transported over a shorter distance. Kabul, Swat and Indus rivers belong to the group of braided streams. On the one hand they have deposited the sand, gravel and clay which they transported over greater distances and on the other hand they have reworked local material. According to the changing locations of the river arms with time, the lithological composition of the alluvial fill varies in both vertical and horizontal directions. The upper layer is often built by a thin layer of aeolian sediments.

SURFACE WATER

The surface water found in the rivers and channels of Peshawar Valley are less mineralized, as suggested by values of the electrical conductivity, which vary between 250 and 500 S/cm. Calcium and hydrogen-carbonate are the most important ions dissolved in it. Magnesium, sodium and sulphate are also important, while chloride, nitrate and potassium are found only in minor amounts. The content of ferrous iron is less than ferric iron which is contained in the suspended load of the river water with values up to 10 mg/l. Because of its low grade of mineralization this surface water is good for irrigation purposes.

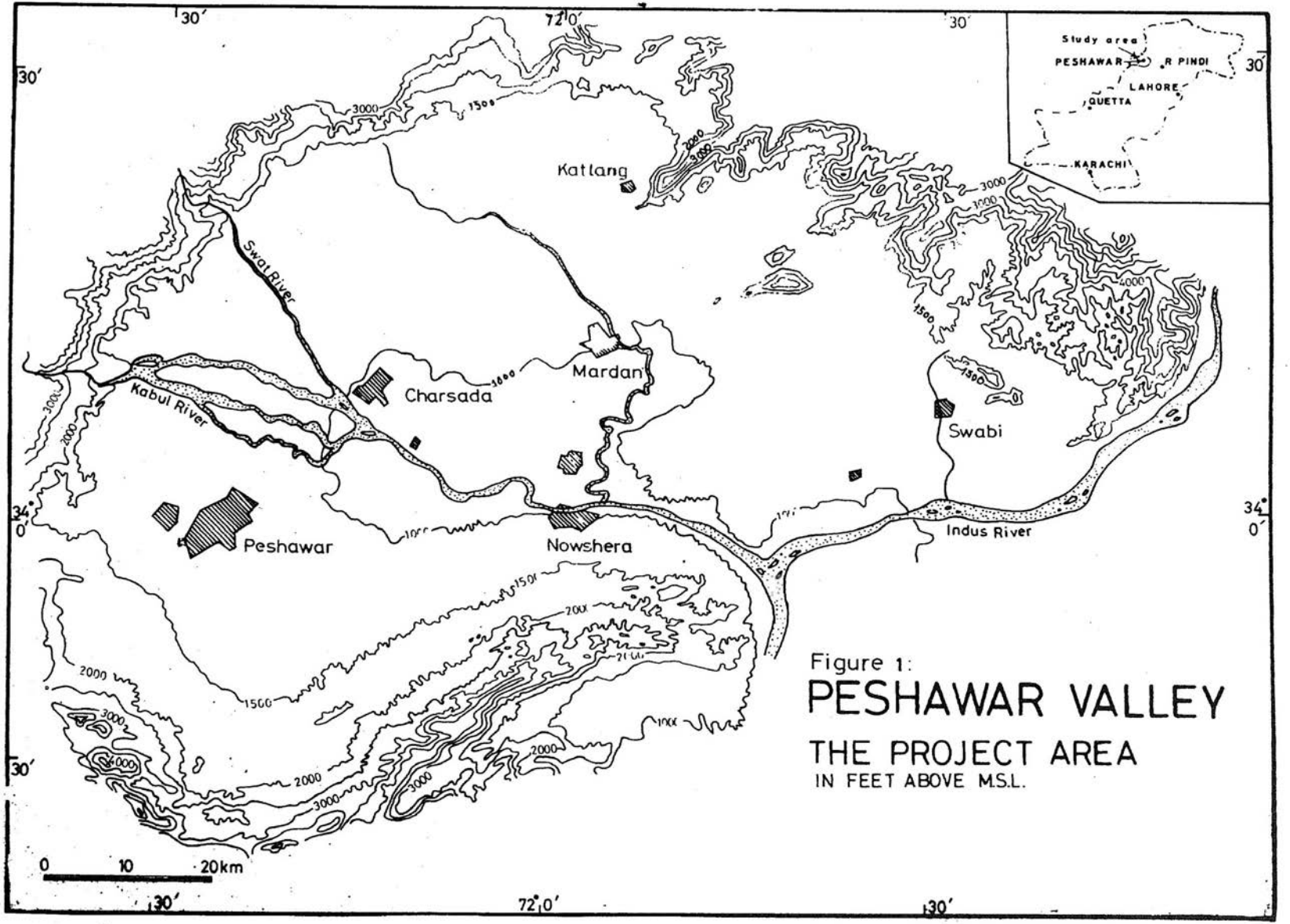
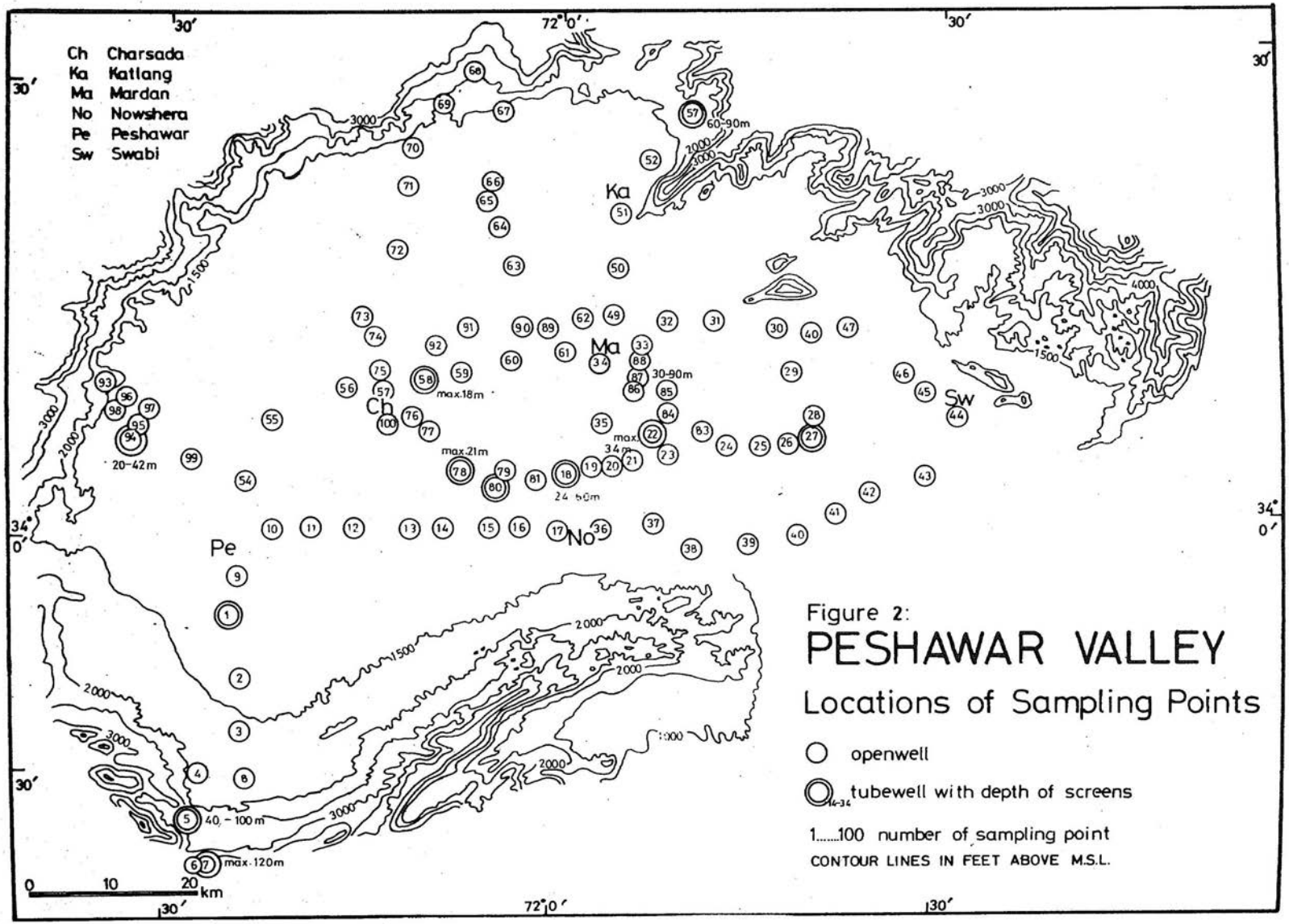


