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DECENTRALIZED TREATMENT OF HARVESTED RAINWATER FROM ROOFTOPS IN BURAIDAH CITY, SAUDI ARABIA

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ABSTRACT

Water scarcity is one of the most sensitive issues of this century. Several countries are posed with the same problem of water scarcity in the Kingdom of Saudi Arabia (KSA). Thus, an optimal use of various water resources, including rainwater, is extremely crucial. However, the quality of water needs to be assessed before any usage. The present study investigated the quality of rainwater in the Qassim region of KSA. The building of Civil Engineering Department, College of Engineering, Qassim University, Buraidah was selected as the experimental site. The rainwater from the roof of the department was periodically collected in from October 2011 to July 2012. The harvested rainwater was assessed for the quality and accordingly treated physically and chemically. First, the collected water was pumped onto a filter paper column, type POSI-FLO® II, to remove the large particles. Subsequently, four cartridge filters with different filter media, followed by reverse osmosis unit, were used for the treatment. The experimental results demonstrated that the characteristics of the harvested and treated rainwater from the rooftops of building in Buraidah could be used for drinking.

Keywords: *Rainwater, physical treatment, chemical treatment, filtration, reverse osmosis.*

1. INTRODUCTION

Water resources planning, development, and management is a topic of intensive research currently. Water resources in the Kingdom of Saudi Arabia (KSA) are limited and require serious efforts for optimal usage. Urban development, high rate of population growth, aridity, high solar radiation, and increasing water demand are stressful on the existing water resources. The Al-Qassim Region, well-established for agriculture, experiences more pressure in this sector as compared to the other areas of KSA since most of the water resources are non-renewable. Therefore, a profound strategy is essential to harvest the rainfall in arid regions. The engineering and management of water resources are being persistently investigated worldwide. Several aspects including management, conservation, and efficient use of water for drinking, industry, and irrigation have been studied in the recent years with an emphasis on rainwater harvesting (RWH) [1-6]. Several methods have been proposed to increase the sources of water supply worldwide; RWH is considered a feasible alternative source [7-10]. Recently, RWH has gained enormous attention in KSA [11-12]. The method can also significantly improve water saving in other countries. For example, Herrmann and Schmida [13] showed that in Germany, the potential of potable water saving by RWH in

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a house might vary from 30–60%, which is demand- and roof area-dependent. Coombes and Kuczera [14] analyzed 27 houses in Australia and found that rainwater usage could promote the potable water saving up to 60%. Ghisi et al. [15] indicated that the potential water saving by RWH in 62 cities in Brazil was 34–92%, with an average of 69% potable water saving. Several other studies have highlighted the various aspects of RWH [16-17]. Adham et al. [18] conducted investigations to identify various sites for RWH. The study proposed that although the site selection is challenging, RWH might provide an alternative water source in semiarid or arid countries. The group highlighted the key methods and criteria developed during the past three decades based on 48 studies describing diverse methods. Some of these methods were designed according to simple biophysical criteria, whereas others were more integrated approaches including socio-economic criteria. The most significant criteria for selecting the suitable sites encompass land use, slope, land cover, soil type, the amount of rainfall, distance to any reservoir, and the cost, which altogether can culminate in a successful RWH project. In addition, the practice of geographic information systems (GIS) combined with hydrological models and the criteria mentioned above may also be highly useful. The quality of the harvested rainwater is mostly low [19] that can be attributed to atmospheric pollutants including particles, microorganisms, heavy metals, and organic substances accumulating in the catchment areas as dry deposition and washouts from the atmosphere during rainfall events. The measured inorganic compounds in the rainwater harvested from most of the roof-yard catchment systems were found to be consistent with those of the World Health Organization (WHO) standards for drinking water. However, the concentrations of some inorganic compounds in the rainwater collected from the road surfaces appeared to be higher than the guideline values for drinking water. In the case where the catchment areas are roads, the rainwater may be contaminated with heavy metals originating from brakes and tires and organic compounds such as polycyclic aromatic hydrocarbons and aliphatic hydrocarbons from incomplete combustion processes. The contaminants comprising of bacteria, viruses, and protozoa may originate from pollution by birds, mammals, and reptiles that have access to catchments and rainwater storage tanks. Therefore, the harvested rainwater is typically unsuitable for drinking without some treatment [20], which should be practical and cost-effective in developing countries. The removal of pollutants from rainwater by filtration techniques is a common practice. Suspended solids (SS) may be removed by filtration. Activated carbon removes organic compounds that contribute to taste and odor [20]. However, the pore space between the sand particles is larger than the smallest suspended particles, rendering simple filtration as insufficient in most cases. For drinking water, the membrane filter systems can effectively remove protozoa, bacteria, algae, and other microorganisms depending on the pore size of the membrane. Nevertheless, the treated water may still contain some viruses, because their dimensions <100 nm allow easy slippage even through minuscule pores. Therefore, the filter systems are coupled with a disinfection system [19]. The present study primarily aims to (1) evaluate the potential physical and chemical processes in the treatment of the harvested rainwater, (2) study the membrane filtration and RO in the treatment of the harvested

