EVALUATION OF GROUNDWATER QUALITY FOR IRRIGATION IN BANGLADESH USING GEOGRAPHIC INFORMATION SYSTEM

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About 75% of water for irrigation in Bangladesh comes from groundwater. As the crop yield is directly related to quality of water used for irrigation, an assessment of groundwater suitability for irrigation is essential for the growth of food production and poverty eradication. An attempt has been made in this paper to study the suitability of groundwater for irrigation in Bangladesh. Geographic information system (GIS) is used for the processing of groundwater quality data collected from 113 locations sporadically distributed over the country and the preparation of groundwater quality maps. The result shows that groundwater of the southwestern part of Bangladesh, which comprises 22.5% area of the country, is highly affected by salinity and sodium hazards. Groundwater in 10.54% area of the country is also contaminated by Arsenic above the permissible level recommended for irrigation.

KEY WORDS: Groundwater Quality, Irrigation, GIS, Bangladesh.

Introduction

Bangladesh is one of most densely populated countries of the world. The ever-increasing population of Bangladesh requires that agricultural production must be increased to meet the food needs of the population. During the last three decades, irrigation coverage has been increased significantly to raise food production levels. The total area under irrigation has been raised from 1.52 million hectares in 1982 to 4.04 millions in 2004. In the absence of adequate surface water in the dry season, irrigation of Bangladesh is heavily dependent on groundwater. During the last twenty years, much of the increase in irrigation has been accomplished through installation of shallow tube-wells. It has been observed that the area under irrigation by surface water has remained more or less static since the early eighties, while the area under irrigation by shallow tube-wells has increased by a factor of about five (Bari and Anwar, 2000). The contribution of groundwater to total irrigated area has increased from 41% in 1982 to 75% in 2004. According to a recent survey report (BADC, 2004), out of total 4.04 millions irrigated land, 3.03 million hectares of land are irrigated by groundwater in 2004. The use of groundwater in irrigation is supposed to increase more in the coming years. The quality of water used for irrigation has a direct effect on crop yields and land degradation (Bernstein, 1975; Solomon, 1985; Lauchli and Epstein, 1990; Malash, 2002). Therefore, assessment of groundwater qual-
ity of Bangladesh is essential for agricultural water management and the growth of food production. Based on this concern, a study of groundwater quality of Bangladesh as a source of irrigation is carried out in this paper.

There are a number of factors that contribute to the quality of water for irrigation. Among those, four criteria are widely considered for the assessment of water quality for irrigation. Those are: (i) total soluble salt content in the water or salinity hazard, (ii) relative proportion of sodium cations to other cations or sodium hazard, (iii) excessive concentration of elements that causes ionic imbalance in plants or toxicity, and (iv) excessive presence of other miscellaneous elements like bicarbonate anion (Ayers and Westcot, 1985). However, the first two criteria are of major concern in water quality for irrigation in Bangladesh. Excess salt increase the osmotic pressure of the soil solution that can result in a physiological drought condition. Even though the field appears to have plenty of moisture, the plants wilt as the water is absorbed by the roots is insufficient to replace that lost from transpiration (Shainberg 1984; Mashali, 1989). It has been found that the application of 1 centimeter of moderately saline irrigation water (640 mg l⁻¹) contributes approximately 69 kg of salt per hectare. Since the amount of irrigation water needed to supply during the rice cultivation period is approximately 122.6 cm ha⁻¹, an amount of 8.5 tons of salt can accumulate per hectare soil in a season. On the other hand, the main problem with a high sodium concentration is its effect on the physical properties of soil. It is always wise to avoid water with high sodium value if it is the only source of irrigation water, as the continued use of sodium water leads to a breakdown in the physical structure of the soil (Hadas, 1982). High soil sodium causes soil clays and organic matter to clog soil pores, reducing water infiltration and soil aeration. Consequently, the soil becomes hard and compact when dry (Rhoades, 1987; Shainberg, 1990). These problems are greater on fine textured soils such as clays and loams. Besides salinity and sodium hazards, excess concentration of arsenic has become a major concern of water quality in Bangladesh. Arsenic at a given concentration in water may be toxic to crop and there is a high probability of inclusion of arsenic in the crop life cycle (Meharg, 2001; Huq, 2002).

