International Journal of the Physical Sciences Vol. 6(7), pp. 1611-1619, 4 April, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.077
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Implication of gravity drainage plan on shallow rising groundwater conditions in parts of ArRiyadh City, Saudi Arabia

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Accepted 1 March, 2011

The population increase and stride development in ArRiyadh city has triggered water consumption exponentially. Excessive utilization of water for domestic and city services has increased infiltration which in turn has led to water level rise in various parts of the city. Keeping in view, damage to man and environments, various drainage schemes were constructed with the objective to check continuous water level rising. The gravity drainages were designed as consisting of horizontal drains collecting groundwater through gravity action. In this paper, effectiveness of drainage systems in lowering water levels has been experimentally analysed. The investigations consist of drilling monitoring wells, performing permeability tests and flow measurements on existing dewatering pipes. The discharge flow rates were measured using different techniques including Manning's formula. Beside flow measurements, effect of gravity drainage was analyzed through continuous water level monitoring within affected areas.

Key words: Gravity drainage, horizontal drains, discharge flow, manning formula, ArRiyadh, Saudi Arabia.

INTRODUCTION

In the past, rapid expansion of industries, construction of new complexes for city services and the construction of new housing schemes has greatly increased the water consumption within ArRiyadh city which in turn, has increased the infiltration of water to the ground. Due to the increase in infiltrating water from these sources and together with the aid of the geological setting, a shallow and rising perched water table was established under most of the urban area.

ArRiyadh water supply is largely governed by imported desalinated water from Arabian Gulf. The pipelines system transports about 1.21 million cubic meter of water per day (ILF, 2009). Groundwater supply is done mainly from Nesah, Nemar, Al-Hair, Minjur and Wasia aquifers. This groundwater is treated in six treatment plants before domestic supply. Groundwater constitutes about 1/3 of total water supply. In Riyadh, water consumption was estimated around 320 l/day/capita (MoWE, 2009). Excessive water usages have induced infiltration to the ground. The possible sources of groundwater recharge are leakages from water networks, cesspools/leaching pits/sub-surface domestic water tanks, excess irrigation within house gardens, water front landscaping and seepage from septic tanks (ADA, 2002). A 30% of total domestic supply is lost as network leakages (Al Zahrani, 2009).

Rising water table has considerable impacts on building foundations, basements, utilities and other infrastructure of the city. Water logging in residential areas may lead to health hazard and other discomforts to the inhabitants (ADA, 1990). Keeping in view the damage to city infrastructure and environment, gravity drainage schemes were implemented to reduce groundwater below safe limits, that is, below foundation levels (ADA, 2002).

This study is based on hydrogeological and geotechnical investigations to evaluate gravity drainage system performance in lowering shallow groundwater rising conditions. In this study, efforts have been made to quantify discharge flow rates of the various dewatering schemes. The effectiveness of drains has been analyzed by monitoring water level in close proximity of drains.

