**A review of Chhattisgarh’s forested watersheds: Research gaps and recommendations**

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**Abstract**

Forests play a crucial role in meeting agricultural, domestic and industrial needs. In addition, it also serves as the basis for providing numerous ecosystem services to society. The central Indian state of Chhattisgarh and third in terms of geographical area covered by forests with an area of 55,7171 km2. These forests attract rain and are the main source of water for the watersheds.

This paper provides a detailed overview of the state’s watersheds. The Mahanadi River Basin (MRB) is the most important and dominant river basin, covering 56.2% of the land area, followed by Godavari RB (28.6%), Ganga RB (13.6%), Bramahani RB (1.0%) and Narmada RB (0.6%). More than 100 research papers from renowned specialist journals were subjected to a detailed and in-depth review. Various aspects of forested watersheds include land use and land cover studies, biodiversity along the watershed catchment area, soil erosion and sedimentation status of dams and reservoirs, various aspects of watershed management, morphometric analysis, stream flow estimation, watershed modelling, and impacts of climate change. Due to steady population growth, industrialization and increasing demand for irrigation and industrial water, watersheds face moderate to severe water stress. River water quality has also deteriorated in various locations due to the discharge of industrial effluents, overuse of agrochemicals and domestic sewage.

The current work also examined the different watersheds of the state of Chhattisgarh and their effective protection measures. The research also aims to examine the importance of forested watersheds in terms of climate change adaptation and the achievement of sustainable development goals. This review may further contribute to the efficient management of the state’s forested watersheds.

**Keywords: River Basin (RB), catchment area, management, forested watershed**

**Introduction**

Chhattisgarh has vast forest resources and accounts for 44% of the state’s total geographic area. These forests are the main reason for the great biodiversity, mineral resources, tribal population, crop diversity and much more. These forests attract rain and give rise to numerous stream/nalas that are converted into rivers. Forests help stabilize soils and filter pollutants (Krieger, 2001).

The watersheds are reservoirs with rich natural resources. The watershed profile divides the terrain into unequal segments with different terrain characterstics based on the natural environmental conditions such as flooding, drought, soil erosion, water-logging, soil erosion and riparian erosion etc. The Catchment area of the river basin are complex and interconnected, interacting with socio-ecological systems (Hand et. al., 2018, Dunham et. al., 2018). Healthy rivers meet all the basic needs of human survival and development (MEA, 2005).

