Analyzing the Seasonal Variation of Groundwater Characteristics in the Attanagalu Oya Basin

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Abstract

Gampaha district which has the second largest population in the country consist of many industrial establishments and residential areas. Attanagalu Oya basin which covers almost entirely the Gampaha district is a major hydrologic feature in determining the seasonal variations of groundwater characteristics in the region.

In this study, the groundwater characteristics in the Attanagalu Oya basin was analyzed both quantitatively and qualitatively to identify variations in the pre and post monsoon periods. The qualitative parameters such as pH, conductance, turbidity, calcium, magnesium, nitrate, phosphorous, ferrous, and heavy metal concentrations were analyzed for samples taken throughout the entire basin for the two time periods pre and post monsoons.

The ground water quantity variations were observed through data loggers and field surveys of water wells. These recorded values were used to model the ground water resources in the region using two numerical models, MODFLOW by USGS and a self-written Fortran code.

The qualitative and quantitative variations were then analyzed spatially and temporally to correlate with the upstream to downstream flow and the monsoonal recharge. The possible reasons for the observed trends and variations were also studied to provide recommendations for the sustainable management of the groundwater resources in the Attanagalu Oya basin.

Keywords: water quality, modelling, MODFLOW, Fortran, Gampaha, monsoon

1. Introduction

Sri Lanka has less or no water scarcity. But there are spatial and temporal scarcities in water within the country. Gampaha district which has the 2nd largest population in Sri Lanka is categorized from moderate to severe going from 1991 to 2025 according to Falkenmark indicator for water scarcity. [1] Sri Lanka is a developing country where, there is no water supply service provided everywhere. So, most of the rural areas are served by the domestic wells for the daily routines. As, there is enough ground water resource in Sri Lanka, if it would be developed quantitatively and qualitatively it should be economically preferable and the rural areas would be developed to use the ground water for industrial applications too by the effective management of groundwater. To determine the seasonal variations of groundwater characteristics some water quality tests should be done to groundwater samples collected during various seasonal periods. These water quality parameters should be tested and compared with international standards and permissible limits so that even minor variations can be detected.

Groundwater modelling has been identified by many scientists to be a major tool in groundwater management. Since groundwater models can simulate response under different conditions, information gained through varying model runs can help decision makers justify their decisions about future [2]. The objective of the study is to analyze the seasonal variation of groundwater quality and generate the initial step of a groundwater model which can be continued with the future well head observations.

1. Methodology

2.1 Seasonal variations of groundwater quality.

Ground water samples collected from the study area in the pre-monsoon and post-monsoon periods of the year 2018 were tested to analyze the major water quality parameters [3]. One liter of water sample was collected from each of the 18 locations covering the entire Attanagalu Oya basin.

The sampling locations were selected so that a representative measurement can be arrived for the whole Attanagalu Oya basin as shown in the Figure 1. In this process, two sampling locations on either side of main stream flows were obtained as given in the diagram below. Special consideration was given to collect samples from locations to depict the upstream – downstream transition.

Two field surveys were carried out in the pre and post monsoon periods of 2018. Same locations were sampled and tested in both surveys for water quality parameters.

Field survey 1 – 29th of June (South West monsoon)

Field survey 2 – 18th of October (Second inter monsoon)

2.1.1 Sampling criteria

a. On either side of stream flow.
b. Closer to industries.
c. Collection within one day.

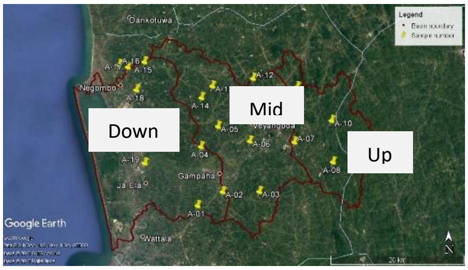

Figure 1 - Sampling locations for the field surveys 1 and 2

Down-stream – 0 – 10 m above MSL
Middle-stream – 10 – 100 m above MSL
Up-stream – 100 – 379 m above MSL

2.1.2 Chemical analysis of samples

The chemical analysis of the samples were conducted using the following instruments and methods. 1) pH – Digital pH meter; 2) Turbidity – Nephlometer; 3) Conductivity – Electrical conductivity meter; 4) Fluoride and Nitrate – HQd (High quality digital) Fluoride and Nitrate meter; 5) Calcium and Magnesium – Complexometric titration (ASTM D511-11); 6) Phosphorous – UV spectrophotometry; 7) Heavy metals (Lead and Chromium) – Atomic absorption spectrometry (ASTM D1687); 8) Ferrous – UV spectrophotometry.

