Report

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Rainwater harvesting for recharging shallow groundwater

This research paper discusses the importance of managing rainwater in order to recharge groundwater sources. It indicates the potential of rainwater harvesting, when properly managed, as a tool to counter depleting water sources and ever-increasing demand for water. It is hoped that this document will be a valuable resource to other organisations and sector stakeholders involved in promoting rainwater harvesting to supplement existing water systems. This document will raise awareness of the importance of rainwater harvesting for recharging groundwater, as well as considering the core areas of Patan City as a potential recharge zone.

The report was written by Kabir Das Rajbhandari from WaterAid in Nepal with support from WaterAid in Nepal's partner Urban Environment Management Society and Sudan Bikash Maharjan. Dr Suresh Das Shrestha provided technical and advisory support in the finalisation of the document. Colleagues from the Advocacy team in Nepal reviewed the document, providing valuable input.

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Cover picture: A school girl at Lalit Kalyan School behind recharged well from harvested rain.
Picture: WaterAid/ Anita Pradhan

Contents

Abbreviation

A&H - Apartment and Housings
AIT - Asian Institute of Technology
AMSL - Above Mean Sea Level
BGL - Below Ground Level
BGR - Bundesanstalt für Geowissenschaften und Rohstoffe
BS - Bikram Sambat
CDG - Central Department of Geology
CGD - Central Groundwater District
DEM - Digital Elevation Model
DHM - Department of Hydrology and Meteorology
DMG - Department of Mines and Geology
DOI - Department of Irrigation
DUDBC - Department of Urban Development and Building Construction
EC - Electrical Conductivity
GF - Geological Formation
GIS - Geographic Information System
GL - Ground Level
GM - Geo-Morphology
GoN - Government of Nepal
GRGF - Gradual Rise and Gradual Fall
GV - Guiding Values
GW - Groundwater
GWD - Ground Water District
HMG - His Majesty's Government
HRZ - High Recharge Zone
IR - Infiltration Rate
IUCN - World Conservation Union
IWRM - Integrated Water Resource Management
JICA - Japan Internation Cooperaton Agency
KMC - Kathmandu Metropolitan City
KTM - Kathmandu
LRZ - Low Recharge Zone
LSMC - Lalitpur Sub Metropolitan City
MBT - Main Boundary Thrust
MLD - Million liters per day
MPPW - Ministry of Physical Planning and Works
MRZ - Moderate Recharge Zone
MSL - Mean Sea Level
NDWQS - National Drinking Water Quality Standard
NGD - Northern Groundwater District
NPC - National Planning Commission
NTU - Nephlometer Turbidity Unit
NWCF - Nepal Water Conservation Foundation
NWSC - Nepal Water Supply Cooperation
Q&Q - Quality and Quantity
RPZ - Recharge Potential Zone
RRGF - Rapid Rise and Gradual Fall
RRRF - Rapid Rise and Rapid Fall
RWH - Rainwater Harvesting
RWH - Rain Water Harvesting
SGD - Southern Groundwater District
Sq. Km. - Square Kilometer
TIN - Triangular Irregular Network
TNTC - Too Numerous To Count
TU - Tribhuvan University
UDLE - Urban Development through Local Efforts
UEMS - Urban Environment Management Society
WAN - WaterAid Nepal
WECS - Water and Energy Commission Secretariat
WHO - World Health Organization
WL - Water Level
WQ - Water Quality
WSSC - Water Supply and Sewerage Corporation

Abstract

Water management is very critical for the growth and development of any economy, more so in a developing countries like Nepal. However, resource is now under stress, because of excessive groundwater abstraction in the course of socioeconomic development and meeting increasing needs of growing population. Therefore, we need to conserve this precious resource while benefiting from it.

The prime objective of the study is to identify the potentiality of rainwater for recharging shallow Groundwater in Patan Area (5 wards of Lalitpur Sub Metropolitan City). The study revealed that Ground Water (GW) flow direction, which was based on elevation difference of water table in 76 wells out of 238 wells, was found in line with surface drainage pattern in Patan (ie from South/ South West to North East/North).

The rainwater recharge system installed for study in 28 wells and 25 pits under natural condition could theoretically contribute 55% of the volume of water (21,453 m^3 - volume contributed by 238 wells from rainfall catchment).

The maximum yearly contribution of 28 wells based on rainfall catchment is 11,787 m^3 on an average and is 78% of the maximum contribution ie 15,114 m^3. Similarly, contribution of 28 wells based on 12 month's Water Level (WL) fluctuation in natural (normal) condition each year on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11) is 63.254 m^3 whereas average and maximum contribution is 43.949 m^3 and 95.758 m^3 respectively.

The average theoretical volume of water that could be contributed by 238 wells based on rainfall catchment is 21,453 m^3, which is70% of total volume contributed by wells and pits (ie 30,662 m^3). 28 sampled wells and 25 pits under natural condition contribute 55% of the volume of water (21,453 m^3) ie more RWH systems installed for harvesting, more (› 21,453 m^3) the possibilities for recharging GW through wells.

When analysed from actual availability of water for recharging for 4 months during monsoon ie Ashad (June/July) – Aswin (Sept./Oct.) on an average of 3 consecutive years based on the fluctuation of water level in the 28 sampled wells in recharged condition, the maximum volume and the total volume of water that can be available for recharging from 28 wells (where RWH systems were installed) are 92.729 m^3 and 64.410 m^3 which are respectively 1.11 and 1.28 times greater than maximum (ie 83.732 m^3) and total volume available (ie 50.295 m^3) for the same period when RWH systems were not installed for those 28 wells.

The maximum and total volume available (average of 3 consecutive years 2065 - 2067) in recharged condition ie in wet (monsoon) season is 2.91 and 3.05 times more than the maximum volume (ie 31.919 m^3) and total volume (ie 21.085 m^3) available for the same period while averaging for 4 out of entire 12 months as mentioned above. Similarly, the maximum, average and total volume available for contribution from all these 238 based on 4 months during monsoon ie Ashad (June/July) – Aswin (Sept./Oct.) on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11) based on the fluctuation of water level in the sampled wells in recharged condition when compared with the 12 months on maximum, average and total volume available for contribution from all these 238 based on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11), is 889.065 m^3, (98% of 904.171 m^3), 581.652 m^3 (131% of 444.239 m^3) and 585.785 m^3 (87% of 676.189 m^3) respectively.

Key words: Rainwater, Recharge, Groundwater, Water-level, Fluctuation, Volume Augmentation

1. Introduction

1.1 Background

Groundwater has now become a major natural resource contributing the water supply system in Kathmandu Valley and people have been using groundwater since ages through dug wells and stone spouts. Usually groundwater gets recharged during rainfall period. Due to urbanization, surface infiltration has been vastly reduced while consumption of groundwater is ever rising (UDLE 1993a). In addition, the over exploitation through excessive abstraction of groundwater (both shallow and deep) resource exceeding its replenishment capacity in the course of socioeconomic development has resulted to experience severe water stress in Nepal, particularly in Kathmandu Valley. In Kathmandu valley, the total annual abstraction is presently estimated at 23.4 million cubic meters, which is much greater than the maximum recharge estimate of 14.5 million cubic meters (WECS, 2002). The consequences are either irreversible in nature or require extended periods to abate. Water level is depleting at an average rate of 2.5m per year (NPC/IUCN, 1995). At present day context, this rate must have been exceeded at for more rates. Therefore, we need to consider how we can conserve this precious resource while taking full advantage of it for the development purposes.

The aquifer system in the valley is isolated and independent to other aquifer system outside the valley. The only source of aquifer recharge in the valley is rainwater but due to unplanned urbanization, the recharge area or open spaces in the valley is getting reduced considerably and most of the rain that falls are drain out unused. Simple calculations suggest that substantial amounts of water could be made available if shallow groundwater can be recharged from rainwater. With a catchment area of 656km^2, Valley receives an annual rainfall of 1,500 mm on an average.

Most of the groundwater resources are mainly renewed (recharged) directly from the precipitation through infiltration into the saturated zone thereby maintaining the recharge potential of an aquifer and this is essential for the sustainability of that aquifer. A key challenge in this regard is to demarcate and preserve the recharging area within the aquifer basin. Suitable and applicable method of recharging groundwater through rainwater may help to solve present water problem in Kathmandu Valley. JICA (1990) worked on sediments and aquifer system and reported that shallow aquifer is potential in reserving water as the leakage from the shallow aquifer into deep one is very low because of underlying clay sediment. UDLE (1993a) distinguished various aquifer zones in Patan (core city area in Lalitpur District) and measured infiltration rates.

Rainwater harvesting is essential because (1) Surface water is inadequate to meet our demand and we have to depend on ground water (2) Due to rapid urbanization, infiltration of rain water into the sub-soil has decreased drastically and recharging of ground water has diminished. Structures to harvest rain require little space. Rain water harvesting is an old technology practiced in the valley but limited only to collect rainwater for the household purpose only and to collect rainwater in the ponds. The report from UDLE (1993 - 1 and 1993 - 2), provides information regarding water table below groundwater level and distribution of aquifer, stone spouts and shallow dug well and revealed that normally ponds and historical drainage called RAJKULO in the past are the means to collect rainwater that recharges shallow aquifer to augment flow discharges of stone spouts (*dhunge dharas*) and traditional dug wells.

This practice of collecting rainwater, after the introduction of municipal water supply system in the valley, was discontinued. As a result, all such ponds are now in very dilapidated conditions and so the traditional wells. However, recharge to shallow groundwater aquifer through soak pits or recharge pits or directly through wells from rainwater harvesting artificially is relatively a new concept of utilizing rainwater in Kathmandu. Artificial recharge to ground water is a process by which the ground water reservoir is augmented at a rate exceeding that obtaining under natural conditions of replenishment. Any man-made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system.

1.2 Statement of the problem

Water management is very critical for the growth and development of any economy, more so in a developing country like Nepal which is endowed with many water resources that need to be conserved, better managed, recharged and channelized for meeting the ever increasing requirements of present trend of urban growth of Nepal which is one of the highest in South Asia region.

Groundwater is a reliable resource for drinking and production both in terms of quantity and quality. However, the resource is now under severe stress in Nepal, particularly Kathmandu Valley because of the excessive groundwater abstraction in the course of socioeconomic development. The consequences of these over exploitation of groundwater are either irreversible in nature or require extended periods to abate. Therefore, we need to consider how we can conserve this precious resource while taking full advantage of it for the development purposes.

Most of the groundwater resources are mainly renewed (recharged) directly from rainwater i.e. precipitation through infiltration into the saturated zone thereby maintaining the recharge potential of an aquifer seems essential for the sustainability of that aquifer. A key challenge in this regard is to demarcate and preserve the recharging area within the aquifer basin.

The aquifer system in the valley is isolated and independent to other aquifer system outside the valley. The only source of the aquifer recharge in the valley is rainwater but due to unplanned urbanization, the recharge area or open spaces in the valley is getting reduced considerably and most of the rain that falls are drain out unused. Simple calculations suggest that substantial amounts of water could be made available if shallow groundwater can be recharged from rainwater. With a catchment area of 656 km^2, Kathmandu Valley receives an annual rainfall of 1,500 mm on an average.

In the context of accommodating growing needs of urbanisation and changing living standards and lifestyles of the people, the increasing number of large scale housing complexes and apartments coming up within the valley. Large number of people residing in a limited space in those housing complexes and high rise apartments need lots of water for their survival and to afford their daily domestic needs. Most of these housing complexes and high rise apartments are located in the peri urban areas within Kathmandu Valley where municipal water supply system is not available. As a result, Groundwater has become the only the source, these builders consider as a viable option. Thus, the exploitation of the local GW is increasing and will be increasing with the unplanned urbanisation in the valley. Parallel to this, the surface area required for the infiltration of the rainwater are gradually getting reduced tremendously due to concretization and increased built up areas. This type of built up activities within the valley is increasing depletion of GW level as replenishment of groundwater is far behind its extraction rate (Water Resource Strategy of Nepal, 2002). Therefore, availability of GW resource is now becoming an emerging issue in the context of water resource management.