Figure 1:

PESHAWAR VALLEY

THE PROJECT AREA

IN FEET ABOVE M.S.L.


Ch Charsada
Ka Katlang
Ma Mardan
No Nowshera
Pe Peshawar
Sw Swabi
72° 0′
30′
34° 0′
3000
2000
1500
4000
60-90m
30-90m
max.18m
max.21m
max. 34m
20-42m
24-60m
40-100m
max.120m
0 10 20 km
Figure 2:
PESHAWAR VALLEY
Locations of Sampling Points
openwell
tubewell with depth of screens
1.....100 number of sampling point
CONTOUR LINES IN FEET ABOVE M.S.L.

HYDROGEOLOGY OF THE STUDY AREA

The Alluvial sediments

As mentioned earlier the alluvial fill of Peshawar Basin is built by alternating layers of clay, silt, sand and gravel. Because of the inhomogeneity of the Quaternary fill, it is not possible to distinguish between certain aquifers. This is why in the following investigations the alluvial sediments are taken as one very inhomogeneous aquifer, whose composition varies both in vertical and in horizontal directions.

The bedrock

Only the bedrock near to the mountains are of hydrogeological interest. In the other parts of Peshawar Valley, excluding some small ranges in the east, the bedrocks are covered with one hundred meters thick alluvial fill and so economically not recommended for installation of wells. The Mesozoic fissured limestones at the southern boundary of Peshawar Valley are important aquifers. Similarly the metamorphic rocks at the western and northern boundary of the plain contain aquifers of lower transmissivity which are suitable for the installation of smaller wells (Rafiq *et al.*, 1983).

Depth of the water table

The measured depths to the water table below the earth's surface were plotted on a map to show variations (Fig.3). Except the region at the boundary to the mountains and an area in the southeast of the basin with depths of 5 to 40m, the depth of the water table in Peshawar Basin is <5m. The areas with the shallow water table belong to irrigated regions, while those with deeper water tables are less irrigated. In the areas with water table of <5m, capillary rise of groundwater and evaporation causes the hazard of salification.

Groundwater flow direction

For the determination of groundwater flow directions a groundwater level elevation map was constructed with the help of the depths to groundwater level and the altitudes of the measuring points (Fig.4). The groundwater flows generally towards the centre of the basin (average gradient 0.004), from where the discharge is in the eastern direction to the Indus Valley, either in the form of groundwater or, after infiltration into the river in form of surface water. In the centre of Peshawar Valley between Nowshera and Nisetta, there is hardly an inclination of the groundwater table, and the velocity of groundwater flow is the slowest than elsewhere. Together with the relatively shallow water table in this region and high evaporation, the hazard of salification is rising.

HYDROCHEMISTRY OF THE GROUNDWATER

Data collection

Sampling points: For sampling purposes 100 dug wells and tube wells, distributed over the entire valley were selected. One of the selection criteria was that the well should be in use, so that no sample from water which was stagnant for a long time in the open well, changing its chemical composition, was taken. The locations of the groundwater sampling points number 1 to 100 and the type of well are shown in Figure 2.

Measurements in the field: In the field soon after taking the samples, the values of those parameters which change quickly with time, were measured. The pH-value, the electrical conductivity (EC-value) and the content of dissolved oxygen were determined by using an electrical pH-meter (WTW PH-59), an electrical conductivity-meter (WTW LF-91) and an electrical oxygen-meter (WTW OX-92). The amount of hydrogen carbonate ions (m-value) was estimated by titration with 0.1N hydrochloric acid and methyl orange as indicator (Bundschuh, 1989; Fresenius *et al.*,1988). The water samples were stored in plastic bottles. The depth of the groundwater table below the earth's surface was determined by using a light plumb line.

