Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2017, Volume 6, Issue 1, pp. 1994-2000
ISSN 2320 - 0243, doi:10.23953/cloud.ijarsg.30

Research Article | Open Access

Estimation and Assessment of Spatial Variations in Water Availability in West Flowing River Basin of Kutch, Saurashtra and Marwar (WFR-KSM basin) using Geospatial Technology

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Publication Date: 5 January 2017

DOI: https://doi.org/10.23953/cloud.ijarsg.30

Abstract The availability and distribution of water varies nationally and regionally. The availability of fresh water is stressed due to growing population coupled with sustainable developmental efforts, the uneven distribution of water resources over time & space, their modification through human use & abuse and many others. The study area is WFR-KSM basin which lies between 67°52' to 75°19' E longitudes and 20°53' to 26°57' N latitudes, covering areas in Rajasthan, Gujarat and whole of Diu. Hydrologically, it is divided into six sub basins and 268 watersheds (India-WRIS). The annual and monsoon season water availability in the basin, its sub basins and watersheds for water year 2013-14 was calculated by SCS curve number method using IMD 0.25 degree rainfall, NRSC NR Census LULC, NBSS & LUP soil data and MODIS evapotranspiration data. The water availability in the basin was estimated to be 34.67 BCM annually and 47.4 BCM in monsoon season ranging from 0 to 505 MCM annually and from 0 to 647.23 MCM in monsoon season in the watersheds of the basin. The spatial interpretation of water availability in watersheds indicated more water availability in the southern part of the basin and less water availability in the watersheds lying in northern part of the basin.

Keywords *Basin; GIS; Remote Sensing; Kutch; Marwar; Rainfall; Runoff; Saurashtra; SCS; Water*

1. Introduction

Water is an essential natural resource for sustaining life on earth. The availability and distribution of water varies spatially. India is endowed with rich water resources but the potable water is limited and varies spatially throughout the country. The availability of fresh water is further stressed due to growing population, developmental efforts, uneven distribution of water resources over time & space, their modification through human use & abuse and many others. All these result in intensifying the pressure on water resources leading to conflict among users and eventually lead to excessive pressure on the environment. These situations demand for proper management of water resources. This, in turn, calls for a reliable and adequate statistics on available water resources and related aspects.

The assessment of water availability means different things to different communities. Many envisions have proposed the concept of national assessment of water availability based on the indicators of the status and trends in storage volumes, flow rates, and uses of water nationwide. There are several spatial scales at which the indicators of water availability could be reported. The assessment would use basic hydrological data collected from different sources by the responsible agencies to create the indicator variables. This process of computing indicators from the basic data would help to elucidate uncertainties in our knowledge of the Nation's hydrological conditions.

In India, the gauge data is not homogenously available for all the catchments. The hydrological modeling approach was followed for the estimation of runoff in the catchments. This paper presents the estimation of water availability in the WFR-KSM basin, its sub basins and watersheds and their spatial interpretation. Here yield is calculated as indicator of water availability in the hydrological units.

2. Literature Review

Barlow (2002) presented the concepts of nationwide assessment of water availability in United States and the variables used to represent the same at several temporal and spatial scales. The lack of runoff information in India is mentioned by Ningaraju, Ganesh Kumar and Surendra (2016). They used SCS-CN method and GIS for the estimation of runoff in ungauged Kharadya milli watershed in Karnataka, India.

SCS-CN method is used globally for the calculation of runoff. Rao et al. (2014) used Land use/land cover (LULC) maps (1:250k scale) prepared using AWiFS sensor data of IRS-P6 satellite generated under Natural Resources Census (NR census) project by Indian Space Research Organization (ISRO) and Soil maps (1:250k scale) of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) in the calculation of runoff. Gangodagamage and Aggarwal (2012) presented the use of LISS-3 data, derived land use and SCS curve number method for the generation of hydrological model for the Bata River basin which is a tributary of the Yamuna River, India. Ahmad and Verma (2016) used SCS-CN method for estimation of runoff depth in Kharun River basin in Chhattisgarh state of India. Choi, Kim and Lim (2016) used SCS runoff curve number for the estimation of approximate amount of runoff in several forested watersheds of Korea. Al-Jabari, Sharkh and Al-Mimi (2016) used SCS method in GIS domain for the assessment of runoff from Wadi Su'd watershed in southern Palestine. Chavda, Makwana, Parmar, Kunapara and Prajapati (2016) used SCS-curve number method in GIS domain for the estimation of surface runoff and water availability in semi-arid Ozat catchment in Gujarat, India. Khatun (2016) used SCS-curve number method in GIS domain for the estimation of surface runoff in Kushkarni River Basin of West Bengal, India. N. Kamuju (2016) used SCS-curve number method using NR census land use land cover as input in GIS domain for the calculation of temporal runoff in Karha river basin in Maharashtra State, India. Haidu and Ivan (2015) used Simplified SCS-CN mode number method for the estimation of volume of water draining from urban rooftops in a municipality of Romania.

