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ASSESSMENT OF SEASONAL BEHAVIOURAL CHANGES OF GROUNDWATER RESOURCES IN KARNATAKA STATE: USING GIS TECHNOLOGY

S. S. Hangaragi*

Groundwater is a dynamic and replenishable precious natural resource, it requires to be monitored regularly and also to be appraised of the changes that take place in its regime. The main objective of this paper is to estimate the seasonal behavioural changes of groundwater resources in the Karnataka state. The groundwater resources of Karnataka state has been assessed and carried out by utilizing Central Groundwater Board (CGWB) and Karnataka State Groundwater Departments (KSGD) secondary database for groundwater behaviour. The CGWB published data of the phreatic aquifer from 1,494 Groundwater Monitoring Stations during May, August, November 2018 and January 2019. The available data have been analyzed on the GIS platform for preparing suitable maps. The total availability of groundwater in Karnataka state is estimated at 16.84 bcm, but groundwater resources have not been exploited uniformly throughout the state. The depth to groundwater level in May 2018, ranged from 0.01 mbgl to 26.95 mbgl, in August 2018 groundwater level ranged from 0.02 mbgl to 28.67 mbgl, in November 2018 observed in the range from 0.05 mbgl to 30.30 mbgl and January 2019 ranged from 0.07 mbgl to 30.70 mbgl. The analysis of groundwater levels fluctuation (rise and fall) measured during the different periods was carried out. The annual groundwater fluctuation during pre-monsoon is observed that 78% of the wells fall below the normal groundwater level, 22% of the wells show rise in groundwater level. During post-monsoon 70% of the wells have shown fall below the normal in groundwater levels, 30% of the wells have shown a rise in groundwater levels. The decadal mean change in groundwater levels show rise/fall in the ranges of 0–2 meters, 2–4 meters, and more than 4 meters. The researcher has opined that this paper will be helpful in regional planning and management of groundwater for various upcoming projects in the study area and the results are given the warning for conscientious usage of groundwater for the overall development of the Karnataka state.

INTRODUCTION

Water is an indispensable natural resource for life. Groundwater is the important source of water supply in many regions, there has been a considerable increase in the demand for freshwater. Groundwater has emerged as the main source for agriculture, domestic, and industry. The rapid growth of urban areas has adversely affected the groundwater quality due to overexploitation and improper waste disposal practices. The major problem is the high salinity of groundwater in irrigation. It is necessary to ascertain the potability of water before it is used for human consumption. In general, groundwater is a reliable source of water for agriculture and can be used flexibly. However, it is important to realize that groundwater is not a resource that could be utilized indiscriminately. Issues such as water logging, salinity, agricultural toxins, and industrial

*Professor, Dept. of Geography, S. R. N. Arts and M. B. S. Commerce College, Bagalkot, Karnataka State, India. E-mail: hangaragiss66@gmail.com

effluents need to be looked upon. As for the environment, groundwater plays a very important role in keeping the water level and flow into rivers, lakes, and wetlands. Groundwater has slowly become the mainstay of India's agriculture and drinking water security as it is considered a dependable source. India is a home to more than 1.3 billion people; the increasing population, urbanization, and non-uniform extraction have accelerated the depletion of groundwater resources. This is reflected in falling groundwater levels and contamination of aquifers. Besides, there has not been adequate thoughtfulness to water conservation, efficiency in water use, water re-use and recycling, groundwater recharge, and ecosystem sustainability. This calls for dedicated plans and schemes to manage this scarce resource.

Sustainable development and efficient management of this scarce resource has become a challenge in Karnataka/India. Increasing population, growing urbanization, and rapid industrialization combined with the need for raising agricultural production. Groundwater has steadily emerged as the backbone of India's agriculture and drinking water security. Contribution of groundwater is nearly 62% in irrigation, 85% in rural water supply, and 45% in urban water supply (MoWR, RD & GR). Groundwater is an annually replenishable resource but its availability is nonuniform in space and time. It is the quantity of groundwater available in the zone of water level fluctuation, which is replenished annually with rainfall being the dominant contributor. Hence, the sustainable utilization of groundwater resources demands a realistic quantitative assessment based on reasonably valid scientific principles. National Water Policy, 2012 has emphasized periodic assessment of groundwater resources on a scientific basis. The trends in water availability due to various factors including climate change must also be assessed and accounted for during water resources planning. To meet the increasing demand of water, it advocates direct use of rainfall, desalination, and avoidance of inadvertent evapotranspiration for augmenting utilizable water resources. According to the National Water Policy, 2012 the safe water for drinking and sanitation should be considered as pre-emptive needs followed by high priority allocation for other domestic needs (including needs of animals), achieving food security, supporting sustainable agriculture and minimum ecosystem needs. Available water, after meeting the above needs should be allocated in a manner to promote its conservation and efficient use.

STUDY AREA

The Karnataka State, situated in the west-central part of peninsular India has a total geographical area of 1,91,791 sq. kms (Fig. 1) which is administratively divided into 30 districts and 176 taluks (January 2019, but as on January 2020 the total number of taluks are 242). Physiographically the State is divided into four regions as the narrow Coastal plain along the west coast running to about 300 kms from Karwar in the north to Mangalore in the south. The track is quite narrow reaching a maximum width of about 40 kms at places. The rivers in Karnataka state flowing towards east and west are found within the boundaries of Karnataka. Most of the rivers originate in the Western Ghats and drain towards the Bay of Bengal and the Arabian Sea (Fig. 2). Almost all the major east-flowing rivers are inter-state rivers. The west-flowing river after a short run joins the Arabian Sea. The rivers of Karnataka are a major source of water for drinking, household purposes, agriculture, industries, source of hydropower, and used for transportation in certain areas. In some instances, they are also vital for the tourism industry in the state. The Malnad region has steep mountain ranges and valleys lying immediately east of the coastal region. The general elevation of the area varies from 200 meters AMSL along the boundary with the coastal plain to 1,872 meters AMSL at Kudremukh. Its width varies from 50 to 100 kms several rivers like Cauvery and Tungabhadra originate from Western Ghats. The Northern part of the State comprises of table land and its general elevation ranges from 300 to 350 meters AMSL. The Eastern districts towards the south form a plateau, which is characterized by rolling topography with sporadic hills. The general elevation in this track varies from 600 to 1000 meters AMSL.

Water resources of Karnataka primarily constitute of surface and groundwater. Rainfall is the basic source of water in the state. The Karnataka state is endowed with limited water resources that are stressed and depleting. Different sectoral demands are growing rapidly. An increase in population, urbanization, industrialization, and rising incomes are putting this resource under stress. Unless water resources are properly developed and managed, the State may face an acute crisis within the next two decades. In the near future, serious destabilization of water sector will be affecting the hydrology, economy, and ecology of the Karnataka state. Because of the occurrence and distribution of rainfall in the State is highly erratic. Karnataka primarily enjoys a tropical climate that is largely dependent on its physiographic and geographic location concerning the Arabian Sea and the monsoons. The state receives the benefit of two monsoons: the North-East monsoon and the South-West monsoon. Karnataka receives a mean annual rainfall of around 1,355 millimeters. More than 73 per cent of this rainfall is received due to the South-West monsoon. The state can be earmarked into three meteorological zones, namely, North Interior Karnataka, South Interior Karnataka, and Coastal Karnataka.

OBJECTIVES

The objectives of this study are:

- to analyze the available groundwater quantity in Karnataka state,
- to assess the seasonal behavioural changes of groundwater resources
- to estimate the seasonal fluctuation of groundwater.

MATERIAL AND METHODS

The dynamic nature of the groundwater resource of Karnataka state has been assessed and carried out by utilizing the Central Groundwater Board (CGWB) and Karnataka state groundwater departments published secondary database. The CGWB monitored data related to the depth of groundwater levels in different seasons of Karnataka state established network of 1,494 monitoring stations (wells) located in the five major river basins (Fig. 2). The CGWB monitored and established the data of four times in a water year (May, August, November, and January) for measuring the annual groundwater level. The district-wise distribution of the number of Groundwater Monitoring Stations in the Karnataka state is given in Table 3. The groundwater levels monitored stations are analyzed to know the variations in groundwater levels in space and time and the regional behaviour of groundwater levels and its status between the periods from May 2018 to January 2019.

The collected necessary dataset of the present study is processed based on the GEC 1997 Methodology under the GIS environment by using geospatial technology for assessing the depth of groundwater levels, and calculated seasonal fluctuations. Based on these results prepared the maps on GWL measurements.

Rainfall System

Karnataka receives 71 per cent of its rainfall from southwest monsoon from June to September and 16 per cent of the rainfall from northeast monsoon from October to December (Table 1 and 2). The south-west monsoon is the determining factor for agriculture in the Karnataka State. When annual rainfall is below 75 per cent of the normal rainfall, considering the data for 80 years (from [illegible] in the Northeastern dry zone and central dry zone, drought occurs in more than 25 per cent of the years (once in four years).

Table 1: Distribution of Seasonal Rainfall in Karnataka (2018–19)

No. of Seasons	Name of Season	Duration (in month)	Actual Rainfall	Normal Rainfall	Average Rainfall in mm (%)	Normal Rainfall in mm (80 years Avg. 1939–2019)
1	South-West Monsoon Season (Kharif)	June–September	1,098	885.4	991.7 (73%)	879
2	North-East Monsoon Season (Rabi)	October–December	241.2	184.9	212.4 (16%)	193
3	Winter Season	January–February	6.2	10.4	8.3 (1%)	13
4	Summer Season	March–May	158.1	126.5	142.3 (10%)	132
	Annual (All Seasons)	June–May	1,513.5	1,195.9	1354.7 (100%)	1,217

Source: Monthly Rainfall Report of DE and S, Bangalore.