2.2 Seasonal variation of groundwater quantity

Groundwater modelling was used for the analysis of groundwater quantity variation during the post and pre monsoon periods.

MODFLOW by USGS

The modeling engine used was MODFLOW 2005 by USGS. The model setup procedure was done through the third-party software Visual MODFLOW Flex Version 2015.1 by Waterloo Hydrogeologic. The model was setup to start from 2018/1/1.

The vertical profile and model structure need to be setup properly at the conceptual modelling stage in Visual MODFLOW. For the determination of the vertical structure of the Attanagalu Oya basin, well log data for 361 well all around the Attanagalu Oya basin were analyzed.

In order to determine the most general trend and layers of different types of soil, a conditional if statement was written for the different lithology classes in excel. The results obtained for the mostly occurring soil types for each layer with their frequency are given below. The results suggested that there are 5 major layers in the region as follows

Table 1 - Vertical profile of layers (mbgl-meters below ground level)

Layer	From (mbgl)	To (mbgl)
Top soil	0	3
Sand	3	10
Clay	10	13
Weathered rock	13	20
Rock	20	60

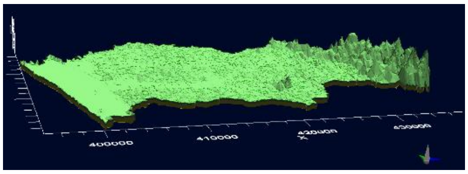

Figure 2 - The model structure with vertical exaggeration of 10

The hydraulic conductivities of each layer in x, y and z layers were assigned by referring to past literature on soil data.

Table 2 - Relevant conductivity values assigned for each layer

Layer	Kx	Ky	Kz
Top soil	0.025 25	0.025 25	0.002 525
Sand	0.001	0.001	0.000 1
Clay	2.40E -09	2.40E -09	2.40E -10
Weathered rock	2.80E -05	2.80E -05	2.80E -06
Rock	1.00E -10	1.00E -10	1.00E -11

The daily rainfall data for 11 stations in the Attanagalu Oya basin was obtained from the meteorological department from 2015 to 2018.

The Thiessen polygon method was used to assign representative values for the whole region.

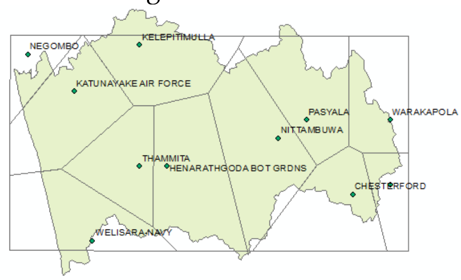

Figure 3 - Thiessen polygon method for the distribution of rainfall

The survey data of the field surveys 1 and 2 were used to create a time schedule data object for varying head conditions for two stress periods of the year. A finite difference grid type was selected with 20 rows and 20 columns. The vertical grids were maintained as uniform thickness layers consisting 10 layers for the entire model domain.

Self-written Fortran program

Unlike in the case of Visual MODFLOW which has a GUI, the self-written Fortran code runs in a command prompt and has no GUI. The model can read only text file inputs and therefore all the required variables were created as text files using ArcMap and ENVI software.

2m resolution LIDAR DEM of Attanagalu Oya Basin was obtained from the Climate Resilience Improvement Project (CRIP). This data was highly accurate but the processing power of the computers available could not handle high resolution data which would result in larger number of grids. Therefore, the data was resampled up to 75m size cells. The resulting grid covering the entire Attanagalu Oya basin consisted of 421 rows and 614 columns.

