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Full Length Research Paper.

Hydrogeochemical characterization of groundwater in Afe Babalola University, Ado-Ekiti Southwestern Nigeria

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Groundwater composition can be altered significantly due to geogenic and anthropogenic inputs from bedrocks and human activities respectively. Such impacted water may be injurious to health if consumed. Water quality depends on the physical, chemical and bacteriological composition of water. Hydrochemical assessment of groundwater within Afe Babalola University (ABUAD) and its adjoining environments was undertaken with the aim of determining its chemical composition and suitability. A total of 26 boreholes were sampled randomly within ABUAD during the dry stable weather condition. Two set of samples were collected from each sampled borehole one for anions and the other one for captions and heavy metals. The water samples were analyzed for heavy metals, cations and anions using Atomic Absorption Spectrometry, Flame Photometry Emission and titration method at the Department of Geology, and Multi-Disciplinary Research Center, University of Ibadan and National Geo-Hazard Research Center, Ibadan respectively. Results obtained were subjected to statistical analysis and qualitative evaluation to determine the quality of the groundwater. The results of the analyses showed cations (major and trace elements) variations in mg/l; Ca^{2+} (14.0 - 69.0), Mg^{2+} (20.0 - 62.3), K^+ (0.1 - 42.5), Na^+ (12.3 - 54.0), Pb^{2+} (<0.01 - 3.93), Cu^{2+} (<1.00-0.43 mg/l; Cd^{2+} (<1.00 - 5.80), Co^{2+} (< 0.01 - 3.86 mg/l) and Cr^{2+} (0.01 - 3.79 mg/l) while anions variations in mg/l HCO_3^- (4.6 - 26.8 mg/l), Cl^- (60.0 - 180.0), NO_3^- (<0.01- 2.8 mg/l) and SO_4^{2-} (0.6 - 4.7 mg/l). The concentrations of anions and major cations in most of the investigated boreholes were found to be chemically conformable with WHO standard for safe water. However, most of the trace elements with exception of Cr and Co were found to be significantly higher than the WHO standards for safe water.

Key words: Groundwater, hydrochemical assessment, Afe Babalola University, Ado-Ekiti (ABUAD), geogenic, anthropogenic.

INTRODUCTION

The source of water for any specific purpose is not as important as the sustainability of water for the desired purpose. The demand of water has increased drastically in recent times. With increasing population,

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industrialization, urbanization and the consequent increase in demand for water both domestic and industrial uses, the attendant increase in the implication of polluted water on man and the environment have been severally studied (Asiwaju-Bello and Akande, 2004; Onipede and Bolaji, 2004).

Groundwater has immensely become an important water supply in urban and rural areas in both developed and developing nations for domestic, industrial and agricultural purposes (Ramkumar et al., 2010; Olayinka et al., 1999). Groundwater is replenished with precipitation and surface run-off. The dominant role of groundwater is clear and their uses and protections are, therefore, of paramount importance to human life and economic activity.

In any hydrogeological setting, surface water and groundwater are the main sources of water supply. These sources of water are prone to contamination and pollution by anthropogenic activities. Until recently, surface water has been the major source of water supply for domestic and industrial uses but, due to high population growth, the government has shown interest in the exploitation of groundwater over the years. Hence the need for water quality assessment for enhanced socio-economic growth and development (Ishaku, 2011).

Safe drinking water is a basic need for human development, and well-being and therefore an internationally accepted human right (Garg et al., 2009). According to Oloke (1997), drinking water can act as a passive means of transporting nutrients into the body system. So therefore, the provision for good quality water for drinking, domestic and agricultural uses is very crucial for sound and good human and environmental health, economic and sustainable development (Al-Bassam and Al-Rumikhani, 2003). Water quality depends on the physical, chemical and bacteriological composition of water. Variation in groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Magesh and Chandrasekar, 2011; Krishna et al., 2011). According to Davis and De Wiest (1966), drinking water standards are based on two main criteria namely; the presence of objectionable tastes, odour and colour and the presence of substances with adverse physiological effects. However, mineral enrichment from underlying rocks can change the chemistry of groundwater, making it unsuitable for consumption (Ako et al., 1990; 2011). In addition, water of poor physio-chemical quality may have adverse health effects causing avoidable economic and human losses. According to Hutchinson and Ridgeway, the water cycle is an obvious mode of transmission of enteric diseases.

Groundwater chemistry is altered as a result of the interaction between the subsurface formation and the percolating water. This brings about the need to understand the influence of the bedrocks on the groundwater system of the study area. Asides this geogenic influence, anthropogenic activity makes groundwater system prone to higher possibility of contamination. Therefore, a proper understanding of the groundwater in the study area is of importance as to maintain good quality water for drinking, domestic, industrial and agricultural purposes.

The present study was carried out to evaluate groundwater quality in Afe Babalola University Ado-Ekiti and its suitability for drinking, domestic and agricultural purposes. Data from this study will not only contribute immensely to improve the understanding of the factors that control groundwater quality and also provide for the first time groundwater quality data in the study area, hence contributing to the sustainable management of groundwater resources in this university.

MATERIALS AND METHODS

The study area (ABUAD) is located within Ado Ekiti southwestern Nigeria (Figure 1). It extends from latitude 07°35'59'' to 36'50''N and longitude E005°18'0''to 18'45''. It has a relatively low relief with isolated hills and inserbergs that are dome-shaped. The climate is characterized by the tropical type influenced by monsoon winds during rainy season with maximum rainfall in October and dry season. Annual temperature ranges between 28 to 30°C with a mean annual rainfall of 1500 mm.

It is located within the Basement Complex of South Western Nigeria. Major lithological units are basically crystalline basement rocks. These rocks include coarse grained charnockite, granite, migmatite gneiss, banded gneiss, with superficial deposit of clay and quartzite (Figure 2). Association of the fine-grained charnockite and the porphyritic biotite-hornblende granite suggest a common age. According to Davis and De-Wiest (1966), crystalline rocks are poor water bearing aquifers because of their low porosity and low permeability. The hydrogeological characteristics of these rocks depend on the degree of weathering and fracturing of the underlying rock within the tropical rainfall belt. The intense deformational structures of these rocks permit adequate aquifer properties needed to generate the well water.

Twenty six (26) water samples were collected randomly from twenty six boreholes between December 2015 and January 2016. Boreholes were allowed to pumped for at least 10 min before sampling. The samples were collected in 1lilter capacity plastic bottles after rinsing with the sample and preserved airtight in order to avoid evaporation. Physical parameters such as TDS, EC and pH of the sampled water sources were determined in situ using pH/EC/TDS/temp perklin multi-meter. Samples were kept under air-condition prior to analysis. Major ions' concentrations (Na^+, K^+, Mg^{2+}, Ca^{2+}) were determined by ion exchange chromatography at the University of Ibadan Multidisciplinary Research Laboratory, trace elements content were determined using AAS at the Department of Geology, University of Ibadan while the major anions (Cl^-, NO_3^-, HCO_3^-, SO_4^{2-} and CO_3^-) were determined by flame photometry emission at the National Geo-Hazard Research Centre, Ibadan. Standard procedures (APHA, 1998) were used. Alkalinity measurements were carried out by acid titration with 0.02N H_2SO_4 added to each sample to reach its titration end point marked by a pH of 4.5. For quality control of the chemical measurements, standards and blanks were used in between runs to provide a measured of background noise, accuracy and precision.

RESULTS AND DISCUSSION

The results of the chemical analyses are presented in

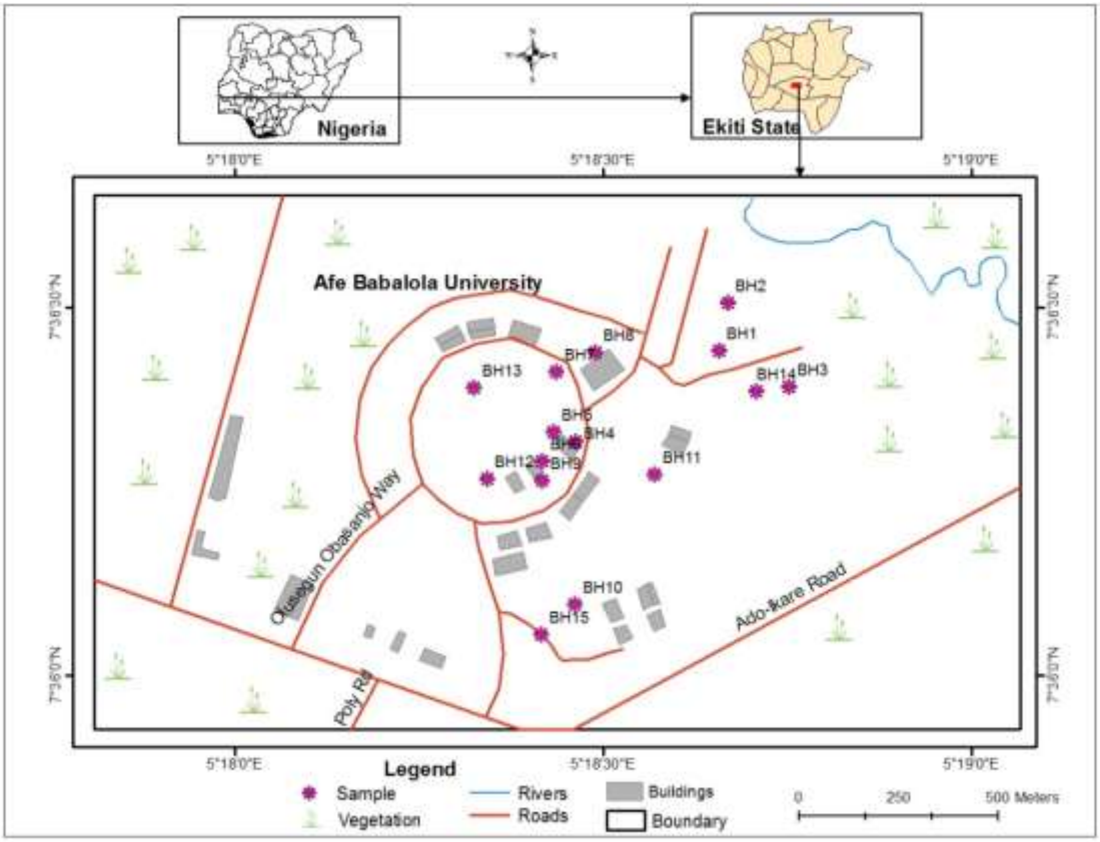


Figure 1. Location map of the study area showing sampling points.

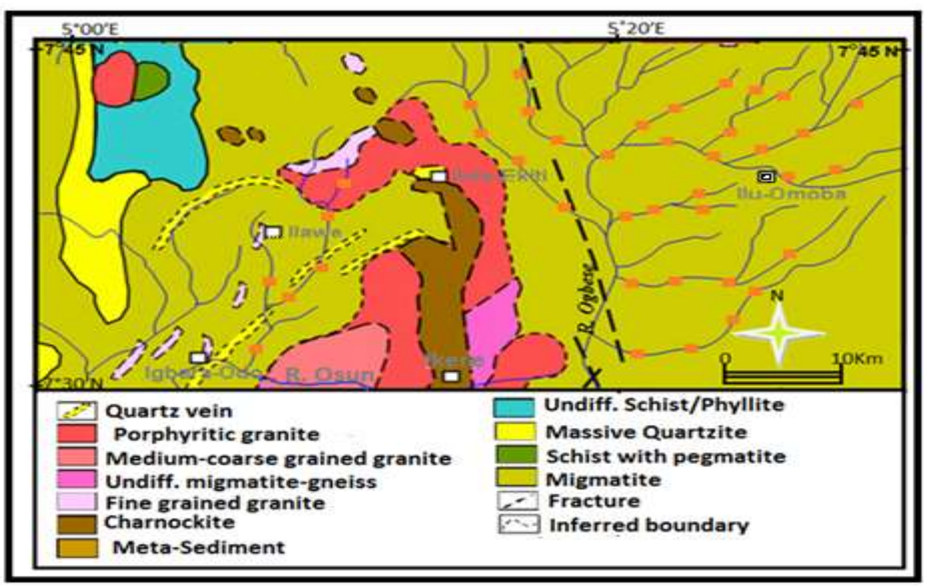


Figure 2. Geological Map of Ado Ekiti.

Table 1. The chemical composition of groundwater depends greatly on the general geology, degree of chemical weathering of various rock types, quality of recharge water and inputs resulting from human

Table 1. Summary of the geochemical results of water samples in the study area.

Chemical Parameters	Minimum	Maximum	Mean	W.H.O. Standard
pH	6.95	8.20	7.56	6.5 - 8.5
EC (µS/cm)	23.7	1243.5	520.3	1400
Pb	<0.01	3.93	3.92	0.01 mg/l
Cu	<0.01	0.43	0.40	1.0 ppm
Cd	<0.01	0.58	0.54	0.005 ppm
Co	<0.01	3.86	3.19	-
Cr	<0.01	3.79	3.21	-
Bicabonate	4.6	26.8	12.6	250 mg/l
Chloride	60.0	180.0	93.1	-
Nitrate	0.00	2.8	1.2	50 mg/l
Sulphate	0.6	4.7	1.7	250 mg/l
Mg	20.0	62.3	36.5	30 mg/l
Ca	14.0	69.0	21.9	75 mg/l
K	0.00	42.5	17.5	12 mg/l
Na	12.3	54.0	25.7	200 mg/l

activities. It is therefore important to understand the groundwater chemistry as it is a main factor in determining its sustainability for drinking, domestic, agricultural and industrial purposes (Subramani et al., 2005).