Water analysis in the laboratory: The analysis was carried out in the geochemical laboratory at Peshawar University. The amount of the dissolved ions were determined by different methods: magnesium, sodium and potassium were analyzed by an atomic absorbtion spectrometer. Sulphate and nitrate were determined with the help of a photometer (HACH DREL/1C) according

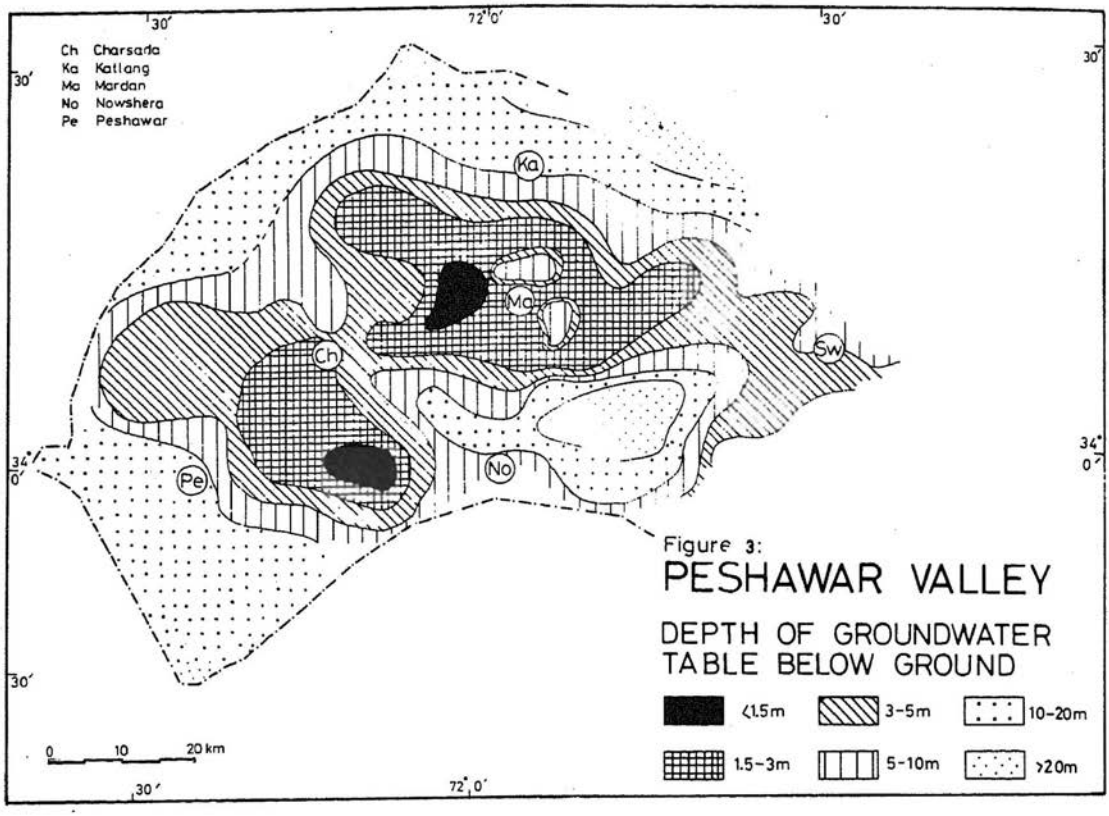


Figure 3:
PESHAWAR VALLEY

