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Rate of evaporation of various water sources with special emphasis on salinity

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ABSTRACT

Salinity is an important criterion in many water quality analyses conducted worldwide to determine its influence on the characteristics of the water bodies. Despite substantial evidence on the influence of salinity on evaporation rates, there remains a notable gap in understanding the holistic effects of these water quality parameters and the climatic factors under different salinity levels have not been thoroughly explored. This study aims to bridge this gap by analyzing the combined effects of these variables on evaporation rates in the Batticaloa district, considering both laboratory-prepared treatments and natural water samples. from the Batticaloa lagoon, irrigation tanks and nearby sea. Throughout the investigation, solid concentrations, temperature, humidity, rainfall, wind speed, solar radiation, and air pressure were measured, and salinity was adjusted in controlled samples. The study identified a noteworthy anomaly that higher salinity levels reduced the correlation between climatic factors and evaporation rates, with an average notable decrease in evaporation rate by 0.044% for every 1% increase in salinity with fit value of $R^2 > 0.9$ for all the different salinity treated samples. The study found that the combined effect of increasing temperature and decreasing water height results in higher evaporation rates over time. Turbidity significantly affected evaporation rates, with higher turbidity slowing down evaporation due to suspended particles, also combined high salinity and turbidity drastically reduced evaporation rates. This research offers insightful information on the circulation of water and the related processes for managing water resources particularly in areas where freshwater and saltwater ecosystems overlap.

Keywords: Evaporation rate, Relative Humidity, Salinity, Temperature, Turbidity

INTRODUCTION

Water, a crucial resource for sustaining life, exists in many forms and is spread throughout various ecosystems. To understand the complex dynamics of water systems, it is important to examine the elements that influence their behavior. One such crucial component is salinity (Onen, 2019), which is a measure of dissolved salts in water and has a substantial impact on the hydrological and ecological properties of aquatic ecosystems.

This study investigates the effect of salinity on evaporation, with a focus on water bodies tucked within the landscape of the Batticaloa District. Nestled on Sri Lanka's eastern coast, this region is endowed with a complex system of lagoons, estuaries, and inland water bodies, each of which contributes uniquely to the area's ecological balance. The combination of salinity levels and evaporation rates in these bodies of water is critical to understand the complex mechanisms that determine their long-term survival and resilience. Evaporation, or the process by which water changes from liquid to vapor and returns to the atmosphere (Britannica, 2023), is a basic component in the Earth's water cycle. However, the effect of salinity on this process adds another degree of complication since dissolved salts change the physical properties of water, changing its thermodynamic characteristics. This complex link between salinity and evaporation is critical, particularly in areas like Batticaloa, where freshwater and saltwater ecosystems coexist. The depletion of water bodies is a major life threat to the surrounding peoples by the means of economic losses and the dusty winds (Wurtsbaugh et al., 2017). Biazar et al. (2020) found that a considerable portion of the water bodies in arid and semi-arid areas is lost through evaporation, and the evaporation from the water bodies has a strong correlation with surface water salinity. In another way, saturated vapour pressure above the water body is the major depending factor for evaporation, but it is affected by the ion activity coefficient (Kokya & Ahmadzadeh Kokya, 2008), which implies the salt concentration of the water bodies (salinity). Therefore, salinity has a substantial effect on evaporation and it should be researched. Accordingly, the present study was conducted to investigate the behavior of the evaporation of different water sources with special reference to salinity and validate through real spatially diversified samples where climatological factors were incorporated for clear understanding.

METHODOLOGY

The experiment was conducted in the field at the Faculty of Agriculture premises, Eastern University, Sri Lanka, near the weather station in local climatic conditions during July and September, where the east coast of Sri Lanka sees weather defined by mild temperatures ranging from 27 to 35 °C, moderating humidity ranges from 60% to 80%, and wind urges with a speed between 1.00 and 1.50 m/s with minimal rainfall (Data from EUSL weather station).

Sample location and collection

Initially, the study identified two major irrigation reservoirs named Unnichai and Rugam and extended to 5 spatially diversified locations in the Batticaloa lagoon named Palameenmadu, Pankudavali, Puthoor, Pillayaradi, Puliyantheevu Fort Park and a water sample from sea at

Kallady as the Batticaloa lagoon is exhibit salinities changed from completely fresh to hyper-saline(Sugirtharan et al., 2014) shown in Figure 1 and labeled as S0, S1, S2, S3, S4, S5, S6, S7 and S8 respectively. Prior to sampling at each location, the sampling cans were rinsed with the sample water that was drawn at a depth of one foot below the water surface. Water samples were collected in 30-liter cans that were labeled with the respective places.

Treatment preparation

Prior to the treatment preparation, the salinity of the water was measured at the Department of Agricultural Engineering, Eastern University, Sri Lanka (AE-EUSL) and salt (NaCl) was added into the water in order to bring out the specified saline concentrations of 0 ppt, 5 ppt, 10 ppt, 15 ppt, 20 ppt, 25 ppt, 30 ppt and 35 ppt and labeled the samples as T0, T1, T2, T3, T4, T5, T6, and T7 respectively.

