Natural (baseline) groundwater quality in the Bist-Doab catchment, Punjab, India: a pilot study comparing shallow and deep aquifers

G. Krishan[1], D.J. Lapworth[2], M.S. Rao[1], C.P. Kumar[1], M. Smilovic[3] and P. Semwal[1]
[1]*National Institute of Hydrology, Roorkee, Uttarakhand, India*
[2]*British Geological Survey, Mclean Building, Wallingford, United Kingdom*
[3]*McGill University, Montreal, Canada*
Email*:drgopal.krishan@gmail.com;djla@bgs.ac.uk*

Abstract: Groundwater is a critical natural resource across the Indo-Gangetic Basin, sustaining agricultural productivity, industry and livelihoods for millions of people. The sedimentary aquifer is used extensively for irrigation and is also an important source of drinking water in growing urban centres. However, this resource is being impacted by anthropogenic activities leading to groundwater pollution, and falling groundwater tables in some regions. It is therefore important to establish an understanding of the spatial variation of the baseline water quality status of groundwater bodies in this heavily impacted aquifer. In this pilot study we have investigated the water quality of both the shallow (<50 m deep) and deep (>50 m deep) aquifers at (19) paired sites across the Bist-Doab catchment (9060 km^2) in Northwest Punjab, India. This paper includes samples collected during February and May in 2013. Groundwater samples were analysed for a suite of major and trace elements as well as field parameters. Preliminary results from across the catchment are presented and the variations in baseline chemistry assessed in both the shallow and deep sedimentary aquifers.

***Keywords*:** Groundwater quality, Bist-Doab, Punjab, shallow and deep aquifers

1. Introduction

Groundwater forms one of the most important sources of water for domestic and agricultural use in this region of Northwest Punjab, India, as well as across much of the Indo-Gangetic Basin. This region of the Punjab is important nationally for the production of cereals and other agricultural products such as sugar, as well as a large range of industrial products, all dependent on groundwater sources [1]. Due to the sustained increase in population in the last four decades, and accompanied agricultural and industrial development, the rate of withdrawal of groundwater has increased [2] resulted in decline of water table [3]. This has led to growing concerns regarding the security of groundwater resources and the economic activity and livelihoods on which they depend. As well as agricultural exploitation, in recent decades unplanned urbanization and industrialization has put a pressure on groundwater, which is an essential commodity [4]. Urbanisation and expanding industry both increase the pollutant loading to groundwater and surface water bodies. This has been known for some time and has prompted several studies in recent years focused on evaluating groundwater resources in this region [5, 6] to inform decision makers and agencies responsible for managing and developing this resource in a sustainable way. An understanding of the natural variation in groundwater quality is essential for a range of purposes; assessing pollution and suitability for drinking water and irrigation; understanding natural geochemical controls and flow paths; imposing regulatory drinking water quality limits and land use management practices [7].

Understanding groundwater-surface water exchange is important from both a recharge and pollution standpoint. Surface waters can act as recharge sources and contaminant pathways for groundwater pollution, for example through leakage from canals and river bank infiltration, and groundwater has an important role in contributing base flow to surface waters. As a result of groundwater recharge processes the pollution loading on the surface will have an impact the water quality status of groundwater at depth. In light of this, it is important to establish an understanding of the spatial variation of the baseline water quality status of groundwater bodies in this heavily used aquifer. This is especially important in relation to human health considerations, due to the reliance on this resource for drinking water [8], as well as understanding the suitability of this resource for irrigation [9], and the impact of nutrient enrichment in groundwater and surface water on the ecological status of the catchment [10, 11].

Several factors such as topography, hydrogeomorphology, geology, drainage pattern, land use and climatic conditions are responsible for controlling groundwater recharge, subsurface flow and year to year changes in groundwater levels. The chemical properties of groundwater are altered by processes taking place in the recharge zone as well as by the geochemical processes that occur during subsurface flow. The natural baseline groundwater quality variation is influenced both natural hydrogeological controls and anthropogenic activities [7, 12-15].

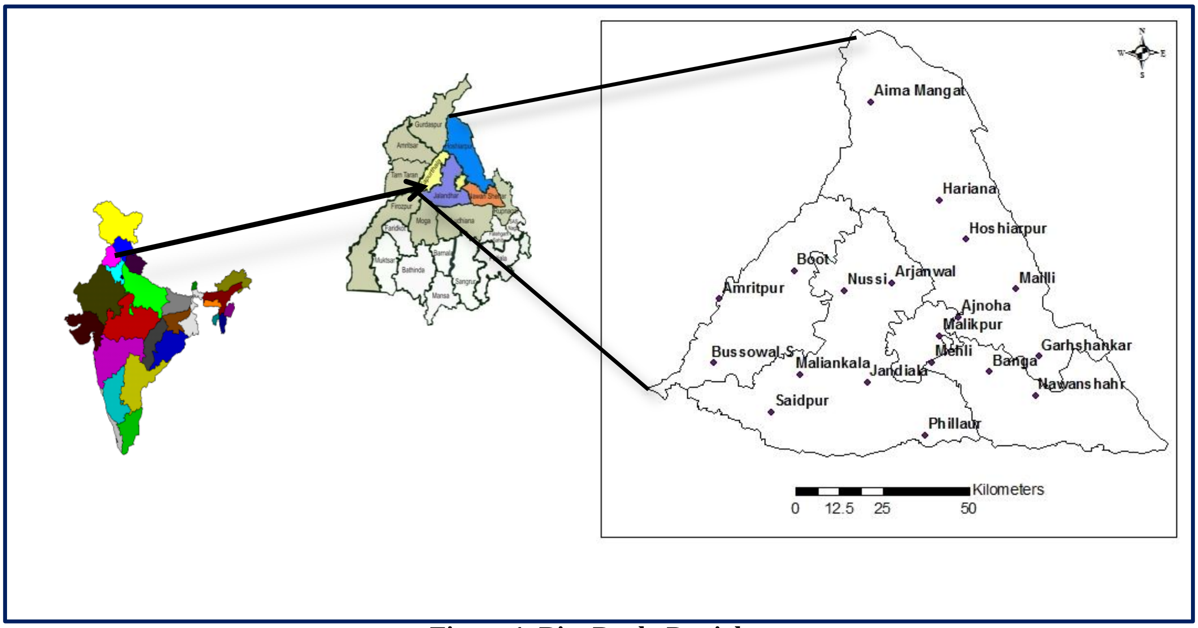

Figure 1. Bist-Doab, Punjab

In the present pilot study, groundwater quality across the Bist-Doab catchment was evaluated using existing tube-wells (deep aquifers >50 m deep) and handpumps (shallow aquifer <30 m deep). A paired sampling design was employed to understand spatial variation in groundwater chemistry of shallow and deep aquifers, along with its suitability for drinking water and irrigation. An important element of this work will be to investigate the distribution of nitrate within the layered sedimentary aquifers, and explore its potential as a conservative tracer of modern recharge, and in doing so shed light on the connectivity and anisotropy of the aquifer system. This will compliment ongoing work investigating the groundwater residence time profiles within the same aquifer. The region under investigation is by no means unique hydrogeologically, and findings from this study will have wider significance for understanding aquifer connectivity and groundwater recharge processes across other parts of the Indo-Gangetic Basin.

