ASSESSMENT OF GROUNDWATER QUALITY IN SUNAMGANJ OF BANGLADESH

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ABSTRACT

In this study, groundwater quality in Sunamganj of Bangladesh was studied based on different indices for irrigation and drinking uses. Samples were investigated for sodium absorption ratio, soluble sodium percentage, residual sodium carbonate, electrical conductance, magnesium adsorption ratio, Kelly's ratio, total hardness, permeability index, residual sodium bi-carbonate to investigate the ionic toxicity. From the analytical result, it was revealed that the values of Sodium Adsorption Ratio indicate that ground water of the area falls under the category of low sodium hazard. So, there was neither salinity nor toxicity problem of irrigation water, so that ground water can safely be used for long-term irrigation. Average Total Hardness of the samples in the study area was in the range of between 215 mg/L at Tahirpur and 48250 mg/L at Bishamvarpur. At Bishamvarpur, the water was found very hard. Average total hardness of the samples was in the range of between 215 mg/L at Tahirpur and 48250 mg/L at Bishamvarpur. At Bishamvarpur, the water was found very hard. It was shown based on GIS analysis that the groundwater quality in Zone-1 could be categorized of "excellent" class, supporting the high suitability for irrigation. In Zone-2 and Zone-3, the groundwater quality was categorized as "risky" and "poor" respectively. The study has also made clear that GIS-based methodology can be used effectively for ground water quality mapping even in small catchments.

Key words: Sodium absorption ratio, residual sodium carbonate, total hardness, magnesium adsorption ratio, kelly's ratio

INTRODUCTION

Huge quantities of groundwater, particularly from the shallow aquifers, are used for irrigation in Bangladesh and in the absence of adequate surface water in the dry season, irrigation becomes heavily dependent on groundwater. The water quality management is essential for long-term irrigation system as it persuades the soil properties. In irrigation water evaluation, emphasis is given on chemical and physical characteristics of water. The toxicity or suitability of groundwater is determined by varying amounts and different ions. The usual toxic elements in irrigation are chlorine, boron, and sodium, which are toxic to sensitive crops at low concentrations. Irrigation water quality is generally judged by some determining factors

such as sodium absorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), and electrical conductance (EC) (Richards, 1954). Along with the above indicators, some additional indices to categorize the groundwater for irrigation like magnesium adsorption ratio (MAR), Kelly's ratio (KR), total hardness (TH), permeability index (PI), residual sodium bicarbonate (RSBC) should be studied.

The location of this study area was the Sunamganj district, which lies in the "North-Eastern Depression" of Bangladesh. The depression is characterized by flat terrain with low land elevation. People of this district are the pioneer users of shallow and deep tube wells for drinking and irrigation purpose. Most of the arable lands are usually irrigated by groundwater to grow crops

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mainly high yielding varieties (HYV) rice and numerous types of vegetables during winter season at the area. According to BGS and DPHE (2001), the vast majority of Sunamganj district have private tube wells, which penetrate shallow alluvial aquifers to depth 10-60 m for drinking purpose. Irrigation boreholes typically tap deeper aquifers in the range of 70-100 m depth. In some areas of the district, deep tube wells abstract groundwater from depths of 150 m or more. The deep tube wells have been installed to avoid high salinity at shallower levels. Shallow hand-dug wells occur in some areas, though they are much less common than tube well.

To safeguard the long-term sustainability of the groundwater resources, the quality of the water needs to be continually monitored. With this view, an attempt has been made to analyze the groundwater quality of Sunamganj district to determine the exact level of physicochemical parameters with special references to suitability of water for drinking purposes and to assess its irrigation suitability for sustainable crop production. The objectives of the study were (i) to find out the different water quality indices. Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium bicarbonate (RSBC), Permeability Index (PI), Total Hardness (TH), Magnesium Adsorption Ratio (MAR) and Kelly's Ratio (KR) and (ii) to prepare water quality map with ARC view (GIS) software.

Groundwater is the major source of irrigation in Bangladesh and there has been a tremendous increase in suction mode irrigation. The characteristics of an irrigation water that seem to be most important in determining its quality are (1) total concentration of soluble salts, (2) relative proportion of sodium to other cations (magnesium, calcium, and potassium), (3) concentration of boron or other elements that may be toxic, and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium (Michael, 1978; Raghunath, 1987).

Between 30 and 40 percent of the net cultivable area of the country is under irrigation (Huq and Naidu, 2002). According to Mridha *et al.*, (1996) about 70% irrigation water and 90% of total potable water in Bangladesh are supplied from groundwater sources. The proportion of irrigation water drawn from groundwater has also significantly changed. The contribution of groundwater in relation to total irrigated area increased from 41% in 1982/83 to 71% in 1996/ 97 and to over 75% in 2001(Ali, 2003). As groundwater is the only limiting resource for further intensification of agriculture, its rational use should be insured in terms of quality and quantity (Sarkar and Hasan, 2006).