DEPTH OF GROUNDWATER TABLE BELOW GROUND

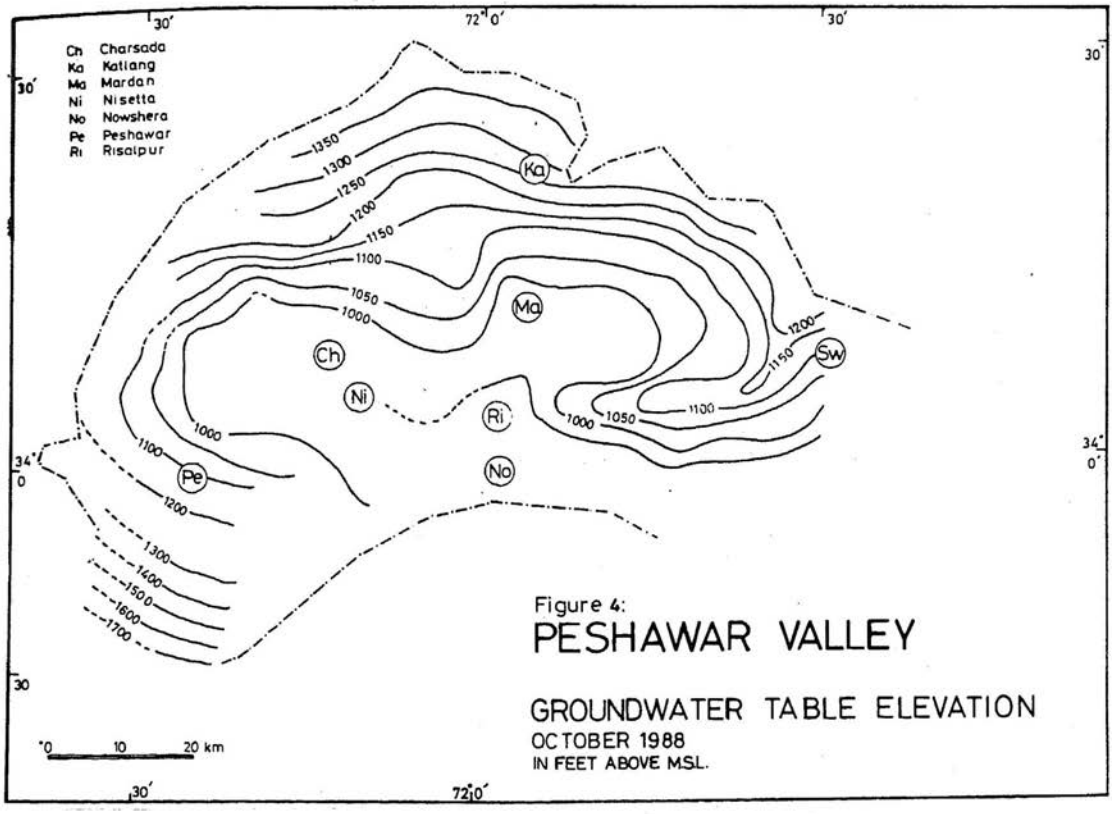
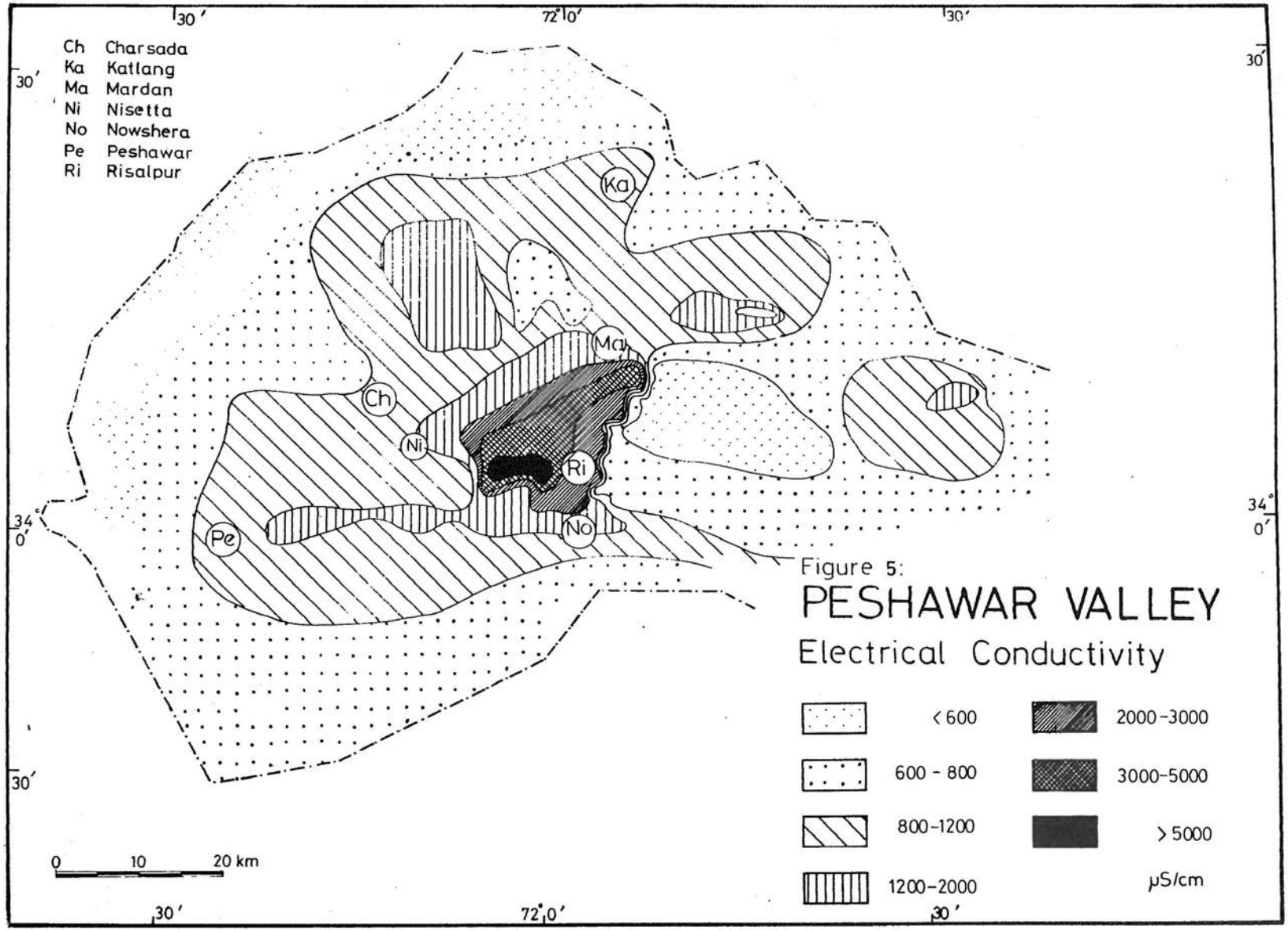


Figure 4:
PESHAWAR VALLEY

GROUNDWATER TABLE ELEVATION
OCTOBER 1988
IN FEET ABOVE M.S.L.


Ch Charsada
Ka Katlang
Ma Mardan
Ni Nisetta
No Nowshera
Pe Peshawar
Ri Risalpur
30′
72°0′
30′
34°0′
Ka
Ma
Ch
Ni
Ri
No
Pe
0 10 20 km
Figure 5:
PESHAWAR VALLEY
Electrical Conductivity
< 600
600 - 800
800-1200
1200-2000
2000-3000
3000-5000
> 5000
µS/cm