In this study, the results of cations (that is, major and trace elements) and anions were subjected to statistical analysis. It was observed that there were significant and wider variability within the anions and the cations with the following order of magnitude among the trace and major elements Pb>Cr>Co>>>>Cd>>Cu, Mg>Na>Ca>K while Cl^- >>>> HCO_3^- >> SO_4^{2-} >NO_3^- among the anions (Tables 1). However, this order of absolute concentrations is not an indication of the relative degree of contamination but depends largely on the threshold values of the respective anions or cations.

Groundwater chemistry

The chemical composition varies over a wide range, and this indicates that the groundwater in the study area is not uniform but differs considerably, both in salinity and ionic composition. The pH values of the studied boreholes varied from 6.95 to 8.20 with an average of 7.56 suggesting that the groundwater within the study area are slightly alkaline in nature but still within the limit recommended by WHO (2004). The EC values ranged from 23.7 to 1243.5 µS/cm with an average of 520.3 µS/cm, the lowest concentration of EC was found in samples collected within the Quarters while the highest concentration was observed in location 24 and 25. The measurement of EC is directly linked to the concentration of ionized substance in water and may be linked directly to the excessive hardness and other mineral contamination.

Mg concentrations generally varied from 20.0 to 62.3 mg/l with an average concentration of 36.5 mg/l (Table 1). The highest concentration of Mg was found in location 9 collected within one of the colleges while the least concentration was observed in location 2 collected within one the Female Halls. The major source of Mg in natural water has been attributed to ions exchange of minerals in rocks and soils by water. Calcium concentration ranged from 14.0 to 69.0 mg/l and has an average concentration of 21.9 mg/l (Table 1). The highest concentration of calcium was found in location 3 while the lowest concentrations were observed in locations 6, 16, 18 and 24. Potassium ranges from 0.01 to 42.5 mg/l, high concentration of potassium water samples in the study area was observed in location 22 while location 3 has the least concentration. Sodium varies from 12.3 to 54.0 mg/l with an average of 25.7 mg/l. Location 17 recorded the highest concentration of sodium while locations 3, 19, 21 and 22 recorded the lowest concentrations.

In the analyzed trace elements, Pb varied from<0.01 mg/l in some of the samples to 3.93 mg/l with an average of 3.92 mg/l, Copper varied from <0.01 mg/l to 0.43 mg/l with a mean concentration of 0.08 mg/l (Table 1). Highest concentration of copper was recorded in locations 19 and 24 collected within one of the Colleges and the Female Halls while its lowest concentrations was observed in location 10 collected from one the Cafeterias. Cobalt ranged from <0.01 to 3.86 mg/l with a mean value of 3.19 mg/l (Table 1). Co recorded its maximum and minimum values in location 4 and 2 respectively. Cadmium concentrations varied from <0.01 to 0.58 mg/l with a mean concentration of 0.54 mg/l (Table 1). The highest concentrations of Cd were observed in locations 20 and 25 collected within the two of the Hostels while its lowest

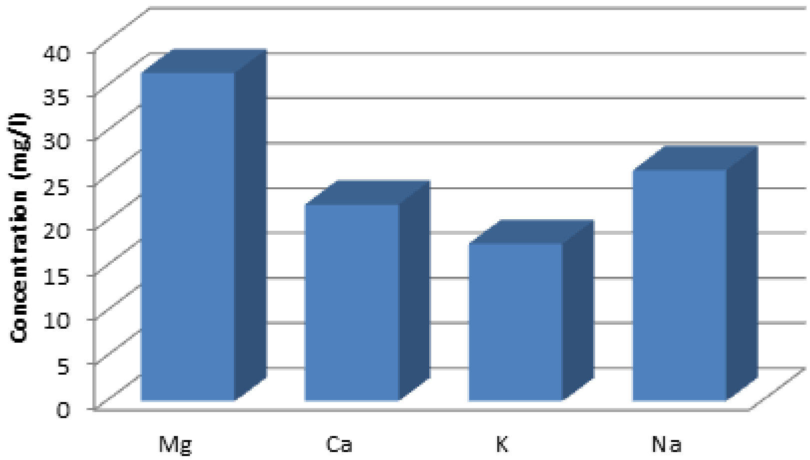


Figure 3. Comparison among the mean values of major elements.

was recorded in location 2. Chromium ranged from <0.01 to 3.86 mg/l, (Table 1), location 22 recorded the highest concentration of Chromium while location 2 has the least concentration. It has been confirmed that Pb and Cd have no beneficial effects in humans even at the lowest concentration and there is no known homeostasis mechanism for them. Any long-term exposure may therefore be expected to progressively cause more disruptions in the normal functioning of the organ systems where the metals are accumulating (Nriagu and Pacyna, 1988).

Similarly, among the anions, Bicarbonate varied from 0.46 to 2.68 mg/l in location 11 and 7 respectively with an average concentration of 1.26 mg/l (Table 1). All the samples were within the desirable permissible limit of WHO (2004) 500 mg/l. The primary source of bicarbonate in groundwater has been linked to dissolution of minerals such as calcite and dolomite. Chloride ranged from 60 to 180 mg/l with a mean concentration of 93.1 mg/l (Table 1). Cl has been described as the most common anion in natural water and it occurs naturally in all types of water. The highest concentration of Chloride (180 mg/l) in the study area is found in location 9 while locations 1, 14, 16, 17, 18, 21, 22 and 26 recorded low Cl^- concentrations. All sampled boreholes' water have their chloride concentrations below the desirable limit of 250 mg/l. Nitrate varied from <0.01 to 28.0 mg/l and a mean concentration of 12.0 mg/l (Table 1). The highest concentration of nitrate was observed in location 8 collected from one of the colleges, another sample collected from another borehole located some few meters away from this borehole within this same premise also recorded the highest chloride concentration among the samples collected for this study. Hot spot of these anions is suspected around this area which may probably be an infiltration from the septic tanks or percolation from the surface run-off. Sulphate varies from 0.6 to 4.7 mg/l with an average of 1.7 mg/l (Table 1). The highest concentration of this anion was recorded in location 12. The sulphate concentrations in all the samples were below the permissible limit of 250 mg/l which shows that the groundwater is free from possible sulphate toxicity. The carbonate values were below detection limits in all the samples analyzed, this could be as a result of the observed pH which was below 8.0.

Comparative study of groundwater quality with WHO standards

From Table 1, the mean values of selected major elements were compared with one another and with the WHO standards. Magnesium showed the highest value (36.5 mg/l), this is followed by sodium (25.7 mg/l) then calcium (21.9 mg/l) while potassium (17.5 mg/l) has the least value (Figure 3). The dominancy of Mg and Na as well as Ca was as a result of enrichment of ferromagnesian minerals in the underlying rocks of the study area which is mainly dominated by charnockite. This clearly demonstrates an interaction between the groundwater and underlying bedrocks weathering. It could be concluded that the origin of these captions are geogenic in nature. Mg and K have their mean values greater than the WHO desirable limit of 30 and 12 mg/l respectively while Na and Ca ions have their means less than WHO recommended limits of 2200 and 75 mg/l respectively.

Similarly, considering and comparing the mean of all the analyzed trace elements that are far greater than the WHO standard (0.01 mg/l) recommended for safe drinking water.

Pb has the highest mean value then Chromium and this is closely followed by Cobalt then Cu while Cadmium has the least mean value (Table 1 and Figure 4). The mean values of Pb, Cd and Cu were compared with the WHO standards for safe drinking water and it was discovered

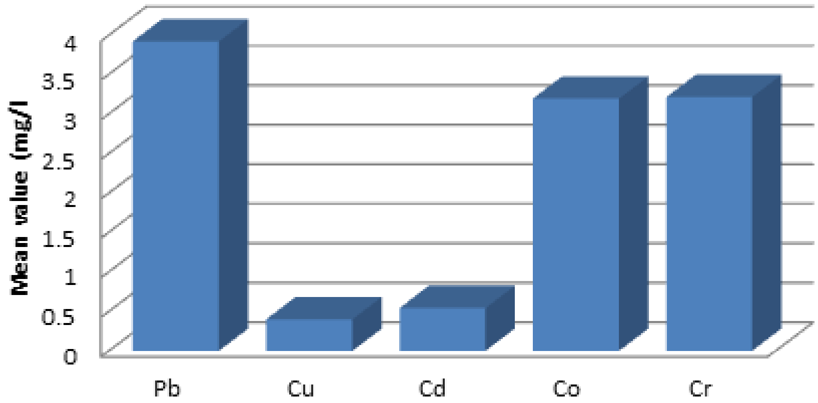


Figure 4. Comparison among the mean values of trace elements.

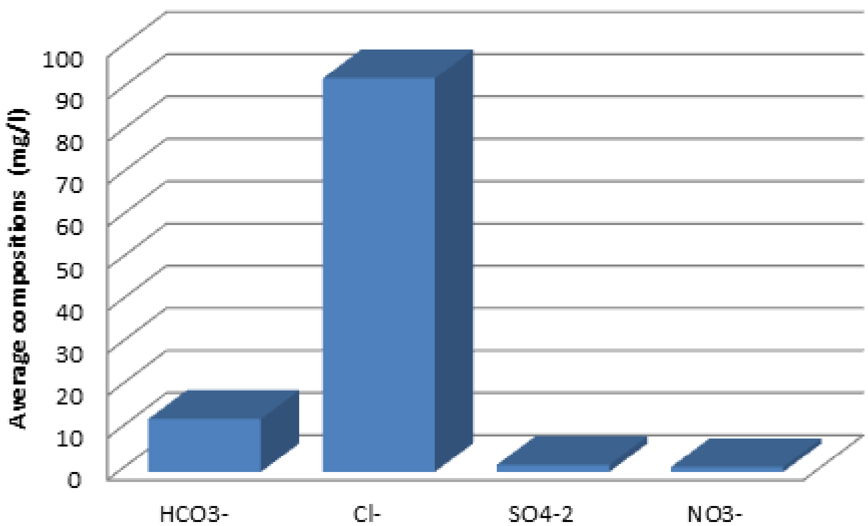


Figure 5. Comparison among the mean values of Anions.

that virtually all the water samples have Cd concentrations significantly higher than the maximum permissible level of Cd (0.005 ppm) in drinking water. Also most of the samples have their Cu concentrations with a mean of 8.0 ppm far above (eight folds) the maximum permissible level of Cu (1.0 ppm) while the average concentration of Pb in some locations is far above the WHO standard for safe water (Table 1, Figure 4). Cr and Co are more of lithogenic than anthropogenic origin while Cd, Pb and Cu can be considered as sourced from anthropogenic origin.

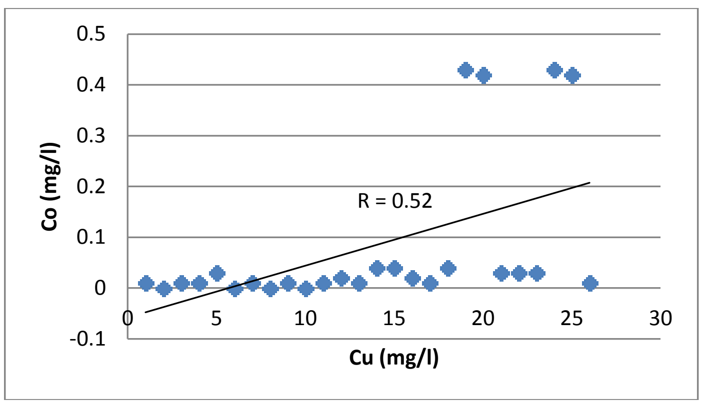
The dominancy of chloride over the other anions is of significant important as it almost marred the concentration effects of other anions. Chloride has an average composition of 93.1 mg/l followed by bicarbonate with a mean concentration of 12.6 mg/l and then sulphate and nitrate with a mean concentration of 1.7 and 1.2 mg/l respectively (Table 1, Figure 5). The mean concentration of these anions were compared with the WHO standards recommended for safe water and it was observed that all the anions were below their recommended values.

Correlation analysis

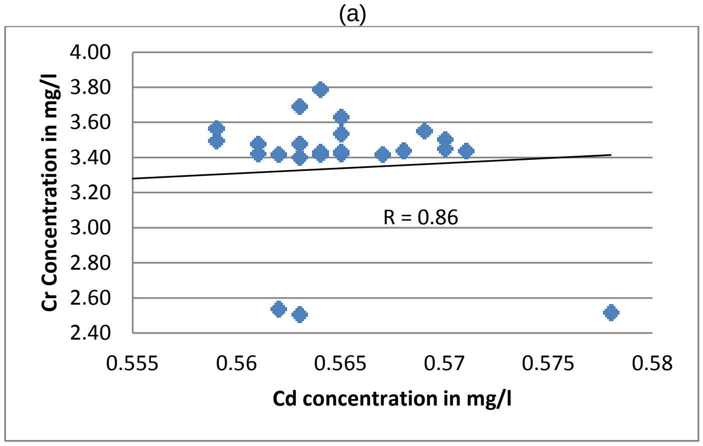
Pearson correlation analysis of the results was undertaken using the Statistical Programme for Social Science (SPSS, window 22.0). Correlation was done to state the relationship among metals and similarities in their geochemical behaviors. The analysis revealed a wide range of variation in the correlation values as both positive and negative correlations were established between some of the elements. The variability in the correlation amongst the elements is an indication that different geochemical factors have influenced their concentration in the samples.

Table 2. Correlation coefficient matrix of chemical parameters of groundwater samples of the study area.