Shahidullah *et al.*, (2000) in their paper, attempted to assess the groundwater quality in a selected area of Bangladesh (Phulpur Upazila of Mymensingh district). Water samples from 14 deep tube wells were analyzed for SAR, SSP and RSC. Their results suggest that there was neither salinity nor toxicity problem of irrigation water, so that groundwater can safely be used for long-term irrigation. But some of them were not suitable for drinking and irrigation uses in consideration of Fe concentration, total dissolved solid (TDS) and pH values. Among the quality determining factors, they observed a linear relationship between SSP and SAR. Quddus and Zaman (1996) studied the irrigation water quality in some selected villages of Meherpur district of Bangladesh. They argued that the major ions present in irrigation water were calcium, magnesium, sodium, bicarbonate, sulphate and chloride. Other ions that may be found in low concentrations were potassium, carbonate, nitrate, iron, boron, and silica, etc. Some of these ions are more or less beneficial and few ions in excess amounts are more or less detrimental for crop growth and soil properties. A similar research was done by Talukder *et al.*, (1998) on Kishoreganj where they reported that irrigation with poor quality irrigation water reduces soil productivity, changes soil physical and chemical properties, creates crop toxicity and ultimately reduces yield. Sarkar and Hasan (2006) investigated the water quality of a groundwater basin in Bangladesh for irrigation use. From their analytical result, it was observed that the compositions of the groundwater samples were within the permissible range of irrigation use, except increased Cl⁻ values, responsible for toxicity problem. Standard water quality parameter indices like pH, EC, SAR, SSP, RSBC, MAR, PI, KR and TH were also found within the acceptable range of crop production.

Study area

Sunamganj Sadar Upazila with an area of 560.76 sq km is bounded by Bishwamvarpur upazila and Meghalaya (India) on the north, Jagannathpur and Derai upazilas on the south, Dowarabazar and Chhatak upazilas on the east, Jamalganj and Bishwamvarpur upazilas on the west. River Surma and Dekar Haor are notable. Sunamganj (Town) stands on the bank of the river Surma (Fig. 1). It was established in late 18th century. It consists of 9 wards and 44 mahallas. The area of the town is 22.16 sq km. It has a population of 49373; density of population is 2228 per sq. km. Sunamganj area of Sylhet Basin is adjacent to the Dauki fault, where little pre-Pleistocene geology is exposed along with the southern edge of Shillong plateau in the north-east. Within Bangladesh the greater Sylhet region is the most enriched in mineral resources.
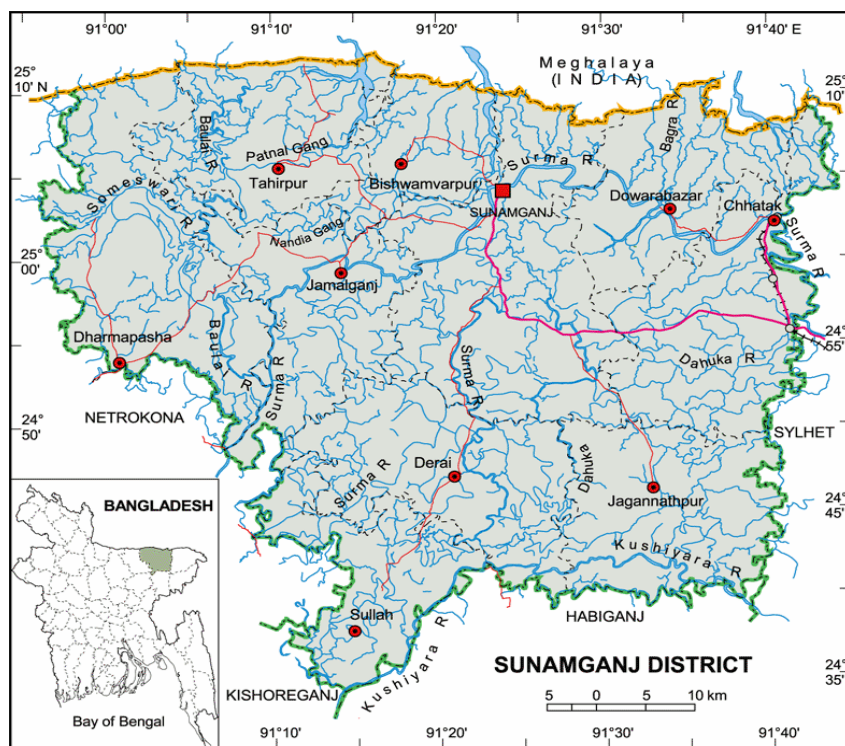