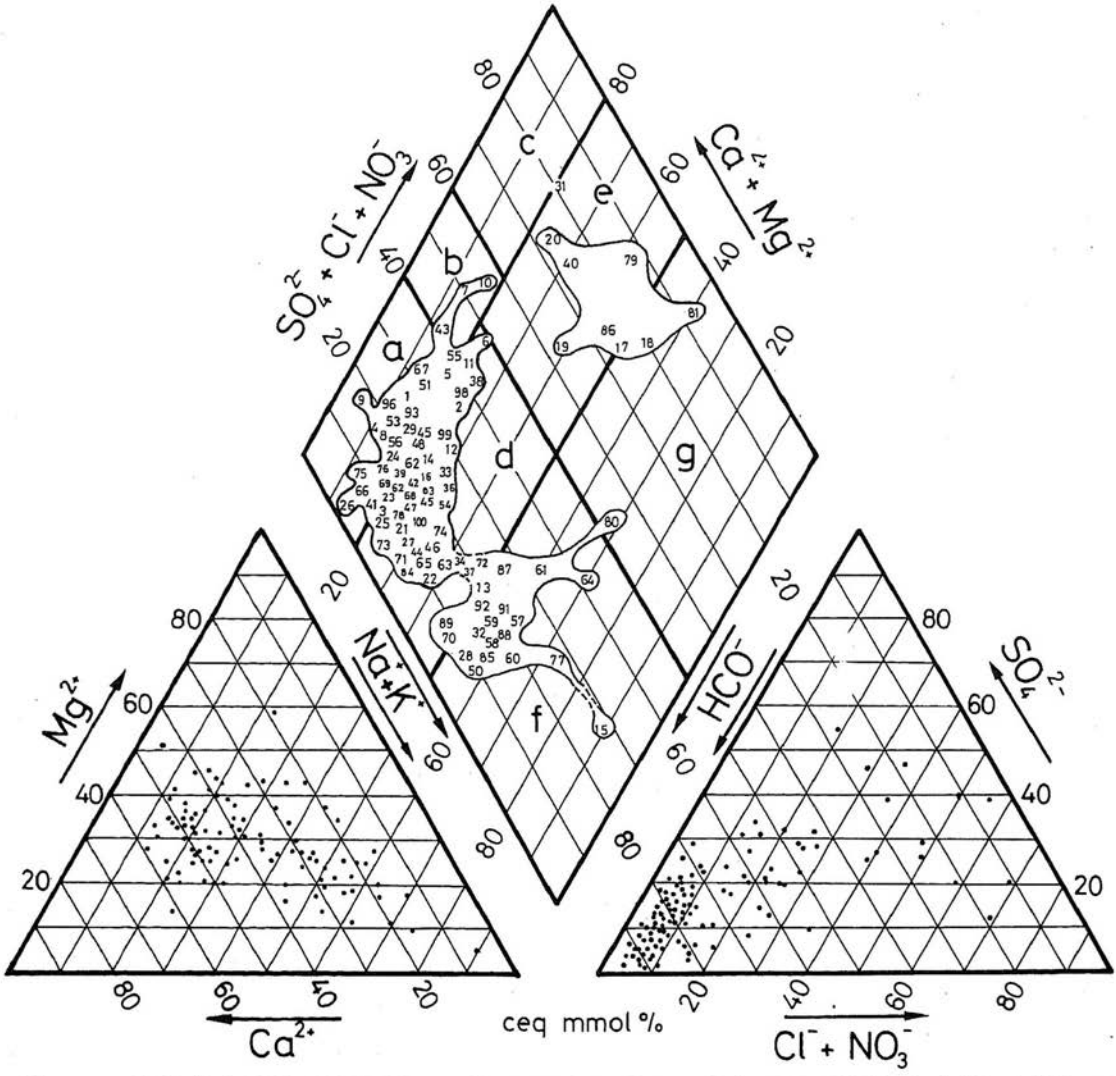


Fig. 6: PRESENTATION OF WATER SAMPLES 1 TO 100 IN THE PIPER DIAGRAM

to the turbidimetric or nephelometric method (sulphate) and cadmium reduction method (nitrate). Chloride was analyzed by titration with mercuric nitrate and calcium by titration with Na2-EDTA and calconcarbonacid as indicator (Bundschuh, 1989; FAO, 1986; Fresenius et al., 1988).

Electrical conductivity

The electrical conductivity (EC-values) gives a general impression of the chemical behaviour and chemical quality of the groundwater. It is a value for the amounts of ions which are dissolved in the water. In Figure 5 the EC-values found in the project area are plotted. The measured values range from 300 μS/cm to 7800 S/cm. While the regions adjacent the mountains and in the eastern part of Peshawar Valley show mostly low EC-values of <800 μS/cm, in the most parts of the basin (area between Peshawar, Nowshera, Nisetta (SW Charsadda) & Katlang) EC-values greater than 800 μS/cm are found. Towards the central part of Peshawar Valley, between Nowshera, Mardan and Charsadda, there is a rapid increase in the electrical conductivity of the groundwater. The maximum is located about 10 km northwest of Nowshera (7780 μS/cm). The distribution pattern of these values corresponds to the maps of depth of water table (Fig.3) and of water table elevation (Fig. 5). The last mentioned map shows a general groundwater flow towards this central area with the high EC-values (>4000 μS/cm) and also with the slow or stagnating flow velocity (low gradient). Since the water table in the central part is low and the water is saline, it shows that the groundwater flowing from the mountains towards the central part of the basin became enriched in dissolved components. This part of Peshawar Valley cannot be used for agricultural purposes, although the surrounding is agricultural. Westwards of Risalpur water coming from different tube wells with an electrical conductivity of about 2130 μS/cm is used for agriculture. Such highly mineralized water is not suitable for irrigation purposes, because evaporation with time leads to an enrichment of salts in the soil and groundwater, ultimately resulting in high salinity. Also in some towns and settlements in this central area of the basin the highly mineralized groundwater is used for drinking. In Risalpur, particularly where the depth of water ranges from 25 to 60m, the water has an electrical conductivity of 2890 μS/cm due to its high contents of sodium, sulphates and chlorides. This value is too high for continuous use and is a hazard for the human health. The eastern boundary of the highly mineralized area is the river Kalpani Nala. Eastward from this, the river, which is dividing the shallow aquifer system, the EC-values of the groundwater are low and vary between 350 and 800 μS/cm. Such low EC-values are also found in groundwater from greater depth of 70 to 120m. Thus, even in the highly mineralized water area between Nowshera, Mardan and Nisetta, there is low mineralized groundwater, which can be useful for drinking and irrigation purposes.

Groundwater classification

This section discusses the relative amounts of different ions in individual water samples. The analytical data were plotted in the PIPER-diagram which is based on a triangle for anions, a triangle for cations and a rhomb in which anions and cations are represented together (see Fresenius *et al.*, 1988, U.S.EPA, 1976). Different types of waters in this rhomb can be divided into the seven fields, i.e. "a to f" (Fig.6). The plots of analysis data from all 100 water samples fall in three areas I to III. The regional distribution of the different types of groundwater shown in Figure 7 is discussed. At the following percental data of the composition the sum of anions and the sum of cations are referred to 100% each and the percental data are referred to the cations (100%) or anions (100%), respectively.

