GROUNDWATER PROTECTION IN KUWAIT: DESIGN OF MONITORING NETWORK AND RECOMMENDED PATH

M. Al-Senafy[1], A. Fadlelmawla, A. Mukhopadhyay, A. Al-Khalid, and K. Al-Fahad

Water Research Center, Kuwait Institute for Scientific Research
Email: msenafy@kisr.edu.kw

ABSTRACT

Being the sole natural water resource, the supplier of about 8% of potable water, and the main provider of irrigation needs, groundwater in Kuwait do merit a program to protect its quality. In an effort to initiate a program for groundwater quality protection, a national monitoring network was conceptually designed to serve as a tool for managing the risks. A network of monitoring wells covering all sources of groundwater in a country is an integral part of the protection measures for this vital resource. Sampling of these monitoring wells at fixed intervals and chemical analyses of the samples collected provide the information necessary for the evaluation of the state of health of the groundwater resources and subsequent measures to be adopted to ensure the continuing usability of the water. The processes, phenomena, and activities that are to be monitored in Kuwait for groundwater protection purpose were identified. The national monitoring network design includes number, location, and type of the monitoring wells required. An estimate of more than 400 wells would be needed to cover the whole of Kuwait. In estimating the requirements of the monitoring network in areas where hazardous anthropogenic activities are taking place, both the intrinsic risk to pollution and the value-weighted risk have been considered. The study recommended six milestones in the path of protecting groundwater quality in Kuwait.

Keywords: quality, wells, anthropogenic.
Received 22 April 2016.Accepted 21, June 2016
Presented in IWTC 19th

1 INTRODUCTION

Quality protection is arguably the most complicated aspect of groundwater management. Many political, economical, and institutional issues must be resolved in order to implement any groundwater protection program. In the heart of it all, the requirements are having sound scientific assessment and management solutions for the threats imposed on groundwater quality. It is therefore the duty of national research institutions to play a role in bringing such programs a step closer to implementation, i.e., by developing the necessary tools for incorporating groundwater protection in the purview of decision making.

Akin to most of the Gulf Cooperation Council (GCC) countries, Kuwait, although suffering from extreme aridity, does not have a program for protecting the quality of its only natural water resource, that is, groundwater. This is mostly due to delayed global recognition of the groundwater vulnerability to surface originating pollution and the intimidating complexity of implementing them.

Kuwait's groundwater resources do merit protection for the reasons as follows: it is the only natural water resource of the country; it provides about 8% of the domestic water supply; practically covers most of irrigation needs; in many cases, decades may pass before a pollution episode becomes fully appreciated; and restoration of the natural quality of the groundwater is, on one hand, very expensive, and on the other hand, low success rate.

The aim of the study was to design and recommend a national monitoring network, as well as regulatory guidelines for groundwater protection. Monitoring the status of the natural resources is fundamental in sound management decisions. The main goal for this monitoring network, which is in general agreement with international practices (ARCMANZ and ANZECC, 1995; EA, 2007; EHS, 2001; Golder Associates, 1995; Logan, 1990; SEPA, 2003), is to provide the information needed in evaluating the current management practices, and if needed, adjust its course. This should apply for both the utilization of the resource and other developmental activities with the potential of impacting said resource.

2 METHODOLOGY

The study was focused, typically, as in the case of groundwater protection programs, on the uppermost aquifer, the Kuwait Group (KG). The study covered all the Kuwaiti territories including the hypersaline areas; however, the emphasis was on the less saline parts of the aquifer system. The reasons for considering the seemingly unusable hypersaline groundwaters were as follows: many perched freshwater tables are present on top of the hypersalinity waters; it is still usable in remote camps where desalination by small reverse osmosis (RO) system is the only source for freshwater; and the Kuwait Environmental Public Authority (EPA) regulations do not allow contamination of any environmental resource even if there is no foreseen function for this resource.

The study covered the aspect of groundwater quality protection, that is, monitoring. A national monitoring network has been conceptually designed. The designed network is composed of more than 400 wells (both existing and new wells), covering the whole country. The overarching aims of this network are to cover the nondevelopment threats (e.g., changes in groundwater quality trends at the national scale) to the groundwater quality and provide the information needed for evaluating the current management practices.