Fig. 1: The map of study area

The reason is geologically known as Surma basin and covers the north eastern parts of the for-deep and folded belt division of Bengal basin which happens to be one of the most prominent tectonically active sedimentary basins of the world. In this region the folded belt represents the uplifted parts of this sedimentary pile. This huge sedimentary body is dominantly composed of sand and mud with subordinate limestone which started depositing in a deep basement (bottom of the basin being composed of igneous metamorphic complex) basin about 50 million years ago with the gradual rise of Himalayas due to collision between Indian and Burmese plates and subsequent erosion. The area has also vast deposed of limestone, peat and glass sand and hard rock gravel (Huq, 1999).

MATERIALS AND METHODS

Water samples were tested according to APHA-AWWA-WPCF (1989). The Sodium Adsorption Ratio (SAR) was calculated by the following equation given by Richards (1954) as:

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \qquad (1)$$

Where, all the ions are expressed in meq/L.
Soluble Sodium Percentage (SSP) was calculated by the following equation (Todd, 1980):

$$SSP = \frac{(Na + K) \times 100}{Ca + Mg + Na + K} \qquad (2)$$

Where, all the ions are expressed in meq/L.
The Residual Sodium Bi-carbonate (RSBC) was calculated according to Gupta and Gupta (1987):

$$RSBC = HCO_3 - Ca \qquad (3)$$

Where, RSBC and the concentration of the constituents are expressed in meq/L.
The Permeability Index (PI) was calculated according to Doneen (1962) by the following equation:

$$PI = \frac{\left(Na + \sqrt{HCO_3}\right) \times 100}{Ca + Mg + Na} \qquad (4)$$

Where, all the ions are expressed in meq/L.
Total Hardness (TH) was calculated by the following equation (Raghunath, 1987):

$$TH = (Ca + Mg) \times 50 \qquad (5)$$

Where, TH is expressed in meq/L (ppm) and the concentrations of the constituents are expressed in me/L.
Magnesium Adsorption Ratio (MAR) was calculated by the equation ((Raghunath, 1987) as:

$$MAR = \frac{Mg \times 100}{Ca + Mg} \qquad (6)$$

Where, all the ionic concentrations are expressed in meq/L.
The Kelly's Ratio was calculated using the equation (Kelly's 1963 as:

$$KR = \frac{Na}{Ca + Mg} \qquad (7)$$

Where, all the ionic concentrations are expressed in meq/L.

RESULTS

The result shows that concentration of sodium (Na^+) was in the range of 0.35 (at Chhatak) to 397.08 (at Tahirpur) mg/L. Sodium Adsorption Ratio (SAR) also influences infiltration rate of water. So, low SAR is always desirable. In the studied samples, SAR values were ranged between 0.10 and 425.18 meq/L shown in Table 1. In the study area, SAR value was highest at Dharmapasa. It is evident from the whole sample set that the SAR value is *excellent* up to 75% of the total samples. Only 13.54 % of them lie in the *poor* category shown in Table 2. Hence, our findings strongly suggest that most of the abstracted groundwater samples from the study area were suitable for irrigation.

The Soluble Sodium Percentage (SSP) values were found from 0.125 at Derai to 98.17 at Dharmapasa meq/L and average was 38.01 meq/L. In the study area, the conductivity value varies from 12 to 1318. More than 5.20% (EC=750 μs/cm) sample of the study area fall under high salinity zone such water should not be used on soils with restricted drainage (Jain *et al.*, 2000).

In the study area, the MAR values were less than the restricted limit except Sunamganj Sadar, Tahirpur, Chhatak, Derai, and Dharmapasa. MAR values at Sunamganj Sadar, Tahirpur, Chhatak, Derai, and Dharmapasa were 89.30, 97.58, 98.57, 71.1 and 91.66 respectively shown in Table 1. In the study area, MAR values were found within a range of 1.86 to 98.66. That is why; those areas might be regarded as less suitable for irrigation.

Average Kelly's Ratio (KR) was found in the range of 0.0144 (at Chhatak) to 37.58 (at Dharmapasa) in the abstracted samples of the different study areas. At Dharmapasa the value is the highest (37.58). Seventy one out of ninety six i.e. 74 percent of total samples (Table 1) were found less than the permissible value of 1.0.

The Residual Sodium Bi-carbonate (RSBC) value of the water samples were found in between (-) 712 mg/L and 353 mg/L at Bishwamvarpur. The positive RSBC value indicates that dissolved calcium and magnesium ions less than that of carbonate and bicarbonate contents. RSBC of the samples was not satisfactory (<5mg/L) according to the criteria set by Gupta and Gupta (1987).

