# GIS based Assessment of Water Resources and Climate Change Impacts across Bundelkhand Region of India

**Gurusamy, B. T[1*], Vasudeo, A. D[2]. and Godbole S. P.[3]**
[1]*Department of Civil Engineering VNIT, Nagpur, India*
[2] *Department of Civil Engineering VNIT, Nagpur, India*
[3]*Dr. Ambedkar Institute of Management Studies and Research, Nagpur*
*Corresponding author email: [*1]guru19april2009@gmail.com*

**Abstract:** This paper focuses on the Water Resources Assessment (WRA) and Impact of Climate Change on water resources across Bundelkhand Region of India. Various GIS based Methodologies for WRA have been used and the results were compared with those adopted by WMO and CWC of India. The distributions of Runoff and that of Water Retention Capacity of land across the Bundelkhand region have been presented. The impacts of various climate change scenarios on the distribution of Rainfall and Potential Evapotranspiration across the region have been analyzed.

**Keywords:** Water Resources Assessment; Impact of Climate Change on Water; Bundelkhand Region of India; GIS based Methodologies; Climate Change Scenarios

## 1. Introduction

In order to standardize a Procedure for Water Resource Assessment (WRA) across a selected Geographical Region, World Meteorological Organization (WMO) had developed a manual for WRA. (WMO, 2012). Accordingly to Assess Water Resources for a selected Geographical Region during the Evaluation period, various influencing factors such as Long-term simulation of catchment behavior, sustainable and exploitable water, Climate Change Scenarios, Development scenarios/Land use change need to be taken into account. Hence analysis about Climate Change Scenarios and its impact during the Evaluation periods becomes the Sub set of WRA. In the year 1993, the natural flow calculated from the observed flow at the terminal site of a basin had been used to determine the natural flow of the basin which had been considered as the available water across the basin in the WRA carried out by CWC (1993). The development of GIS based WRA models was not enough during those periods. The catchment behavior had been assumed to be embedded in the runoff pattern observed at the terminal site of the watershed/basin. In the 2017 Reassessment of Water Availability in India, WRA models included the criteria specified by the WMO and thereby various parameters such as land use, land cover, climate and other catchment characterizing variables were included with the help of GIS based methodologies for the WRA report published by CWC in the basin wise scale (CWC, 2017). It has been reported by NWDA that Bundelkhand region of India is one of the water deficit area across India and has been given first priority position for providing water resources through Ken-Betwa link component of NRLP of India (NWDA, 2017). The sustained drought occurring over this Region had also been reported by National Institute for Disaster Management (Gupta, 2014). According to the report of NIH, the ground water in Bundelkhand is limited to only Weathered rock mantle and hence the region is suffering for drinking water during Summer months. NIH is also carrying out sustained research to increase the Ground Water Recharge Potential through proper location and design of Artificial Recharge Structures across the region with the help of GIS based methodologies and implementation of IWRM criteria (NIH, 2018). Many Research Publication including Thomas (2016) were discussing about the drought vulnerability across Bundelkhand region using the parameter standardized precipitation index (SPI). Hence, the focus is directed or diverted towards this Bundelkhand Region of India for the assessment of water resources and that of climate change impact on water.

## 2. Materials and Methods

Even though the Chitrakoot District of UP and Datia district of MP are not included in the Bundelkhand Region as per the Wikipedia based sources, the publication of NIDM about the boundary of Bundelkhand Region as shown in Fig.1 has been considered in this review paper.

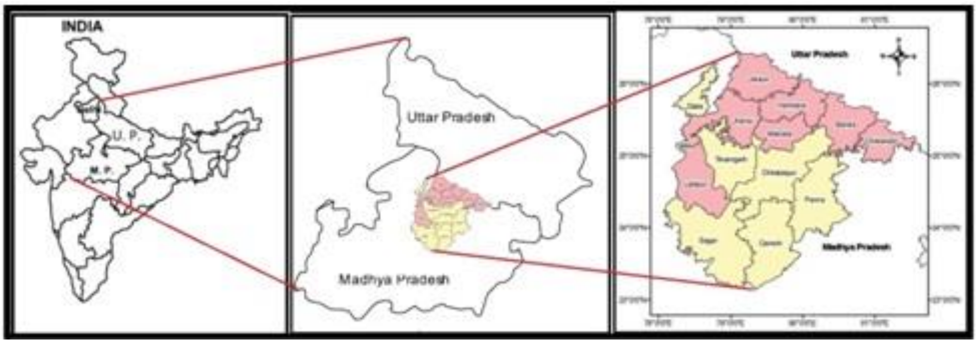



**Fig. 1** Location of Bundelkhand Region across MP and UP States of India (Gupta, 2014)

As per the Ganga Basin Report (CWC, 2014) about 3.77% of Sagar district and 5.91% of Damoh district is lying in the Narmada Basin and those area covering about 790 sq.km is not included in the analysis. Even though the district area published by National Informatics Centre (NIC, 2019) of Government of UP an MP are different with respect to that published by CWC (2014), the district area data provided by CWC has been used to find the weighted average rainfall across Bundelkhand region using the District wise monthly rainfall data series published by India Meteorological Department(IMD) and India Water Portal (IWP).

