CHARACTERIZATION OF HARVESTED RAINWATER QUALITY FROM SEOUL CITY – KOREA

M.Y. Han[a,*], H.I. Saleh[b], I.Y. Lee[a], Y.J. Kim[a]

[a,*] School of Civil, Urban & Geosystem Eng., College of Eng.,
Seoul National University, Korea
[b] Civil Eng. Dept., Faculty of Eng., Menoufia Universiy, Egypt

Abstract

Rainwater harvesting is currently practiced widely in several countries worldwide on scales that vary according to rainwater availability as a mean of providing on-site supply of fresh water for isolated areas or those lacking proper water supply system. Different factors affect the quality of harvested rainwater mainly the multi-components of the collection system installed. In order to breakdown and assess the effects of different collection stages on collected water to be further supplied to served communities, wet deposition, bulk deposition, roof catchment area, and storage time were investigated on a currently installed system in Seoul National University in South Korea. Results showed that cations and anions accumulations resulted from both wet and bulk depositions while heavy metals were 3 to 7 times higher in bulk deposition, all being less than allowable limits for potable quality. Heterotrophic plate counts and coliforms were detected and increased with storage time, similarly were alkalinity and hardness, other parameters being relatively stable following storage. The study denotes the system capability of providing reliable source of water supply while recommending precautions to be considered.

1. Introduction

Several countries consider the direct collection of rainwater as a potential procedure that provides on-site water storage for further different uses (Appan, 1999; Simmons et al. 2001; Zobrist et al. 2000). Most harvested rainwater uses are direct towards non-potable water uses as gardening and toilet flushing in urban and rural areas as a substitute for greywater systems that were also introduced to minimize the burden on using freshwater resources; this may further extend to the use of water as potable. Certainly this will rely on the quality of collected water and on the addition of further treatment units to remove objectionable components from water. Several investigations addressed the deposited particles and aerosols from the air in Seoul and other Korean areas (Ro et al. 2001; Kim et al. 2001; Kim and Park 2001), studies also investigated yellow sands deposition during storm events on the Korean peninsula.

Basic rainwater collection system relies on providing: (1) catchment area as building roofs, (2) collection and transport channels, gutters and pipelines, (3) storage facility namely the rainwater collection tank; and (4) discharge means through pumping or any other mean. Considering these elements, a wide variety can be encountered when implementing a rainwater collection system as in different finishing materials for the roofs, presence of metals or painted surfaces, the material of rainwater collection tank, etc. Therefore, investigating the effect of these different components helps developing comprehensive understanding about changes occurring in rainwater quality through various collection steps.

Air emissions and depositions on catchment areas surfaces affect the initial quality of collected rainwater. In this context, Korea has launched a program for effective collection and use of rainwater. This trend is encouraged on the national level in view of limited sites available for constructing mega projects for rain and storm water storage and use. The aim of this paper is to characterize rainwater quality from Seoul city, at the selected study site, through a dedicated rainwater harvesting system especially installed for this purpose. The investigation targets the collected rainwater quality and the changes induced by several factors as catchment area and storage time.

2. Materials and Methods

2.1 Collection System

In order to investigate rainwater quality, a collection system was planned and installed in Seoul National University Campus the location of which is as shown in the approach map in Fig. 1. The collection system includes the following components as illustrated in Fig. 2 (showing also sampling points) were all components were installed on the roof of the building except for the main rainwater collection tank that was installed at ground level next to the building. The different components of the system served for the followings:

Direct Rainwater Collection (Wet Deposition): An acrylic plate with an inverse pyramid shape was installed for direct catchment of rainwater through an area of 0.70m x 0.70m. This water is under no influence of other collecting components and was used in measuring pH and turbidity for the freshly collected rainwater.

*Batch Collection (Bulk Deposition):*An artificial roofing structure from fiberglass-reinforced plastic (FRP) was installed equipped with a small storage tank from Polyethylene (PE) material to allow direct collection of rainwater through FRP material meanwhile eliminating the effect of concrete material, that represents the material for catchment area at the building.