3. Study Area

The study area is located in western India which is defined by the rivers flowing westwards towards the Arabian Sea with their respective drainage areas. The basin enclosing this area is West Flowing River Basin of Kutch, Saurashtra and Marwar (WFR-KSM basin). The basin boundary is represented by basin delineated on west flowing rivers of Kutch and Saurashtra including Luni in India-WRIS project (Water Resources Information System) project and having area 1, 84,865.96 Sq. Km (GIS). The basin is spread over western India in the states of Rajasthan (13 Districts), Gujarat (13 Districts), and Daman & Diu (1 District). The area represents wide diversity of relief features and variability in terms of topography. In the west lie shallow wetlands of Rann of Kutch; eastern area is bounded by river Banas and hilly terrain of Aravalli chain; northern part is represented by Luni River which is an active tectonic

sedimentary basin and southern part is covered by other important smaller rivers such as Shetrunji, Machhu, Rupen and Bhader.

Hydrologically, the WFR-KSM Basin is divided into six sub-basins and 268 watersheds. The sub basins are named according to main river system in them, Luni Upper Sub-basin (38.03%), Luni Lower sub-basin (15.81), Saraswati sub-basin (14.77%), Drainage of Rann sub-basin (11.50%), Bhadar and other WFR sub-basin (10.02%), and Shetrunji and other EFR sub-basin (9.87%).

4. Goal and Objectives

The goal of this research was to estimate the water availability in WFR-KSM basin, its sub basins and watersheds along with their spatial assessment using geospatial techniques. The objectives to attain this goal were (1) To calculate water availability using hydrological modeling, and (2) To analyze the spatial variations in water availability. The water availability was calculated for the annual and monsoon season of the water year 2013-14 i.e. from June 2013 to May 2014.

5. Software and Data Used

The softwares used were Arc map 10, Geospatial Modeling Environment (GME), MS excel and ASAP utilities (excel add in) tool. The data used were IMD Precipitation grid (0.25° x 0.25°) of year 2013-14; NR census LULC (1: 250k) by NRSC/ISRO for the year 2013-14; Soil texture layer at 1:50k scale from NBSS & LUP; and MODIS 0.05 degree evapotranspiration (ET) data which is 1 square km monthly gridded dataset for the year 2013-14.

6. Analytical Methods Used

The water availability was calculated for each hydrological unit using SCS Curve Number Method in Arc Map environment. The SCS curve number method also known as the hydrologic soil cover complex method was developed by Soil Conservation Service (SCS) of United States Department of Agriculture (USDA) is a simple method used to calculate direct runoff based on rainfall by using antecedent soil moisture conditions, soil, land cover and the curve number (CN) which characterizes the runoff potential of the soil land cover complex (SCS). The method is well established and widely used.

The basis of SCS curve number equation is water balance equation that can be expressed as

$$P = I_a + F + Q \qquad \text{..... (1)}$$

Where P is total precipitation, I_a is initial abstraction, Q is direct runoff and F is cumulative infiltration excluding I_a and Q. There are two assumptions along with the water balance equation: First concept states that the ratio of actual amount of direct runoff (Q) to maximum potential runoff (= P - I_a) is equal to the ratio of actual infiltration (F) to the potential maximum retention, S. The equation is:

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad \text{..... (2)}$$

The second concept is that the amount of initial abstraction (Ia) is some fraction, represented by λ, of the potential maximum retention (S), given by

$$I_a = \lambda S \qquad \text{..... (3)}$$

Combining the equations (1), (2) and (3), For P>λS; and Q=0 for P≤λS

$$Q = \frac{(P - I_a)^2}{P - I_a + S} = \frac{(P - \lambda S)^2}{P + (1 - \lambda)S}$$

The curve number represents a dimensionless number which is a representation of potential maximum retention (S) of the catchment. The S as well as CN depends on soil-vegetation-land use complex of the catchment along with antecedent runoff conditions prior to the rainfall. The S and CN are defined as

$$S = \frac{25400}{CN} - 254; \text{ and } CN = \frac{25400}{S + 254}$$

The CN is a dimensionless parameter ranging from 0 for infinitely abstracting catchment indicating zero potential retention (S = ∞) to 100 for impervious catchment. The CN depends on soil type, antecedent runoff conditions and land use land cover.