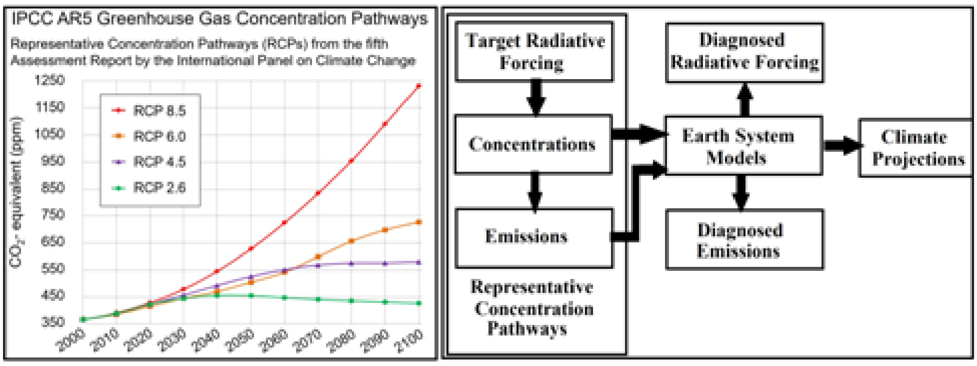


**Fig.2** RCP Scenarios defined by IPCC as a forcing Function applied to Earth System Model to get Climate Projection (Collins, 2013)

Climate Change Scenarios defined by Intergovernmental Panel on Climate Change (IPCC) (Collins, 2013) as shown in Fig.2 in the form Representative Concentration Pathways (RCPs) acting as a forcing function to excite the Earth System Models (ESM) in order to get climate projection for the future, have been used for the analysis of the Climate Change Impact on the Temperature and Precipitation across the Bundelkhand Region of India. Even though there are four such Scenarios had been defined as in Fig.2, the impact of RCP 4.5 alone has been discussed in this Review Paper. The emissions of all green house gases has been converted into equivalent $CO_2$ emission. As a review paper no primary data have been presented except for the organization, interpretation and logical reasoning of the results published by various literatures based on the hydrological analysis carried out using various GIS based Methodologies including SWAT based hydrological Modelling.

## 3. Results and Discussion

The annual average seasonal Monsoon Rainfall as well as Non-Monsoon Rainfall series across Bundelkhand region has been graphically presented as in Fig.3 and Fig.4 respectively.

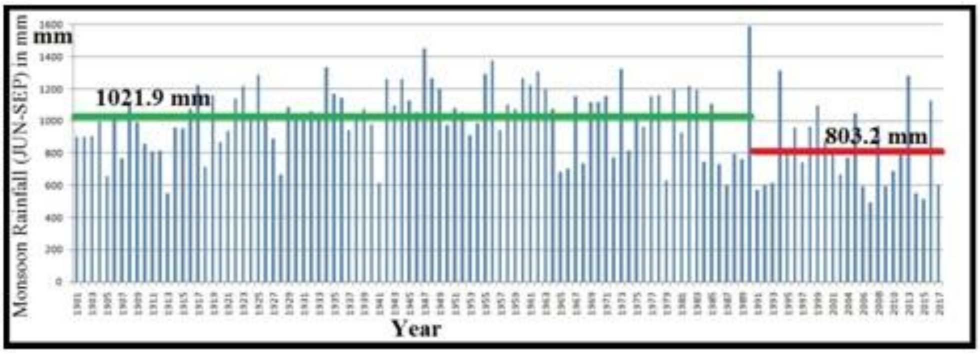



**Fig.3** Decreasing Pattern of Monsoon Rainfall across Bundelkhand Region of India (IMD)

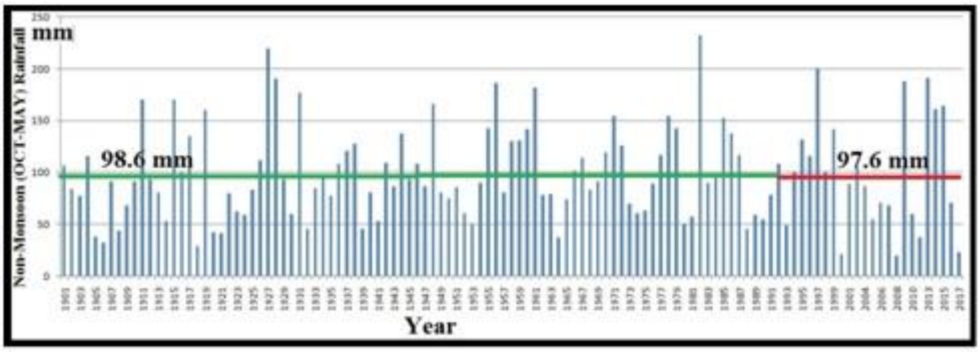



**Fig.4** Pattern of Non-Monsoon Rainfall across Bundelkhand Region of India (IMD)

The average Monsoon Rainfall after 1990 is observed to be decreased by more than 20 % of the long term average of monsoon rainfall estimated using 90 years of data from 1901 to 1990. No such decrease has been observed in Non-Monsoon Rainfall pattern.

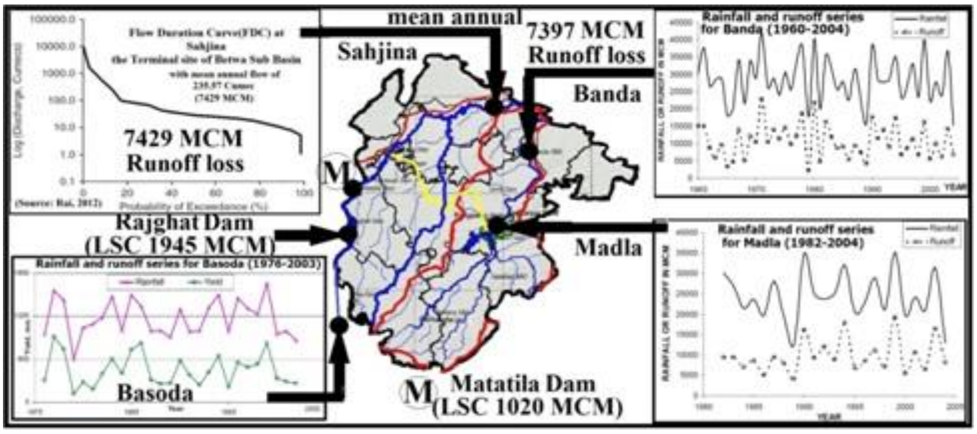
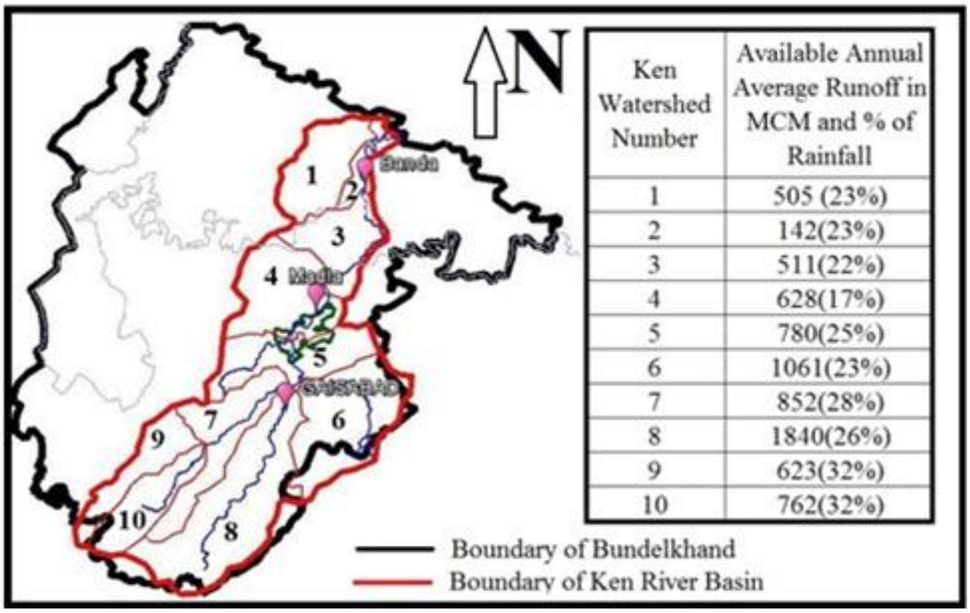



