Seasonal Variation of Use of Irrigation Water and Its Management: Case study in West Bengal

Synopsis Submitted by

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Irrigation water management means to manage the irrigation water as crop requirements. The process of storing and supplying irrigation water is considered as irrigation water management. Globally, dams and reservoirs are used to manage the seasonal use of irrigation water. According to World Commission on Dams report (2000), half of the world's large dams were constructed completely for irrigation and about 30–40% of the 271 million hectares of irrigated lands depend on dams globally. Dams are approximated to supply around 12–16% of world food production. About 1 billion people rely on food produced by reservoir associated irrigation. Maximum dam projects not just have the purpose of economic benefits, but also deal with the entire socio-economic growth of the people in the region. The major irrigation projects, which are dependent on dam construction, also prevent the migration of rural people to the cities, giving them a higher standard of living in their native areas. Without irrigation projects, it is impossible to produce any kind of crop on most of the land in the world.

Previous studies related to the impact of reservoirs on LULC revealed that the maximum study on reservoirs focused on reservoir sedimentation, impact of reservoirs on climate changes, soil erosion, ecosystem, and livelihood of the local people. Very few articles have been found on the impact of reservoirs on LULC change. Especially for West Bengal, India, very few articles were found on the impact of reservoirs in LULC change. Moreover, almost no research so far has been done about the seasonal variation of irrigation water of the Shali reservoir in Bankura, West Bengal and its impact on agricultural production. Therefore, in the present research, an attempt has been made to explore the seasonal variation of irrigation water of the Shali reservoir giving special emphasis on water management in the Rabi (winter) period.

Shali reservoir also known as Gangdua dam is a medium irrigation project run by the Irrigation & Waterways Department (I&W Dept.) under the Government of West Bengal. The reservoir is situated at the origin of river Shali near Bhairabpur village of Gangajalghati block in the Bankura district. Shali reservoir stores the rainfall and coveys through the river Shali in the Shali river basin (SRB) area. Three types of irrigation are provided by this reservoir: a) irrigation through the Shali river system, b) lift irrigation from the reservoir and c) river lift scheme. The SRB is situated in the north-eastern part of the Bankura district in West Bengal, India. Shali is a right-bank stream of the river Damadar which flows the northern portion of the Bankura district and it is positioned between 23°07′N to 23°26′N latitude and 87°3′E to 87°38′E longitude. The entire area of the basin is around 727.23 km2. Shali basin comprises the portion of Gangajalghati, Barjora, Sonamukhi and Patrasayer blocks and 339 villages. The major branches of the Shali river are the Subhankari Kanjar River (Nodi), Seengai Nodi, Jungne Nodi, Setaljar Nodi, and Badai Nodi

Objectives

The present study examines seasonal irrigation water management through the Shali reservoir irrigation project and its impact on agricultural development. Thus, the key objectives of the present study are as below.

- To study the geographical and socio-economical properties of the Shali river basin
- To examine the seasonal water-level trend of the Shali reservoir.

- To identify suitable irrigation lands of the Shali river basin.
- To analyse the impact of the Shali reservoir scheme on LULC and predict future LULC maps.
- To assess the impact of irrigation through the Shali reservoir on seasonal crop production.
- To examine the impact of Shali reservoir irrigation on irrigation intensity, cropping intensity and agricultural labour intensity.
- To analyse the distribution of irrigated areas under the command area of the Shali river and reservoir
- To summarise the conclusions, recommendations and discussions about the future research scopes.

Methods

Several geospatial and statistical methods are incorporated to justify the objectives of the study as discussed below.

- Mann Kendall trend analysis has been applied to identify the seasonal water level trend of the Shali reservoir and seasonal crop production.
- Linear regression (LR) method has been used to determine the correlation between the Shali reservoir and the river water level. Besides, the correlation between irrigation and cropping intensity.
- Revised universal soil loss equation (RUSLE) and Satellite remote sensing (SRS) to estimate the sedimentation level of the Shali reservoir.
- SWOT (strength, weakness, opportunities, and threat) analysis has been applied to identify the strength, opportunities, weaknesses and threats of the Shali reservoir.
- Analytical Hierarchy Process (AHP) and weighted overlay analysis have been applied to discover suitable irrigation lands in the Shali basin area.
- Random Forest (RF) classifier has been applied in LULC classification to identify the LULC classes precisely.
- The Cellular Automata method has been applied to predict future LULC pattern
- A confusion matrix has been generated to justify the LULC classification results.
- The Z-Score method has been implemented to identify the village-wise distribution of irrigated areas.
- ARIMA (Autoregressive Integrated Moving Average) method has been adopted to identify future trends in the crop production area
- Rice mapping has been done using Sentinel 1 SAR datasets
- Irrigation, cropping and agricultural labour intensity analysis has been performed to recognise the influence of the Shali reservoir irrigation project on agricultural advancement.
- Multiple Linear Regression (MLR) has been applied to identify the correlation between Irrigation, cropping and agricultural labour intensity.