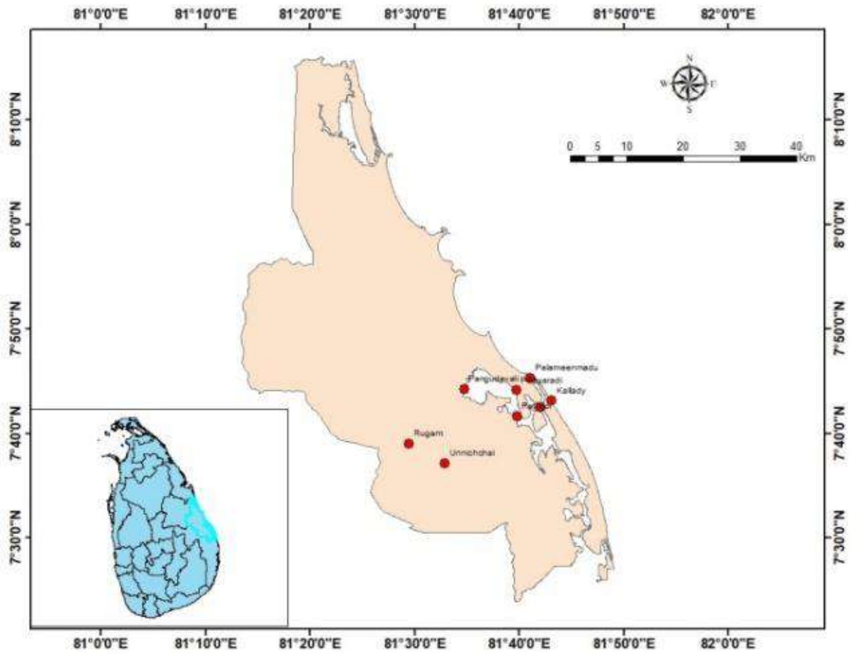

Figure 1. Water sample locations

Measurement and data collection

Climate factors

The major climatic factors that contribute to the changes in evaporation of water are atmospheric temperature (˚C), relative humidity (%), rainfall (mm), wind Speed (m/s), solar radiation (W/m^2) and atmospheric pressure (mbar). The study was carried out in the month of September from 10th to 23rd (14 days), where the climate is slightly sunny with no rainfall (Table 1). The numerical values of all the above factors were measured from the weather station (Model 2000 series watch dog WS), installed at the AE-EUSL premise to ensure the accuracy of the study.

Table 1. Values of climatic factors

Day	Atmospheric Temperature (˚C)	RH (%)	Rainfall (mm)	Wind Speed (m/s)	Solar Radiation (W/m²)	Atmospheric Pressure (mbar)
1	33.08	79.86	0.00	1.48	274.1	1006.82
2	33.96	79.86	0.00	1.19	275.2	1007.15
3	34.14	81.09	0.00	1.55	246.0	1007.06
4	34.23	77.85	0.00	1.21	241.3	1006.96
5	35.59	81.02	0.00	1.45	275.0	1008.57
6	35.66	79.23	0.00	1.54	242.5	1010.14
7	36.10	74.36	0.00	1.32	250.6	1010.45
8	36.43	79.43	0.00	1.56	271.2	1008.55
9	36.97	79.11	0.00	1.44	276.6	1008.11
10	36.52	78.95	0.00	1.30	253.0	1008.52
11	36.08	81.00	0.00	1.27	229.2	1008.39
12	36.57	76.07	0.00	1.32	249.5	1008.01
13	36.98	79.33	0.00	1.34	257.0	1007.89
14	36.49	78.33	0.00	1.50	240.0	1008.15

Water quality parameters

The samples were transferred to the laboratory after the in-situ measurements taken at each location for Temperature and water quality parameters such as Electrical Conductivity (EC), pH and Total Dissolved Solids (TDS). A digital pH/EC/TDS meter (HANNA-Model HI 98130, make) was used, where turbidity and salinity were assessed using a turbidity meter and refractometer, respectively. Before the measurement's instruments were calibrated at the water quality lab of the Department of Agricultural Engineering, Eastern University, Sri Lanka (AE-EUSL). Total Solids (TS) were measured by evaporating water sample in an already weighted dish (W_0), and then drying the residue in an oven at 105 °C (W_s). The weight difference between the oven dried dish + sample and the initial weight of the dish (W_s-W_0) represents the total solids.