**Fig. 5** Available Annual average Surface Runoff and Surface Storage at selected locations across Bundelkhand (NWDA, 2014)

Available average annual Surface Runoff volume observed at different locations of Bundelkhand region has been graphically presented in the Fig.5. The Live Storage Capacities of two major Reservoirs located in the Betwa portion are also presented. Each of the Betwa & Ken basin has reported to have more than 7000 MCM annual runoff loss to Yamuna River.




| Ken Watershed Number | Available Annual Average Runoff in MCM and % of Rainfall |
|---|---|
| 1 | 505 (23%) |
| 2 | 142(23%) |
| 3 | 511(22%) |
| 4 | 628(17%) |
| 5 | 780(25%) |
| 6 | 1061(23%) |
| 7 | 852(28%) |
| 8 | 1840(26%) |
| 9 | 623(32%) |
| 10 | 762(32%) |

**Fig.6** Available Annual Average Surface Runoff across Ken Portion of Bundelkhand (Himanshu, 2016)

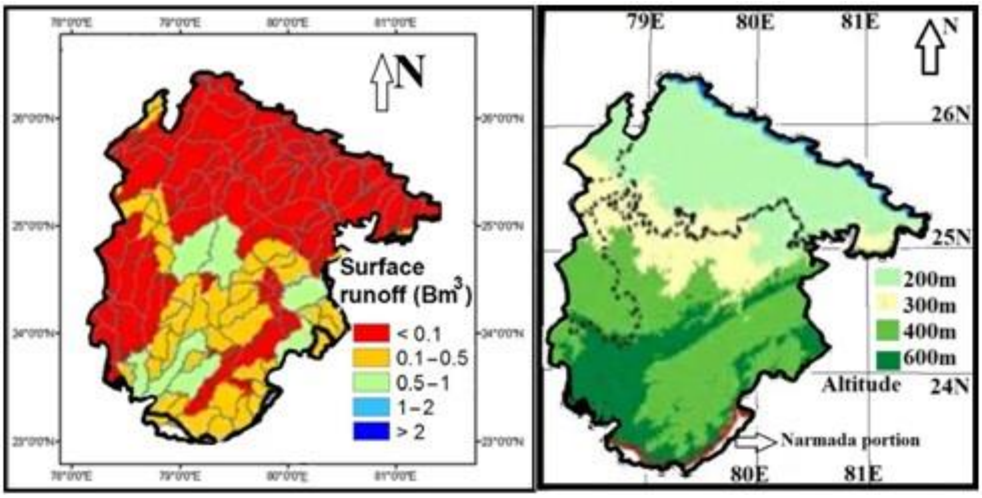



**Fig.7** Distribution of Annual Average Runoff Producing Capacity of Watersheds (Muthuwatta, 2017) and that of altitudes across Bundelkhand (Nandargi, 2018)

Based on the water balance analysis of Himanshu (2016) over Ken River Basin using Soil and Water Assessment Tool (SWAT), the estimated runoff distribution pattern across Ken portion of the Bundelkhand Region have been presented in Fig.6. More than 25% of rainfall has been converted in to runoff in the south end high altitude Vindhyan range region of Ken Basin. About 45 % of rainfall has been reported as Evapotranspiration across the Ken basin. Similar attempt had been made by Muthuwatta (2017) to determine the Runoff distribution pattern across Ganga River Basin (GRB) using SWAT based hydrologic analysis. The Distribution of annual average Runoff producing capacities of watersheds lying inside the Bundelkhand region of Ganga Basin alone presented in the Fig.7 and is compared with corresponding altitude using the terrain topography presented by Nandargi (2018). The historical attempt to utilize the runoff loss in the form of development of Live Storage Capacities across the Ken and Betwa basins has been presented in the Fig.8. Because the Bundelkhand region is located in the downstream side of the Betwa and Ken Basins, the entire LSC of both basins can be made useable to the Region.