Table 2: Average Rainfall of Karnataka State: 2018–19 (from 1178 Rain-Guage Stations)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall	2	3	8	37	91	189	272	199	160	134	45	11	1151
Seasons	Winter/ Autumn		Summer			South-west/ Kharif period				North-east/ Rabi period			Annual
Rainfall	13		128			820				190			1151
%	1		11			71				17			100

Source: Monthly Rainfall Report of DE and S, Bangalore.

Groundwater Availability from Recharge by Rainfall

The total availability of groundwater in Karnataka state is estimated at 16.84 bcm, but groundwater resources have not been exploited uniformly throughout the state. The exploitation of groundwater in the arid/dry zone taluks of North and South interior of Karnataka state is high as compared to Coastal, Malnad and irrigation command areas. In 2019 groundwater recharged in monsoon season by the sources of rainfall were 6.59 bcm and by other sources like canals, surface water irrigation, groundwater irrigation, tanks, ponds and water conservation structures boosting the 4.36 bcm of groundwater recharged, but in non-monsoon season by the sources of rainfall 2.67 bcm and other sources 3.22 bcm recharged in Karnataka state. The annual total groundwater recharge capacity by all source was 16.84 bcm out of this quantity discharged groundwater quantity by the natural process was 2.05 bcm. Out of the total available annual groundwater resources are used for various purposes like domestic, industry, agriculture, etc and remaining large quantity of available groundwater i.e., 14.79 bcm extracting through pumping from the bore and open wells in the Karnataka state.

The total availability of groundwater in Karnataka state is estimated at 16.84 bcm. Groundwater resources have not been exploited uniformly throughout the state. The exploitation of groundwater in the arid zone/dry taluks of North and South interior Karnataka is high as compared to Coastal, Malnad and irrigation command areas. Water is deficient for drinking, agricultural, and industrial use in dry zone taluks of North and south interior Karnataka, where adequate surface water is available, utilization of groundwater resources is minimum. Out of 176 taluks, 94 taluks fall under the category of 'safe zone'. 27 taluks are recorded under the category of is 'semi-critical stage'. Further, groundwater exploitation has exceeded more than 90% of the available groundwater resource in 8 taluks, and are recorded under the 'critical stage'. Besides these 47 taluks fall under the category of 'over-exploitation stage'. In Karnataka state, the critical and over-exploited 55 taluks fall under critical condition because of nearly 4 lakh bore and dug wells are located in these taluks and irrigate approximately an area of 7.5 lakh hectares of agriculture land. In 2018–19 due to over-exploitation of groundwater resources, more than 1.86 lakh dug-wells have dried-up. Shallow bore wells have failed and yield in deep bore wells declined. The area irrigated by groundwater extraction structures has decreased in recent years. Consequently, more than Rs. 2,000 crores of investment made by the farmers on the construction of wells, pumping equipment, pipelines, and other infrastructures development, etc., have become infructuous.

Though Karnataka enjoys a substantial amount of rainfall and has a significant quantity of water resources, it is not enough to meet the ever-increasing water requirement of the state. Karnataka suffers repetitive droughts. Despite the availability of water from the river systems and tanks, Karnataka faces the serious issue of 67 per cent of its landmarked for irrigation in the dry tracts. With a rapidly increasing population and improved living standards, the pressure on the water resources is constantly on the rise. The per capita availability of water resources reduces gradually. The erratic behaviour of rainfall and the Inter-State River Water disputes aggravate the problem. The impact of climate change on the water resources cannot be ignored. Siltation of water bodies, misuse of resources, poor management of catchment area, all add to the stressful water resource situation in the state. Groundwater is the major source of drinking water in Karnataka. Over 90 per cent of the drinking water supply schemes in the rural areas of the state are based on groundwater. This overexploitation causes the fast decline of groundwater resources. The result is the scarcity of safe drinking water across many parts of Karnataka. To cater to the water requirement of the expanding population, the existing water resources must be conserved and prevented from further degradation and depletion. The judicious and economic use of water resources for agricultural, industrial, and domestic purposes can help in solving the problem to a large extent.

RESULTS

Depth of Groundwater Levels

The groundwater monitoring network comprises of 1,494 stations data has been used in the present study. For measuring the groundwater levels in the 1,494 notified stations/wells monitored four times in a year during the months of May-2018, August-2018, November-2018 and January-2019. The dug wells were monitored between 1st to 10th day during January and November, in May and August dug wells are monitored for 20 to 30 days.

Depth of groundwater level in May-2018

The depth to groundwater level measured in 1,494 monitored CGWB stations data has been recorded in the Karnataka state during May 2018, ranged from 0.01 mbgl to 26.95 mbgl. Out of these nearly 278 wells were found to be dry during the monitoring period. In remaining 1,216 wells are analysed as 5% wells have groundwater level less than 2 mbgl, 21% have groundwater level in the range of 2 to 5 mbgl and 45% of the wells have groundwater level in the range of 5 to 10 mbgl. About 71% of the analysed wells have groundwater level within 10 mbgl; besides this 27% of the wells have shown moderately deep groundwater levels of 10 to 20 mbgl, and deep groundwater levels of > 20 mbgl are found in remaining 2% of the monitoring wells (Table 3).

Table 3: District-wise Average Depth of Groundwater Table/Level in Karnataka State: 2018–19

Sl. No	Name of the District	Total No. of Groundwater Monitoring Stations	Depth of Groundwater Table (in mbgl)							
			May-2018		August-2018		November-2018		January-2019	
			Min	Max	Min	Max	Min	Max	Min	Max
1	Bagalkot	29	2.83	25.96	1.14	28.67	1.92	30.30	1.67	30.70
2	Bangalore Rural	24	2.08	19.20	1.36	13.30	1.91	19.20	2.32	19.90
3	Bangalore Urban	20	0.01	12.47	0.15	7.45	0.92	8.98	0.71	16.63
4	Bellary	30	1.65	19.65	0.76	21.35	0.35	21.35	1.82	21.35
5	Belgaum	91	0.42	21.23	0.02	21.23	0.65	21.23	0.73	21.23
6	Bidar	42	3.58	23.12	0.38	21.57	0.42	16.38	0.94	16.25
7	Bijapur	69	-0.54	18.50	1.05	18.50	0.80	25.10	1.19	26.00
8	Chamarajnagar	20	2.32	18.20	1.80	18.20	1.71	18.20	2.12	18.20
9	Chikkaballapur	14	2.03	19.10	1.36	13.30	1.91	19.20	2.32	19.20
10	Chickmagalur	78	0.90	19.90	0.03	17.45	0.30	17.45	0.71	17.45
11	Chitradurga	36	0.80	18.10	0.80	18.10	1.00	18.10	0.80	18.10
12	D. Kannada	101	1.35	15.18	0.10	9.65	1.37	12.65	1.60	13.73
13	Davanagere	57	0.80	15.30	0.12	19.23	0.60	13.80	0.75	14.30
14	Dharwar	26	1.98	20.77	1.28	26.80	1.27	8.60	1.80	28.58
15	Gadag	23	0.84	26.45	4.44	26.45	3.82	26.45	4.05	29.10
16	Gulbarga	56	2.78	24.40	0.30	20.67	0.10	15.77	0.21	15.77
17	Hassan	86	0.85	24.00	0.74	21.25	0.78	24.00	0.57	24.00
18	Haveri	30	1.35	19.49	1.23	16.04	0.93	18.75	1.78	19.65
19	Kodagu	73	1.28	18.40	0.68	16.85	1.35	19.62	1.10	16.64
20	Kolar	28	0.66	13.60	0.03	13.60	0.27	13.60	0.08	9.49
21	Koppala	36	1.90	16.10	1.33	16.92	1.00	16.90	1.78	17.90
22	Mandya	51	0.37	26.95	0.41	26.95	0.21	26.95	0.13	25.95
23	Mysore	61	0.43	23.50	0.38	22.50	1.00	22.46	1.16	23.50
24	Raichur	52	1.15	11.30	0.20	13.20	0.05	13.20	0.07	13.20
25	Ramanagara	21	2.08	19.20	1.34	13.10	1.91	19.50	1.32	19.20
26	Shimoga	80	0.77	21.21	0.67	13.51	0.37	16.41	0.80	27.69
27	Tumkur	59	0.80	12.40	0.19	12.40	0.70	12.40	2.05	12.45
28	Udupi	60	2.20	14.20	0.20	9.07	0.71	11.11	1.22	13.80
29	U. Kannada	63	1.33	10.90	0.10	16.35	0.56	16.48	1.10	16.18
30	Yadgir	20	2.78	24.40	0.30	20.67	0.10	15.77	0.21	15.77
	Total	1,494	-0.54	26.95	0.02	28.67	0.05	30.30	0.07	30.70

Source: Central Groundwater Board (CGWB) and Karnataka state groundwater departments published secondary data of groundwater level of the phreatic aquifer from 1,494 Groundwater Monitoring Stations collected data of the months of May, August, November 2018 and January 2019.

The depth to groundwater level ranges of < 2, 2 to 5, 5 to 10, 10 to 20, and > 20 mbgl shown in Fig. 3 of Karnataka state as on the data set of May 2018. The map shows that the most common depth to groundwater level range in Karnataka State is 5 to 10 mbgl. The depth of groundwater level of < 2 mbgl is observed as isolated patches in parts of Bangalore Urban, Shimoga, Tumkur, Kolar, Kodagu, Chikkamagaluru, Hassan, Davanagere, Mysore and Chitradurga. Besides these, the depth of groundwater levels in the range of 2 to 5 mbgl, 5 to 10 mbgl, and 10 to 20 mbgl are noticed in almost all the districts of Karnataka State. But the depth to groundwater level of > 20 mbgl is observed in parts of Gulbarga, Bidar, Gadag, Koppala, Hassan, Mandya and Mysore districts.