Evaporation

All treated samples and spatially collected samples were controlled with free evaporation with a "Class A" U.S. evaporation pan which was accepted by most of the researchers(Chu *et al.*, 2012; Zhang, 2015), at the field of AE-EUSL. The "Class A" U.S. evaporation pan has 250 mm in height and 1207 mm in diameter, it was installed on a timber platform, leveled and set on a flat area of land free from bushes, trees, and other obstructions. Similar to that, eight identically sized basins were placed close to the evaporation pan, each measuring 500 mm (sample water filled up to 250 mm) in height and 750 mm in diameter to identify the daily evaporation rates (Water level reduction taken at the site every day in the same time, referred as evaporation rate with unit mm/day) as shown in Figure 2.

Figure 2. (a) Class A evaporation pan (b) Basins used at the field for evaporation

RESULTS AND DISCUSSION

The weather conditions which may influence the evaporation of the surface water as mentioned by (Rayner, 2007; Liu et al., 2011) were recorded in the present study and shown in Table 1, which indicates the fact that no rainfall occurred during the research. The first week (1 to 7th day) weather data are respect to the evaporation rates of collected water samples from diverse water sources in the Batticaloa district (spatial variation), whereas the second week (7 to 14th day) data are respect to the evaporation rates of prepared treatments (with different saline concentrations).

Table 1 shows the in-situ observed data of the weather conditions where the experiment was carried out. It is noted from Figure 3, that the evaporation rate increased with the temperature, solar radiation and wind speed as stated by several authors (Arnell & Reynard, 1996; Beare & Heaney, 2002; Schouten et al., 2011; Özgür & Koçak, 2015). Conversely, the increase in relative humidity decreased the evaporation, Farhat (2018) also reported similar results. A high R^2 of 0.78 was obtained for the temperature, only for the sample with less initial concentration of salinity (5 ppt) and it is noted that with the increase of salinity, the correlation of evaporation with climate factors is getting reduced. Despite this, relative humidity, solar radiation and wind speed did not significantly correlate with any level of salinity by fitting $R^2 < 0.15$, the results underscore the presence of other influential factors affecting evaporation as the evaporation rate varies throughout the experiments.

This study mainly focuses on understanding the effect of salinity on the evaporation rate of the water surface. In order to determine the effect of salinity, other water quality parameters of each sample were measured and presented in Table 2 and Table 3 for treated (T) and collected (S) samples respectively. The collected data of evaporation rates obtained daily for different saline concentrated treatments were analyzed for distribution and the summary is given in Figure 4, where the considerable difference in mean and skewness represents the effect of salinity on evaporation as salinity is only the controlled parameter.