7. Methodology

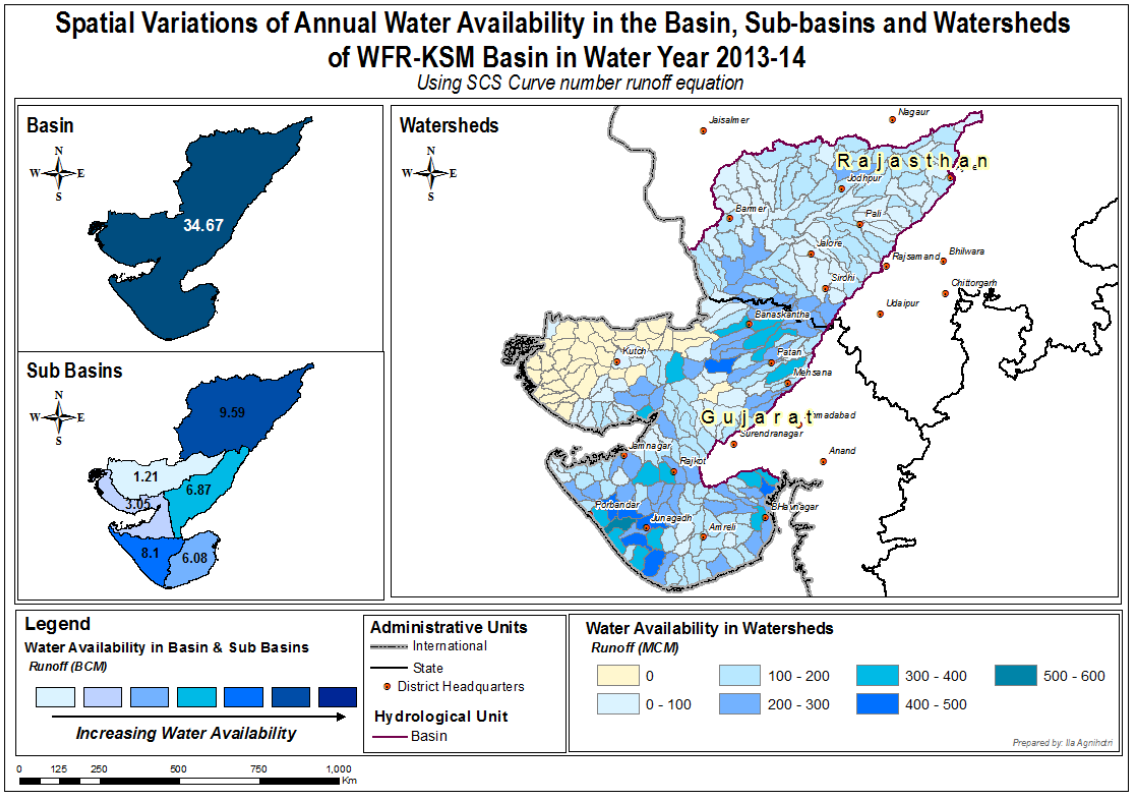
Annual and monsoon season (June to September) water availability were calculated for the basin, six sub basins and 268 watersheds (hydrologic units), using the subsequent steps. IMD rainfall data was converted in 0.25 degree grid. MODIS evapotranspiration (ET) data was downloaded and converted in 0.05 degree grid layer. The rainfall and ET values were assigned to basin, sub basins and watersheds in Geospatial Modelling Environment. The LULC and Soil layers were prepared for hydrological modeling. The runoff was calculated for each hydrological unit using SCS Curve number method in Arc Map environment. The calculated values were converted in volume terms, were spatially mapped and interpreted using Arc Map.