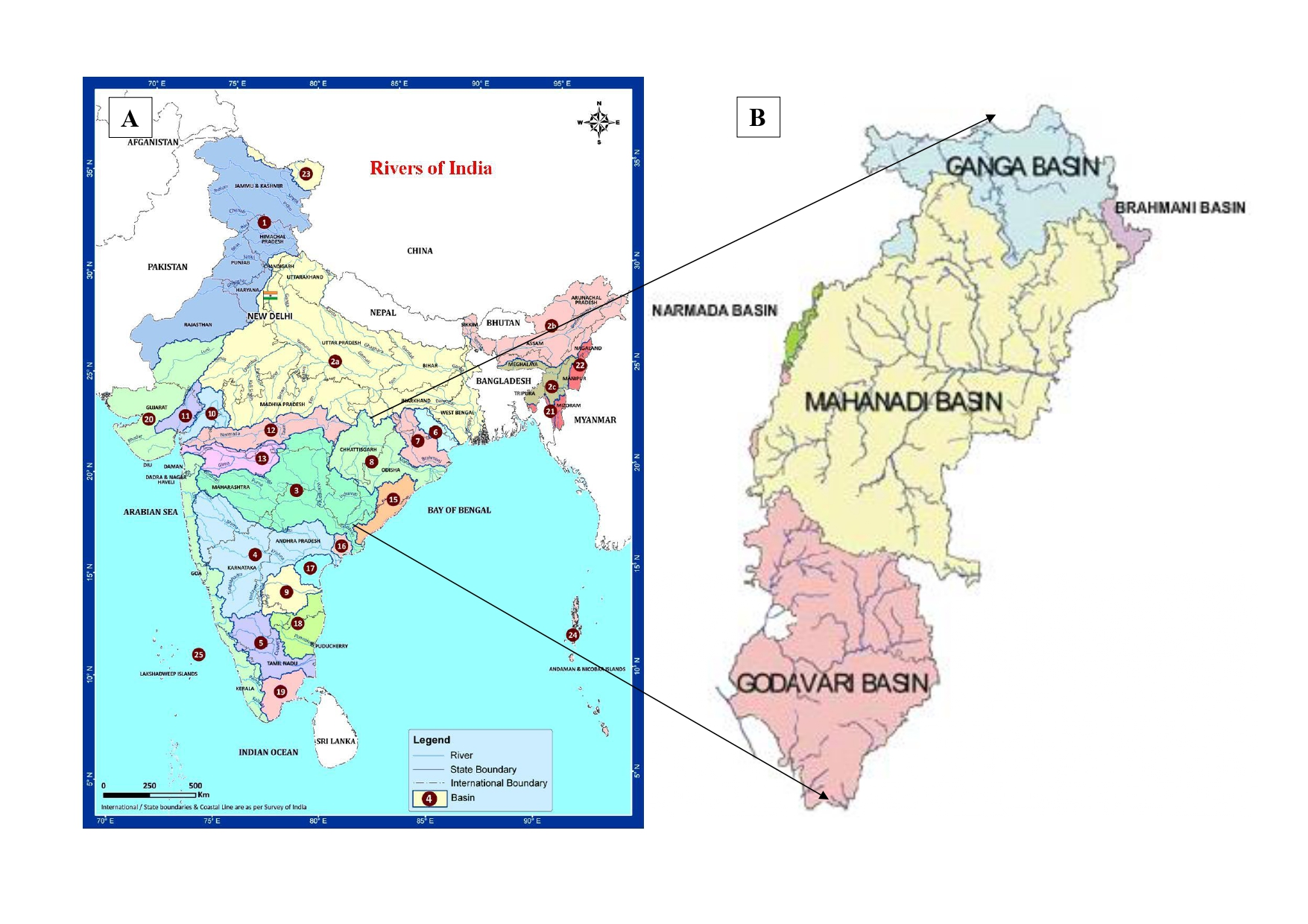
The United Nations Sustainable Development Goals to achieve water quantity and quality are mentioned directly in SDG6 (Clean water and sanitation) and secondly in SDG3 (Health and well-being) and SDG11 (Sustainable cities and communities) as well as SDG12 (Responsible Consumption and Production) and SDG14 (Life Below Water) (UNDP, 2015). The state of Chhattisgarh has a geographical area of 1,35,100 km2 and is divided into five river basins: Mahanadi Basin, Godavari Basin, Ganga Basin, Brahmani Basin and Narmada Basin. The Mahanadi Basin covers the maximum geographic area of 75,858.11 km2 (56.15 %) in the state, followed by the Godavari Basin at 38,694.36 km2 (28.64 %), the Ganga Basin at 18,406.65 km2 (13.62 %), the Brahmani Basin with 1,394.45 km2 (1.03 %) and the Narmada Basin with 743.66 km2 (0.55 %). The major watersheds of the state are the Hasdeo, Sheonath, Arpa, Maand, Tandula and Kharung watershed.

Forested watersheds have a dynamic landscape that enriches the rivers. They play a very important role in meeting agricultural, domestic and industrial needs. Forested watersheds also provide diverse ecosystem services of immense value. These help capture and store water, allowing for seasonal water flow and thus contributing to the quantity and quality of water available. The amount and quality of water flowing from forested watersheds is important for agriculture, power generation, municipal water supply, recreation, habitat for aquatic fauna such as fish and wildlife species (Krieger, 2001) etc.