On the other hand, average TH of the samples in the study area was in the range of 215 mg/L at Tahirpur and 48250 mg/L at Bishamvarpur. At Bishamvarpur, the water was very hard. Besides,

the samples were moderately hard in Sunamganj Sadar, Jamalganj, Tahirpur, Chhatak and Dowarabazar. The piper trilinear diagram for critical water samples is shown in Fig. 2. The cation plot in the diagram reveals that majority of critical samples falls in no dominant type, whereas anion plots indicate the majority of critical water samples fall in Bi-carbonate.
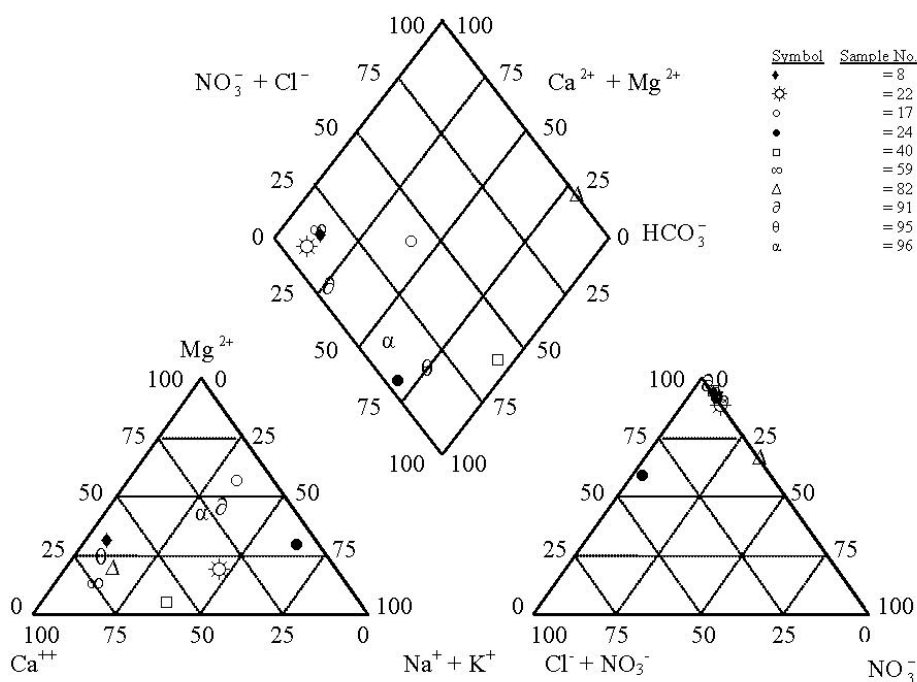

Fig. 2: Piper trilinear diagram showing chemical character of groundwater

DISCUSSION

There is a significant relationship between SAR values of irrigation water and the extent to which sodium (Na^+) is absorbed by the soil. If water used for irrigation is high in sodium (Na^+) and low in calcium, the cation change complex may become saturated with sodium (Na^+). This can destroy the soil structure owing to dispersion of the clay particles. Besides, Soils containing large proportion of sodium (Na^+) with carbonate and chloride or sulphate are termed as alkali or saline water, respectively (Todd, 1980). Presence of sodium (Na^+) in irrigation water reacts with soil to reduce permeability and its repeated uses makes the soil impermeable, while high sodium leads to development of alkali soil. High sodium saturation also directly causes calcium deficiency. Frequent irrigation with high sodium (Na^+) water for a considerable duration makes the soil plastic and sticky in wet condition and form clods and crust on drying condition. In contrast, presence of calcium or magnesium salts in irrigation water retards the evil effect of sodium by increasing the permeability of the soils (Punmia and Lal, 1981; Asaduzzaman, 1985).

Based on the classification after Wilcox (1995)

for SSP, 35% groundwater samples were fall under '*excellent*' class and only 9% of them were under '*poor*' class. 29% samples belong to '*fair*' and 26% were fall under '*good*' which indicate that all these water could be safe for irrigation.

The quality of irrigation water depends primarily on the total concentration of dissolved constituents. The salts present in the water bodies affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth.

At the same level of salinity and SAR, adsorption of sodium by soils and clay minerals is more at higher Mg: Ca ratios. This is because the bonding energy of magnesium is less than that of calcium, allowing more sodium adsorption and it happens when the ratio exceeds more than 4 (Michael, 1978). It was also reported that soils containing high levels of exchangeable magnesium causes infiltration problem (Ayers and Westcot, 1985). In the present study, most of the samples contained the ratio of magnesium and calcium below 4 (90 out of 96). High MAR causes a harmful effect to soil when it exceeds 50.