A number of studies have been carried out to observe the effect of groundwater quality on the yield and growth of crops in Bangladesh. Gain et al. (2004) reported that due to the high value of salinity in the southern part of Bangladesh, growth and yield of rice are comparatively less than that is irrigated with low saline water. They observed that growth of rice plants decreases with the increase of salinity in irrigation water. Miah et al. (2004) conducted a survey in the southwestern districts of Bangladesh and reported a reduction in crop yield due to low quality of irrigated water. They also observed that increasing trend of salinity in southwest region of Bangladesh is reducing the farmers’ interest to cultivate various agricultural crops. The fruit trees like mango, betle nut, coconut, date palm, giant taro, jackfruit, black berry, wax jambu etc. are disappearing gradually. Besides the declining tree species, reducing soil fertility, increasing disease and insect infestation in field crops, increasing human and animal diseases are the major impact of increasing salinity in the coastal areas of Bangladesh. Prolonged use of poor quality water for irrigation also causes a detrimental effect on soil and proper management is essential for reducing the soil degradation. In the present paper, besides the common groundwater quality survey, suitability of groundwater for irrigation of paddy and wheat, which are the main cultivation of Bangladesh, is also assessed. The groundwater quality data jointly collected by British Geological Survey (BGS) and Department of Public Health Engineering (DPHE), Bangladesh in 1998 are used for the study (Kinniburgh, 2001).

For hydrogeological studies over a large area, it often requires to assimilate information from many sites, each with a unique geographic location. GIS is well suited for efficiently storing, manipulating, analyzing and display large amount of spatial data as well as non-spatial data (Shahid, 2000). Therefore, GIS is used in the study for the processing of groundwater quality data and mapping of groundwater quality for irrigation.

In the next section of the paper, a brief description of geography and irrigation of Bangladesh is given. This follows a discussion on the methods used for the analysis of irrigation water quality. Next, the procedures for data processing and mapping are described. The results obtained by the study are given in the last section of the paper.

**Geography and irrigation of Bangladesh**

Bangladesh is a country situated in south Asia. Total land of the country is 143,998 km² with a population of 149.7 million. The density of population is 1,039 per km², which is among the highest in
the world. Geographically, it extends from 20°34'N to 26°38'N latitude and from 88°01'E to 92°41'E longitude. Except the hilly southeast, most of the country is a low-lying plain land. Climatically, the country belongs to sub-tropical regions where monsoon weather prevails throughout the year. The average temperature of the country ranges from 7.2°C to 12.8°C during winter and 23.9°C to 31.1°C during summer. The average relative humidity for the whole year ranges from 78.1% to 70.5% with a maximum in September and a minimum in March (Rashid, 1991). The average annual rainfall varies from 1329 mm in the northwest to 4338 mm in the northeast.

Bangladesh is primarily an agrarian economy. Agriculture is the single largest producing sector of the country's GDP and employing around 60% of the total labor force. Though nearly 100 different kinds of crops are presently grown in Bangladesh, rice is the principal one which grows in all the three crop growing seasons of the year and covers about 79% of the total cropped area. Crops in Bangladesh are grown both under rain-fed and irrigated conditions. However, irrigated agriculture is usually associated with high-productivity and more or less stability with an assured water supply. Consequently, the trend of irrigated agriculture has been increasing in Bangladesh. Before 1960’s, farmers were used to grow crops under rain-fed conditions. Systematic irrigation started in the early 1960s, with the introduction of deep tube-wells and low-lift pumps. Four types of irrigation methods are commonly used in Bangladesh viz. basin method, border method, furrow method and sprinkler method. However basin method is mostly used specially for the irrigation of paddy (Islam, 2003).

Almost 75% of irrigation water in Bangladesh comes from groundwater. There are three groundwater systems in Bangladesh (UNDP, 1982): Upper Shallow Unconfined Aquifer, Middle Confined Aquifer also known as Main Aquifer, and Deep Confined Aquifer. Over most of the country the uppermost shallow aquifer is used for extraction of water for irrigation. This aquifer exists below the upper clay and silt unit of depth ranging from less than a meter to several hundred meters. The thickness of the shallow aquifer ranges from a few meters in the northwest to a maximum of 60m in the south. The aquifer material varies from fine to very fine sand, in places inter bedded or mixed with medium sand. Discontinuous thin clay layers often found to separate these sand layers (UNDP, 1982).