The design of the network included the design of wells, their locations, parameters to be sampled, and sampling interval. Finally, the study discussed and recommended six milestones that should be achieved to implement groundwater protection program in Kuwait.

3 DISCUSSIONS

The number of wells to be required for monitoring a process, phenomenon, or activity, the distribution pattern of the wells, and their design will depend on the nature of the activity to be monitored, its effect on the groundwater resources, and the nature of the hydrogeological conditions prevailing in the area to be monitored. Discussions on the general design of the wells, the initial estimate of their number, and distribution for each of the activity types subsequently follow.

3.1 Lateral Cross Boundary Recharge

Given the disposition of the potentiometric head contours in the Dammam formation and the Kuwait Group aquifers and the predominantly resulting southwest to northeast flow directions, the wells will be located near the southern and southwestern borders of Kuwait at a rough spacing of 20 km. The only exception would be at the southeastern corner of the country where the potentiometric levels are almost perpendicular to the borders suggesting little or no cross boundary recharge. Since the wells should monitor quality of water in the different horizons of the Dammam Formation and the KG (Lower, Middle and Upper Members of Dammam Formation and Lower and Upper KG), albeit, these should either be wells drilled to different depths or nested wells, sampling different horizons. Thus, the maximum depths of these wells will be in the range of 300–450 m. The wells should have a minimum diameter of 150 mm to allow pumps with sufficient lift to be lowered in the wells for pumping from a depth of 100 m or more and a screen interval of about 5 m, covering the stratigraphic horizon of interest. Based on this logic, a total of 15 to 20 monitoring sites will be needed, with each site, having sampling provision for three to six horizons within the KG and the Dammam Formation. The location of the monitoring sites should be distributed uniformly along the border with existing monitoring wells integrated in the network.

3.2 Regional Groundwater Quality Change Trends

Since the wells should monitor water quality at different levels of the Dammam Formation and the KG aquifers, multiple or nested wells at each site will be called for, and the following provisions should be considered. As the water salinity in the Dammam Formation aquifer exceeds 10,000 mg/l, and the aquifer reaches deeper depths toward the north, northeast, and east, the need to sample the lower horizons becomes less important, and only one well open to the whole aquifer would suffice. In North Kuwait, where depth to the Dammam Formation may reach 500 m or more and water becomes very saline to brine, the aquifer does not need to be monitored at all. On the basis of similar argument, for the Kuwait Group aquifer, only the upper part may need to be monitored in the extreme northeastern parts of the country, including the Bubyan Island. The well casing diameter should be 150 mm, as long as water has to be pumped from a depth of 80 m or more. For shallower depths to water where lower capacity pumps may be used, the casing diameter may be 100 mm.

3.3 Groundwater Mixing between Aquifers

As aforesaid, generally, an upward movement of water from the Dammam formation to the KG aquifer is expected over most of Kuwait. In the central and southwestern parts of Kuwait, this natural order of movement has been reversed due to human exploitation of the aquifers in these areas. The effects of this flow reversal on water quality may be monitored through wells sampling of both the aquifers to trace the level of mixing and the attendant changes in water quality located in the brackish water fields and in the Wafra Farm area (i.e., where both Dammam Formation and the KG aquifers are exploited). In North Kuwait, Dammam Formation is not exploited because of its large depth and highly saline nature, and no monitoring of this aquifer should be needed. Special design specifications related to the depth of the monitoring wells should be considered as mentioned in the previous sections. It is expected that 10 such sites will be required for the brackish water fields and 2 to 4 sites should be sufficient for the Wafra area.

3.4 Saline Water Incursion

In the brackish water fields, the continuous pumping has resulted in significant declines in the potentiometric levels of both KG and Dammam Formation aquifers. This decline is causing both vertical and lateral inward flow from adjacent areas/depths. However, the detrimental effects of lateral movement are likely not that serious, because of very gentle salinity gradient in that direction. Accordingly, the monitoring will be mainly focused on the upward movement of the saline waterfront; although, a few wells may be drilled in the upstream sides of the producing fields for tracking the lateral movement. To satisfy their purpose, these wells need to be deep enough to provide early detection of any upward movement of the saline front. Therefore, the wells will be completed in Dammam formation only with relatively large diameter casings, 100–150 mm to enable pumping from such depths. The screens may cover 5 to 10 m at depths of about 10 m above the saline front. Approximately, 10 deep wells distributed among the well fields may be required to be completed at the same sites used in monitoring the vertical mixing. In North Kuwait, the sharp increase in salinity in vertical and lateral directions away from the freshwater lens calls for monitoring both fronts. Five to ten wells will be needed for this field alone, due to its fragility. Similar wells may be drilled in the Raudhatain Field with screen intervals not exceeding 5 m in length (very sharp salinity variations) and should be located against the cleanest parts of each aquifer zone.