STUDY AREA

ArRiyadh city is located in the middle of Arabian Peninsula

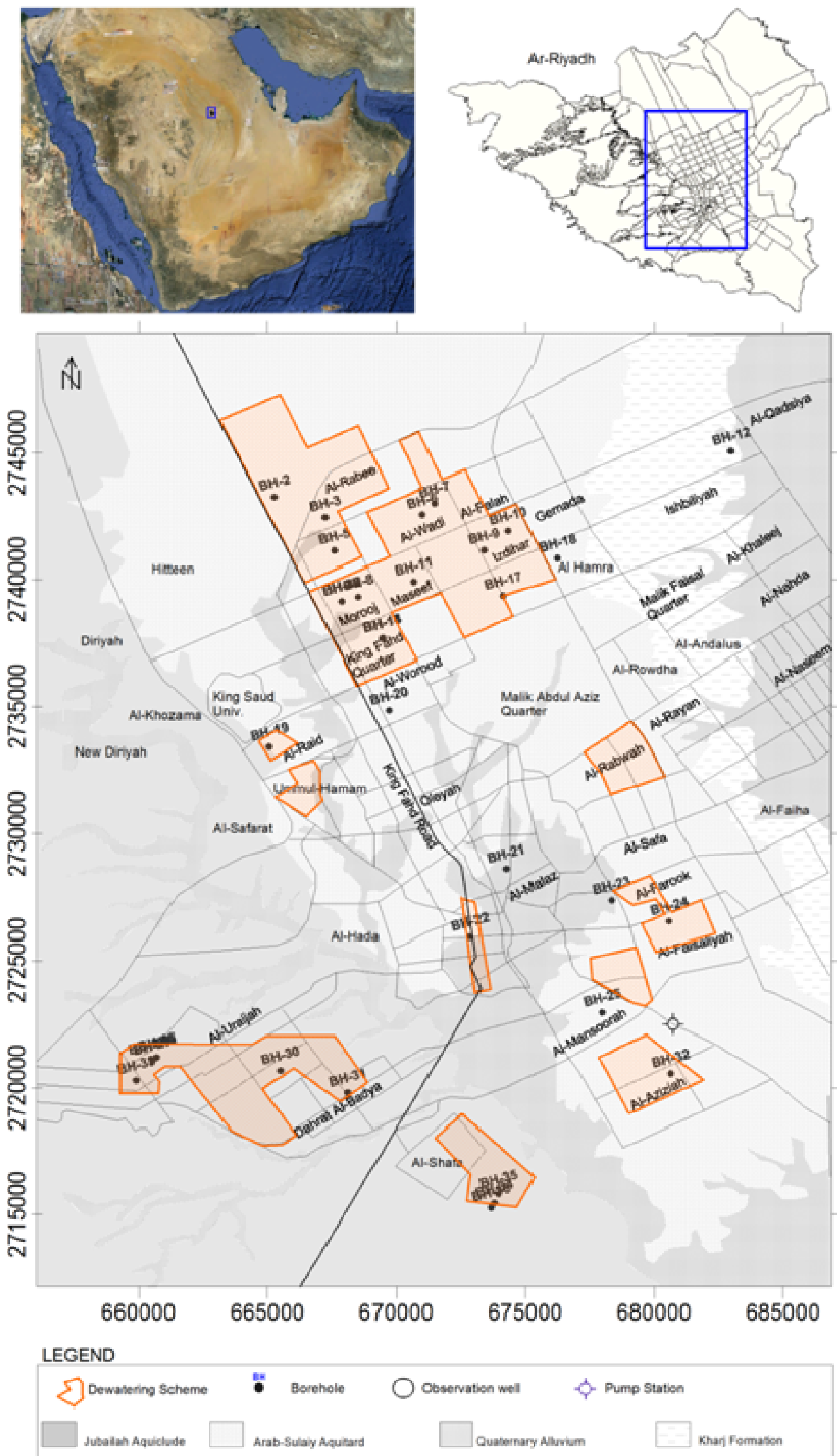
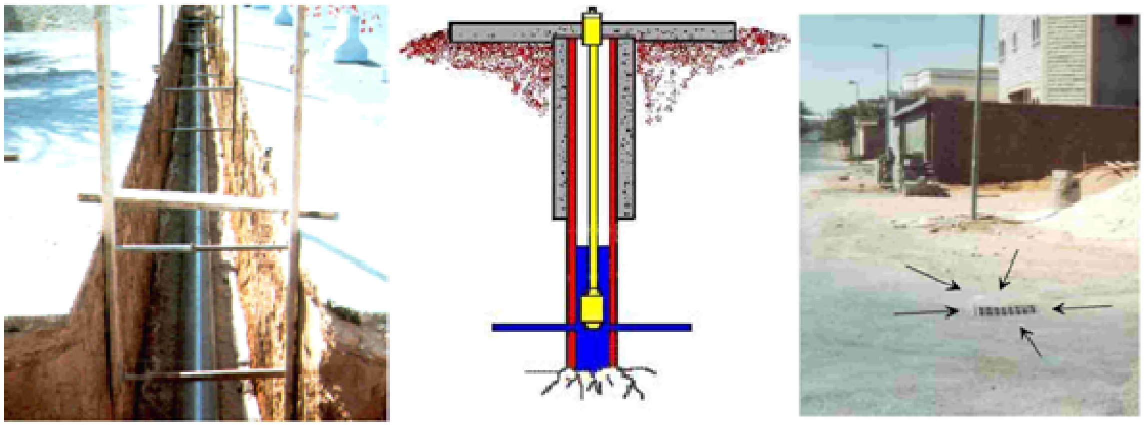