1.3 Objective

The prime objective of the study is to identify the potential of rainwater for recharging shallow groundwater aquifer in core Patan.

Specific objectives: The specific objectives of this study are to:

- Understand the surface infiltration rate and hence recharge rate to suggest potential recharge zones along with the groundwater flow direction within the study area in Patan.

- Estimate the volumetric agumentation in shallow groundwater due to recharge from rainwater.

- Study effect of rainwater in the quality of shallow groundwater aquifer

1.4 Assumption, consideration and limitation

The following assumptions or considerations were made while preceding this project work:

- Basin level concept which should have been considered for this type of study has not been adopted whereas only administrative boundary has been considered for delineating the area for the study

- It is assumed that in a long term basis of water balance, the inflow and outflow of water (including evaporation loss from wells and recharge pits, lateral flow after infiltration and ex-filtration due to subsurface flow etc.) balance each other

- Rainfall pattern (if any) in the two successive years i.e. in 2008 and 2009 is assumed to be unchanged

- The possible contribution in augmenting recharged volume of water in the aquifer due to rainwater harvested in other non sampled wells (if any) are not taken into account

- Built up area in the delineated project area might get increased reducing natural recharging (replenishing) area and its subsequent effect in recharge of aquifer and its calculation is not considered

- Daily water consumption from a particular well throughout the year was assumed constant however the water consumption may vary from one well to another well.

2. Methodology

Artificial recharge is one many techniques used to manage water resources and is being promoted as a significant solution to water scarcity in many nations. Aquifers (Groundwater) can be recharged in two basic ways - naturally and artificially. In natural recharge, the rainwater or surface water get percolated into shallow and deep aquifer by itself through uncovered soil surfaces and fissures on the rock mass. Artificial recharge to the aquifer is the process of draining the rain water or surface water into the aquifer by constructing simple civil structures. This concept of channelizing surface rainwater into dug wells and recharge (soak) pits is possibly to revitalize the wells which are dry up or have reduced water level considerably compared to the past.

The methodology here relates only on the artificial recharge of groundwater aquifer by introducing rainwater through dug-wells and recharge (soak pits) considering RWH is a promising solution that helps to qualitatively improve contaminated groundwater aquifers by reducing concentration of pollutants by dilution *(Policy and Design Issues in Rainwater Harvesting: Case in South Asia, M. Sundaravadivel, J Kandasamy and S. Vigneswaran)*

For the successful accomplishment and execute the quality results of the research/project study, the following steps, as mentioned in "Flow Chart on Methodology Conceptualized for Study Project" in subsequent page, was undertaken as a methodology during the study.

2.1 Preliminary work

The study on "Potential of rainwater for recharging shallow groundwater aquifer in Greater Kathmandu" has been carried out in the following four stages:

a. **Collection of data:** Primary from field and Secondary through review of Literatures & interactions.

b. **Field assessment:** Considering Patan area (under Lalitpur Sub Metropolitan City) being one of the potential recharge areas within Kathmandu valley, the study is mostly concentrated in this area.

c. **Site selection:** Selection of sites suitable to meet the objectives of the study is critical for the success of the study and is dependent upon several factors including local hydro-geology, topography, and also types of facilities available for harvesting rainwater for artificial recharge of groundwater.

d. **Field observation:** The field observation was carried out for monitoring water level in 76 wells. Similarly, water quality analysis was carried out for all the well water in 76 wells. Similarly, infiltration tests were also carried out to understand the recharge rate and its recharge potential of the wells as well as of the area.

   The details of Site Selection and Field Observation are discussed below:

2.2 Site selection

Number of wells and locations for installing recharge (soak) pits for sample observations were identified; estimated the catchment area under influence of rainfall within the reach of identified wells and pits. In this context, following factors were considered for the selection of sites:

a) **Spatial distribution:** Sampling locations were selected so as to include most of the areas as possibly could, to hold maximum potential for rainwater recharge and considering the water scarce situation of the area. The areas where ground water level has dropped considerably were selected/identified for this study as de-saturated aquifer conditions which indicate high potential for recharge. Besides, these areas are also facing acute shortage of water due to unreliability of city supply and heavily dependent on the traditional water sources like traditional dug wells, stone spouts and spring sources which are again drying up due to numerous reasons.

b) **Geology and geomorphology:** Sites were located in different geological formations in core areas of Patan having predominance of Kalimati and Chapagoan Formation and geomorphologic conditions so as to observe the effect of sediment type and locations on the recharge potential. Similarly the study sites were located on terraces, slopes and low lying areas to find the most effective locations for groundwater recharge. Different previous studies indicated that Patan area is a potential for recharging hydro-geologically as the area prevails

Flow chart on methodology conceptualized for study project

Methodology of the study

Preliminary works

Literature reviews

Review of previously studied relevant documents, reports, papers.

Selection of sampling sites

Sampling sites were selected on the basis of High, Moderate and Low Recharge zone with reference to previous studies or secondary information

Field works

Data collection and analysis

- Maps regarding Recharge Potential Zone were developed also referring previous research/studies locating samples in Lalitpur & Kathmandu (focus will be in Lalitpur);
- Minimum 25 sample sites (attempt were made to undertake more sites) were identified and selected for study and data collection
- Data on seasonal variation in water level in shallow aquifer through wells were collected from the selected wells from sampling sites; and other relevant data were also collected from secondary data/information from previous relevant reports and study papers.
- Geological maps, Rainfall data were generated referring to DHG and DHM; and previous studies and literatures;
- Infiltration test and rate were identified based on the collected data, recharge potential zones identified in maps (hydro-geological maps) and their analysis

Water quality

- Water Quality assessment of the ground water collected was done for pre-monsoon, monsoon (rainy season) and post monsoon season to understand the efficacy of rainwater in improving groundwater.
- The data on WQ was collected both from field and from secondary information through reports and study papers.

Report Preparation

Documentation, computation, analysis and interpretation

- The data on WQ was collected both from field and from secondary information through reports and study papers.
- Necessary data were computed with an aid of computer aided software.
- Finally the analysis and interpretation will be done on the basis of these data.

Map preparation

Location map of sample site, recharge potential maps were prepared using geological maps of DMG as base map using GIS software

Preparation of report

- After completion of data collection, its analysis, study report, draft study report was prepared and consulted with the experts for inputs and feedbacks.
- After incorporating feedbacks and inputs, final report was prepared and shared with the relevant sector actors

with large numbers of dug wells for monitoring water level, installing RWH and recharging system.

c) **Consent of the owners:** Consent of the owners or the community is very important for the successful and smooth collection of data and implementation of the study. Therefore, the areas were also selected, particularly identification of wells and areas for installing recharge (soak) pits were made based on the willingness of community people to cooperate for undertaking the study and to initiate rain water harvesting for recharging groundwater.

2.3 Field observation

A. Determination of infiltration rate

The infiltration rate of the delineated area was determined area wise and point wise in the following ways:

Point wise: Infiltration tests carried out in some of the sample wells within and nearby the study area to determine the Infiltration rate by percolation test, using infiltrometrer, and recovery test in the wells and recharge (soak) pits.

Area wise: Depending upon the type of formation the delineated area for the study falls on, the sediment type with reference to that formation including its infiltration rate within the delineated study area was determined. The different types of geological formation were determined from the review of literatures regarding distribution of Fluvio-Lacustrine Sediments of Kathmandu Valley.

i. **Infiltration test:** During the infiltration test, the water level in the well was primarily measured and the level of the water in the well was raised by adding the water through the pipe/ tanker into the well. Then the water level was measured at a regular time interval. The representative infiltration rate thus calculated is considered as an average of the total number of data collected from the tests conducted in wells or pits or through inflitrometer.

Infiltration test in wells: Altogether, 7 wells were selected from different sampled locations for this test and data on infiltration tests were collected accordingly in May 2009. The infiltration test in these wells were carried out by two methods i.e. percolation test and recovery test.

Infiltration test in recharge pits: The infiltration test through recharge pits were done by excavating the pit to a diameter varying from 91 cm to 121 cm and the wall of the pit was concreted so no lateral flow of water from the wall takes place. The bottom of the pit was open so that maximum infiltration could occur. 4 pits were tested for in the field and infiltration test. 3 out of 4 are within the study area whereas one pit is nearby area.

Infiltration test using infiltrometer: In addition to the field test conducted for determining infiltration rate of the area delineated for the study, number of infiltration test records conducted by previous study for 6 different aquifers were also reviewed and considered to interpolate and extrapolate for determining the infiltration rate of the other wells and pits, which are within the study area, but were not tested.

Similarly, Infiltration was tested in 8 locations through infiltrometer and the infiltration rate was recorded accordingly. Out of 8, one location was tested with double ring infiltrometer and verified the result with the test result concluded by previous study conducted by S. B. Maharjan, 2008 and remaining was tested by using single infiltrometer.

ii. **Determination of infiltration rates of the wells and pits considered for this study:** The study on assessing potentiality of rainwater in recharging GW is concentrated in 1.5 km^2 covering 5 wards (7, 8 18, 19 & 20) of Lalitpur Sub Metropolitan City (LSMC) i.e. core areas of Patan. 25 different sites i.e. 7 dug wells, 4 recharge pits, 8 using inflitrometer and 6 in aquifers etc. were selected to determine infiltration rates directly from the field tests. Out of 238 wells located in Patan Study Area, 72 wells and 25 recharge pits were considered for determining infiltration rate within the study area in Patan. Infiltration test results of 7 wells and 4 pits were used to understand the infiltration rates of other 72 wells by plotting infiltration contours for interpolation so that infiltration rates could be determined. In this way, the infiltration rates of the remaining wells and pits (that were not tested) were determined through interpolation from the infiltration contour map created by means of Digital Elevation Model (DEM).

B. Determination of volume augmentation in shallow GW due to harvesting rainwater:

i. **Recharge pits:** Locations for installing 25 recharge pits were identified in the open areas like courtyard, bahals and other abundant/open spaces to trap rainwater that falls on the surface. The pits were constructed to help recharge groundwater from rainwater by directing rainwater from rooftops, paved/unpaved area.

As the size of pits to be constructed depends on catchment area, rainfall, infiltration rate etc., the depth of the pits can be estimated by the ratio of maximum amount of rainfall in the site to the area of the pit. The diameter of pits required is calculated using following equation:

$$h = 1/a * (A * C * R - K * a)$$

Where, a = Area of pit (fixed);
h = depth of pit; A = Catchment area of rainwater;

C = Runoff coefficient of Catchment;
R = Average Annual Rainfall;
K = Infiltration/Recharge rate

ii. **Water level monitoring in the wells:** Altogether 77 wells out of 238 were selected in Patan area for the study. Water Table in 77 wells of the study area was monitored twice a month at a regular frequency of 15 days throughout the year to observe the fluctuation of water level naturally (i.e. without harvesting rain); understand the natural replenishment of shallow groundwater; and acquaint data on potential water table fluctuations.

   a. **Sampled wells (wells with RWH systems installed):** 28 wells out of 77 wells were selected in Patan area for installing rainwater harvesting systems for direct sampling during the study period. Rainwater recharge facilities in the dug wells were constructed in 28 sampled wells to help recharge groundwater.

   b. **Monitoring in wells:** 49 wells out of 77 were selected for the study in Patan area for monitoring the fluctuation of water table due to rainwater harvested in the sampled 28 wells and to understand the contribution of these wells in recharging groundwater.

iii. **Calculating volume augmentation in shallow GW due to harvesting rainwater:** Rainwater harvesting in any area depends on the factors like area of catchment, rainwater harvesting, (runoff) coefficient, and average annual rainfall.

C. **Effect of rainwater on the quality of shallow groundwater:**
Analysis of water quality data collected before, during and after collection of rain water in the wells will be conducted through regular monitored in three different seasons i.e. pre monsoon, monsoon and post monsoon.