Bangladesh has a large proportion of groundwater potentially available for further development. However, despite plentiful water resources, poor groundwater quality for irrigation especially salinity is one of the major limitations to development. High salinity and sodium in some parts of Bangladesh has affected the crop production and soil problems (Islam, 2003).

Methodology

There are four basic criteria for evaluating water quality for irrigational purposes, viz. salinity hazard, sodium hazard, excessive concentration of toxic elements and excessive presence of other miscellaneous elements. In groundwater of Bangladesh salinity hazard, sodium hazard and excessive concentration of arsenic, nitrate-nitrogen and chloride has been reported to occur. Measurement of these quantities in groundwater and their classifications are described in the following subsections.

**Salinity hazard**: Salinity in groundwater can be measured either indirectly by measuring the ability of water to conduct an electrical current or directly measuring the presence of various salts in water. According the techniques used for the measurement of salinity, it is expressed in two different ways, either as electrical conductivity or total dissolved salts (TDS). Total dissolved salts are expressed in parts per million (ppm) or milligrams per liter (mg l⁻¹). Irrigation water is classified into three categories based on salinity, which considers the potential for damaging plants and the level of management needed for utilization as an irrigation source (Ayers and Westcot, 1985). The classification of irrigation water based on salinity by Ayers and Westcot (1985) is given in Tab. 1. Water with salinity less than 450 mg l⁻¹ is generally suitable for irrigation without problems. Successful use of water with salinity in a range between 500 and 2000 mg l⁻¹ depends upon soil conditions and plant tolerance to salinity. It might cause damage to plants with low tolerance to salinity. However, plant growth and quality can be improved with excess irrigation for leaching, and periodic use of low salinity water and good drainage. Under typical summer stress growing conditions, salinity of irrigation water should ideally not exceed 1500 mg l⁻¹ soluble salts. Irrigation water with salinity above this level damages plants even have high tolerance to salinity. It is unsuitable as an irrigation source for any length of time (Ayers and Westcot, 1985).
**Sodium hazard**: Sodium hazard in groundwater is determined by calculating sodium absorption ratio (SAR). SAR relates the concentration of sodium ($\text{Na}^+$) to the concentration of calcium ($\text{Ca}^+$) and magnesium ($\text{Mg}^+$) as,

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\left(\frac{\text{Ca}^+ + \text{Mg}^+}{2}\right)}}$$

where $\text{Na}^+$, $\text{Ca}^+$ and $\text{Mg}^+$ are expressed in milliequivalents per liter (meq l$^{-1}$). The higher the $\text{Na}^+$ in relation to $\text{Ca}^+$ and $\text{Mg}^+$, the higher the SAR. Irrigation water is classified into three groups \((\text{Ayers and Westcot}, 1985)\) according the SAR values (Tab. 1). Water with SAR value less than 10 is suitable for any crop. Water with SAR within a range of 10 to 24 may cause problems on fine texture soils and sodium sensitive plants, especially under low-leaching conditions. For irrigation with water having SAR of this range requires good sodium tolerant plants along with special management such as the use of gypsum. Irrigation water with SAR values more than 24 are harmful for crops in most soils, except with high salinity (1280 mg l$^{-1}$), high calcium levels, and the use of gypsum.

Toxic materials: Direct toxicity to crops may result from some specific trace elements in irrigation water. When such element is added to the soil through irrigation, it may be inactivated by chemical reaction, or it may build up in the soil until it reaches a toxic level. There is a long list of elements that can cause toxic effect on crops. However, in groundwater of Bangladesh only Arsenics, Nitrate-Nitrogen and Chloride are found to exist beyond permissible level. Irrigation water is classified into two to three groups according the concentration of those toxic elements \((\text{Ayers and Westcot}, 1985)\), which is given in Tab. 1.