Sample	Cu	Cd	Co	Cr	HCO_3^-	Cl^-	NO_3^-	SO_4^{2}	Mg	Ca	K	Na
Cu	1											
Cd	0.126	1										
Co	**-0.809****	**0.478***	1									
Cr	-0.375	**0.861****	**0.843****	1								
HCO_3^-	0.226	0.229	-0.065	0.157	1							
Cl^-	-0.147	**-0.483***	-0.187	**-0.436***	-0.212	1						
NO_3^-	-0.297	-0.181	0.125	-0.101	**-0.723****	**0.539****	1					
SO_4^{2}	-0.244	-0.097	0.136	0.004	-0.237	0.287	0.169	1				
Mg	-0.079	0.042	0.086	0.028	-0.242	**0.479***	0.306	0.126	1			
Ca	-0.065	**-0.572****	-0.283	**-0.475***	-0.102	0.305	-0.051	0.205	0.119	1		
K	-0.166	-0.085	0.073	-0.050	0.062	-0.003	0.041	0.142	-0.216	-0.227	1	
Na	-0.219	**-0.647****	-0.185	**-0.495***	0.013	0.313	0.026	0.139	-0.103	0.093	0.230	1



(a)



(b)

Figure 6. Scatter plots showing variations among a) Co vs Cu b) Cr vs Cd.

From Table 2, Cr and Cd (0.86) as well as Cr and Co (0.84) showed strong and positive correlate (Figure 6). This is a direct relationship which implies that similar geochemical processes have been responsible for their co precipitation. K, Na, Ca, Mg, Co, Cd and Cu exhibit low to negative correlations ranging from 0.48 to -0.81 with one another. This may be attributed to the fact that dissolution of metals in the aqueous phase is controlled by the chemical character and solubility of the respective metal as well as other chemothermodynamic conditions.

Table 3. Results of the R-Mode factors analysis.

Sample	1	2	3	4	5	Com.
Cr	**0.92**	0.35	-0.00	0.12	0.05	0.99
Cd	**0.91**	0.03	-0.27	-0.09	0.20	0.95
Co	**0.63**	**0.68**	0.25	0.21	-0.08	0.98
NO_3^-	-0.33	**0.71**	-0.24	**-0.47**	-0.13	0.90
HCO_3^-	0.33	**-0.60**	0.28	0.35	**0.45**	0.86
Mg	-0.17	**0.45**	**-0.56**	0.16	**0.46**	0.78
SO_4^2	-0.21	**0.45**	0.16	0.23	0.30	0.42
K	-0.02	0.08	**0.66**	**-0.44**	0.31	0.73
Na	**-0.57**	0.01	**0.61**	-0.08	0.09	0.70
Cu	-0.10	**-0.77**	**-0.47**	-0.29	0.20	0.94
Ca	**-0.59**	-0.03	-0.11	**0.64**	-0.23	0.82
Cl^-	**-0.68**	**0.41**	-0.16	0.03	**0.41**	0.82
Initial Eigen values	3.49	2.61	1.66	1.18	0.93	
% of Variance	29.11	21.77	13.84	9.85	7.78	
Cumulative %	29.11	50.88	64.72	74.57	82.35	

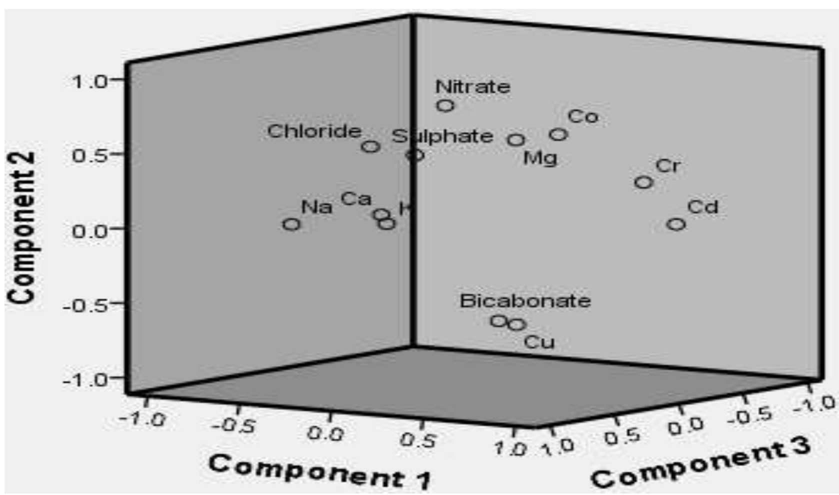


Figure 7. Screen plot of R-mode analysis showing elemental fractionations.

However, when compared to the WHO standards, the observed concentrations of these metals were generally below the permissible levels of drinking water. Although, this does not mean an absence of contaminations as the observed low concentrations could be attributed to partitioning and accumulation within the immediate environment of the aquifer. Therefore, possible change in the chemothermodynamic conditions can lead to remobilization into liquid phase.

R-Mode analysis

Principal component (PC) analysis was performed on the groundwater data for better understanding of their interrelationships and probable source of major ions. Table 3 presents the results of the R-mode components analysis, eigen values and associated variance explained in the chemical data.

Factor 1 accounts for 29.11% of the total variance with eigen value of 3.49. This component is strongly and positively loaded with Cd, Co and Cr, strong but negatively loaded with Cl^- and moderately loaded with Cu (Table 3). This implies that all these parameters have similar source of input. Factor 2 is strongly and positively loaded with Co and HNO_3^- but negatively loaded with Cu and NO_3^-. This factor accounts for 21.8% of the total variance with eigen value 2.6. Factor 3 has the highest positive loadings of Na and K and accounts for 13.8% of the total variance. Factor 4 has the highest positive loading for Ca which accounts for almost 10% of the total variance while Factor 5 is weakly and positively loaded with Mg, HNO_3^- and Cl^- (Table 3 and Figure 7).

Conclusions

This study has thrown light on the hydrogeochemistry and quality of groundwater in Afe Babalola University. The dominancy of Mg and Na was as a result of enrichment of ferromagnesian minerals in the underlying rocks of the study area which is mainly dominated by charnockite and quartzite. This clearly demonstrated interaction between the groundwater and the underlying bedrocks. All the water samples are found to have their major cations and anions to be fairly conformable with the WHO Standards for safe drinking water with the exception of K. However, trace elements such as Pb, Cd and Cu their concentrations far above the WHO recommended standard for safe drinking water which implies that these borehole waters are not suitable for drinking. If the present concentrations of Cd and Pb continue to increase with time without been attended to, there is possibility of Pb and Cd health hazards outbreak in the nearest future in some of the locations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessment of Assela Town municipality waste water discharge effect on the chemical and bacteriological water pollution load of Anko River

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Assela, one of the developing towns in the south eastern central zone of Ethiopia, is located 175 km away from the Capital City of Addis Ababa. Anko River divides the town into two separate parts. In rural areas, water from Anko River is used for drinking and sanitation purposes. However, sewage from residential areas and Assela Hospital directly enters the river, affecting its quality. The objective was to determine Anko River water pollution status by the influence of wastewater discharge in Assela town. The cross sectional study design was conducted. The sampling techniques were wastewater samples taken from Assela Hospital waste water discharge site, upstream and downstream sites of Anko River for laboratory analysis in Addis Ababa. The average results of chemical and bacteriological parameters such as BOD_5 from 11.8 to 131.9 mg/L; COD from 115.7 to 206.2 mg/L, ammonia from 8.4 to 42.4 mg/L, nitrate varied from 1.6 to 3 mg/L, nitrite from 0.1 to 0.2 mg/L, and phosphate values varied from 2.1 to 6.3 mg/L, faecal coliform counts/100 ml varied from 180 to 600 and total coliform beyond WHO recommended for wastewater discharge. The correlations among the bacteriological and chemical properties were observed in the studied sites. Ammonia with phosphate, BOD_5 and COD had a significant positive correlation (r = 1.000, at P-value at 0.01, respectively). Nitrate had negative significant correlation with phosphate, BOD_5, COD and FCF(r = - 1 and -0.820, P-value < 0.01) and phosphate correlated with BOD_5, COD and FCF (r = 1 and 0.820, at P-value at 0.01, respectively). BOD_5 correlated with COD and FCF (r=1 and 0.820 with P-value at 0.001 respectively). Water borne diseases may be transmitted due to waste pollution of Anko River. Therefore, Assela town health departments have to take intervention measures on proper Anko River water treatment. Also, to reduce the faecal and total coliform organisms applying waste water treatment system with sand filtration followed by post chlorination systems must be recommended by Assela Hospital and municipality.

Key words: Water quality, indicator, water borne diseases, bacteriological and chemical water property.

INTRODUCTION

Wastewater refers to water whose quality is affected by the contribution of anthropogenic activities. Waste water discharged from agricultural activities, industries, residential houses, institutions and commercial areas

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pollutes drinking water sources (Akter et al., 1999.).

Health care waste generated from health care establishments like health centres, hospitals, laboratory offices, health post and clinics along with the composition of health care waste consists of organic and inorganic substance including microorganisms. Hospital waste had serious health hazard to the health workers, visitors, patients and nearby communities. The hospital waste is classified into infectious and general wastes (Akter et al., 1998) comprising both the liquid and dissolved substance generated within the hospital environment (FFEPA, 1991; Heen, 1999); the majority of general waste of non-hazardous particles such as kitchen waste, paper and plastics, whereas parts of human fetus, blood and body fluid, are hazardous pathological waste.

Infectious wastes are suspected to contain pathogens (bacteria, viruses, parasites, or fungi) in large amount. They cause diseases in susceptible hosts, which include culture and stock of infective agents from laboratory waste, waste from surgery, etc; sharp waste, sharp items that could cause cuts or puncture wounds, including needles, hypodermic needles, scalpel and other blades, knives, infusion sets, saws, broken glass, and nails. Waste materials and pharmaceutical wastes cause damages to persons handling hospital equipment like knife, needle, broken glasses, and scalps. These wastes include pharmaceutical products (drugs and chemicals) that are returned from wards, contaminated or expired products; chemical wastes consist of discarded solid, liquid, and gaseous chemicals. They include diagnostic and experimental work and from cleaning, housekeeping, and disinfecting procedures. WHO (1999) reported that, about 85% of hospital waste is non-hazardous, 10% infective and 5% not infective.

United States of America, while about 15% of hospital waste is regarded as infective. In India, it was reported that the value could increase from 15% to 35% depending on the total amount of hospital waste generated, while in Pakistan about 20% of hospital waste could be found potentially infective or hazardous (Agarwal, 1998).

The public health significance of water quality must be considered from water borne disease transmission perspective. Many infectious diseases are transmitted by water through fecal-oral route. Diseases contacted through drinking water kill about 5 million children annually and make 1/6th of the world population sick (WHO., 2004). Water is vital to our existence in life and its importance in our daily life makes it imperative that thorough microbiological and chemical examinations be conducted on water. Potable water is water that is free from disease producing microorganisms and chemical substances that are dangerous to health (Lamikaran, 1999)

Sewage discharge is one of the problems presently facing South Africa and several efforts are being vigorously made to control it. Water contaminated by effluents from various sources is associated with heavy disease burden (Okoh et al., 2007) and this could influence the current shorter life expectancy in the developing countries compared to developed nations (WHO, 2002.).

Sewage discharges are a major component of water pollution, contributing to oxygen demand and nutrient loading of the water bodies; they promote toxic; algal blooms leading to a destabilized aquatic ecosystem (DWA and WRC, 1995, Morrison et al., 2001; DWA and WRC, 1995, Morrison et al., 2001, WRC, 1995).

At present, limited or no reports dealing with the water quality of Anko River had appeared in the literature. Hence, with the aims of assessing temporal variations and thereby encouraging public awareness of the water quality of the Anko River, the present chemical analysis and microbiological study was conducted to evaluate pollution caused by human influences along the river.

This study would help the consumers of Anko River water to understand the current quality status for under taking home made water treatment as immediate solutions of their surface water quality management systems. It also contributes the scientific way of reducing pollution generated by waste source controlled by Assela municipality.

This study also suggests that Assela Hospital should wake up to the current treatment of wastewater polluted in Anko River in order to improve surface water quality and to protect consumers' health.

Finally, it may direct interested professionals and stakeholders to undertake intervention on Anko River better surface water quality in the future.

The objective of this study was to determine Anko River water pollution status by the influence of wastewater discharge in Assela Town.

MATERIALS AND METHODS

Study area

Assela, one of the developing towns in the South eastern central zone of Ethiopia, is located 175km from the capital city of Addis Ababa. The town has fourteen kebeles. The town is crossed with one river, known as Anko which separate the town into two parts. In rural areas, Anko River water was used for domestic purposes. However, sewage from residential areas and Assela Hospital near the river was directly expelled into the river, thus affecting the water quality.

Study design

The cross sectional study design was conducted to assess the level of water pollutants from different sources. The water samples were analyzed by different laboratory investigation results in Addis Ababa. The result of every water chemical and bacteriological properties was taken for scientific analysis.