3. Study area

3.1 Location

The study area constitutes 5 wards (7, 8, 18, 19 and 20) in Patan, a core urban area of Lalitpur Sub-Metropolitan City (LSMC) of Lalitpur District, Kathmandu Valley. The study area lies on the terrace which gently slopes to the north. Refer figure – 1. Wards 7 and 8 lie on the eastern part of the study area and is on the downward slope from the west to the east. Ward 18 lies on the down slope to the north from wards 19 and 20. The study area, which is around 1.5 km^2 out of 15.15 km^2 of LSMC, consists of mainly gravel and sandy gravel lying on top of basically fined grained layer of Kalimati clay. Patan, the study area, is bordered by Bagamati and Manohara Rivers in the Northern side and Ring Road surrounds Patan city in the Eastern, Southern and Western sides.

3.2 Geomorphology and topography

The area exhibits diversity of topography from steeps slopes to flat terraces. The valley floor is situated at an average elevation of 1,350m, and the lowest elevation is 1220m at the southern end of the valley. The central part of the valley consists of very gentle and flat lands with elevations of about 1,300m to 1,400m, whereas surrounding part of the valley is steep mountain ranges of more than 2,000m elevation

Kathmandu Valley consists mainly of alluvial plains, alluvial and colluvial fans, fluvial and lacustrine terraces, and steep to very steep sloping mountains. Two major geomorphic units are the valley floor and the surrounding hills. The valley floor is gently sloping towards the centre and is dissected in the radial direction by the network of rivers giving rise to various separate landmasses with steep slope or scarp faces along the sides. The heights of this scarp are generally 10-20m and the width extends to some hundreds of meters.

3.3 Population

The total population of Lalitpur Sub Metropolitan City is 1,62,991 with a family size of 4.7. The total area of LSMC is 15.15km^2 whereas the study area covers 1.5km^2. The population density of the area is 10,758 per km^2 (CBS, 2003).

3.4 Water supply system in Patan

The study area, i.e. Patan has two types of water distribution function. In core area of the Patan (where our study area lies), people still depend upon traditional dug wells and stone spouts totally for water, while in outside the core area or in the newly built area people are relying upon Kathmandu Upatyaka Khanepani Limited's (KUKL – the then Nepal Water Supply Corporation – NWSC) water distribution system which is not functioning satisfactorily.

The existing water supply system facility does not guarantee a sufficient water services as the total water demand of Patan is 31 MLD against the maximum total supply of 24 MLD (UDLE, 1993). In the study area, 20% of the total population does not have access to piped water supply facilities which in fact depend on the traditional water sources like stone spouts and dug wells the source of which is none other than shallow groundwater. There are 238 dug wells in Patan area which have been the main sources of water for people living in the core of the city where NWSC pipelines still fails to provide water totally. There are substantial and widespread leakage in piped water supply distribution system and this has been estimated to be around 43% of leakage and wastage due to old pipes and poor connections in pipe lines (UDLE, 1993-2).

3.5 Groundwater

Ground water is extracted in an unregulated manner by the use of deep tube wells by big hotels, apartments and housings, large scale industrial and commercial establishments. Thousands of individual households use shallow dug wells tube wells. There is no monitoring of usage to ensure adequate recharge. There is considerable stress on the finite ground water potential of the valley and signs of over extraction are becoming evident – falling water levels, reduced supply and caving. Sustainable withdrawal from the aquifer is estimated at 26.3 MLD compared to the current ground water abstraction rate of 58.6 MLD (Stanley, 1994 and Metcalf and Eddy, 2000).

3.6 Hydro-geological set-up of Patan

The two types of aquifer are identified in the valley sediment of Patan, which is separated by separating layer of nearly impermeable Kalimati Clay. The Kalimati clay formation consist thick clay layers with occasional silt and sand bed within lignite layers, with the clay and silt belts being carbonaceous in places. The surface of Kalimati clay has been slanted some 3-40 towards North forming base for shallow aquifer. Kalimati clay is exposed all around Patan, study area. Most rivers are incised into the Kalimati clay.

Patan's shallow aquifer catchment area comprises Patan itself and a thin panhandle like extension of some 12 km towards the mountain range in South. In the immediate surroundings of Patan, the sediments overlying Kalimati clay consists of silty sandy gravel with occasional boulder and clay layers and lignite of Chapagaon formation (DMG 1998). The lower terrace deposit of the Bagamati's recent flood plain is widely deposited along the river and its tributaries but the flood plain deposits are not in direct hydraulic contact with the shallow aquifer. The shallow aquifer is aligning with the dug wells and stone spouts of Patan.

In reference to Shallow groundwater level of the Patan area, the groundwater level was encountered at 4.0m to 10.5m below ground level in the central part of the area. The areas of highest groundwater level generally coincide with areas of lower permeability (Joshi, H. R., 2006). Some 10-15m can be taken as an average for Patan's shallow aquifer thickness. South of Patan, the shallow aquifer thickness increases to 22 – 25m at Patan Industrial Estate, and even to 37m in Sunakothi (Hermann Erb, 1993).

Recharge to the shallow aquifer is exclusively through water squeezed from the confining strata or leakage from the unconfined shallow aquifer through the confining strata. Leakage from the shallow aquifer into deep aquifer can be expected to be very low because of the Kalimati clay acting as a very strong aquitard if not as an aquiclude (JICA, 1990).

4. Interpretation

All together 238 dug wells are located in the study area ie core areas of Patan out of 238 wells, 77 wells were selected randomly (convenient sampling) for the present study including 28 wells installed (equipped) with Rain Water Harvesting (RWH) systems and 49 wells considered as monitoring/reference wells for monitoring the Water Level before WL fluctuations. These wells were selected based on the suitable for water level measuring and; before keenness cooperation of the owners for the study. In addition, 25 recharge pits were also considered for the study to determine infiltration rate within the study area in Patan. The water levels are monitored at 15 days interval throughout the year for 3 consecutive years (From Baisakh 2065 – Poush, 2067 ie from April, 2009 – December 2010) even after harvesting rainwater from the installed facilities.

4.1. Recharge Potential Zone (RPZ)

The recharge potential zones of the study area were categorised into High (H), Moderate (M) and Low (L) based on the following basis: ie a. Infiltration Rate, b. Geology and c. Geomorphology. The categorization of recharge potential with reference to the infiltration rate criteria was done as mentioned below in Table – 1.

Table – 1: Categorization of recharge potential with infiltration rate

Recharge potential area	Infiltration/Recharge rate	
	(m/sec)	(cm/min)
High (H)	$>4\times10^{-5}$	0.24
Moderate (M)	2×10^{-5} to 4×10^{-5}	0.12 to 0.24
Low (L)	$<2\times10^{-5}$	0.12

Source: Joshi and Shrestha (2008)

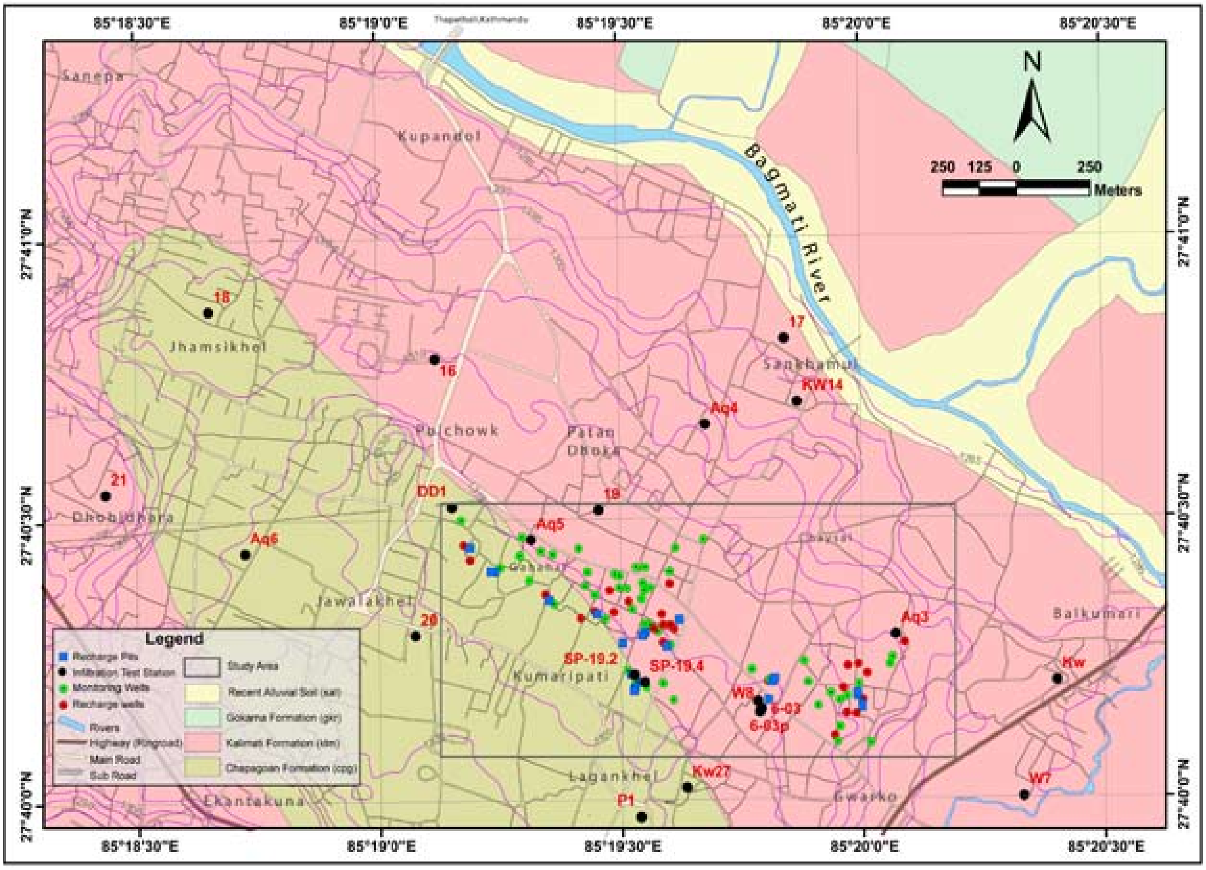


Figure – 1: Location of the study area with showing infiltration test sites and sampled wells.

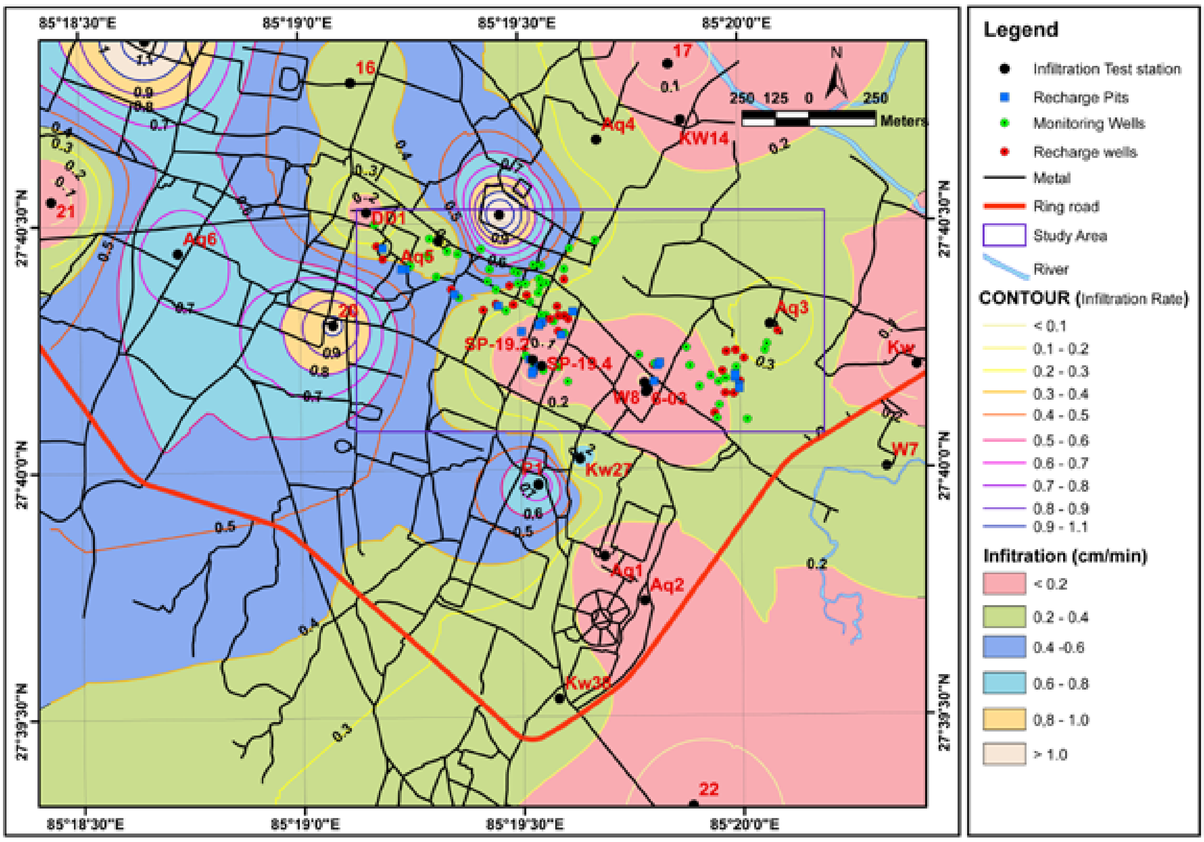


Figure – 2: Location of the study area with showing infiltration test sites and sampled wells.