In the study area, the abstracted samples contained trace amount of CO_3. But HCO_3 contents were found to vary from 25 (at Sunamganj sadar) to 480 (at Tahirpur) mg/L. Mean value of bicarbonate ion concentrations was 140.2 mg/L. It was reported that irrigation waters rich in bicarbonate content tend to precipitate insoluble calcium and magnesium in the soil as their precipitates which ultimately leaves higher sodium proportion and increase SAR value (Michael, 1978) as:

$$2HCO_3^- + Ca^{2+} = CaCO_3 + H_2O + CO_2 \uparrow$$

It was also reported that although ordinary bicarbonate is not to be a toxic ion, but it is reported to cause zinc deficiency in rice and severe when it exceeds 2 meq/L in water used for flooding growing paddy rice (Ayers and Westcot, 1985). At Dharmapasa the value is the highest (37.58). But, Kelly (1963) suggested that this ratio for irrigation water should not exceed 1.0. Seventy one out of ninety six i.e. 74 percent of total samples were found less than the permissible value of 1.0 showing a good balance of sodium, calcium and magnesium ions.

The positive residual sodium bicarbonate (RSBC) Value indicates that dissolved calcium and magnesium ions less than that of carbonate and bicarbonate contents. RSBC of the samples was not satisfactory (<5mg/L) according to the criteria set by Gupta and Gupta (1987).

Permeability Problem (PI) occurs when normal infiltration rate of soil is appreciably reduced and hinders moisture supply to crops which is responsible for two most water quality factors as salinity of water and its sodium content relative to calcium and magnesium. Highly saline water increases the infiltration rate. Relative proportions of other different cations or balance of some cations and anions defined by SAR, SSP, KR, MAR, TH, RSBC etc. also the indicators of permeability problem. PI values varied from 2.4 (at Sunamganj Sadar) to 366938.8 meq/L (at Chhatak).

Development of GIS map based on number of tube-wells

The GIS techniques used in this study (Fig. 3) demonstrated their capability in groundwater quality mapping. The maps we were able to create offered a pictorial representation of groundwater quality throughout the Sunamganj district, and allowed us to delineate clearly whether the groundwater found within specified locations was suitable or unsuitable for purposes of drinking and irrigation. To do this, we had divided the Sunamganj district into three zones based on number of tube wells available in the study area: Zone-1 consisted of Chhatak and Dowarabazar. Sunamganj Sadar, Tahirpur and Bishwamvarpur were in zone-2 and the rest of the areas: Jamalganj, Jagannathpur, Derai, Sulla and Dharmapasa belong to zone-3 (Fig. 4). As it is clear from the above observation that iron, nitrate, SAR, SSP, KR, MAR, TH, RSBC is the critical parameters. The map was prepared based on the above parameters.

