STUDY OF GROUND WATER RECHARGE-ABILITY IN THE CONTEXT OF URBANIZATION, USING REMOTE SENSING AND GIS, ERNAKULAM DISTRICT, KERALA

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Abstract

Growth of urban areas results in significant changes in the physical properties of the land surface. The consequence is increase in area of impervious surface resulting in enhanced surface runoff and reduced infiltration which declines the ground water reduction and quality. In order to facilitate a sustainable urban ground water management practise, an understanding of long term spatial and temporal hydrologic variations is essential. This study is an attempt to quantify the impact of long term land use changes due to urbanization on surface runoff and groundwater table in Greater Cochin, comprises of Cochin as well as the major towns surrounding Cochin within Ernakulam district. The available satellite data is integrated in a GIS platform to quantify the impact of changing land use pattern on prevailing hydrology. Effective impervious area, runoff for peak rainfall and water depth contour map was calculated and generated using previous and present ground water data which indicates that overall ground water depth is getting deeper from previous years. Runoff to recharge ratio was calculated and the results were used to generate graphs plotted between effective impervious area (EIA) and runoff to recharge ratio of the study area. These plotes clearly indicate the linear increase in runoff to recharge ratio with EIA. Thus, the present study clearly shows that the increase in urbanization have negatively impacted the ground water hydrology of the study area.

Keywords: *Urbanization, Runoff, EIA, Water Depth Contour, RS and GIS*

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1. INTRODUCTION

Growth of urban areas results in significant changes in the physical properties of the land surface. The consequence is increase in area of impervious surface resulting in ground water table depletion, enhanced surface runoff and reduced infiltration[1]. This will eventually result in alteration of the prevailing ground water table resulting in altered hydrologic system. In order to facilitate a sustainable urban water management study, an understanding of spatial and temporal hydrologic variations for long periods is necessary, GIS and Remote Sensing has been widely using as the powerful tool for detecting urban growth [2],[3],[4],[5]&[6]. The global urban proportion raising exponentially, half of the world population is currently living in cities and it is estimated that by 2025 this will increase to over 67% [7]. This means that the importance and impact of cities are much greater than ever before [8].

The consequence of urban expansion with no environmental perspective is a deterioration of the water sources and a reduction in the supply of safe water to the population, or a scarcity of quality water. The process of transformation of rainfall to runoff is highly complex, dynamic, non-linear, and exhibits temporal and spatial variability, further affected by many and often interrelated physical factors[9]. The simulation of rainfall-generated runoff is very important in various activities of water resources development and management such as flood control and its management, scheduling and design of irrigation, drainage works, design of hydraulic structures and hydro-power generation etc. Ironically, determining a robust relationship between rainfall and runoff for a watershed has been one of the most important problems for hydrologists, engineers, and agriculturists [10].[11]&[12]. However, the most important factor that affects the calculation of runoff is the changing land use pattern. Temporal variation in the land use pattern alters the infiltration and ground water recharge capacity of an area. In the long run, such an alteration in the prevailing hydrologic system can result in acute water shortage problems[13]. As more and more population moves to urban region, the demand for water in an urban region increases in many folds. Thus as the demand increases exponentially the availability takes a negative trend. Hence, scientific studies are necessary to quantify the change or the reduction in the ground water resource, the increase in the surface runoff and the measures that can be taken to nullify the effect.

2. STUDY AREA

The study area (Fig.1) comprises of Cochin urban agglomerate within Ernakulam district, comprises of 1 corporation, 8 muncipalities, and 33 panchayaths lies between 9˚ 47 ˈ and 10˚16 ˈ N Latitude and 76˚12 ˈ and 76˚28 ˈ E longitude with an area of 810 sq.km. It is situated in the central part of Kerala state with Lakshadweep Sea on the west. Cochin is a major port city of the west coast of India and is also known as the Queen of Arabian Sea. The district is drained by the Periyar and its tributaries on the north and Muvattupuzha River on the south. The city of Cochin is rapidly growing towards north ward with the announcement of major industrial projects in the last few years. Cochin witnessed a high rate of population growth and fast developing trends in the past 30 years. As per the census of urban population of Cochin is 14.77 lakh in 2001, which is 47.56% of total district population, the growth is 68.02% in 2011, so the total growth rate is 20.46% within 10 years.