rainwater, and (3) provide suggestions and recommendations regarding the improvement of the quality and quantity of the harvested rainwater in KSA.

2. STUDY AREA

Figure. 1(a) shows the location map of the study area. Figure. 1(b) shows the building that was used for RWH. The area of the rooftop of the building was approximately 960 m^2 and height 4.5 m. Qassim is a well-established agricultural region in Saudi Arabia, also known for dates. The experimental site was located in the Qassim University Campus in Miladah near Prince Nayef bin Abdulaziz Regional Airport. The coordinates of the study area were: Latitude Longitude 26° 20' 47" N. 43° 45' 47.71" E. The weather of Qassim is almost similar to that of Riyadh, the capital of the KSA. The average annual rainfall is approximately 140 mm/year. The highest and lowest temperatures are 50 °C in summer and 0 °C in winter, respectively.



Fig. 1(a). Location map of the study area



Fig. 1(b). Building used as the experimental site for rainfall harvesting

3. MATERIALS AND METHODS

The quality of the drinking water complied with the standards of SAS in KSA. A comparison between the quality of the existing bottled drinking water used in KSA and that achieved by WHO and SAS is summarized in Table 1 [21, 22, 23].

TABLE 1: EXISTING BOTTLED DRINKING WATER QUALITY IN KSA AND QUALITY STANDARDS [21, 22, 23]

Constituent	Units	SAS	WHO	Existing water quality in KSA
p^H	-	6.5–8.5	6.0–8.5	7.18
TDS	MG/L	1500	1000	226.5
TURBIDITY	NTU	25.0	5.0	-
CALCIUM (Ca)	MG/L	200	200	36.6
MAGNESIUM (Mg)	MG/L	30–150	100	14.1
TOTAL HARDNESS	MG/L	500	500	168
MANGANESE (Mn)	MG/L	0.05	0.1	-
IRON (Fe)	MG/L	1.0	0.3	-
CHLORIDE (Cl)	MG/L	600	250	-
FLUORIDE (F)	MG/L	0.6–1.0	0.6–1.7	0.81
COLIFORM	NO./100 ML	0	0	0
FECAL COLIFORM	NO./100 ML	0	0	0
SAS= SAUDI ARABIA STANDARD *WHO= WORLD HEALTH ORGANIZATION* *KSA= KINGDOM OF SAUDI ARABIA*				

