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Artificial Groundwater Recharge Methods in Lalitpur Metropolitan City, Nepal

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Abstract

Groundwater has been used from past centuries to fulfill the water demand of people in the valley. However, at the present scenario, groundwater extraction has moved beyond ground's natural recharge capacity which has caused depletion of groundwater level. As people are being aware about this issue, they don't have enough open space to let monsoon water percolate inside the earth. So, they have started artificial groundwater recharge methods in the dense settlement areas of Lalitpur Metropolitan City (LMC).

Key Informant Interviews (KIIs) and a survey were deployed to collect information about the artificial groundwater recharge systems being practiced in LMC. In the similar way, recharge methods being employed were compared with a manual developed by CSE, India for recharging groundwater. According to the study, different agencies have been involved in artificial groundwater recharge. They are using seven types of recharge methods altogether. However, all of these methods have used well shaped structure to infiltrate water to shallow aquifer. Beside recharge well, they have used almost common types of filter material with different proportion to separate sediment load from runoff water that is supposed to be recharged. likewise, certain recharge methods have sedimentation chamber too. Altogether, three types of catchment areas are used for groundwater recharge and there also exists variation in the catchment area from one method to the next method. Additionally, all of these recharge methods do not have any provision to tackle with water contamination.

However, artificial groundwater recharge systems that are being implemented in LMC have some short comings which can be seen during the design and operation phase. So, it will be a great idea for the agencies to develop a proper design for recharge methods which can operate smoothly in the coming days ensuring water quality.

Keywords

Artificial Groundwater Recharge; Recharge well; Catchment area; Filter material.

Introduction

Groundwater is thought of as liquid water flowing through shallow aquifers, but technically it can also include soil moisture, permafrost, and immobile water in very low permeable bedrock. Edwards, Williard [1] define groundwater as water filled in the fractures and voids in the underground areas. In the similar way, water that remains exposed in the surface of the ground is the surface water. However, Surface water and groundwater sources are not easily separable as they are inter-related [2]. People have been using groundwater and surface water since the ages all over the world for various purposes.

Due to urbanization and several other factors, surface water sources are being limited in Kathmandu valley and people are now using underground water for daily purposes. Groundwater is a major natural resource contributing the water supply in Kathmandu Valley and people have been using groundwater since ages through dug wells and stone spouts[3]. At the present condition, groundwater contributes for about 40% of the water supplied in the urban areas of Kathmandu valley [4]. To meet the ever-increasing demand of water in Kathmandu valley due to rise in population, groundwater is being profoundly extracted[5]. Although, groundwater is being extracted since last few decades, we still lack updated information about the situation of groundwater in Kathmandu valley [6,7]. Both shallow and deep aquifers are being heavily exploited for groundwater in Kathmandu valley [8]. Geological Structure consisting permeable rock materials that are capable of holding as well as releasing water is termed as aquifer [9] and the level at which groundwater is found is termed as water table. This situation has resulted in the increase of groundwater extraction than its natural recharge i.e. 5.5 MCM/year in the Kathmandu valley [8]. The area for natural recharge of groundwater is continuously decreasing as the built-up area has been increasing considerably inside valley. According to Ishtiaque, Shrestha [10], agricultural land within the valley has been reduced significantly after 1989. Extensive and prolonged use of groundwater resources that exceeds the natural recharge of groundwater, causes groundwater depletion [11]. That is why, depletion of groundwater level is seen in Kathmandu valley too [12].

To overcome the consequences of groundwater depletion within Kathmandu valley, some of the agencies have been involved in recharging groundwater artificially. In the case of Lalitpur Metropolitan City (LMC), core area is suitable for recharging shallow aquifer but now this area has dense settlement and in the same way, pre-existing ponds are also being encroached day by day [13]. This situation leads to think about artificial groundwater recharge in the core area of LMC. Artificial groundwater recharge is a mechanism that directs water spreading in the surface towards the ground through recharge well or modifying natural conditions[14]. Different methods are being used for artificial groundwater recharge in Kathmandu valley [15]. However, these several methods employed for artificial groundwater recharge are yet to be enlisted together. So, this study is designed to compile the methods that are engaged for groundwater recharge in LMC and compare the existing recharge methods with each other.