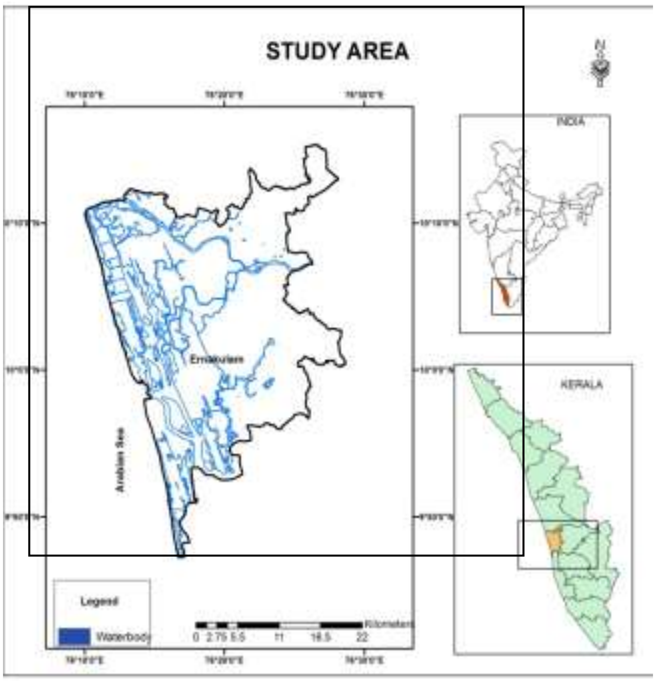


Fig.1 Study Area

As per the BIS standards the water consumption in Ernakulum city was 22,000m^3 L in 2001, 33,000m^3 L after a decade. Expansion of urban areas significantly impacts the environment in terms of ground water recharge, water pollution, and storm water drainage.

3. MATERIALS AND METHODS

Topographic sheets of 1:50000 of year 1968 and satellite images of Landsat 2010 are used to study the changes in land use variation from last three decades. After the land use classification was done, the built up area with high density was classified as effective impervious area.

Surface runoff was calculated for each land use category using SCS-CN method [14]. The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. On the basis of field observations, this potential storage S (millimeters or inches) was related to a 'Curve Number' CN which is a characteristic of the soil type, landuse and the initial degree of saturation known as the antecedent moisture condition (AMC). Each soil type is assigned a hydrological soil group based on the infiltration characteristics. The CN varies with the soil condition.Where, The runoff equation is given by:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad (1)$$

Q is the runoff
P is the rainfall

S is the potential maximum soil moisture retention after runoff begins. I_a is the initial abstraction, or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and it is generally assumed that $I_a = 0.2$ S

The runoff curve number, CN, is then related by

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

The potential maximum retention is calculated by the formula (2).

Historic rainfall data from IMD for a period of 33 years (Fig.2&3) will be used to quantify runoff. The recharge corresponding to rainfall for unconfined shallow aquifer was also found out. Then relation between Effective impervious area (EIA), run off and recharge was devised. From the 35 years well data obtained, the pre monsoon and post monsoon water depth level for the subsequent years was plotted and the long term trend analysis for each of the well falling within the study area was carried out.

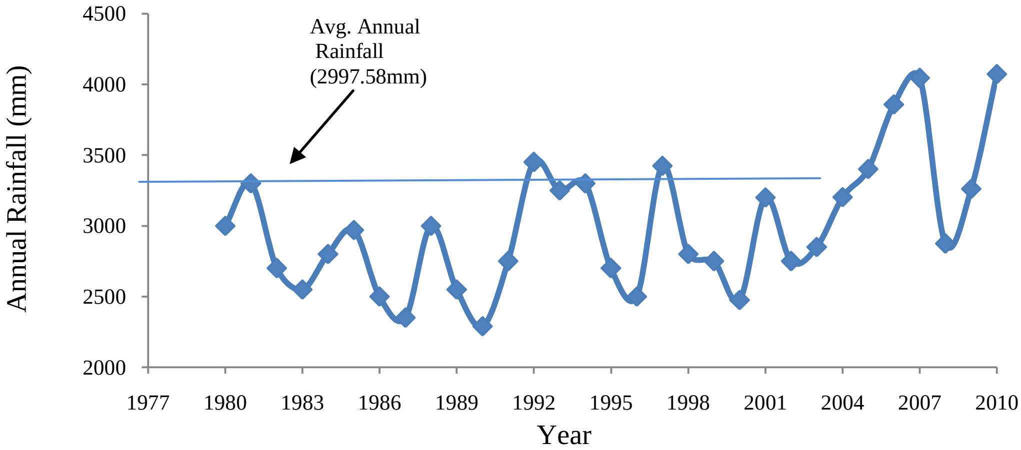


Fig.2. Annual rainfall variation for 33 years (Ernakulam)