2. Study area

The Bist-Doab is a triangular region and covers an area of 9060 km^2**.** The word “Doab” signifies the region between two rivers namely, Satluj and Beas, in the present study. It comprises the Nawanshahr, Hoshiarpur, Kapurthala and Jalandhar districts of Punjab State, India. It is bounded by Siwalik range in the north-east, the river Beas in the north and west sides and the river Satluj in south and east-south. The area lies between 30°51'N and 30"04'N latitude and 74"57' and 76"40'E longitude (Figure 1). The study area is part of the Indo-Gangetic alluvial plain and is drained by the Satluj and Beas rivers and their tributaries. The drainage density is high in the NE strip bordering the Siwalik hills, but it is moderate to low in the rest of the area with sub-parallel and sub-dendritic patterns. In the plain area the gradients are low, with a regional gradient of around 0.4 m/km towards the SE [16].

The Beas and Satluj, two perennial rivers, rise in the high Himalayas and traverse long distances in the Himalayan and Siwalik zone before entering the state of Punjab. Bist Doab area is also comprised of Kandi region and central plains. In Kandi region, north-east portions of Hoshiapur and Nawanshehar there are deeper groundwater tables, due to the change in topography this is also considered the recharge area for the deeper plain aquifer system. The Jalandhar and Kapurthala districts occupy the Central Plains of the Bist-Doab. Some parts of Nawanshahr and Jalandhar districts are irrigated through canal, while most of the area of Bist-Doab is irrigated through groundwater. The present day geomorphic features were formed in response to changes in climate during the late Pleistocene-Holocene, overlain by tectonic activity of the Himalaya [17]. The sedimentary aquifers of the alluvial plain in the Bist-Doab catchment are composed of sands and gravels (late Pleistocene and Holocene). These take the form a succession of hydraulically interconnected aquifers of varying transmissivities, some of which are thought to be confined by clay and in places Kankar (largely nodular calcium carbonate) deposits [16].

3. Sampling and analysis

Groundwater sampling from 19 paired shallow and deep sites was carried out during February and

May 2013 across the Bist-Doab catchment (Fig. 1, Table 1). Filtered (0.45μm) water samples were collected in pre-washed plastic bottles. The sample locations were recorded using Garmin global positioning system. Groundwater chemistry was monitored carefully for a range of field parameters including electrical conductivity (EC), pH, oxidation-reduction potential (ORP) temperature measurement using a flow-through cell and when these parameters were stable, samples were collected. Field alkalinity was determined by titration using 50 ml sample and 1.6 N sulphuric acid, bromocresol green was used as the titration indicator. The unacidified sampling bottles were carefully filled just to overflowing to ensure no air bubble was trapped inside the sample container. The samples were properly labelled, brought to the laboratory and stored at 4 °C to avoid any major chemical alteration prior to analysis.

The un-acidified sub-samples were analysed for major anions F^-, Cl^-, NO^{-}_3, SO_4^{--} and acidified sub-samples for the following cations Ca^{++}, Mg^{++}, Na^+, K^+ using Dionex Ion Chromatograph ICS-5000 at National Institute of Hydrology, Rookree. For analysis of anions and cations before performing the analysis, Ion Chromatograph was calibrated using anion mixture standards and cation mixture standards (supplied by Dionex). In addition, trace elements were analysed by ICP-MS at BGS laboratories, UK.

4. Results and Discussion

The physiochemical characteristic of groundwater for shallow and deep aquifers in Bist-Doab, Punjab has been shown in Table 2 & 3, respectively. The pH values in samples were varying from 6.5 – 8.1 for shallow aquifers and 7.0 -8.2 in deep aquifers. The highest value for pH was observed at deep aquifer sample of Govindwal. The slightly alkaline pH was observed at Govindwal, Garhshankar and Bussowal, which may be due to the influx of HCO_3^- ions in the groundwater aquifer as a result of percolation of rain water through soil [18-19]. The EC is an indicator of salinity and also signifies the amount of TDS. EC of collected water samples ranges from 209 – 1816 μS/cm for shallow aquifers (Fig. 2) and 201 – 1123 μS/cm (Fig. 3) for deep aquifers. In shallow aquifers, high EC was found Mailli, Boot, Bussowal, Jandiala, Saidpur and highest was observed at Hoshiarpur Temple and in case of deep aquifers the highest was observed at Phillaur.

Table 1: Sample collection details

Sr. No.	Site Name	District	Longitude (E)	Latitude (N)	Depth (m)	
					Shallow	Deep
1	Banga	Nawanshahr	75.5°9'36.4"	31°10'04.4"	16.0	100.0
2	Mailli	Nawanshahr	75.4°8'51.4"	31°12'47.6"	40.0	150.0
3	Phillaur	Jalandhar	75.4°47'26.2"	31°01'24.1"	30.0	80.0
4	Malikpur	Phagwara	75.4°50'07.5"	31°16'55.6"	25.0	160.0
5	Nawanshahr	Nawanshahr	76°07'11.5"	31°07'33.1"	30.0	130.0
6	Memdwal Khurd	Hoshiarpur	76°04'12.7"	31°24'07.3"	45.0	80.0
7	Hariana	Hoshiarpur	76°50'29.6"	31°38'06.2"	50.0	160.0
8	Aima Mangat	Hoshiarpur	75°37'57.6"	31°53'32.5"	20.0	85.0
9	Arjanwal	Jalandhar	75°41'44.2"	31°25'13.5"	10.0	140.0
10	Jandiala	Jalandhar	75°37'07.8"	31°09'46.4"	30.0	60.0
11	Saidpur	Jalandhar	75°19'43"	31°05'06.1"	35.0	122.0
12	Mallian Kalan	Jalandhar	75°24'57.1"	31°10'57.4"	35.0	130.0
13	Busowal	Kapurthala	75°09'17.5"	31°12'49.2"	9.0	130.0
14	Boot	Kapurthala	75°23'52.1"	31°27'11.6"	10.0	130.0
15	Garmsankar	Hoshiarpur	76°08'07.8"	31°13'34"	18.3	45.7
16	Hoshiarpur Temple	Hoshiarpur	75°55'09"	31°31'55.4"	45.7	64.0
17	Ajnoha	Hoshiarpur	75°53'46.4"	31°19'36"	67.0	121.9
18	Nussi Pind	Jalandhar	75°33'2.5"	31°24'02"	21.3	152.4
19	Gouindwal	Kapurthala	75°10'21.8"	31°22'49.5"	7.6	76.2