Sampling

Water samples were collected from the Assela hospital treated final

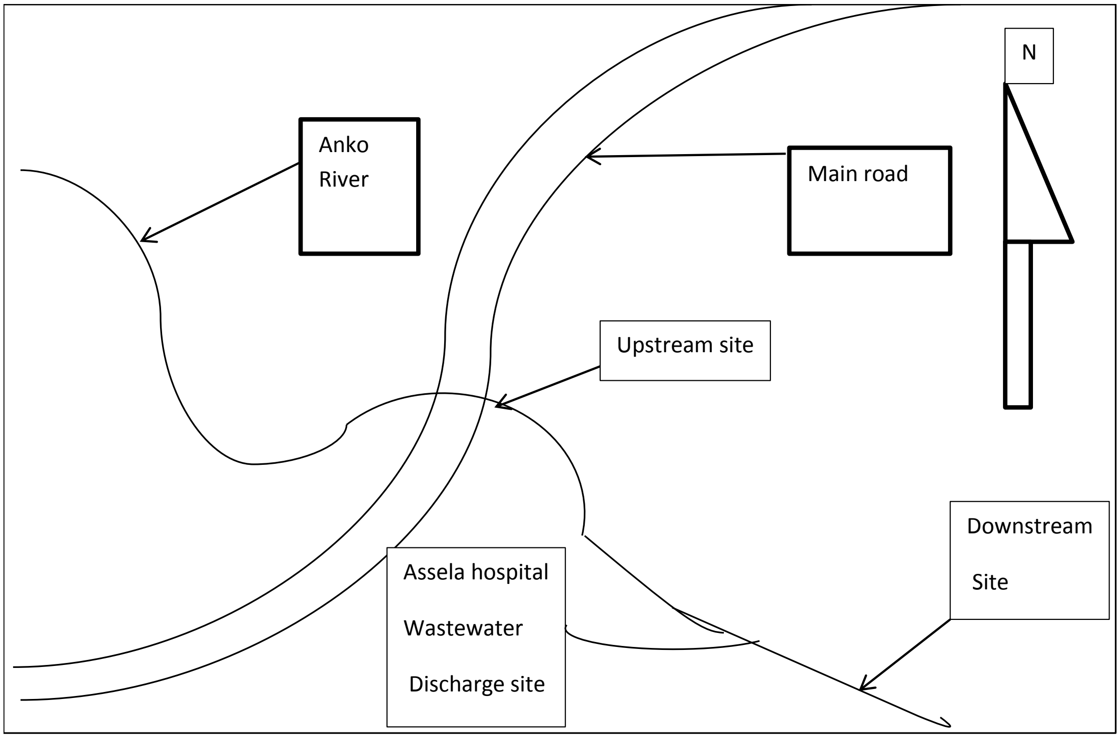

Figure 1. A sanitary survey water sampling site for laboratory analysis, Assela Town, November, 2012.

effluent, discharge point, 500 m downstream and upstream of the discharge point (Figure 1). Samples were collected monthly between April, 2012 and November, 2012. Samples were collected in plastic containers, pre-cleaned by washed and rinsed in tap water, 1:1 hydrochloric acid and finally with pure tap analysed wastewater.

Sampling technique

Before sampling, bottles were rinsed three times with sample water before being filled with the sample. The actual samplings were done midstream by dipping each sample bottle at approximately 20-30 cm below the water surface, projecting the mouth of the container against the flow direction. The samples were then transported in cooler boxes containing ice to Water Works Design and Supervision Enterprise Laboratory for analyses within 2 to 4 h after collection.

Chemical analysis

The concentrations of orthophosphate, nitrate, nitrite, ammonia , biochemical oxygen demand and chemical oxygen demand were determined in the laboratory by the standard spectrophotometric method (DWAF, 1999) using the spectroquant NOVA 60 photometer (Merck Pty Ltd).

Bacteriological analysis

Bacteriological characteristics were determined as described by Bezuidenhout et al. (2002). The most probable number- multiple tube technique was used for total and faecal coliform enumeration. SPSS version 20 software was used for carrying out the statistical analysis of the data.

RESULTS AND DISCUSSION

Ammonia generally arises from aerobic and anaerobic decomposition of nitrogenous organic matter. Urine of humans and animals yields large quantities of ammonium carbonate and hence sewage is rich in free ammonia. Average ammonia nitrogen contents of Anko River water at the tested sample stations were 8.4 to 42.4 mg/L (Table 1).

The maximum ammonia nitrogen was recorded in the second sample stations of hospital wastewater discharge site while minimum was at the upper stream site of sample station of the study sites (Figure 2).

Free ammonia, an indicator of aquatic pollution might be harmful to aquatic animals in Anko River mainly due to anthropogenic activities, municipal and sewage contaminations. In the present study, the concentration of ammonia- nitrogen was also found higher due to sewage discharge into the river by drains from hospital wastewater. The lower concentration of ammonia nitrogen was found at station A, a pristine site in the river.

Nitrate, the most highly oxidized form of nitrogen compounds is commonly present in surface and ground water because it is the end product of aerobic decomposition of organic nitrogenous matter. Unpolluted

Table 1. Average results of bacteriological & chemical laboratory analysis Water Works Design and Supervision Enterprise Laboratory Service Sub Process Water Quality Section from Anko river November, 2012GC.

Parameters	Up stream	Hospital wastewater treatment plant	Down stream
Ammonia (mg/L NH_3)	8.4	42.4	25.4
Nitrite (mg/L NO_2)	0.2	0.1	0.2
Nitrate (mg/L NO_3)	3	1.6	2.3
Phosphate (mg/L PO_4)	2.1	6.3	4.2
BOD_5 (mg/L)	11.8	131.9	106.3
COD (mg/L)	115.7	206.2	161
Total Coliform Per 100 ml	excess	excess	excess
Fecal Coliform Per 100 ml	220	600	180

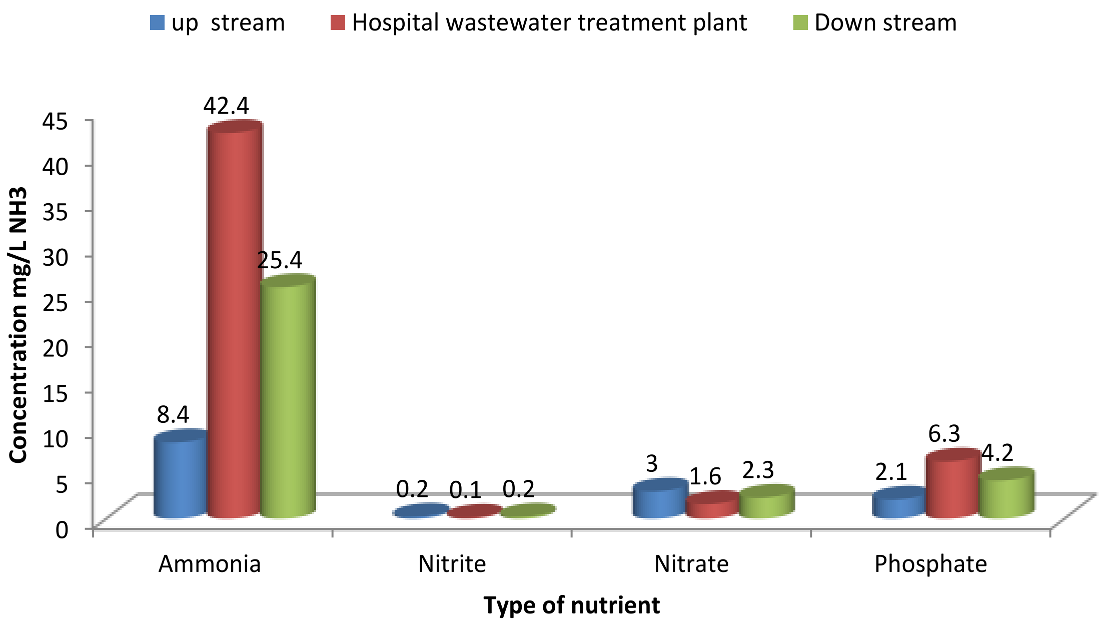

Figure 2. The laboratory result of nutrient concentration of Anko River, Assela Town, November, 2012.

natural waters usually contain only minute amounts of nitrate (Jaji et al., 2007). The average nitrate concentrations in each station are shown in Table 1. In this study, the nitrate-N concentrations ranged between 1.6 and 3 mg/L. The South African guideline for nitrate in sewage effluent is 1.5 mg/L NO3 - as N (Government Gazette, 1984).

The effluents did not meet this standard. It is important to note that nitrate level in the treated final effluent could be a source of Eutrophication for receiving water as the obtained values exceeded the recommended limit. The effluent from the treatment works might be considered as a source of nitrate into the receiving water body. The high nutrient levels in the upstream discharge point of the receiving water may be as a result of diffuse sources from settlement and agricultural runoff.

Nitrite levels in drinking-water are usually below 0.1 mg/l (WHO, 2011). The total nitrite levels obtained during the study period slightly exceeded the regulatory limits at upstream and downstream sites. Thus nitrite considered to pose a problem to communities when the receiving water body was used for domestic purposes. This may give rise to methaemoglobinemia (Fatoki et al., 2003).

However, it is important to note that the nitrite from the treated final effluents could be a source of Eutrophication for the receiving water bodies as the values obtained from the wastewater treatment plant exceeded the recommended limits for no risk of 0 to 0.5 mg/L as N (DWAF, 1996d) .

Nitrogen in the form of ammonia (NH_3) and nitrates (NO_3-) and phosphorus are essential nutrients to plant life, but when found in excessive quantities, they can stimulate excessive and undesirable plant growth such as algal blooms. Eutrophication could adversely affect the use of rivers and dams for recreation purposes as the covering of large areas by macrophytes could prevent access to waterways and could cause unsightly and malodorous scum which could lead to the growth of blue-green algae and release toxic substances (cyanotoxins) into the water systems. These substances are well known to cause the death of farm livestock (Holdsworth, 1991) and this must be a matter of concern in the Eastern Cape as this receiving water body is used for drinking by the farm livestock.

Moreover, it is well known that Eutrophication could increase the treatment cost of drinking water through filter clogging in water treatment works (Murray et al., 2000) (Table 1).

The orthophosphate –P contents varied from 2.1 to 6.3 mg/L. High phosphate levels were found in effluent zone of the second sampling stations than the other sites in receiving water body. The possible reason could be a consequence of Assela hospital wastewater dilution effect. However, the level of phosphate in water systems that would reduce the likelihood of algal and other plant growth is 5 µg/L (DWAF, 1996c). Other investigators had pointed out that Eutrophication-related problems in temperate zones of aquatic systems begin to increase at ambient total Phosphorous concentrations exceeding 0.035 mg/L. In warm-water systems, the values range between 0.34 and 0.70 mg/L (Rast and Thornton, 1996).

These represent nutrient threshold levels beyond which there had been a corresponding increase in the risk and intensity of plant-related water quality problems (OECD, 1982).

Comparison of the result obtained in this present study from the receiving watershed with some receiving water bodies, e.g. Keiskamma River (0.03 to 2 mg/L) (Morrison et al., 2001), Osun River (0.064 mg/L) (Olajire and Imeokparia, 2001) and Mukuvisi River (0.9- 11.7 mg/L) (Mathuthu et al., 1993) showed higher phosphate concentrations than that obtained in this study. In water quality studies, nitrogen and phosphorus are the nutrients most commonly identified as pollutants (Figure 2).

Biological oxygen demand

BOD determination is still the best available single test for assessing organic pollution. Singh and Rai, (1999) observed BOD of water samples value was indication for entry of organic waste in the River Ganga at Varansi and showed that high values are indication of organic pollution.

Lower levels of BOD at the sampling sites indicated that the Kistobazar Nala is not polluted by sewage disposal, animal waste, etc. and this could be attributed to sparse distribution of agricultural fields in its catchment area (Bhatt et al., 2001). Fokmare and Musaddiq, (2002) recorded high value of biochemical oxygen demand in Purna River and concluded that the river was highly polluted due to organic enrichment. Chavan et al., (2005) observed the creek water of Thane district (Maharashtra) showed high values of BOD and stated that the origin of these pollutants is mainly from the entry of effluents from surrounding industries. (Kelkar and Nanoti, 2005).

Higher level of BOD was observed by Tiwari et al., (2005). This may be due to sewage contamination in River Ganga at Bihar. Begum and Harikrishna, (2008) observed low level of BOD, indicating less pollution status of River Cauvery.

High levels of BOD were found in some areas of Haraz River at Iran mainly due to waste disposable at those sites (Keramat, 2008). Saksena et al., (2008) observed BOD ranged between 0.60 to 5.67 mg/L in Chambal River, and suggested that this stretch of the river was free from organic pollution. Anko River under study was BOD from 11.8mg/L at upper Station to 131.9 mg/L at lower Station (Figure 3). The second station which was Assela hospital wastewater discharge sites had a status of high organic pollution in the river.

Chemical oxygen demand

COD test is quite useful in finding out the pollution strength of industrial waste and sewage. Chemical oxygen demand is the amount of oxygen required for a sample to oxidize at its organic and inorganic matter. (Shrivastava and Patil, 2002) had observed COD value ranged from 74 to154 mg/L at Tapti River in Khandesh region. The value of COD showed that the water at Bhalgaon area in River Manjara, River Dhanegaon was not potable (Akuskar and Gaikwad, 2006).

Pillay, 2004) evident higher COD due to organic matter discharged by Fish farms and other sources like sewage. The effect of Ganga action plan was studied by Kelkar and Nanoti, 2005) and noticed the recovery of river health from organic load by reduction in COD values at Varansi.

Higher COD was observed by Chavan et al., 2005) in a stream at Thane district mainly due to pouring of industrial waste and municipal sewage. Tiwari et al., 2005) observed high level of COD in river at various places of Bihar mainly due to raw sewage, municipal waste, industrial effluents and anthropogenic disturbances.