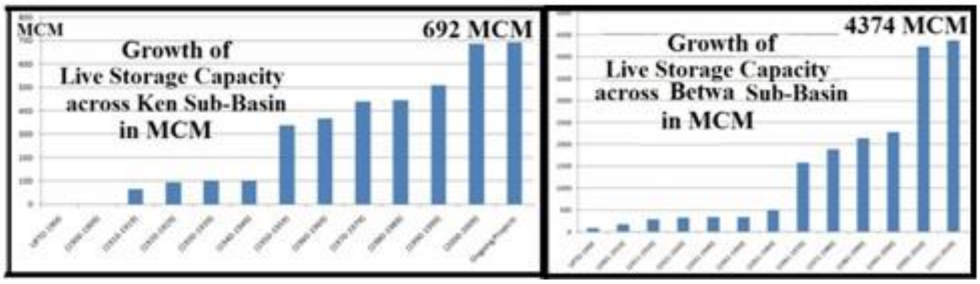



**Fig.8** Live Storage Capacities developed across Ken and Betwa sub-basins and available for Bundelkhand (DSO, 2009 and Rai, 2012)

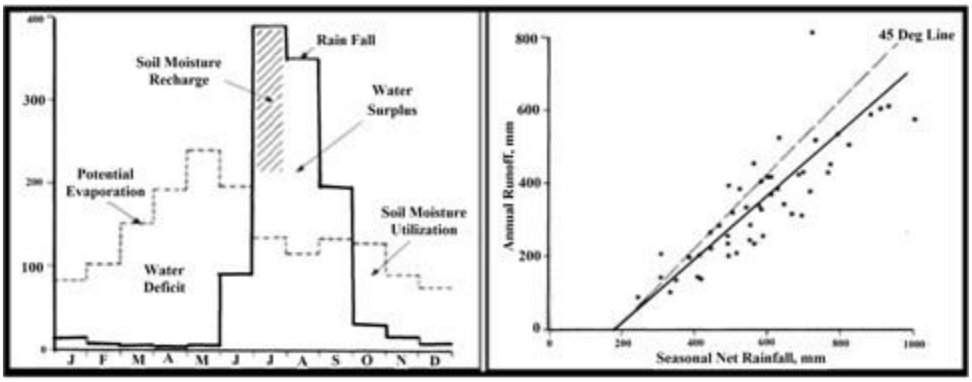



**Fig.9** Monthly Soil Water Balance and Potential Evapotranspiration and Annual average Runoff across Betwa portion of Bundelkhand (Sutcliffe, 1981)

Sutcliffe (1981) had presented the monthly variation of Soil Water Balance , Potential Evapotranspiration (PET) and Runoff across Betwa portion of Bundelkhand as shown in Fig.9. Highly seasonal characteristics of Rainfall, relatively high runoff coefficient and high value of PET had caused for severe soil moisture deficit in the summer months to bring down the dry season as drought prone. A typical Assessment of Water Resources and water demand across Ken, Betwa and Sind River basins reported by Rai (2012) is shown in Table.1.

**Table.1** Typical Assessment of Water Resources and Water Demand across Sub basins Occupying Bundelkhand Region of India (Rai, 2012)

| Basins | DWR | CWR | IWR | GWR | SMS | NGW | SWR | TWR | S/D |
|---|---|---|---|---|---|---|---|---|---|
| Sind | 167 | 13786 | 33 | 13986 | 4890 | 3442 | 1888 | 10220 | −3766 |
| Betwa | 288 | 26456 | 58 | 26801 | 7671 | 5701 | 11803 | 25175 | −1626 |
| Ken | 137 | 12808 | 27 | 12973 | 5041 | 3113 | 8089 | 16244 | +3271 |

DWR Domestic Water Requirement, IWR Industrial Water Requirement, CWR Crop Water Requirement, GWR Gross Water Requirement, SMS Soil Moisture Storage, NGW Net groundwater availability, SWR Surface Water Resources, TWR Total Water Resources, and S/D Surplus/deficit (All Units in MCM)

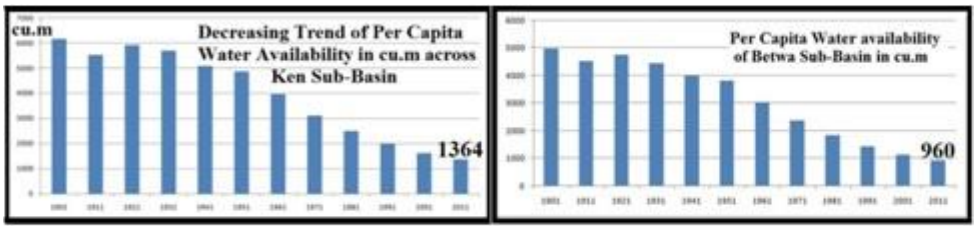



**Fig.10** Per Capita Water Availability across Ken and Betwa portion of Bundelkhand (CWC)

Using the available Surface Water Resources estimates across Betwa and Ken River Basin provided by (Rai, 2012), the decreasing trend of Per Capita Water availability across Betwa and Ken Basin were calculated and presented in the Fig.10.

**Table.2** Dynamic Annual GW Resources of Bundelkhand Region of India (CGWB, 2017)

| State | District | Total Annual GW Recharge (MCM) | Total Natural Discharges (MCM) | Annual Extractable GW Resources | Current GW Extraction (MCM) | | | Stage GW Extraction (%) | GW Exploitation Categorization |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Irrigation | Industrial & Domestic | Total | | |
| MP | Chhatarpur | 1035 | 50 | 985 | 576 | 32 | 608 | 62 | Safe |
| MP | Damoh | 409 | 26 | 383 | 196 | 27 | 223 | 58 | Safe |
| MP | Datia | 366 | 18 | 347 | 126 | 14 | 140 | 40 | Safe |
| MP | Panna | 476 | 27 | 450 | 143 | 22 | 164 | 37 | Safe |
| MP | Sagar | 1094 | 59 | 1034 | 570 | 34 | 603 | 58 | Safe |
| MP | Tikamgarh | 540 | 27 | 513 | 338 | 36 | 374 | 73 | Semi-Critical |
| UP | Banda | 633 | 37 | 596 | 361 | 40 | 402 | 67 | Safe |
| UP | Chitrakoot | 391 | 25 | 367 | 275 | 25 | 300 | 82 | Semi-Critical |
| UP | Hamirpur | 452 | 23 | 429 | 284 | 26 | 309 | 72 | Semi-Critical |
| UP | Jalaun | 1131 | 70 | 1061 | 483 | 40 | 523 | 49 | Safe |
| UP | Jhansi | 894 | 45 | 849 | 392 | 29 | 422 | 50 | Safe |
| UP | Lalitpur | 421 | 21 | 400 | 287 | 26 | 313 | 78 | Semi-Critical |
| UP | Mahoba | 229 | 11 | 218 | 177 | 14 | 191 | 88 | Semi-Critical |
| | Total | 8071 | 439 | **7632** | 4208 | 365 | **4573** | 60 | Safe |