I : This group of water samples belongs to the PIPER fields "e" and "g". The points mostly lie near the boundary of two fields. Field "e" represents *alkaline earth freshwater with higher contents of alkalies prevailing sulphatic* and field "f" represents *alkaline freshwater prevailing sulphatic-chloritic.* The groundwater with 25-65% alkalies (dominantly sodium), 60-90% sulfate and chloride and <40% hydrogen carbonate (% of anions or cations)

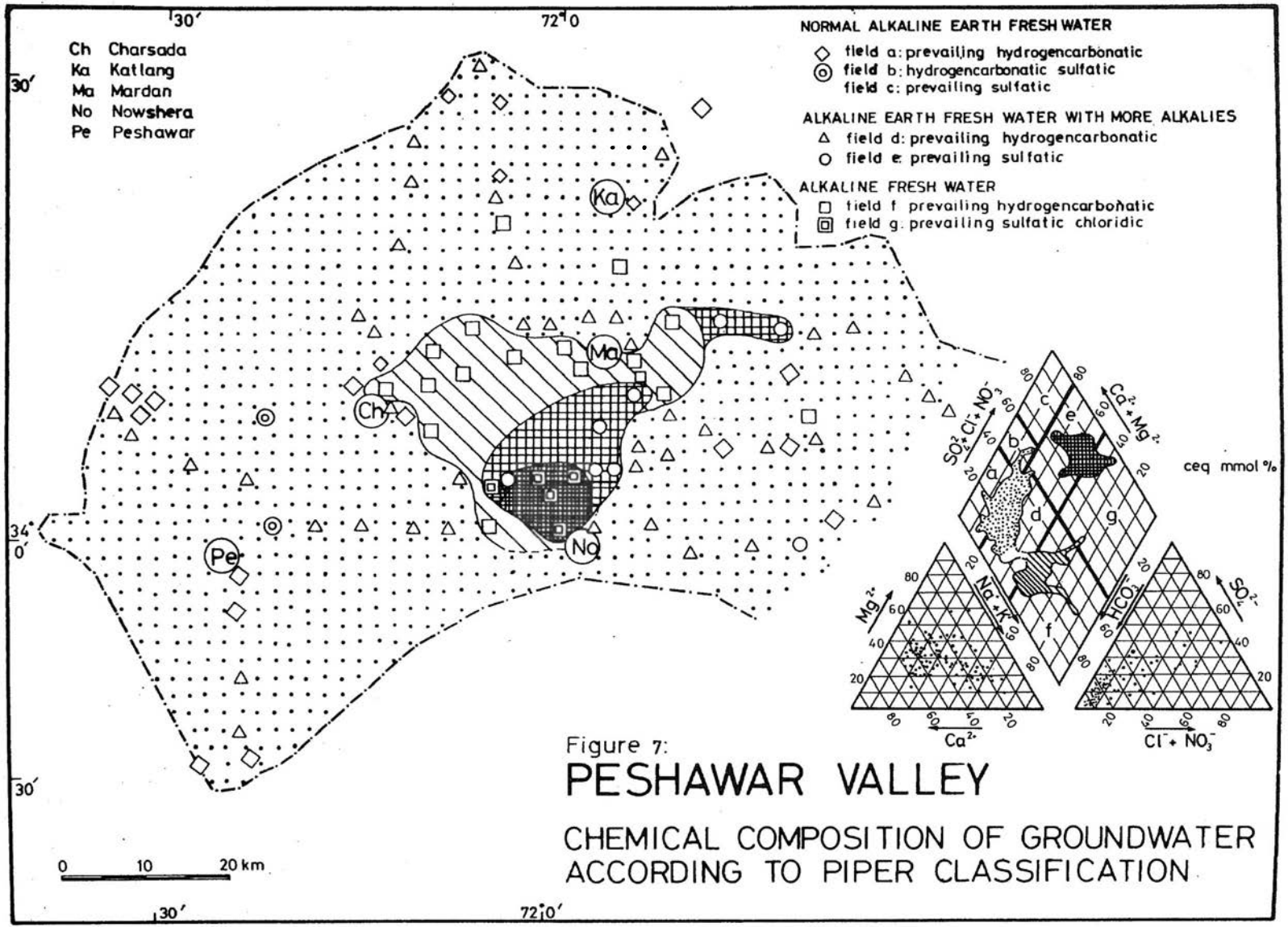


Figure 7:

PESHAWAR VALLEY

CHEMICAL COMPOSITION OF GROUNDWATER ACCORDING TO PIPER CLASSIFICATION

are found in the centre of Peshawar Basin between Nowshera and Mardan (Fig.7). By comparison with the map of EC-values (Fig.5) it can be seen that the area of these types of water (I) corresponds with the region of the highest EC-values ($\geq$2000 μS/cm).

II : The second group of groundwater samples belongs to the PIPER field "f" and to the boundary zone of field "f" and "d". Field "f" represents *alkaline freshwater prevailing hydrogen carbonatic*. This type of groundwater also occurs in the centre of Peshawar Basin north-and westward of the above described water group (i.e, type I) belonging to the PIPER fields "e" and the upper part of "g" and has EC-values between 800 and 2000 μS/cm. Group II is characterized by 40 to 80% alkalies (dominantly sodium), 10 to 30 (50)% sulfate and chloride and 70 to 90 (50)% hydrogen carbonate ions.

III : This group represents the maximum number of the water samples. In most cases the samples occur in the PIPER fields "d" and part of "a" with higher alkalies, but a few samples lie in field "b". Groundwater samples from group III are characterized by 10 to 40% alkalies (dominantly sodium), 5 to 50 % sulfate and chloride and 50 to 95% hydrgen carbonate. No regional distribution or trend of these water samples in Peshawar is recognizable.

DISCUSSION

Group I (PIPER fields "e" & "g") is isolated from both of the other groups of water samples. There are no intermediate points. This can be used as a hint that water-group I belongs to a single, isolated, aquifer. Between watergroup II (PIPER field "d" and "f") and group III there are a few intermediate points. It seems that in general watergroup II also belongs to a separate aquifer layer which may have some connections with other surrounding aquifers (mixed zone). But in the complex structured alluvial fill of Peshawar Basin it is impossible to resolve such questions in the absence of additional subsurface information. The water samples of group I (PIPER fields "a,d & b") cover a wide range and, as mentioned above, there is no recognizable regional trend in the project area. The relatively great variability of these water samples (Fig.7) is due to the great vertical and horizontal lithological inhomogeneity of the alluvial fill.

pH-values

The measured pH-values are shown in Figure 8. These range from 6.5 to 8.1 and there are regional differences that can be distinguished. In the southwest and in the centre of Peshawar Valley the pH-values are <7 while in the eastern part these range from 7.5 to 8.1. The rest of the valley is characterized by values between 7 and 7.5.

Temperature

The temperatures observed in the well waters range from 21 to 26°C. The exposure of the dugwells to the sun, the depth of water table and the air temperature as function of time are the main factors influencing the temperature of the well water. So the temperatures measured in dugwells are not the real temperatures of the aquifer. Only the water comming from the tubewells shows the aquifer temperature, but their number is too low to give more detailed information on the geothermal gradient.