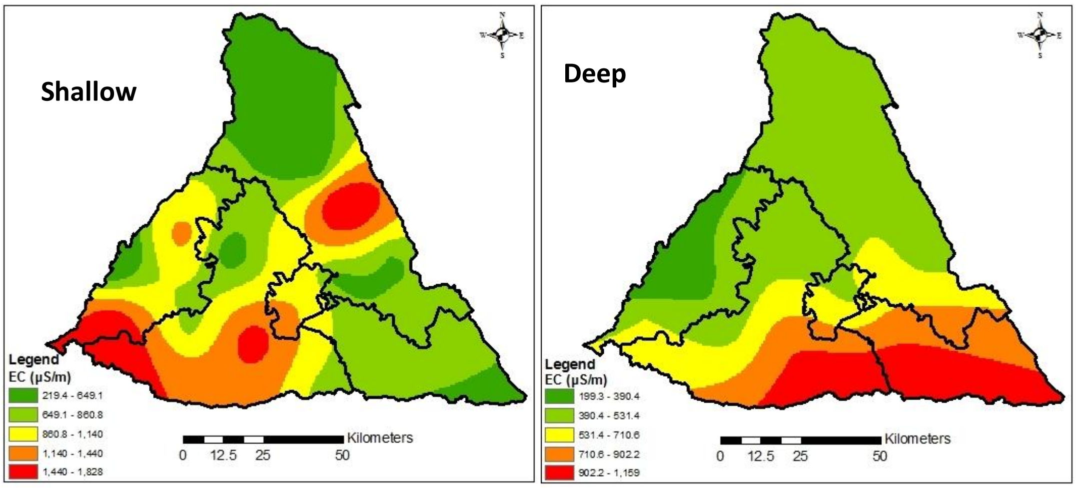

Fig. 2 EC map of shallow and deep aquifers

4.1. Major ions

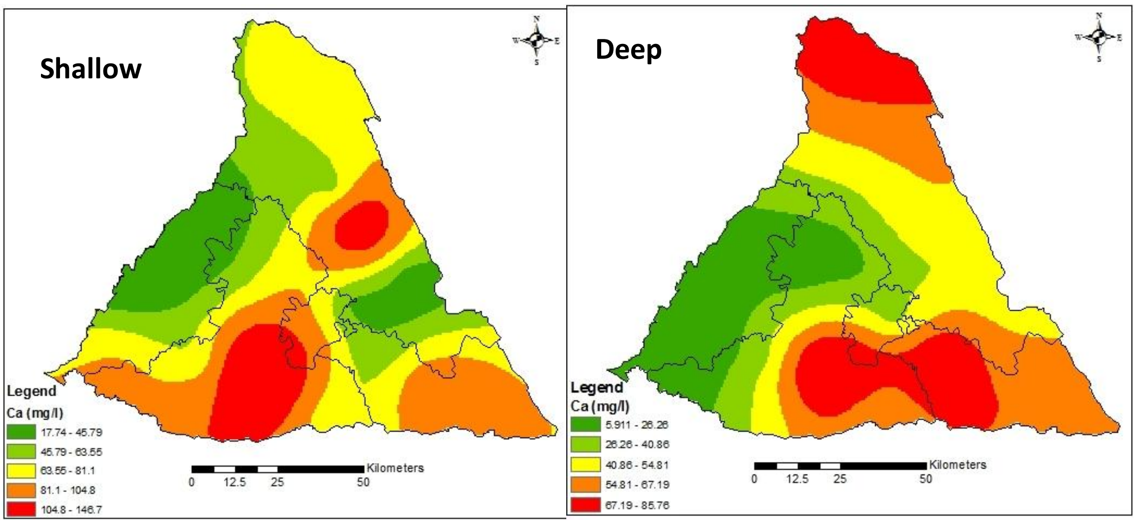

Fig. 3 Ca^{2+} map of shallow and deep aquifers

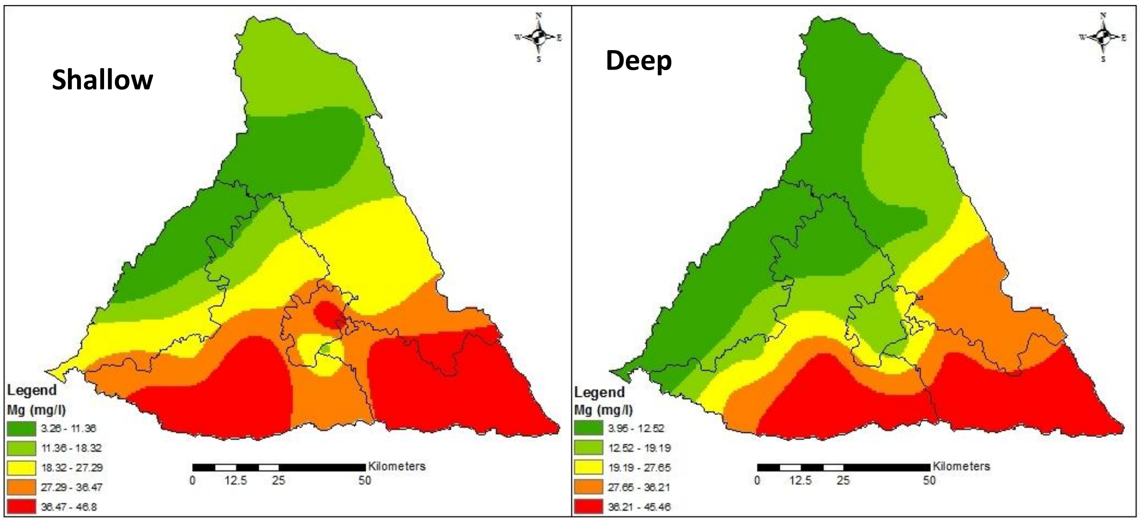

Fig. 4 Mg^{2+} map of shallow and deep aquifers

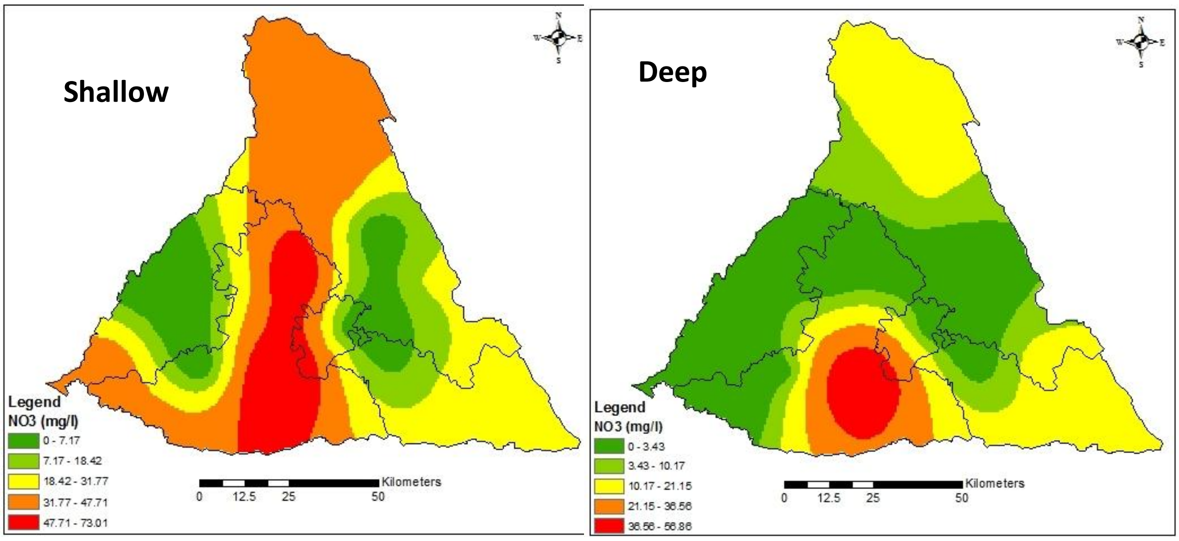

Fig. 5 NO_3^- map of shallow and deep aquifers

The Ca^{2+} and Mg^{2+} are the most abundant elements; the groundwater in Ca^{2+} may readily dissolve from carbonate rocks and lime stones or can be leached from soil. The dissolved Mg^{2+} concentration is lower than Ca^{2+} in the groundwater. The Ca^{2+} contents in water samples range from 24.8–146.7 mg/L in shallow aquifers and 16.6–85.4 mg/L in deep aquifers(Table 2,3; Fig. 3), while Mg^{2+} concentration varied from 5.4–46.5 mg/L in shallow aquifers and 5.9–43.5 mg/L in deep aquifers (Table 2, 3; Fig. 4). No water sample of study area has Ca^{2+} and Mg^{2+} content above the permissible limit. Na^+ and K^+ are naturally occurring elements in groundwater. Industrial and domestic waste also adds these salts to the groundwater, making it unsuitable for domestic use. High concentration of Na^+ in drinking water may cause heart problems. Further, higher Na^+ content in irrigation water may cause salinity problems and may render the soil barren [20]. The Na^+ concentration varied from 6.2–262.3 mg/L in shallow aquifers and 5.8–128.4 mg/L in deep aquifers and the samples for shallow aquifer taken at Bussowal and Boot exceed the permissible limit 200 mg/L [8, 21]. K^+ is an important cation and plays a vital role in intermediately metabolism. It is also important for Na^+–K^+ exchange pump. The K^+ content of groundwater of Bist-Doab varied from 1.3 – 22.3 mg/L in shallow aquifer and 1.9-7.3 mg/L in deep aquifers. K^+ also regulates the stomatal activity of leaves and hence plays a very significant role in crop physiology involving transpiration losses and gaseous exchange in respiration and photosynthesis.