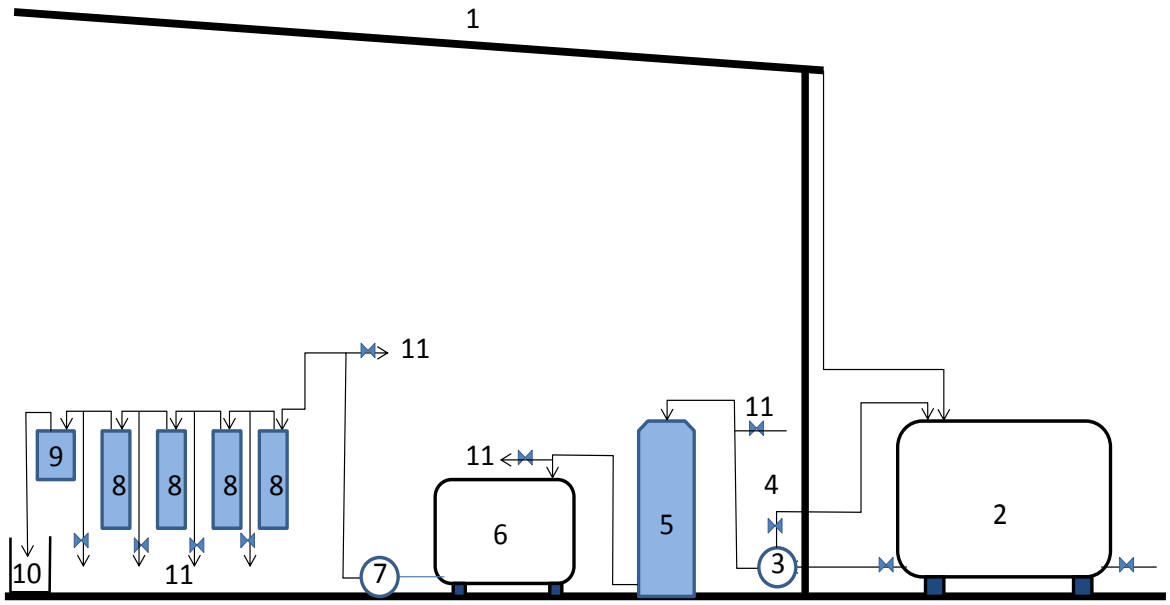

Fig. 2. Schematic representation of the rainwater harvesting (RWH) and treating system. 1: roof; 2: 1 m^3 storage tank; 3: pump; 4: valve for water recirculation; 5: paper-filter column; 6: 0.3 m^3 water storage tank; 7: pump; 8: cartridge filters; 9: reverse osmosis (RO) unit; 10: container for treated water; 11: sampling valve.

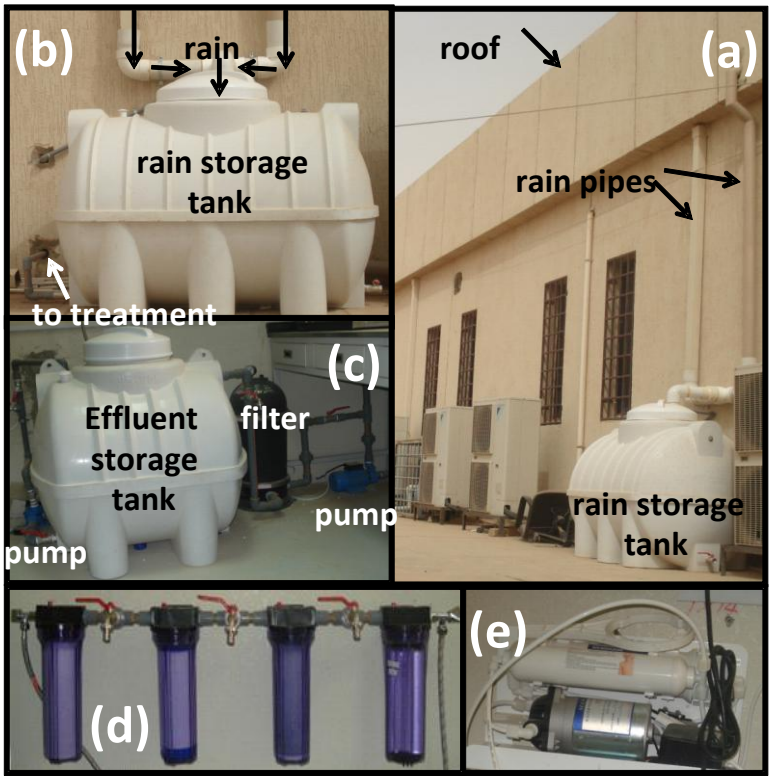

Fig. 3. Images of the experimental set-up. (a): rainwater collection system; (b): rainwater storage tank; (c): filter-paper column and pre-treatment step; (d): cartridge filters; (e): RO unit.