**Table.3** Ground Water Level Scenario across Bundelkhand (CGWB, 2013)

| State | District (2011) | District Area in sq.km (CWC) | District area in sq.km (NIC, 2019) | 2012 Pre-Monsoon GW Level (mbgl) | 2012 Post-Monsoon GW Level (mbgl) | 2012 Monsoon season GW level rise (m) |
|---|---|---|---|---|---|---|
| MP | Chhatarpur | 8342.32 | 8687 | 5.49-14.88 | 2.26-9.24 | 3.23-5.64 |
| MP | Datia | 2587.42 | 2691 | 4.50-27.30 | 1.90-27.00 | 0.3-2.6 |
| MP | Panna | 6825.17 | 7135 | 1.90–20.80 | 0.70–17.65 | 1.2-3.15 |
| MP | Sagar | 9858.18 | 10252 | 2.63-36.50 | 1.20-20.21 | 1.43-16.38 |
| MP | Tikamgarh | 4873.1 | 5048 | 3.34-14.52 | 2.01-11.31 | 1.33-3.21 |
| MP | Damoh | 7068.37 | 7306 | 2.62-25.00 | 0.20-8.55 | 2.42-16.45 |
| UP | Chitrakoot | 2964.5 | 3216 | 8.60-22.90 | 2.92-15.43 | 5.68-7.47 |
| UP | Hamirpur | 4101.03 | 4121.9 | 4.08-29.32 | 2.22-28.82 | 0.5-1.86 |
| UP | Jalaun | 4401.29 | 4565 | 1.48-31.20 | 0.56-29.65 | 0.92-1.55 |
| UP | Jhansi | 4874.66 | 5024 | 2.95-15.12 | 2.47-15.07 | 0.05-0.48 |
| UP | Mahoba | 2762.6 | 2884 | 3.58-12.26 | 2.90-12.02 | 0.24-0.68 |
| UP | Banda | 4359.05 | 4413 | 2.75-26.95 | 1.40-22.50 | 1.34-4.45 |
| UP | Lalitpur | 4854.02 | 5039 | 3.59-10.58 | 1.87–5.59 | 1.72-4.99 |
| | Total | 67871.71 | 70381.9 | 1.48-36.50 | 0.56-27.00 | 0.05-16.45 |

Based on the Ground Water Estimation Methodology given in GEC (1997), the district wise estimated dynamic Ground Water Resources across Bundelkhand is shown in Table.2. The values of district wise percentage Stage Ground Water Extraction as defined, monitored and published by CGWB (2019) are also shown in the Table.2. The sensitivity of Ground water level for the Monsoon season is presented in the Table.4 using the Pre-Monsoon and Post-Monsoon level of Ground Water Table.

**Table.4** Comparison of Water Availability and Water Balance Parameters of Ken and Betwa with that of Ganga, Godavari and all India Basins (CWC, 2017) & (Rai, 2012)

| Name of the Basin | Rain Fall (BCM) | Surface Water Availability (BCM) Natural Runoff | Replenishable Ground Water Potential (BCM) | Evapotranspiration (BCM) | 2011 population Per Capita Surface Water availability (cu.m) | 2011 Population Density per sq.km | LSC in BCM & % of Rain | Per Capita Surface Water LSC in cu.m | Density of Surface Water Availability (MCM per sq.km) |
|---|---|---|---|---|---|---|---|---|---|
| All India | 3880 (100%) | 1914 (49.3%) | 452 (11.7%) | 1514 (39%) | 1580 | 374 | 304 (7.8%) | 252 | 0.59 |
| Ganga (India) | 914 (100%) | 525 (57.4%) | 172 (18.8%) | 217 (23.8%) | 1595 | 382 | 56 (6.1%) | 171 | 0.61 |
| Betwa basin | 47.2 (100%) | 11.8 (25%) | 5.7 (12.1%) | 29.7 (62.9%) | 960 | 282 | 4.4 (9.3%) | 350 | 0.27 |
| Godavari Basin | 365 (100%) | 117 (32 %) | 47 (12.9%) | 201 (55.1%) | 1604 | 234 | 44 (12%) | 603 | 0.37 |
| Ken basin | 32.6 (100%) | 8.1 (24.8%) | 3.1 (9.5%) | 21.4 (65.7%) | 1364 | 214 | 0.7 (2.1%) | 115 | 0.29 |

Relative magnitude of Water Balance Parameters and Water Resources availability of Ken and Betwa basin are compared with that Ganga, Godavari and all India Basins as in Table.4. (Total Rainfall Inflow = Surface Runoff outflow + GW Recharge + Evapotranspiration) is the equation based on simple Water Balance Model has been used to find actual Evapotranspiration. The major issue observed from the Table.4 is the relatively high Evapotranspiration(ET) of Ken and Betwa basin having more than 60% rainfall while that of Ganga Basin and Godavari basin average ET is respectively about 24% and 55%. Anyhow based on the Water Balance Analysis across KRB, carried out by Murty (2014) using 25 years data (1985-2009) it has been reported that out of the annual average rainfall of 1132 mm, 23% has been observed as runoff loss and 4% for Ground Water replenishment and the remaining 73% has been accounted as Evapotranspiration. SWAT based Hydrologic Modelling had been done by Shakti (2017) to estimate various water balance parameters across Betwa sub-basin. The model was validated using 28 years from 1976-2003 water balance data observed by IMD across various meteorological stations located across Betwa sub basin. The seasonal variation of estimated water balance parameters are shown in Fig.11.