Depth of groundwater level in August-2018

The depth to groundwater level measured during August 2018, the results show that the depth of groundwater level ranged from 0.02 mbgl to 28.67 mbgl observed in the 1,370 stations, remaining 124 wells were found to be dry. Out of 1,370 groundwater level recorded wells about [illegible] of wells have the groundwater level less than 2 mbgl, [illegible] of wells have groundwater level in the range of 2 to 5 mbgl and [illegible] of the wells have groundwater levels in the range of 5 to 10 mbgl. About [illegible] of the analysed wells have groundwater level within 10 mbgl depth. Moderately deep groundwater levels of 10 to 20 mbgl are observed in 13% of wells and deep groundwater levels of > 20 mbgl are found in about 1% of the observed wells (Table 3). The depth to groundwater level in the ranges of less than 2, 2 to 5, 5 to 10, 10 to 20, and more than 20 mbgl results show Karnataka state map (Fig. 4) were prepared as per the data of August 2018. This map shows that the groundwater levels in the range of 2 to 5 and 5 to 10 mbgl are the general groundwater levels prevalent in the State. Groundwater levels in the range of less than 2 mbgl occur in small patches in parts of almost all the districts except Bagalkot, Gadag, Haveri, and Ramanagara districts. The depth to groundwater levels between 10 to 20 mbgl are observed as patches in almost all the districts except in Bangalore Urban, Chikkaballapura, Dakshina Kannada and Udupi districts, while groundwater levels deeper than 20 mbgl occur as small patches in parts of Bagalkot, Koppala, Dharwad and Gadag districts.

Depth of groundwater level in November-2018

The depth to groundwater level recorded in November 2018 observed in the range from 0.05 mbgl to 30.30 mbgl in 1,420 data monitored wells. Out of these [illegible] wells have groundwater level less than 2 mbgl, 32% of wells have groundwater levels in the range of 2 to 5 mbgl and [illegible] of wells have groundwater levels in the range of 5 to 10 mbgl. Thus, about [illegible] of the observed wells have groundwater level within 10 mbgl; moderately deep groundwater levels of 10 to 20 mbgl are found in 16% of the wells and deep groundwater levels of > 20 mbgl are found in about 1% of the monitoring wells (Table 3). A map (Fig. 5) showing the depth to water level in the range of < 2, 2 to 5, 5 to 10, 10 to 20, and more than 20 mbgl in Karnataka state as per November 2018 data. The depth of groundwater levels in the range of less than 2 mbgl occur in small patches of almost all the districts of Karnataka State except Gadag, Dharwad, Haveri, Bagalkot, Mysore, Chamarajnagar, Kodagu, Hassan, Ramanagara and Dakshina Kannada districts. The map shows that the groundwater levels in the range of 2 to 5 and 5 to 10 mbgl are the general groundwater levels prevalent in the State. The depth of groundwater level between 10 to 20 mbgl is observed as small patches in almost all the districts except in Bangalore Urban, Chikkaballapura and Udupi districts and groundwater level deeper than 20 mbgl occur as a small patch in Gadag, Koppala, Bagalkot and Dharwad districts.

Depth of Groundwater Level in January-2019

The depth to groundwater level observed in the Karnataka state during January 2019 ranges from 0.07 mbgl to 30.70 mbgl. Out of the 1,494 monitored wells about 178 well stations were found to be dry during this period, so remaining 1,316 wells [illegible] data analysed as [illegible] of the wells have of groundwater level during November 2018 as compared to the groundwater levels of May 2018. The remaining 329 wells accounting for 22% have been recorded under the category of fall in depth of groundwater levels (Table 4). In the rising category, the groundwater level in the range 0 to 2 meter is observed in 508 wells accounting for 34% of the monitoring wells. The rise in depth of groundwater level in the range of 2 to 4 meters and more than 4 meters has been recorded in 374 wells (25%) and 299 wells (20%) respectively. In the groundwater fall category of 0 to the 2-meter range were observed in 239 of wells accounting for 16% of analyzed wells. Falls in groundwater level in the range of 2 to 4 meters and more than 4 meters are seen in 45 wells (3%) and 30 wells (2%) respectively.

Fig. 8 depicting the fluctuation in groundwater levels in November 2018 as compared to May 2018 showing rise/fall in the ranges of 0 to 2 meters, 2 to 4 meters, and > 4 meters observed in Karnataka state from May 2018 to November 2018. This figure shows that a rise in groundwater level in the range of 0 to 2 meters is observed in a major part of Karnataka State and also rise of groundwater level in the range of 2 to 4 meters is observed as patches in almost all districts of Karnataka State.

The groundwater level rises of more than 4 meters were noticed in all districts of Karnataka State except Bellary, Chitradurga, Bangalore Urban, Chamarajnagar, and Kolar districts. Groundwater level fall of less than 2 meters is recorded in parts of all the districts of the State except Bidar and Yadgir districts and fall in the range of 2 to 4 meters is noticed in parts of Bagalkot, Bidar, Bellary, Bijapur, Chamarajnagar, Chikkamangalur, Chitradurga, Dharwad, Davanagere Gadag, Gulbarga, Hassan, Kodagu, Koppala, Kolar, Mysore, Mandya, Ramanagara, Raichur, and Tumkur districts. Falls in the groundwater level of more than 4 meters were observed in parts of Bagalkot, Bellary, Gadag, Chitradurga, Mysore, Bijapur, Hassan, Kodagu, and Raichur districts.

Change in depth of groundwater level from May 2018 to January 2019

The groundwater level data from 1,494 wells station were analyzed to know the seasonal change in groundwater level in January 2019 with that of May 2018. Out of 1,494 stations, 1,368 wells station data were compared and the remaining 126 stations could not be compared due to the non-availability of data for a particular station in the current season. On the whole, 821 wells accounting for 60% of the data analyzed wells have recorded a rise in groundwater level during January 2019 as compared with the groundwater level of May 2018. The remaining 547 wells accounting for 40% have recorded a fall in groundwater levels (Table 4). In the rising category, the depths of groundwater level in the range 0 to 2 meter are observed in 520 wells accounting for 38% of the analyzed wells. The rise in groundwater level in the range of 2 to 4 meters and more than 4 meters were recorded in 219 wells (16%) and 164 wells (12%) respectively. In the fall category, the fall of groundwater level in the range of 0 to 2 meter were observed in 342 wells accounting for 25% of analyzed wells. Falls in groundwater level in the range of 2 to 4 meters and more than 4 meters are observed in 82 wells (6%) and 41 wells (3%) respectively.

The fluctuation in groundwater level in January 2019 as compared to May 2018 showing rise/fall in the ranges of 0 to 2 meters, 2 to 4 meters, and > 4 meters index-based Map were prepared (Fig. 9). The rises in groundwater level in the range of 0 to 2 meters were observed in the major part of Karnataka State. The groundwater level rise in the range of 2 to 4 meters was observed as patches in almost all the districts except Chamarajnagar and Kolar districts. Rise of groundwater depth observed as more than 4 meter were noticed in all the districts of Karnataka except Bangalore Rural, Bellary, Chitradurga and Davanagere districts. The depth of groundwater level fall of less than 2 meters and 2 to 4 meters is observed in parts of all the districts except Bidar. Fall in groundwater level of more than 4 meters were observed in all the districts except Bangalore Urban, Belgaum, Udupi and Uttara Kannada districts.

Table 5: District-wise Decadal Mean Fluctuations of Groundwater Level in Karnataka State

Sl. No.	Name of the District	Total No. of Groundwater Monitoring Stations	Range of Groundwater Fluctuation (in meters) January 2009 to January 2019			
			Rise		Fall	
			Min	Max	Min	Max
1	Bagalkot	29	0.08	1.32	0.08	16.37
2	Bangalore Rural	24	0.27	5.30	0.16	11.06
3	Bangalore Urban	21	0.37	4.63	0.02	11.33
4	Bellary	33	0.21	1.05	0.17	7.34
5	Belgaum	91	0.07	2.88	0.04	7.32
6	Bidar	42	0.23	12.43	0.11	4.09
7	Bijapur	69	0.07	2.59	0.06	9.92
8	Chamarajanagar	29	0.14	3.43	0.54	7.57
9	Chikkballapur	11	0.27	5.30	0.16	11.06
10	Chickmagalur	78	0.01	4.11	0.01	6.98
11	Chitradurga	36	0.68	1.47	0.17	11.85
12	D. Kannada	101	0.24	4.05	0.01	8.47
13	Davanagere	57	0.20	3.17	0.08	8.87
14	Dharwar	26	0.04	3.82	0.37	10.37
15	Gadag	23	0.05	2.28	0.30	8.99
16	Gulbarga	55	0.04	4.95	0.68	6.65
17	Hassan	86	0.03	1.23	0.01	16.54
18	Haveri	30	0.63	1.67	0.10	13.56
19	Kodagu	73	0.38	6.47	0.11	7.87
20	Kolar	28	0.02	10.01	0.23	2.84
21	Koppala	36	0.11	2.19	0.09	4.50
22	Mandya	51	0.18	1.99	0.06	9.96
23	Mysore	61	0.16	3.71	0.03	13.06
24	Raichur	52	0.63	3.76	0.25	6.89
25	Ramanagara	21	0.27	5.30	0.16	11.06
26	Shimoga	88	0.29	1.93	0.02	16.41
27	Tumkur	52	0.01	6.02	0.07	7.89
28	Udupi	80	0.01	6.13	0.03	6.61
29	U. Kannada	83	0.03	1.65	0.01	6.01
30	Yadgir	30	0.04	4.95	0.09	6.65
	Total	1,494	0.01	12.46	0.01	16.54

Source: 1) Central Groundwater Board (CGWB) and Karnataka state groundwater departments Published secondary data of groundwater level of the phreatic aquifer from 1,494 Groundwater Monitoring Stations collected data of the months of May, August, November 2018 and January 2019.

