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Spatial variability of the infiltration rate in sodic soils of KASBE Digraj of Sangli district

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Abstract
An experiment entitled, "the spatial variability of infiltration rates in sodic soils of KASBE Digraj of Sangli District" was conducted in March 2023. Total 23 soil samples site were selected representing sodic soils of KASBE Digraj village. These sodic soils were analyzed for its physical and chemical properties, infiltration rates of selected locations. The research further explores infiltration rates in sodic soils of KASBE Digraj, unveiling spatial and temporal variability widely from 0 to 210 mm per min, with notable differences between specific sites. An analysis of the cumulative infiltration rates over time highlighted the sodic soil's ability to absorb and retain more moisture, with values increasing from 113.91 mm at 2 minutes to 362 mm at 90 minutes. Correlations between cumulative infiltration rates and physico-chemical properties revealed that positive associations with electrical conductivity (0.355*) and negative relationships with calcium carbonate (-0.361*), bulk density (-0.434**), exchangeable sodium (-0.471**) and cation exchange capacity (-0.351*).

Keywords: Sodic soil, infiltration rate, cumulative infiltration rate

Introduction
Salinization and alkalinization area in Maharashtra are projected to be 0.184 and 0.423 mha, respectively. About 11.2% of the soil discovered is sodic soil, while 10.4% is saline soil. Sodic soils are found in several districts of Maharashtra, including Sangli, Aurangabad, Beed, Osmanabad, Latur, Nanded, Parbhani and Jalna. The highest sodicity affected area is found in Ahmednagar district, it is followed by Nashik, Aurangabad, Sangli, Pune and Solapur (Ladha and Jat 2010) [14].

Sodic soils are prevalent in Sangli district including the talukas of Miraj, Palus, Walwa and Tasgaon. They found that the extent of sodic soils in Sangli District is around 28,900 hectares, which is 3% of the total area of the Sangli. Particularly in the Walwa, Tasgaon and Miraj talukas are the Krishna Valley's deep black soils, which are found in irrigated regions. These soils are clayey in texture and dark black in colour. These soils cover 3,892 square kilometers in total (Ghuge and Patil 2013) [7].

The global expansion of soil salinization has resulted in an annual loss of an additional 0.25-0.5 million hectares of land. The formation of salts is primarily attributed to irrigation water, which contributes to the increasing salinization issue. As a consequence, soil sodicity negatively impacts soil structure, causing a reduction in soil aeration, leaching and infiltration rates (Anonymous 2018). The effects of salinity and sodicity on soil structure and hydraulic properties specifically in arid and semi-arid regions. The findings shed light on the pressing need to address these challenges to ensure sustainable agricultural practices in affected areas. (Eldstein *et al.* 2010) [5].

Excessive soluble salts negatively affect soil permeability and structure, leading to reduced plant growth. Sodic and saline-sodic soils encounter specific physical processes that result in structural issues like clay slaking, swelling, dispersion, surface crusting and hard setting. These challenges, in turn, have implications for tillage and germination in sodic and saline-sodic soils. Moreover, they impact water and air movement, plant-available water holding capacity, root penetration, runoff and erosion (Qadir *et al.* 2003) [22].

The measurement of soil infiltration rate holds significant importance in various aspects, such as optimizing irrigation and drainage efficiency, ensuring an adequate water supply for plant growth and metabolism, increasing crop yields and minimizing erosion (Adenji *et al.* 2013) [2].

Accurate knowledge of soil infiltration rate is essential for reliable predictions and control of soil and water-related environmental hazards. Estimating cumulative infiltration is crucial for understanding water entry and distribution within the soil. Soil properties play a crucial role in determining the rate of infiltration, making them essential parameters to consider. Moreover, effective hydraulic evaluation and on-farm water management heavily rely on the soil's infiltration properties. The behavior of infiltration directly influences critical variables in irrigation systems, including inflow rates, run length, application time, percolation depth and tail water runoff (Adenji *et al.* 2013) [2].

Infiltration regulates water reserves that may be used to fill groundwater wells and prevents water runoff and soil erosion. The capacity and rate of infiltration are influenced by the soil's texture, structure, vegetation, water content, temperature and amount of rainfall (Saddiq *et al.* 2016) [26].