Figure 2. illustrates a schematic representation of the system for harvesting and treating the rainwater. The rainwater was harvested from the roof of the building of Civil Engineering Department, Qassim University and stored in a 1 m^3 tank as shown in Figure 3(a) and 3(b), respectively. Subsequently, the water was pumped to a filter paper column, type POSI-FLO® II as demonstrated in Figure 3(c) for the removal of large particles. The height and diameter of the filter paper column were 102 and 41 cm, respectively, and the effective area of the filter paper was 4.6 m^2. The pre-treated water was collected in a 0.3 m^3 tank [Figure 3(c)], and then, pumped to the four cartridge filters as in Figure 3(d) with different filter media, followed by transfer to the RO unit [Figure 3(e)]. The media used in the four cartridge filters comprised of nylon, granular activated carbon (pore size = 10 µm), granular activated carbon (pore size = 5 µm), and powder activated carbon, sequentially. The diameter and height of each cartridge were 10 and 25 cm, respectively. The system was operated to treat either raw or settled rainwater. In order to prevent the raw water from settling, a part of it was recirculated to the 1 m^3 storage tank. On the other hand, to operate the system with settled rainwater, the SS of raw water were allowed to settle in the storage tank by 1-day retention. At every condition, the filter paper column treated the water at two different flow rates (10 and 20 L/min, respectively). The stored effluent obtained from the filter paper column was treated by the four cartridge filters at a flow rate of 1 L/min, followed by the RO unit, which has flow rates of 0.75 and 0.25 L/min for permeation and rejection, respectively. The physical and chemical treatments of the harvested rainwater were evaluated by jar tests. In this method, two coagulants were utilized, alum and cationic polyacrylamide polymer. The jar tests were performed at different doses. The durations of rapid mixing, flocculation, and sedimentation in the jar tests were 1, 20, and 30 min, respectively.

4. RESULTS AND DISCUSSION

4.1 CHARACTERISTICS OF THE HARVESTED RAINWATER

The rainwater was collected and treated from October 2011 to July 2012. Figure 4 presents the average monthly rain precipitation from 2005 to 2012 in the Qassim Province [24]. Figure 5 presents some events of rainfall in the Qassim region, which exceeds 5 mm/event during the past ten years (2007–2016). The average annual precipitation from 2005 to 2012 was 95.9 mm, indicating that the precipitation was relatively low.

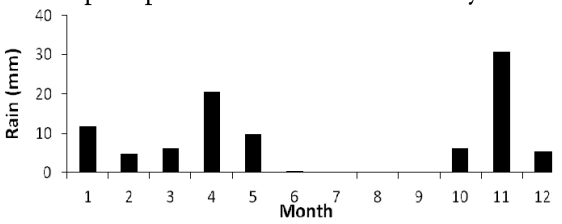

Fig. 4. Mean precipitation in Qassim Province from 2005 to 2012

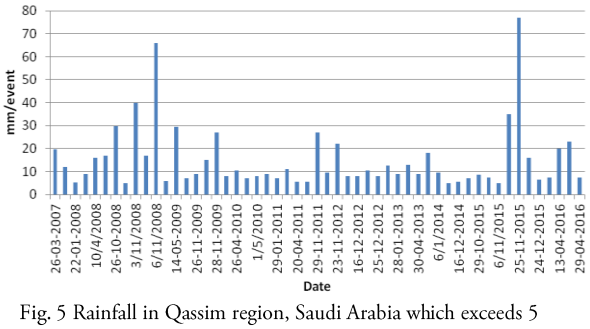

Fig. 5 Rainfall in Qassim region, Saudi Arabia which exceeds 5 mm/event (2006-2016)

Table 2 shows the characteristics of the harvested rainwater. The data on the quality of rainwater of some previous events are described in Table 3 [25] and can be compared with the current results. Some of the reference values were found in agreement with the present study, while a few varied; for instance, the pH values corroborated, conductivity was about half of the present results, and TDS (total dissolved solids),

alkalinity, and hardness were higher in the present study than the previous results. Furthermore, the harvested rainwater exhibited a relatively high concentration of SS as compared to that reported by results of previous studies performed in other places. This phenomenon may be attributed to the sandy weather and the harvest of the rainwater without excluding the first flush. Thus, the collected rainwater presented an optimum pH, a significant amount of SS and TDS, and sufficient alkalinity. It also exhibited low concentrations of the other compounds (nitrate, nitrite, ammonium, sodium, and copper). Therefore, the removal of SS by disinfection can produce treated rainwater with drinking water quality.