2) Central Groundwater Board (CGWB) and Karnataka State Groundwater Departments Published Secondary Data of Groundwater Level-2008.

groundwater level < 2 mbgl, about 29% of wells have groundwater levels in the range of 2 to 5 mbgl and 41% of the wells have groundwater levels in the range of 5 to 10 mbgl. About 77% of the data observed wells have groundwater levels below the 10 mbgl. But moderately deep groundwater levels observed in 22% of wells as 10 to 20 mbgl groundwater level and deep groundwater levels of > 20 mbgl are found in about 1% of the analyzed wells (Table 3). A total of 178 stations were found to be dry during the period.

A map of Karnataka state showing the depth to groundwater level in the ranges of < 2, 2 to 5, 5 to 10, 10 to 20, and > 20 mbgl of January 2019 (Fig. 6). The groundwater level in the range of 5 to 10 mbgl is the general groundwater level prevalent in the Karnataka state. Groundwater levels in the range of less than 2 mbgl occur as small patches in parts of almost all the districts of Karnataka state except Bangalore Rural, Chamarajnagar, Gadag, Dharwad, Haveri, Tumkur and Udupi districts. The depth to groundwater level in the range of 2 to 5 mbgl is observed in all the districts. Depth to groundwater levels between 10 to 20 mbgl are observed in almost all the districts except in Bangalore Urban district and groundwater level more than 20 mbgl occur as small patches in Bagalkot, Bijapur, Dharwad, Gadag, Hassan and Mysore districts.

Fluctuations in Groundwater Levels

The analysis of groundwater levels fluctuation (rise and fall) measured during the different periods was carried out. In pre-monsoon season the depth of groundwater levels measured during May 2018 is compared with the depth of groundwater levels during August 2018, November 2018, and January 2019 to know the seasonal fluctuation level. The depth of groundwater levels measured for a given month during consecutive years are compared to know the annual range of fluctuation in the Karnataka state. Further groundwater levels of each measurement are compared with the mean groundwater levels in the same months of the preceding decade to know the long-term changes.

Change in depth of groundwater level from May 2018 to August 2018

Groundwater levels from 1,494 wells station were analyzed to know the seasonal change in groundwater levels in May 2018 with that of August 2018. Out of 1,494 stations, 1,272 stations were compared and the remaining 222 stations could not be compared due to the non-availability of data for a particular station in the current season. On the whole 1093 wells accounting for 73% of the observed wells have recorded a rise in groundwater level during August 2018 as compared to the groundwater levels of May 2018. The remaining 401 wells accounting for 27% have recorded a fall in groundwater levels (Table 4). In the rising category, the groundwater levels in the range 0 to 2 meters are observed in 508 wells accounting for 34% of the total observed wells. The rise of groundwater level is in the range of 2 to 4 meters, more than 4 meters were observed in 314 wells (21%) and 448 wells (30%) respectively. The fall in depth of groundwater level range from 0 to 2 meter were observed in 149 wells, it accounts for 10% of the observed wells in the study area. In the fall of groundwater level in the range of 2 to 4 meters and more than 4 meters are seen in 45 wells (3%) and 15 wells (1%) respectively. Fig. 7 depicting the fluctuation in groundwater levels in August 2018 as compared to May 2018.

Change in depth of groundwater level from May 2018 to November 2018

The depth of groundwater levels data from 1,494 wells station were analyzed to know the seasonal change in groundwater level in May 2018 concerning November 2018. Out of 1,494 stations, 1272 stations were compared and the remaining 222 wells could not be compared due to the non-availability of data for a particular station in the current season. On the whole, 1,165 wells accounting for 78% of the total observed wells have been recorded under the rising category in depth

Table 4: District-wise Average Fluctuations in Groundwater Level in Karnataka State: 2018–19

Sl. No.	Name of the District	Total No. of Groundwater Monitoring Stations	Range of Groundwater Fluctuation (in mts)											
			May-2018 to August-2018				May-2018 to November-2018				May-2018 to January-2019			
			Rise		Fall		Rise		Fall		Rise		Fall	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	Bagalkot	29	0.18	16.50	0.10	2.71	0.02	17.30	0.15	4.34	0.14	17.25	0.02	4.74
2	Bangalore Rural	24	0.09	15.20	0.21	5.30	0.15	5.25	0.01	3.46	0.06	3.75	0.07	4.30
3	Bangalore Urban	20	0.10	6.00	0.14	0.60	0.04	1.04	0.05	2.58	0.22	5.86	0.06	4.16
4	Bellary	33	0.07	6.55	0.01	4.70	0.27	3.60	0.05	4.70	0.23	2.62	0.17	4.70
5	Belgaum	91	0.28	14.50	0.30	1.25	0.10	10.35	0.16	0.91	0.01	10.73	0.17	2.05
6	Bidar	42	1.23	13.81	0.15	2.75	2.10	16.91	1.54	3.50	1.08	15.85	1.84	4.80
7	Bijapur	89	0.10	9.50	0.08	5.68	0.05	8.37	0.25	6.60	0.05	7.98	0.02	7.50
8	Chamarajanagar	29	0.79	7.44	0.25	8.75	0.35	7.00	0.10	8.75	0.10	7.21	0.01	8.75
9	Chikballapur	11	0.09	15.20	0.21	5.30	0.15	5.25	0.01	3.46	0.06	3.75	0.07	4.30
10	Chickmagalur	78	0.10	13.70	0.07	2.83	0.02	13.49	0.18	4.58	0.02	12.65	0.06	4.14
11	Chitradurga	36	0.15	4.04	0.03	2.00	0.10	2.65	0.04	10.70	0.23	3.75	0.40	10.70
12	D. Kannada	101	0.30	9.35	1.34	3.39	0.03	9.20	0.01	5.06	0.10	7.80	0.03	6.43
13	Davanagere	57	0.08	5.56	0.34	6.08	0.05	5.80	0.03	2.73	0.05	3.08	0.10	4.45
14	Dharwar	26	0.16	9.57	0.30	8.30	0.04	5.40	0.10	7.83	0.10	5.20	0.02	7.83
15	Gadag	23	0.14	4.27	0.10	3.64	0.03	10.51	0.24	6.19	0.82	15.40	0.10	5.44
16	Gulbarga	56	0.09	15.20	0.21	5.30	0.54	21.76	1.29	2.30	0.02	17.81	0.26	6.10
17	Hassan	86	0.05	12.22	0.02	8.50	0.03	6.60	0.03	9.73	0.01	6.33	0.01	10.73
18	Haveri	30	0.65	13.37	0.84	1.74	0.26	15.52	1.18	3.07	0.22	12.20	0.05	7.75
19	Kodagu	73	0.01	9.25	0.76	6.00	0.05	5.70	0.15	12.02	0.01	7.50	0.01	6.34
20	Kolar	28	0.06	4.36	0.01	2.37	0.01	4.43	0.10	3.92	0.01	4.74	0.08	5.78
21	Koppala	36	0.06	4.03	0.24	3.54	0.05	7.40	0.20	3.00	0.12	6.08	0.24	5.10
22	Mandya	51	0.28	9.10	0.05	3.73	0.26	9.35	0.06	2.80	0.03	8.12	0.10	6.15
23	Mysore	61	0.05	13.14	0.03	8.86	0.05	10.40	0.06	7.10	0.17	10.55	0.10	7.10
24	Raichur	52	0.05	6.37	0.16	8.27	0.10	7.45	0.05	7.05	0.15	6.65	0.22	9.66
25	Ramanagara	21	0.09	15.20	0.21	5.30	0.15	5.25	0.01	3.46	0.06	3.75	0.07	4.30
26	Shimoga	86	0.02	11.04	0.90	3.90	0.02	12.51	0.01	0.89	0.03	5.87	0.08	13.20
27	Tumkur	52	0.20	6.06	0.01	0.70	0.09	7.49	0.10	4.03	0.01	5.48	0.04	8.25
28	Udupi	80	0.69	9.60	0.21	5.30	0.58	0.56	0.01	1.29	0.03	9.05	0.11	2.90
29	U. Kannada	83	0.06	12.15	0.70	1.71	0.33	11.43	0.23	1.00	0.03	6.80	0.60	1.58
30	Yadgir	30	0.09	15.20	0.21	5.30	0.51	21.76	1.29	2.30	0.02	17.81	0.26	6.10
	Total	1,494	0.01	15.20	0.01	8.80	0.01	21.76	0.01	12.02	0.01	17.81	0.01	13.20

Source: Central Groundwater Board (CGWB) and Karnataka state groundwater departments published secondary data of groundwater level of the phreatic aquifer from 1,494 Groundwater Monitoring Stations collected data of the months of May, August, November 2018 and January 2019

Decadal mean fluctuation of groundwater level (January 2009 to January 2019)

The mean groundwater level for the period January 2009 to January 2019 is analysed and compared with the groundwater level of January 2019 data of 1,494 CGWB observed stations. It is seen that, out of the 1,494 stations about 1,045 stations accounting for 70% have fall in the groundwater level during January 2019 as compared to the preceding decadal mean and the remaining 449 stations accounting for 30% have shown a rise in groundwater level (Table 5). In the groundwater level rise category, a rise of 0 to the 2-meter range is recorded in 344 stations accounting for 23% of analysed wells. Rise of 2 to 4 meters and more than 4 meters is seen in 75 stations (5%) and 30 stations (2%) respectively. In the fall category, a fall in groundwater level in the range of 0 to 2 meters is recorded in 687 wells accounting for 46% of analysed wells. Fall in groundwater level of 2 to 4 meters and more than 4 meters range is seen in 254 wells (17%) and 104 wells (7%) respectively.