Dissolved oxygen

The investigated groundwater shows contents of dissolved oxygen varying between 1 and 7.2 mg/l. This corresponds to a saturation of 10 to 95% at the temperature range discussed above. So there is no reducing water in Peshawar Basin. It has to be taken into consideration however that the oxygen content measured in open wells can only be taken as a rough approximation. Because of the contact with atmosphere temperature changes can take place.

The anions

Hydrogen carbonate: The content of hydrogen carbonate ions in most of the analyzed water samples is in the range of 300 to 600 mg/l. Only the samples from the less mineralized groundwater areas between Nowshera and Swabi and at the northern boundary to the metamorphic rocks (Fig. 5) have lower hydrogen carbonate contents (200-300 mg/l). The highly mineralized water between

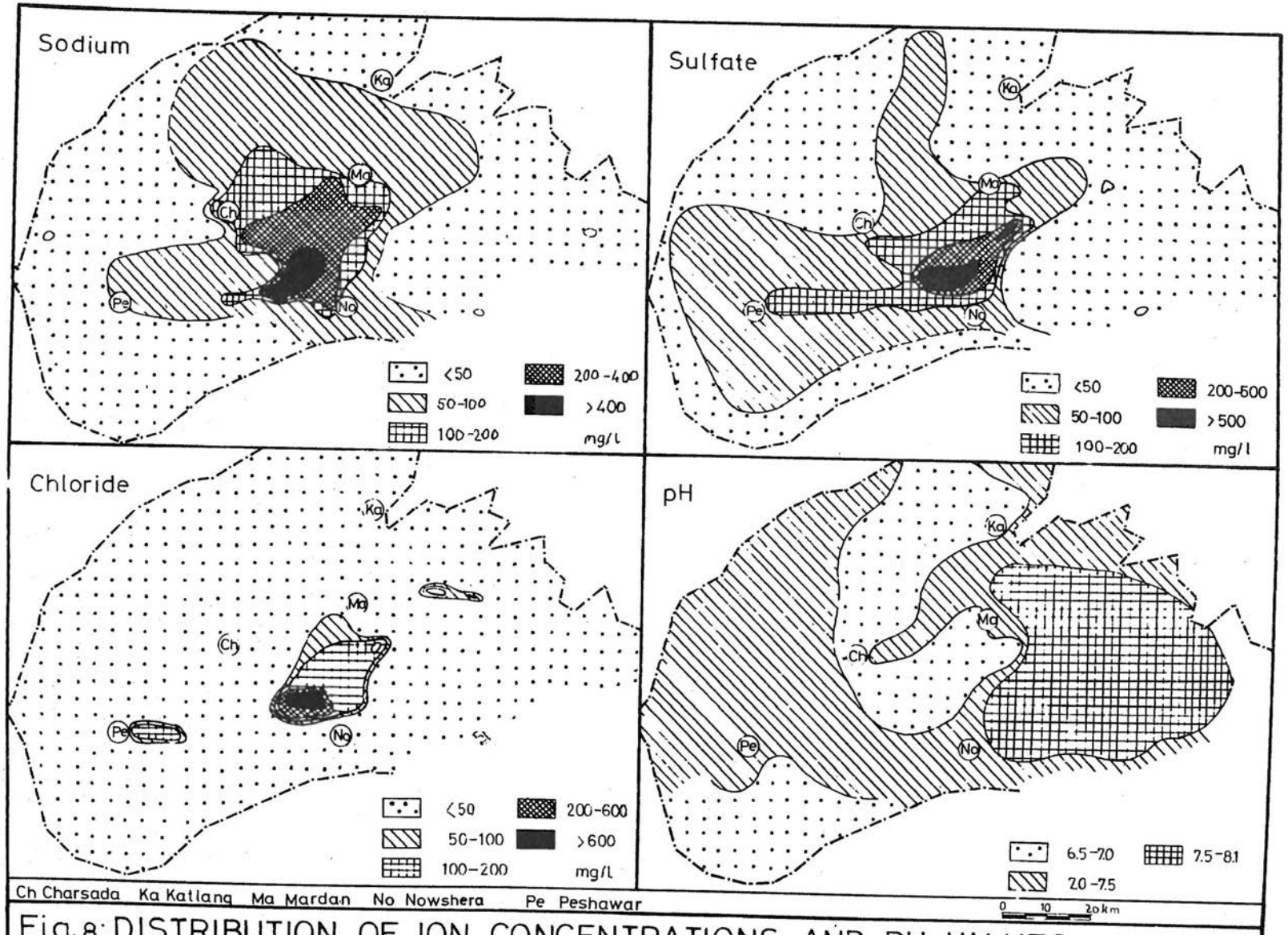


Fig. 8: DISTRIBUTION OF ION CONCENTRATIONS AND PH-VALUES IN THE GROUNDWATER OF PESHAWAR VALLEY

Nowshera, Mardan and Nisetta also shows similarly low hydrogen carbonate concentrations. In the rest of the Peshawar Basin the hydrogen carbonate contents vary between 300 and 600 mg/l. Because of abrupt variations over short distances no regional trend can be recognized. These variations are caused by the lithologically inhomogeneous aquifer system.

Sulfate: The distribution of the sulfate content in the groundwater of Peshawar Basin is shown in Figure 8. The distribution pattern is similar to that recognizable in Figure 6, where the EC-values are plotted. With sulfate contents less than 50 mg/l at the boundary of Peshawar Valley, the values rise towards its centre. Between Peshawar, Nowshera, Charsadda and Mardan sulfate concentrations between 100 and 1170 mg/l were found. The small stripe of higher values (100-200 mg/l) eastwards of Peshawar is situated along the Grand Trunk Road to Nowshera and may be caused anthropologically by the industries and wastes comming from the road traffic.

Chloride: Compared with the distribution of sulfate in the groundwater samples the chloride concentration plotted in Figure 8 shows much more uniformity. Certain wells show higher chloride locally, which is caused by anthropogenic pollution (i.e. eastwards of Peshawar downstreams of the city). The highly mineralized groundwater between Nowshera, Nisetta and Mardan also shows higher chloride concentrations between 50 mg/l in the vicinity of Mardan and 1240 mg/l northwest of Nowshera. In all other areas of Peshawar Valley the chloride content is <50 mg/l and in most of the cases <20 mgl.