TABLE 2: CHARACTERISTICS OF THE HARVESTED RAINWATER (EVENTS NOV-2011)

Parameter	Unit	Value
SS	mg/L	15
Turbidity	NTU	24
TDS	mg/L	262
Conductivity	mS	0.67
Sodium	mg/L	3
Iron	mg/L	0.03
NO_3-N	mg/L	5
NO_2-N	mg/L	0
NH_4-N	mg/L	0.5
Copper	mg/L	0
Hardness	mg/L	175
Alkalinity	mg/L	120
pH	-	7.84

TABLE 3: RAINWATER ANALYSIS OF SOME PAST EVENTS [25]

COLLECTION DATE	SAMPLE NO	pH	COND (ms/cm)	TDS	ALKALINITY	HARDNESS	SODIUM	NO_3
03-1994	1	7.41	0.3	146	70	115.8	6.53	0.17
04-1994	2	7.73	0.28	158	105	132.4	3.62	0.17
04-1994	3	7.85	0.29	114	76	75.7	6.5	0.51

Figure 6 demonstrates that high turbidity removal can be achieved by coagulants, alum or polymer, at a high dose. Moreover, the amount of particles in the harvested rainwater was comparatively lower, as a low dose of coagulant was applied for the removal of turbidity in the surface water. The results of the jar test revealed low turbidity in the treated rainwater, which is lower than that of the drinking water. Plain sedimentation of the harvested rainwater for one day in the storage tank results in a significant reduction of the raw water turbidity. Therefore, treating the rain water with coagulant is significantly better than plain sedimentation.

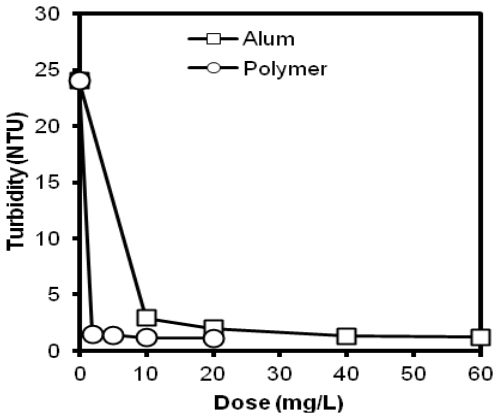

Fig. 6. Jar test results showing the effect of alum and polymer in turbidity removal at different coagulant doses at 1 min mixing time

Figure 7 demonstrates the results of the rainwater (raw or settled) treatment in the filter paper column.