Alkalinity of water is mainly due to the presence of CO_3^{2-} and HCO_3–. It is a measure of the ability of water to neutralize acids. CO_3^{2-} and HCO_3– in water are present mainly in association with Ca^{2+} and Mg^{2+}. HCO_3^- ranged from 89.1–859.4 mg/L in shallow aquifers and 87.8–593.7 mg/L in deep aquifers. High alkalinity does not pose a health risk but can cause problems such as alkali taste to water. Alkalinity is a big problem for industries; if alkaline water is used in boiler for steam generation then it may lead to formation of scale and embrittlement and the lowered efficiency of electric water heater. The main sources of drinking water in the studied area are hand-pumps and tubewells.

In general, it has been observed that groundwater contains a higher amount of F^- dissolved from geologic conditions while surface water typically contains lesser amount of F^- [20]. Furthermore, usually the F^- levels are more in the shallow aquifers in alluvial plains but in the present case in majority of the samples the concentration of F^- was found relatively high in shallow aquifer (hand pump) than deep aquifer (tube well). This could be due to difference in the geochemical condition in aquifer. The optimal drinking water concentration of F^- for dental health generally ranges from 0.5 to 1.0 mg/L and depends upon the volume of consumption and uptake and exposure from other sources. The WHO permissible limit of F^- in groundwater is 1.5 mg/L. The value of F^- ranged from 0.2-1.1 mg/L in shallow aquifers and 0.1-1.2 mg/L in deep aquifers and no sample exceeds the permissible limits.

Cl^- occurs naturally in some sedimentary bed rock layer, particularly shales. Cl^- is soluble in water and moves freely with water through soil and rocks. Cl^- is more persistent in nature than nitrate as it is not readily consumed by microorganisms. High content of Cl^- may give a salty taste to groundwater and can corrode pipes, pumps and plumbing fixtures. People who are not accustomed to high chlorine in drinking water are subjected to laxative effects. Cl^- concentration in the study area varied from 4-225.5 mg/L in shallow aquifers and 1.3 to 88.4 mg/L in deep aquifers. SO_4^{2-} is a naturally occurring ion in almost all kinds of water bodies and is a major contributor to total hardness. SO_4^{2-} content more than 250 mg/l is objectionable for domestic purposes, beyond this limit SO_4^{2-} causes gastro-intestinal irritation. All the water samples of Bist-Doab area had SO_4^{2-} content within permissible limits, ranging from 4.5 – 154.6 mg/L for shallow aquifers and 2.2-52.8 mg/L in shallow aquifers.