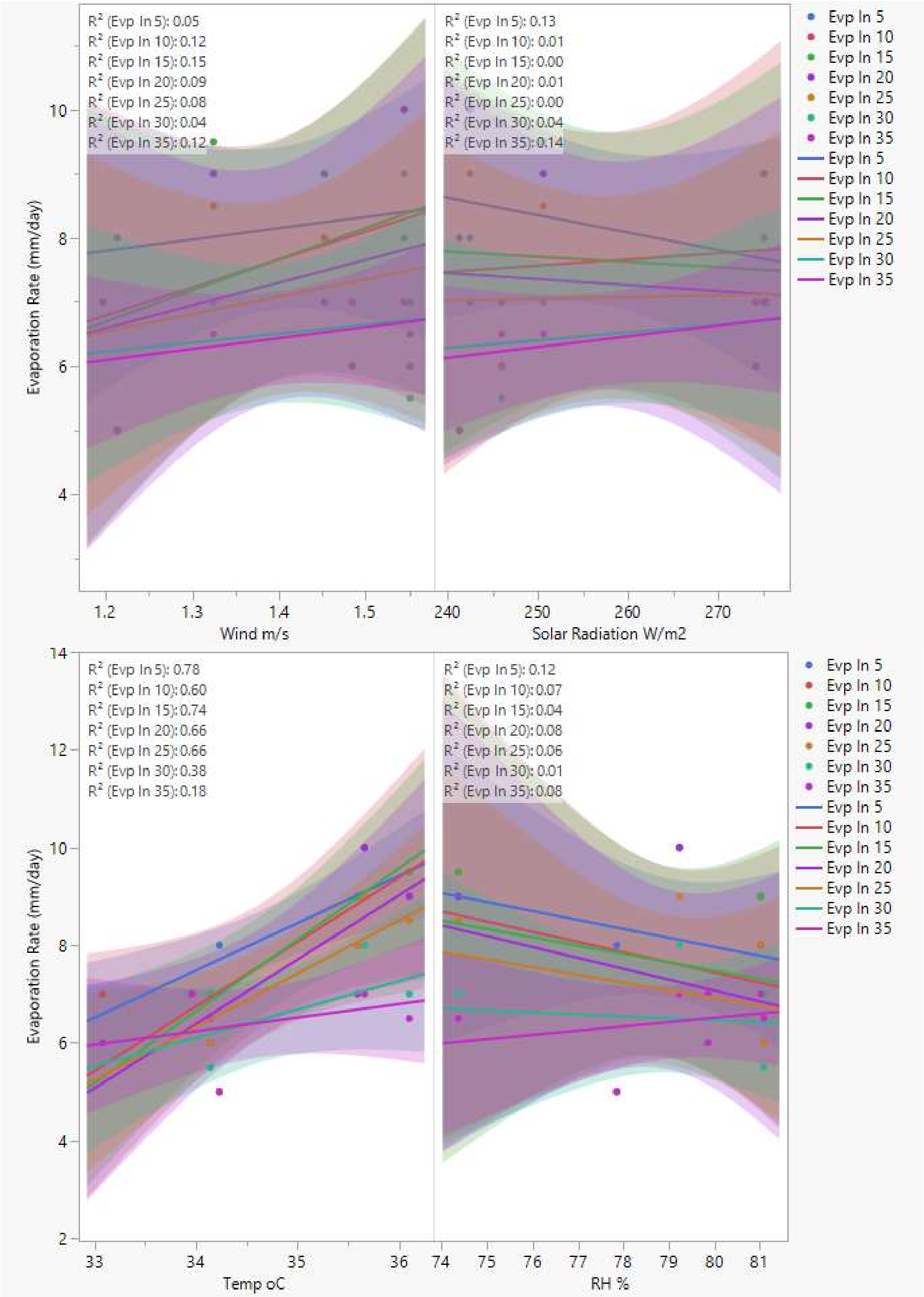

Figure 3. Variation of evaporation with climatic factors

Table 2. Water quality parameters for treated samples

Treatment	Salinity (ppt)	pH	EC (mS/m)	Turbidity (FTU)	Total Solid (ppt)
To	0.0	7.0	0.410	1.37	0.020
T1	5.0	6.7	7.250	1.04	5.030
T2	10.0	6.5	8.540	1.04	10.02
T3	15.0	6.4	9.180	0.91	15.01
T4	20.0	6.3	9.550	0.97	20.03
T5	25.0	6.2	9.790	1.03	25.02
T6	30.0	6.1	9.930	0.90	30.03
T7	35.0	6.0	10.03	1.14	35.03

Table 3. Water quality parameters for collected samples

Sample	Place	pH	EC (mS/m)	Salinity (ppt)	Turbidity (FTU)	Total solid (ppt)
So	Well water	7.0	0.410	0.00	1.020	0.0200
S1	Fort park	8.1	8.790	14.0	3.080	14.640
S2	Pankudavali	8.1	6.750	6.00	4.850	7.0200
S3	Pillayaradi	9.0	7.140	18.00	37.18	8.2800
S4	Palameenmadu	8.7	9.050	16.0	20.000	18.200
S5	Unnichai	8.6	0.050	1.00	5.680	1.0400
S6	Rugam	9.1	0.100	0.00	28.61	0.1600
S7	Kallady	8.4	10.05	35.0	1.790	61.120
S8	Puthoor	9.0	7.990	8.00	8.230	10.230

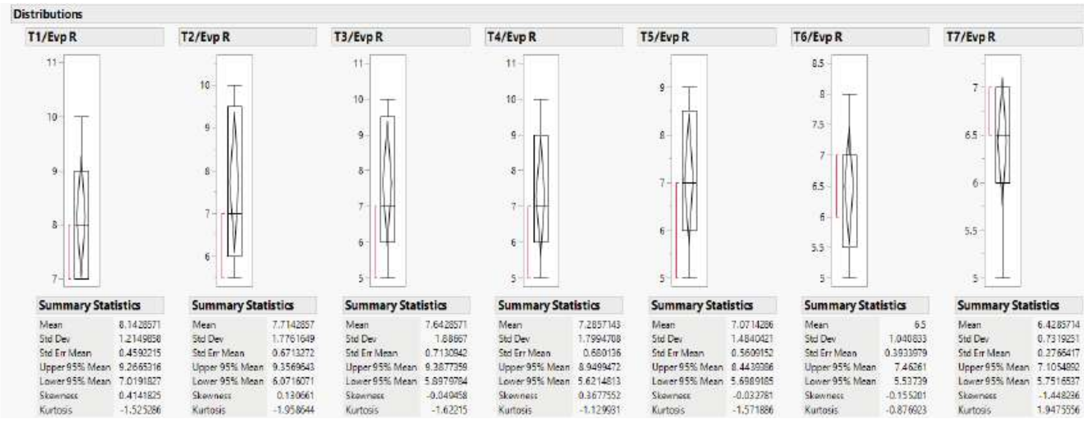

Figure 4. Distribution of data of evaporation rates of each treatment

Similar to Lee (1927) and Suchan & Azam (2021), the evaporation rate decreased with the increase of salinity for all the treatments and samples as graphically illustrated in Figure 5 and Figure 6. Despite that, the present study deviates slightly from Lee (1927) finding that for every 1% increase in the salinity, the evaporation rate was reduced by 0.01%, while the present study analyses the variation by changing the salinity from 5 ppt to 35 ppt with 5 ppt interval, where the relation is identified as every 1% increase in salinity there was a 0.044% of the decrease in evaporation rate. In contrast, the relationships between the evaporation rate and salinity of the treatments were fitted with the $R^2 > 0.9$, where it does not happen for the spatially collected samples shown in Figure 7. The major difference observed is the turbidity and it was addressed in Table 2 and Table 3, where the turbidity of treated samples is approximately 1 Nephelometric Turbidity Unit (NTU) and the collected samples vary significantly from 1 – 37 NTU. It is identified that in turbid water where particles are high, once the water gets evaporated, water surface itself forms a suspended film and slows down the evaporation process, also weak Van der Waals forces between suspended particles and water molecules may also be another reason which reduces the evaporation rate with time.