Main Collection Facility: The main rainwater collection surface used in this study was an engineering building concrete roof that used to discharge rainwater through a selected sloped surface of 15m x 15m. As the building is more than 20 years old, roofing material also moderately suffered from aging and weathering effects as seen in some cracks in the finished surface. The collected rainwater was discharged through a vertical drainage pipe to the storm water drainage network. The piping system was modified at the ground level to connect directly with the main storage tank instead of discharging to storm water drain. The main collection tank is made from PVC and has 280 Liters capacity; it is located at the ground level adjacent to the building. The tank served for long-term water storage, where pH and EC were continuously monitored and water samples were withdrawn at different time intervals to assess the effect of storage on water quality.

Fig. 1 Location of rainwater collection site in Korea

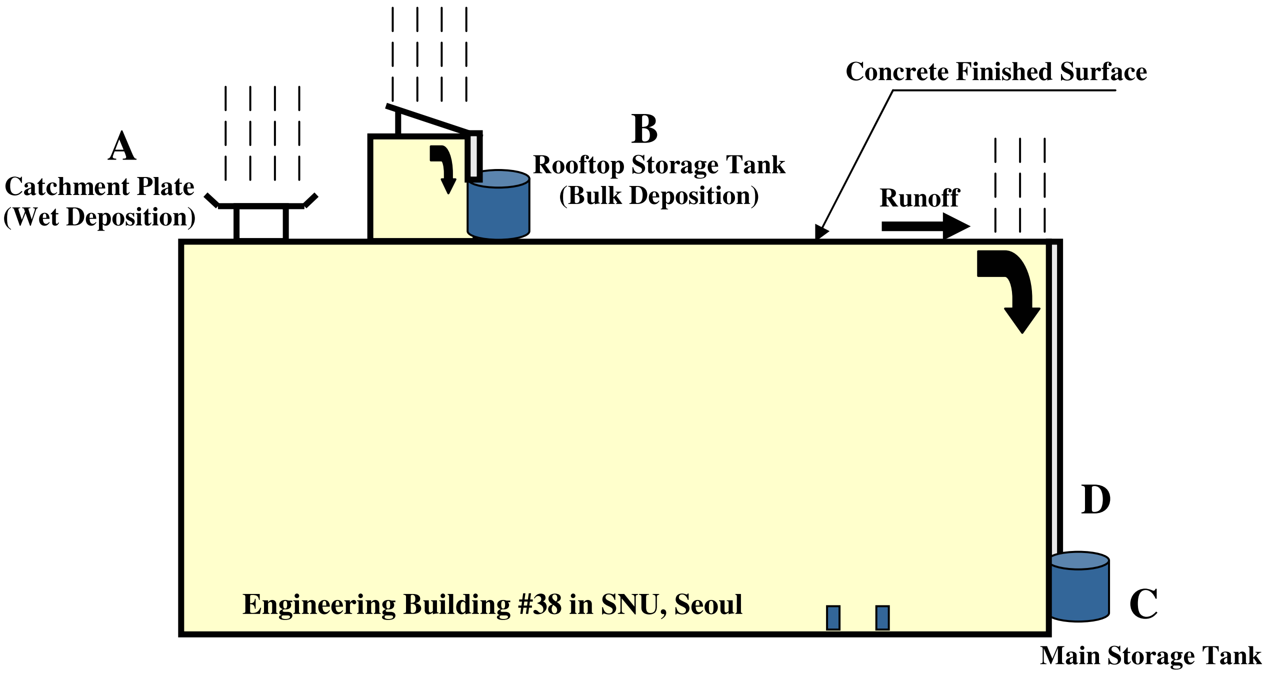

Fig. 2 Main components of rainwater collection system

2.2 Monitored Parameters and Sampling Locations:

Several parameters were monitored specially those related to water quality limits. Therefore, analyses included anions, cations, heavy metals, bacterial indicators, and other general parameters as pH, EC, etc. In order to further investigate the changes occurring in rainwater quality, four main sampling locations were established and the collected samples were analyzed as per the relevant standards. Selected sampling points for this study were:

Sampling Point A: from the acrylic plate assigned for direct collection of rainwater representing the quality of fresh rainwater.