Groundwater quality map for irrigation was drawn based on Sodium adsorption ratio (SAR) and Soluble sodium percentage (SSP) values after Ayers and Wester (1985), Eaton (1950), Todd (1980) and Wilcox (1950) respectively. The maps for irrigation purposes are shown in the following Figs. 5, 6, 7, and 8, respectively. It was unambiguous from all the figures that, in Zone-1,
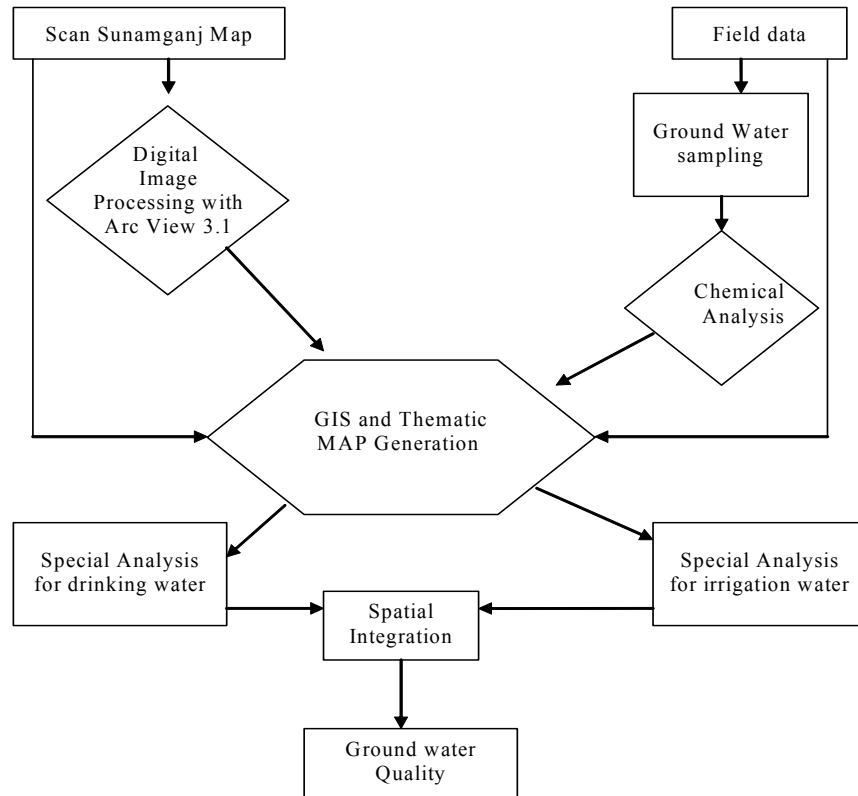
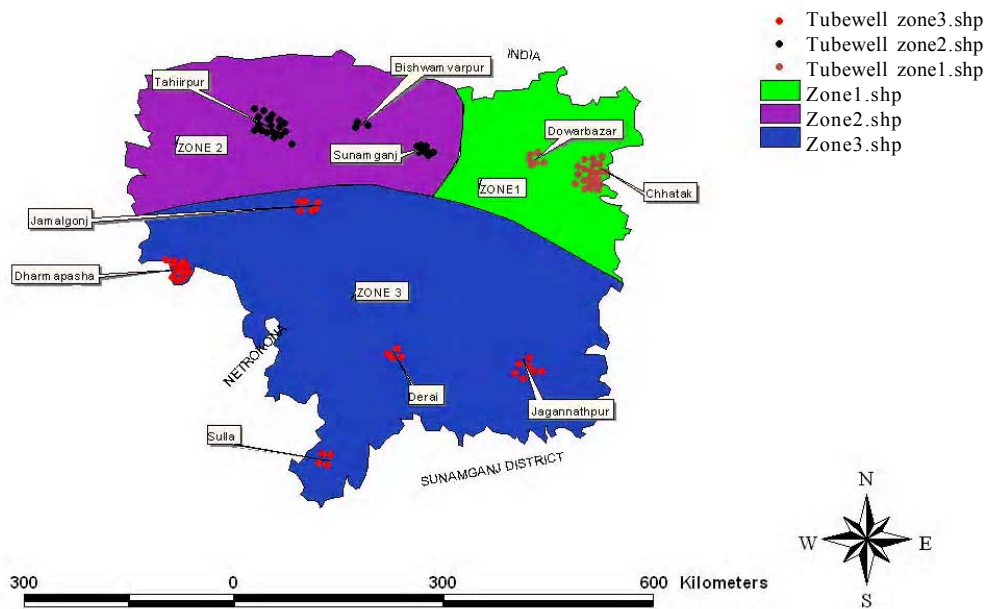Fig. 3: Methodology used for groundwater mapping by using GIS technique