Nitrate concentrations were on average three times higher in the shallow groundwaters compared to the deep groundwaters (Table 2, 3; Fig. 5). However, several of the deeper sites had significant nitrate concentrations (>10 mg/L) indicating a significant component of modern recharge, however, due to the low dissolved oxygen and mildly reducing conditions (Eh) de-nitrification cannot ruled out for other sites with low nitrate. Two shallow sites and one deep site had nitrate concentrations >50 mg/L, in excess of WHO drinking water quality standards.

4.2 Percent Sodium

Sodium plays an important role in evaluating the groundwater quality for irrigation as it causes an increase in the soil hardness and reduction in its permeability [22]. High concentration of sodium causes soil mineral particles to disperse and less water to infiltrate [23]. Its effect becomes as infiltration rate of a soil is reduced to the extent that the crops does receive adequately amount of water. The sodium percentage (Na %) is calculated using the equation:

$$\% \, Na = \frac{Na^{+}+K^{+})x100}{(Ca^{++}+Mg^{++}+Na^{+}+K^{+})}$$

The Na % in shallow aquifer indicates that 1 sample is excellent, 7 samples are good, 7 samples belong to permissible criterion leaving 2 samples of groundwater in doubtful category (Table 4) and only 1 sample taken from Boot in unsuitable category. The Na % in deep aquifer indicates that 2 samples are excellent, 7 samples are good, 6 samples belong to permissible criterion leaving 3 samples of groundwater in doubtful category (Table 4) and only 1 sample taken from Bussowal in unsuitable category. Thus, 18 groundwater water sampling locations water can be used for irrigation leaving only four sampling locations unsuitable for irrigation. Adsorption of sodium on clay by its exchange with Mg^{2+} and Ca^{2+} Ions takes place when sodium is high. This results in poor permeability and drainage of soil, leading to restricted air and water circulation in it and thus makes it hard [22, 24-25]. The areas with high value (doubtful) of Na % in shallow aquifers are Mailli and Boot while in deep aquifers are Arjunwal, Boot and Nussi pind.

4.3 Sodium Absorption Ratio (SAR)

It is used to measure of alkali/sodium hazard to crops. The excessive sodium content relative to the calcium and magnesium reduces the soil permeability and thus inhibits the supply of water needed for the crops. It is an important parameter to determine the suitability of groundwater for irrigation. The excess sodium or limited calcium and magnesium are evaluated by SAR [26].

$$SAR = \frac{Na^{+}}{\text{Sq. Root } (Ca^{++}+Mg^{++})/2}$$

The SAR values for the samples are shown in Table 5. The SAR value's indicated that only 1 taken from shallow aquifer at Boot belong to doubtful (S3) category.

4.4 Trace elements

In the shallow sites elevated Zn concentrations were found, mean concentrations of 740 μg/L, compared to deeper sites (mean = 24 μg/L). Significantly higher average concentrations for Pb, Cu and B were also found in the shallow sites compared to deeper sites, also indicative of contamination of the shallow aquifer. Lead concentrations in the shallow sites exceeded the WHO drinking water standard of 10mg/L on three occasions. Uranium concentrations were high but comparable on average (16 and 18 μg/L) for the deep and shallow aquifers respectively. Three shallow sites and one deep site exceeded the WHO drinking water limit for U of 30 μg/L. Iron concentrations were on average twice as high in the shallow sites compared to the deeper sites, but groundwaters in both groups had overall low concentrations with average values of 260 μg/L in the shallow sites and 32 μg/L in the deep sites. Arsenic concentrations were below the WHO drinking water quality limit of 10 μg/L on all occasions, average concentrations of <1.4 mg/L for both deep and shallow sites, however one site, the Hoshiarpur Temple, did have concentrations approaching this limit (9.6 μg/L).

5. Conclusions

The hydro-chemical analysis of the study reveals that the groundwater of the study area is very good in terms of trace metals, such as chromium, manganese and iron, however the shallow aquifer does show evidence of contamination from nitrate and trace elements including B, Zn, Pb and Cu at a small proportion of sites. Uranium concentrations are high for both the shallow and deep aquifers (average concentrations >15 μg/L), however, WHO drinking water standards were exceeded in only 10% of sites investigated in this study. Arsenic concentrations were below 10μg/L on all occasions. The groundwater is well suited for irrigation based on the sodium absorption ratio.

6. Acknowledgement

The work was carried out under BGS-DFID project and the funding received is duly acknowledged. Authors thank Director, NIH for his constant support and encouragement. Authors thank Prof. Alan McDonald and Dr. Helen Bonsor for all the cooperation provided during the study.

7. References:

[1] A.K. Vashisht, Status of Water Resources in Punjab and its Management Strategies, Journal of Indian Water Resources Society, 28: 1-8, 2008.

[2] S.S. Kaushal, P.M. Groffman, L.E. Band, C.A. Shields, R.P. Morgan, M.A. Palmer, K.T. Belt, G. T. Fisher, C.M. Swan, and S.E.G. Findlay. Interaction between urbanization and climate variability amplifies watershed nitrate export in Maryland. Environmental Science & Technology 42, 5872–5878, 2008. 10.1021/es800264f

[3] Gopal Krishan, A.K. Lohani, M.S. Rao, and C.P. Kumar, Optimization of groundwater monitoring network in Bist-Doab, Punjab. In: Proceedings of an International conference "India Water Week 2013-Efficient Water Management: Challenges and Opportunities" (IWW-2013), 08-12 April 2013 at New Delhi, India. Pp. 274, 2013.

[4] R. Kumari, C.K. Singh, P.S. Datta, N. Singh and S. Mukherjee, Geochemical modelling, ionic ratio and GIS based mapping of groundwater salinity and assessment of governing processes in Northern Gujarat, India. Environ Earth Sci., 2012, doi:10.1007/s12665-012-2067-3

[5] M.S. Rao S Khobragade, B. Kumar and R.D. Singh (Eds)., Proceedings of the regional workshop on water availability and management in Punjab, National Institute of Hydrology, Roorkee, India, pp 422, 2010.