Determination of Infiltration Rate and categorization of aquifer in the study area (Patan): Infiltration rate broadly depends upon rainfall and soil characteristics. The infiltration rates observed from the wells and pits (within the study area as well as outside the study but nearby it) were tested and analysed during the study. The infiltration rate was determined in the field by investigating (testing) in some of the dug wells and recharge (soak) pits within and nearby (outside) study area undertaking percolation test in wells and recharge pits; and recovery test in wells only.

a. **Point wise:** Infiltration tests were carried out in 25 sampled sites as mentioned above to determine the Infiltration rate by percolation test, using infiltrometer, and recovery test in the wells and recharge (soak) pits.

   Infiltration tests were carried out in 25 sampled sites to determine the Infiltration rate by percolation test, using infiltrometer, and recovery test in the wells and recharge (soak) pits. With infiltration test determined for each site, the contours of the infiltration rate of the wells and pits were plotted in the location map (Refer Figure – 2). This contour map of IR was used as a basis for understanding the IRs of other wells within the study areas through contour interpolation in the map. Similarly, based on the available infiltration rates according to geological formation, aquifer type formation, and geomorphology, the wells and pits were categorised as mentioned in the Table – 2.

According to the Table – 2, dug wells have higher (average is 0.292 cm/min with variation from 0.1 – 0.4 cm/min among 76 wells) recharge (infiltration) rate than that of soak pits (average is 0.192 cm/min with variation from 0.1 – 0.32 cm/min among 25 pits) due to their access directly to the aquifer horizons. Therefore the study area in general could be considered as high recharge potential area though it can further be divided into High, Moderate and Low in particular based on their infiltration rates as mentioned in Table - 1.

Table – 2: Summary of the infiltration rate calculations.

Recharge potential area	Soak pits	Avg. infiltration rate	Avg. infiltration	wells	Geological formation	Avg. infiltration rate	Aquifer type	Avg. infiltration rate	Weighted avg. IR (cm/min)
High (H)	9	0.3167	46	0.3674	6	0.7903	4	0.4325	0.4034
Moderate (M)	7	0.1500	22	0.1705	0		0		0.1665
Low (L)	9	0.1000	4	0.1000	4	0.0400	2	0.0858	0.0859

b. **Area wise:** The area wise infiltration rate was determined in the following way:

i. **Geological formation wise:** Infiltration contours are plotted based on the infiltration rate determined from the field investigations and other secondary information obtained for the wells, soak pits, and aquifer types considered during the study. The wells, soak pits and identified aquifers were located in the map within the study area. The study area is demarcated according to geological formation. The analysis indicates that area considered for this study lies in 2 geological formations:

- Chapagaon formation (cpg): 10 out of 25 soak pits, 12 out of 72 wells, 4 out of 10 formations and 3 out of 6 aquifer formation type fall under this Chapagaon formation which is at the South (S) and South-West (SW) of the area. This formation composed of coarse gravel sediment and is thus considered as high recharge potential zone.

- Kalimati Formation (klm): Similarly, 15 out of 25 soak pits, 60 out of 72 wells, 6 out of 10 formations and 3 out of 6 aquifer formation type fall under this Kalimati formation which is at the North (N) of the area. This formation composed of fine clay sediment and is thus considered as low recharge potential zone.

Table – 3: Categorisation of recharge potential according geological formation wise

Recharge potential area	Number of soak pits	Wells	Geology map	Aquifer type	Geological formation wise
High (H)	10	12	4	3	Chapagaon(cpg)
Moderate (M)	0	0	0	0	Chapagaon(cpg)
Low (L)	15	60	6	3	Kalimati(klm)
Total	**25**	**72**	**10**	**6**	Kalimati(klm)

According to Table – 3, 10 out of 25 soak pits, 12 out of 72 wells, and 3 aquifer types fall under high recharge zone and remaining in low recharge zone. None lies in moderate zone.

ii. Geo-morphological condition wise: The different types of geo-morphological condition that was observed within the study area helped to understand the infiltration rates and recharge potentials. Based on the infiltration contours plotted for the study area mentioned above, infiltration rate of each category of geomorphology was determined and categorised as per the Table - 1 mentioned.

All the wells, soak pits, geological formation and aquifer types etc. are grouped accordingly based on their geomorphology as mentioned in the Table – 4 with reference to their infiltration rates.

As the recharge mostly takes place during monsoon season and by this time, ground water level rises higher (near the surface) in the Low land areas. The low land area, which due to high water table rejects the rainwater recharge, is therefore considered as low recharge potential zone whereas the high land (terraces) is considered as high recharge potential area. That is why points located on the terraces are considered to have relatively higher infiltration rates than those located on low lands due to high water level in lowlands which rejects rainwater recharge.

c. **Ward wise:** The spatial distribution of the study area into 5 wards as mentioned are categorised into H, M and L recharge potential zones with reference to the infiltration contours plotted for the area. The Table - 5 provides a summary of ward wise categorisation of recharge potentials.

Table – 4: Categorisation of recharge potential according geomorphologic wise.

Recharge potential area	Number of soak pits	Wells	Geology map	Aquifer type	Geological formation wise
High (H)	25	63	7	4	HL
Moderate (M)	0	8	0	2	SL
Low (L)	0	1	3	0	LL
Total	**25**	**72**	**10**	**6**	
High (H)	25	63	7	4	HL
Moderate (M)	0	8	0	2	SL
Low (L)	0	1	3	0	LL
Total	**25**	**72**	**10**	**6**	

When we critically look the spatial classification (ward wise), 3 wards (8, 18 and 20) out of 5 are found to have high RPZs whereas 2 (7 and 19) wards are within moderate recharge zones respectively. Similarly, when interpreted from the map, ward 21, 20, 5, 12 and 6 are found in High RPZ, whereas part of 6, 11, 8 and 7 are within Moderate RPZ and part of 7 and 9 are also within low RPZ. The average infiltration of this High RPZ is within the range of 0.35 cm/min and that of Moderate RPZ is 0.19 cm/min.

Table – 5: Ward wise categorisation of recharge potential

	RPZ						Average infiltration Rate wrt RPZ							
wards	high		Moderate		Low		High		Moderate		Low		Infiltration	Weighted recharge
	pits	Wells	Pits	wells	pits	Wells	Pits	Wells	Pits	Wells	Pits	Wells	rate	potential
7	4	2	0	11	3	0	0.25	0.25	0	0.18	0.1	0	0.19	M
8	0	9	2	3	0	0	0	0.34	0.15	0.15	0	0	0.27	H
18	1	20	0	0	0	0	0.3	0.39	0	0.00	0	0	0.39	H
19	1	6	5	6	6	3	0.5	0.36	0.2	0.17	0.1	0.1	0.19	M
20	3	9	0	1	0	0	0.4	0.37	0	0.20	0	0	0.36	H

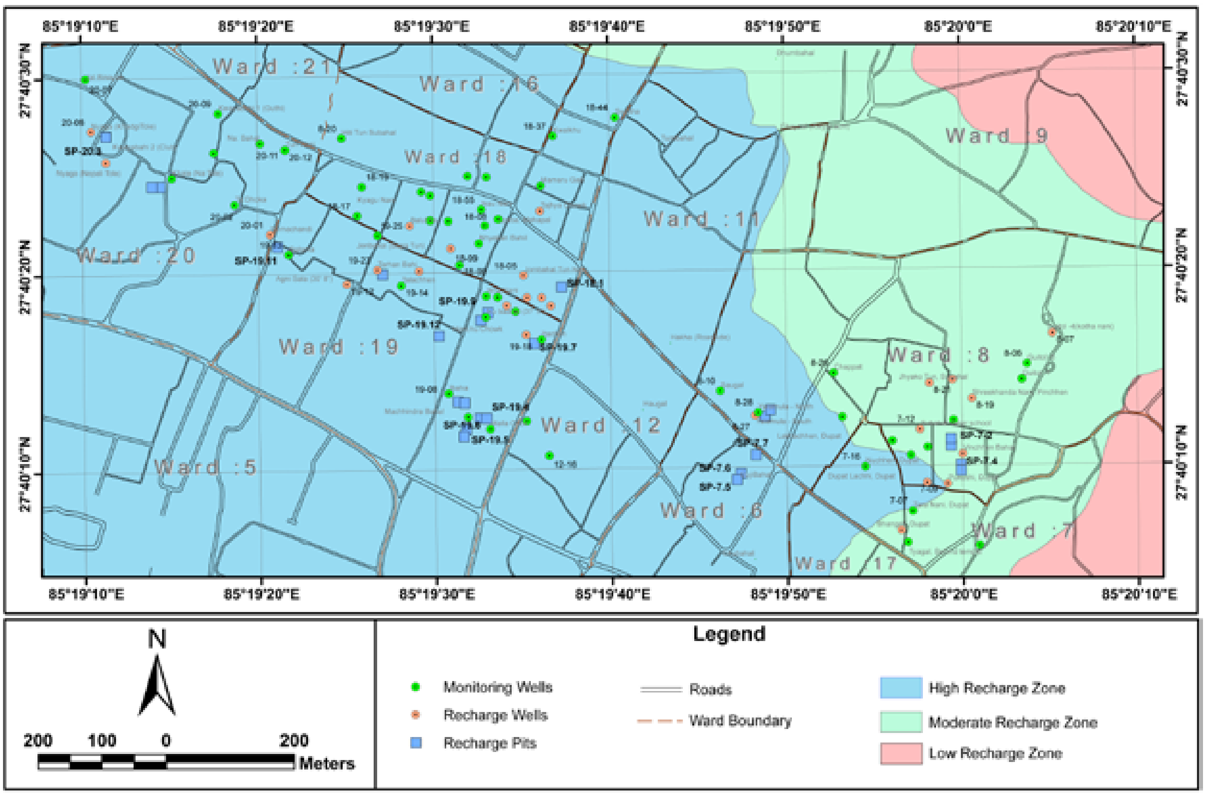


Figure – 3: Recharge potential zone of the study area

On the basis of these results the potential recharge zone is delineated within the study area as shown in Figure - 3.

4.1.1. Interpretation

- The study shows that local geology and geomorphologic factors exert strong influence in the subsurface and lateral flow and hence in the GW recharge rates. Areas dominated by coarse sediments like sand and or gravel of Chapagaon formation have high to moderate infiltration rate compared to Kalimati formation with fine grained sediments like clay dominance has low infiltration rate. Similarly, geo-morphologically also, the areas with high land (terraces) have high, slope Land have moderate and low land have low recharge potentials as low lying areas rejects groundwater recharge in monsoon due to high water level.