Investigated the prediction of soil infiltration rate, recognizing the significance of effective water management in this regard. Enhancing control over soil infiltration can offer solutions to various challenges, such as mitigating flooding, reducing water pollution in surface and groundwater, stabilizing declining water tables, ensuring proper irrigation in agricultural fields, and minimizing the negative impact of Na^+ accumulation on the physical properties of cultivated soil. (Rashidi *et al.* 2014) [23].

There was very little information available in the literature about the spatial variability of infiltration rate in sodic that damaged the soils of KASBE Digraj in the Sangli District. Hence, the present investigation will be undertaken to study the spatial variability of infiltration rate in sodic soils of KASBE Digraj of Sangli District.

Materials and methods

The present research program, conducted in March 2023, focuses on the "Spatial Variability of Infiltration Rate in Sodic Soils of KASBE Digraj of Sangli District". A total of 23 locations representing sodic characteristics were chosen for the study (Table 1). The study area is located in the KASBE Digraj village, Miraj Taluka, Sangli District, Maharashtra State, India which is located on the bank of *Krishna River*. KASBE Digraj receives average annual rainfall of about 453.78 mm mainly received in the period of monsoon i.e., from June to October. Climate is dry and characterized by hot summer and mild winter. Total cultivable area of village is 1097.35 ha out of which about 568 ha. 51.76% has been affected by salinity and it is increasing day by day. Out of total salt affected area 325 ha area is under use of sub-surface drainage system for soil reclamation. (Padalkar *et al.* 2012) [20].

Table 1: The coordinate system of locations collected in sodic soils of KASBE Digraj, Sangli.

Sr. No.	Location of sample	GPS Reading	
		Latitude	Longitude
1	KD 1	16º53.353" NL	074º30'605"EL
2	KD 2	16º53'31" NL	074º30'602" EL
3	KD 3	16º53'418" NL	074º30'585" EL
4	KD 4	16º53'344" NL	074º30'710" EL
5	KD 5	16º53'811" NL	074º30'021" EL
6	KD 6	16º53'863" NL	074º30'001" EL
7	KD 7	16º53'845" NL	074º30'036" EL
8	KD 8	16º53'664" NL	074º30'048" EL
9	KD 9	16º53'038" NL	074º30'249" EL
10	KD 10	16º53'186" NL	074º30'211" EL
11	KD 11	16º53'413" NL	074º30'437" EL
12	KD 12	16º53'974" NL	074º30'451" EL
13	KD 13	16º53'935" NL	074º29'912" EL
14	KD 14	16º53'887" NL	074º29'854" EL
15	KD 15	16º53'921" NL	074º30'395" EL
16	KD 16	16º53'890" NL	074º30'537" EL
17	KD 17	16º55'126" NL	074º30'219" EL
18	KD 18	16º55'144" NL	074º30'226" EL
19	KD 19	16º53'527" NL	074º30'151" EL
20	KD 20	16º53'651" NL	074º30'132" EL
21	KD 21	16º53'997" NL	074º30'066" EL
22	KD 22	16º53'895" NL	074º30'501" EL
23	KD 23	16º53'893" NL	074º30'496" EL