3.5 Potential Hazardous Activities on or near Ground Surface

This monitoring category includes various anthropogenic activities on and near the ground surface with wide range of nature, risk level, types of pollutants, and potential consequences of pollution. Accordingly, monitoring needs are expected to vary as well. One requirement should remain common among all the monitoring schemes of this category, which is the need for up and downstream monitoring wells. As explained previously, the number and the distribution of the monitoring wells required in the vicinity of these hazardous activities should be directly related to the level of risk from groundwater pollution at the site, as indicated by the groundwater pollution risk map. In determining the priority of monitoring at a hazardous site and its intensity; however, the intrinsic risk to pollution should be weighed by the value of the underlying groundwater.

3.6 Agricultural Activities

The unconfined KG aquifer that is directly affected by the return water from irrigation should be the target for monitoring the effects of agricultural activities on groundwater in these areas. The pollution risks in all three farm areas are very high. Therefore, close monitoring of the groundwater quality and levels in these areas should be of high priority. The typical up and downstream monitoring wells scheme (one upstream and two or more downstreams for this particular case with a groundwater mound formed below the farm), which is usually followed in surface originating pollutants would be applicable to Sulaibiya farm only, where irrigation water is mostly reused reclaimed wastewater. In Wafra and Abdally farms, the multiple pumping of the groundwater, over irrigation and probably the presence of impervious shallow layers have formed a complicated hydrogeological situation where it is rather difficult to distinguish up and downstream directions for these multiple nonpoint sources. Accordingly, the monitoring wells for those two farms will be allocated all around and within the agricultural area. For all three farms, the monitoring wells will be shallow with 5-m screens located at the top 10 m of the water table, as is usually the case for monitoring surface originating pollutants. Two wells for each farm will be drilled to deeper depths to estimate the extent of the pollutant plumes. Caution should be taken in identifying the water table in Wafra, as perched water tables are expected to be present, and as all of these wells are expected to be within the range from 25- to 40- m depth.

3.7 Oil-Related Activities

The oil refineries, as well as other oil-related plants, are potential sources of groundwater pollution, and this has been substantiated by earlier studies (Al-Senafy et al., 2004). The intrinsic risk of pollution to groundwater is very high in the refinery areas. Nonetheless, the groundwater in these areas is saline and at its discharge zone, and therefore, cannot be utilized, and is not posing any threats of spreading pollution in the aquifer. Accordingly, and in the context of national monitoring network, the focus would be on the overall monitoring of the groundwater discharging to the marine environment, rather than monitoring the specific point sources within the facilities. Hence, the monitoring wells will be allocated along the shoreline downstream of those plants. These wells (three wells per facility) should be sufficient and be shallow with screens, accessing the top five meters of the groundwater. A few additional wells (two per facility) may need to be drilled in the upstream of these plants to adequately cover the baseline characteristics of the groundwater and extent and intensity of the pollution plumes down gradient. The existing monitoring wells in the refinery areas and PIC plant, may be incorporated in the national network.

The underground tanks of the gasoline stations are notorious for their leakage potential. The majority of these stations are located in the urban areas that stretch along the coast, where the risk of pollution may be high to very high. It would be worthwhile to have at least one monitoring well at the downstream side of the underground storage tanks of the petrol stations. Depending on the location of the petrol stations, the depth of these wells should range from about 10 m near the coastal parts to 30–40 m along the Sixth Ring Road. The pump stations located in areas, where the depth to water exceeds 30 m, may not need monitoring.

Besides, monitoring of existing and old brine and oil disposal pits in the oil fields where the intrinsic risks range from high to very high, will also be needed to ensure the integrity of the groundwater.