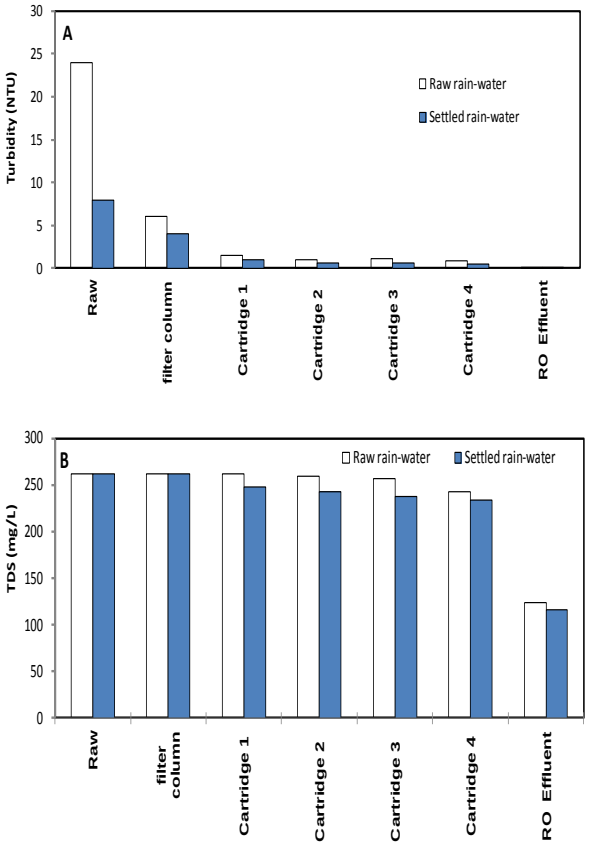

Fig. 7. Results of continuous treatment of the rain water

A minimum of two stages of cartridge filters are required for obtaining an effluent with characteristics similar to that of the drinking water (turbidity <1 NTU). Moreover, the results also emphasize the importance of sedimentation as a pre-treatment of the rainwater. The rainwater has a TDS of 262 mg/L, which is lower than that required for water supply in KSA (500 mg/L). In addition, applying RO can achieve a significant reduction in TDS depending on the operational conditions. Figure 7 also demonstrates that the filter column has no effect on TDS; however, cartridges 1, 2, 3, and 4 and RO reduce the TDS from 262 to 250 mg/L, 250 to 247 mg/L, 247 to 244 mg/L, 244 to 240 mg/L, and 240 to 120 mg/L, respectively. Since KSA continually experiences water scarcity; the utilization of the harvested rainwater needs to be optimized. The experimental results demonstrate that the characteristics of the harvested rainwater from the roof of the College of Engineering building, Qassim University, are superior to that of the surface water. The settling of the harvested rainwater leads to a significant reduction in SS that can increase the performance of the subsequent steps. The filter column can remove the fine particles that were not removed by settling, making it optimal for irrigation. For turbidity <1 NTU, two cartridge filters (textile and coal) are required to treat the effluent of the filter column; however, this water is suitable in the house only for toilet flushing and clothes washing. Furthermore, an additional RO step is essential to obtain drinking water. Fig. 8 summarizes the different proposed steps for treatment of the harvested rainwater and the reuse of the treated water. The proposed systems for the treatment and reuse of harvested rainwater can be applied in small communities (separate houses or buildings).

5. SUMMARY AND CONCLUSIONS

The experimental results concluded that the characteristics of the harvested rain from the roof of a building in Buraidah are superior to that of the surface water. The settling of the harvested rainwater leads to a significant reduction in SS, which in turn increases the performance of the subsequent steps in the treatment. The water treated by filter column can be used for irrigation or swimming pools. A turbidity of <1 NTU can be obtained by subjecting the effluent of the column to two cartridge filters (textile and coal). Then, the treated water can be utilized for secondary purposes, such as toilet flushing and clothes washing. Drinking water is obtained by an additional RO step. The jar test results concluded that the high turbidity could be removed by coagulants. Alum represents a cost-effective coagulant producing a large

amount of inorganic sludge, while the polymer represents an expensive coagulant producing a low amount of sludge. Thus, coagulation and sedimentation can be applied to the treatment of a large volume of rainwater in a small area. The present study affirmed the quality of rooftop harvested rainwater as appropriate. Depending on the local environmental conditions, RWH may provide a supplementary supply, an alternative supply, or the only feasible, improved supply, especially in urban areas. In order to meet these challenges, it is recommended that the Government of KSA implement the rooftop RWH mandatory for all buildings. RWH primarily consists of collection, storage, and subsequent use of the captured rainwater as either the principal or as a supplementary source of water. Both potable and non-potable applications are recommended. However, further studies to investigate simple treatment techniques are essential.