Maps of (DEC-FEB) temperature and (April-Sep) Precipitation changes in 2016–2035, 2046–2065 and 2081–2100 with respect to 1986–2005 in the RCP4.5 scenario for 75th percentiles of the distribution of the CMIP5 ensemble are shown in Fig.12 and Fig.13 respectively. This includes both natural variability and inter-model spread. The RCP 4.5 Model based Climate projection predicts a temperature rise of about 0.5 deg per every 10 years as in Fig.12. This may cause for corresponding increase in Potential Evapotranspiration

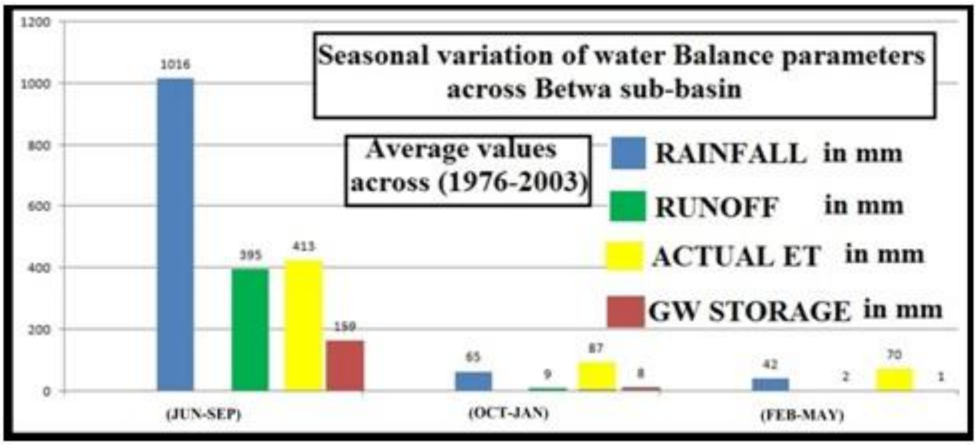



**Fig.11** Seasonal variation of Water Balance Parameters across Betwa Basin (Shakti, 2017)

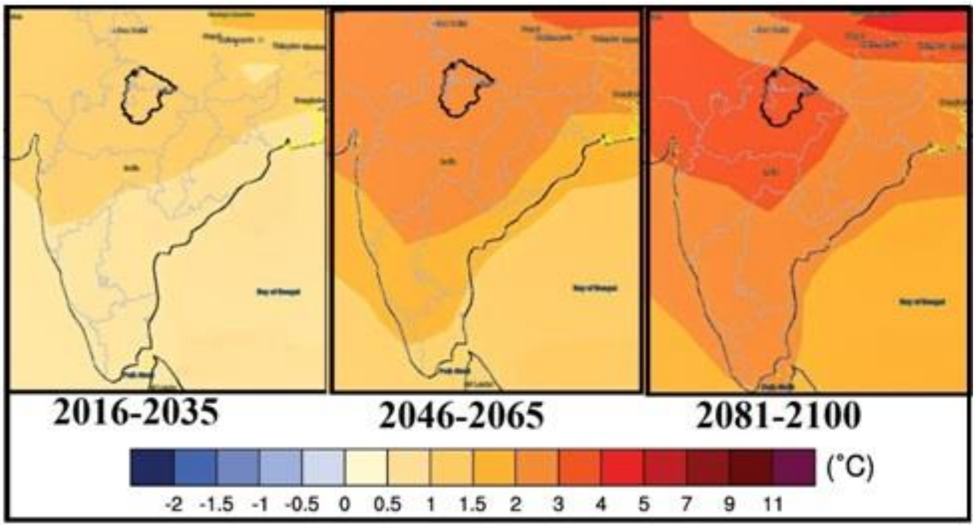



**Fig.12** DEC-FEB Temperature Change across Bundelkhand based on RCP 4.5 (IPCC, 2013)

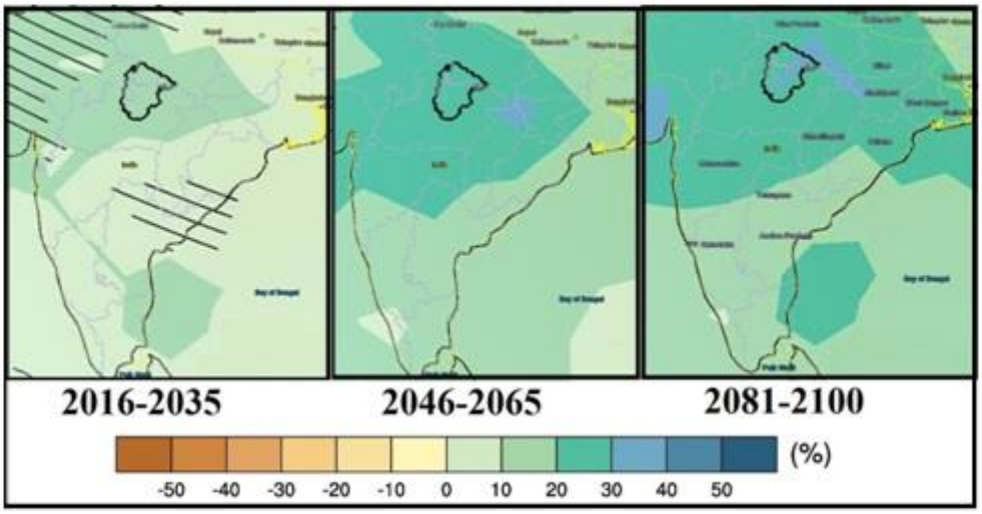



**Fig.13** APR-SEP Precipitation Change across Bundelkhand based on RCP 4.5 (IPCC, 2013)

Even though the impact of Climate Change Scenario based on RCP4.5 over precipitation across Bundelkhand is expected to increase as shown in Fig.13, the actual observed Monsoon Rainfall in the recent years is in deceasing trend.