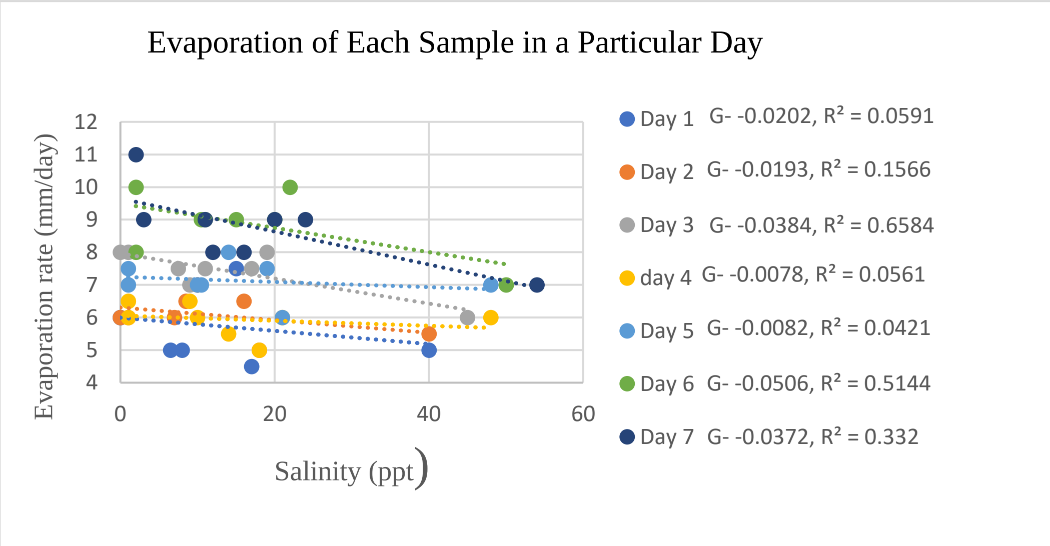

Figure 5. Daily evaporation of each collected sample

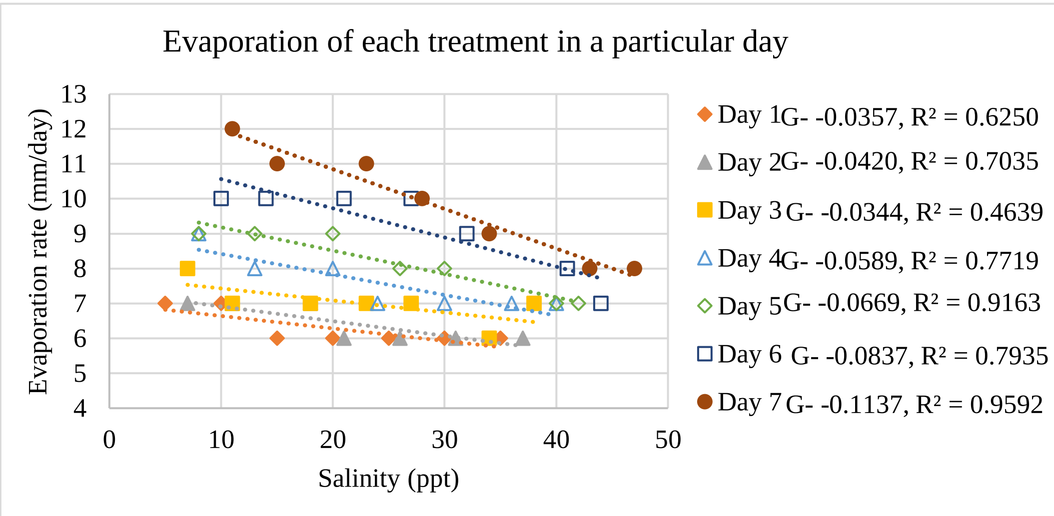

Figure 6. Daily evaporation of each treatment

The study measured the evaporation rates and respective salinity for each treatment and the collected samples. Where it is noted that the gradient of the line of fit is decreasing from 1.36 – 0.14 when the initial saline concentration is increasing from 0 – 40 ppt respectively. With time the water column height in the basin decreases, therefore the rate of evaporation might increase with the decrease in water height by validating the conclusion of Doe, 2021 that the water height decreases, the surface area-to-volume ratio increases, leading to a significant rise in evaporation rates. In addition, it is noted that the temperature is also increasing continuously with time, where the study found a considerable positive correlation for evaporation rate with temperature. Therefore, it can come to an understanding that the combined effect of both temperature and the decrease in water height pave the way to increase in water evaporation rate with time. However, as the study identified, the gradient is decreasing (Green marked in Figure 7) with the increase in saline concentration validating that the salinity is having a significant effect on evaporation rates.