Organisation of the thesis

Chapter 1

This chapter comprises the development of irrigation in India with special emphasis giving on West Bengal. It also discusses traditional and modern irrigation water management processes. Several irrigation sources and irrigation methods have been discussed. Besides, major irrigation projects in India have been discussed. A comparative analysis between different types of irrigation water sources and irrigation intensity of districts of West Bengal was also performed. Brief literature reviews have been done on the reservoir and its impact on agricultural development. Lastly, the research gap has been identified, discussed the choice of the study area, methods, and objectives.

Chapter 2

In this chapter, the geographical and socio economical properties of the Shali basin have been examined. In the geographical category, geology, geomorphology, relative relief, river network, forest cover, soil, rainfall and temperature have been considered. Whereas, the socio economical category is comprised of population density, literacy rate, industry, agriculture, road network and amenities, etc.

Chapter 3

This chapter comprises three segments. In the first segment, the main reasons behind the erection of the Shali reservoir have been discussed. In the second segment, the Shali reservoir's annual and seasonal water level fluctuations have been analysed. Prior to water level fluctuation analysis, sediment level estimation of the Shali reservoir has been performed. In the third segment, a SWOT analysis of the Shali reservoir has been done.

Chapter 4

The entire study has been divided into five segments. In the first segment, LULC classifications are performed using supervised classification with Random Forest (RF) method for the period from 1986 to 2021. In the second segment, change detection has been performed for the periods from 1986 to 2006 and from 2006 to 2021. LULC change matrices are also developed. In the third segment, block-wise temporal LULC change and block-wise comparison of agricultural lands have been analysed. In the fourth segment, village-wise temporal changes in agricultural lands are illustrated. Lastly, in the fifth segment, the future land use pattern is projected by applying the cellular automata (CA) approach. Here, MOLUSCE (Modules for Land Use Change Evaluation) a QGIS plugin, has been applied to simulate the future LULC scenario of 2031. This plugin requires some specific input data sets such as LULC classified maps of 2006 and 2021, DEM and transportation networks of the study area.

Chapter 5

This chapter has two segments. In the first segment weights of 12 parameters such as elevation, slope, rainfall, LULC, soil group, distance to the river, clay, sandy, silt, nitrogen, pH and organic carbon have been generated through the AHP and weighted overlay analysis has been applied to generate irrigation suitability map. Block-wise and village-wise suitability comparisons are also performed.

Chapter 6

This chapter comprises two segments. In the first segment, block-wise irrigated mean and standard deviations have been analysed for 1991, 2001, and 2011. While in the second segment, the village-wise distribution of irrigated areas was analysed using the Z-score method for 1991, 2001, and 2011.

Chapter 7

This chapter is also categorised into two segments. In the first segment, the major produced crops: rice/ paddy, potato, wheat, and mustard of the Shali basin have been discussed. Meanwhile, in the second segment seasonal crop mapping has been done by applying remote sensing techniques. Rice is the main crop of this region, therefore rice mapping has been done to produce a clear view of the rice production area.

Chapter 8

This chapter has been classified into three segments. In the first segment, a block-wise comparison of irrigation, cropping and agricultural labour intensity has been done. In the second segment, village-wise comparisons of irrigation, cropping and agricultural labour intensity have been discovered. In the third segment correlation analysis has been performed. The linear regression analysis has been done between irrigation and cropping intensities. Multiple linear regression has been performed between irrigation, cropping and agricultural labour intensities.

Chapter 9

This chapter delineates the conclusion, limitations, and future research scopes.