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Study Area and Methodology

This study was carried out within the core area of LMC (Figure 1), which is one of the vibrant cities in Nepal. To gain the objective of this study, mainly two methods were used during the field work i.e. key Informant Interviews (KIIs) and site observation as well as survey of artificial recharge structures. KIIs was carried out with the focal persons of the agencies who are involved in the construction of artificial groundwater recharge system within LMC and people living around these recharge systems. This gave us idea about the exact place where recharge system is constructed and methods, they have deployed for it.

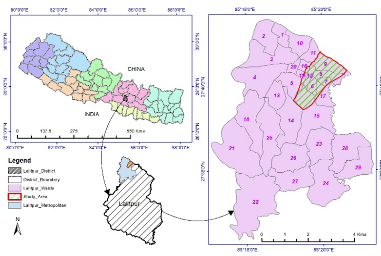

Figure 1: Study area

Moreover, this provided information about the dimensions of the recharge structure and materials they have used in the field. In addition to this, field survey was carried out to get dimensions of recharge structure for which the implementing agency could not provide secondary data. In the similar way, field survey was used to verify secondary data provided by concerned agencies. Site observation gave information about the type of catchment area that is used for recharging groundwater. After collecting all the required information about artificial groundwater recharge methods, the comparison was made among the recharge structures based on the individual components that form a complete recharge structure. Furthermore, recharge structures were compared with the guideline known as "A water harvesting manual for urban areas: case studies from Delhi" developed by Centre for Science and Environment (CSE) for artificial groundwater recharge.

Results and Discussion

Methods of artificial groundwater recharge

Here recharge methods refer to the structures that are used for recharging groundwater and these structures help to recharge water coming from rooftop, paved and walking street (concrete) areas. Organizations involved in the artificial groundwater recharge in the core area of LMC are; Urban Environment Management Society (UEMS), Centre for Integrated Urban Development (CIUD), Environmental Camps for Conservation Awareness (ECCA), and LMC office.

The main motto of all the recharge methods is to recharge groundwater. In the similar way, all the recharge methods have been using well shaped structure to recharge groundwater and they have single recharge well for one recharge method. However, there exist some differences between these recharge methods. First difference can be seen as the presence or absence of sedimentation chamber along with the recharge well. Furthermore, sedimentation chamber of type-III has filter material whereas others do not have it. So, they do not have uniformity in having filter material in sedimentation chamber. Although, each recharge method is using single recharge well for recharging groundwater, the depth varies from 2.4 to 10 m. This confirms, the recharge well does not have the same depth and in the same way, diameter of one well differs from the next in many cases. Though, gravel, boulder, pebble, pieces of brick, coarse and fine sand have been used as filter materials, use of filter materials by composition and volume in recharge well differs from one recharge method to the next recharge method. Irrespective of all other types of recharge method, recharge well of type-III does not have any filter material in it. While comparing the recharge materials used in recharge well, its volume varies from 8.33% in the case of type-II to 62.5% in the case of type-VII. For the purpose of maintenance, only the type-III has kept manhole. This can help type-III to be more sustainable than others, as they do not have proper provision for the maintenance during operation phase. Although, three types of catchment areas are being used for the recharge systems in LMC, for some recharge systems single type of catchment is used and for few other recharge systems two types of catchment areas are used in combined form. In addition to this, catchment area of one recharge method varies from the next. The variation can be seen from 106.4 to 1095.5m^2. Among all the recharge methods, type-IV has the drainage hole at the upper part of recharge well and this helps to drain water, when all the water from catchment area cannot be recharged through recharge well. At the same time, other recharge systems may have problem when their recharge well cannot infiltrate water through it during the peak flow.

Technical aspect of recharge methods

To know the effectiveness of the recharge methods, some of the technical aspects are discussed here;

Size of recharge well and filter material: Rainwater takes some time to percolate into the soil. Therefore, the recharge structure must have the capacity to hold water which comes from catchment area during peak rainfall intensity period. So, before designing recharge well we must have information about catchment area (A), runoff coefficient (C) and peak rainfall intensity in 15 minutes (R). According to CSE [16], water collected from the catchment is given by volume of runoff water from the catchment during peak rainfall intensity (V) = A*R*C. Using this formula, required volume of the well was calculated (Table 1).

Table 1: Required and actual volume of recharge well.