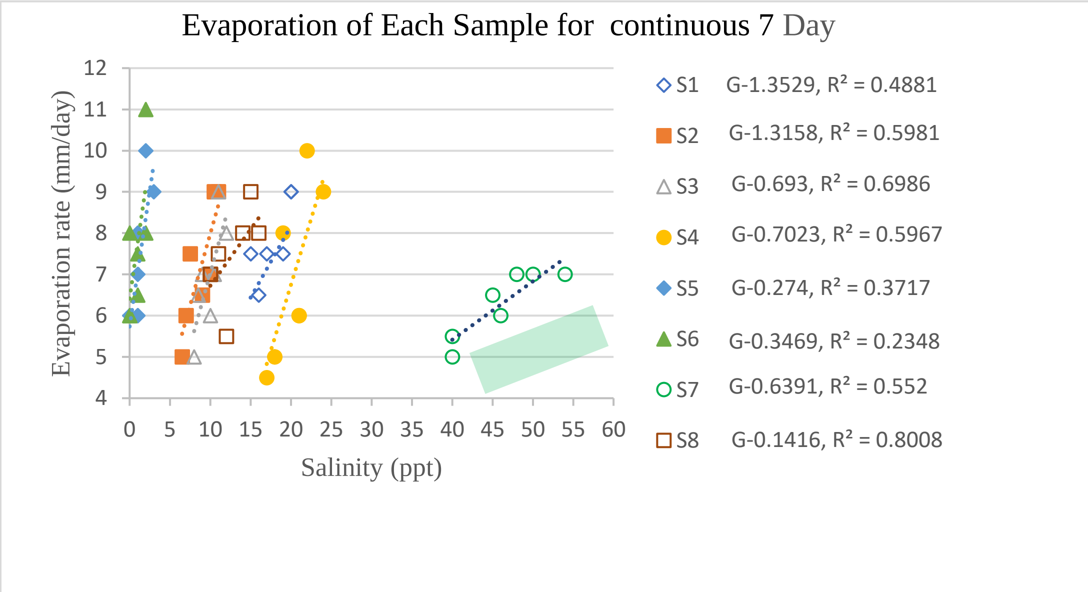

Figure 7. Evaporation rate of spatially collected samples for continuous 7 days

For further understanding, the spatially collected samples were plotted for the same scenarios as shown in Figure 8 and validated the same conclusion. To validate the combined effect of salinity, and turbidity on the evaporation the surface plot is drawn as shown in Figure 9. Where the red colored surface proves that an increase in salinity does not effectively reduce the evaporation. In contrast, the blue surface validates the concept that the combined effect of both high salinity and high turbidity drastically reduces the evaporation.