Major findings

a) Shali reservoir is a medium irrigation project governed by the Irrigation and Waterways Department, Government of West Bengal, situated in Gangajalghati Block, Bankura district of West Bengal. This man-made reservoir was formed at the origin of the Shali River. Shali reservoir stores rainfall and provides irrigational water through the Shali River using the river lift irrigation technique in the Shali River basin area. The Shali River basin comprises part of four blocks i.e., Gangajalghati, Barjora, Sonamukhi and Patrasayer. The Shali River basin area gets a minimum amount of rainfall than the other parts of the Bankura district, thus Shali reservoir was made to store rainfall. Uneven topography is another important factor behind the construction of the Shali reservoir. Before the construction of the Shali reservoir due to high elevation and slope maximum amount of water flowed as surface runoff. The Shali basin area is covered with lateritic uplands which have low water holding capacity, So, reservoir construction is necessary and the groundwater level is poor in the Shali River basin than in other parts of the Bankura district. These are the main factors behind the erection of the Shali reservoir.

b) The water level of the Shali reservoir is dependent on rainfall. the water level trend from 1990 to 2021 of the Shali reservoir shows a positive trend which signifies that the water level has increased in the Shali reservoir. The Shali reservoir area gets a minimum amount of rainfall during winter and pre-monsoon seasons. So, the water level reduces this time. The average water level in the winter season is around 8.85 m. The MK trend Z value of winter water level is around 1.57 which represents a very low increasing trend. In pre-monsoon season average water level reduces to 8.81 m. During monsoon, it gets the maximum amount of rainfall. So, the water level also increases. The average water level is around 8.91 m. the MK trend z value is around 2.71 which indicates a high increasing trend from 1990 to 2021. In post-monsoon, the amount of rainfall decreases, so the water level also reduces in post-monsoon. The average water level in post-monsoon is around 8.89 m. the MK trend analysis z value is around 1.96 which determines an increasing trend. In the Shali reservoir, a high-water level trend has been observed in monsoon and post-monsoon, and a low positive trend was observed in pre-monsoon and winter. Study reveals that the Shali reservoir can provide irrigation water throughout the season.

c) Supervised classification with a random forest algorithm has been used to determine the transformation in LULC after the creation of the Shali reservoir irrigation project from 1986 to 2021. The study reveals a huge transformation in the LULC of the Shali River basin area. After the construction of the Shali reservoir around 52% growth in agricultural land has been observed from 1986 to 2021 in the Shali River basin area. between 2006 to 2021, maximum transformation in LULC has been observed. A huge number of forest areas and barren lands are transformed into agricultural land. Along with the agricultural development, built-up areas also increased. Block-wise agricultural development was also analysed. The Shali reservoir is constructed in the Gangajalghati block. In 1986, the Gangajalghati block was covered with dense forest covers and 0.23% was under agricultural land. In 2021, around 50% of the Gangajalghati block is under agricultural land. The block-wise agricultural land comparison reveals that from 1986 to 2021, around 29% of agricultural land has been increased in Gangajalghati block. In the Barjora block, only 5% of agricultural land has been increased. Whereas around 47% of agricultural land decreased in the Sonamukhi block and 8% increased in the Patrasayer block. Shali reservoir is in Gangajalghati block, so maximum agricultural development has occurred in Gangajalghati block. The predicted LULC map of 2031, also shows that the amount of agricultural land will be increased by around 57%. Thus, it has been proven that the Shali reservoir plays a vital role in agricultural development in the Shali basin area.

d) The AHP has been applied to discover suitable irrigation lands for the Shali River basin. AHP is a multi-criteria decision-making process which needs several criteria, so 12 criteria are selected: slope, relief, soil group, soil texture (clay, sand, silt), soil properties (nitrogen, pH, organic carbon), LULC, rainfall and distance from the river. A normalized pairwise matrix has been created to generate the criteria weight of each factor. The result shows that the Shali basin has around 64% irrigation-suitable land. These suitable lands are observed along the Shali River and north, north-eastern, and north-western portions because these portions are covered with fertile luvisols which are widely used for cropping and rich in nitrogen and organic carbon. Block-wise suitability analysis shows that Sonamukhi block has the maximum amount of very high irrigation suitable land but Gangajalghati and Barjora blocks have the maximum amount of high irrigation suitable land. These two blocks are situated near the reservoir (upper portion of the Shali basin); therefore, they are getting more irrigational water than the other two blocks. The village-wise irrigational suitability reveals that the villages near the river have high irrigation-suitable lands. So, it can be said that the distance to the river is playing a major role because it determines the irrigation water availability.