Sal is the predominant tree species found in most of the region’s forested watershed. The other forest tree species found are Teak (*Tectona grandis*), Bija (*Pterocarpus marsupium*), Saja (*Terminalia tomentosa*), Mahua (*Madhuca indica*), Dhaora (*Anogeisus latifolia*), Arjuna (*Terminalia arjuna*), Tendu (*Diospyros melanoxylon*), Tinsa *(Ougeinia dalbergioides),* Neem *(Azadirachta indica),* Salai *(Boswellia serrate),* Kasai *(Bridelia retusa),* Harra (*Terminalia chebula*), Khair (*Acacia catechu*), Imli (*Tamarindus indica*), Amla *(Embilica officinalis*), [*Amaltas*](http://en.wikipedia.org/wiki/Amaltas) *(*[*Cassia fistula*](http://en.wikipedia.org/wiki/Cassia_fistula)*)*, Khamhar (*[Gmelina arborea](http://en.wikipedia.org/wiki/Gmelina_arborea))*, Babool (*Acacia nilotica*), Shisham (*Dalbergia letifolia),* Palash (*Beutea monosperma),* Gular *(Ficus glomerata),* Bhirra *(Chloroxylon swietenia),* Ber (*Ziziphus mauritiyana*), Haldu(*Adina cordifolia*), Karra (*Cleistanthus collinus*), Baheda (*Terminalia belerica*), Bamboo (*Dentrocalamus strictus*), Semal *(Bombax ceiba),*  Bel *(Aegel marmelos),* Mango (*Mangifera indica L*.) etc. Wild fauna is rich in the forested watershed i.e. Tiger, Panther, Barking Deer, Langoor, Wild dog, Striped [hyenas](http://www.britannica.com/EBchecked/topic/279204/hyena), [Blackbucks](http://www.britannica.com/EBchecked/topic/68470/blackbuck), Spotted Deer, [Gaur](http://www.britannica.com/EBchecked/topic/227183/gaur) , [Sambar](http://www.britannica.com/EBchecked/topic/520407/sambar),  [Sloth bear](http://www.britannica.com/EBchecked/topic/548961/sloth-bear), [Wild boar](http://www.britannica.com/EBchecked/topic/1843748/wild-boar) and Four-horned [antelope](http://www.britannica.com/EBchecked/topic/27166/antelope) etc.

Forested watersheds generally provide high quality for the integrated land management system. This paper provides an overview of the research being conducted in the state watersheds. Potential research gaps are identified and few recommendations for the proper and sustainable use of watersheds are mentioned.

**Study area-**The state of Chhattisgarh was seperated from Madhya Pradesh on November 1, 2000. The geographic extent of the state is between 17o46’ and 24o5’ N latitude and 80o15’ to 84o20’ E longitude (Jhariya et. al., 2015). The state has five major river basin i.e Mahanadi, Godavari, Ganga, Brahmani and Narmada. Most of the major rivers originates in the forested region in the form of small streams and later, after meeting their tributaries, turn into large rivers. The state’s average annual rainfall is over 1200 mm. This state has distinct summer, monsoon and winter seasons.



**Fig 1. A) Map of India showing major river basin B) Major river basins of Chhattisgarh state**

**Materials and Methods**

This article examines the watersheds of the state of Chhattisgarh using different approaches. It includes reviews and data collection. Literature searches on forested watersheds, watersheds, Chhattisgarh river basins, morphometric analysis, state dams and reservoirs etc. were conducted in online databases, published by researchers (from Science Direct, Web of Science, SpringerLink, Wiley, Taylor and Francis, MDPI etc). Secondary data was collected from the reports and data published by the central and state governments. From the publications between 2001 and 2023, reviews, theoretical and empirical works on the relevant topics were selected. The reviews focused on assessing of the Chhattisgarh state’s watersheds, river basins, dams and reservoirs , forests types, watershed management practices, biodiversity and many more.