Sampling Point B: from the small PE storage tank at the roof providing data about collected rainwater without the effect of concrete collecting surface.

Sampling Point C: from main rainwater storage tank providing most data for this study.

Sampling Point D: from the first flush port at the ground tank and can be used either to collect the first flush for analysis or after proper cleaning and during rainy events can represent the quality of freshwater after the effect of concrete collection surface but without mixing with the previously stored water in the main tank (this was the case used in the current study).

For the majority of rainy events, collected volumes of rainwater exceeded the capacity of the storage, and analysis of several parameters of newly collected rainwater were conducted. Periods with no rainy events helped estimating the changes happening in stored water without additional effect of newly collected rainwater. Measurements of cations and anions were according to Standard Methods for Water and Wastewater Analysis, heavy metals were detected using flame spectrophotometer, bacterial indicators analysis were conducted in SNU microbiological lab according to relevant standards.

3. Results and Discussions

Rainwater precipitation results in entrapment of particulate matters in the air as well as gases transferring from gaseous to liquid phases. This effect is termed as *wet deposition* and is represented in this study by sample point *A* where the collecting plate is kept clean before rain events. The rainfall characteristics thus are directed to the effect of rain alone in depositing additional material from the air. When dust and particulates depositions are allowed to settle on the catchment area, water collected after rainfall events reflect a situation of *bulk deposition* where both the effects of wet deposition and solids deposition and accumulation during dry days on the surface are reflected. In the current work, this case is represented by the case of sample point *B*.

As the main concern in the system of collecting and using rainwater would be the quality of the collected and stored water, more discussions are concerned with this stored water represented in sample point C. Data from this sampling point represents the effect of bulk deposition and catchment surface material on stored water quality. Sample D allows incorporating the effect of bulk deposition and surface area without the cumulative storage effect. Results of chemical and bacterial analysis for different samples of collected rainwater form different sampling points are herein discussed. The study was concerned with the possible alteration in stored water quality, as normal practice in rainwater harvesting is a long period storage of water for further use especially at times with deficiencies in fresh water resources. Therefore, samples from main collection tank were withdrawn after 20 days of storage of samples used in the first campaign for complete analysis of the different parameters as was carried out before.

3.1 pH and Turbidity

Variations of pH values for collected rainwater in the main tank throughout the monitoring period are shown in Fig. 3. Various rainfall amounts were precipitated during the monitoring period. Values of water pH after mixing in the rainwater tank were within the range of 4.0 to 7.0, however most frequent values measured for pH were around 5.6. Fluctuations were noted between minimum and maximum pH values especially for rain events of 40-60 mm. Rainwater in urban industrialized areas is frequently acidic due to air emissions of sulfur and nitrogenous oxides, pH in clear air is around 5.6 and it is normal that fluctuations in its values occur especially with less rainwater precipitation. The site of rainwater collection at Seoul National University is located in a well-landscaped area, far from traffic congestions or industrial emissions; it is thus normal to record such pH values. Rain events with very small precipitation did not induce noticeable variations in collected water pH. Large precipitation also tends to result in asymptote pH values of collected rainwater. An increase of pH value was recorded and attributed to the effect of concrete that elute alkaline elements into the water. Along a period of 13 days with no rain, a gradual decrease in pH value was also monitored.

Turbidity values measured for the different samples varied from 1 to 20 NTU. One exceptional value of 40 NTU occurred following a dry period of 10 days hence high accumulation of particulates at the collection surface took place. Kim and Park (2001) studied sand depositions showing that mean particle diameters may amount to 4μm during some intense deposition periods. Chun et al. (2001) characterized the dust depositions with diameters ranging from 0.3 to 25μm. Kulshrestha et al. (1996) demonstrated that the rate of particles deposition was related to the local wind speed at deposition sites. Turbidity variations in collected rainwater are shown in Fig. 4 where a general trend is the increase in both maximum and minimum turbidity values with the occurrence of rain events. Maximum values of turbidity are intensified in events preceded by longer dry days allowing for higher deposition of dust and particulate matters on collection surface. High intensity rainfall events preceded by other rainy days have less effect on turbidity increase due to excessive cleansing of collecting surfaces.