Water quality suitability for paddy and wheat: The level of salinity suitable for irrigation depends on crop tolerance and soil permeability. Salinity levels suitable for irrigating paddy and wheat in different soils are given in Tab. 2 \((\text{deHayr}, 2004)\). Continued use of irrigation water with salinity greater than 3072 mg l$^{-1}$ in clayey soil, 1728 mg l$^{-1}$ in loom soil and 1024 mg l$^{-1}$ in sandy soil reduces the growth and quality of rice. Detrimental effects are greatest during prolonged droughts when irrigation water is the sole source of water and irrigation amounts typically do not exceed evapotranspiration. For irrigation in wheat field, a salinity value less than 6016 mg l$^{-1}$ is suitable in clayey soil, 3392 mg l$^{-1}$ in loom soil and 1984 mg l$^{-1}$ in sandy soil.

### Data processing and suitability mapping

For the study of arsenic contamination in groundwater, British Geological Survey (BGS) and Department of Public Health Engineering (DPHE), Bangladesh, jointly collected groundwater samples from 119 sites in Bangladesh in the month of July 1998 \((\text{Kinniburgh}, 2001)\). They examined the water

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**Table 1.** Water quality criteria for irrigation \((\text{Ayers and Westcot}, 1985)\).

<table>
<thead>
<tr>
<th>Degree of restriction on use</th>
<th>None</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity [mg l$^{-1}$]</td>
<td>&lt; 450</td>
<td>450 – 2000</td>
<td>&gt; 2000</td>
</tr>
<tr>
<td>SAR</td>
<td>&lt; 10</td>
<td>10 – 24</td>
<td>&gt; 24</td>
</tr>
<tr>
<td>Arsenics [mg l$^{-1}$]</td>
<td>&lt; 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate-Nitrogen [mg l$^{-1}$]</td>
<td>&lt; 5</td>
<td>5 – 30</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Chloride [mg l$^{-1}$]</td>
<td>&lt; 4</td>
<td>4 – 10</td>
<td>&gt; 10</td>
</tr>
</tbody>
</table>

**Table 2.** Tolerance of paddy and wheat to salinity in different soils \((\text{deHayr}, 2004)\).

<table>
<thead>
<tr>
<th>Crops</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity threshold [mg l$^{-1}$] for crops growing</td>
<td></td>
</tr>
<tr>
<td>Rice (Paddy)</td>
<td>High</td>
</tr>
<tr>
<td>Wheat</td>
<td>3072</td>
</tr>
<tr>
<td></td>
<td>6016</td>
</tr>
</tbody>
</table>
sample for measuring the contents of 53 constituents of groundwater including Arsenic, Sodium, Calcium, Magnesium, Chloride and different salts, toxic and heavy elements. The data were collected mainly from tube-wells operating at shallow depth except in some places where data were collected from deeper aquifer. In the present study, data that were collected from shallow aquifer are used for the assessment of groundwater quality for irrigation as the shallow aquifer is mainly used for irrigation in Bangladesh. The location of groundwater sample collection points is shown in Fig. 1.

Fig. 1. The location of groundwater sample collection points.

The groundwater quality data are incorporated in a Geographic Information System (GIS) for processing and analysis. The contents of different salts values are added to get the value of salinity in groundwater. The SAR is calculated from the Sodium, Calcium and Magnesium contents using Eq. (1). The toxic and heavy elements, which exist above the permissible levels for irrigations are also identified. Only Arsenic, Nitrate-Nitrogen and Chloride contents in some extents are found in some places above the permissible level. The point values of salinity, SAR and toxic elements are used to prepare the corresponding raster grid maps using kriging method (Journel and Huijbregts, 1981; Isaaks and Srivastava, 1989). Variograms are computed to fit the data and obtain best interpolation. The grid values of the raster maps are classified according the ranges given in Tab. 1 to prepare thematic maps. First, the thematic maps of toxic and other miscellaneous elements in groundwater are prepared. Figs 2a), b) and c) are showing the maps of chlorides, nitrates-nitrogen and arsenics in groundwater of Bangladesh. These maps are integrated by using GIS to prepare the thematic maps of toxicity in groundwater, which is shown in Fig. 3a). Next, the maps of salinity and SAR are prepared as shown in Figs 3b) and c) respectively. Finally, the thematic maps of salinity, SAR and toxicity in groundwater are integrated using the intersect method in GIS to prepare the map of groundwater suitable for irrigation, which is shown in Fig. 4. The variograms used for kriging of groundwater quality data for the preparation of thematic maps of Chlorides, Nitrate-Nitrogen, Arsenics, salinity and SAR are shown in Figs 5a), b), c), d) and e) respectively.