**Results and discussion**

Numerous researchers studied the water bodies, river basins and watersheds of the state of Chhattisgarh (Table 1) divided into different approaches such as impacts of dams/reservoir construction, land use land cover change analysis, geomorphological/ morphometric survey, water quality analysis, modelling, climate change and river meandering.

**Table 1: Approach for studying the watersheds of Chhattisgarh**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No.** | **Approach** | **Watershed studied** | **Brief discussion** | **References** |
| 1 | Construction of dams/ reservoirs | Arpa River | Impact of the Arpa River Check Dams on the Bilaspur district microenvironment | Bhat and Geelani, 2013 |
| Kelo River | Development, displacement and rehabilitation of tribal communities, Raigarh | Kujur and Kumar, 2019 |
| Seismic hazard estimation | Major dams of C.G, Sindum dam | Tripathi et. al., 2009, Parashar et. al., 2015 |
| Sedimentation and soil erosion | Sedimentation of Ravi Shankar Sagar reservoir, Kodar reservoir, Kulhan watershed, Pairi watershed and other Chhattisgarh reservoirs | Jaiswal et. al., 2019, Dadoria et. al., 2017, Bikram and Tiwari, 2022, Ahmad and Verma, 2013, Devatha et. al., 2015, Kumar et. al., 2020 |
| 2 | Land Use Land Cover analysis | Maniyari River, Gej sub watershed, Bamni sub watershed, Tangarbahri Milli watershed, Tesua sub watershed, Khudia dam | LULC change analysis and change detection of the watersheds catchment area. | Bej and Baghmar, 2022, Singh et al., 2019, Singh et. al., 2011, Bhagat et. al., 2019, Singh, A.K. 2017, Mahato, 2022 |
| 3 | Geomorphological/  morphometric study/ estimation of stream flow/  Water balance modelling | Arang watershed, Arpa river basin, Mand river  Piperiya watershed, Seonath river, Tandula reservoir | Geomorphological parameters of Arang watershed, Quantitative analysis of Arpa river Basin morphometric properties, Rainfall Analysis, Watershed Sustainability Index (WSI), statistical analysis of rainfall, Variation of water flow using SWAT Model | Kumari and Kumari, 2014, Koshale and Mahato, 2022, Baghel et. al., 2021, Chandniha and Kansal, 2017, Chandniha et. al. 2014, Swain et. al., 2018, Verma et. al., 2016, Jaiswal et. al., 2019, Soni et. al., 2022, Jaiswal et. al., 2009 |
| 4 | Water quality | Kharun river | Assessment of water quality of the Kharun River. | Mise and Mujawar, 2017 |
| Hasdeo river | Organic and inorganic pollutants on the Hasdeo river water quality | Bhaskar et. al., 2020 |
| Rajim river | Pollution due to rice mill | Shrivastava and Sharma, 2020 |
| Tandula watershed | Nitrate pollution on ground water | Jhariya et. al., 2019 |
| Tandula Dam | Hydrobiological status | Meshram, 2013 |
| Somni watershed | Ground water pollution due to disposal of hazardous waste | Shrivastava, 2015 |
| Mahanadi river | Fish Fauna diversity of Mahanadi River in Raigarh district | Patel et. al., 2016 |
| 5 | Biodiversity | Kelo and Maand river | Cat fish diversity of River Kelo and Mand | Tamboli and Jha, 2012 |
| Dhudwa dam | Study of Fungal diversity | Sharma and Praveen, 2011 |
| Balamdi watershed | Forest diversity | Bijalwan, 2010, Bijalwan et. al. 2009 |
| 6 | Climate change, Management and significance | Mahandi river | Management of water resources for climate resilent | State Center for Climate Change, 2019 |
| Arpa river | Cultural, Economic and Environmental Significance of Arpa River | Chandrakar and Dhuria, 2020 |
| Dhangaon microwatershed | Micro level planning for Dhangaon microwatershed | Patel and Khalkho, 2019 |
| Andhiyarkore watershed | Site selection for water storage | Vinze and Ahmad, 2022 |
| Samoda watershed | Delineation of ground water potential sites | Indulekha and Jhariya, 2020 |
| Arpa | Origin and Contribution of Important Tributaries to Arpa River | Bhat et. al., 2012 |
| Upper Kharun catchment | Climate change impact on water resources | Kumar et. al., 2017 |
| 8 | River Meandering | Maniyari river | Meandering of Maniyari river | Mahato, 2023 |