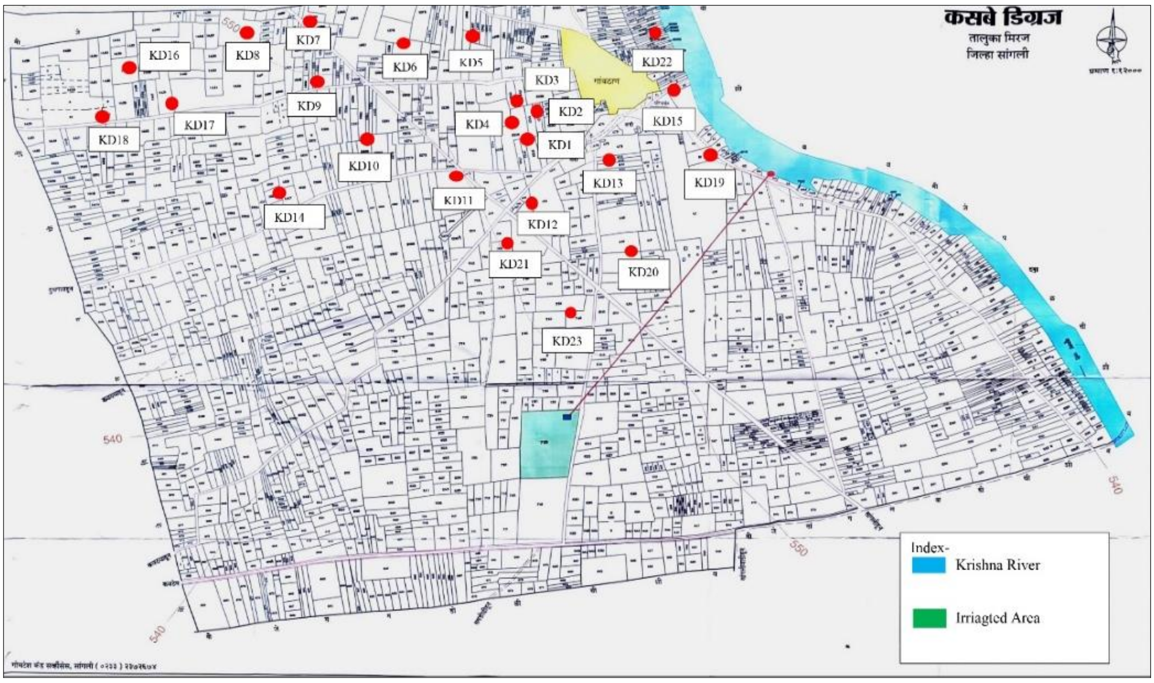

Plate 1: Map of location of soils spots for measurement of infiltration rate of KASBE digraj of sangli district

Double Ring Infiltrometer

The standard double ring infiltrometer set consists of two iron concentric rings. The outer ring has a diameter of 60 cm and a height of 30 cm and is made of 14-gauge rust-resistant galvanized steel sheet and the inner ring has a diameter of 30 cm since a height of 30 cm and it is used to measure the infiltration rate of water. Both rings are designed with one side sharpened for easy insertion into the soil, while the other side remains hard. Both rings are driven 15 cm deep into the soil using a steel plank.

To measure the infiltration rate of soil, the following experimental procedure was followed. First, the outer ring was filled with water, while water was added to the inner ring to achieve a depth of approximately 15 cm. The water level in both rings was carefully maintained at roughly the same level to prevent water seepage between them. After pouring the water, the infiltration depth in the inner ring was estimated by using a measuring scale at regular time interval. The water level in the inner ring was measured using the measuring scale, with readings taken at small time intervals. Finally, the infiltration rate was calculated using the provided formula:

$$\text{Infiltration rate (cm h}^{-1}\text{)} = \frac{\text{Initial water depth (mm)} - \text{Final water depth (mm)}}{\text{Time required (min)}}$$

GPS based soil samples were collected from the sodic soils of the KASBE Digraj Village, specifically from a depth of 0-20 cm, at a distance of approximately one meter from the infiltration ring. These samples were carefully collected and stored in polythene bags. Subsequently, the soil samples were air-dried. Once dried, they were grinded in a wooden mortar and pestle, sieved with 2 mm sieve. This sieving process ensured that the soil samples obtained a consistent particle size for further soil physical and chemical analysis. Soil samples were analysed for soil colour using Munsell soil colour chart, soil textural class by international pipette method (Kilmer and Alexander 1949) [12], bulk density, particle density, porosity and maximum water holding capacity by Keen Box method (Keen and Raczkowski 1921) [11], hydraulic conductivity by using constant head permeameter method (Page *et al.* 1982) [21] infiltration rate using double ring infiltrometer method (Xu *et al.* 2012 [32]. The soil pH was measured by using potentiometric method (Jackson (1973) [9] and electrical conductivity were measured 1:2.5 soil suspension by conductometric method (Jackson (1973) [9]. The organic carbon content of soil was determined by wet oxidation method (Nelson and Sommers 1982). The calcium carbonate ($CaCO_3$) content of soil was determined by acid neutralization method (Allison and Moodie 1965) [3]. The exchangeable Ca^{2+} and Mg^{2+} were determined by using versanate method (Page *et al.* 1982) [21], also the soil samples analyzed for Avail. K^+ and Na^+ by using flame photometer (Knudsen and Peterson 1982) [13], the soil samples were analysed for available N by the alkaline permanganate method (Subbiah and Asija 1956) [31], available P (Olsen- P) by 0.5 M $NaHCO_3$ extraction (Olsen *et al.* 1954), available K (NH_4OAc) by 1N neutral NH_4OAc extraction on flame photometer (Knudsen and Peterson 1982) [13], cation exchange capacity by 1N neutral NH_4OAc extract (pH 7.0) (Sarma *et al.* 1987) [27], exchangeable sodium percentage and sodium adsorption ratio by using formula i.e. ESP (%) = (Exchangeable Sodium (Na^+) / (Cation Exchange Capacity) × 100 and SAR = {Na^+ / √ (Ca^{2+} + Mg^{2+})}. Saturation paste extracts of the sodic soil samples were analyzed includes pHs by potentiometric and EC by conductometric method (Richards 1954) [24]. Carbonates, bicarbonates, chlorides and sulphates were determined using titrimetric method (Richards 1954) [24]. Calcium and magnesium analyzed using versanate method (Page *et al.* 1982) [21] and lastly sodium and potassium were determined using flame photometer (Knudsen and Peterson 1982) [13]. The correlation coefficients between physical and chemical properties were estimated by using the method outlined by Gomez and Gomez (1987) [27].