## 5. Conclusions and Recommendations

To bring down the impact of Flood and Drought produced by highly seasonal pattern of both Rainfall and Runoff across Ken and Betwa Basin, Ken-Betwa Link Project with a live storage capacity more than 2500MCM, at Daudhan dam site has been proposed by NWDA as shown in Fig.14. As given in Table.4 the LSC as a % of Rainfall in Ken Basins is relatively low, and to increase the Water Retention Capacity of the Basin, this Project will be highly useful. The 75% dependable yield at the proposed Daudhan dam site having catchment area 19633 sq.km is estimated to be 6590 MCM. The maximum observed flood in the Ken was 20150 Cumecs in the year 2005. Muthuwatta (2017) have reported that more than 30% of flood discharge at Bihar is from Ghaghara and Yamuna Lower Sub-Basin which includes Ken and Betwa river basins. By proper design of Reservoir Routing using Daudhan Reservoir and Channel Routing using the Link canal of Length more than 218 km the impact of Flood can be reduced. Increased water storage capacity across the Bundelkhand can reduce the impact of Summer drought and also can increase dry season crop productivity. Out of the total Cultivable Command area of 515210 ha, the enroute Command area is about 60294 ha which covers the Chhatarpur and Tikamgarh districts of MP and Mahoba and Jhansi districts of UP. Hence this Project is Recommended for consideration towards successful implementation to reduce water scarce scenario of Bundelkhand Region.

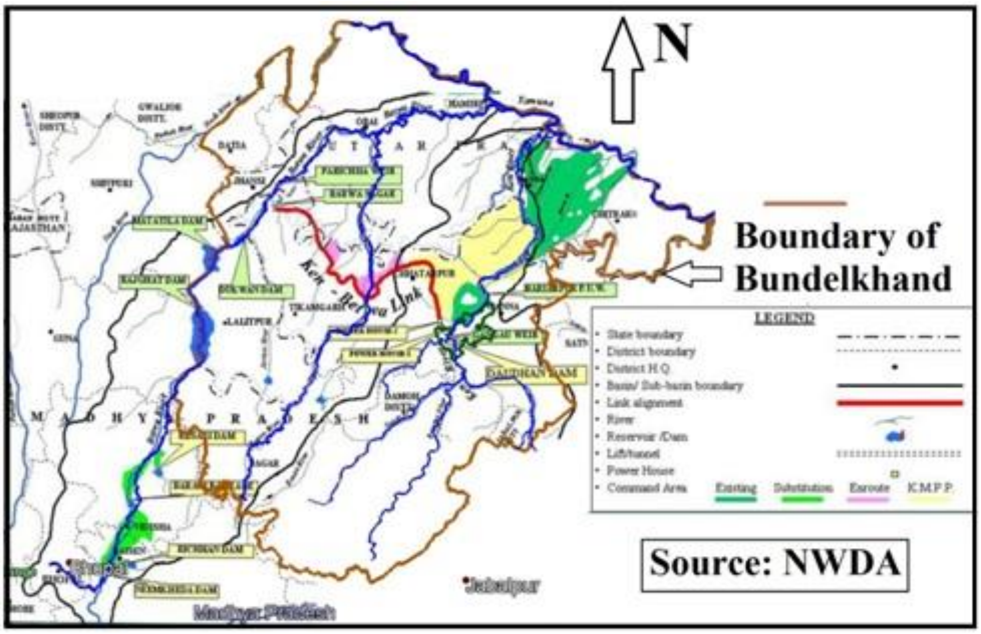



**Fig.14** Proposed Ken-Betwa Link Project to bring down the drought and to increase dry season irrigation across Bundelkhand (NWDA, 2010)

USACE (2015), had reported that large volume of water can be stored and recovered beneath a relatively small surface footprint using properly designed Artificial Recharge Structure located preferably adjacent to large and flowing water bodies to enhance the capacity of the system similar to rechargeable battery. This Concept had been named as Aquifer Storage & Recovery (ASR) Technology. CGWB (2007) had developed a Manual for Artificial Recharge as a standard for the Efficient Implementation and Operation of ASR System to enhance the performance of increased Recharge in order to bring down the impact of Flood and Drought. Owusu, (2017), has reported about the successful adaptation of various ASR system to bring down the Flood level for the flood-prone areas of northern Ghana in west Africa and to achieve dry-season irrigation. Hence to enhance the Ground Water Replenishment Potential and thereby to increase water retention capacity across Bundelkhand, efficient location, design, implementation, maintenance and management of ASR structures is also recommended for Consideration. Revelle (1975) had reported a Concept called as Ganges Water Machine (GWM) to reduce the impact of Flood and Drought produced by highly seasonal Characteristics of rainfall and Runoff. Accordingly intensified pumped Ground Water Use before monsoon can increase Sub Surface Storage (SSS) potential of the basin. Proper design of Recharge Structure will restore SSS water availability. Such Pump-Recharge-Pump strategy is having similar behavior of Reciprocating Machine and hence called as Ganges Water Machine. Amarasinghe (2016) has reported that the suitability of the Ganga basin for the successful implementation GWM concept which depends on the distribution of Ground Water Consumptive Water Use (CWU) as a percentage of Recharge. The distribution of Ground Water CWU and the Potential for the application GWM concept across the Ganga basin including Bundelkhand Region is shown in Fig.15. From this result it is interpreted that there is reasonable potential for the implementation of GWM across Yamuna Lower Sub-Basin including Bundelkhand Region. Based on the Report of Khan et al. (2014), proper ground water Management through conjunctive water use strategy in the form of distributed pumping and recharge across Ganga River basin (GRB) with the implementation of GWM can bring down sizable flood volume in UP below Allahabad. Hence it is recommended for consideration to implement the GWM concept across Bundelkhand Region by proper location and design of Artificial Recharge Structure and ensure the efficient application of Conjunctive Water use Management Strategy in order enhance GW replenishment potential across the region and to reduce the impact of Flood.