3.8 Effects of the 1991 Gulf War

The freshwater fields of Raudhatain and Umm Al-Aish in North Kuwait have been contaminated by the oil spills, combustion products of hydrocarbon and the seawater used for extinguishing the oil fires. Both the intrinsic risk and the value-weighted risk for groundwater pollution are very high for these two areas. As yet, no discernible evidence of groundwater contamination from this event has however been observed in the brackish water fields of central and south Kuwait. Accordingly, monitoring is needed only for Al-Raudhatain and Umm Al-Aish fields. It is worth noting that with many potential sources of pollution, significant release of contaminant to the groundwater that have already taken place, and presence of a host of pollutants detections, of which are analytically challenging, the traditional approach of monitoring the source would not be practical. An alternative approach might be to monitor the potential pathways that can lead the pollutant to the two depressions. Even though this relatively easier approach would require an extensive hydrological study to determine such pathways; albeit, it still remains the only practical approach. It is not feasible at this stage, to estimate the number of needed wells. There are already a total of 115 monitoring wells distributed over 69 sites in Raudhatain and Umm Al-Aish areas, and it is expected that only minor additions would be needed.

3.9 Urban Developmental Activities and Infrastructure

Just like all major cities, Kuwait City hosts numerous potential sources of pollution. Some of them are major enough to be singled out for specific monitoring (e.g., industrial areas). The majority however, are either small, but widely spread sources (house gardens and roadside greeneries) or nonpoint sources extensively covering the city (e.g., wastewater network). Although the intrinsic risk of pollution is high, the value-weighted risk is often moderate due to the high salinity of groundwater in the coastal areas where Kuwait City is located. Accordingly, monitoring of this category will not be focused on specific sources of pollution, but rather on obtaining an overall image of the groundwater quality beneath the city and on detecting any changing trends. It is envisaged that 40 to 60 wells distributed over the city and its suburbs will be needed. The wells would mostly be shallow accessing the top 20 m of the KG aquifer.

3.10 Industrial Activities

Currently, there is no groundwater monitoring activity in and around the industrial areas (other than some oil-based ones) of Kuwait. All three designated industrial areas (Amgara, Subhan and Sulaibiya) are located within the zones of very high intrinsic pollution risk (>0.92). The value-weighted risk is, however, very high (> 1.49) for Sulaibiya area only. The same is moderately high (1.27–1.36) for Amgara and somewhat high (1.12–1.18) for Subhan. Thus, in the establishment of the monitoring facilities, Sulaibiya area should have precedence over the other two, and Subhan area will have the lowest priority. Initially, at least one upstream (at a distance of 500 – 1000 m from the area perimeter) and two downstream wells (at distances of 500 m and 1000 m from the border of the area) will be drilled in each of the three industrial areas. From the available information on depth to groundwater, to sample the top part of the saturated zone, the wells need to reach depths of 10–30 m in these areas. The screen length should range between 3 and 5 m. At a later stage, monitoring wells may be needed within the industrial areas for the purpose of continuous monitoring of particular sources.

3.11 Landfills

Of the three landfills studied by Al-Senafy et al. (2003), based on analytical evidence, two (Seventh Ring Road and Amgara landfills) were considered serious sources of pollution for the groundwater. These two landfills are also located in areas with high risk of groundwater pollution. Accordingly, monitoring schemes of 4 to 5 wells distributed up and downstream of each of the two sites, deemed to be hazardous, are needed. The Mina Abdullah landfill was considered to have much lower threat to the quality of the groundwater, as it was thought to be protected by thick unsaturated zone (≥ 60 m) and a 13-m thick silicified zone at the contact of the Dammam Formation and the KG. Therefore, only one upstream and one downstream wells have been proposed for monitoring this landfill. Additionally, there is an abandoned landfill site in Qurain that also needs to be monitored. The wells should have 10- to 15- m screens that tap top of the water table. Monitoring of other landfill sites should depend on their locations, depth to groundwater, and types of pollutants suspected to be released by them.

3.12 Interaction between Groundwater and Marine Resources

The monitoring of the quality of the groundwater discharged to the Arabian Gulf and Kuwait Bay is of interest only at areas where significant alterations of the groundwater quality are expected. This applies to Kuwait City and oil-related industries. Since the monitoring of the oil-related industries has been discussed earlier, this section is focused on Kuwait City. This monitoring category will require a series of shallow (maximum depth of 15 m) monitoring wells at a spacing of about 20 km or less all along the coastline (as close as possible to the shoreline) of Kuwait City.