Results and Discussion

Physical properties of sodic soils of KASBE Digraj

The sand ranged in between 3.145% to 17.5%. The silt content ranged between 27.5% to 32.28%, while the clay content ranged from 55% to 64.57%. All the collected sodic soil samples were clayey in texture contributing to compacted soil structures, reducing pore space's high content of Na^+ and consequently lowering infiltration rates. Similar findings were also reported by Mamedov *et al.* (2001) [16]. The bulk density ranged from 1.35 Mg m^{-3} to 1.52 Mg m^{-3}. There was a slight increase in bulk density of sodic soils. Similar findings were also reported by Maliwal and Somani (2014) [15]. The particle density values ranged between 2.49 Mg m^{-3} to 2.76 Mg m^{-3}. The MWHC values ranged in between 50.35% to 60.28%. The porosity values span a ranged from 49.11% to 57.28%. The FC values ranged in between 48.92% to 54.69%. The PWP values ranged in between 13.98% to 15.62%. The Available Water values ranged in between 34.94% to 39.06%. The Hydraulic Conductivity values ranged from of 0.02 cm h^{-1} to 0.33 cm h^{-1}. The low HC values were because of high clay content and low porosity. Similar findings were also reported by Srivastava *et al.*, (2014) [29].

Chemical properties of sodic soils of KASBE Digraj

The pH values ranged in between 8.33 to 8.87. The pH was alkaline in nature. Similar findings were also reported by Sabah *et al.* (2014) [25] and Maliwal and Somani [15]. The EC values ranged in between 1.24 dS m^{-1} to 3.2 dS m^{-1}. The EC values indicates that soils are sodic in nature. The organic carbon values between 0.23% to 0.89%. Organic carbon values were low to high in category. The $CaCO_3$ values ranged between 7.5% to 14.25%. The soils were found to be calcareous in nature. The value of N ranged from 113 kg ha^{-1} to 213 kg ha^{-1}, P ranged from 2.29 kg ha^{-1} to 7.66 kg ha^{-1} for P and K ranged from 348 kg ha^{-1} to 389 kg ha^{-1}. The available N content was low, available P was very low and available K was very high in sodic soil. The values of Ca^{2+} ranged from 10.07 meq 100 g^{-1} to 11.66 meq 100 g^{-1}, Mg^{2+} ranged from 5.36 meq 100 g^{-1} to 7.54 meq 100 g^{-1}, Na^+ ranged in between 10.26 meq 100 g^{-1} to 14.43 meq 100 g^{-1} and K^+ ranged from 7.98 meq 100 g^{-1} to 8.90 meq 100 g^{-1}. The CEC values ranged between 46.6 meq 100 g^{-1} to 60.73 meq 100 g^{-1}. CEC capacity of soil was high however sodium cation was dominant as compared to Ca^{2+}, Mg^{2+} and K^{+}. Exchangeable Sodium Percentage (ESP) levels ranged between 18.49% to 29.53%. The studies conducted by Kazman *et al*. (1983) [10], Mamedov *et al*. (2001) [16] closely align reinforcing its observations regarding the relationships between exchangeable sodium percentage, wetting rate, soil texture and their effects on infiltration rate.