To study the suitability of groundwater for irrigation in paddy and wheat fields, thematic maps of salinity in groundwater and soil permeability are used. Soil map of Bangladesh given in Bangladesh Country Almanac (BCA, 2004) is used to regroup the polygons according their permeability values and the preparation of the thematic map of soil permeability of Bangladesh, which is shown in Fig. 6. Groundwater salinity map is first integrated with the soil permeability map. The polygons of the integrated map are then classified according the salt tolerance ranges of paddy and wheat in different soils given in Tab. 2 to prepare the maps of groundwater suitable for irrigating in paddy and wheat fields. The maps are shown in Figs 7a) and b) respectively.

Results and discussion

The study shows that groundwater in 8.31% area of Bangladesh is contaminated by very high salinity, 9.47% with very high SAR and 38.65% with toxic and other miscellaneous elements. Groundwater in 10.54% area of Bangladesh bears Arsenics above the permissible levels for irrigation. Areal distribution of salinity, SAR and toxicity in groundwater of Bangladesh is given in Tab. 3.

The groundwater suitability map for irrigation shows that groundwater in 22.5% area of Bangladesh is unsuitable for high salinity, sodium or toxicity. 32.33% area is moderately suitable and 45.16% area is suitable for irrigating any crop. The overall
Fig. 2. Maps of a) chlorides, b) nitrate-nitrogen, and c) arsenics contents in groundwater of the Bangladesh.

Obr. 2. Mapy a) chloridov, b) dusíčnanového dusíka, c) arzénu v podzemných vodách Bangladeša.
Fig. 3. Thematic maps of a) toxic and miscellaneous elements, b) salinity, and c) sodium absorption ration (SAR) in groundwater of the Bangladesh.

Obr. 3. Mapy a) toxických a ďalších prvkov, b) zasolenosti, c) sodíkového adsorpčného pomery (SAR) v podzemných vodách Bangladeša.
The groundwater salinity levels vary widely from place to place and with seasons in a year. Irrespective of location, the common trend in Bangladesh is an increase in salinity with time from November-December to March-April until the onset of the monsoon rains (Islam, 2003). Usually July-August is the period of minimum salinity, January-February of intermediate salinity and March-April of maximum salinity. The maps are prepared in this paper by using data collected during the month of July. Therefore, the maps show the least saline affected groundwater zone of Bangladesh in a year.

It can be observed from Fig. 4 that groundwater in the coastal area of Bangladesh is highly affected by salinity and sodium hazards. There has been an increase intrusion of salinity particularly along the coastal areas in the southwest of the country. Historical data shows that over the last two decades the area affected by salinity has expanded remarkably (AGL, 2000). The causes of groundwater salinity increase have both natural and anthropogenic causes. Natural causes include tidal surges due to cyclones or exceptionally high tides, which push the salinity front further into the groundwater. The anthropogenic causes include reduced availability of fresh water, drying up of rivers and saline water intrusion from the sea into the Ganges basin area due to the withdrawal of the Ganges River water upstream outside the boundaries of Bangladesh and upland shrimp culture causing seepage of saline water from the shrimp ponds into the groundwater. Another major cause of salinity in the groundwater of coastal aquifer is due to the induced flow of salt water into fresh water aquifers caused by improper groundwater development. This increase reinforces the need for proper monitoring and controlling

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**Table 3.** Areal distribution of different groundwater quality parameters in Bangladesh.