[6] Gopal Krishan, M.S. Rao, C.P. Kumar, Prabhat Semwal, Naresh Tuli and G.S. Gill, Groundwater quality and stable isotopic composition in Southwest, Punjab. In: Proceedings of International conference on "Integrated Water, Waste Water & Isotope Hydrology IC-WWISH-2013", 25-27 July 2013 at Bangalore University, Bangalore, India. III (VI): 6-10, 2013

[7] W. M. Edmunds, P. Shand, P. Hart and R.S. Ward, The natural (baseline) quality of groundwater: a UK pilot study. Sci. Tot. Environ., 310(1-3): 25-35, 2003.

[8] World Health Organization (WHO). Guidelines for Drinking-water Quality. Third Edition. 1st Addendum to vol.1. WHO Press, 20 Avenue Appia, 1211 Geneva 27,Switzerland., 2006 (http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf)

[9] S. Siebert, J. Burke, J. M. Faures, K. Frenken, J. Hoogeveen, P. Doll and F. T. Portmann. Groundwater use for irrigation – a global inventory. Hydrol. Earth Syst. Sci., 14, 1863–1880, 2010. *doi:10.5194/hess-14-1863-2010*

[10] N.S. Robins, Groundwater quality in Scotland: major ion chemistry of the key groundwater bodies, Sci Total Environ 294:41-56, 2002.

[11] K. Kruawal, F. Sacher, A. Werner, J. Müller and T.P. Knepper, T. P., Chemical water quality in Thailand and its impacts on the drinking water production in Thailand. Sci Total Environ, 340:57-70, 2005.

[12] T. Subramani, L. Elango and S.R. Damodarasamy, Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India. Environ Geol 47: 1099–1110, 2005.

[13] H. Vijith, and R. Satheesh, Geographical information system based assessment of spatiotemporal characteristics of groundwater quality of upland subwatersheds of Meenachil River, parts of Western Ghats, Kottayam District, Kerala, India. Environ Geol 53(1):1–9, 2007.

[14] B. Nas and A. Berktay, Groundwater quality mapping in urban groundwater using GIS. Environ Monit Assess 160(1–4):215–227, 2010.

[15] C.K. Singh, S. Shashtri and S. Mukherjee, Integrating multivariate statistical analysis with GIS for geochemical assessment of groundwater quality in Shiwaliks of Punjab, India. Environ Earth Sci 62(7):1387–1405, 2011.

[16] R. Bowen, Hydrogeology of the Bist Doab and adjacent areas, Punjab, India, Nordic Hydrology, 16: 33-44, 1985.

[17] K.P. Singh, Significance of Paleochannels for hydrogeological studies – a case study from alluvial plains of Punjab and Haryana States, India. In: Singh VP & Kumar B (Eds)., Subsurface-Water Hydrology, Kluwer Academic Pub, 245-249, 1996.

[18] S. Mor, K Ravindra, R.P. Dahiya, and A. Chandra, Leachate characterization and assessment of groundwater pollution near

municipal solid waste landfill site, Environ Monit Assess 118:435-456, 2006.

[19] M. Kumar, K. Kumari, A.L., Ramanathan, and R. Saxena, A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two agriculture dominated districts of Punjab, India. Environ. Geology 53:553-574, 2007.

[20] K. Ravindra, Meenakshi. Ameena, Monika. Rani, and A. Kaushik, Seasonal variation in physico-chemical characteristics of river Yamuna in Haryana and its ecological best-designated use, J Environ Monit 5:419, 2003.

[21] World Health Organization, Guidelines for drinking-water quality incorporating first addendum to Third Edition. Recommendations Geneva 1:595, 2008.

[22] M.N. Tijani, Hydrochemical assessment of groundwater in Moroarea, Kwara State, Nigeria. Environ Geol 24:194–202, 1994.

[23] M. Jalali, Salinization of groundwater in arid and semi-arid zones: an example from Tajarak, Western Iran. Environ Geol 52:1133–1149, 2007.

[24] R. Collins and A. Jenkins, The impact of agriculture and land use on stream chemistry in the middle hills of the Himalayas, Nepal. Journal of Hydrology, 185:71–86, 1996.

[25] A. Saleh, F. Al-Ruwih and M. Shehata, Hydrogeochemical process operating within the main aquifers of Kuwait, J Arid Environ 42:195–209, 1999.

[26] K.R. Karanth, Ground water assessment, development and management. Tata McGraw Hill, New Delhi, 1987.

Table 2: Major ions analysis of shallow aquifers

Site name	Temp. (^oC)	Eh (mV)	EC (μS/cm)	pH	Ca	Mg	Na	K	Field HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F^-
					mg/L								
Banga	26.6	-2.1	719.0	7.2	57.0	39.9	46.3	6.6	481.5	4.8	9.8	5.7	1.2
Mailli	26	51.5	1061.0	7.3	36.9	24.7	179.4	4.9	616.8	19.0	39.3	19.0	1.1
Phillaur	27	17.9	924.0	7.1	73.5	32.1	76.5	6.6	443.7	45.2	35.6	38.8	0.4
Malikpur	25	41.6	981.0	7.1	66.9	45.1	88.6	6.6	626.6	15.9	11.6	3.0	0.3
Nawanshahr	26	-60.5	909.0	7.1	96.7	42.0	48.5	5.3	497.4	27.0	41.5	21.2	0.5
Memdwal Khurd	26	251	681.0	6.9	85.9	16.6	40.2	2.1	395.0	9.0	5.3	30.8	0.2
Hariana	25	4.9	489.0	7.4	60.6	11.2	17.9	1.7	240.1	14.2	10.2	37.7	0.3
Aima Mangat	24	120.4	526.0	6.6	66.5	14.0	19.9	11.1	217.0	30.7	18.5	36.2	0.1
Arjanwal	24	93	906.0	6.9	75.7	23.4	85.8	1.3	441.3	39.6	26.1	61.6	0.4
Jandiala	25	39	1539.0	6.5	146.7	46.5	131.8	7.0	655.8	151.2	36.6	72.7	0.2
Saidpur	26	35.8	1375.0	6.9	89.4	38.4	158.2	6.1	468.1	125.3	154.6	33.1	0.5
Mallian Kalan	25	15	845.0	7.3	67.5	27.5	83.6	7.4	471.8	40.3	29.0	<0.02	0.2
Busowal	25	13	1737.0	7.0	78.3	25.1	262.3	9.0	859.4	87.0	114.6	40.2	0.4
Boot	26	-61	1213.0	7.3	30.0	8.9	226.4	22.3	649.7	48.9	79.0	<0.02	0.6
Garmsankar	24	32	745.0	7.1	69.2	37.7	32.8	3.5	402.3	10.6	4.5	17.9	0.4
Hoshiarpur Temple	24	-23	1816.0	6.9	128.8	21.6	142.9	3.1	598.5	225.5	79.1	0.0	0.2
Ajnoha	_	-130	620	7.56	43.9	19.0	30.7	3.45	370.6	5.70	<0.05	<0.02	0.6
Nussi Pind	24	-41	549.0	7.5	56.6	16.3	12.9	4.2	251.1	6.5	28.9	29.9	0.2
Gouindwal	25	-0.6	209.0	8.1	24.8	5.4	6.2	3.2	89.1	5.7	6.3	1.2	0.2
Minimum	24.0	-130.0	209.0	6.5	24.8	5.4	6.2	1.3	89.1	4.8	4.5	0.0	0.1
Maximum	27.0	251.0	1816.0	8.1	146.7	46.5	262.3	22.3	859.4	225.5	154.6	72.7	1.2
Average	25.2	20.9	939.2	7.1	71.3	26.1	89.0	6.1	461.9	48.0	40.6	28.1	0.4
S.D.	1.0	79.3	432.8	0.4	30.4	12.7	75.2	4.7	184.4	59.4	41.2	20.7	0.3