Saturation Paste Extract Properties of Sodic Soil in Sodic Soils of KASBE Digraj

The pHs values ranged between 8.39 to 8.92. The ECe values ranged between 2.47 dS m^{-1} to 3.87 dS m^{-1}. Similar results were also close in conformity with Sabah *et al*. (2012) [25] and Gao *et al*. (2019) [6]. The carbonates value ranged between 1.8 meq L^{-1} to 4.8 meq L^{-1}. Bicarbonate values ranged between 9.1 meq L^{-1} to 15.7 meq L^{-1}. The chloride concentrations ranged between 3.9 meq L^{-1} to 4.16 meq L^{-1} and sulphate values ranged between 1.14 meq L^{-1} to 7.95 meq L^{-1}. Calcium ion concentrations ranged between 3.2 meq L^{-1} to 5.8 meq L^{-1}. Magnesium ion concentrations ranged between 0.6 meq L^{-1} to a 3.6 meq L^{-1}. Sodium ion concentrations ranged between 32.13 meq L^{-1} to 49.47 meq L^{-1} potassium ion concentrations range from a minimum of 0.06 meq $L^{-1}$to a maximum of 1.26 meq L^{-1}. Singh *et al*.'s (2011) [28] study, we found alignment in the impact of sodium ions on soil hydraulic properties. The anions bicarbonate concentration was higher followed by chlorides, carbonate, sulphates, respectively. Na^{+} showed higher concentration followed by Ca^{2+}, Mg^{2+} and K^{+}. The SAR values ranged between 15.09 to 21.30. The SAR values were greater than 13 in all the locations of sodic soils. Similar findings were also reported by Aboukarima *et al*. (2018) [1] and Gao *et al*. (2019) [6].

Infiltration rate and cumulative infiltration rate of sodic soils of KASBE Digraj of Sangli District

The estimated infiltration rates and cumulative infiltration rates of sodic soils of KASBE Digraj of Sangli District are depicted in Table.2 and graphically presented in Fig.1and Fig. 2. The study of Infiltration was conducted on 23 locations of sodic soils of KASBE Digraj village of Sangli District. The results indicated that the sodic soils might have the lower infiltration rates due to high mean value of clay and lower mean values of silt followed by sand, the observed infiltration rates in sodic soils of KASBE Digraj of Sangli District were recorded over a specific period of time, ranging from 2 minutes to 90 minutes.

At the beginning of the observation, at 2 minutes, the infiltration rate was the highest, with a value of 117.39 mm h^{-1}. However, as time progressed, the infiltration rate gradually decreased. After 5 minutes, it dropped to 75.16 mm h^{-1}, indicating a substantial decline. Further, at 10 minutes, the infiltration rate decreased even more, reaching 38.08 mm h^{-1} and by 20 minutes, it dropped to 24.78 mm h^{-1}. As time continued to elapse, the infiltration rate in the sodic soils of KASBE Digraj village continued to decrease at a slower pace. At 30 minutes, the rate was recorded at 18.78 mm h^{-1}, and at 60 minutes, it had declined to 15.81 mm h^{-1}. Finally, after 90 minutes of observation, the infiltration rate reached its lowest value, measuring only 12 mm h^{-1}. From the data, it is evident that the infiltration rate in sodic soils tends to decline over the time increases. This decreasing trend of infiltration rate in sodic soils could be attributed to various factors, such as platy structure, low porosity and the presence of excess Na^{+} ions.

Table 2: Spatial variability of infiltration rates in sodic soils of KASBE Digraj