On the other hand, the potential of inland invasion of the seawater due to pumping was considered significant only in the vicinity of the Atraf well field. Monitoring wells (3 – 5 in number) will be required near the northeastern tip of this field to track the possible intrusion, once the field is on regular production.

3.13 Parameters to be Monitored

To make it manageable, the number of chemical parameters to be analyzed for samples collected from each of the monitoring sites will be determined on the basis of the types of contaminants that are expected to be released by the source process, phenomenon or activity being monitored. For all wells, groundwater level will be measured prior to sample collection. Thus, for determining the overall background quality of the lateral recharge across the political boundary of Kuwait, a few basic physicochemical parameters such as electrical conductivity (EC), dissolved oxygen (DO), and pH, the major cations and anions, a few trace metals, sulfides (that can be important for brackish to saline water from depth) and organic contents, total organic carbon (TOC), and total organic matter (TOM) that can be used, as easily determined proxies for hydrocarbons picked up from natural or anthropogenic sources will be of concern.

It is assumed that the water entering the country across the political boundary is in pristine condition; although, it is very much possible that anthropogenic activities upstream and beyond the boundary of Kuwait have already affected groundwater entering the country, at least to some extent. The same parameters will be targets for the assessment of the trends for regional groundwater quality change, degree of mixing between the waters of Dammam

Formation and KG aquifers through inter-aquifer vertical flow and changes due to lateral movement and vertical up-coning due to withdrawal from established water fields. To assess the threats from potential hazardous human activities, the selection of parameters will be more varied depending on the type of hazard. Thus, in agricultural areas, nitrates and phosphates derived from fertilizers and pesticides used for the protection of the crops and plants will be the main targets as groundwater pollutants. Crude oil, refined products, and various hydrocarbon-based compounds act as pollutants for groundwater in the oil production, refining, and petrochemical industries. In the urban areas, microbes, various organic and inorganic compounds used in daily life, trace metals and pharmaceuticals disposed in the sewer lines and as solid wastes contaminate the underlying groundwater when it is at shallow depths (≤ 10 m) and should be the targets for analysis. The landfill sites are important sources of hydrocarbons, organic, and inorganic compounds, trace metals, chemicals derived from pesticides and pharmaceuticals, and microbes that can contaminate groundwater and should be monitored. Apart from hydrocarbons and organic compounds derived from them and trace metals that are generated by military activities, radioactive materials used in modern weapons can contaminate groundwater around military installations and should therefore be analyzed for samples collected from the monitoring system around these installations. Due to their effects on the coastal environment and ecology, nutrients, hydrocarbons, trace metals, radioactive materials, and microbes discharged by groundwater to the sea need to be monitored.

4 CONCLUSIONS

Being the sole natural water resource, the supplier of about 8% of potable water and the main provider of irrigation water, groundwater in Kuwait do merit a program to protect its quality. In an effort to initiate such a program, this study has been conducted with the intention of recommending paths for groundwater protection; and hence, a national monitoring network was conceptually designed to serve as a tool for managing the risks. A network of monitoring wells covering all sources of groundwater in a country is an integral part of the protection measures for this vital resource. Sampling of these monitoring wells at fixed intervals and chemical analyses of the samples collected provide the information necessary for the evaluation of the state of health of the groundwater resources and subsequent measures to be adopted to ensure the continuing usability of the water. The processes, phenomena and activities that are to be monitored in Kuwait for the purpose of groundwater protection are the following: lateral cross boundary recharge; regional groundwater quality trend, mixing between groundwater of Dammam formation and KG aquifers; groundwater withdrawal in the production fields; potential hazardous activities like agriculture, oil exploration, production, refining, transportation and distribution, other industrial activities, military movements, urban development and associated landfills; interaction between groundwater and seawater at the discharge zones along the Arabian Gulf coast; and gaps in countrywide spatial coverage after provisions for monitoring the aforementioned processes, activities, and phenomena are made. The number, location, and type (shallow or deep, single, nested, or multilevel) of the monitoring wells required for the comprehensive monitoring of the effects of the aforementioned on the groundwater resources of the country have been estimated, and a conceptual design of the monitoring network has been presented that may require more than 400 wells covering the whole of Kuwait. In estimating the requirements of the monitoring network in areas where hazardous anthropogenic activities are taking place, both the intrinsic risk to pollution and the value-weighted risk that take into account the usefulness of groundwater at the locations concerned have been considered. Some of the existing local monitoring networks can be integrated in the planned network, thus, reducing the overall cost for the implementation of the network.