<table>
<thead>
<tr>
<th>Quality parameters</th>
<th>Area [km²]</th>
<th>Area [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>11961.83</td>
<td>8.31</td>
</tr>
<tr>
<td>Moderate</td>
<td>55876.17</td>
<td>38.80</td>
</tr>
<tr>
<td>Low</td>
<td>76159.99</td>
<td>52.89</td>
</tr>
<tr>
<td>SAR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>13634.69</td>
<td>9.47</td>
</tr>
<tr>
<td>Moderate</td>
<td>10585.68</td>
<td>7.35</td>
</tr>
<tr>
<td>Low</td>
<td>119777.60</td>
<td>83.18</td>
</tr>
<tr>
<td>Toxic and other miscellaneous elements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>55658.63</td>
<td>38.65</td>
</tr>
<tr>
<td>Low</td>
<td>88339.37</td>
<td>61.35</td>
</tr>
</tbody>
</table>
Fig. 5. Variograms used for the preparation of thematic maps of a) chlorides, b) nitrate-nitrogen, c) arsenics, d) salinity and e) SAR by kriging.

Obr. 5 Variogramy použité na přípravu máp a) chloridov, b) dusičnanového dusíka, c) arzénu, d) zasolenia, e) sodíkového adsorpčného poměru interpolačnou metodou (kriging).
methods for salt-water intrusion. To control the increased salinity in groundwater the proper balance has to be maintained between water being pumped from the aquifer and the amount of water recharging it. Constant monitoring of the salt-water interface is necessary in determining proper control measures.

As the surface water in the southwestern region of Bangladesh is also highly saline, there is no alternative except to use deeper groundwater for irrigation in the region, as the water of this aquifer is relatively low in salinity. As the exploration of groundwater from deep aquifers is sometimes expensive, the crop variety having high salt tolerance could be cultivated in the coastal region. Gain et al. (Gain, 2004) reported that rice variety BR11 has tolerance to certain level of salinity in respect of plant height, number of tillers and biomass production. Therefore, this variety of paddy could be cultivated in the saline zone of the coastal regions of Bangladesh. Some alternative cultivation of crops that have high salt and sodium tolerance can also be done in the region.

Continuous use of saline water for irrigation may cause high soil salinity. Good drainage is essential to leach soluble salts through the soil profile. The better the drainage, the better one can keep soluble salts in the root zone within tolerable limits. Poorly drained soils accumulate salts due to poor drainage. Sandy soils are usually best suited for saline irrigation because of easy drainage. Unfortunately, the soil in most of the southwestern coastal zone of Bangladesh is clayey in nature. Therefore, drainage, leaching and changes to more salt tolerant crops are necessary in the region to avoid the impact of long-term salinity build-up. Some cultural practices can also be adopted for possible short-term or temporary control of salinity such as more frequent irrigation, land grading, timing of fertilization and methods of seeding. In the area of high level of salinity, a soil drainage and reclamation program can be carried out and short-term cropping changes can be made. After soil reclamation, the permanent cropping pattern can be determined by water quality. In a few instances, an alternative water supply from deeper aquifer can be used periodically to diminish a quality-related hazard.

Conclusions

Bangladesh is blessed by plenty of groundwater resources. A huge amount of this resource is used for irrigation, domestic and other uses. There is still a large proportion of groundwater potentially available for further development. However, poor quality of groundwater for irrigation in the coastal zone of Bangladesh is one of the major problems of this resource. Proper management steps to maintain the balance between groundwater charging and recharging, and constant monitoring of the salt-water interface is necessary to control the land-ward ex-

<table>
<thead>
<tr>
<th>Groundwater quality</th>
<th>Area [km²]</th>
<th>Area [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>32402.82</td>
<td>22.50</td>
</tr>
<tr>
<td>Moderate</td>
<td>46560.66</td>
<td>32.33</td>
</tr>
<tr>
<td>High</td>
<td>65034.52</td>
<td>45.16</td>
</tr>
</tbody>
</table>
Fig. 7. Groundwater suitability maps for irrigating a) paddy, and (b) wheat fields.

Obr. 7. Mapa vhodnosti podzemných vôd na zavlažovanie a) ryžových polí, b) pšenice.

pansion of salinity. High salinity and sodium in southwestern coastal parts of Bangladesh has been affected the crop production and soil problems. Proper management and favorable cultural practices are necessary in the region to avoid the impact of long-term salinity build-up.

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VYHODNOTENIE KVALITY PODZEMNEJ VODY PRE ZÁVLAHY V BANGLADEŠI PRI VYUŽITÍ GEOGRAFICKÉHO INFORMAČNÉHO SYSTÉMU

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