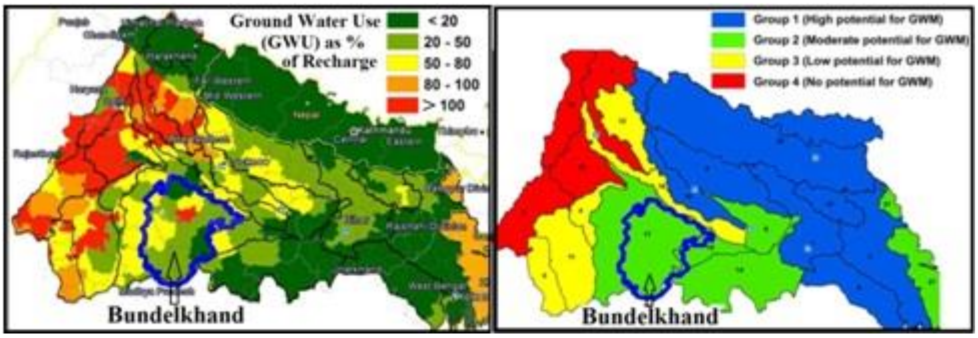



**Fig.15** Applicability of GWM Practices as a function of % GW extraction to increase Water Retention Capacity across Bundelkhand (Amarasinghe, 2016)

**Acknowledgements**

The research facilities that have been provided by the administration of VNIT, Nagpur, the water resources data that have been published by Government of India through its Sub-ordinate organizations such as CWC, CGWB, NWDA, IMD, NRSC and WRIS and Various Services such as Web, Google Earth, Wikipedia & Search Engines available through internet communications are acknowledged.

**References**

Amarasinghe U. A, et al.(2016),"Reviving the Ganges water machine: potential and challenges to meet increasing water demand in the Ganges River Basin. Colombo, Sri Lanka: International Water Management Institute (IWMI). 42p. (IWMI Research Report 167). doi: 10.5337/2016.212

CGWB, 2007, "Manual on Artificial Recharge of Ground Water" Central Ground Water Board, Ministry of Water Resources, Government of India.

CGWB, 2013, "District wise Ground Water Information Booklet", Central Ground Water Board, Ministry of Water Resources, Government of India.

CGWB, (2019) "National Compilation on Dynamic Ground Water Resources of India, 2017", Department of Water Resources, RD & GR, Government of India.

Collins M R et al. 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on

Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1029–1136, doi:10.1017/CBO9781107415324.024.
CWC 1993, “Reassessment of water resources of India” Central Water Commission Ministry of Water Resources, Government of India.
CWC, (2017), "Reassessment Of Water Availability In India Using Space Inputs". Ministry of Water Resources, Government of India.
CWC and NRSC 2014. Ganga Basin Report Version 2.0. Central Water Commission and National Remote Sensing Centre, CWC Publications, Ministry of Water Resources, Government of India.
DSO, 2009, Dam Safety Organization of Central Water Commission CWC, 2009 “National Register of Large Dams”, CWC Publications, India.
GEC (1997) Ground Water Estimation Methodology, Report of the Groundwater Resources Estimation Committee, Ministry of Water Resources, Government of India
Gupta, A. K., Nair, S.S., Ghosh, O., Singh, A. and Dey, S. (2014). Bundelkhand Drought: Retrospective Analysis and Way Ahead. National Institute of Disaster Management (NIDM), New Delhi, Page 148.
Himanshu S K, Pandey A and Shrestha P, "Application of SWAT in an Indian river basin for modeling runoff, sediment and water balance", Environmental Earth Science (2017) 76:3 DOI 10.1007/s12665-016-6316-8
IPCC, 2013: Annex I: Atlas of Global and Regional Climate Projections [van Oldenburg, G.J., M. Collins, J. Arblaster, J.H. Christensen, J. Marotzke, S.B. Power, M. Rummukainen and T. Zhou (eds.)]. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1311–1394, doi:10.1017/CBO9781107415324.029.
Khan M R, et al (2014), Water resources management in the Ganges basin: A comparison of three strategies for conjunctive use of groundwater and surface water", Water Resources Management 28(5): 1235-1250.
Murty P, et al. (2014). Application of Semi distributed hydrological model for basin level water balance of the Ken basin of Central India. Hydrological Processes. 28. 4119–4129. 10.1002/hyp.9950.
Muthuwatta L, et al. "Reviving the “Ganges Water Machine”: where and how much?" Hydrol. Earth Syst. Sci., 21, 2545–2557, www.hydrol-earth-syst-sci.net/21/2545/2017/ doi:10.5194/hess-21-2545-2017
Nandargi S and Shelar A, "Rainfall and Flood Studies of the Ganga River Basin in India", Annals of Geographical Studies Volume 1, Issue 1, 2018, PP 34-50
NIC, (2019), National Informatics centre, Government of Utter Pradesh and Government of Madhya Pradesh, India http://www.mp.nic.in/district.asp and http://up.nic.in/districts.htm
NIH, (2018) "A Glimpse of Research and Development at National Institute of Hydrology", NIH Roorkee Publication.
NWDA, “Detailed Project Report (DPR) of Ken Betwa Link Project Phase I and II” 2010 and 2014 respectively Ministry of Water Resources, Government of India, New Delhi

NWDA, Annual Report 2017, Ministry of Water Resources, Government of India, New Delhi

Owusu S, et al, 2017. Adapting aquifer storage and recovery technology to the flood-prone areas of northern Ghana for dry-season irrigation. SriLanka. International Water Management Institute Working Paper 176. 35p.

Rai R.K. et al., (2012), The Yamuna River Basin, Water Science and Technology Library 66, 13 Springer Science and Business Media B.V. DOI 10.1007/978-94-007-2001-5_2, C

Revelle R, Lakshminarayana V (1975) Ganges water machine. Science 188(4188): 611-616.

Shakti S, Ashish P & Umesh C C (2017) Hydrological simulation of the Betwa River basin (India) using the SWAT model, Hydrological Sciences Journal, 62:6, 960-978, DOI: 10.1080/02626667.2016.1271420

Sutcliffe, J. V., Agrawal, R. P. and Tucker, J. M., 1981. The water balance of the Betwa basin, India. Hydrol. Sci. Bull., 26 (2), 149–158.

Thomas, et al. (2016), "Drought indicators-based integrated assessment of drought vulnerability: A case study of Bundelkhand droughts in India" Natural Hazards DOI 10.1007/s11069-016-2149-8

USACE, 2015, "Aquifer Storage & Recovery (ASR) | Regional Study", http://www.saj.usace.army.mil/Portals/44/docs/FactSheets/ASR_FS_June2015_web.pdf United States Army Corps of Engineers

WMO, (2012), "Technical Material for Water Resources Assessment", World Meteorological Organization, Chair, Publications Board ISBN 978-92-63-11095-4