- Dug wells have higher (average infiltration rate of 0.292 cm/min) infiltration rate and have high recharge potential compared to soak pits (average infiltration rate of 0.192 cm/min). As dug wells have higher recharge rates than the pits, dug wells in open spaces like like *bahals* and *chowks* with larger communities are good structures for recharging shallow groundwater. From the study of 5 wards, 3 wards (8, 18 and 20) are found to have high recharge potential (RP) whereas two (7 and 19) wards have moderate. The average infiltration of this High RPZ is within the range of 0.35 cm/min and that of Moderate RPZ is 0.19 cm/min

4.2. Determination of ground water flow direction

Previous existing data of water table (wherever exists) were used; and wherever it didn't, the fluctuation in water table in the wells were observed by asking the locals. Based on the water level of the groundwater table, its elevation was established with reference to Mean Sea Level (MSL) which was considered as a datum. For the analysis of the GW flow direction in the study area, the water level elevation was established with reference to the mean sea level and the flow direction was concluded as the highest elevation to lowest elevation.

The elevation difference of the water table monitored throughout the year in the 76 wells helped to determine the fluctuation of water level in the wells. These data were used to plot and project topographic elevations by using Triangular Irregular Networks (TIN); and generate the contours of water level in the area by generating a Digital Elevation Model (DEM) for both dry (pre-monsoon) and wet (monsoon) seasons. The flow direction of the water level was then identified from the contour values. The Figures - 4 and 5 showed that the water level elevation and flow direction during Pre Monsoon and Monsoon season respectively

The water level fluctuation in the whole area varies within 11 – 13m at its maximum both in Pre Monsoon (varies from 1,297m to 1,310m) and in Monsoon (varies from 1,300m to 1,311). In both the seasons, the lowest water level is in the East-Central Part (ie Guitol) whereas the highest water level is in the South (S) and South West (SW) part of the study area. In the whole area, the yearly average water level fluctuation is found to be 2m, whereas in some location (Balukha), variation was observed up to 5m. The depth to water table contours from Southern part of the area sloping downwards to North towards Bagamati River indicating that groundwater contours Above Mean Sea Level (AMSL) decreases from South-West to North-East. This decrease in AMSL contour indicates the flow direction from S to NE towards the Bagmati River in the North of the study area. At Northern Patan the flow direction is nearly towards West to East direction as groundwater contours (AMSL) decreases towards North-East and Eastern direction. Hence, aquifers in Patan work as a huge tank where rainwater can be

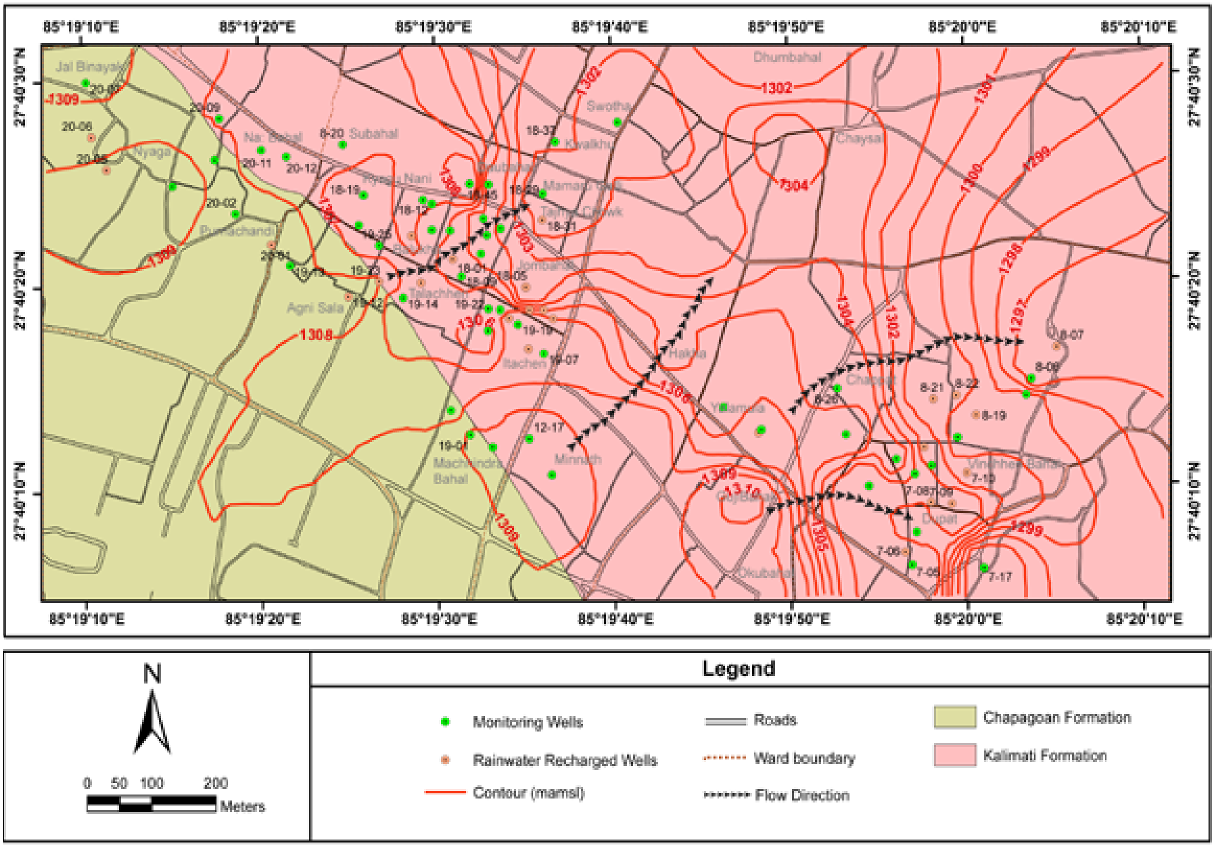


Figure – 4: Groundwater contour above mean sea level (AMSL) showing flow direction during Pre-monsoon season

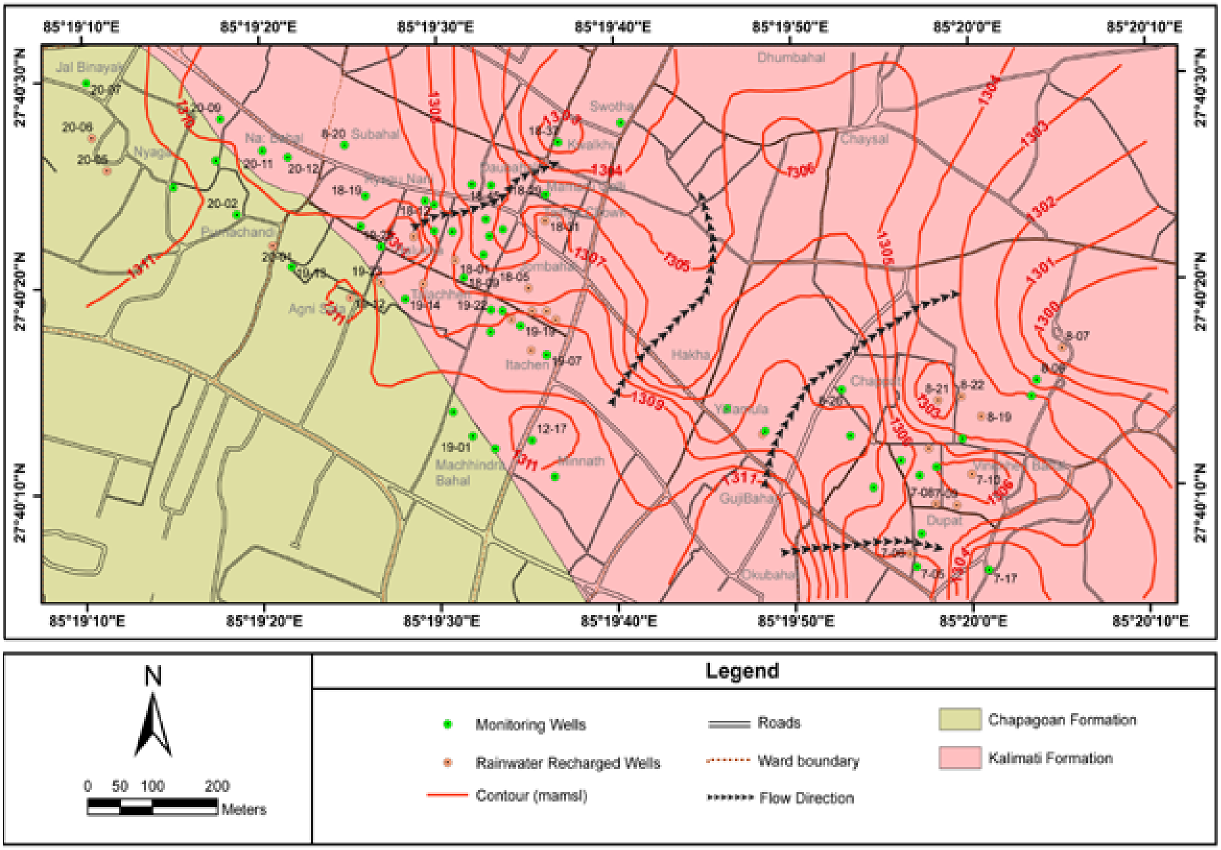


Figure – 5: Groundwater contour above mean sea level (AMSL) showing flow direction during Monsoon season

stored during monsoon and extracted during dry season. Put this in conclusions

Groundwater contours of AMSL of 1,304, 1,306 and 1,308m around Mangalbajar, Mahapal, Ikhalakhu, Daubahal, Kwalkhu, and Swotha area are widely separated showing consistency of water table around the subsurface of these areas. Shallow dug wells are clustered very closely in this area which is very densely populated requiring huge amount of water daily. Due to over extraction of groundwater from wells, groundwater flow seems to be concentrated in this area to balance the GW level around Mangalbajar. Lots of new private dug wells are being constructed by locals in Gabahal, Mahapal, Mangalbajar, Daubahal, Swotha and Chyassal which enhance the quantity of water being extracted thus decreasing water level of the area.

Groundwater contours AMSL with highest value 1310m runs from Kanibahal, Gujibahal, Saugal, Tangal, Agnisala, Balukha, Gabahal, Natole, Chabhal, Patandhoka and towards Bakundoole making this area suitable for groundwater recharge through Ponds or wells then in a usual pattern groundwater contours AMSL decreases towards North-East and Eastern direction. Groundwater contours AMSL comes close together at Eastern part of the city near Bagamati River and Manohara River at Guitol, Vinchhe Bahal and Tyagah showing steep sloping trend of water table at the area, but direct groundwater seepage to the River is blocked by black clay of Kalimati formation around Shankhamul and Balkumari sealing the possible leaking part making Patan area suitable for groundwater recharge and extraction. Hence aquifers in Patan city work as a huge tank where rainwater can be stored during monsoon and extracted during dry season.

The shallow groundwater flow direction thus determined from South/South West (S/SW) to North East/North (NE/N) was in conformity with flow direction identified by UDLE – 1993 -1 for Patan in general and also confirms the fact that shallow groundwater aquifer flows in line with the surface drainage flow pattern which in case of Patan is from South (S) to North East (NE) and East (E) direction ie towards Bagamati River which lies in the Northern Part of the study area. Therefore, this establishes the fact that the depth of shallow water table aquifer depends on the topographical position and surface drainage patterns of the area.

Thus, from the analysis of the WL fluctuation of the study area, it clearly indicates that the area has large potential for ground water recharge. However, some area in the Northeast and East part of the area (in wards 7 and 8) have high potential of recharging as they could not hold water till dry months which is due to high permeability because of gravel layer zone (which has comparatively high permeability) and flow direction of groundwater from these areas (wards) as indicated by the WL contour maps shown in Figures – 4 and 5.