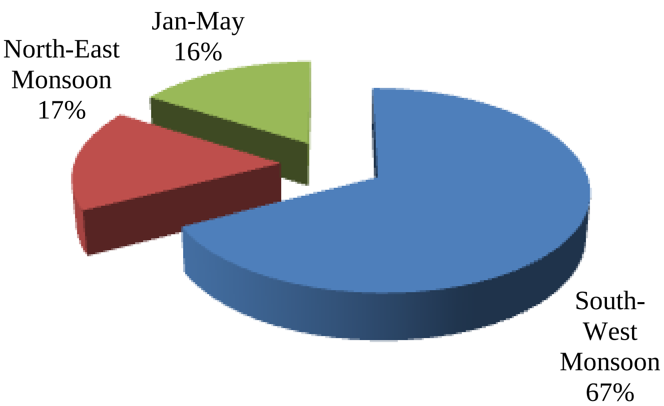


Fig.3. Seasonal average rainfall

From the same data, the contour map of water depth for pre monsoon and post monsoon period was prepared for the study area and water fluctuation studies were carried out. The percentage change in water level for a period of 33 years for the study area was found out.

4. RESULTS AND DISCUSSION

4.1 Land Use Map of Study Area

Intense human utilisation of land resources throughout the entire history of mankind has resulted in significant changes to the land use and land cover which in turn affects the hydrology of the catchment area [15],[16],[17],[18]&[19]. In the present study due to intense human utilisation built up area has increased while the land use and land cover change phenomenon is highly accelerated. Paddy field abridged 42% during the four decades.

It caused the rate of reduction of saturated ground condition, which directly influences the recharge ability of the study area.

The land use was categorized into built up area, cultivated land, fallow land, paddy field, waste land and water body (Fig.4, Table.1). The built up area covered 21.7 km^2 in 1968, which increased to 145.5 km^2 in the year 2010.

Table.1. Land use changes of the study area.

LAND USE	***PERCENTAGE AREA(km^2)***	
Years	**1968**	**2010**
Built-up area	2.68	17.96
Cultivated land	57.35	54.25
Fallow land	8.48	7.57
Paddy field	17.97	7.61
Water body	13.12	12.57
Sandy feature	0.4	-
Waste Land	-	-

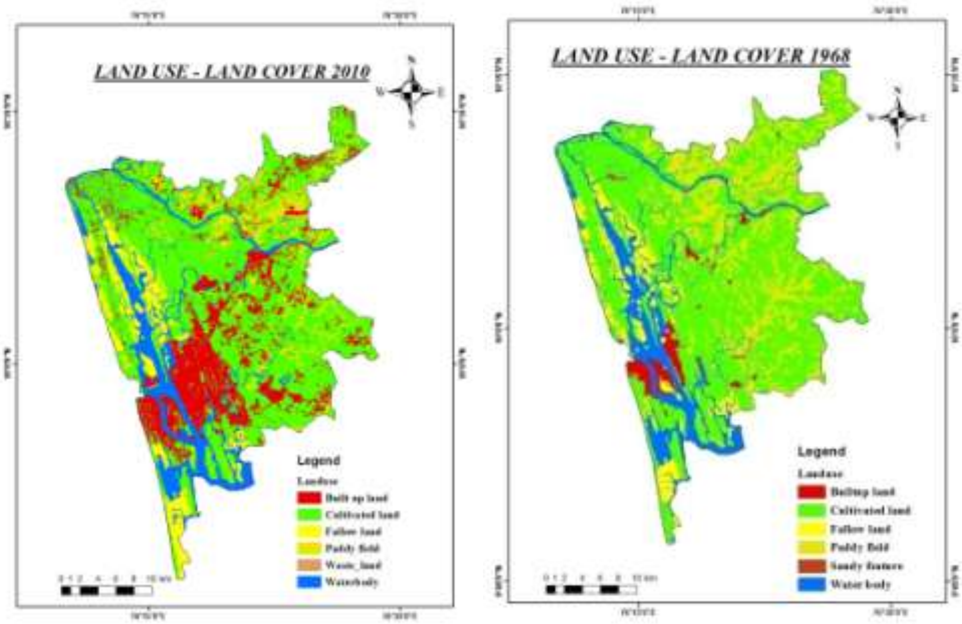


Fig.4. Land use map for a period of 1968 – 2010.