Table 3: Major ions analysis of deep aquifers

Site name	Temp. (°C)	Eh (mV)	EC (µS/cm)	pH	Ca	Mg	Na	K	Field HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F^-
					mg/L								
Banga	25.4	18.6	854.0	7.1	82.7	37.0	45.8	6.0	466.9	62.7	14.4	1.0	0.6
Mailli	26	32.7	648.0	7.3	44.3	31.9	46.7	6.4	431.5	8.4	7.6	0.5	0.7
Phillaur	27	76	1123.0	7.1	56.9	43.5	128.4	7.3	593.7	43.1	52.8	26.2	0.6
Malikpur	29	9.8	510.0	7.5	35.4	17.1	48.2	4.4	308.4	3.1	2.8	<0.02	0.3
Nawanshahr	25	55	731.0	7.1	67.8	37.3	33.7	5.3	437.6	15.5	10.9	11.4	0.5
Memdwal Khurd	26	208	441.0	7.3	64.6	13.0	17.2	1.9	260.9	2.9	2.2	16.4	0.2
Hariana	28	117	435.0	7.3	50.8	15.0	20.1	2.0	269.4	3.3	3.8	11.0	0.3
Aima Mangat	26	233	451.0	7.3	68.1	10.5	12.5	4.0	235.3	13.5	8.0	11.1	0.2
Arjanwal	26	-93	458.0	7.5	23.0	12.3	65.4	3.2	312.1	2.9	3.0	0.2	0.4
Jandiala	26	150	859.0	7.0	85.4	41.4	45.6	4.8	352.3	88.4	27.3	56.9	0.5
Saidpur	_	-79	634.0	7.3	30.3	28.4	66.5	7.3	409.6	1.3	16.2	0.3	0.3
Mallian Kalan	29	-134	445.0	7.4	31.8	18.9	40.2	4.6	284.0	3.9	5.3	0.0	0.4
Busowal	_	71	540.0	8.0	11.6	5.9	96.8	2.3	212.1	34.0	46.5	<0.02	0.4
Boot	27	68	405.0	7.6	20.1	9.6	56.5	3.3	292.6	2.6	5.9	0.0	0.4
Garmsankar	24	135	772.0	7.1	59.3	32.0	31.0	3.0	415.7	12.5	6.0	12.3	0.4
Hoshiarpur Temple	24	293	439.0	7.5	49.4	11.8	21.6	2.0	196.3	24.5	12.0	1.7	0.3
Ajnoha	25	180	630.0	7.3	42.6	28.8	46.0	4.0	376.7	3.4	4.4	0.0	0.6
Nussi Pind	25	147	493.0	7.7	19.9	12.2	63.3	2.9	301.1	4.1	3.7	0.1	1.1
Gouindwal	24	89	201.0	8.2	16.3	6.6	5.8	2.4	87.8	6.3	6.4	0.8	0.2
Minimum	24.0	-134.0	201.0	7.0	11.6	5.9	5.8	1.9	87.8	1.3	2.2	0.0	0.2
Maximum	29.0	293.0	1123.0	8.2	85.4	43.5	128.4	7.3	593.7	88.4	52.8	56.9	1.1
Average	26.0	83.0	582.6	7.4	45.3	21.7	46.9	4.0	328.6	17.7	12.6	8.8	0.4
S.D.	1.6	111.0	212.9	0.3	22.4	12.5	29.6	1.8	115.3	23.8	14.4	14.6	0.2

Table 4: Classification of groundwater on sodium percentage

%Na	Water class	No. of samples		Samples (%)	
		Shallow	Deep	Shallow	Deep
<20	Excellent	1	2	5.29	10.53
20-40	Good	7	7	36.84	36.84
40-60	Permissible	7	6	36.84	31.58
60-80	Doubtful	2	3	10.53	15.79
>80	Unsuitable	1	1	5.26	5.26

Table 5: Classification of groundwater based on SAR values

SAR	Water class	No. of samples		Samples (%)	
		Shallow	Deep	Shallow	Deep
<10	Excellent	16	18	84.21	94.74
10-18	Good	2	1	10.53	5.26
18-26	Doubtful	1	-	5.26	-
>26	Unsuitable	-	-	-	-