3.2 Cations and Anions

Samples collected from different sampling points were analyzed for concentrations of different cations and anions as shown in Table 1. The comparison of wet and bulk deposition results denotes that the ratio *bulk/wet* greater than 1.0 reflects the effect of deposited particulates in introducing additional chemical species to the collected rainwater. Anions and cations as sodium, potassium, chlorides, sulfates, and ammonium increased in concentration and may be attributed to deposition of salts particulates or aerosols in air as $CaCO_3$, KNO_3, Al_2O_3, NaCl, $CaSO_4.2H_2O$, and Fe_2O_3 typically existing in the dust in Seoul area as denoted by Ro et al. (2001). They also indicated that the four major chemical species observed in the dust were alumino-silicate, carbonaceous, $CaCO_3$, and SiO_2 containing species.

Kim et al. (2001) detected the presence of ammonium sulfates in both fine and coarse dust depositions in Korea, this would explain the relatively high ratio of NH_4^+ in bulk to wet deposition. However, the concentration was relatively low and was not further detected upon contact with the concrete collection surface and in the storage tank. Other parameters as alkalinity and hardness are provoked mainly from wet deposition as measured directly after rainfall events. However, long-term storage may result in additional variations in water quality as discussed later. Sulfates and nitrates concentrations detected in collected rainwater were 0.66 and 1.64 mg/l respectively. Zobrist et al. (2000) reported similar values in collected water from selected sites at Switzerland. Generally sulfates relate to contaminants release from industrial emissions while nitrates are related with vehicles emissions. Values reported for sulfates and nitrates are relatively low due to the environment in which the system is installed far from industrial emissions and having low traffic besides being on a mountainous area.

Values of hardness and alkalinity are quite similar for both wet and bulk depositions showing that the main mechanism of their addition to the system is through wet deposition. This value was noticeably higher in water collected from the concrete roof that induced instantaneous increase in alkalinity upon contact with collecting surface. Storage effect of harvested rainwater had another distinguished effect when the stored water was not subject to newly introduced harvested rainwater. Increases in alkalinity and hardness values were observed (from 16.5 to 34 and from 13 to 36 mg/l respectively). A possible interpretation of this is the dissolution of calcium or magnesium from collected particulates giving rise hardness producing elements in the solution. Previous works showed the possibility of calcium carbonate dissolution from particles already deposited, also altering the pH of the solution (Tanner, 1999). This would stimulate increased alkalinity and hardness besides decreasing the pH for more existence of bicarbonate forms instead of carbonates. Townsend et al. (1999) carried out leaching investigations on construction and demolition wastes showing that concrete was a main source of leaching of anions and cations into leachate solution, therefore, inducing an increase in total dissolved solids concentrations. As these leaching experiments were conducted on raw waste material, it is expected that similar behavior emanate from the roof material but with low effect may occur due to washing from successive rainfall events.