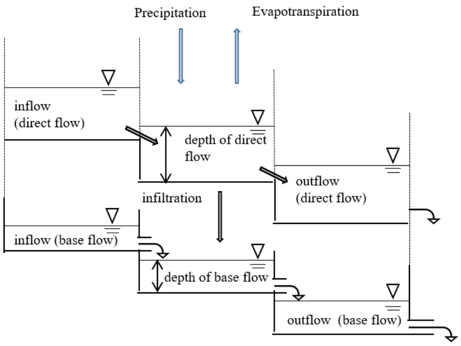

Figure 4 - Concept of the model structure for the self-written Fortran program

Binary map making code written in Fortran language was used to create binary maps for recharge and evapotranspiration for each cell in the model domain. This code uses the following data to calculate the precipitation and evapotranspiration for each cell in the model domain.

a. Elevation data
b. Model region (catchment)
c. Latitude of each cell

Inverse distance method is used for the interpolation of values for all the cells in the grid. The following equation was used for the calculation of the evapotranspiration for each cell. (Hargreaves et al, 1985)

$$ET_0 = 0.0023\,(T_m + 17.8)(\sqrt{T_{max} - T_{min}})R_a$$

T_m is daily mean air temperature [°C],
T_{max} is daily maximum air temperature [°C],
T_{min} is daily minimum air temperature [°C],
R_a is extraterrestrial radiation [MJ m^{-2} day^{-1}].
R_a is computed from information on the location of the site and time of the year.

The extraterrestrial radiation, Ra, for each day of the year and for different latitudes is estimated from the solar constant, the solar declination and the time of the year.

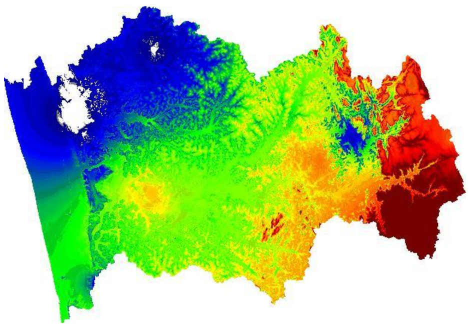

Figure 5 - Water height for surface flow (The visualization done using ENVI from the output bin file.The red color shows high intensity while blue color shows low intensity.)

3. Results and Discussion

Groundwater quality parameters

The highest concentration of Calcium and Magnesium observed in both the surveys was 28 mg/L and 28.8 mg/L respectively, which is below the maximum permissible limit of 100 mg/L and 30 mg/L respectively.

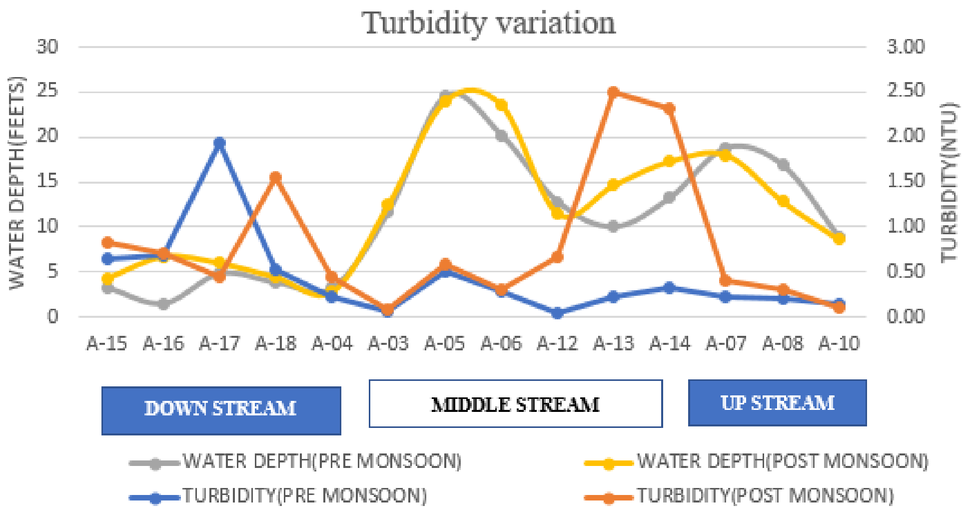

Figure 6 - Turbidity variation with the change of water depth in the upstream, downstream and middle stream for pre and post monsoon