4.2 Effective Impervious Area Estimation

Increased impervious cover directly influences surface water runoff and watershed imperviousness which directly affects the ground water quality and quantity. Earlier studies implemented an increase of 6% impervious surface will cause a steep decrease in stream insect community and increase in water temperature [20],[21]&[22].

After the land use classification was done, the built up area with high density was classified as effective impervious area (Fig.5). Compared to the area of impervious cover in the year 1968, a drastic change can be observed in 2010 due to urbanization. A comparison between the effective impervious areas showed that it is increased from 2.68% in 1968 to 17.96% in 2010. This might cause the decreased infiltration and increased surface run off.

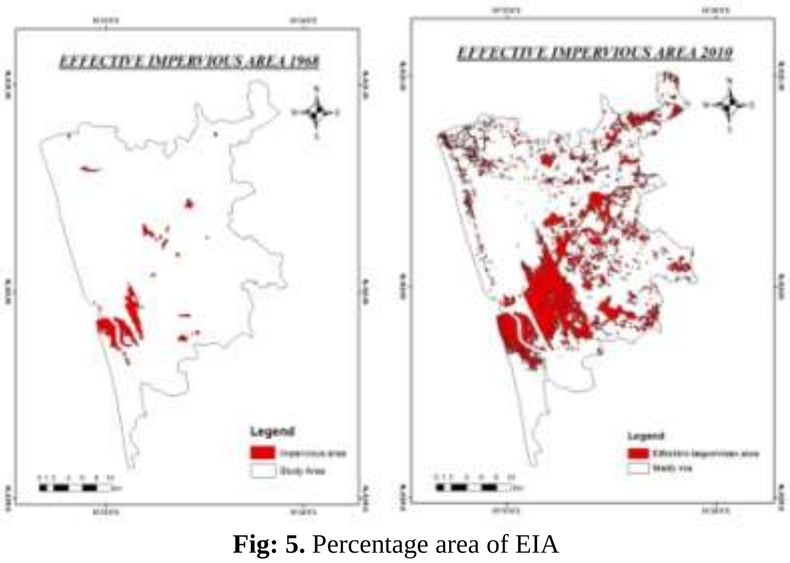


Fig: 5. Percentage area of EIA

4.3 Builtup Area

The settlement of the study area has dominated after the growing up of industries and port. As a fast growing tier II metro the settlement is gathered mostly on the both sides of national highway and attach to coastal and port region. the growth of city towards rural areas are also not negligible impact on the regional water balance [23]&[24].Urbanisation initiating new abstraction regimes, radically changing patterns and rates of recharge affects quantity and quality of the underlying ground water [25]. The water depth contour map of the study area for pre-monsoon and post-monsoon season for the years 1981 to 2014 were generated (Table.2 and Fig.7).