Soil erosion is a common and serious problem of watersheds as reported by various researchers (Devatha et. al., 2015). The main reason for this are a shifting cultivation, over-expoitation of land, non-compliance with soil protection measures and exposure of the top layer of soil in hilly areas. Excessive erosion removes nutrient-rich soil and increases sedimentation of reservoirs, reducing their storage capacity.

Water quality is an important issue of global reflection and action (Al-abadi et. al., 2014, Jin and Ray, 2014). Jhariya (2019) assessed the nitrate pollution of the Tandula watershed using the GIS-based DRASTIC model. The study reported pollution of ground-water resources from over-use of nitrogenous fertilizers in agricultural fields. Kumar et al. (2020) studied different models to access soil erosion and sediment yield in the Pairi watershed using the USLE and MUSLE equations. Martin et. al. (2020) studied model performance in hydrological processes under climate, land scenario and forest management in small forested watersheds. Soni et. al. (2022) reported that the water demand of the capital Raipur is projected to increase by 52.38% by 2038 compared to 2016, but the river flow is likely to decrease by 35% due to climate change and land use changes.

The hydrological investigation and behavior of watersheds depend on geomorphological features. The morphometric study of watersheds of different river basins has been studied and analyzed by many researchers (Mandal et. al., 2022, Khoshale and Mahato, 2022, Baghel et. al., 2021, Kumari and Kumari, 2021). The result shows that most of Chhattisgarh’s river basins are natural.

Fig 2. Approaches for studying watersheds of Chhattisgarh

Patel and Khalkho (2019) studied and evaluated microlevel planning of Dhangaon microwatershed in Bemetara district of Chhattisgarh. Their study described in detail about the site selection for establishment of water harvesting structures, thus enabling water conservation at local level.

Bijalwan (2010) studied the diversity of woody vegetation in the dry tropical forest of Chhattisgarh. This study found the highest IVI values for Diospyros melanoxylon, Boswellia serrate, Madhuca indica and Cleistanthus collinus in the understory of degraded forests in different directions. The study shows the poor regeneration pattern in the degraded forest. The effects of forest cover on water yield have been studied by numerous researchers (Li et. al., 2017). The delineation of ground-water potential zones of the Samoda watershed was studied by Indulekha and Jhariya (2020).

The Piperiya Watershed Sustainability Index (WSI) was compiled by Chandniha et. al. (2016). Their study found that this watershed flows in the hilly areas, that are mostly inhibited by tribal peoples and coal mines and coal washing plants are numerous, polluting both the surface and ground-water of the region.

Sharannya et. al. (2018) reported that pressures on water resources are likely to increase in the coming years due to increasing water demand, and drier and warmer climates. Much research (Mahato et. al., 2022, Lee et. al. 2018, De Girolamo et. al., 2017) has focused on the sustainable management of small forested watersheds. Giri and Mohanty (2022) focused on increasing land productivity through the use of agri-photovoltaic systems, which alongside energy production, may represents a better option for maximizing productivity and income generation for farmers.

Koshale and Mahato (2020) monitored the LULC of Ratanpur, which is well known for its water conservation structures especially ponds. The study found that the region’s water area decreased from 3.76% to 2.06% between 1989 and 2015. Thus, over a certain period of time, there has been a continuous decline in the water surface. Therefore, great attention should be paid to rivers and watersheds.