Figure 1. Base map of the study area.

between 24°29′ to 24°58′ N and 46°29′ to 46°58′ E (Figure 1). ArRiyadh was a small town prior to shifting of the administrative capital from Makkah to ArRiyadh in 1953 (Othman, 1995). The city grew from an area of 1 km^2



(a) (b) (c)

Figure 2. Gravity drainage system; (a) half perforated horizontal pipe; (b) horizontal shaft; (c) surface inlet.

in the 1930's to one of more than 1,500 km^2 in 1990. In 1950, the population was about 30,000; and by 2000, it was estimated to be 4,549,000 and growing at a rate of 2.76% per year, down from the rate of growth between 1990 and 1995 which was 3.95% (UNHSP, 2003). The population of Riyadh is expected to rise up to 5 million at the end of 2009 (SAPR, 2008).

Physiographically, Riyadh forms a plateau tilted to the East and South-East. The central part of the city, running from north to south, has relatively flatter gradient. The natural drainage of the eastern Riyadh region is towards east which is severely affected by developmental activities throughout the region (ADA, 1990).

Geologically, ArRiyadh region outcrops weathered to massive limestone. From west to east, the outcrops of Jubaila formation, Arab-Sulaiy formation, central alluvium, Kharj formation and eastern alluvium constitute general geology of the region. Quaternary alluvium is often intercalated with clay/gypsum lenses (ADA, 1990).

MATERIALS AND METHODS

The study consisted of drilling monitoring wells, installation of piezometers, performing permeability tests and flow measurements. The permeability tests were performed at in-situ bore wells, creating differential head by filling water up to the top of casing and recording the change in water level in borehole with time, till water level become constant. The same boreholes were fitted with PVC standpipe, slotted all the way in four rows with interval of 1 cm and slot length of 10 cm. The flow in dewatering pipes were measured by using different techniques such as, using Manning's approximation of free surface flow driven by gravity, pumping from sealed bottom at downstream side using flowmeter, measurement of time required to fill up a known volume, and by measuring flow at pumping station. Short duration water level monitoring was carried out in close vicinity of drain networks. For this, boreholes were made at 5 m intervals away from the drains. The overall effect was monitored with the help of continuous water level monitoring at permanent observation wells.

GRAVITY DRAINAGE IN ARRIYADH

ADA has implemented 23 major drainage projects covering a distance of 217 km with the objective to lower and maintain the water level up to safe limits, that is, below the foundation level. Subsurface or gravity drains have been constructed at locations where the groundwater reached near or to ground surface. The gravity drainage schemes are located within ArRiyadh city, covering various districts mainly in northern and the southern parts. Dewatering projects were designed as horizontal drains collecting water by gravity action. At comparatively flatter areas, the drains were also designed to carry storm water generated due to infrequent rainfall event. The horizontal pipes with perforation from the top half were placed within drains so as to receive percolated water from gravity action (Figure 2a). Apart from horizontal excavations, wells with horizontal shaft were constructed at specified locations with their upper end linked with existing network of horizontal drainage system (Figure 2b). The inlets at the surface allow infrequent storm water to flush in the same drainage system (Figure 2c). The average construction cost of gravity drains has been estimated as 1.3 million Saudi Riyals /km (ADA, 2002).

The accumulated water in horizontal pipes flows through gravity as open channel flow and collected at two pumping stations, that is, at the Shemaisy and Washem intersections where the collected water is pumped to Wadi-Hanifah and Wadi Al Batha through two giant channels. For evaluation of drainage systems, representative areas were analyzed for detailed investigations which include permeability tests, discharge flow estimations, chemical analyses and monitoring water level trends.