A map (Fig. 10) depicting the change in groundwater levels showing rise/fall in the ranges of 0-2 meters, 2-4 meters, and more than 4 meters. The rise in groundwater level of less than 2 meters was noticed as patches in almost all the districts of Karnataka State as small patches. Rise in the range of 2 to 4 meters was observed in parts of Bidar, Gulbarga, Yadgir, Raichur, Chikkamagalur, Tumkur, Chikkaballapura, Dakshina Kannada, Kodagu and Mysore districts. Rise of more than 4 meters of groundwater level were observed as small patches in parts of Bidar, Chikkaballapura, and Tumkur districts. The major part of the Karnataka state shows a fall in groundwater level as compared to decadal mean groundwater level of 2009–2019 concerning the January 2019 groundwater level. Fall in groundwater level of less than 2 meters and 2 to 4 meters is noticed in the parts of almost all the districts of Karnataka State. Fall of groundwater level of more than 4 meters is observed as small patches in all the districts except Bangalore Urban and Kolar districts.

CONCLUSION

The seasonal behavioural changes of groundwater resources in Karnataka state assessed based on observed groundwater monitoring 1,494 stations data of four times in a year especially in January, May, August, and November. The rainfall received in Karnataka state during the year 2018-19 was 881 mm, the annual normal rainfall varies from as low as 112 mm at Chamrajanagar district to as high as 4,582 mm at Uttara Kannada district. During the year 2018, the State as a whole recorded 17% of the district shows normal rainfall, and 23% of wells show excess rainfall and 60% shows deficit rainfall. During pre-monsoon 2018, shows about 71% of the wells show depth to groundwater level within 10 mbgl. During post-monsoon 2018, about 83% of the wells showing depth to groundwater level within 10 mbgl. Annual fluctuation during pre-monsoon 2018 it is observed that, 78% of the wells in the Karnataka state show a fall in groundwater level and 22% of the wells in the state show rise in groundwater level. During post-monsoon 2018 about 70% of the wells in the State show a fall in groundwater levels and 30% of the wells in the State show a rise in groundwater level. The decadal mean groundwater level of 2009–2019 concerning May 2018, 70% of wells showing fall in groundwater level, and 30% of the wells show rise in groundwater level. Decadal mean groundwater level of 2009–2019 concerning January 2019, 76% of wells show fall in groundwater level, and 24% of the wells show a rise in groundwater level in Karnataka State.

The groundwater resources are replenished through rainfall and other sources like return flow from irrigation, canal seepage, recharge from groundwater bodies, water conservation structures, etc. The annual groundwater recharge has been assessed as 16.84 bcm and the annual extractable groundwater resource is 14.79 bcm. The current annual groundwater extraction is 10.34 bcm. Because of the overexploitation of groundwater resources in all the 47 taluks of Karnataka state instead of recommending additional groundwater abstraction structures, methods of augmenting the measures such as artificial recharge structures, rainwater harvesting are recommended. Drip and micro-irrigation are to be encouraged for water use efficiency. This will help to minimize groundwater withdrawal and building up of groundwater resources. In recent years many states of India have implemented water recycling projects successfully. In addition to this, dual water supply systems in the upcoming areas for potable and non-potable water separately are to be considered as a viable option to minimize the pressure on freshwater supply. These recommendations could be implemented through public awareness and training through Central/State administration, which will go a long way in realizing the civic responsibility towards a very important element of life "water" for sustainable development.

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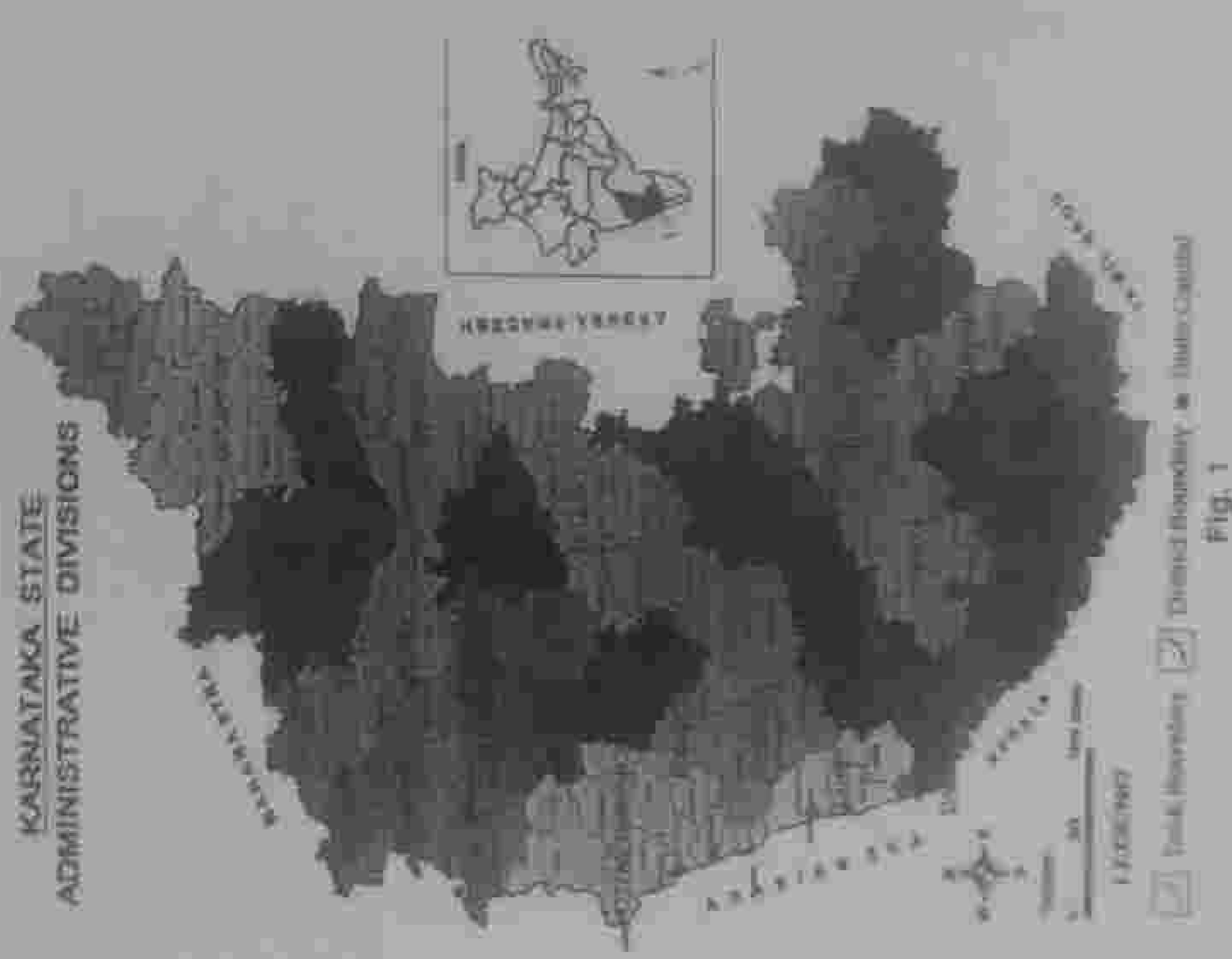