The biggest environmental crisis facing the world today is climate change, ground-water loss and biodiversity loss. The recently developed climate change scenario predicts an increase in air temperature of up to 5oC and changes in precipitation patterns by the year 2100 (IPCC, 2014). Climate change is likely to affect water distribution, runoff, quality, rate of erosion and sedimentation pattern, rate of evaporation, and many other aspects. These changes affect human well-being by altering water availability, land use management and food production (Cai et. al., 2016, Reed et. al., 2013). A changing climate is likely to affect surface and ground water resources due to expected changes in received precipitation. Evapotranspiration (Garner et. al., 2017, Kirby et. al., 2016) and changes in precipitation frequency and intensity are likely to increase surface runoff, leading to flood risk and reduced ground water recharge (Trenberth, 2011). A rise in temperature is likely to increase evaporation rates in both lotic and lentic waters. This increases the need for irrigation, which is the largest water consumption (Wang et. al., 2012). Khanday and Javed (2008) studied the impact of climate change on the LULC of the Chopan watershed, M.P. The study concluded that bodies of water and wetlands have the property of retaining heat, thereby lowering the day-time air temperature of the surrounding areas. The result also showed that micro-scale climatic changes in terms of precipitation and temperature variations are related to albedo changes, which in turn could be LULC modifications.

Kumar et. al. (2017) studied the effects of climate change on the water resources of the Upper Kharun catchment area. Numerous studies on the impacts of climate change on watersheds and river basins have been conducted worldwide. Only the Kharun River in the state of Chhattisgarh has been studied (Soni et. al., 2022) from a climate change perspective. Many rivers and water bodies are likely to dry in the near future (Uddin and Jeong, 2021, Sponseller et. al., 2013, Vorosmarty et. al., 2010, Tockner & Stanford, 2002), which would put a strain on existing water resources. Ground water consumption for many activities is likely to increase stress, which is likely to widen the gap between demand and supply. Therefore, fresh-water resources must be protected and effective water conservation and harvesting structures must be created at various locations. There should be a proper plan for surface water development sites, rain water harvesting sites, infiltration tanks, check dams, anicuts etc. They should be constructed in appropriate locations for in-situ water conservation as well as for replenishment of ground water resources.

**Key research gaps**

Research has evidently shown that forested watersheds plays a unique and critcal role in meeting society’s water needs. It also provides protection for biodiversity. Unresolved issues include the occurrence of exotic aquatic flora and fauna in rivers and streams, declining water quantity and quality water demand and supply gap studies, ecosystem services provided by watersheds, conservation efforts, and water protection and biodiversity the region. Emphasis should also be placed on studies of riparian buffer zones, and the impact of mining and agriculture on water resources.

Only 3% of Chhattisgarh’s water resource studies include potential future scenarios. Thus, there are immense opportunities for further research in river and watershed management.

**Conclusion**

This paper provides an summary of the current status of studies on watersheds in the state of Chhattisgarh state. The paper also identifies research issues that need to be addressed for the idea of conservation issues. The present paper will be helpful for the judicious and effective utilization of the water resources, as well as for the preparation of plan for an effective use and a water resource management plan. More broadly, there is a requirement for a improved understanding of the biodiversity of forested watersheds and their interplays with each other.

We hope that this work will provide policy makers, academicians and researchers with key information on how to maximize forested watershed conservation efforts, more regulated sand mining and the promotion of ground water recharge.

**Recommendation**

* Water loss through reservoir seepage/leakage and evaporative loss should be studied in detail to minimize water loss.
* Assess the diverse ecosystem services provided by the state’s forested watersheds.
* Monetary valuation can help compare ecosystem services provided by forested watersheds. This will contribute to more effective use and conservation of natural resources. The lack of water resources can cause severe stress in the region. Thus, the assessment can also contribute to the restoration of damaged ecosystems.
* It involves the involvement of local and relevant authorities/communities/stakeholders in watershed conservation.

**Declaration of interest**

None

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