Interpretation

- The average water level fluctuation in the whole area is found to be 2m. The AMSL contour within the study area indicates that the flow direction of shallow GW aquifer is from South/South West (S-SW) to North/North East (N-NE) direction confirming in line with the surface drainage pattern. Therefore, aquifers in Patan work as a reservoir where rainwater can be stored in monsoon and extracted in dry season. The recharge structures like ponds which play a vital role in shallow aquifer recharge, are therefore lined up more or less in a NNW-SSE direction which is almost perpendicular to GW flow direction (eg clusters of ponds in Lagankhel and Pulchowk).

- The variation in WL fluctuation in the wells is probably due to the difference in water bearing formation (aquifer) underlying the wells and the difference in hydro-geological parameters like hydraulic conductivity of the aquifer material. The subsurface geology varies so much that even wells nearby differ from each other. Aside from the subsurface hydrogeology, the surface topography also plays a vital role in aquifer recharge and subsurface flow of water.

- Thus, from the analysis of the WL fluctuation of the study area, it clearly indicates that the area has large potential for ground water recharge. However, some area in the Northeast and East part of the area (in wards 7 and 8) have high potential of recharging as they could not hold water till dry months which is due to high permeability because of gravel layer zone (which has comparatively high permeability) and flow direction of groundwater from these areas (wards) as indicated by the WL contour maps.

4.3. Interpretation on volume augmentation (Recharge) in shallow ground water due to recharge from rainwater

Rainwater harvesting in any area depends on the factors like area of catchment, rainwater harvesting, (runoff) coefficient, and average annual rainfall. The *Theoretical Volume* (V_{Th}) of water available within the study area is a maximum (upper limit) volume of water that is available for replenishing GW annually. The volume augmentation in shallow GW due to rainwater has been determined based on 77 wells out of which 28 wells were installed with RWH systems whereas 49 wells without having installed with RWH systems were used as monitoring wells particularly for monitoring the WL fluctuations.

Volume calculation from an average annual rainfall in the wells and pits:
The volume of water that could be contributed from wells and pits for recharging GW can be determined annually.

The maximum and minimum volume of water that could be made available annually, by all the wells and pits, based on 34 yrs rainfall data of wet season and dry season within the study area are 39,315 m^3 and 22,440 m^3 respectively. However, the contribution of 238 wells during the same period is 27,507 m^3 and 15,679 m^3 respectively and both of them are 70% of total volume contributed by wells and pits during the same period. Similarly, the contribution of 238 wells, on an average, is only 21,453 m^3 which is 70% of total volume contributed by wells and pits (ie 30,662 m^3). The sampled 25 pits and 28 wells under natural condition (when RWH system is not installed) contribute 11,787 m^3 of water in a year which is 55% of the volume of water (21,453 m^3). This indicated that if we could install more systems for harvesting rainwater for recharging GW through wells, we could harvest more than 21,453 m^3. Refer Table – 6 for details.

Table – 6: Volume of water contributed from wells and pits for recharging GW

S.N.	Average rainfall (m)	Normal (Average) of 34 yrs (1975 -2009)		Wet season) (Max^m of 34 yrs - 1978		Dry season (Min^m of 34 yrs - 1992)	
		Monthly 1.433	Yearly 0.139	Monthly 1.837	Yearly 0.592	Monthly 1.047	Yearly 0.087
Step – I							
1	Total theoretical volume of water available (m^3) [V_{TH} = Total study area * Avg Rainfall * Runoff Coefficient]	1,774,391	172,510	2,275,126	571,278	1,296,817	147,866
	Average catchment area of each well based on 28 recharge wells is 75.599 m^2						
Step – II							
2	Total volume of water available from catchment of 25 pits (m^3) [sum of catchment area of each pit X Avg Rainfall X Runoff Coeff]	9,209	895	11,808	3,802	6,731	561
3	Total volume of water contributed from 28 wells (m^3)	2,578	251	3,306	1,064	1,884	157
4	Total volume of water that can be contributed from 28 wells and 25 pits (m^3) [2 + 3]	11,787	1,146	15,114	4,866	8,615	718
5	Total volume of water contributed from 49 monitoring wells for recharging (m^3) [Average Rainfall X 0.85 X 75.372 X 49]	4,051	394	5,194	1,672	2,961	247
6	Total volume that can be contributed by 77 wells (ie 28 sampled wells and 49 monitoring wells) (m^3) [3 + 5]	6,629	645	8,500	2,737	4,845	404
7	Total volume that can be contributed by 77 wells and 25 pits (m^3) [4 + 5]	15,838	1,540	20,308	6,538	11,576	965
	Total number of additional wells in the area **(available 238 wells in the study area – considered 77 wells for the study) is 161**						

Table – 6: Volume of water contributed from wells and pits for recharging GW

S.N.	Average rainfall (m)	Normal (Average) of 34 yrs (1975 -2009)		Wet season) (Max^m of 34 yrs - 1978		Dry season (Min^m of 34 yrs - 1992)	
		Monthly 1.433	Yearly 0.139	Monthly 1.837	Yearly 0.592	Monthly 1.047	Yearly 0.087
8	Total volume contributed by 161 additional wells for recharging (m^3) [Average Rainfall X 0.85 X 75.372 X 161]	14,824	1,441	19,007	6,119	10,834	903
9	Total volume that can be contributed by wells only (m^3) [6 + 8]	21,453	2,086	27,507	8,656	15,679	1,307
10	Total volume that can be contributed by wells and pits (m^3) [2 + 9] = (2 + 3 + 5 + 8)	30,662	2,981	39,315	12,658	22,440	1,867

Volume calculation from the fluctuation of water level in the wells: Considering fluctuation of water table in a year in each individual well under observation, volume of water that could be contributed for recharging GW through them in particular can be determined annually. Two steps were involved as mentioned below in this calculation process.

Step – (a): Calculation of Volume in Natural Condition (V_N): This is a condition in which fluctuation of water level is monitored without harvesting rainwater in 28 sampled wells ie in a natural (normal) condition. Similarly, volume of water available for recharge in the wells that were not taken into consideration during this study was also calculated.

When analysed from actual availability of water for recharging from rainwater within 3 years of duration (2065 -2067) under normal (natural) condition based on the fluctuation of water level in wells, the maximum and minimum volume that can be available for recharging from all the 238 (24 RWH + 49 M + 161 Remaining) wells are respectively 904.171 m^3 and 162.897 m^3. The Average volume available for recharge from all the wells within the study area is 444.239 m^3. Similarly, the total volume available from all the 238 wells within the study area is 676.189 m^3 which is 75% of maximum volume actually available on an average within 3 yrs and is 65% of the maximum volume actually available out of 3 consecutive years ie in 2065 - 2067 (2008/09 - 2010/11).

This average recharge volume (ie 676.189 m^3) is only 3.2% of 21,453 m^3 ie total volume that could be harvested theoretically in normal condition through

Table – 7: Volume augmented WRT fluctuation of water level in natural condition

Volume augmented (m³) (based on the 12 months' Data from each year since 065 - 067 BS ie 2008/09 – 2010/11)	**Dry season (Min) (V_{MinN})**	**Wet season Max (V_{MaxN})**	**Normal season average (V_{AvgN})**	**Available ($V_A = V_{AvailN(wn)}$)**	**Dry season (Min) (V_{MinN})**	**Wet season max (V_{MaxN})**	**Normal season average (V_{AvgN})**	**Available ($V_A=V_{AvailN(wn)}$)**
a. Natural (Normal) condition	**Calculation for 12 months (A)**				**Averaging for 4 months (B)**			
Volume of Water available for recharge from 28 sampled wells throughout the year	6.439	90.096	39.961	50.893	2.146	30.032	13.320	16.964
Volume of Water available for recharge from 49 monitoring wells throughout the year	39.596	204.331	102.660	118.317	13.199	66.817	34.220	39.439
Volume of Water available for recharge from 161 additional wells throughout the year	96.378	631.983	293.191	515.179	32.126	203.849	97.730	171.724
Volume of water available from all the 238 wells for recharging GW throughout the year	**142.412**	**926.410**	**435.811**	**684.380**	**47.470**	**300.699**	**145.270**	**228.127**
2066 (2009/10)								
Volume of Water available for recharge from 28 sampled wells throughout the year	6.950	83.010	36.267	60.190	2.317	27.670	12.089	20.063
Volume of Water available for recharge from 49 monitoring wells throughout the year	33.423	157.457	81.767	98.007	11.141	52.486	27.256	32.669
Volume of Water available for recharge from 161 additional wells throughout the year	83.298	499.829	243.643	416.531	27.766	166.610	81.214	138.844

Volume augmented (m^3) (based on the 12 months' Data from each year since 065 - 067 BS ie 2008/09 – 2010/11)	Dry season (Min) (V_{MinN})	Wet season Max (V_{MaxN})	Normal season average (V_{AvgN})	Available ($V_A = V_{AvailN(wn)}$)	Dry season (Min) (V_{MinN})	Wet season max (V_{MaxN})	Normal season average (V_{AvgN})	Available ($V_A = V_{AvailN(wn)}$)
a. Natural (Normal) condition	**Calculation for 12 months (A)**				**Averaging for 4 months (B)**			
Volume of water available from all the 238 wells for recharging GW throughout the year	**123.670**	**740.295**	**361.677**	**574.729**	**41.223**	**246.765**	**120.559**	**191.576**
2067 (2010/2011)								
Volume of Water available for recharge from 28 sampled wells throughout the year	17.755	114.169	55.619	78.679	5.918	38.056	18.540	26.226
Volume of Water available for recharge from 49 monitoring wells throughout the year	47.666	220.934	116.633	137.260	15.889	73.645	38.878	45.753
Volume of Water available for recharge from 161 additional wells through out the year	157.609	710.706	362.976	553.528	52.396	236.902	120.992	184.506
Volume of water available from all the 238 wells for recharging GW throughout the year	**222.609**	**1045.809**	**535.228**	**769.458**	**74.203**	**348.603**	**178.409**	**256.486**
Averaging for 3 consecutive years (2065 – 2067 ie 2008/09 – 2010/11)								
Volume of Water available for recharge from 28 sampled wells throughout the year	10.382	95.758	43.949	63.254	3.461	31.919	14.650	21.085

Volume augmented (m^3) (based on the 12 months' Data from each year since 065 - 067 BS ie 2008/09 – 2010/11)	**Dry season (Min) (V_{MinN})**	**Wet season Max (V_{MaxN})**	**Normal season average (V_{AvgN})**	**Available ($V_A = V_{AvailN(wn)}$)**	**Dry season (Min) (V_{MinN})**	**Wet season max (V_{MaxN})**	**Normal season average (V_{AvgN})**	**Available ($V_A = V_{AvailN(wn)}$)**
a. Natural (Normal) condition:	**Calculation for 12 months (A)**				**Averaging for 4 months (B)**			
Volume of Water available for recharge from 49 monitoring wells throughout the year	40.228	194.241	100.354	117.862	13.409	64.316	33.451	39.287
Volume of Water available for recharge from 161 additional wells throughout the year	112.288	614.173	299.937	495.074	37.429	202.454	99.979	165.025
Volume of water available from all the 238 wells for recharging GW throughout the year	**162.897**	**904.171**	**444.239**	**676.189**	**54.299**	**298.689**	**148.080**	**225.396**

238 wells. If 25 soak pits were also considered we could harvest 30,662 m^3 at most optimum. The total volume might be more as there are further more possibilities of installing recharge pits in most part of the study areas to contribute in augmenting in shallow GW aquifer. Refer Table – 7 for details.

Step – (b): Calculation of volume in recharged (After harvesting rainwater) condition (V_R):

This is a condition in which fluctuation of water level is monitored with the installation of rainwater harvesting systems in 28 sampled wells ie in a recharged condition. Similarly, volume of water available for recharge in the wells that were not considered during this study was also calculated.