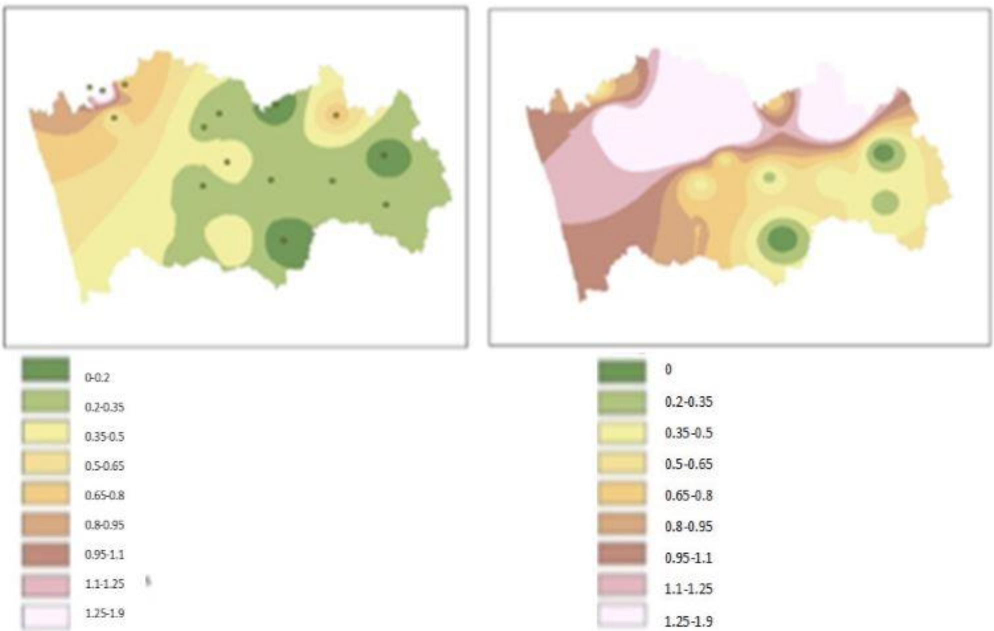

Figure 7 - Spatial variation of turbidity (NTU) in the Attanagalu Oya basin from pre monsoon (left) to post monsoon (right)

In the pre-monsoon the turbidity is within permissible limits (WHO-5NTU & SLS-2NTU). And the turbidity is high in downstream wells and low in upstream wells, after raining the post monsoon period shows an increment in turbidity. The spatial map shows the increment in turbidity in the wells over the seasonal changes from pre-monsoon to post monsoon. According to the turbidity the quality of water is good, having high transparency and suitable for drinking according to the chemical properties without any contamination. However further testing should be carried out to evaluate the microbiological parameters to assess the suitability for drinking In the pre-monsoon the pH is lower than the allowable least limit (6.5). The water is slightly acidic. And the pH is decreased, and the average is 5.5 which is the representing pH of rainwater. But before the rain also the water is acidic, and the acidity is high in the downstream wells due to the industrial discharges. Water is less suitable for drinking in both pre-monsoon and post monsoon seasons considering pH value. Generalized chemical analysis results are given in the following tables. The generalization criteria considered are listed as follows. Drinking water standards considered-World Health Organization and Sri Lankan Standards.

Comparison carried out relatively to the up stream pre monsoon water parameters and going from pre monsoon to post monsoon.

Table 3 - Generalized chemical analysis results for Turbidity, pH, Conductivity, Fluoride, and Nitrate.