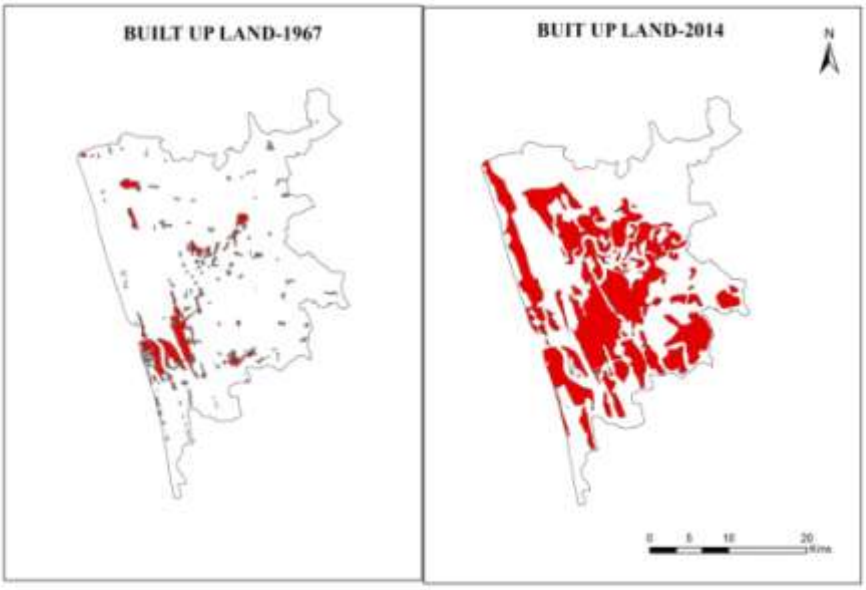
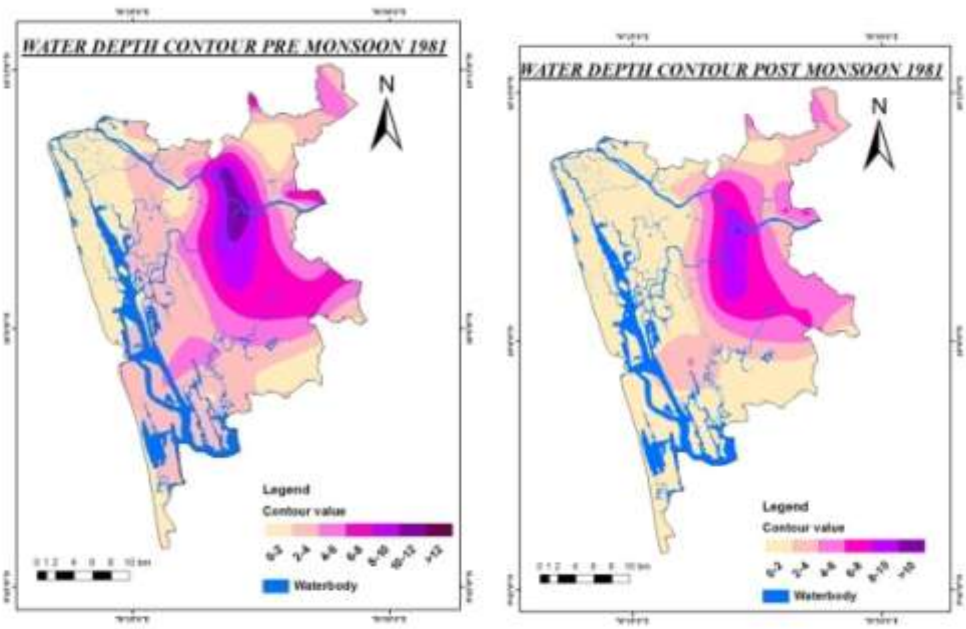


Fig.6. Builtup land of the study area (Source: Google Earth)

The settlement was 110 km^2 in 1967 from toposheet 1:50000, and which is 280 km^2 in recent days (google map, 2014)(Fig.6), that is around 4,75,000 buildings are marked in the study area, those are perfect impervious structures.

4.4 Water Depth Contour Map

The regional climate and hydrological cycle changes with landuse and landcover has a direct Out of 33 years of rainfall, 10 years received more than average rainfall, though the annual average rainfall is within the range throughout the year of analysis. It is clear that the depth to water surface increased in pre monsoon than that in the post monsoon. It illustrates an increasing water depth trend from 1981 to 2014's as a result of enlarged urbanization.



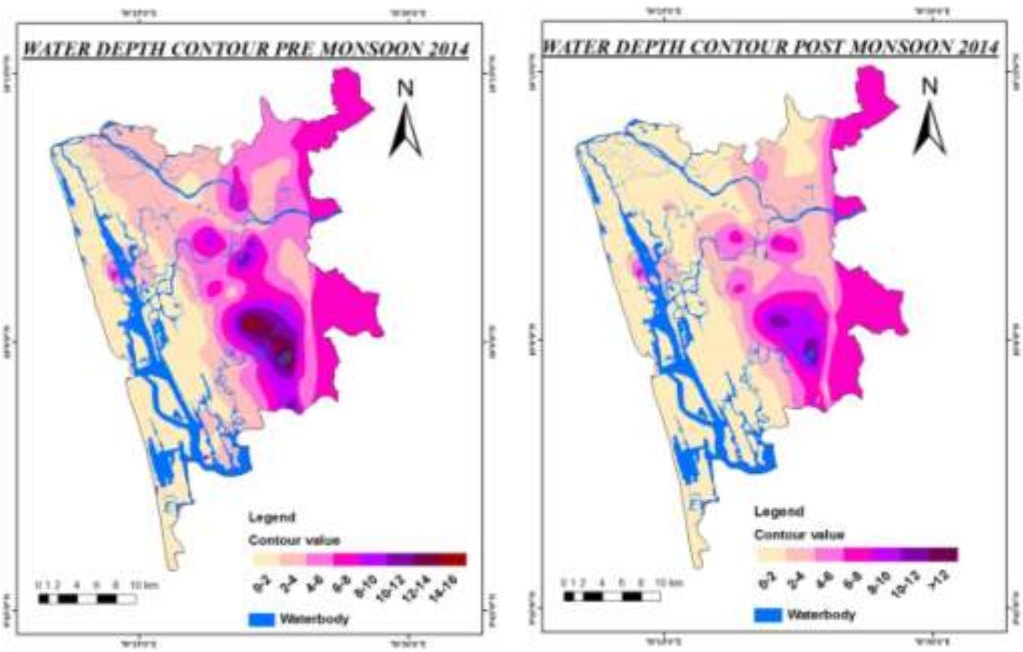


Fig.7. Water depth contour of pre and post monsoon over a period from 1981 to 2014 with respect to average rainfall (IMD).