Table 6: Trace element analysis of shallow aquifers

Site name	Mn	Total Fe	B	Cr	Co	Cu	Zn	Mo	Cd	Pb	U	Se	As
	µg/L												
Banga	8.0	58.0	111.0	<0.05	0.1	33.5	289.6	3.8	0.1	22.0	10.6	16	0.22
Mailli	11.3	11.0	247.0	1.0	0.0	7.0	1034.7	5.1	0.1	4.8	28.5	12	0.41
Phillaur	21.5	73.0	168.0	0.1	0.2	5.1	434.0	2.1	0.0	3.2	9.3	0.2	0.42
Malikpur	92.5	5.0	248.0	<0.05	0.2	226.4	7474.1	1.5	0.1	26.3	34.6	26	0.26
Nawanshahr	93.6	1830.0	62.0	0.1	0.3	4.5	56.4	3.6	<0.01	0.7	27.9	<0.1	0.15
Memdwal Khurd	12.5	30.0	34.0	0.1	0.1	57.5	743.6	0.5	0.0	1.1	4.6	0.7	0.11
Hariana	71.9	133.0	28.0	0.1	0.1	7.1	495.1	0.4	0.1	6.6	2.0	0.1	1.01
Aima Mangat	2.8	57.0	27.0	0.1	0.0	1.6	52.4	0.1	0.0	0.5	0.9	2.4	0.36
Arjanwal	2.1	21.0	158.0	0.1	0.0	12.0	276.5	0.3	0.0	3.6	8.1	0.5	0.24
Jandiala	7.9	277.0	152.0	0.3	0.4	17.8	1229.9	0.3	0.1	3.3	3.9	0.1	0.45
Saidpur	3.0	65.0	336.0	0.1	0.0	2.7	179.5	2.0	0.1	0.5	64.4	4.8	0.47
Mallian Kalan	59.1	19.0	187.0	0.1	0.2	17.5	696.9	1.2	0.1	0.4	23.9	1.0	0.18
Busowal	410.9	22.0	225.0	<0.05	0.1	2.0	37.5	0.8	0.0	0.3	70.4	8.0	0.27
Boot	227.5	128.0	225.0	<0.05	0.1	0.4	8.7	15.5	<0.01	0.2	17.1	0.6	1.81
Garmsankar	127.3	40.0	55.0	<0.05	0.2	70.7	265.3	1.6	0.3	13.9	27.7	1.7	0.27
Hoshiarpur Temple	854.6	400.0	131.0	<0.05	0.4	0.4	10.4	1.1	0.0	0.2	7.4	<0.1	9.66
Ajnoha	51.9	1576	83.0	<0.05	0.1	1.3	646	3.8	0.1	1.0	3.1	<0.1	0.1
Nussi Pind	236.5	56.0	119.0	<0.05	0.1	1.1	120.5	0.1	0.2	1.9	6.7	1.8	4.52
Gouindwal	169.2	95.0	26.0	0.1	0.0	8.2	6.5	1.7	0.0	0.1	1.8	0.3	0.97
Minimum	2.1	5.0	26.0	0.1	0.0	0.4	6.5	0.1	0.0	0.1	0.9	0.1	0.1
Maximum	854.6	1830.0	336.0	1.0	0.4	226.4	7474.1	15.5	0.3	26.3	70.4	25.5	9.7
Average	129.7	257.7	138.0	0.2	0.1	25.1	739.9	2.4	0.1	4.8	18.6	4.7	1.2
S.D.	205.7	520.4	90.3	0.3	0.1	52.6	1670.3	3.5	0.1	7.6	20.3	7.3	2.3

Table 7: Trace element analysis of deep aquifers

Site name	Mn	Total Fe	B	Cr	Co	Cu	Zn	Mo	Cd	Pb	U	Se	As
	μg/L												
Banga	1.5	24.0	69.0	<0.05	0.0	6.4	14.1	5.0	0.0	2.4	22.4	1.3	0.56
Mailli	13.1	69.0	133.0	<0.05	<0.01	15.5	42.1	9.0	0.0	4.4	19.7	0.6	0.85
Phillaur	9.3	5.0	214.0	1.3	0.0	5.3	34.6	3.6	<0.01	1.1	20.1	0.7	0.65
Malikpur	15.9	24.0	104.0	<0.05	0.0	3.4	79.0	1.7	<0.01	0.9	11.8	<0.1	1.18
Nawanshahr	21.8	10.0	72.0	<0.05	0.0	9.5	70.0	3.8	0.0	2.4	25.4	1.2	0.74
Memdwal Khurd	3.1	4.0	19.0	1.3	<0.01	3.9	5.9	1.4	<0.01	0.7	3.4	1.2	0.77
Hariana	8.9	2.0	30.0	1.8	0.0	3.0	32.6	2.4	0.0	0.3	5.6	0.8	0.65
Aima Mangat	28.5	2.0	20.0	<0.05	<0.01	1.7	51.5	0.1	0.0	0.4	1.2	2.6	1.49
Arjanwal	48.4	64.0	174.0	<0.05	0.0	1.3	22.0	3.6	<0.01	0.4	15.1	0.1	1.53
Jandiala	0.5	4.0	66.0	3.4	0.0	1.5	10.4	2.8	<0.01	0.2	19.4	1.5	0.55
Saidpur	18.1	78.0	228.0	<0.05	0.0	<0.4	19.8	2.1	<0.01	0.2	26.2	<0.1	0.96
Mallian Kalan	14.6	106.0	99.0	<0.05	0.0	1.2	19.1	3.5	<0.01	0.5	18.1	<0.1	1.87
Busowal	5.9	9.0	115.0	<0.05	<0.01	2.0	5.7	5.3	<0.01	0.2	12.1	0.3	5.94
Boot	10.8	51.0	128.0	<0.05	<0.01	1.5	7.2	10.4	<0.01	0.5	12.1	0.4	2.76
Garmsankar	64.9	<1	57.0	<0.05	0.1	11.5	10.3	1.8	<0.01	0.2	38.7	5.1	0.47
Hoshiarpur Temple	137.6	<1	29.0	0.1	0.1	<0.4	21.0	2.3	0.0	0.1	5.8	0.2	0.84
Ajnoha	56.5	12.0	129.0	<0.05	0.0	<0.4	2.0	4.7	0.1	0.1	19.3	<0.1	0.89
Nussi Pind	13.3	52.0	251.0	<0.05	<0.01	0.5	10.5	10.3	<0.01	0.2	18.2	<0.1	1.65
Gouindwal	21.0	32.0	15.0	<0.05	0.0	1.2	3.5	0.8	<0.01	0.1	6.5	<0.1	0.9
Minimum	0.5	2.0	15.0	0.1	0.0	0.5	2.0	0.1	0.0	0.1	1.2	0.1	0.5
Maximum	137.6	106.0	251.0	3.4	0.1	15.5	79.0	10.4	0.1	4.4	38.7	5.1	5.9
Average	26.0	32.2	102.7	1.6	0.0	4.3	24.3	3.9	0.0	0.8	15.8	1.2	1.3
S.D.	32.5	32.0	72.8	1.2	0.0	4.3	22.3	3.0	0.0	1.1	9.2	1.3	1.3