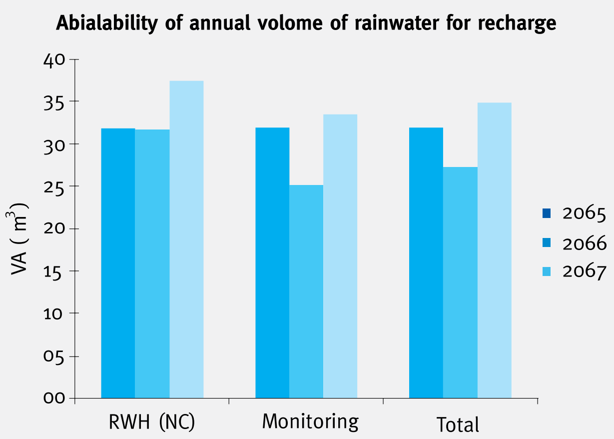
When rainwater was harvested in the 28 sampled wells, the other monitoring wells will also have increased in their water level. The percentage increment in water level in the sampled wells (after installation of RWH system) could well be utilised to predict the volume in 49 monitoring wells. Similarly, assuming the same percentage increment in their average water level, augmentation in volume in other 161 additional wells (that were not considered during this study) can also be predicted.

The maximum yearly contribution of 28 wells based on rainfall catchment is 11,787 m3 on an average whereas maximum contribution is 15,114 m3. Similarly, contribution of 28 wells based on 12 month's WL fluctuation of wells in natural (normal) condition each year on an average of 3 consecutive years (2065 -2067 ie. 2008/09 – 2010/11) is 63.254 m³ whereas average and maximum contribution is 43.949 m³ and 95.758 m³ respectively. Among the 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11), maximum contribution has been made in a year 2067 (2010/11) according to which contribution of 28 wells based on 12 month's WL fluctuation of wells in natural (normal) condition year is 78.679 m³ whereas average and maximum contribution is 55.619 m3 and 114.169 m³ respectively.

When analysed from actual availability of water for recharging for 4 months during monsoon ie Ashad (June/July) – Aswin (Sept./Oct.) on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11) based on the fluctuation of water level in the sampled wells in recharged condition, the maximum volume and the total volume of water that can be available for recharging from 28 wells (where RWH systems were installed) are 92.729 m³ and 64.410 m³ which are respectively more by 1.11 and 1.28 times greater than maximum (ie 83.732 m³) and total volume available (ie 50.295 m³) for the same period actually available for recharging in natural (normal) condition (when compared to 2065-2008/09 when RWH systems for the sampled 28 wells were not installed.

However, The maximum and total volume available (average of 3 consecutive years 2065 - 2067) in recharged condition ie in wet (monsoon) season is therefore increased by 2.91 and 3.05 times greater than maximum volume (ie 31.919 m³) and total volume (ie 21.085 m³) available for the same period while averaging for 4 out of entire 12 months as mentioned above.

The maximum, average and total volume available for contribution from all these 238 based on 4 months during monsoon ie Ashad (June/July) – Aswin (Sept./Oct.) on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11) based on the fluctuation of water level in the sampled wells in recharged condition when compared with the 12 months on The maximum, average and total volume available for contribution from all these 238 based on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11), is 889.065 m³,



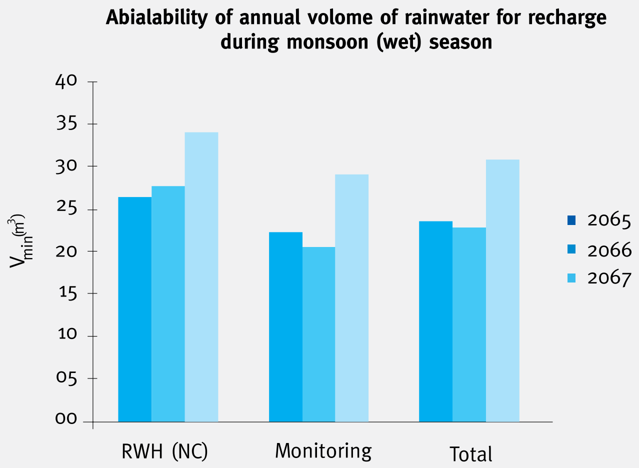


Table – 8: Volume augmented WRT fluctuation of WL in the wells

In Natural (Normal) Condition based on the Data from Mid April 2008/09 – December 2010 (ie 12 months (Baisakh – Chiatra) 2065 BS, 2066 BS and 9 months (Baisakh – Poush 2067)									In Recharged Condition Based on the Data of 4 Months (ie April (Baisakh) – July (Shrawan) for 2065 BS (2008/09), 2066 BS (2009/10) and 2067 (2010/11)							
Volume augmented (m³)	**Minm** (V_{MinN})	**Maxm** (V_{MaxN})	**Average** (V_{AvgN})	**Available** $(V_A = V_{AvailN(wn)})$	**Minm** (V_{MinN})	**Maxm** (V_{MaxN})	**Average** (V_{AvgN})	**Available** $(V_A = V_{AvailN(wn)})$	**Minm** (V_{MinN})	**Maxm** (V_{MaxN})	**Average** (V_{AvgN})	**Available** $(V_A = V_{AvailN(wn)})$	**Minm** (V_{MinN})	**Maxm** (V_{MaxN})	**Average** (V_{AvgN})	**Available** $(V_A = V_{AvailN(wn)})$
a. Natural (Normal) condition:	**Calculation for 12 months (A)**				**Averaging for 4 months (B)**				**Calculation for 4 months during Monsoon (C)**				**Diff between Recharged and Natural (Normal) Average (D = C - B)**			
2065 (2008/09)																
Volume of Water available for recharge from 28 sampled wells throughout the year	6.439	90.096	39.961	50.893	2.146	30.032	13.320	16.964	20.71	83.73	56.77	50.29	18.56	53.70	43.45	33.33
Volume of Water available for recharge from 49 monitoring wells throughout the year	39.596	204.331	102.660	118.317	13.199	66.817	34.220	39.439	86.58	187.46	142.12	96.43	73.38	120.64	107.90	56.99
Volume of Water available for recharge from 161 additional wells throughout the year	96.378	631.983	293.191	515.171	32.126	203.849	97.730	171.724	247.91	633.63	458.45	385.71	215.78	429.78	360.72	213.99
Volume of water available from all the 238 wells for recharging GW throughout the year	**142.412**	**926.410**	**435.811**	**684.380**	**47.471**	**300.699**	**145.270**	**228.127**	**355.20**	**904.82**	**657.33**	**532.44**	**307.72**	**604.12**	**512.06**	**304.32**
2066 (2009/10)																
Volume of Water available for recharge from 28 sampled wells throughout the year	6.950	83.010	36.267	60.190	2.317	27.670	12.089	20.063	14.24	82.14	47.59	61.11	11.92	54.47	35.50	41.05
Volume of Water available for recharge from 49 monitoring wells throughout the year	33.423	157.457	81.767	98.007	11.141	52.486	27.256	32.669	52.27	151.94	100.08	94.75	41.13	99.45	72.83	62.08

Volume augmented (m^3)	In Natural (Normal) Condition based on the Data from Mid April 2008/09 – December 2010 (ie 12 months (Baisakh – Chiatra) 2065 BS, 2066 BS and 9 months (Baisakh – Poush 2067)								In Recharged Condition Based on the Data of 4 Months (ie April (Baisakh) – July (Shrawan) for 2065 BS (2008/09), 2066 BS (2009/10) and 2067 (2010/11)							
	Minm (V_{MinN})	Maxm (V_{MaxN})	Average (V_{AvgN})	Available ($V_A = V_{AvailN(wn)}$)	Minm (V_{MinN})	Maxm (V_{MaxN})	Average (V_{AvgN})	Available ($V_A = V_{AvailN(wn)}$)	Minm (V_{MinN})	Maxm (V_{MaxN})	Average (V_{AvgN})	Available ($V_A = V_{AvailN(wn)}$)	Minm (V_{MinN})	Maxm (V_{MaxN})	Average (V_{AvgN})	Available ($V_A = V_{AvailN(wn)}$)
a. Natural (Normal) condition:	**Calculation for 12 months (A)**				**Averaging for 4 months (B)**				**Calculation for 4 months during Monsoon (C)**				**Diff between Recharged and Natural (Normal) Average (D = C - B)**			
Volume of Water available for recharge from 161 additional wells throughout the year	83.298	499.829	243.643	416.531	27.766	166.610	81.214	138.844	139.58	488.53	308.19	348.95	111.81	321.92	226.98	210.11
Volume of water available from all the 238 wells for recharging GW throughout the year	**123.670**	**740.295**	**361.677**	**574.729**	**41.223**	**246.765**	**120.559**	**191.576**	**206.09**	**722.61**	**455.87**	**504.81**	**164.87**	**475.85**	**335.31**	**313.24**
2067 (2010/11)																
Volume of Water available for recharge from 28 sampled wells throughout the year	17.755	114.169	55.619	78.679	5.918	38.056	18.540	26.226	23.37	112.31	65.68	81.82	17.46	74.26	47.14	55.60
Volume of Water available for recharge from 49 monitoring wells throughout the year	47.666	220.934	116.633	137.260	15.889	73.645	38.878	45.753	63.80	220.50	136.31	131.44	47.91	146.85	97.44	85.68
Volume of Water available for recharge from 161 additional wells throughout the year	157.188	710.706	362.976	553.518	52.396	236.902	120.992	184.506	200.11	706.95	429.76	506.84	147.72	470.05	308.77	322.33
Volume of water available from all the 238 wells for recharging GW throughout the year	**222.609**	**1045.809**	**535.228**	**769.458**	**74.203**	**348.603**	**178.409**	**256.486**	**287.29**	**1039.76**	**631.75**	**720.10**	**213.08**	**691.16**	**453.35**	**463.61**

	In Natural (Normal) Condition based on the Data from Mid April 2008/09 – December 2010 (ie 12 months (Baisakh – Chiatra) 2065 BS, 2066 BS and 9 months (Baisakh – Poush 2067)								In Recharged Condition Based on the Data of 4 Months (ie April (Baisakh) – July (Shrawan) for 2065 BS (2008/09), 2066 BS (2009/10) and 2067 (2010/11)							
Volume augmented	Minm	Maxm	Average	Available	Minm	Maxm	Average	Available	Minm	Maxm	Average	Available	Minm	Maxm	Average	Available
(m^3)	(V_{MinN})	(V_{MaxN})	(V_{AvgN})	($V_A = V_{AvailN(wn}$)	(V_{MinN})	(V_{MaxN})	(V_{AvgN})	($V_A = V_{AvailN(wn}$)	(V_{MinN})	(V_{MaxN})	(V_{AvgN})	($V_A = V_{AvailN(wn}$)	(V_{MinN})	(V_{MaxN})	(V_{AvgN})	($V_A = V_{AvailN(wn}$)
a. Natural (Normal) condition:	**Calculation for 12 months (A)**				**Averaging for 4 months (B)**				**Calculation for 4 months during Monsoon (C)**				**Diff between Recharged and Natural (Normal) Average (D = C - B)**			
Averaging for 3 consecutive years (2065 – 2067 ie 2008/09 – 2010/11)																
Volume of Water available for recharge from 28 sampled wells throughout the year	10.382	95.758	43.949	63.254	3.461	31.919	14.650	21.085	19.440	92.729	56.681	64.410	15.980	60.810	42.031	43.325
Volume of Water available for recharge from 49 monitoring wells throughout the year	40.228	194.241	100.354	117.862	13.409	64.316	33.451	39.287	67.549	186.632	126.172	107.540	54.140	122.316	92.721	68.253
Volume of Water available for recharge from 161 additional wells throughout the year	112.288	614.173	299.937	495.074	37.429	202.454	99.979	165.025	195.868	609.704	398.799	413.836	158.439	407.250	298.820	248.811
Volume of water available from all the 238 wells for recharging GW throughout the year	**162.897**	**904.171**	**444.239**	**676.189**	**54.299**	**298.689**	**148.080**	**225.396**	**282.858**	**889.065**	**581.652**	**585.785**	**228.559**	**590.376**	**433.572**	**360.389**

(98% of 904.171 m^3), 581.652 m^3 (131% of 444.239 m^3) and 585.785 m^3 (87% of 676.189 m^3) respectively. Refer graphical presentation and table 8 for details.