Table.2. Variation of post monsoon water depth with years in study area

Contour(m)	Area (%)			
	Pre monsoon		**Post monsoon**	
	1981	**2014**	**1981**	**2014**
0-2	26.46	32.42	55.96	52.01
2-4	40.99	25.87	18.94	18.86
4-6	14.89	16.86	13.99	10.94
6-8	11.3	17.66	7.99	14.78
8-10	4.67	3.4	3.1	2.65
10-12	1.66	2.19	0.02	0.74
12-14	0.03	1.41	-	0.02
14-16	-	0.17	-	-

With the increase in impervious area the surface runoff increases and recharge decreases. As per the SCS-CN curve number method the calculated total runoff increased from 50.78Mm^3 in1968 to 54.64Mm^3 in 2010 for the study area (Table.3). Simultaneously recharge decreased from 30.19Mm^3 in 1968 to 26.33 Mm^3 in 2010. From the determined result the land use land cover change results in tremendous increase of impervious surfaces which directly influence the runoff volume.

Table.3. The Effective impervious area, runoff, recharge and run off to recharge ratio

Year	**EIA (km^2)**	**Runoff(Mm^3)**	**Recharge (Mm^3)**	**Ratio**
1968	21.70	50.78	30.19	1.68
2010	145.46	54.64	26.33	2.08

5. RUNOFF AND RECHARGE

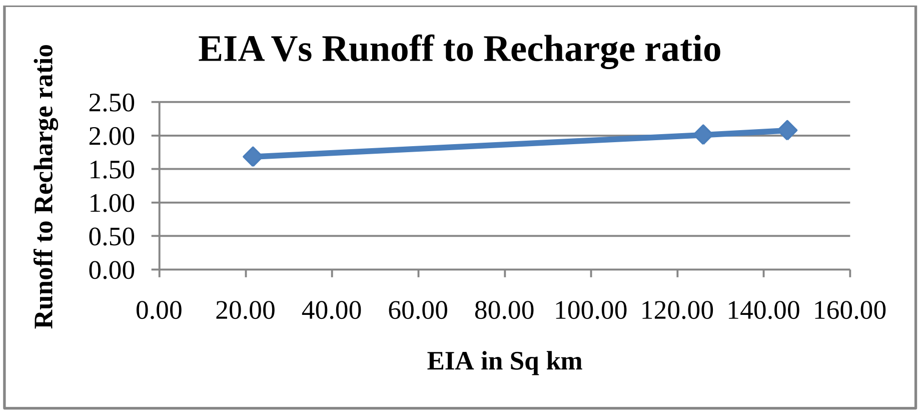


Fig.8. Effective impervious area, runoff, recharge and run off to recharge ratio

5.1 Relation between Effective Impervious Area (EIA), Runoff and Recharge

The land use map clearly indicates the augmented imperviousness from 1968 to 2010. It was due to significant rate of change in the residential, commercial and industrial areas within the study area. The increase in runoff and reduction in recharge during these years clearly providing evidence of the impact of urbanization. The graph plotted (fig.8) between Effective Impervious area (EIA) and run off to recharge ratio of the study area is linear, which shows increasing urbanization indicating effective impervious area and runoff were amplified and a decline in recharge or infiltration to the soil.

6. CONCLUSION

It can be seen from the study that the builtup area has increased 17.96% during the last 42 years. These high dense urban area is again classified as effective impervious area. The rate of change of EIA caused an astonishing runoff over the area. The rainfall distribution is almost uniform in the study area over the period. As such, the increasing runoff will cause a low recharge rate. The available water from a storm event will full fill the required water for the present day population of the city, but the unplanned drainage systems and rain water harvesting programmes are not implimented as per the requirement. The hydrograph stations of CGWB in the high dense populated urban centres of Edappalli and Fortcochin has shown an annual decline of 2cm in water level for a period of 1978-2001. The relation between EIA, runoff to recharge determination clearly indicating the impact of urbanization. From the study it is clear that a sustainable management plan is needed to save our motherland from severe drought.

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