RESULTS

Permeability tests

The permeability values were obtained at 40 borehole locations using falling head technique. For comparison purposes, various dewatering schemes have been divided into 9 districts; Um-al-Hamam, Azizia, Towaiq, King Fahd Road, Maseef, Morooj, Khaldiyah, Faisaliah and Badiah. Individual borehole was filled with water up

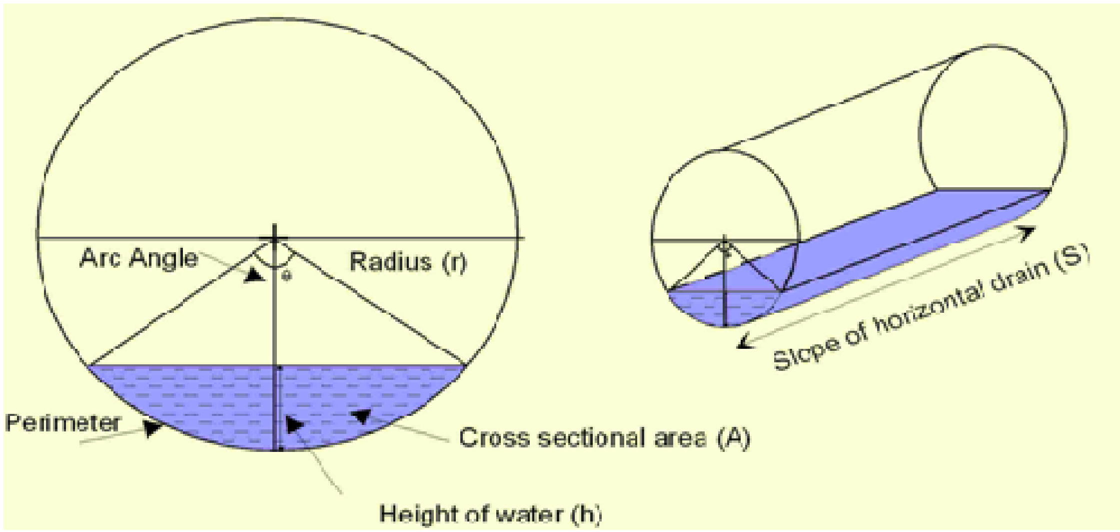


Figure 3. Schematic diagram of horizontal drain for flow estimation using Manning's formula.

to the top of casing. The change in head was recorded with time till the water in borehole became static. Using following equation; the permeability of each location was obtained.

$$k = \frac{A}{F(t_2 - t_1)} \log_e \left(\frac{h_1}{h_2}\right)$$

Where, k= permeability of the test section; F= intake factor; h_1= variable head measured at time t_1; h_2= variable head measured at time t_2; A= cross sectional area of borehole casing.

The low permeability of geologic formations greatly influences the efficiency of drains in dewatering the shallow horizons. In the areas of low permeability, the effect of drainage system in lowering the water levels may become very local and even point specific. The permeability values at 40 locations vary from 0.0012 to 0.631 m/day. The average permeability at north, central and western part is 0.04, 0.015, and 0.189 m/day, respectively.

Measurement of discharge flows

The measurements of flows were made; (i) using Manning formula; (ii) pumping at sealed bottom; and (iii) flow measurement at existing pumping station.

Using Manning's formula

The Manning formula is an empirical approximation for open channel or free surface flow driven by gravity. The discharge rate of each drainage network, based on the slope and diameter of each pipe, was estimated at the end points using Manning's formula, which states;

$$V = \frac{1}{n} R^{\frac{2}{3}} \sqrt{S_e}$$

Where V= mean velocity of flow; R= hydraulic radius; S_e= Slope of energy grade line (meters/meter); *N*= Manning's roughness.

Manning's roughness coefficient values are used in the Manning's formula for flow calculation in open flow channels (Gioia and Bombardelli, 2002). A schematic diagram of horizontal drains is shown in Figure 3. Values of the roughness coefficient (*n*) are assigned as 0.012 for new projects and 0.02 for old projects (Linsley et al., 1958). The slope (S_e) values range between 0.00195 and 0.0021. The discharge flow rate at various locations is given in Table 1.