Fig. 4: Number of tube-wells in different zones of the study area
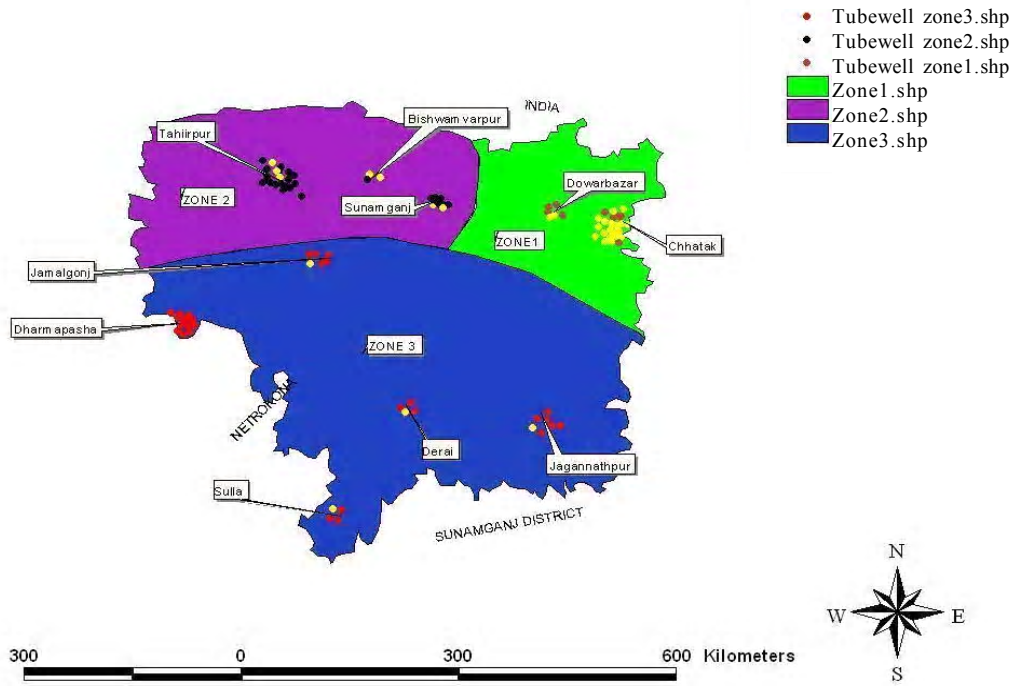
Fig. 5: Number of tube-wells within excellent irrigation category
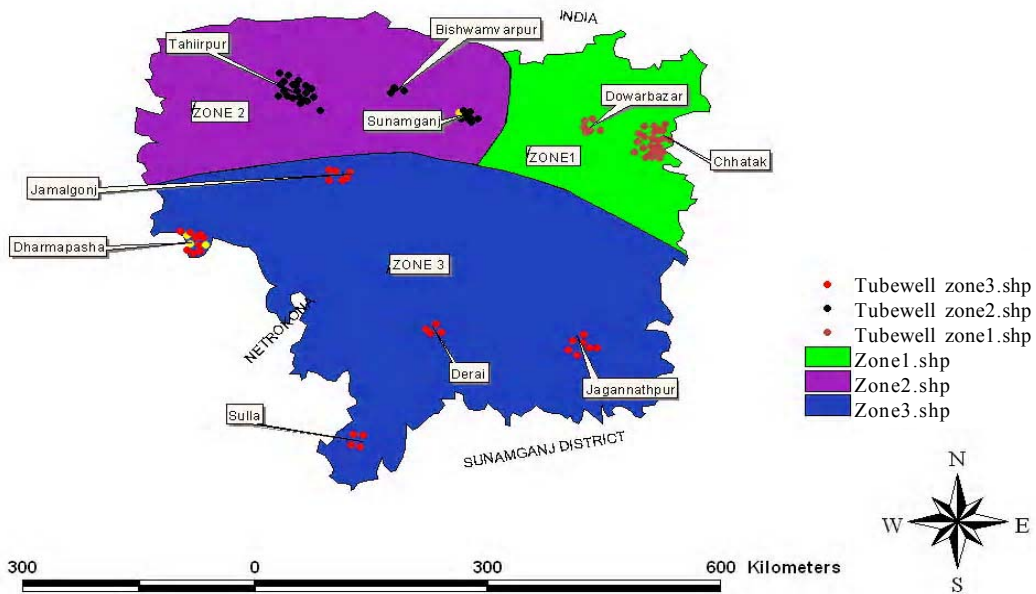

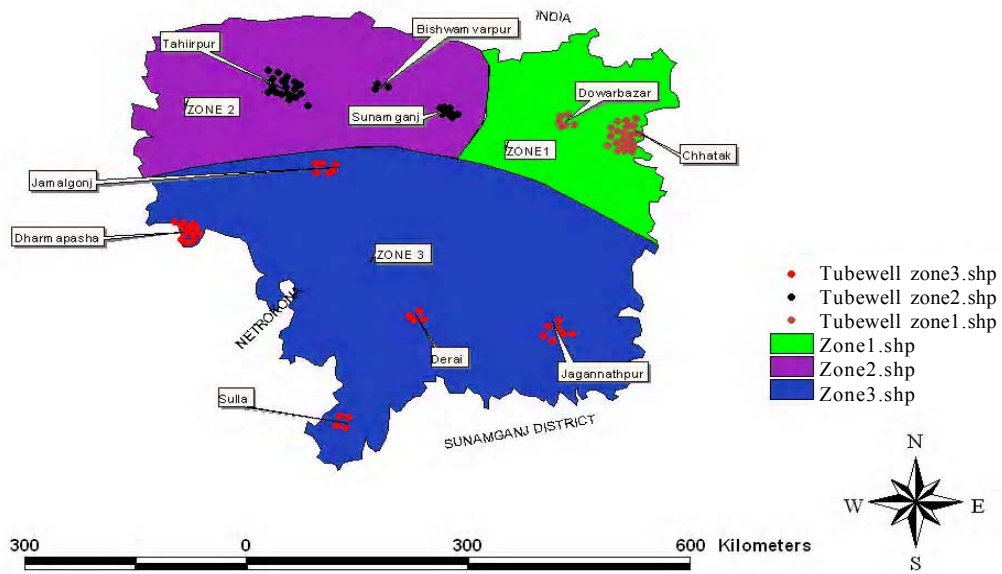Fig. 6: Number of tube-wells within fair irrigation category