Locations	Time (min)											
	2	5	10	20	30	40	50	60	70	80	90	100
KD 1	120	40	12	18	6	12	6	18	6	12	12	-
KD 2	150	60	24	30	24	30	24	24	-	-	-	-
KD 3	180	20	24	6	6	6	-	-	-	-	-	-
KD 4	120	140	60	36	42	30	12	12	12	-	-	-
KD 5	90	40	36	24	12	12	-	-	-	-	-	-
KD 6	120	100	24	54	30	48	30	30	36	36	36	-
KD 7	150	120	60	18	12	6	6	6	-	-	-	-
KD 8	180	140	120	72	54	36	36	36	-	-	-	-
KD 9	90	80	48	18	18	18	-	-	-	-	-	-
KD 10	60	100	72	36	18	18	18	18	18	-	-	-
KD 11	90	20	12	18	12	12	12	12	-	-	-	-
KD 12	90	100	72	30	36	18	18	12	18	18	18	-
KD 13	90	20	12	6	6	6	6	6	6	-	-	-
KD 14	90	20	18	15	6	6	6	-	-	-	-	-
KD 15	60	70	30	24	12	6	6	6	-	-	-	-
KD 16	150	60	18	9	6	6	6	-	-	-	-	-
KD 17	90	40	12	18	6	6	18	12	6	18	6	6
KD 18	120	100	48	36	36	36	-	-	-	-	-	-
KD 19	120	60	48	24	30	30	30	30	30	-	-	-
KD 20	90	80	48	18	18	18	18	18	-	-	-	-
KD 21	120	60	24	24	12	6	6	6	-	-	-	-
KD 22	210	120	48	30	36	36	36	-	-	-	-	-
KD 23	120	80	24	6	6	6	6	-	-	-	-	-

The infiltration rates in sodic soils of KASBE Digraj, Sangli District, were monitored at various time intervals, ranging from 2 minutes to 90 minutes. The cumulative infiltration rates at each time were noted over time. At the initial 2-minute mark, the cumulative infiltration rate was recorded as 113.91 mm h^{-1}. As time progressed, the soil's ability to absorb water increased, and at the 5-minute mark, the rate rose to 179.56 mm h^{-1}. This indicates that the soil's permeability improved, allowing water to penetrate more efficiently. Continuing the observation, at the 10-minute interval, the cumulative infiltration rate further increased

Table 3: Observed infiltration rate (mm h^{-1}) in sodic soils of KASBE Digraj of Sangli District

Time (min)	Infiltration Rate (mm h^{-1})	Infiltration Rate Average (mm h^{-1})
2	2700	117.39
5	1728.8	75.16
10	876	38.08
20	570	24.78
30	432	18.78
60	174	15.81
90	8	12

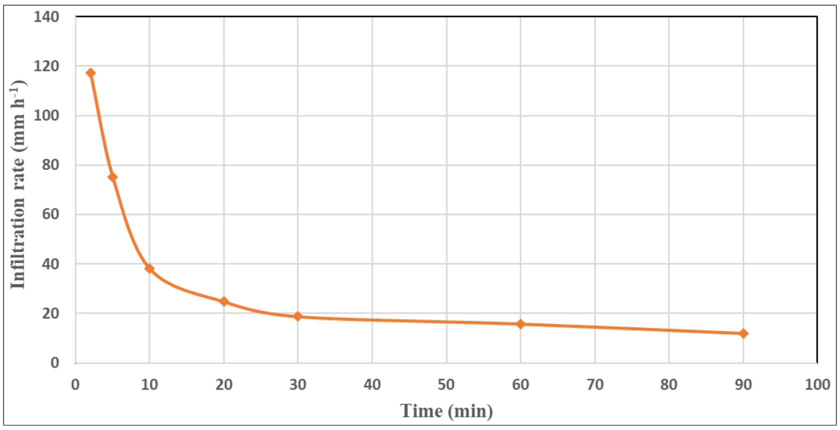

Fig 1: Infiltration rate vs. time of sodic soils of KASBE Digraj of Sangli District

to 228.86 mm h^{-1}. The soil continued to demonstrate its water-absorbing capabilities as the rate kept rising. By the 20-minute mark, the cumulative infiltration rate reached 253.65 mm h^{-1}, signifying a consistent trend of enhanced water penetration into the sodic soils. The 30-minute mark, the cumulative infiltration rate rose to 273.47 mm h^{-1}, showing that the soil's ability to facilitate water infiltration remained steady over time. Even after an hour (60 minutes), the soil exhibited a high infiltration rate of 343.27 mm h^{-1}. Finally, after an observation period of 90 minutes, the cumulative infiltration rate in the sodic soils reached 362 mm h^{-1}. The infiltration rates observed in sodic soils of KASBE Digraj village are influenced by various soil parameters. Sodic soil conditions, characterized by high clay content and excess sodium ions, have a notable impact on infiltration behavior. The presence of clay particles in the soil can lead to compaction, reducing soil permeability and hindering water penetration. Additionally, the high sodium content can further exacerbate soil dispersion and reduce infiltration rates. Factors responsible for sodic soil conditions in the area may include poor drainage, inappropriate irrigation practices, and high levels of sodium in the irrigation water.