Fig. 1

Fig. 2

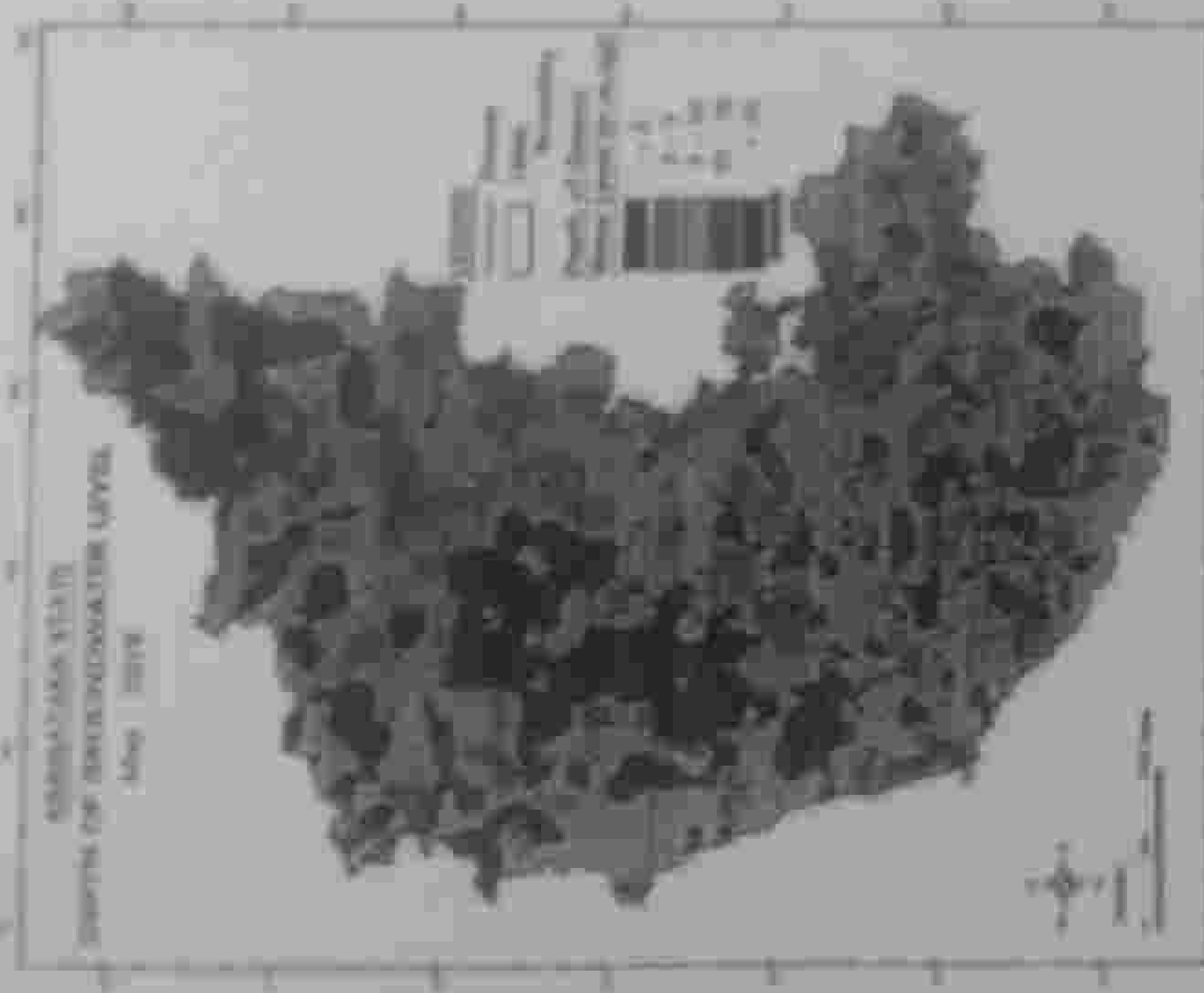

Fig 3

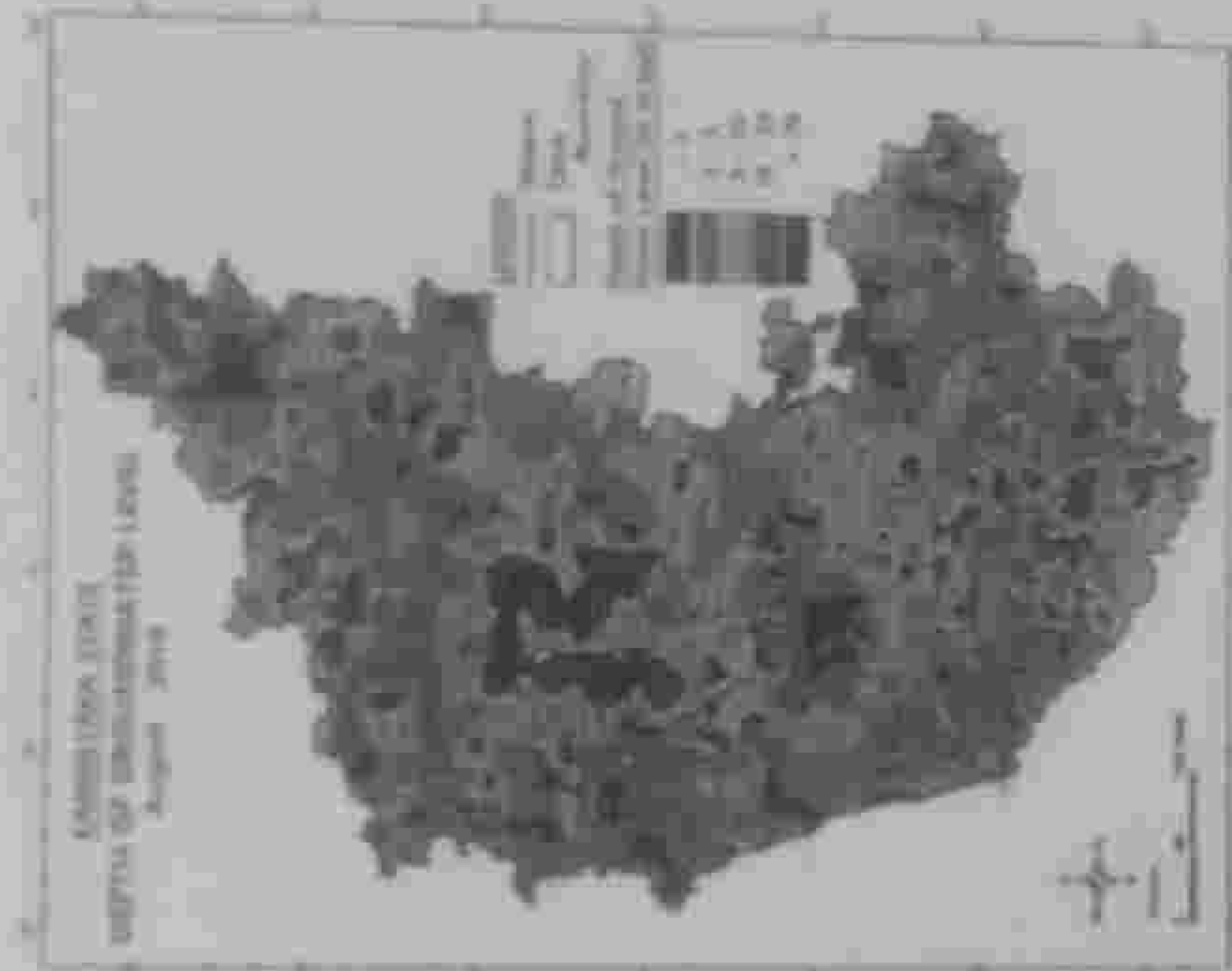

Fig 4

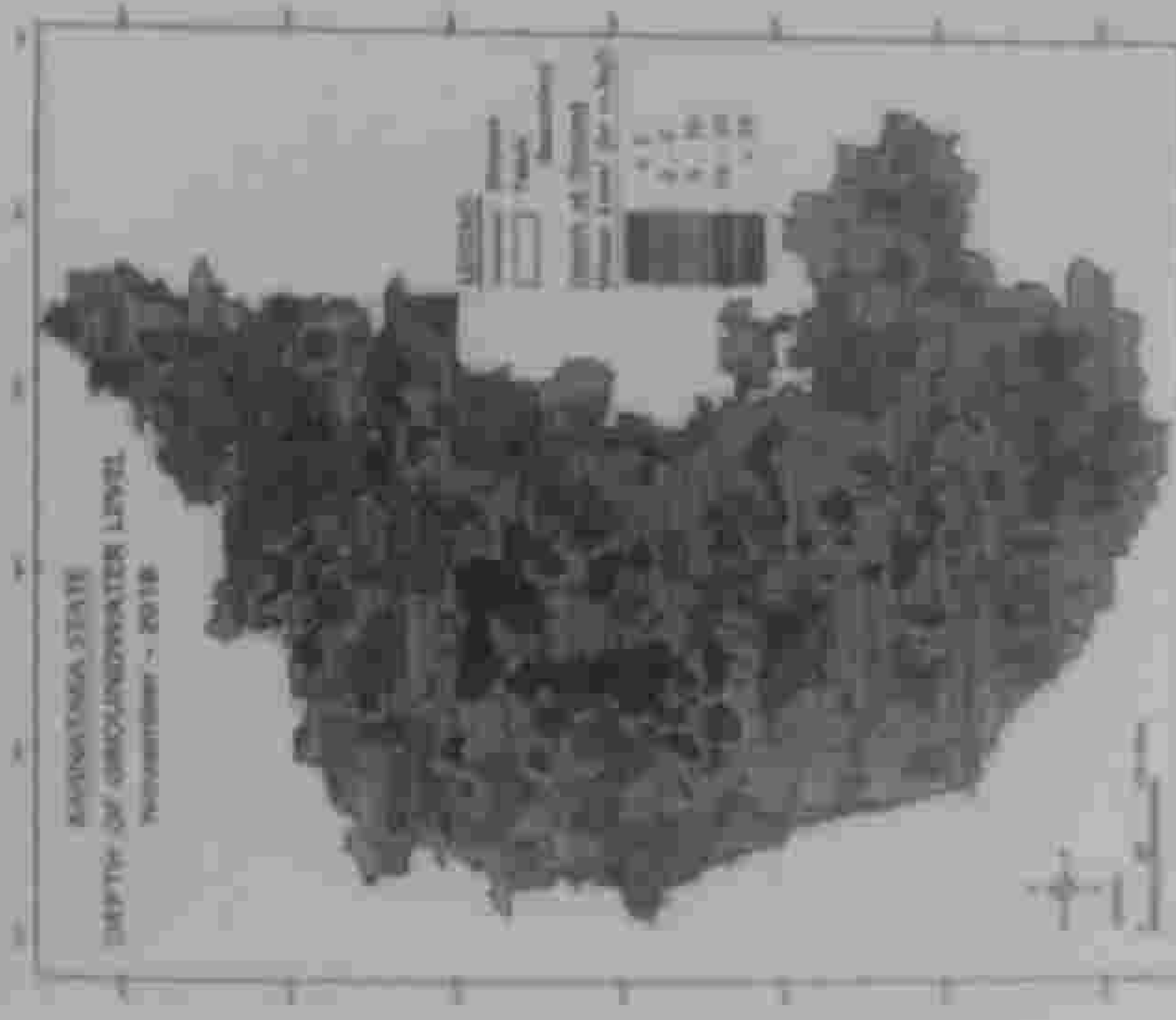

Fig 5

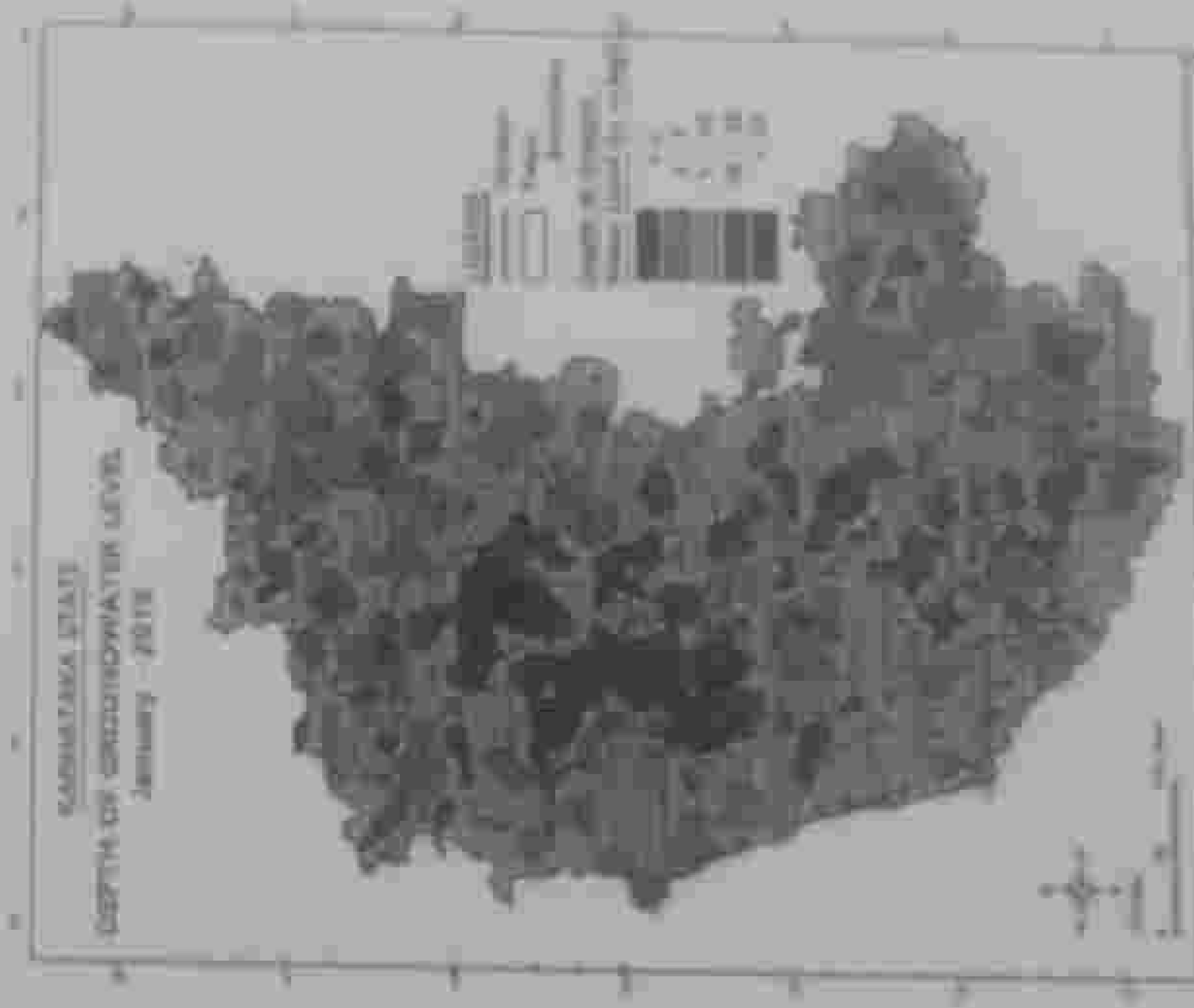

Fig 6

KARNATAKA STATE