Nitrate: In 80% of the samples the nitrate concentrations are less than 20 mg/l. The rest have nitrate contents ranging from 20 to 50 mg/l.

The cations

Calcium : In most of the samples (85%) the calcium concentration range from 30 to 100 mg/l. There is no recognizable regional variation. The differences in the concentration are caused by the inhomogeneous aquifer system. Only some of the highly mineralized groundwater samples from the central part of the Peshawar Valley show higher contents of calcium reaching up to 260 mgl.

Magnesium: The magnesium concentrations, like those of calcium show a uniform distribution, generally varying between 15 and 50 mg/l (94% of the samples). Only in some of the highly mineralized groundwater samples from the centre of Peshawar Basin, the magnesium content is higher and reaches up to 240 mg/l.

Sodium: In contrast to calcium, magnesium and potassium, sodium shows the greatest regional differences in concentration. Its regional distribution is shown in Figure 8. There is a significant rise of the sodium content from the boundary of the plain towards its centre between Nowshera, Mardan and Charsadda. While near the mountains the sodium concentration is <50 mg/l, it reaches to the 100 mg/l mark near Katlang, Peshawar and Nowshera. In the centre of the basin between Nowshera, Charsadda and Mardan the values are higher than 200 mg/l and a maximum of 850 mg/l is found about 10 km northwest of Nowshera. This regional distribution of sodium concentration is similar to that of the EC-values (Fig. 6). Therefore, sodium is considered the most important cation responsible for the differences of EC-values in Peshawar Basin.

Potassium: Compared with calcium, magnesium and sodium , potassium is a cation of minor importance in the groundwater of Peshawar Valley. In most of the water samples its concentration is between 1 and 6 mg/l. Only the highly mineralized area in the centre shows higher values of up to 22 mgl.

Summary

The distribution of the different anions in the studied area shows that the different grades of mineralization of groundwater are predominantly caused by sulfate and chloride while hydrogen carbonate and nitrate are regionally less variable. The low values of nitrate and chloride in most of the area indicate that the groundwater pollution caused by the use of fertilizers is low in the Peshawar Valley.

In the groundwater of Peshawar Valley, the concentrations of calcium, magnesium and potassium are of uniformity compared

with sodium. According to this study sodium is the most responsible cation for differences in the grade of mineralization and the types of water in the area.

CONCLUSIONS

1. The dominant aquifer system in Peshawar Valley is built up by a very heterogeneous alluvial fill of alternating layers of clay, silt, sand and gravel which reaches a thickness of more than 250m in the central part of the plain. Only in the vicinity of mountains surrounding the basin, hard rock aquifers are present.

2. The depth of the groundwater table is less than 5m, except in the vicinity of themountains and in a smaller region in the southeast of the plain, where it ranges from 5 to 30m. Because of high water table and the high evaporation rate in the former case the hazard of salification exists.

3. There is a general groundwater flow towards the centre of the basin from where the discharge is in southeastern direction towards the Indus Valley.

4. The EC-values which are a function of the grade of water mineralization increase from $<\mu$800 S/cm in the vicinity of mountains to values $>\mu$2000 S/cm in the central part of the basin. Areas between Nowshera, Mardan and Nisetta show a rapid rise up to 7780 μS/cm.

5. The chemical classification after PIPER shows that in the major part of Peshawar Basin groundwater belongs to the types *normal alkali earth freshwater prevailing hydrogen carbonatic* and *alkali earth freshwater with higher contents of alkalies prevailing hydrogen carbonatic*. Only in the central part of the plain between Nowshera, Mardan and Nisetta exist highly mineralized groundwater belonging to PIPER-types *alkali freshwater prevailing hydrogen carbonatic* and *alkali freshwater prevailing sulfatic-chloritic*.

RECOMMENDATIONS

Use as drinking water

From the hydrochemical point of view the quality of groundwater in Peshawar Valley, except in its centre, is good. The groundwater in the central part between Risalpur (NW Nowshera), Mardan and Nisetta with EC-values >2000 μS/cm containing great amounts of sulfate, chloride and sodium should be abandend for drinking purposes, particulary in Risalpur where EC-value of 2900 μS/cm are recorded and also a great concern is shown by the general public. Drilling of deeper wells or clean water supply through pipe lines are recommended.

Use as irrigation water

In Peshawar Valley mostly low mineralized surface water with EC-values of 400 μS/cm or low mineralized groundwater are used for irrigation purposes. But in its central areas (e.g. west of Risalpur) where this quality is not available, groundwater with high EC-values of about 2500 μS/cm is obtained from wells for irrigation. In this area the water table is less than 5m deep. Under such circumstances a high degree of evaporation elevate the salinity of soil due to enrichment of ions dissolved in the groundwater below. Deeper wells are therefore recommended to minimize the process of salification.

Acknowledgements: At first I would like to thank Professors M. Qasim Jan and Arif A.K. Ghauri of the National Centre of Excellence in Geology, University of Peshawar, for providing the opportunity to use the facilities of their institution (labs., computers and transport) during the investigation. I also owe considerable gratitude to all the other agencies and institutions especially WAPDA and the Geological Survey of Pakistan for their cooperation and to DAAD (German Academic Exchange Service) for sponsoring this investigation programme. I would also like to thank the faculty and students of the National Centre of Excellence in Geology for their manyfold help, and two anonymous reviewers for useful comments.

* Data available from author on request.

REFERENCES

Bundschuh, J., 1989. Introduction to quantitative water analysis: a practical guide for hydrogeologists. Institute of Geology and Palaeontology, Tübingen, West Germany, 54p.

FAO, 1986. Codex Alimentarius: methods of analysis for natural mineral waters. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fresenius, W., Quentin, K.E. & Schneider, W., 1988. Water Analysis: A practical guide to physico-chemical, chemical and microbiological water examination and quality assurance. Berlin (Springer), 804p.

Rafiq, M., Ahmad, I. & Tahirkheli., T.1983. A geological map of the surrounding of the Peshawar plain. Geol. Bull. Univ. Peshawar, 6, 189.

U.S. Environmental Protection Agency,1976. Quality criteria for water. Office of Water and Hazardous Materials, Washington, D.C., 256p.