In Gomati River at Sultanpur the COD is indicative of pollution in the river (Singh and Singh, 2007). The COD values fluctuated between 17.5 and 54 at River Cauvery showing beginning of organic pollutants (Begum and Harikrishna, 2008). Higher organic load at Haraz River, Iran at certain points is due to waste water discharge by some fish farm (Keramat, 2008). Marchese et al., 2008) noticed COD between 48 from 51 mg/L showing creation of pollution due to nearby industries and human disturbances through infrastructure works at Salado River (Argentina). Little abundance of COD in Kosi River, Uttrakhand indicates the pristine nature and good health of river (Bhandari and Nayal, 2008). In Anko River,

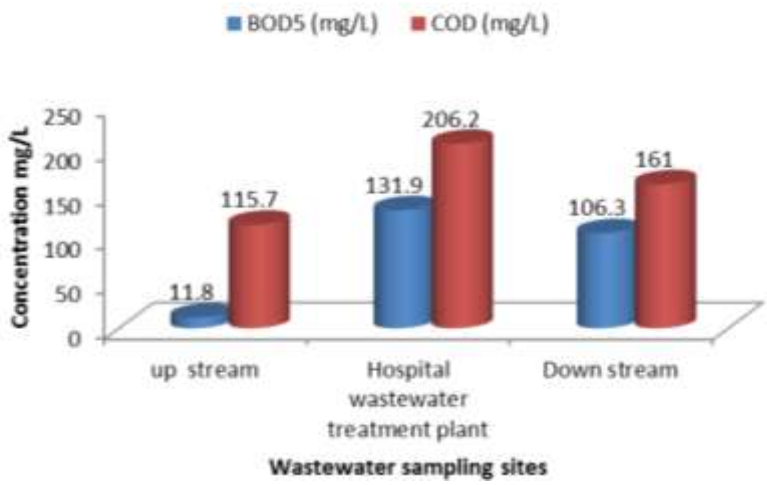

Figure 3. The laboratory result of chemical water parameter of anko river, Assela Town, November, 2012

Table 2. Pearson correlations among the bacteriological and chemical properties Anko River water in Assela, November, 2012.

Correlation	Stations	Ammonia	Nitrite	Nitrate	Phosphate	BOD_5	COD	TCF	FCF
Stations	1	0.500	0.000	-0.500	0.500	0.500	0.501	-0.682	-0.086
Ammonia		1	-0.866	-1.000**	1.000**	1.000**	1.000**	0.292	0.820
Nitrite			1	0.866	-0.866	-0.866	-0.866	-0.731	-0.996
Nitrate				1	-1.000**	-1.000**	-1.000**	-0.292	-0.820
Phosphate					1	1.000**	1.000**	0.292	0.820
BOD_5						1	1.000**	0.292	0.820
COD							1	0.292	0.819
TCF								1	0.787
FCF									1

**: Correlation is significant at the 0.01 level (2-tailed).

maximum COD was recorded as 206.2mg/L at the second station as it receives high pollution load.

The correlations among the bacteriological and chemical properties of water are studied and the results are presented in Table 2. There was no significant correlation observed between Ammonia and changes in TCF. But Ammonia with Phosphate, BOD_5, COD and FCF exhibited a significant positive correlation (r = 1.000, 1.000, 1.000 and .820 at P-value < 0.01, respectively).

Ammonia with Nitrite and NO_3 - indicated a negative correlation(r = -0.866 and -1.000, P-value < 0.01). Nitrite was negatively significantly related with phosphate, BOD_5, COD, TCF and FCF (r = -.866, -0.731and -0.996 P-value < 0.01). Also, nitrate exhibited negative significant correlation with phosphate, BOD_5, COD and FCF(r = - 1 and -0.820, P-value < 0.01) and phosphate positively correlated with BOD_5, COD and FCF (r = 1 and 0.820, at P-value < 0.01, respectively). BOD_5 positively correlated with COD and FCF (r=1 and 0.820 P-value <0.001 respectively) (Table 2).

This would help to understand the nature of these bacteriological and chemical variables and their species speciation in the effluent and receiving watershed. It was generally known that an increase in concentration of pollutants will occur during low flows when point sources dominate.

Bacteriological analysis

Heterotrophic count (HPC) measures a range of bacteria that are naturally present in the environment (EPA, 2002). The total bacterial counts for all the water samples were generally high exceeding the limit of $1.0X10^2$ cfu/ml which is the standard limit of heterotrophic count for drinking water (EPA, 2002). The high total heterotrophic count is indicative of the presence of high organic and dissolved salts in the water. The primary sources of these bacteria in water are animal and human wastes.

These sources of bacterial contamination include surface runoff, pasture, and other land areas where animal wastes are deposited. Additional sources include

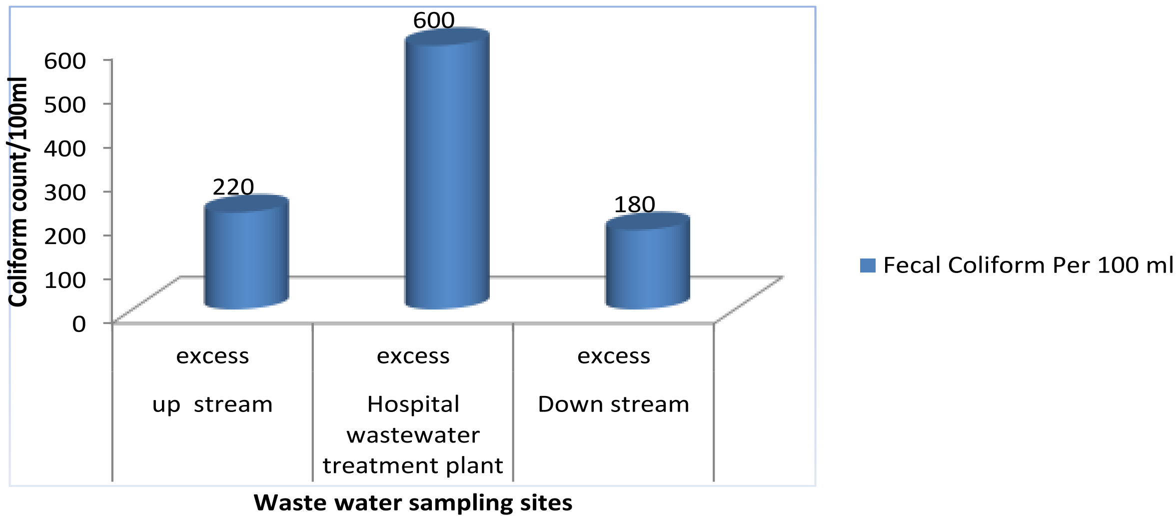

Figure 4. The laboratory result of bacteriological indicator organism in Anko River, Assela Town, November, 2012.

seepage or discharge from septic tanks, sewage treatment facilities and natural soil /plant bacteria (EPA, 2002). These contaminants were reflected in the highest bacterial load obtained in this study for the Anko River (Figure 4).

Accordingly, the total coliform counts for all samples were exceedingly high; the EPA maximum contamination level (MCL) for coliform bacteria in drinking water of zero total coliform per 100ml of water (EPA, 2003). The high coliform count obtained in the samples may be an indication that the water sources are faecally contaminated (EPA, 2003, M.I. and Eneuzie, 1999). None of the water samples complies with EPA standard for coliform in water.

According to EPA standard, every water sample that had coliform must be analyzed for either fecal coliforms or *E. coli* (EPA, 2003) with a view to ascertaining contamination with human or animal waste and possibly pathogenic bacteria or organism, such as *Gardia* and *Cryptosporidium* may be present (EPA, 2003).

CONCLUSION AND RECOMMENDATION

Proper waste water treatment, control of anthropogenic activities to prevent raw sewage from entering water body would be the key to avoiding bacterial contamination of drinking water. It was evident that water borne diseases were due to improper disposal of refuse, contamination of water by sewage, surface runoff, therefore Assela town health departments must be organized to educate the risk populations on the proper disposal of refuse, treatment of sewage and the need to purify our water by homemade water treatment, to make it fit for drinking because the associable organisms were of public health significance being implicated in one form of infection or the other.

In areas lacking in tap water as in rural dwelling, educative programmers must be organized by researchers and government agencies to enlighten the villagers on the proper use of surface water. Assela municipality would have to strengthen hygiene and sanitation activities to control untreated waste water discharge to surface water sources like Anko River. Assela Hospital waste water treatment was not completely effective treatment system. So to reduce the faecal and total coliform organisms additional treatment system with sand filtration followed by post chlorination systems constructions must be recommended urgently. Other private agency and stakeholders can also apply waste water treatment principles with the implementations of environmental health law of public health proclamations, 2000GC.

Abbreviations

BOD, Biochemical oxygen demand; **COD,** chemical oxygen demand; **EPA,** Environmental Protection Agency; **FCF,** fecal coliform count; **HPC,** heterotrophic count; **MCL,** maximum contamination level; **TCF,** total coliform count; **WHO,** World Health Organizations.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Applications of soft tools to solve hydrological problems for an integrated Indian catchment

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Emergence of a hydrological forecasting model based on past records is crucial in solution of problem. In water resource and hydrology, to build the estimation model based upon the hydrological records, generally requires traditional time series analysis and modelling. Estimation can be done either by using Artificial Intelligence (AI) techniques, or by some traditional methods. The present work uses two data driven techniques, namely Artificial Neural Network (ANN), and Linear Genetic Programming (LGP) to estimate runoff by mixing the data of four gauging stations and evaluating on one catchment out of total five catchments namely Shivade, Shigaon, Gudhe, Amble and Belwadi catchments in the Krishna basin of India, and further the results are compared. The accuracy of model developed was judged by error measures criteria and by drawing time series and scatters comparative graphs. Three types of models are developed considering different combinations. All these models performed considerably well as seen from their performances. From the results it is found that ANN and LGP techniques performed equally well. However LGP performance is better as compared to ANN; as modelling approaches are examined, using the long-term observations of yearly river flow discharges.

Key words: Hydrological process, artificial neural network, linear genetic programming, forecasting runoff, meteorological parameters.

INTRODUCTION

In hydrological process runoff estimation is perpetually based upon the observations of rainfall on the upper catchments which is very often supplemented by rainfall in the adjoining catchment. Addressing relationship to rainfall-runoff is most complex hydrological phenomena because of temporal and spatial variability of watershed and many numbers of variables are involved in this process. Hydrologists have attempted to understand this relationship to forecast stream flow and they have developed many models to stimulate this process. The flow of river can be predicted from Rainfall-Runoff models which use hydrological and climatic data or by stream flow models which utilize the hydrological data (Jain and Kumar, 2007).

A vast number of model structures usually a combination of linear and non-linear function have been

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developed and implemented since early 1960s (Todini, 1998). Considering the use of the observational data and the description of the physical process the most commonly applied classification is empirical or black box model, conceptual or gray box model, and physically or white box models (Haykin, 1994).

An initial model based on measured rainfall runoff is called empirical or black box model. These models depend upon the observational data and also on the calibrated input-output relations without the description of the processes. (e.g. Transfer function models, unit hydrograph and empirical regression approaches). Second type models are conceptual or grey box models. In these models the basic processes, that is snowmelt, infiltration, and evaporation are separated to some extent but the algorithms will be calibrated with reference to the input-output relationship e.g. Stanford Water shed Model (SWM), Hydrological Simulation Model (HBV) (Bergström, 1976), Model Trees (MT) (Quinlan, 1992) and Least Square Support Vector Machines (LSSVM) (Suykens et al., 2002). Third type is called physically based or white box. These models are based on the mathematical-physics equations of mass and energy transfer of the river basin which intends to minimize the need of calibration by using the watershed characteristics as the model parameters, e.g. System Hydrologic Europeen (SHE) (Abbott et al., 1986), Institute of Hydrology Distributed Model (IHDM) (Beven and Kirkby, 1979) and the Thales (Grayson et al., 1992). A code such as TOPMODEL (Beven et al., 1987).

Scope and objectives of the study

The main objective of this study was to develop an ANN and LGP models which serve as the benchmarks for an integrated Indian catchments. To achieve this objective, the area selected for the present study was upper Krishna Basin situated on western regions of Maharashtra, India, and lies between latitude 13° 07' N and 19° 20' N and longitudes 73° 22' E and 81° 10' E. The details of the research carried out by many researchers worldwide are mentioned in subsequent paragraph.

In the past decades, artificial intelligent data driven technique such as ANN, was used to model a wide range of the hydrological processes as they are having ability to model the nonlinear systems very efficiently (Tokar and Johnson, 1999; Thirumalaiah and Deo, 2000; Chang et al., 2002; Sivakumar et al., 2002; Zhang and Chiew, 2009; Googhari et al., 2010). These approaches are developed without taking directly the account of the physical laws underlying the hydrological process and the models were developed only by reusing the information from the hydrological time series (De Vos and Rientjes, 2005; Jothiprakash and Magar, 2012) considered ANFIS models for developing the lumped data rainfall-runoff relationships by considering monthly data and for an intermittent runoff system of Kanand River in Maharashtra State India as a case study. Charhate and Kote (2009) used ANN and Genetic Programming to predict reservoir inflow for Koyana Reservoir of Krishna River basin. They demonstrated the capability of prediction of reservoir inflow in the catchment for weekly and monthly values. Kote and Jothiprakash (2009) identified the performance of ANN'S time lagged recurrent networks (TLRN) with time delay, gamma and laguarre as their memory structure for predicting the seasonal (June– October) reservoir inflow with a monthly time step for Pawana reservoir, of the upper Bhima River Basin, in India. Kote and Jothiprakash (2009) studied the performance of TLRN with AR, ARMA and ARIMA for intermittent reservoir in series using monthly time step for Yadgaon Reservoir in Upper Bhima River Basin India. Mandal and Jothiprakash (2012) applied artificial neural networks (ANNs) to predict the next time step rainfall using lagged time series of observed rainfall data of long term at Koyna Dam, Maharashtra, India.