FLUCTUATION OF GROUNDWATER LEVEL
May - 2018 to August - 2018

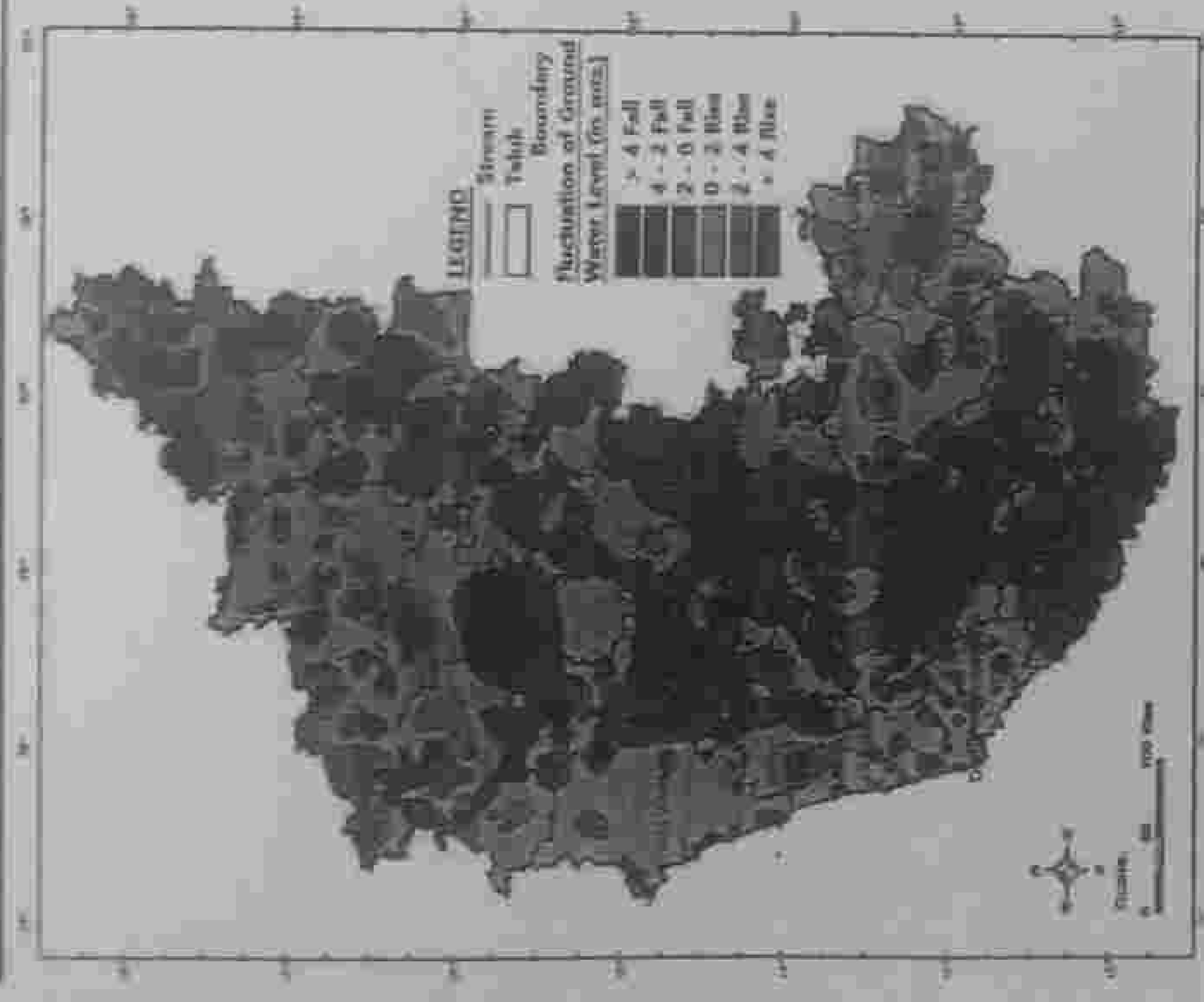

Fig. 7

KARNATAKA STATE
FLUCTUATION OF GROUNDWATER LEVEL
May-2018 to November-2018

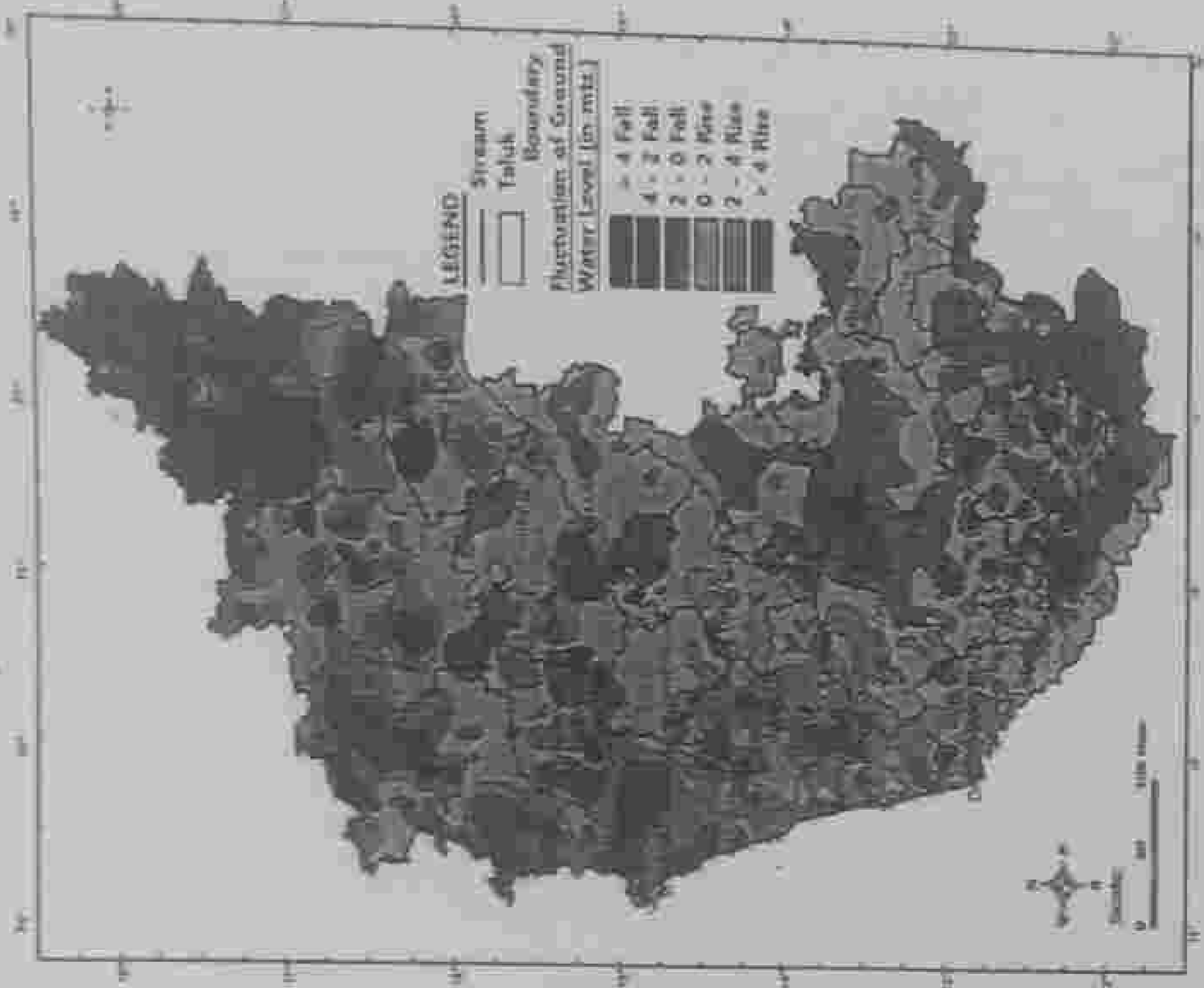

Fig. 8

KARNATAKA STATE