e) The Z score method has been applied to identify the village-wise distribution of irrigated areas. The analysis shows that the number of low-irrigated villages has been reduced from 1991 to 2011. In 1991, around 78% of villages have low irrigated areas but in 2001 it reduced to 64%. But in 2011 around 51% of villages have low irrigated areas. Thus, it can be considered that after the construction of the Shali reservoir the number of irrigated areas has increased in the Shali basin area but maximum development has been discovered near the Shali Riverside villages.

f) The major crops of the Shali basin are rice, potato, wheat, and mustard. After the creation of the Shali reservoir around 640 ha of crop production area has increased from 1995 to 2020. Rice is the dominant crop and three types of seasonal rice (Aus, Aman and Boro) have been cultivated, around 585 ha of rice production area has been increased from 1995 to 2020. The MK trend analysis of crops shows that potato has the maximum trend which means potato production area has increased more than other crops. Both kharif and rabi production areas have been increased in the Shali River basin area. Rice mapping also shows a positive change in the rice production area. It can be said that after the creation of the Shali reservoir crop production area has increased especially in the Rabi season.

g) The study reveals a positive change between irrigation, cropping and agricultural labour intensity from 1991 to 2011 in the Shali River basin area. Irrigation intensity has increased by around 19%, cropping intensity by around 32% and agricultural labour intensity by around 26%. Prior to the Shali reservoir irrigation project only kharif crops were cultivated but after the creation of the Shali reservoir irrigation project both the kharif and rabi crops are cultivating. The correlation analysis shows a positive correlation between irrigation and cropping intensity. In 2001, the correlation is 0.79 and in 2011 is 0.72 which indicates a declining correlation between irrigation and cropping intensity. It signifies that the dependency of cropping intensity on irrigation is reducing. The main reason would be the use of high-yield seeds, fertilizer and modern types of machinery which enhances the crop production area. the number of agricultural labours also increased from 1991 to 2011 and the correlation between irrigation and cropping intensity also intensified over time. The economy of the Shali basin area is rural, maximum people of the Shali basin are engaged in agricultural activities and the growth of irrigation and cropping intensity has generated huge employment which intensified the agricultural labour intensity over time. Gangajalghati and Barjora blocks are situated upper portion of the Shali basin, thus they get more irrigation water than Sonamukhi and Patrasayer blocks.

The overall study discloses that after the creation of the Shali reservoir villages of Gangajalghati and Barjora blocks are getting maximum benefit than the other two blocks.

Recommendations

It is proved that the Shali reservoir has a great impact on the Shali reservoir area. It acts like a life saviour to the people of the Shali basin area. There are some suggestions and recommendations made for prospects.

- After the creation of the Shali reservoir, irrigation intensity has been accelerated in the Shali River basin area but the villages of Gangajalghati and Barjora blocks are getting more irrigation water due to their location than the other two blocks i.e., Sonamukhi and Patrasayer. These two blocks yielded more quick flow than Gangajalghati and Barjora blocks. Therefore, it is advisable to imply rainwater collecting structures to store monsoonal rainfall that will help to increase irrigation intensity in future. The rainwater harvesting structures known as Hapa have already been implemented in the Hirbandh and Khatra blocks of the Bankura district. Hapa is a rainwater collecting arrangement which is financed by the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS).
- During the study period, it has been observed that there is a communication gap between the reservoir authority and farmers. The reservoir authority does not inform the farmers before the water is discharged from the reservoir. therefore, huge misuse of water has been observed. The Shali reservoir maintenance officials should inform the villagers before water is released from the reservoir. Social media can be a good option for this purpose.
- The reservoir authority has no idea about the amount of water that farmers are getting for irrigation. Thus, each farmer is not getting an equal amount of irrigation water. Affluent farmers have modern types of machinery, so they are collecting more irrigation water from the Shali river than poor farmers.
- The farmers do not know about crop water requirement (CWR), therefore, sometimes crops are affected due to over-irrigation. Hence, the I&W Dept. should implement awareness programs which will help farmers to learn the proper usage of irrigation water.
- Reservoir sedimentation is a big problem. It reduces the water holding capacity of the reservoir. In the case of the Shali reservoir, no sedimentation analysis has been found. The I&W Dept. should implement the desilting programme in the Shali reservoir.
- The reservoir site has no proper electric lights, so electrification of the reservoir site is compulsory. Solar lights can be a good option for this purpose.
- In the reservoir site, only one rain gauge station is available which is very old. Therefore, modern meteorological data collection systems are needed.
- The reservoir site has the potential to convert into a tourist spot. According to villagers' opinion, many seasonal birds visit here. This place is already used as a picnic spot during the winter. So, the beautification program along the reservoir site should be launched with

the help of the Irrigation and Tourism department. The irrigation and tourism department should start boating facilities in the Shali reservoir which will boost tourism.