Even though ANNs are having various good features, still they are suffering because of the limitations such as difficulty in selecting the appropriate training algorithm as well as time consuming efforts for developing the structure. In spite of this limitation there is some scope still for optimizing specific parameters of the network by finding the structure of ANN and training algorithm. To achieve robust learning from the given set of patterns, various kinds of neural networks mechanism are explored in the past. Very few researchers have used Time-Lag Recurrent Neural Network (TLRN and Jordan Eleman network for developing the models, hence attempt has been made to develop the model using TLRN and Jordan Eleman networks of ANN to the present study area. The neural network developed by Neuro solutions is used to develop the models in this work.

In recent days to overcome the drawbacks of the conventional methods certain new techniques such as AI based Artificial Neural Networks (ANN) and Linear Genetic Programming (LGP). GP models are used by many researchers (Londhe and Charhate, 2010; Charhate and Kote, 2009; Jothiprakash et al., 2009; Patel and Ramachandran, 2015) for different basins in Maharashtra as compared to LGP and there is the potentiality of LGP models to further explore different catchments of the Krishna Basin, Maharashtra, India.

LGP models are based upon Automatic Induction of Machine codes by Genetic Programming (AIMGP) and the fitness of LGP is evaluated by Mean Square Error (MSE). Developing of the LGP models was done by the software Discipulus (Francone, 2004).

GP is relatively a new technique based upon Darwin's natural theory of evolution. Koza (1992) has developed a general method for the induction of symbolic computer programs. The method can be applied to any problem for which a "fitness function" can be defined. This function determines how good a particular program is at solving a given task. Using techniques from genetic algorithms, GP discovers solutions without the need for pre-specifying the size or structure of the program. Genetic programming is a form of inductive machine learning. It evolves a computer program for performing an underlying process as defined by a set of training sample (Whigham and Crapper, 2001). The concept of GP was introduced by (Koza, 1992) and in this the programs are represented as tree structures and expressed in the LISP (List Processing (programming language / lots of Infuriating and Silly Parenthesis) as it is a functional programming language (Babovic and Keijzer, 2000; Brameier and Banzhaf, 2001; Guven, 2009). Generally GP can be considered as an application to solve complex nonlinear problems because its solution describes the input-output relationship. Recently, LGP has emerged a subset, which represents the graph based upon functional structure. It evolves the programs in an imperative programming language (C/C++) and hence it is termed as Linear Genetic Programming (Brameier and Banzhaf, 2001). In LGP the name “linear” refers to the structure of the imperative program representation and it does not stand for functional genetic programs and hence LGP represents highly nonlinear solutions in this context (Brameier and Banzhaf, 2001; Guven, 2009).In LGP, maximum size of the program is usually restricted to avoid over growing of programs without any conditions (Brameier, 2004).LGP is having its main advantage of producing the models that build the understandable structure which mentions that LGP models will exhibit a great potential to prioritize and screen the input variables. In LGP one can involve different parameters such as its population size, rate of mutation, crossover rate, functional set, homogenous crossover rate, program size and number of demes.

From the literature review, it can be observed that many researchers have used only rainfall (P) data to predict the run-off (Q). Few studies have used the inclusion of climatic parameters to decide upon the maximum accuracy which describes the phenomena of rainfall-runoff process in order to estimate runoff. Hence this study uses both hydrological data and climatic data as variables to describe the physical phenomena of the rainfall-runoff process, in order to estimate runoff (Q). Also the meteorological parameters are added to the input to examine the accuracy of the model and inclusion of such parameters to decide upon the maximum accuracy.

METHODOLOGY

Study area and data

The area selected for the present study was Upper Krishna basin located in the western regions of Maharashtra, India lying between latitudes 13° 07' N and 19° 20' N and longitudes 73° 22' E and 81° 10' E. The location of the gauge discharge site along with the location of rain gauge stations in the catchment is shown in Figures

Figure 1. Location of Shivade catchment.

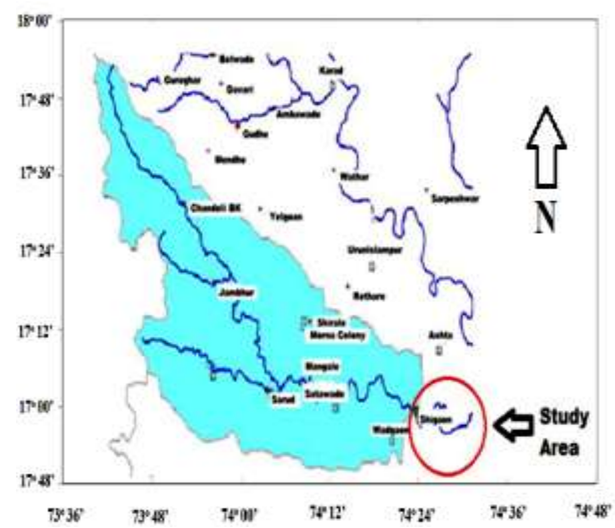


Figure 2. Location of Shigaon catchment.

1 to 5. The average annual rainfall in the Krishna Basin is 784mm. The South west monsoon sets in the middle of June and withdraws during mid of October. About 90% of the rainfall occurs during the monsoon period of which more than 70% of the annual rainfall occurs during July, August and September.

The observations of daily rainfall and runoff values, and the values of meteorological parameters such as pan evaporation, wind speed, humidity, and minimum and maximum temperatures pertaining to all catchments for the years 2002-2010 were obtained from the Hydrological Data Center Nasik, Maharashtra, India.

Model development

The model building here involved mixing the entire data base for the collected hydrological and meteorological parameters of the study area. Data for training was the data of the four catchments

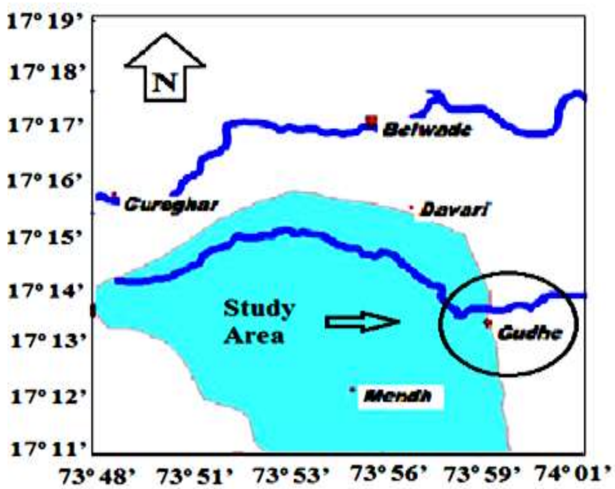


Figure 3. Location of Gudhe catchment.

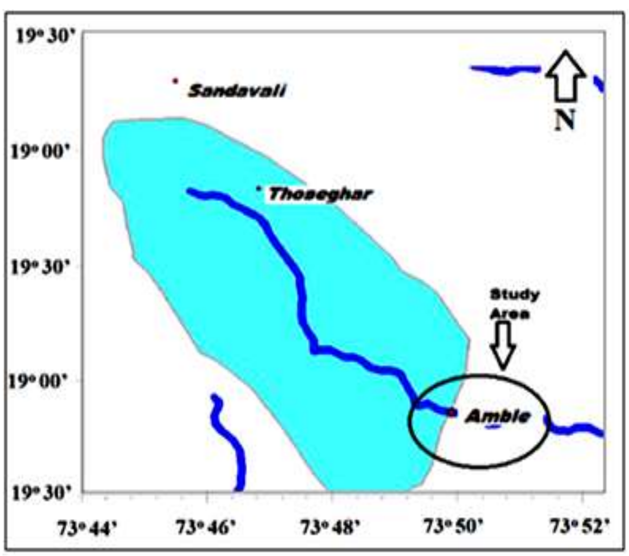


Figure 4. Location of Amble catchment.

amongst the data sets of five catchments available for all 9 years and for testing the entire data that was available in the individual catchment. Data usage and parameters considered for developing model based on combined data and evaluating on the individual catchment are mentioned in Table 1.The models developed by considering various options are given in Table 2. Model 1 was developed considering average rainfall of all rain gauge stations in the catchment and models 2 was developed considering distributed rainfalls at the rain gauge stations and while developing model 3 one by one meteorological parameters were added along with the distributed rainfalls as input to see the accuracy of the model. The data division for ANN and LGP model was kept for training and not testing.

In building the various models by considering this method care was taken to vary the training data set from the total available set depending upon the availability of data set for testing the respective

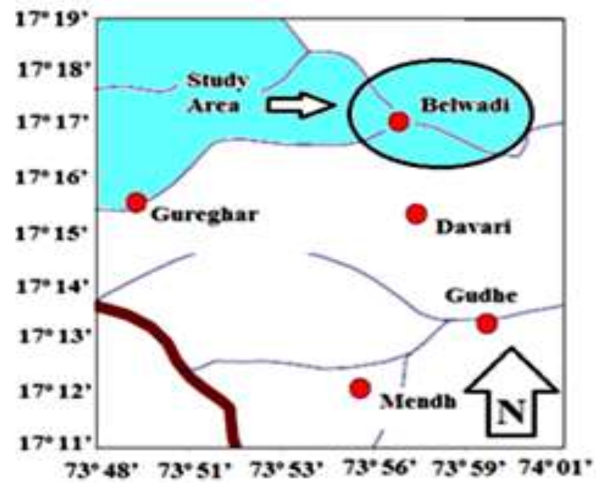


Figure 5. Location of Belwadi catchment.

catchments so that testing the developed model can be done for the individual catchment. Large numbers of trials were conducted. The time series plot and scattered plot between observed and predicted values are drawn to judge for qualitative analysis. As discussed above combined data base of four catchments and estimating the runoff values of remaining catchment the models are developed. The following training testing options are considered based on the catchment size. The model methodology used is same as discussed in previous section, that is, Model 1, Model 2, and Model 3.and the training testing pattern is shown in Table 3.

Performance indicators

The performances of the developed models using ANN and the LGP tools are evaluated by considering the performance evaluation indicators such as Correlation Coefficient (R), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE) using the equations as mentioned below from Equations 1 to 3.

Pearson's Correlation Coefficient *(R)* =

$$\frac{\sum_{t=1}^{N}[Q_{obs}(t)-\overline{Q_{obs}}][Q_{est}(t)-\overline{Q_{est}}]}{\sqrt{\sum_{t=1}^{N}[Q_{obs}(t)-\overline{Q_{obs}}]^2}\sqrt{\sum_{t=1}^{N}[Q_{est}(t)-\overline{Q_{est}}]^2} \quad (1)$$

Root Mean Square Error (RMSE) =

$$\sqrt{\frac{\sum_{t=1}^{N}\{Q_{est}(t)-Q_{obs}(t)\}^2}{N}} \quad (2)$$

Mean Absolute Error (MAE) =

$$\frac{\sum_{t=1}^{N}|\,Q_{est}(t)-Q_{obs}(t)|}{N} \quad (3)$$

Where-$Q_{obs}(t)$ is the observed value of discharge at time 't', $Q_{est}(t)$ the estimated value of discharge at time 't', 'N' the total number of data points, $\overline{Q_{obs}}$ the mean value of Observed discharge $\overline{Q_{est}}$, the mean value of estimated discharge.

RESULTS AND DISCUSSION

For the estimation of runoff various ANN models were

Table 1. Data usage and parameters considered for developing model based on combined data and evaluating on the individual catchment.

Name of Catchment	Available data set	Considered data set		Parameters considered		
		Training	Testing	Model No. 1	Model No. 2	Model No. 3
Shivade	5998	4871	1187		P_1 to P_{18}	P_1 to P_{18} + + MEP + MTN + MTX + MHS + MWS
Shigaon	5998	4880	1118		P_1 to P_9	P_1 to P_9 + + MEP + MTN + MTX + MHS + MWS
Gudhe	5998	4773	1225	$P_{avg.}$	$P_1$to P_4	P_1 to P_4 + + MEP + MTN + MTX + MHS + MWS
Amble	5998	4744	1254		P_1 to P_3	P_1 to P_3 + + MEP + MTN + MTX + MHS + MWS
Belwadi	5998	4783	1215		$P_1$to P_2	P_1+P_2 + MEP + MTN + MTX + MHS + MWS

Where 'P' = Rainfall; 'Q' = Runoff, MEP = Maximum Pan Evaporation; MTX = Maximum Temperature; MTN = Minimum Temperatures; MHU = Maximum Humidity; MWS= Maximum Wind speed.

Table 2. Model development on combined catchment data.

S/No.	Input for model building (Training)	Output for model (Testing)
1	Data base from Shigaon, Gudhe, Amble, Belwadi Catchments	Data base of Shivade Catchment
2	Data base from Shivade, Gudhe, Amble, Belwadi Catchments	Data base of Shigaon Catchment
3	Data base from Shivade, Shigaon, Amble, Belwadi Catchments	Data base of Gudhe Catchment
4	Data base from Shivade, Shigaon, Gudhe, Belwadi Catchments	Data base of Amble Catchment
5	Data base from Shivade, Shigaon, Gudhe, Amble Catchments	Data base of Belwadi Catchment

Table 3. Results of model testing for Shivade catchment.