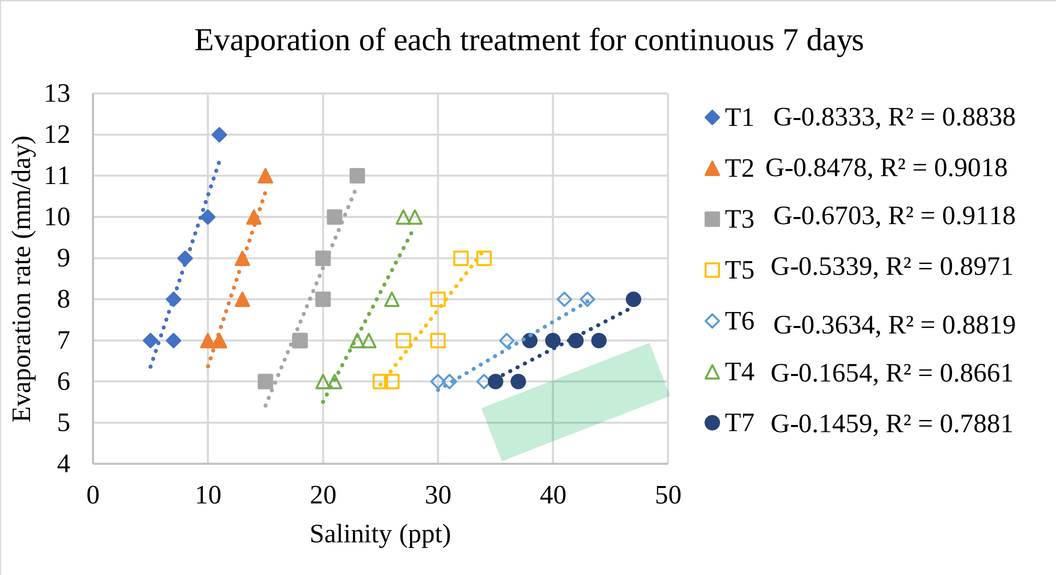

Figure 8. Evaporation rate of treated samples for continuous 7 days

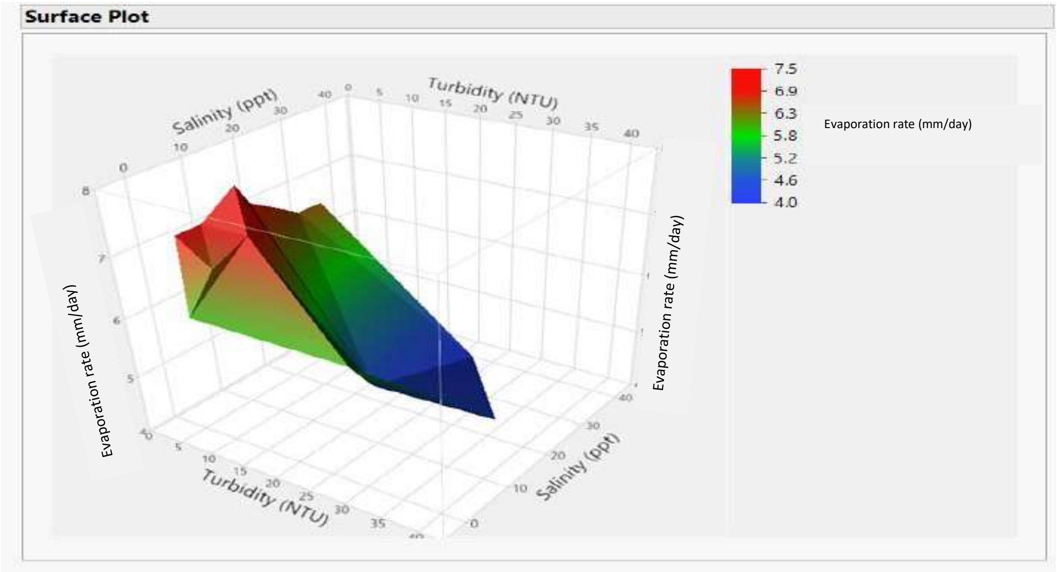

Figure 9. Combined effect of both salinity and turbidity on evaporation

CONCLUSION

The temperature, solar radiation, and wind speed positively influenced evaporation rates, whereas relative humidity has a negative correlation. Higher salinity levels reduced the correlation between climatic factors and evaporation rates, with a notable decrease in evaporation rate by 0.044% for every 1% increase in salinity. There is a strong correlation between evaporation rates and salinity in controlled treatments ($R^2 > 0.9$), but not in spatially collected samples, highlighting the influence of other factors like turbidity. Turbidity significantly affected evaporation rates, with higher turbidity slowing down evaporation due to suspended particles, also Combined high salinity and turbidity drastically reduced evaporation rates. The study found that the combined effect of increasing temperature and decreasing water height results in higher evaporation rates over time. Therefore, it is recommended to analyze the influence of different turbidity levels by changing the water column height on the evaporation rates.

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Culture and identity of indigenous ethnic communes in changing social order: The case of coastal Vedda communities in Eastern Sri Lanka

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ABSTRACT

The study takes the ethnic identity of coastal Vedda communities of the Eastern province of Sri Lanka to analyze the impacts of social changes and cultural assimilation on identity shifts of those indigenous ethnic communities. This study sets its theoretical background on constructivists' paradigm that ethnic identity is not a static phenomenon, but it's a formation of social and historical processes. It is a descriptive study based on a qualitative method, and primary data collection was done by ethnographic fieldwork. This study comparatively looks at two different clusters of Vedda villages in Vaharai and Kiran Divisional secretariats of Batticaloa district. Initially, the coastal Vedda people tended to blend in with the Tamil ethnic populations in the nearby villages, losing their unique identity. Nonetheless, they were unable to completely give up their native culture and merge into the Tamil ethnic community. Instead, they continued to practice some traditional cultural practices that seemed essential to their social survival in their communities. The traditional understanding of their nature does not align with their assimilated society today. Their spiritual beliefs are presented to the new values. Contrasted identities among Vedda people with regard to their worldview resulted from the confronted realities between culture, nature, and supernature. Since new values affect the worldview of those in the community who share a sense of identity, they should be adapted to nature and accommodated into its supernature when they integrate with the existing traditional values of culture. Coastal Vedda people had identity uncertainty due to their confused worldviews, assimilated way of life, and retention of tangible cultural aspects.