Recharge type (I)	Volume of water from catchment area during peak rainfall intensity (II) = (A*R*C) L	Required volume/ size of well (III) = (2/3 of II) L	Actual volume of well (IV) = $\pi d^2h/4$ L	Criteria (V)
I	1179.33	786.22	2234.29	Meet
II	487.81	325.20	2413.03	Meet
III	479.86	319.91	18232.22	Meet
IV	1072.87	715.25	2871.39	Meet
V	444.75	296.50	2430.96	Meet
VI	3856.16	2570.77	6415.64	Meet
VII	3856.16	636.53	2799.55	Meet

In the similar way, CSE [16] recommends size of well must have capacity to hold two third volume of runoff water from catchment

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area that generates during peak rainfall period, so that, it can act as buffer to hold water before recharging. In the case of LMC, all the recharge wells constructed have enough capacity to hold water that comes from catchment and the agencies must be conscious about this in coming days too. However, the amount of filter material used in recharge well is questionable. Filter material used in the recharge well occupies large volume of recharge well and this significantly reduces void space within recharge well. This reduced space within recharge well can have negative consequences to hold two third proportion of runoff water that comes during peak rainfall period. Only recharge type-I, II have filter material that inhabits less than 10% of recharge wells volume and type-III does not have filter material within it. It is recommended to have around 10% filter material by volume in recharge well. So, the implementing agencies must be conscious about it Table 2 and 3.

Operation and maintenance (O & M): Once the recharge system comes in operation, it requires maintenance in certain interval of time as the sediment load that comes along with the runoff water settles in the filter material and blocks water passing from it. However, type-V have manhole which is used for maintenance purpose and others do not have it. This situation brings a question in front of us; will these recharge methods work in a sustainable way, without the proper provision of operation and maintenance (O & M)? Moreover, in the case of type-VII, recharge method's efficiency has been already diminished according to the key informant. This has resulted flooding in the street during heavy rainfall.

Soil profile and hydro-geology: Although, soil texture, water table level and land use play an important role for recharging groundwater [17,18], almost all the developers of artificial groundwater recharge system in LMC consider first gravel layer in the ground as the suitable zone to recharge groundwater irrespective of soil type, depth of water table and local topography. Moreover, groundwater level is encountered at about 4 to 10.5m beneath the ground level in LMC [3] and depth of recharge well being constructed varies from 2.4 to 10m. In this situation, recharge well does not meet groundwater level each time and it will be difficult for recharge well to contribute effectively for recharging shallow aquifer as some places have clay soil in between the depth of recharge well and groundwater table. In the same way, Pandey, Shrestha [7] say; it is essential to have an idea about the potential of aquifers to recharge water. So, before constructing recharge well, we must have a site-specific idea about groundwater level and the probability of existing aquifer to recharge water.

Water quality: Groundwater in the urban area has higher chance of contamination than in the rural settlements due to the various municipal sources [19]. However, agencies involved in the artificial groundwater recharge do not seem to be conscious about it and the key informants deny the possibility of groundwater being polluted through artificial groundwater recharge. Majority of them claim that, they are using rooftop as the catchment area and there is very low probability of water getting contaminated with it. Likewise, others backup their recharge method denying the presence of hazardous chemicals in the surrounding of recharge method. This brings a serious concern in front of us; are these artificial recharge systems safe enough to recharge groundwater? To some extent, the contamination can be managed in case of rooftop catchment area by flushing out the first runoff from the catchment when the summer monsoon (June-September) starts. Nepal receives around 80% of annual rainfall during the month of June to September [20,21]. But the situation becomes problematic when the catchment is paved area and it becomes sterner with the walking street (concrete).

Way forward

The groundwater is now being limited and, in some cases, it has moved far behind its natural availability due to multiple reasons. Most importantly, change in land use is inevitable at the present context in Kathmandu valley and this is changing 6% of rechargeable areas to impermeable area in every 10 years [22]. No doubt, this demands the best strategies to recharge the groundwater and provides positive vibes for the coming days. In this situation, artificial groundwater recharge method can be the best way to recharge groundwater in the areas with limited open spaces.

Although, multiple artificial groundwater recharge methods are being practiced in LMC, they are supposed to have problem in the coming days and one of the oldest recharge methods (type-VII) is already experiencing problem. There can be multiple reasons behind it but for sure design faults, such as: no provisions of proper operation and maintenance as well as ignorance of local geological conditions are the major ones. Yet, appropriate methods developed to recharge groundwater can really help to solve problems related to groundwater depletion [6]. Joshi and Shrestha [13] mention; effective groundwater recharge during the monsoon in LMC can help to tackle the problems related to depletion of groundwater level. However, utmost concern should be given to hydrogeological condition of a site, such as permeability and porosity of soil as well as depth and hydraulic conductivity of aquifer before setting an artificial recharge system [23]. This ultimately helps for the efficient planning purpose and provides a better outcome.