Model No.	Input parameters	Tool	R	RMSE	MAE
1	Shivade Model 1	ANN	0.854	243.09	109.30
	P_{avg}	LGP	0.91	102.806	3.9271
2	Shivade Model 2	ANN	0.863	178.99	80.926
	P_1+ $P_{2+}$$P_3$ +P_4+P_5 + P_6 +P_7 + P_{8+} P_{9+} P_{10}+ $1_+$$P_{12}$ +P_{13}+P_{14}+ P_{15} +P_{16} + P_{17+} P_{18}	LGP	0.91	98.109	1.7233
3	Shivade Model 3	ANN	0.81	158.03	82.381
	P_1 + P_2+ P_3 + P_4 + P_5 + P_6 +P_7 + P_8 + P_9 + P_{10}+ P_{11}+ P_{12} +P_{13} + P_{14} + P_{15} + P_{16} + P_{17} + P_{18} + MEP + MTN + MTX + MHU + MWS	LGP	0.92	101.321	-4.021

developed based on input, number of hidden layers, neurons in hidden layers and activation function. Using the available data set and architecture the model was developed by changing the number of input parameter, number of hidden layers and number of hidden nodes. The models architecture for Shivade, Shigaon, Gudhe, Amble and Belwadi catchment consists of a layer with 1, 18, 23; 1, 9, 14; 1, 4, 9; 1, 3, 8 and 1, 2, 7, respectively as input parameters with 1 hidden layer and an output layer. Many trials were carried out to decide the number of hidden layers. Models with various combination of training algorithm and transfer functions were trained till the error reached minimum. The model was tested for estimation on unseen data to see the performance of the model. The LGP models that are developed are based on the selection of various control points, that is, fitness function, in terms of mean square error, initial population size, mutation frequency (95%), and the cross-over frequency (53%).

The software Discipulus, designed by AIM Learning and RML Technologies, Inc., Littleton, Colorado, U. S. was used to develop the LGP models. All the forecasting models that are developed were tested for nine years of data that is available in the respective catchments and the evaluation with reference to qualitative and quantitative was done by means of Correlation coefficient (R) between the observed and predicted values and plotting scattered plots between the same. Root Mean Square Error (RMSE) was used to measure the differences between value (Sample and population values) predicted by a model and the values actually observed. Mean Absolute Error (MAE) was used to

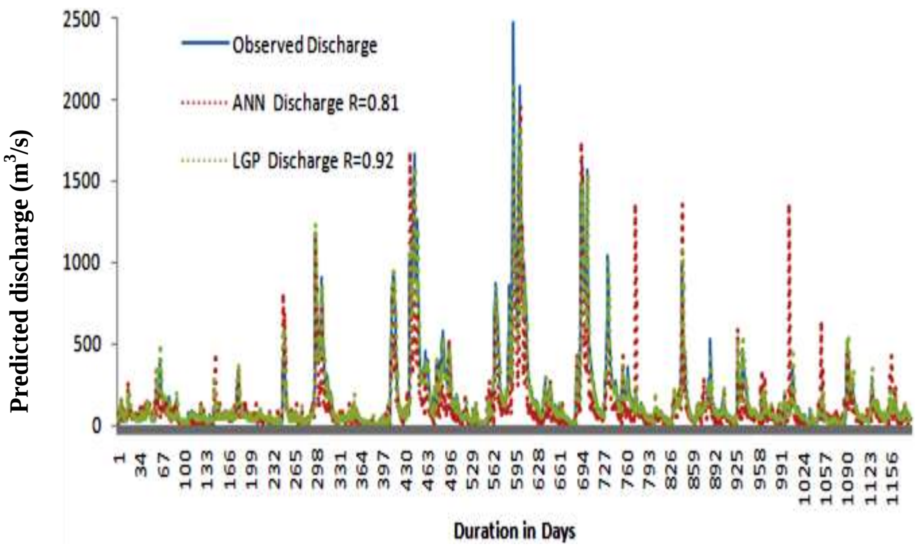


Figure 6. Time series plot of combined catchment data tested on Shivade Catchment, ANN and LGP Model 3.

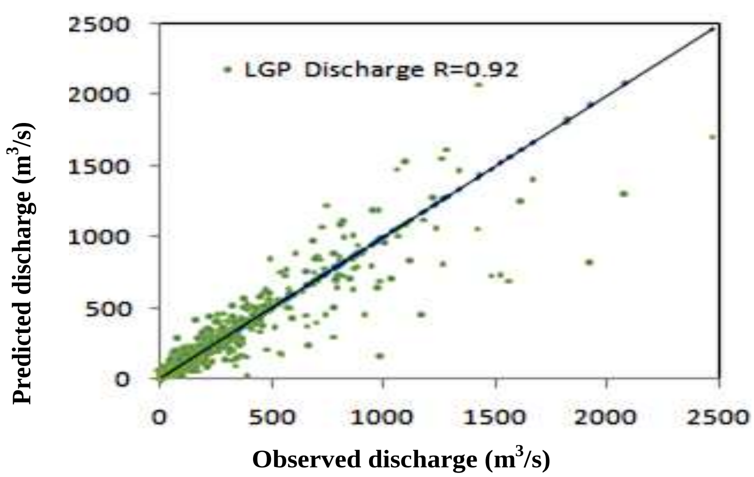


Figure 7. Scatter plots of combined catchment data and evaluating on Shivade Catchment Model 3 in testing with LGP

measure the accuracy of model with respect to the eventual outcomes. Number of trials was considered for developing the models. Their performances are discussed below. The one which showed better performances is considered. The results are tabulated in Tables 3 to 7.

Observations from Table 3 indicate LGP models for all 3 models developed using LGP tool have good performances. Model 1 in comparison with ANN is having correlation coefficient of 0.91 and 0.92 and keeping all the performance evaluation measures low. Amongst them Model 3 where meteorological parameters are added to distributed rainfalls performed well having correlation coefficient of 0.92, indicating the effect of meteorological parameters on the predicted discharges. The time series plot and the scatter plot for the combined data between the estimated and observed values of model 3 are shown in Figures 6 and 7 and confirmed the observations.

The performance of models developed using ANN and LGP tools was fairly equal in all aspects. Even though both the tools have over predicted its values, the models developed by considering LGP tool has little bit over predicted its peak value of discharges and it has captured almost all the peaks for lower and upper value as compared to ANN tool.

Thus for Shivade catchment models, the LGP tool performed well in terms of accuracy of predictions and in the situation of extreme events. However ANN tool

Table 4. Results of model testing for Shigaon catchment.

Model No.	Input parameters	Tool	R	RMSE	MAE
1	Shigaon Model 1	ANN	0.981	106.75	70.26
	P_{avg}	LGP	0.973	107.296	-4.144
2	Shigaon Model 2	ANN	0.91	333.87	188.165
	$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9$	LGP	0.91	90.754	-5.262
3	Shigaon Model 3	ANN	0.862	386.21	233.23
	$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9$ + MEP + MTN + MTX + MHU + MWS	LGP	0.92	92.504	-9.484

Table 5. Results of model testing for Gudhe catchment.

Model No.	Input parameters	Tool	R	RMSE	MAE
1	Gudhe Model 1	ANN	0.873	97.81	94.83
	P_{avg}	LGP	0.84	29.473	-4.08
2	Gudhe Model 2	ANN	0.846	66.05	57.50
	$P_1 + P_2 + P_3 + P_4$	LGP	0.84	29.473	3.01
3	Gudhe Model 3	ANN	0.8565	390.60	250.62
	$P_1 + P_2 + P_3 + P_4$ + MEP +MTN + MTX + MHU+ MWS	LGP	0.87	29.072	1.05

Table 6. Results of model testing of Amble catchment.

Model No.	Input parameters	Tool	R	RMSE	MAE
1	Amble Model 1	ANN	0.8409	102.077	92.68
	P_{avg}	LGP	0.85	26.608	1.823
2	Amble Model 2	ANN	0.8228	73.80	144.48
	$P_1 + P_2 + P_3$	LGP	0.85	26.703	-1.644
3	Amble Model 3	ANN	0.8698	483.31	291.55
	$P_1 + P_2 + P_3$ + MEP + MTN + MTX + MHU + MWS	LGP	0.8717	26.707	-0.910

seems to perform marginally well, because of the splitting criteria of the input and more over ANN also suffers from the drawback of not predicting extreme events unless they are trained for the similar extreme events. Moreover, the correlation coefficient of LGP tool models was increased after inclusion of meteorological parameters indicating the effect of meteorological parameters on the observed values of discharges. This might be because of the larger size and shape of the catchment. Hence, it clearly indicates characteristics of the catchment play an important role in deciding the performance of models. The performance of LGP was good as compared to ANN with a reason that the models developed using LGP provide inherent functional relationship explicitly over other technique like ANN. Moreover in LGP, the input and target variables as well as functional sets are defined initially and learning method finds both optimal structure of the model and its coefficients. LGP approach is also having the ability to automatically select input variables that are beneficial in model developing and discards those that do not contribute, as such it reduces substantially the dimensionality of the input variables.

Similar models were developed for the remaining catchments namely Shigaon, Gudhe, Amble and Belwadi. The models were developed keeping in mind the variation in catchment area. The results obtained are shown in Table 4 for Shigaon catchment, Table 5 for Gudhe catchment, Table 6 for Amble catchment and Table 7 for Belwadi catchment and the time series plot and scatter plot are shown in Figures 8 and 9 for Shigaon catchment, Figures 10 and 11 for Gudhe catchment, Figures 12 and 13 for Amble catchment, Figures 14 and 15 for Belwadi catchment respectively.

From Tables 4 to 7 and Figures 8 to 15 it confirms that combined catchment data model is working fine for all the catchments. The combined catchment data model has shown considerably good performance with addition of meteorological data and consistency was maintained.

Table 7. Results of model testing of Belwadi catchment.

Model No.	Input parameters	Tool	R	RMSE	MAE
1	Belwadi Model 1	ANN	0.8689	97.11	88.66
	P_{avg}	LGP	0.775	36.279	2.9614
2	Belwadi Model 2	ANN	0.7449	178.53	136.741
	$P_1 + P_2$	LGP	0.75	35.524	-1.0948
3	Belwadi Model 3	ANN	0.7267	178.78	170.350
	$P_1 + P_2 +$ MEP + MTN + MTX + MHU + MWS	LGP	0.83	36.602	-6.3832

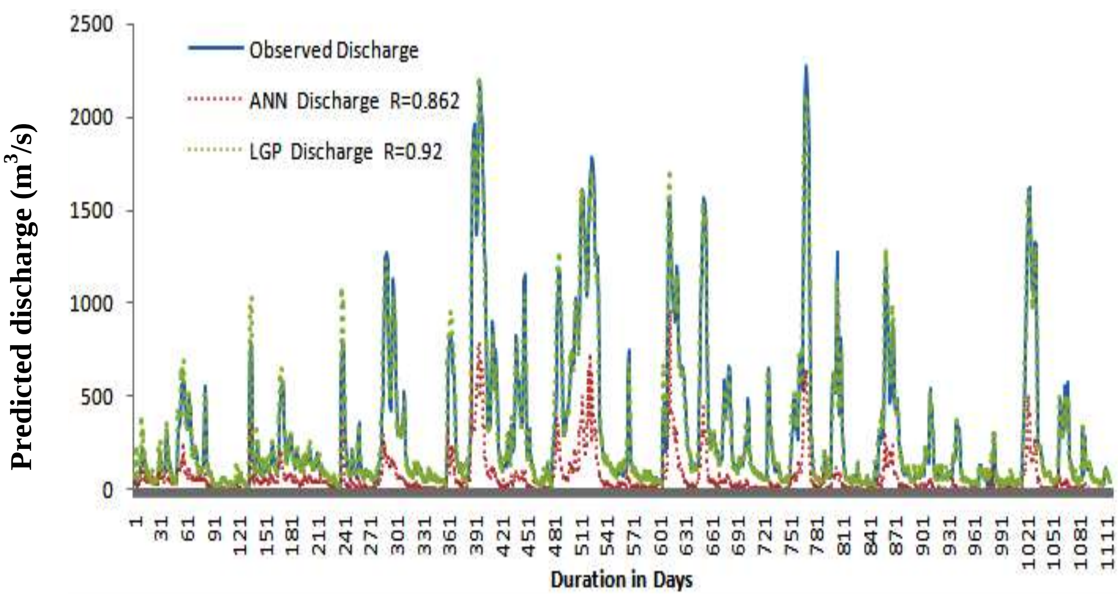


Figure 8. Time series plot of combined catchment data tested on Shigaon Catchment, ANN and LGP Model 3.