Flow measurement in existing dewatering pipe

Flow measurements in existing pipe were carried out in eight locations at different areas to check the steady rate of water flow. In this technique, the outlet of the drainage network was closed with plastic basin (drum). Water was allowed to build up into the plastic basin to certain level which was maintained after commencement of pumping. The quantity of water discharged through the pump has been measured using a flowmeter. The alternative method for finding the water flow involves the measurement of the time required to fill up a known volume. The discharge flow at selected location is given in Tables 2a and b.

Table 1. Discharge flow rate using Manning's formula.

S. No.	Location	Diameter of pipe (m)	Height of water (m)	Width of water (m)	Q (l/min)
1	Raid 1	0.375	-	-	(No flow)
2	Raid 2	0.455	0.02	0.18	24.6235
3	Tuwaiq	0.455	0.1	0.38	629.391
4	Suwaidi	0.8	0.09	0.46	697.725
5	Badiah	0.475	0.04	0.28	94.572
6	Uraijah	0.375	0.025	0.16	31.3005
7	Uraijah-W	0.8	0.09	0.5	697.725
8	Rabwah	0.375	0.02	0.18	18.9642
9	Rabwah	0.375	0.04	0.24	83.0909
10	Shifa	0.265	0.08	0.26	285.281
11	Waha	0.6	0.05	0.36	171.858
12	Nafal	0.45	0.17	0.44	1821.29
13	Maseef-1	0.3	0.025	0.083	27.1312
14	Maseef	0.45	0.075	0.32	344.757
15	Morooj	0.5	0.05	0.32	155.426
16	Nuzha	0.45	0.065	0.32	255.26
17	King Fahd Quarter	0.5	0.02	0.098	22.0299

Table 2a. Flow measurement in existing dewatering pipe using plastic drum.

Location	Average time to fill plastic drum (s)	Volume of drum(l)	Flow (l/min)
Morooj	29.9	210	425
Uraijah-W	17.21	210	727
Uraijah	64.22	210	196
Khalidyah	26.92	210	468
Faisaliyah	32.6	210	397

Table 2b. Flow measurements in existing dewatering pipe at constant level.

Location	Total time (min)	Height of water above pipe invert level (cm)	Average flow-meter reading (cu.m)	Flow (l/min)
King Fahd Quarter	0-20	9	6.6	22
Maseef-1	0-25	20	13.6	27
Aziziah	0-30	32.5	21.5	106

Flow measurement at pumping station

A flow measurement was carried out in existing pumping station in Al Aziziah district. To determine the amount of water recharge and discharge with time, measurements were made at every 5 min for duration of 2 h using a dip-meter. The pump operates automatically by sensor when it reaches a certain level of water and discharges into the storage tank of 3.0 × 4.4 × 13.1 m dimensions.

The amount of recharge and discharge in the tank was calculated using equation;

$$Q = \frac{h_2 - h_1}{t_2 - t_1} \times A$$

Where, Q= Recharge/discharge rate; h_1= water level at time (t_1); h_2= water level at time (t_2); A= area of the tank.

The rate of discharge and recharge flow within and from the water tank was estimated using above formula which is 0.144 and 0.233 m^3/min.

Chemical analysis of discharge water

During discharge flow measurement, impurity like fecal material and foreign particles were reported in discharged water at some places. This indicated the pollution of discharge flow through illegal joining of sewer pipes to existing drainage networks. The chemical analyses of drained groundwater samples confirmed the presence of