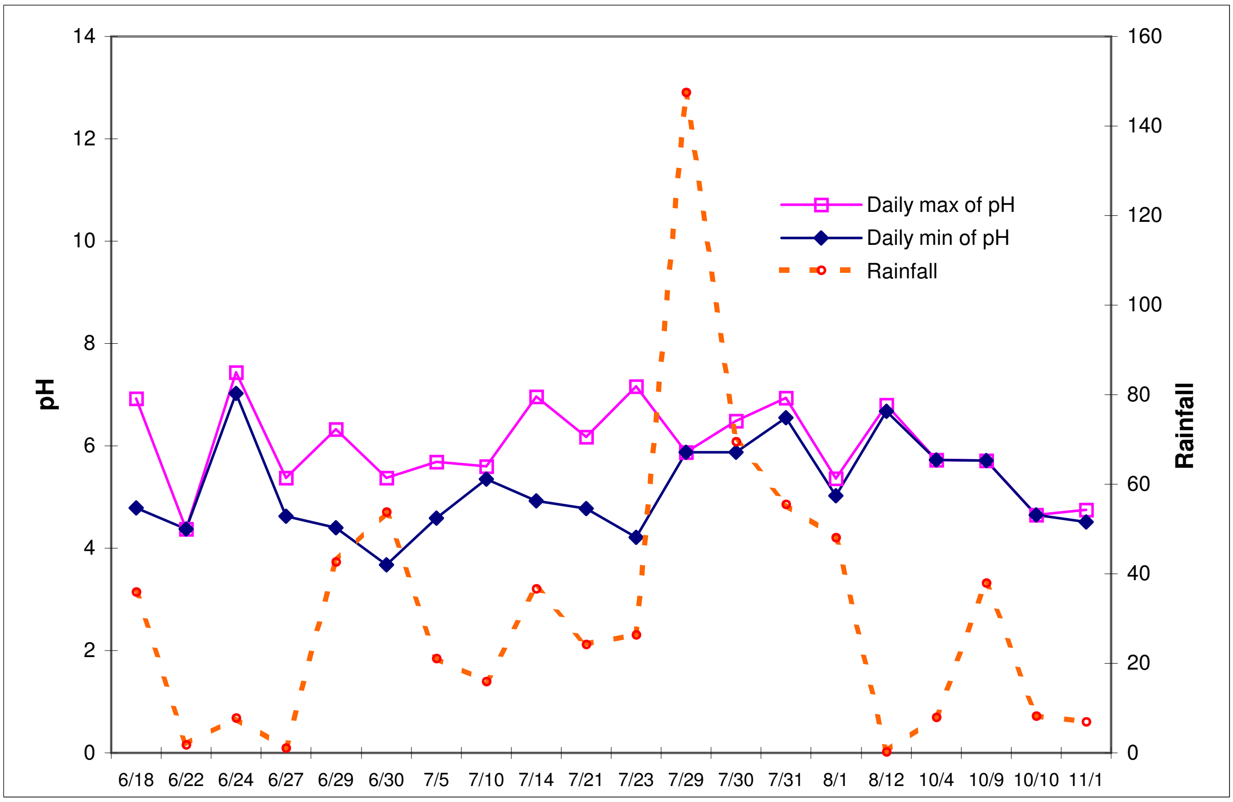

Fig. 3 pH variations with collected rainwater

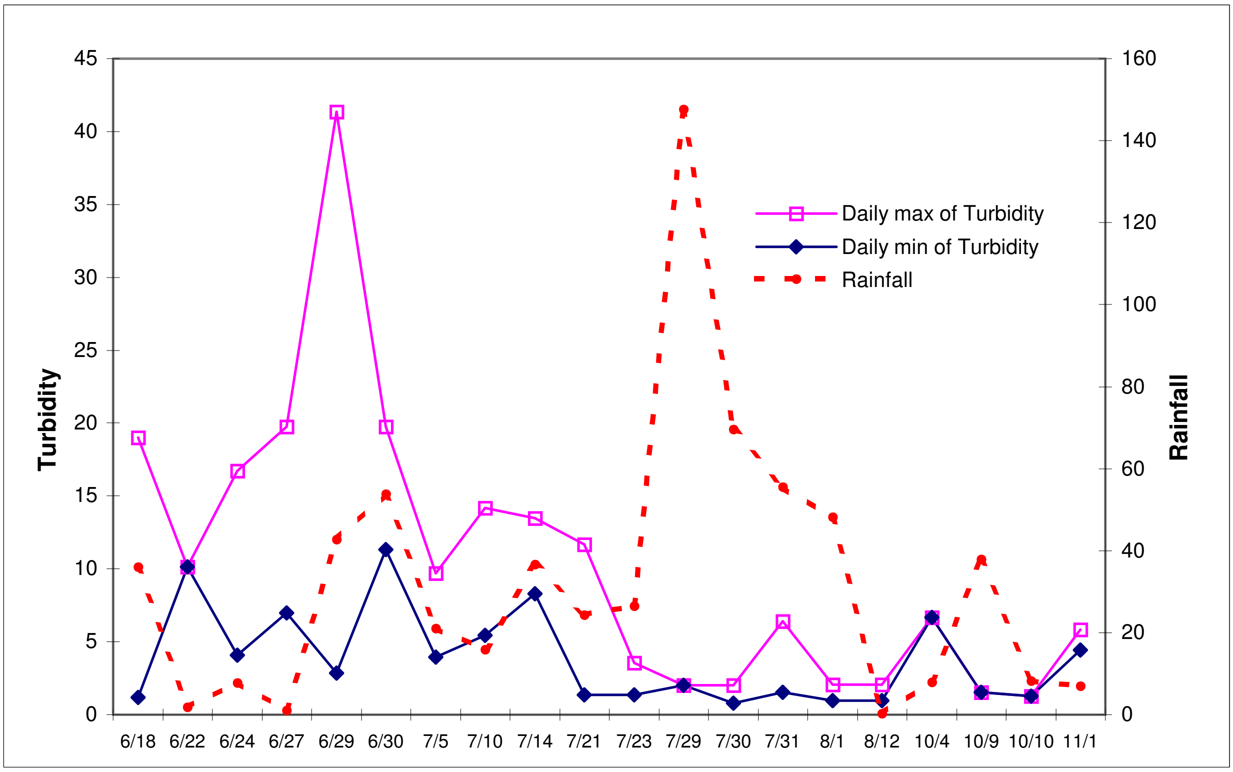

Fig. 4 Turbidity variations with collected rainwater

Table 1 Anions and cations concentrations in harvested rainwater (mg/l)

Parameter	Wet deposition	Bulk deposition	Bulk/wet	From main collection surface	Stored water	Guidelines (WHO)
Na^-	0.29	0.65	2.24	2.5	2	200
K^+	0.18	0.22	1.22	1.57	0.32	
NH_4^+	0.01	0.27	27	N.D.[a]	N.D.	1.5
Alkalinity as $CaCO_3$	0.5	0.5	<=1.0	16.5	16.5	
Hardness as $CaCO_3$	3	1	<=1.0	17	13	
Cl^-	0.84	1.72	2.05	2.02	1.84	250
SO_4^{2-}	0.66	1.11	1.68	2.48	2	250
NO_3^-	1.64	1.15	<=1.0	1.49	1.21	50
F^-	N.D.	N.D.		N.D.	N.D.	
NO_2^-	N.D.	N.D.		N.D.	N.D.	3
PO_4^{3-}	N.D.	N.D.		N.D.	N.D.	

[a] Not Detected

3.3 Heavy Metals

Selected heavy metals were investigated for there existence in collected rainwater and their concentrations are as shown in Table 2. The results show that some of the studied metal originates during wet deposition as Al, Zn and Pb from fine particulates in the air deposited by the direct effect of rainfall precipitation. However, greater effect is viewed with bulk deposition where 3 to 7 times the deposited amounts are introduced by the previously deposited dust during dry periods. Al and Pb showed concentrations approaching those limited for potable quality.

Kim et al. (1998) studied heavy metals concentrations in dust collected from residential and traffic areas south of Seoul in Taejon Korea, and reported varying mean concentrations of 24 – 168, 28 – 178, and 107 – 491 μg/g of collected dust for Cu, Pb and Zn respectively. Ma et al. (2001) showed that crustal elements such as Ca, Fe, Mg, and Na appeared to accumulate in coarse size particulates, whereas chemical components with relation to anthropogenic sources such as Pb and Zn were observed to accumulate in the finer fraction of deposited particulates. These results indicate that deposited particulates are also a source of heavy metals increase in collected rainwater. However, the detected concentrations are all lower than those allowable for potable water quality.