- The Shali reservoir's water is also used for drinking purposes; therefore, water quality monitoring of reservoir water is necessary.
- The Shali reservoir can be used for pisciculture. It will enhance the economic growth of the villagers of Shali reservoir.
- The Shali reservoir is situated in a very remote place which is inaccessible to tourists. Therefore, it is advisable to provide public transport facilities for tourists.
- The Shali basin is comprised of five protected forests but vegetation cover trend analysis reveals that the amount of dense vegetation cover has decreased over time from the period 1995 to 2020. The dense vegetation covers are transformed into agricultural lands that reduce annual rainfall and increase land surface temperature and air quality. Whereas, after 2015, a slight improvement in the total area of vegetation cover has been noticed which may have been due to the yearly afforestation programme such as National Afforestation Programme (2009) by India's Govt. Lastly, it can be said that the Shali reservoir increases agricultural development. Simultaneously, it affects the environmental balance. So, it is advisable that Govt. should implement awareness schemes to balance this situation.

Limitations

The foremost limitation to conducting the study is data availability. The water level data of the reservoir is available but the water usage data is not available. There is no proper data regarding the water discharge of the reservoir and reservoir sedimentation level. Farmers also have no idea how much water they are using from irrigation. Therefore, to generate data geospatial techniques have been incorporated into this study. Due to Covid 19 pandemic, it was impossible to collect data from the farmers, thus secondary data sets were used. A guide curve is needed to be prepared to regulate the gates of the Shali dam.

Future research scopes

There are certain future research scopes on the Shali reservoir and Shali River basin which are listed below.

- A perception study of the villagers on the Shali reservoir irrigation project.
- Determining the area and volume of the Shali reservoir by comparing digital elevation models.
- Water quality analysis of Shali reservoir.
- Climate change impact on Shali reservoir performance
- Analysis of siltation in Shali reservoir and Shali river
- Life period analysis of the Shali reservoir

List of Journal Publications

1. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (2022). Estimation of seasonal water yield using InVEST model: a case study from West Bengal, India. *Arabian Journal of Geosciences*. 15, 1293. https://doi.org/10.1007/s12517-022-10551-2 (SCI and Scopus indexed).

2. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (2022). Extreme rainfall pattern analysis for drought prone Shali reservoir area in West Bengal of India. *Mausam*. 73(4), 843–858. https://doi.org/10.54302/mausam.v73i4.1481 (SCI and Scopus indexed).

3. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (2023). Use of support vector machine and cellular automata methods to evaluate impact of irrigation project on LULC. *Environmental Monitoring Assessment*. 195, 3. https://doi.org/10.1007/s10661-022-10588-6 (SCI and Scopus indexed).

4. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (June 2022). Irrigation land suitability analysis using AHP and GIS for medium irrigation scheme in West Bengal, India. Irrigation and Drainage, Wiley, *under major revision*.

5. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (May 2022). Monitoring Temporal transformation and health status of vegetation coverage and its effect on climatic parameters using Google Earth Engine of an eastern India river basin. Remote Sensing in Earth Systems Science, Springer Nature, *under major revision*.

List of Presentations in National/International Conferences

1. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (2020). A review on the decadal irrigation system of Shali water reservoir. IOP Conference Series: Earth and Environmental Science, 2020 6th International Conference on Environment and Renewable Energy (ICERE 2020) organized by Hong Kong Chemical, Biological & Environmental Engineering Society at Hanoi, Vietnam. [Earth and Environmental Science, 505, 012023. https://doi.org/10.1088/1755-1315/505/1/ 012023]

2. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (2020). Impact of Shali Reservoir on Gangajalghati Block: A case study. Two Day International Seminar on Sustainable Development & Inclusive Growth, Methods to Methodology, sponsored by The Department of Higher Education, Govt. of West Bengal, Organized by Dept. of Geography and Dept. of Statistics, Lady Brabourne College on 3rd and 4th March, 2020.

3. Halder, Subhra, Das, Subhasish, & Basu, Snehamanju (2020). Review on Rainwater Harvesting Structures like Hapa for Sustainable Agricultural Development in Bankura District. International Conference on Sustainable Water Resources Management under Changed Climate at Gandhi Bhawan Auditorium, Jadavpur University, Kolkata during March 13 – 15, 2020.