5 RECOMMENDATIONS

More often than not, a long and intimidating path needs to be taken before achieving the objective of groundwater quality protection. While technical tools development are within the ambit of hydrogeological studies, the implementation of the various controls is achieved through a mix of voluntary actions, rules, and regulations imposed by local and regional governments. As the discussion section is focused on the hydrogeological/technical tools needed for groundwater protection, and in order to complete the picture, this section recommends the overall path for protecting the groundwater (including institutional, regulative, and public participation issues). A review of groundwater protection policies and practices adopted in a few of the advanced countries of the world (mainly, United States of America, Canada, United Kingdom, and Australia) has been carried out. The aim of the review was to understand the main areas of concerns and the basic philosophy that is being followed to ensure sustainability and adequate availability of good quality groundwater to meet various water needs of communities. The review highlights the varying degrees of details with which different regions in the world are trying to protect their groundwater resource. Nonetheless, the main elements of this protection attempts have remained, to a large extent, common among the various protection schemes. These elements are as follows: control of the storage, handling, use, and disposal of potential contaminants; control of activities that may adversely affect groundwater quantity and quality (i.e., activities inherently hazardous to groundwater quality such as agriculture); and contingency plan for minimizing the extent of any adverse alteration of groundwater quality. Having those elements as the core for Kuwait's groundwater protection program, and based on what has been done elsewhere, the study identified the six milestones on the path to protecting groundwater quality in Kuwait as follows:

- Building a planning team for groundwater protection (GWPT) in Kuwait,
- Identifying and characterizing present and future potential sources of contamination,
- Dividing the country into zones according to the level of strictness needed in protecting the groundwater,
- Formulating policies for the management of the aforementioned protection zones (including best management practices and prohibition of activities),
- Developing a contingency plan, and
- Supporting public education and participation.

While all steps are necessary, the formulation of the GWPT is the engine needed for mobilizing and streamlining the protection efforts. It is recommended to initiate the protection efforts by an awareness campaign that addresses key decision makers.

ACKNOWLEDGMENTS

The authors would like to extend their appreciation to the Kuwait Foundation for the Advancement of Sciences (KFAS) for partially funding the project. The unlimited support of the Kuwait Institute for Scientific Research (KISR) management has been pivotal in carrying out the various tasks of the project.

REFERENCES

Al-Senafy, M.; A. Fadlelmawla; K. Al-Fahad; A., Al-Khalid; A. Al-Omair; and R. Al-Kandari. 2003. Evaluation of potential impacts of selected municipal landfills on groundwater quality. Kuwait Institute for Scientific Research, Report No. KISR 6795, Kuwait.

Al-Senafy, M.; A. Fadlelmwala; K. Al-Fahad; A. Al-Haddad; A. Al-Khalid; E. Azrag; and K. Hadi. 2004. Assessment of potential groundwater contamination and associated environment impacts at PIC plants in Shuaiba, Kuwait. Kuwait Institute for Scientific Research, Report No. KISR7376, Kuwait.

ARCMANZ and ANZECC. 1995. *Guidelines for Groundwater Protection in Australia*. Australian Water and Wastewater Association, Artarmom, NSW.

EA. 2007. *Groundwater Policy and Practice, Part 4: Legislation and Policies – Public Consultation 2007*. Environment Agency, Rotherham, UK.

EHS. 2001. *Policy and Practice for the Protection of Groundwater in Northern Ireland.* Environment and Heritage Service, Belfast.

Golder Associates. 1995. *Fraser River Action Plan: Groundwater Quality Protection Practices.* Environment Canada, Vancouver, BC.

Logan, T.J. 1990. Agricultural best management practices and groundwater protection. *Journal of Soil and Water Conservation* **45**(2):201–206.

SEPA. 2003. *Groundwater Protection Policy for Scotland (Version 2)*. Scottish Environment Protection Agency, Stirling, Scotland.