The data reveals significant spatial and temporal variability in infiltration rates among sodic soils in the KASBE Digraj area of Sangli district. This variability has implications for land amelioration and reclamation. water management strategies. By understanding these dynamics, stakeholders can make informed decisions to optimize water usage and promote sustainable agricultural practices in the region of KASBE Digraj of sodic soil. A non-linear regression analysis was conducted on the infiltration rate data over time for the sodic soils in the region of KASBE Digraj, located in Sangli District. The resulting equation from this analysis is given as:

Infiltration Rate (Y) = $61.282e^{-0.022X}$ (R^2 = 0.6532)

The coefficient of determination (R^2) for this equation is 0.6532, which indicates that 65.32% of the variability in the infiltration rate can be explained by the time variable. The coefficient of determination (R^2) for this exponential equation is 0.7403, suggesting that about 74.03% of the variability in the cumulative infiltration rate can be attributed to the time variable. These regression models provide valuable insights into the behavior of infiltration rates in sodic soils of KASBE Digraj.

Table 4: The observed cumulative infiltration rate (mm h^{-1}) in sodic soils of KASBE Digraj of Sangli District

Time (min)	Cumulative Infiltration Rate (mm h^{-1})	Cumulative Infiltration Rate Average (mm h^{-1})
2	2620	113.91
5	4130	179.56
10	5264	228.86
20	5834	253.65
30	6290	273.47
60	3776	343.27
90	1448	362

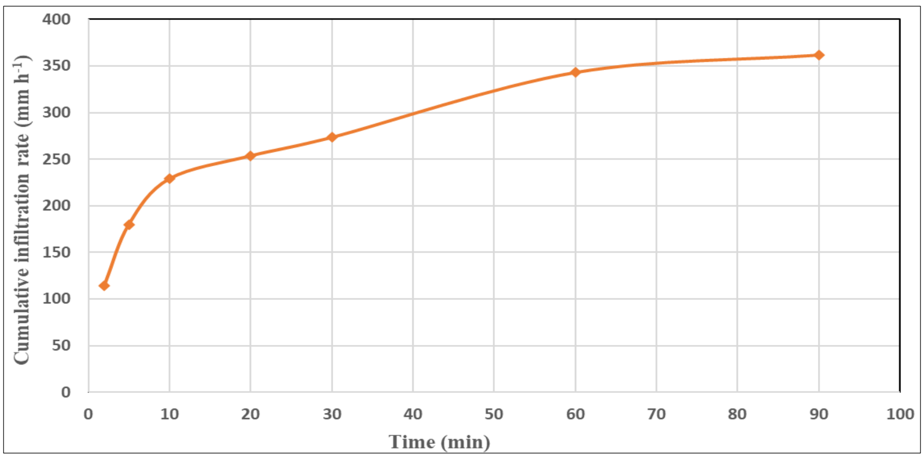

Fig 2: Cumulative infiltration rate vs. time of sodic soils of KASBE Digraj of Sangli District

Furthermore, a separate exponential regression analysis was performed on the cumulative infiltration rate data of the same sodic soils in KASBE Digraj. The exponential equation obtained from this analysis is.

Cumulative Infiltration Rate (Y) = $172.81e^{0.01X}$ ($R^2 = 0.7403$)

The electrical conductivity shows a significant positive correlation with the cumulative infiltration rate and negative correlations exist between clay content, bulk density, calcium carbonate levels, exchangeable sodium and cation exchange capacity with cumulative infiltration rate mentioned in table 5.

Table 5: Correlation coefficient between soil physico - chemical properties and cumulative infiltration rate

Parameters	C IR
EC	0.355*
BD	-0.434**
$CaCO_3$	-0.361*
Na	-0.471**
CEC	-0.351*

Conclusion

From the above study it can be concluded that, the physical properties like texture, bulk density, hydraulic conductivity along with chemical properties such as exchangeable sodium, sodium adsorption ratio, exchangeable sodium percentage, pH and electrical conductivity showed the impact on behavioral pattern of infiltration. The above mentioned physico-chemical properties harm the entry of water in soil profile resulted in reduction of infiltration rate. Presence of more amount of clay greatly influences the infiltration behaviour of sodic soils.

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