Elevation	Season	Turbidity (NTU)	pH	Conductivity(µS/cm)	Fluoride (mg/L)	Nitrate(mg/L)
Up Stream	Pre-Monsoon	Within Limits	Within limits	Within limits	Within limits	Within limits
	Post-Monsoon	Increased but within limits	Less than the minimum pH (variation is high)	Increased but within limits	Increased but within limits	Increased but within limits
Middle Stream	Pre-Monsoon	Increased but within limits	Lower than the minimum limit	Within limits	Within limits	Within limits
	Post-Monsoon	Increased but within limits	Less than the minimum pH (variation is high)	Increased but within limits	Increased but within limits	Increased but within limits
Down Stream	Pre-Monsoon	Increased but within limits	Less than the minimum pH	Increased but within limits	Within limits	Within limits
	Post-Monsoon	Increased but within limits	Less than the minimum pH (variation is high)	Increased and decreased but within limits	Within limits	Increased but within limits

Table 4 - Generalized chemical analysis results for Phosphorous, Ferrous, Calcium, Chromium and Lead

Elevation	Season	Phosporous (mg/L)	Ferrous (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Chromium (mg/L)	Lead (mg/L)
Up Stream	Pre-Monsoon	Beyond limits	Within limits	Within limits (soft water)	Within limits (soft water)	<0.01	<0.01
	Post-Monsoon	Decreased but beyond limits	Within limits	Increased but within limits	Increased within limits	<0.01	<0.01
Middle Stream	Pre-Monsoon	Beyond limits	Within limits	Within limits (soft water)	Within limits (soft water)	<0.01	<0.01
	Post-Monsoon	Decreased but beyond limits	Within limits	Increased but within limits	Increased within limits	<0.01	<0.01
Down Stream	Pre-Monsoon	Beyond limits	Within limits	Within limits (soft water)	Within limits (soft water)	<0.01	<0.01
	Post-Monsoon	Decreased but beyond limits	Within limits	Increased but within limits	Increased within limits	<0.01	<0.01

4. Conclusions and Recommendations

The general groundwater quality of the Attanagalu Oya basin in the pre monsoon period is more suitable and safer for drinking while the quality deteriorates with the monsoon rainfall. The prolonged infiltration through the subsoil with the cease of surface run-off tend to buffer and re-clean the groundwater resources in the region. This trend of temporal variation in post monsoon groundwater quality emphasize the requirement for pre-treatment of groundwater used for drinking followed by the monsoon rainfall. The general public should be made aware to use suitable pre-treatment techniques especially for drinking water following the monsoon period.

The water quality parameters like turbidity, pH, and conductivity increase, following the monsoon rainfall period for the whole Attanagalu Oya basin. The trends in the levels of contamination observed from upstream to downstream suggest that the variations depend on the type of contaminant.

The levels of Nitrate and Phosphate which are major agricultural byproducts of groundwater contaminants are much more prominent in the upstream regions of the Attanagalu Oya basin. This observation emphasizes the requirement for the proper monitoring of run-off from agricultural fields in the Attanagalu Oya basin and the locals in the vicinity of such agricultural fields should be made aware to be vigilant about such contaminations of their drinking water resources.

The downstream regions were much more influenced by turbidity and pH which are associated with effluents from industrial establishments. However, the content of heavy metals like Lead and Chromium in the vicinity of highly industrialized downstream regions of the Attanagalu Oya basin is below 0.01 ppm level which concludes that these regions are yet to be contaminated. Further sampling is required to identify localized contaminations from the industries and their impacts on the groundwater resources.

The study of groundwater modelling for the region should be continued with more field surveys and observation well data in order to achieve satisfactory levels of valid results. A well-maintained record or archive of well head data is lacking in Sri Lanka and with the continuation of seasonal field surveys, a useful database of groundwater heads can be compiled which will be useful for future groundwater modelling work and related research. The established groundwater models can then be calibrated with the future observations. The use of self-written codes like the Fortran code used in the study can be easily adjusted for Sri Lanka conditions unlike in the case of complex modelling software like MODFLOW. The required data for inputs like constant heads and subsurface layers are difficult to access in Sri Lanka. A collection of groundwater level observation data along with their qualitative analysis would provide compulsory information for successful modelling of groundwater resources in the Attanagalu Oya basin. The inadequacy of data for model calibration and validation is a major problem faced in the process of groundwater modelling which can be overcome by the maintenance of a national level groundwater head observation and well record.

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6. References

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