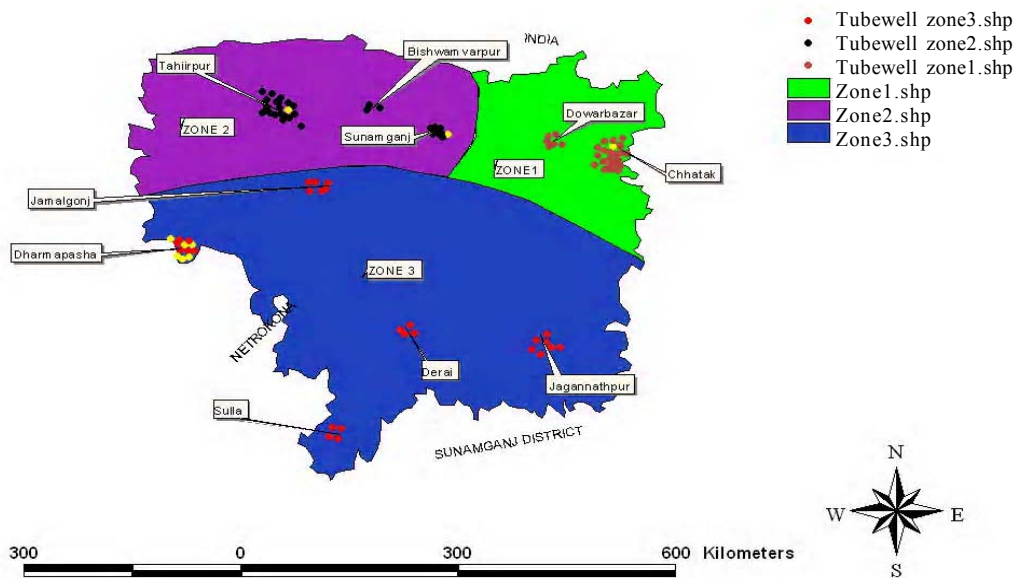Fig. 7: Number of tube-wells within good irrigation category

Fig. 8: Number of tube-wells within poor irrigation category

70% samples were *excellent* and 3 % were *poor*. Whereas, in Zone-2 and Zone-3, 21% and 12% samples were *excellent* and 65% and 18% are of *poor* classes respectively. These figures also indicate that rests of the samples were within the class of either *good or fair*. It should be pertinent to mention that the groundwater quality parameters among the three Zones, only Zone-1 were fall into '*excellent*' class and supporting highly the suitability condition for irrigation. On the other hand, Zone-2 is more risky compare to Zone-3 because this zone was categorized into '*poor*' classes.

It was evident from the analysis of water quality index of Sodium Adsorption Ratio (SAR) that seventy five percent of the total samples of our study area falls under the category of low sodium hazards (in excellent category i.e. <10), which reveals that the groundwater of Sunamganj district is free from any sodium hazard. Average Total Hardness of the samples in the study area was in the range of between 215 mg/L at Tahirpur and 48250 mg/L at Bishamvarpur. At Bishamvarpur,

the water was found very hard. Besides, the samples were moderately hard in Sunamganj Sadar, Jamalganj, Tahirpur, Chhatak and Dowarabazar. In case of Average Kelly's Ratio (KR) seventy one out of ninety six i.e. 74 percent of total samples were found less than the permissible value of 1.0 showing a good balance of sodium, calcium and magnesium ions. The result also indicates a good tilth condition of the soil with no permeability problem. Regarding Magnesium Adsorption Ratio (MAR) fifty five out of ninety six i.e. approximately 58 percent of total samples were obtained within the acceptable standard of 50. From irrigation point of view, it can be asserted that in zone-1, 70 percent samples were excellent and 3 percent were poor, where as in zone-2 and in zone-3, only 21 percent and 12 percent samples were excellent but 65 percent and 18 percent belong to poor classes respectively. The rest of the samples were fall in either good or fair categories. So, the irrigation water quality map (shown in Figs. 5-8) shows that the groundwater of the area is desirable or moderately desirable for irrigation purposes.

Table 1: Summary statistics of different indices

Parameter	Concentration			
	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Std. Dev. (mg/L)
SAR	0.1014426	425.1833	15.29665	46.06878
SSP	0.1254486	98.17142	38.01237	27.03063
MAR	1.865285	98.57507	1.74277	25.75847
KR	0.0144126	37.58125	1.74277	4.538934
PI	2.403184	366938.8	9271.161	44603.72
TH	215	48250	3018.481	5003.516
RSBC	-712	353	111.1434	114.9313

Table 2: Limits of some parameter indices for rating groundwater quality and its sustainability in irrigation

Category	EC (µhoes/cm)	RSC (me/l)	SAR	SSP	Sustainability for irrigation
I	<117.509	<1.25	<10	<20	Excellent
II	117.509-503.61	1.25-2.5	10-18	20-40	Good
III	>503.61	>2.5	18-26	40-80	Fair
IV	-	-	>26	>80	poor

*According to Ayers and Wester (1985), Eaton (1950), Todd (1980) and Wilcox (1950) respectively

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