Table 2 Heavy metals concentrations in harvested rainwater (ppb)

Metal	Wet deposition (w)	Bulk deposition (b)	b/w	From main collection surface	Stored water	Guidelines (WHO)
Al	4.66	34.04	7.3	140.8	96	200
Cr	0.13	0.4	3.1	1	0.6	50
Mn	0.85	3.14	3.7	6.2	3.6	100
Cu	2.91	10.22	3.5	6.1	5.5	1000
Zn	11.44	57.66	5	20	17.3	3000
As	0.98	3.92	4	2.7	2.8	10
Cd	0.1	0.42	4.2	0.15	0.16	3
Hg	<0.10	<0.10		<0.10	<0.10	1
Pb	8.77	29.01	3.3	6.2	6.27	10

Results also showed noticeable increase in Al concentration upon contact with concrete collection surface denoting the possibility of Al elution. Hillier et al. (1999) studied the long term leaching of concrete surface to detect toxic metals concentrations in the leachate. Along the detection period (256 days), toxic metals presence (as Cr, Cu, As, Zn, Pb) was below detection limits. However, the leaching experiments were conducted on newly cast concrete with de-ionized water thus no effects of surface cracks or rainwater quality are taken into considerations. On the other hand, Townsend et al. (1999) showed that construction waste resulted in leachate containing high concentrations of Al. Regarding the very small heavy metals concentrations (in the order of ppbs) it can be said that most heavy metals concentrations even after storage in the main rainwater collection tank are within the same order of magnitude except for Al again that showed a slight decrease after mixing with previously stored water that may be a dilution effect, however, not confirmed with the lack of information about previous Al concentration. One other possibility would be slight transformation of Al into hydroxide form precipitating in the tank bottom.

3.4 Bacterial Indicators

Collected rainwater samples were analyzed for the presence of bacterial indicators as shown in Table 3. Coliform bacteria were detected in the collection tanks in addition to an increase in heterotrophic plate count thus indicating some microbial degradation of stored water. Microbial indicators presence in stored rainwater is a common problem reported in different developed and developing countries (Appan 1999; Simmons et al. 2001; Delhi 2000) and is often noticed due to bacterial growth within the storage tank with the existence of required growth elements. Therefore, appropriate measures would be recommended for water disinfection if the stored water is to be used for potable purposes. Use of disinfection technologies as UV light or the periodic addition of disinfectants is commonly practiced depending on the type of water use and extent of available investments.

Finally, the comparison of analysis results of collected rainwater samples with tap water quality indicated that all inorganic parameters including heavy metals remain below that detected in tap water either from fresh samples or after storage. Storage time did not affect the different studied parameters concentrations except for a decrease in an increase in water alkalinity and hardness.

Table 3 Bacterial indicators in collected and stored water

Parameter	**Sample Location**	**Directly after rain**	**After 20 days storage**	**Potable Water Guidelines**	**Greywater requirement**
Coliform (# / 100 ml)	Storage Tank	10	11	0	0 – 10
	Bulk Deposition	1	N.D.[a]		
HPL[b] (# / 100 ml)	Storage Tank	620	5000	100	-
	Bulk Deposition	63	580		

[a] Not Detected

[b] Heterotrophic Plate Count

4. Conclusions

The investigation of harvested rainwater quality from Seoul city led to the characterization of collected water from the study site during the period of June to December 2001. Variations in pH and turbidity values were influenced by both the amount of rainfall and the dry period preceding the rainfall event, pH and turbidity values of 4.0 to 7.0 and 1 NTU to 20 NTU were recorded respectively. Results showed that variations in anions and cations concentrations were partly shared between wet and bulk depositions as indicated by the ratios *b/w*. For heavy metals the case was different where the majority of metals (all within ppb concentrations) were due to bulk deposition as indicated by the large *b/w* ratio ranging from 3 to 7 times wet deposition effect. This was attributed to the effect of deposited particulates during dry periods. Higher Al concentrations detected after water contact with collecting surface was referred to possible elution from the concrete surface. Inorganic parameters were lower than limits required for potable water quality. However, bacterial indicators where higher than those recommended, thus requiring further interpretation if the collected water is to be used for potable purposes. Stored water quality remained unaltered with respect to most inorganic components with an increase in alkalinity and hardness (2 times), and an increase in bacterial indicator existence (8-9 times) after 20 days of storage as can be expected in quiescent water. The increase of alkalinity was attributed to dissolution of hardness producing elements as calcium from collected particulates as calcium carbonates. Finally, practices for collection surface periodical cleaning may reduce the effect of wet deposition on changing water quality especially in heavy metals concentrations.

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