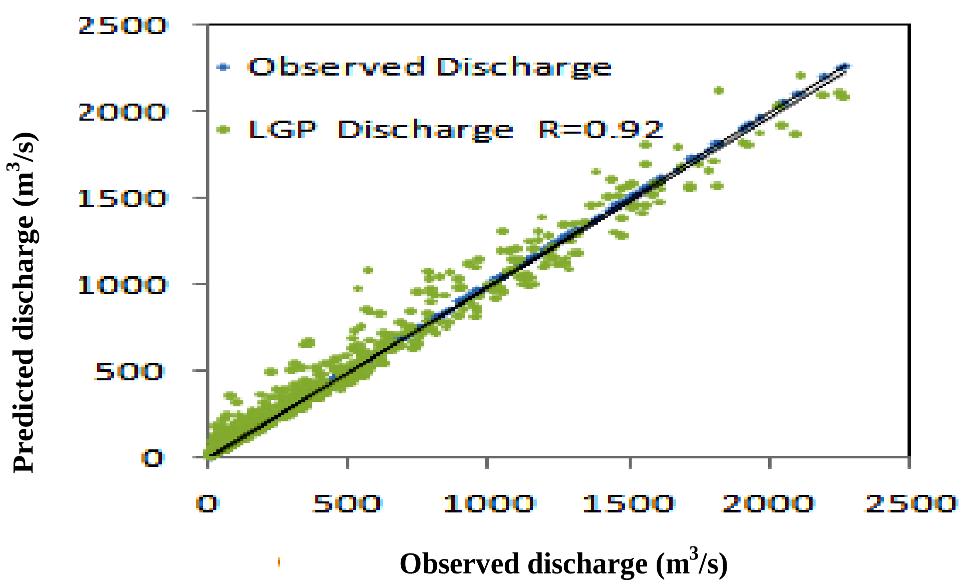


Figure 9. Scatter plots of combined catchment data and evaluating on Shigaon Catchment Model 3 in testing with LGP.

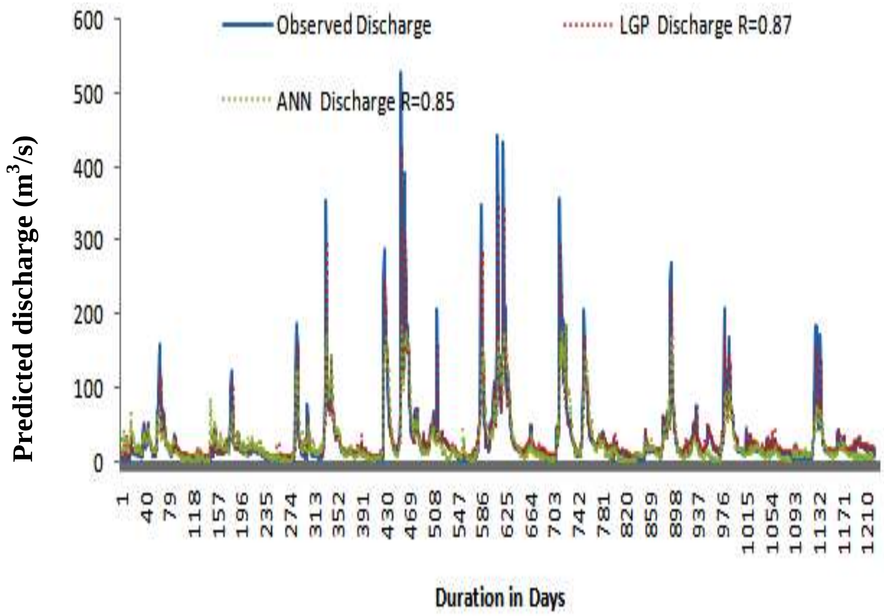


Figure 10. Time series plot of combined catchment data tested on Gudhe Catchment ANN and LGP Model 3.

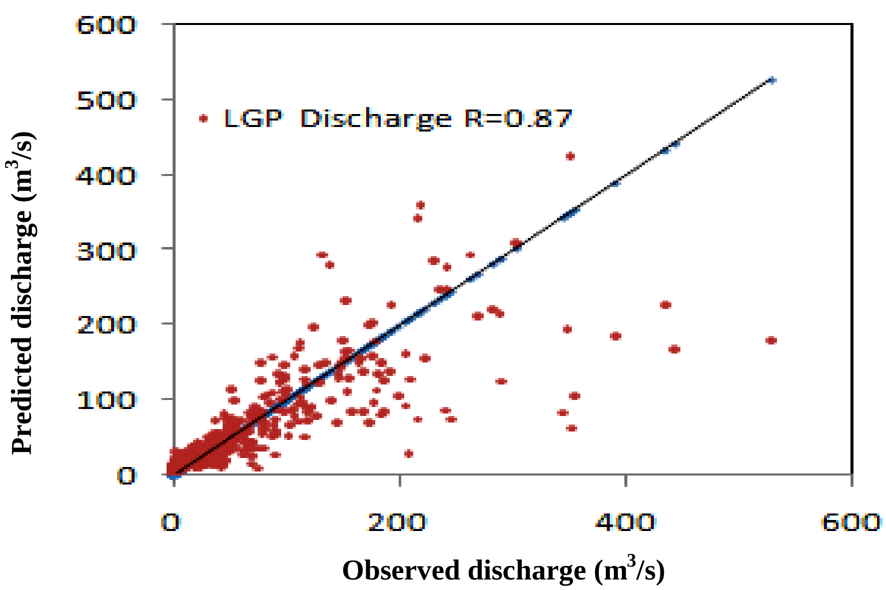


Figure 11. Scatter plots of combined catchment data and evaluating on Gudhe Catchment Model 3 in testing with LGP.

From the above results, it can be seen that combined catchment data base models developed on catchment area wise and mixing of data is a substitute in case the data from any catchment is missing and is termed as a robust model. Also, it was observed that the performance in testing the models the large catchment areas showed better results as observed in model performance criteria.

Conclusion

The main objective of this study was to develop an ANN and LGP models which serves as the benchmarks for integrated Indian catchments and to present an informative comparison of the data driven techniques viz. ANN and LGP for estimation of runoff for the study area

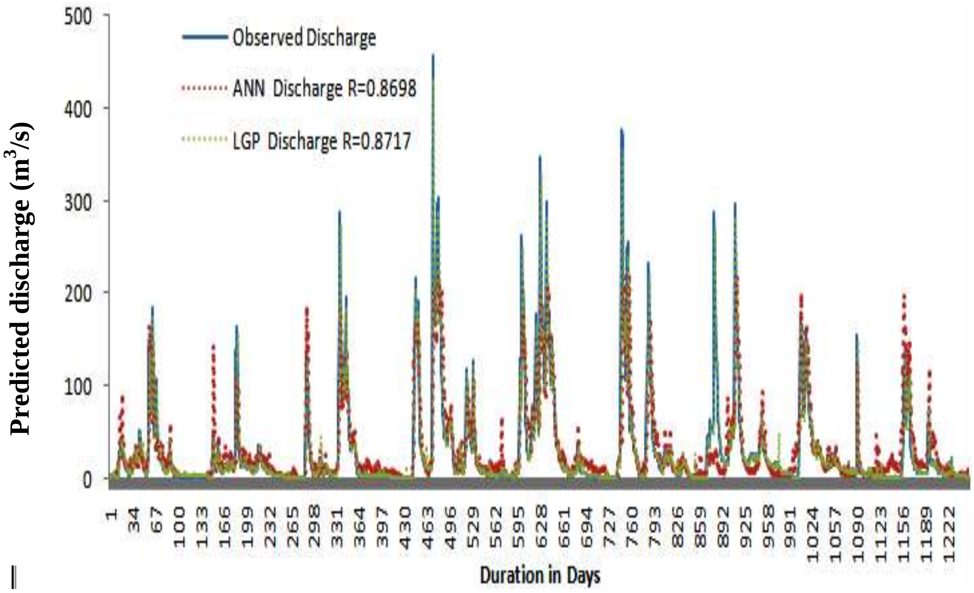


Figure 12. Time series plot of combined catchment data tested on Amble Catchment ANN and LGP Model 3.

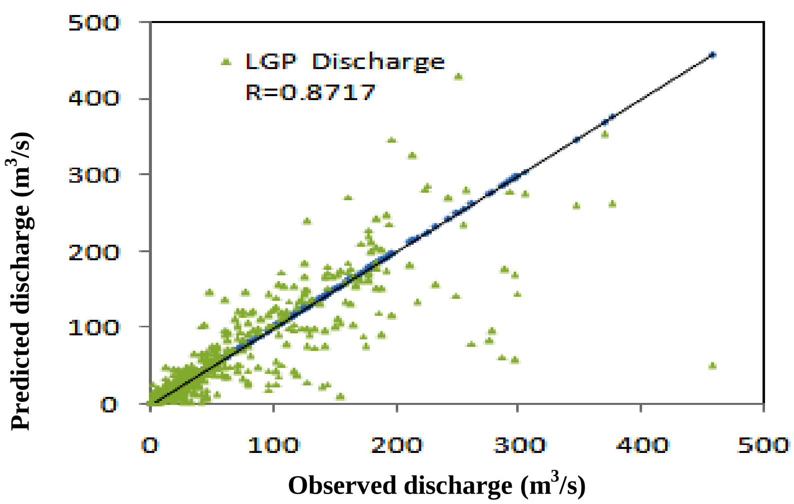


Figure 13. Scatter plots of combined catchment data and evaluating on Amble Catchment Model 3 in testing with LGP.

of Shivade, Shigaon, Gudhe, Amble and Belwadi catchments of Krishna River Basin. In comparing the performance evaluation of these data driven techniques it reveals that both the models have performed reasonably well. However, the performance of LG.P model found to be much better as compared to ANN for the models in which only rainfalls are considered as input parameters for estimating the discharges. The inclusion of meteorological parameters was also studied along with characteristics of the terrain. Hence, an attempt was made to develop the models taking both rainfall and meteorological parameters as input parameters in estimating discharges. For all the catchments, the combined catchment data model has shown considerably good performance with addition of meteorological data and consistency was maintained. The performance of LG.P was good in comparison with ANN for estimating the discharges. It can also be seen from time series that LG.P models have quite well estimated the peak values of discharges. It is observed that the LG.P model is much more efficient than either of the other models for estimating discharges of the streams. It can also be

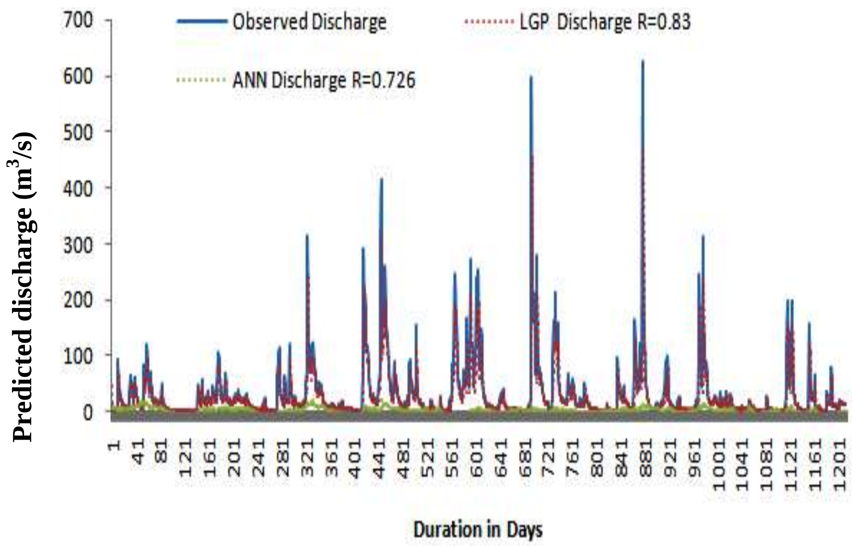
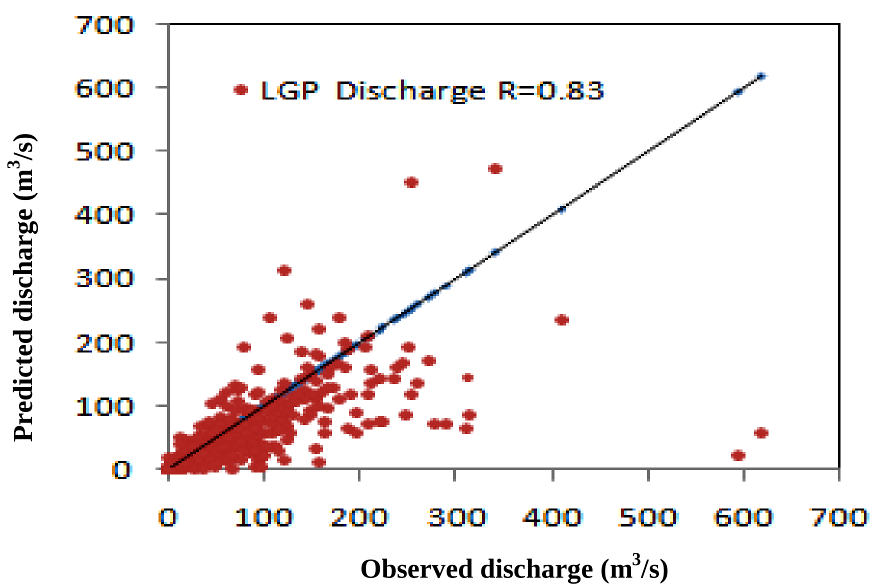


Figure 14. Time series plot of combined catchment tested on Belwadi Catchment ANN and LGP Model 3.



Figures 15. Scatter plot of combined catchment data and evaluating on Belwadi Catchment Model 3 in testing with PGP.

mentioned that, the results of the model are influenced by the data variability. It is noteworthy that the negative inflow values are due to the noise and uncertainty of the data since the observed daily inflows are measured using automatic rain gauges. The models developed by mixing the data of the catchments can be a substitute in case the data of one of the catchment is missing and can be termed as robust model also whenever there is no information of the meteorological parameters. Models 1 and 2 for all the catchments can be treated as an addition models. For all the catchments, the effect of characteristics of the catchment and the influence of the meteorological parameters were observed in predicting the runoff as discussed above. LGP models performances were found to be good in comparison with ANN because it has captured all the lower and higher values of peak discharges and has kept all performance evaluation errors very low in various conditions. The study carried out here can be extended to various catchments in other part of the world to see the robustness of the models.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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