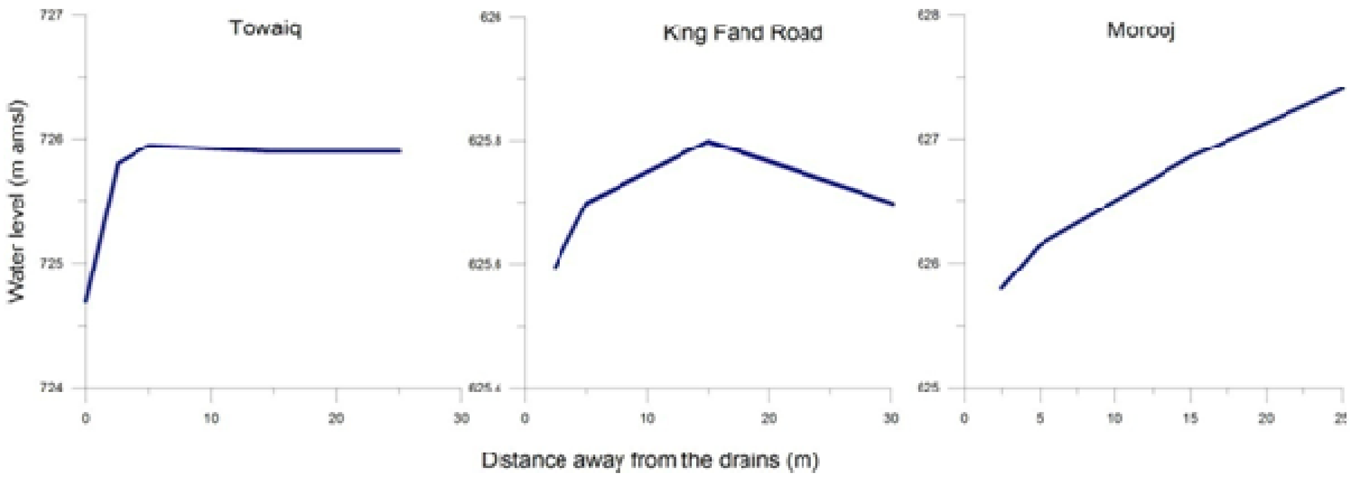


Figure 4. Water level recession trend away from the drainage schemes.

coliform, ranging from <1 to >2000 (colony forming units) CFU/100 ml. The presence of coliform in water indicates recent contamination of the groundwater by human sewage. This led to the conclusion that at places where CFU is found, discharge flow also contributes surface waste flow. Therefore, efficiency of drainage cannot be judged, although, ground check can be made to counter illegal linkage of gravity drains with surface activities.

Water level monitoring

The effect of gravity drainage on water level was analyzed spatially through closely spaced, water level monitoring network. It was observed that the effect of gravity drainage at King Fahd Road lasts only at 15 m away from the drains (Figure 4). Similarly, at Tuwaiq, the effect reached only 2.5 m away, that is, remained confined to the vicinity of the drainage channel. However, water level recession follows a linear trend with distance away from the drains at Marooj. At above three locations, different water level recession trends were observed which, in all likelihood, are related to permeability of the region which controls the groundwater discharge to drains. The average permeability of King Fahd Road, Towaiq and Marooj is 0.0745, 0.181 and 0.042 m/day, respectively. Although, Tweeq corresponds with comparatively high k value but groundwater recession is confined to the drainage channel. This reflects quick variation or the spottiness of k value. Since recharge directly linked with overlying population and its water utilization pattern, therefore, short term trend cannot be relied. Long term water level monitoring was utilized to decipher the effects of gravity drains in lowering water level.

In Maseef and Khaldiya district, the water level started showing recession after the year 1990, which corresponds with the time of completion of drainage system. However, after the completion of sanitary system during the year 2000, water level has shown significant decline at both observation wells (Figure 5a). At Um-al-Hamam and King Fahd Road region, water level reveals a continuous declining trend (Figure 5b). This indicates proper functioning of gravity drains within these regions.

In Aziziah and Towaiq district, water level has acquired a slow rising trend (Figure 5c). The event of sudden rise in water level at both monitoring wells indicates human interference. The presence of coliform (>2000 CFU) in drained water at Towaiq confirms the connections of sewer system with the gravity drains which seems responsible for poor performance of the gravity drains. The detailed comparison of various drains schemes has been summarized in Table 3.