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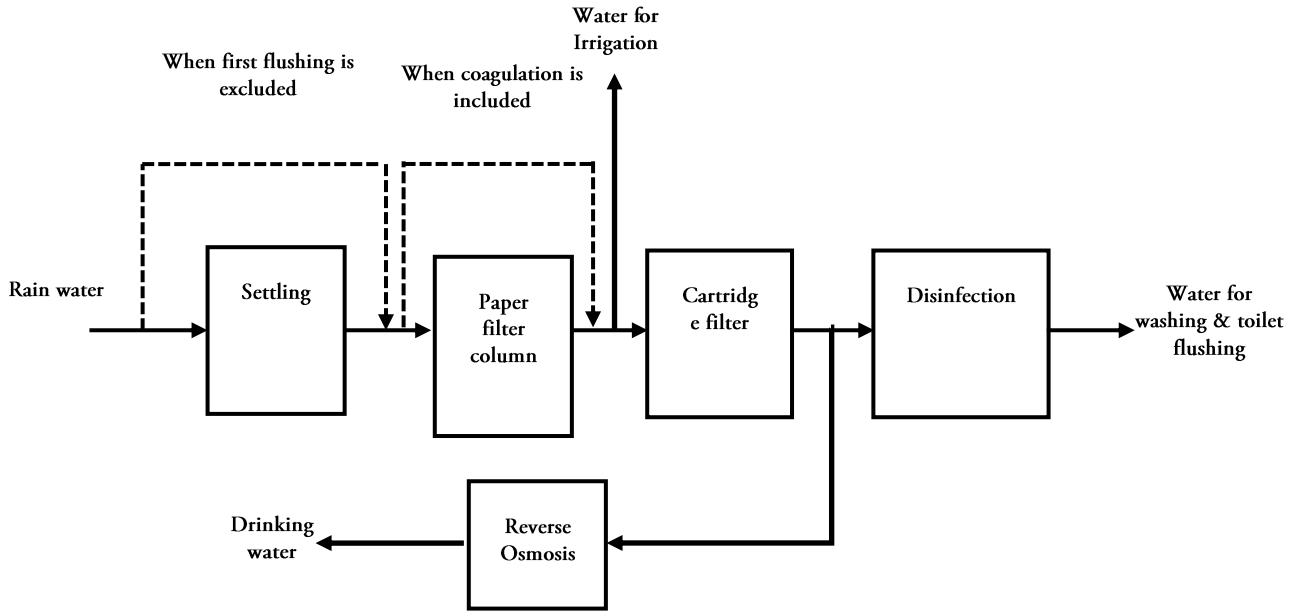

Fig. 8. Proposed treatment steps for harvested rainwater and the reuse of the treated water

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دراسة ومعالجة مياه الأمطار المجمعة من أسطح المباني في مدينة بريدة، المملكة العربية السعودية

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[1] في اعارة من جامعة الأسكندرية - مصر

الملخص:

ندرة المياه هي واحدة من أكثر القضايا حساسية في القرن 21. المملكة العربية السعودية مثل العديد من البلدان الأخرى والتي تواجه مشكلة ندرة المياه. الاستخدام الأمثل للموارد المائية المختلفة بما في ذلك مياه الأمطار مهم للغاية. لا بد من التحقق من نوعية المياه قبل أي استخدام. في هذه الدراسة تم التحقق من جودة مياه الأمطار في منطقة القصيم في المملكة العربية السعودية. تم جمع البيانات من خلال التجارب الحقلية والمعملية. تم اختيار قسم الهندسة المدنية، كلية الهندسة -جامعة القصيم بريدة كموقع تجريبي. تم جمع مياه الأمطار من سطح قسم الهندسة المدنية في خزان خلال الفترة من أكتوبر 2011 إلى يوليو 2012. تمت معالجة مياه الامطار بطرق فيزيائية وكيميائية. تم اختبار عينات من مياه الأمطار في المختبر لمعرفة نوعيتها وتم التعامل معها وفقا لذلك. وكخطوة أولى تم ضخ المياه التي تم جمعها إلى عمود مرشح والذي كان يستعمل في إزالة الجزيئات الكبيرة وقد استخدمت لذلك أربع مرشحات تتبعها وحدة التناضح العكسي لإتمام المعالجة. اظهرت النتائج التجريبية أن خصائص مياه الأمطار من اسقف المباني في بريدة يمكن استخدامها للشرب بعد المعالجة المقترحة.