4.4. Groundwater/rainwater quality

Different parameters of the water quality are the matter of concerns for different purpose according to uses of ground water. World Health Organization (WHO) has recommended drinking water guideline value for more than 120 parameters among them relatively important parameter for drinking purpose are discussed here. The analysis of rainwater in 7 different locations indicated that rainwater is comparably safe from physio-chemical point of view and indicated coliform contamination which in case of Nayabazar is comparatively less.

Groundwater quality was tested in 14 wells during Monsoon (in July - August 2009) Pre-monsoon (mid of April 2010) and Monsoon seasons (mid of July 2010) to analyse the seasonal variation in water quality. Similarly, only 25 wells (in which rainwater harvesting systems were installed) are tested for WQ analysis. The sampled wells were located in the 5 wards of the study area ie 7, 8, 18, 19 and 20 respectively. The groundwater quality has been analysed with reference to National Drinking Water Quality Standards (NDWQS) in two basic ways to understand the effect of rainwater in the water quality; ie (a) Natural Condition (No Rain Water Harvest System Installed) and (b) Recharged Condition (After Harvesting Rainwater).

Similarly, based on the WQ analysis of 7 parameters (ie 3 physical ie pH, turbidity, and EC, 3 chemical ie iron, nitrate and ammonia, and 1 biological ie fecal coliform) in harvested rainwater from the installed RWH systems in wells, Nitrate and Coliform contamination was found considerably high where as rest of the parameters are found within the limits of NDWQS of Nepal. Regarding physio-chemical parameters being within the standards, one of the many reasons might be the dilution effect of rainwater over the constituents by mixing of clean water (Rainwater) in monsoon season.

However the nitrate and fecal contamination, which varies depending upon the extent of contaminant in the catchment as well in its conveyance system, might be due to following reasons:

- The pollution attributed from fertilizers practiced in the nearby farm and from cross contamination from sewage and organic pollution resulting high concentration of coliform and nitrate due to poor drainage systems nearby.

- Possibilities of harvested rain getting cross contaminated from the roof catchment and its conveyance system due to not availability of first flushing mechanisms etc. to avoid air contamination as well as contamination in catchment area.

- Introduction of the pollutants to the wells from the surroundings during infiltration in monsoon season and subsequent flow to GW through subsurface and lateral flow in dry months was restricted near to the source.

- Unsanitary practice of using buckets by the people in drawing water from the wells.

5. Conclusion

Local geology and geomorphologic factors exerts strong influence in the recharge of GW, sub-surface and lateral flow and hence in the GW recharge rates. Geologically, Chapagaon formation has High Recharge Potential and Kalimati has low. Similarly, geo-morphologically also, the areas with high land (terraces) have high, slope Land have moderate and low land have low recharge potentials as low lying areas rejects GW in monsoon due to high WL. Dug wells have higher (0.292cm/min) infiltration rate and have high recharge potential compared to pits (0.192cm/min) due to their direct access to aquifer horizon. Hence, dug wells in open spaces with larger communities could be good options for recharging shallow groundwater. From the studied 5 wards, wards 8, 18 and 20 are high RPZ whereas 7 and 19 have Moderate RPZ. The average infiltration of this High RPZ is 0.35cm/min and that of Moderate is 0.19cm/min.

In General, average direction of shallow GW aquifer flow from S/SW to N/NE direction and towards Bagamati (North) thus confirming in line with the direction of surface drainage pattern. Therefore, aquifers in Patan work as a reservoir where rainwater can be stored in monsoon and extracted in dry season. The recharge structures like ponds are therefore lined up more or less in a NNW-SSE direction which is almost perpendicular to GW flow direction. The analysis of WL fluctuation of the study area also clearly indicates it has large potential for ground water recharge. However, some area in the NE and East part of the area (in wards 7 and 8) have high potential of recharging as they could not hold water till dry months because of high permeability (due to gravel layer zone) and flow direction.

The average theoretical volume of water that could be contributed by 238 wells based on rainfall catchment is 21,45m^3, which is70% of total volume contributed by wells and pits (ie 30,662m^3). 28 sampled wells and 25 pits under natural condition contribute 55% of the volume of water (21,453m^3) ie more RWH systems installed for harvesting, more (> 21,453m^3) the possibilities for recharging GW through wells.

The maximum, average and total volume available for contribution from all these 238 based on 4 months during monsoon ie Ashad (June/July) – Aswin (Sept./Oct.) on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11) based on the fluctuation of water level in the sampled wells in recharged condition when compared with the 12 months on The maximum, average and total volume available for contribution from all these 238 based on an average of 3 consecutive years (2065 -2067 ie 2008/09 – 2010/11), is 889.065m^3, (98% of 904.171m^3), 581.652 m3 (131% of 444.239m^3) and 585.785m^3 (87% of 676.189m^3) respectively.

The WQ analysis of 7 parameters (three physical, three chemical and one biological) for harvested RW in seven different locations assured safe except nitrate and fecal which was observed more in Monsoon after harvesting than in pre Monsoon. This may be due to the pollution attributed from cross contamination of organic pollution due to poor sewerage and drainage systems; possibilities of harvested rain getting cross contaminated from the roof catchment and its conveyance system due to not availability of first flushing mechanisms etc.; and unsanitary practice of using buckets in drawing water from the wells.

Equations applied for determining augmentation of volume in shallow groundwater due to recharging from rainwater

Explanations	Equations (formulae)
Theoretical volume of water available within study area (V_{Th})	$V_{Th} = A \times R_{avg} \times C$
Volume of water that can be recharged through wells (v_{Rw})	$(v_{Rw1}) = a_{w1} \times R \times$
Vol. recharged through N wells is (v_{Rw})	$(v_{Rw}) =$ Sum of $(v_{wR1} + v_{wR2} + \ldots\ldots + v_{wRn})$
Where, V_{Th} = Maximum Volume of water available for recharge (m^3) = Theoretical Volume R_{avg} = Average annual Rainfall (m) from the 20 years' monthly rainfall data a_{w1} = Catchment Area of each well A = Catchment of Study area (potential area for recharge within the study area) (m^2) R = Average Annual Rainfall C = Runoff coefficient = 0.85	
Diameter of Recharge (Soak) Pits	$h = 1/a*(A*C*R - K*a)$
Volume of water that can be recharged by each pit (v_{Rp1})	$(v_{Rp1}) = C \times a_{p1} \times R$
Vol. recharged through N number of pits (v_{Rp})	$(v_{Rp}) =$ sum of $(v_{Rp1} + v_{Rp2} + \ldots\ldots + v_{Rpn})$
Where, a = Area of pit (fixed); h = depth of pit; A = Catchment Area of rainwater; C = Runoff coefficient of Catchment; R = Average Annual Rainfall; K = Infiltration/Recharge rate; a_p = Catchment Area of each Pit	
Volume of water that can be recharged by each pit (v_{Rp1})	$(v_{Rp1}) = C \times a_{base}(_{p1}) \times f_p$
Total volume that can actually be recharged through pits	$v_{Rfn} = v_{Rfp1} + v_{Rfp2} + \ldots\ldots + v_{Rfpn}$
Vol. of water that could not be recharged or wasted through pits	$vw = v_{Rp} - v_{Rfn}$
Total volume recharged through N wells and pits (V_{TR})	$(V_{TR}) = v_{Rw} + v_{Rfn}$
Where, v_{Rfp1} = Volume that can actually be recharged (infiltrated) through each pit; $(a_{base(p1)})$ = base Area of each Pit; f_p = Infiltration rate of each pit	

<table>
<tr><th>Explanations</th><th>Equations (formulae)</th></tr>
<tr><td>Maximum Volume of water that can be recharged (made available) by each well ($V_{N(w1)}$)</td><td>$\mathbf{V_{N(w1)} = V_{AvailN(w1)} = V_{max} - V_{min} = (h_{max} - h_{min}) X A_{base(well)}}$</td></tr>
<tr><td>Volume through n number of wells $V_{N(wn)}$</td><td>$\mathbf{V_{N(wn)} = \sum(v_{N(w)} = (v_{N(w1)} + v_{N(w2)} +.......+ v_{N(wn)}}$
$\mathbf{= \sum(h_{max} - h_{min})_{N(wn)} * A_{base(wn)}}$</td></tr>
<tr><td colspan="2">Where,
h_{max} = Max^{m} Height of Water Level achieved in a year;

h_{min} = Min^{m} Height of Water Level achieved in a year

$A_{base(well)}$ = Base (infiltrating) Area of well;

$V_{N(w1)}$ = Max^{m} Volume of water available in normal (natural) condition for recharge in each well</td></tr>
<tr><td>Average volume of water available for recharge due to “n” number of wells ($V_{(avg)N}$)</td><td>$\mathbf{v_{avg(w1)N} = h_{avg} X A_{base(w1)}}$
Average Height of WL $\mathbf{(h_{Navg}) = (h_{max} + h_{min})/2}$
$\mathbf{V_{(avg)\ N} = \{ (v_{avg})_{w1N} + (v_{avg})_{\ w2N} + (v_{avg})_{wnN} \}}$</td></tr>
<tr><td colspan="2">Where,
$v_{avg(w1)N}$ = Average Volume of water available in for recharge in each well

= Practically possible volume of water that could be tapped for recharging.</td></tr>
<tr><td>Volume of water available for recharge through wells that are not considered ($V_{tot(avg)Own'}$)</td><td>$\mathbf{V_{tot(avg)Own'} = n' X H_{avg} X A_{base(avg)}}$</td></tr>
<tr><td colspan="2">Where,
$H_{avg} = h_{avgN} = h_{avg1} + h_{avg2} + ...+ h_{avgn}$ = Average of sum of average height of WL fluctuation in each well (that were not considered)
$A_{base(avg)} = (A_{base\ w1} + A_{base\ w2}$ ....+ Abase wn)/n’ = Average of sum of area of the base of the wells height (that were not considered)</td></tr>
<tr><td>Calculation of Volume in Recharged (After Harvesting Rain) Condition (V_R):</td><td>$\mathbf{V_{R(w1)} = V_{max(R)} - V_{min(R)} = = (h_{max} - h_{min}) X A_{base(well)}}$
$V_{tot(w)R} = (V_{R(w1)} + V_{R(w2)} + V_{R(wn)})$</td></tr>
<tr><td>Volume through n number of wells ($V_{AvailN(wn)}$)</td><td>$\mathbf{V_{AvailN(wn)} = \sum(h_{max} - h_{min})_{N(wn)} * A_{base(wn)}}$
$\mathbf{= \sum(v_{N(w)} = (v_{N(w1)} + v_{N(w2)}}$
$\mathbf{+.......+ v_{N(wn)}}$</td></tr>
<tr><td colspan="2">Where,
$V_{R(w1)}$ = Max^{m}. Volume of water available during rainy season for recharge in each well
=Practically possible volume of water that could be tapped for recharging during rainy season.
h_{max} = Max^{m} Height of WL achieved due to rainfall (during observation period)
h_{min} = Min^{m} Height of WL achieved due to rainfall (during observation period)
$A_{base(well)}$ = Base (infiltrating) Area of well</td></tr>
<tr><td>Average volume of water available for recharge due to “n” number of wells ($V_{avg(Rw1)}$)</td><td>$\mathbf{V_{avg(Rw1)} = h_{avg} X A_{base(w1)}}$

$\mathbf{V_{(avg)R} = \{ (V_{avg})_{\ Rw1} + (V_{vg})\ R_{w2} +.........+ (V_{avg})\ R_{wn} \}}$</td></tr>
<tr><td colspan="2">Where, $V_{avg(Rw1)}$ = Average Vol. of water available rainy season (condition) for recharge in each well</td></tr>
<tr><td>If, n’ = no of wells that were not considered during the study, then volume of water available for recharge through the wells that are not considered for study, then</td><td>$\mathbf{V_{tot(avg)Own'} = n' X H_{Ravg} X A_{base(avg)}}$
Where, $\mathbf{A_{base(avg)} = (A_{base\ w1} + A_{base\ w2} ....+ A_{base\ wn})/n'}$</td></tr>
</table>

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