DISCUSSIONS

Most of the gravity drainage networks are situated within areas of Arab-Sulaiy formation. The Arab-Sulaiy formation displays wide variation in permeability values which ranges from 0.007 to 0.0745 m/day. The drainage network in western part traversed through Jubailah formation where permeability values are 0.032 and 0.631 m/day at Badiah and Uraija (W). During the commencement of the study, a linear relation between permeability and drained groundwater flow was anticipated but result shows that discharge flow rates bear no such relation. This may be due to the fact that average k value which is based on 3 to 4 point borehole tests, that is, not representing a particular district. Moreover, chemical analyses of the drained groundwater samples confirmed the presence of coliform, ranging from <1 to >2000 (colony forming units) CFU/100 ml. The presence of coliform in water indicates recent contamination

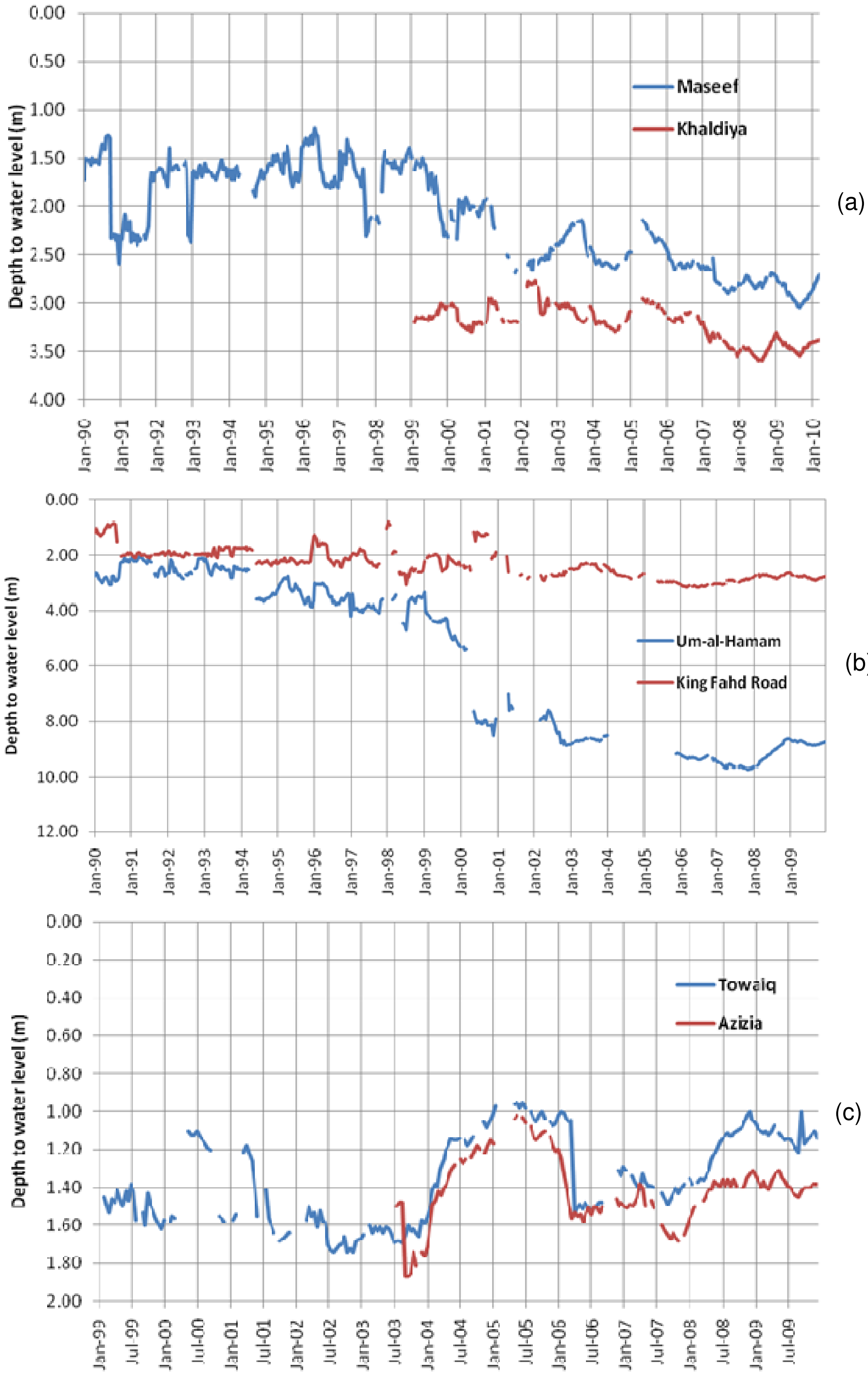


Figure 5. Water level monitoring at a) Maseef and Khaldiya b) Um-al-Hamam and King Fahd Road and c) Towaiq and Azizia districts.