FLUCTUATION OF GROUNDWATER LEVEL
May-2018 to January-2019

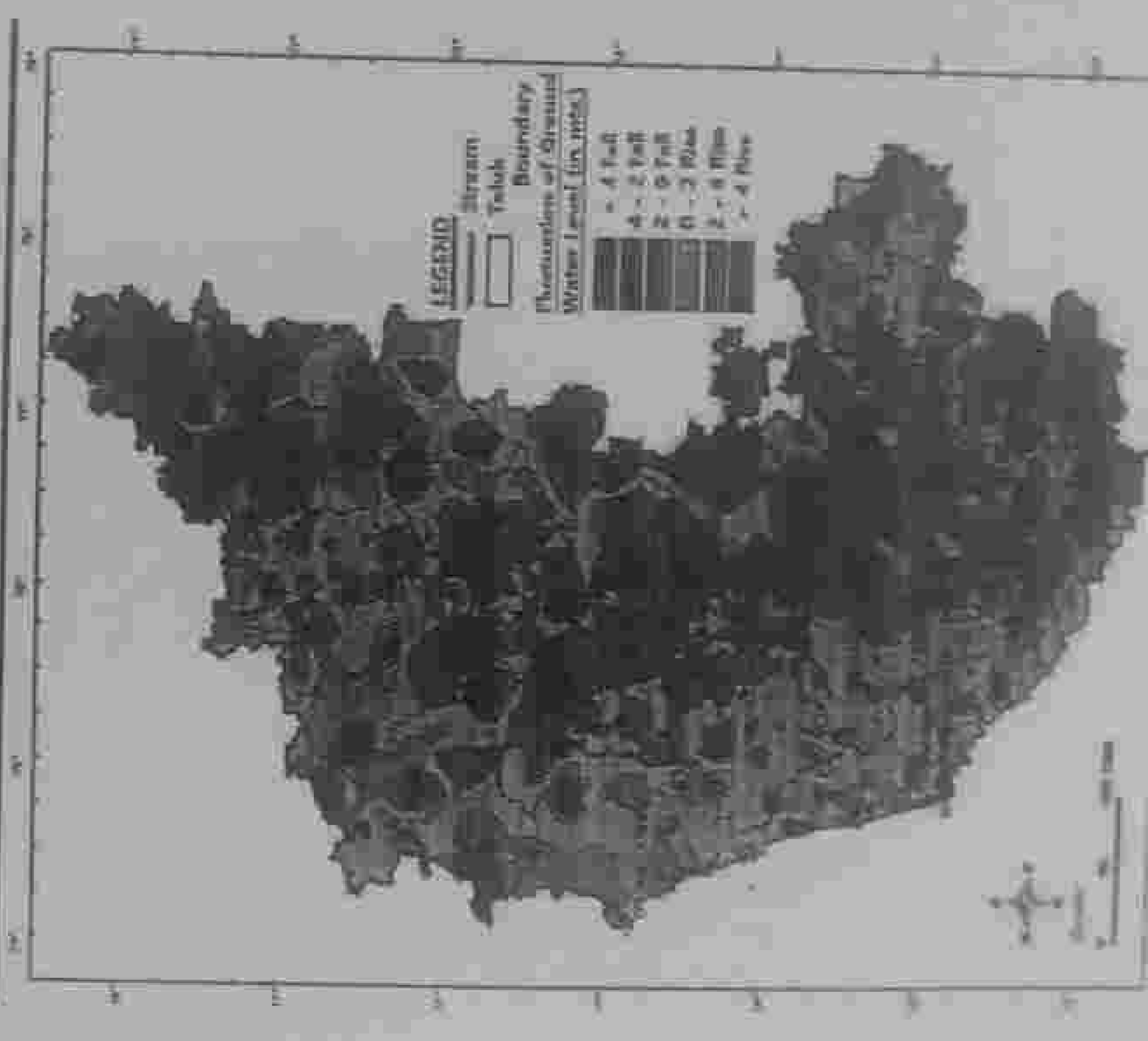

Fig. 9

KARNATAKA STATE
DECADAL MEAN FLUCTUATION OF GROUNDWATER LEVEL
January-2009 to January-2019

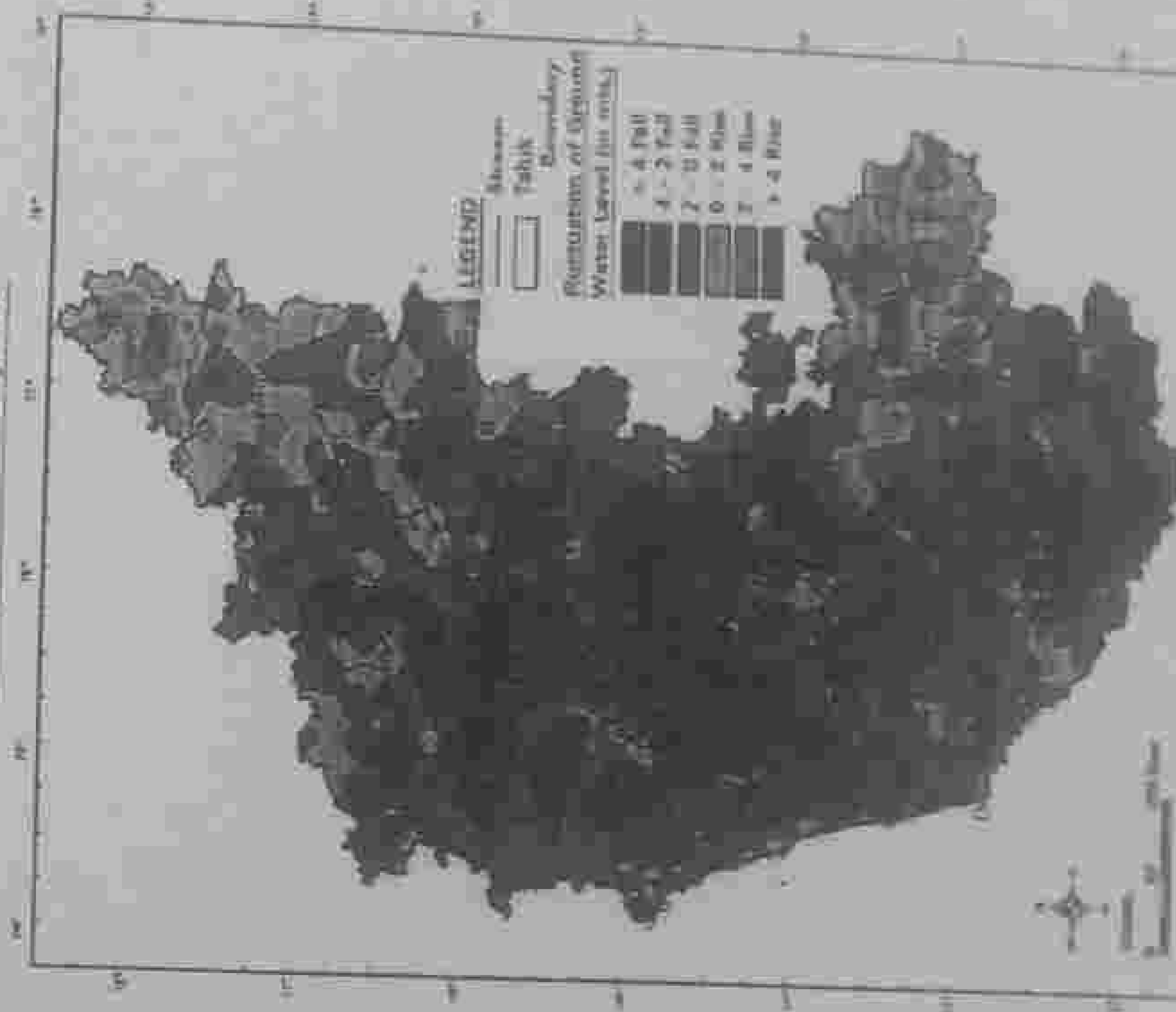

Fig. 10