For recharging groundwater, core area of LMC is suitable from both, geological and meteorological prospective [13] and in the same way, clay soil along Bagmati river does not allow recharged water to pass into the river. According to JICA [24], water does not easily pass from shallow aquifer to deep aquifer in LMC due to the presence of clay sediment in between them. This helps to recharge shallow aquifer with the help of artificial groundwater recharge methods and subsequently help to raise water level in the nearby areas in dug wells and stone spouts. In addition to this, a study in capital city of Bangladesh, Dhaka, shows a rise in water table at the place with artificial groundwater recharge [25]. So, it makes clear that artificial groundwater recharge is working in some parts of the world and we can try it in LMC with a precise plan. This can ultimately help us to maintain water level in shallow aquifer. But adequate concern should be given to the quality of water that is used for artificial groundwater recharge by the agencies involved in this task. Once the groundwater gets contaminated, it's really hard to get rid of it which causes a severe negative impact on the human being directly as well as indirectly.

Conclusion

People have used shallow groundwater aquifer since past to fulfill their water demand. But at present, extraction is massive which has caused water level to fall down and to cope with this situation, artificial system of recharging started. Different agencies are involved in artificial groundwater recharge and use different structures for it. However, all the recharge methods have recharge well as common recharge structure in LMC and other components associated with this are different such as: depth of well, volume and type of filter material used, catchment type and presence or absence of sedimentation chamber. The problem with recharge systems in LMC is not giving adequate concern to local geological condition and lacks proper provision for operation and maintenance. Moreover, agencies involved in artificial groundwater recharge do not seem to have serious concern towards water quality. So, proper planning is required

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before going for artificial groundwater recharge.

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Table 2: Artificial recharge methods in LMC

Recharge method components/ Recharge type	**Sedimentation chamber**		**Recharge well**						**Type of catchment**	**Catchment area (m²)**	**Implementing agency**
	Yes/ No	Filter material	Number	Depth (m)	Diameter (Inch)	Filter material and its volume		Operation & maintenance (Manhole)			
						Filter material	Volume of well occupied by filter material (%)				
I	Yes	-	1	2.5	42	Gravel	9.09	Absent	Rooftop and paved	289.1	UEMS
II	No	-	1	2.7	42	Gravel	8.33	Absent	Rooftop	116.7	UEMS
III	Yes	Boulders, Coarse and fine sand	1	10	60	-		Present	Rooftop	114.8	UEMS
IV	Yes	-	1	4.9	34	Boulders, Coarse and fine sand	43.75	Absent	Rooftop and paved	298.1	CIUD
V	No	-	1	3	40	Boulders, pebbles and sand	61.76	Absent	Rooftop	106.4	ECCA
VI	No	-	1	5.5	48	Pieces of bricks and pebbles	18.22	Absent	Paved	1095.5	LMC
VII	Yes	-	1	2.4	48	Boulders, Coarse and fine sand	62.5	Absent	Walking street (concrete) and paved	310	CIUD

Table 3: Volume of runoff water from catchment during peak rainfall intensity.

Recharge type	**Catchment area (m²)(A)**				**Runoff coefficient (C)**			**Peak rainfall intensity in 15 minutes (R) (m/0.25h)**	**Volume of runoff water from catchment (m³)(B)**			
	A*	**B***	**C***	**Total (A*+B*+C*)**	**A***	**B***	**C***		**A***	**B***	**C***	**Total (A*+B*+C*)**
I	245	44.1		289.1	0.95	0.8		0.0044	1.0241	0.155232		1.179332
II	116.7			116.7	0.95			0.0044	0.4878			0.487806
III	114.8			114.8	0.95			0.0044	0.47986			0.479864
IV	35.7	262.4		298.1	0.95	0.8		0.0044	0.149226	0.923648		1.072874
V	106.4			106.4	0.95			0.0044	0.44475			0.444752
VI		1095.5		1095.5		0.8		0.0044		3.85616		3.85616
VII			310	310			0.7	0.0044			0.9548	0.9548

A*: Rooftop, B*: Paved, C*: Walking street (concrete)

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