Table 3. Detailed comparison of drainage schemes within various districts.

Districts	Hydrogeological setup	Drainage system installed	Area (m2)	Average pemeability (m/day)	Measured flow (lit/min.)	Coliform (CFU/100 ml)	Depth to groundwater	
							1990	2010
Umm-al-Hamam	Arriyadh Aquifer-Jubailah Fm	Jun-97	-	-	-	-	1.5	>3.5
Aziziah	Arab-Sulaiy Fm	Oct-93	640000	0.028	106	>2000	1.6	2.55
Towaiq+Uraija (w)	Jubailah Fm	May-96	800000	0.181	1358	>2000	1.3	1.5
King Fahd Road	Arab-Sulaiy Fm	May-94	180000	0.0745	22	<1	1.14	2.72
Maseef	Arab-Sulaiy Fm	Jan-90	80000	0.062	185.9	1840	1.8	2.7
Murooj	Arab-Sulaiy Fm	Jun-94	1120000	0.042	580.426	1040	2.25	
Khaldiah	Arab-Sulaiy Fm	Oct-98	800000	0.007	468	<1	2.76	3.05
Faisaliah	Arab-Sulaiy Fm	Feb-92	440000	0.008	397	<1	0.95	1.15
Badiah	Jubailah Fm	Jan-90	200000	0.032	94.57	<1	0.9	0.95

of the groundwater by human sewage at places like Aziziah, Towaiq, and Maseef, where the gravity drains have been illegally linked with sewer lines. Although a quantitative assessment of sewer flow couldn't be made. Therefore, continuous water level monitoring within affected areas has been made to analyze the role of drainage network in lowering the water levels. The cost of damage to environment and infrastructure was difficult to measure in terms of capita. Therefore, cost benefit analysis of gravity drains can't be performed.

Validation of roughness coefficient 'n' was done by comparing measured and calculated values of discharges at four locations; Uraijah-W, King Fahd Quarter, Maseef, and Morooj. Applying measured flow values in Manning's formula, new 'n' values were estimated. At first three locations, 'n' equals to 0.0115, 0.012, 0.012, respectively; this is same as applied standard value. However, at Morooj, a different value of n which is 0.00439, was estimated.

CONCLUSION

The permeability values at 40 locations show large variation, ranges from 0.0012 to 0.631 m/day. Using different techniques, discharge rates were observed at drainage outlets ranging from 22 to 1821 liter/minute. No flow to drain was observed at Al-Reid, implying that the water level fell below drain level. At Umm-al-Hamam district water level has reached below the drainage networks due to installation of sanitary network. Therefore, at unsewered areas of western ArRiyadh, the designed sanitary system is recommended to be used as temporary drainage system. The gravity drainage system is apparently working well at Maseef, King Fahd Road and Khaldiya. However, the practice of illegal linkage of sewer lines is affecting the performance of gravity drains at some districts particularly at Aziziah and Towaiq districts.

Dewatering through drains has improved water logging problem and the probability of health hazards. Inundation of basements and deep foundations has also improved through dewatering drains. It has been made possible for new buildings to connect their private dewatering system to the network where water level has reached to a depth of >4 m. Initially, all projects were constructed with flushing system but it has not been used in any of them. Therefore, it has been suggested that new drainage schemes should be constructed without flushing system. It is also suggested that alternate dewatering schemes should be installed within the areas of extremely low conductivity.

ACKNOWLEDGEMENT

The author is thankful to ArRiyadh Development Authority, ArRiyadh for providing required data used in the study.

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