8. Results

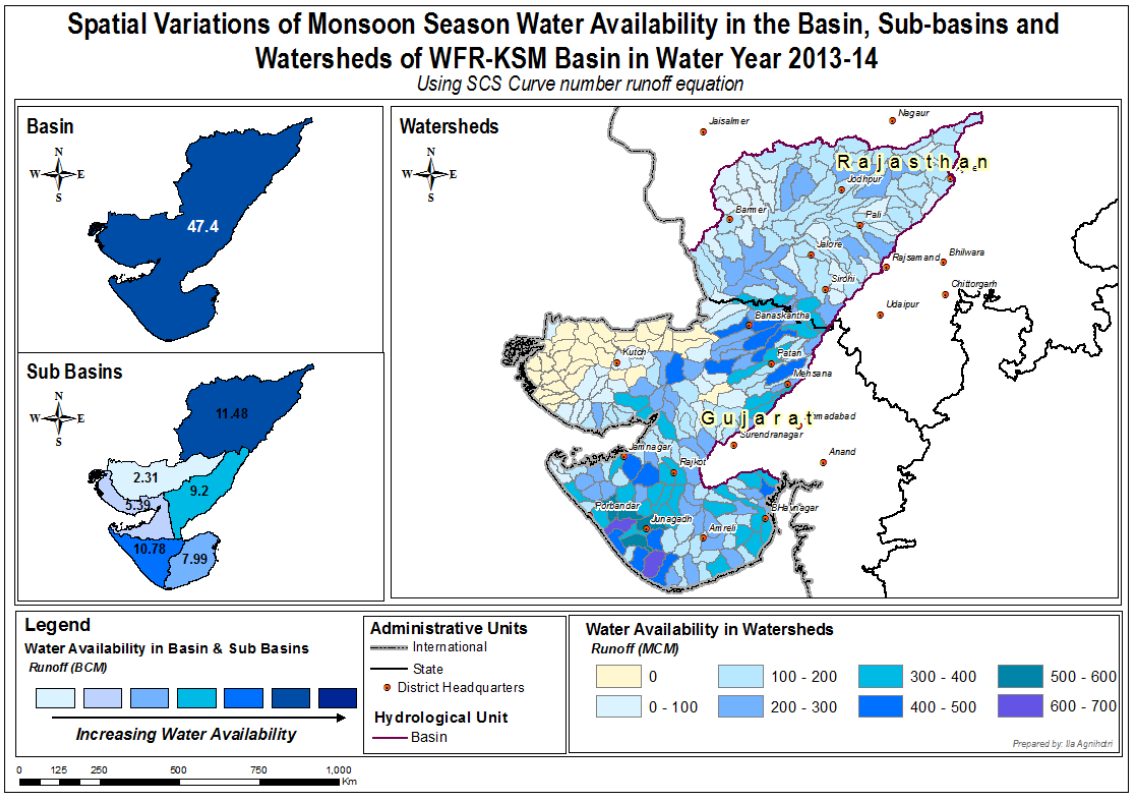
Annual and monsoon season water availability was calculated for WFR basin, its sub basins and watersheds in water year 2013-14. The water availability is represented by the surface runoff which was calculated using SCS curve number method in average antecedent runoff conditions.

The annual water availability in the basin was estimated to be 34.67 BCM. The sub-basin wise water availability ranges from 1.21 BCM in Luni lower sub basin to 9.59 BCM in Luni upper sub basin. The watershed wise average water availability ranges from 0 in the watersheds of Kutch district to 505 MCM in the southern coastal part of the basin in the border of Junagadh and Porbandar districts. The minimum value was 0 and maximum value varies from 458.57 to 545.51 MCM. The annual water availability in the watersheds of WFR-KSM basin for the water year 2013-14 is depicted in Map 1.

The monsoon season water availability in the basin was 47.4 BCM. The sub-basin wise water availability ranges from 2.31 BCM in Luni lower sub basin to 11.48 BCM in Luni upper sub basin. The watershed wise average water availability ranges from 0 in the watersheds of Kutch district to 647.23 MCM in the southern coastal part of the basin in Junagadh district. The minimum value was 0 and maximum value varies from 561.71 to 695.53 MCM. The monsoon season water availability in the watersheds of WFR-KSM basin for water year 2013-14 is depicted in Map 2.



Map 1: *Annual Water Availability in WFR-KSM Basin, its Sub-basins and Watersheds*



Map 2: *Monsoon Season Water Availability in WFR-KSM Basin, its Sub-basins and Watersheds*

The spatial variations of water availability were assessed in terms of pattern of water availability in watersheds. Water availability in the watersheds varies spatially. The watersheds in Gujarat were exhibiting more water availability as compared to those in Rajasthan (<300 MCM). More water availability was observed in monsoon season in the watersheds facilitating the differentiation in water availability disparities in the watersheds of Rajasthan and Gujarat. The watersheds with high runoff were clustered in the southern part of the basin near Junagadh district. A cluster of watersheds in Kutch district were exhibiting no water availability as most of this region is characterized by saline marsh and runoff in saline marsh does not contribute to fresh water availability.

9. Conclusion

The annual water availability in the basin was estimated to be 34.67 BCM ranging from 1.21 BCM to 9.59 BCM in sub-basins and from 0 to 505 MCM in the watersheds. The monsoon season water availability in the basin was estimated to be 47.4 BCM ranging from 2.31 BCM to 11.48 BCM in sub-basins and from 0 to 647.23 MCM in watersheds.

The spatial variations in terms of pattern of water availability in the watersheds indicated that the water availability increases from northern to southern part of the basin with more runoff clustering in southern watersheds lying in Gujarat and a cluster of watersheds with no freshwater runoff in Kutch district. More water availability was observed in monsoon season in the watersheds facilitating the differentiation in water availability disparities in the watersheds of Rajasthan and Gujarat.

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