Keywords: Assimilation, Ethnopolitics, Marginalization, Social transformation, Worldview

INTRODUCTION

There are three types of Vedda communities in Sri Lanka; Rock or Forest dwelling Veddas, Village Veddas and Coastal Veddas identified by studies on indigenous people in Sri Lanka (Seligmann & Seligmann, 1911). Ethnographic studies on Vedda communities in Sri Lanka revealed that a larger number of Veddas culturally intermingled with the dominant ethnic groups in their areas and particularly integrated into Sinhalese or Tamil ethnic communes (Wijesekera, 1964; De Silva & Punchihewa, 2011). However, in the post-war period, tendencies have been triggered towards re-indigenization of Veddas and revitalization of aboriginal identity.

This study is based its attention on coastal Veddas, scattered in maritime villages of the Eastern province of Sri Lanka, as a distinctive cultural group among Sri Lankan Veddas. From antiquity, they were identified as aboriginal communities of the region. However, their aboriginal status has not been gloriously reputed by Tamil caste communities and though coastal Vedda communities were not traditionally included in the Tamil caste hierarchy, according to their status ranking, Tamils deemed Vedda as the lowest status group. At the outset, indigenous culture, a semi-nomadic lifestyle, illiteracy and economic backwardness caused their identity-based marginalization by the other communities living in the vicinity of coastal Vedda villages. Development intervention by the state and non-state actors and related modernization activities exerted significant influence on bringing about socio-economic changes among coastal Vedda communities and impacted their indigenous culture. Gaining socio-economic advancements, to avoid marginalization, coastal Vedda people started to adopt Tamil culture and assimilate with Tamil communities, which predominantly inhabited their region. However, they could not entirely intermingle with Tamils since coastal Vedda communities have been kept on having certain indigenous cultural elements in their social life and therefore, their aboriginal identity is still recognizable for other ethnic communities living in the region.

The main argument of this study revolves around a theoretical underpinning that ethnic identity is not a static phenomenon since no fixed aspects determine the identity of a group. It is all about the contexts of the group living in and their conduct with other groups living around (Brass, 1974). In the coastal Vedda case, identity is shaped by their social conduct with other ethnic groups and historically manipulated throughout the contexts during the war and post-war periods. Their indigenous identity has been negotiated as Tamil ethnic identity and Tamil indigenous identity.

Coastal Veddas in the eastern province gradually intermingled with Tamil caste communities and denied explicitly revealing their aboriginal identity since they experienced victimization of marginalization due to their lower status attached to their indigeneity (Thangarajah, 1995). Indeed, they took intentional measures to relinquish their aboriginal identity and thus purposefully avoid maintaining material aspects of their Vedda culture; dialects of their language, attires, hunting and gathering in subsistence and so on and let their community adopt elements of Tamil ethnic culture. However, they have not given up their religious and ritual tradition. They continued to maintain symbolic aspects in ritualistic tradition and have shown resistance towards Sanskritization and conversion to Christianity. This, in turn, helps to persist material social facts of their group identity and such traditional elements of their indigenous ritual tradition serve to maintain their group boundary and solidarity, separating them from adjacent Tamil caste communities.

METHODOLOGY

This descriptive study is based on a phenomenological methodology which is quite appropriate for gaining a meaningful understanding of the social and cultural life of community people (Desjarlias & Throop, 2011). Qualitative information of the study was collected through ethnographic fieldwork of selected coastal Vedda villages in Eastern Province of Sri Lanka. Interviews, focus groups, case histories and field observation were used as tools for primary data collection. Secondary information was collected from previous studies related to identity and Vedda communities and from related reports and documents in state administrative institutions. In the case of sampling, purposive sampling was used to select the informants for Key Informant Interviews (KII) and personal interviews and Random and Convenient sampling methods were used to select participants for Focus Group Discussion (FGD). For the case studies, informants were selected based on Snowball sampling methods.

This study was also a comparative study of two different communities of an ethnic group. The study based its research area on selected coastal Vedda communities in the Eastern province to serve the objectives of the study. This study comparatively looks at two different clusters of Vedda villages; villages located Vaharai Divisional secretariat of Batticaloa district (Vaharai cluster) and villages scattered in the Kiran Divisional secretariat of Batticaloa district (Kiran cluster). In Vaharai, Kunchan kulam, Maruthankerni kulam, Andan kulam and Kaddumurivu villages were selected for the field works.

Theoretical settings of ethnic identity

In sociology, it was David Riesman who first used the term ethnicity in 1953 (Glazer & Moynihan, 1975). However, there were also considerable conceptual developments in understanding ethnicity in social anthropology. The primordial approach was the earliest position of understanding of ethnicity. Proponents of this approach argued that ethnicity is a static phenomenon and natural among human beings. Later, contrary to this earliest view, there was an approach that viewed ethnicity as a social phenomenon that is socially and historically constructed.

For the Primordial approach, a person's identity depends on his/her group identity. Without any group affiliation, an individual cannot get a personal identity (Thompson, 1989). Anthony Smith was the pioneer in this way of approach. His proposition is that an "*ethnic*" consists of six features; a collective name, a common myth of origin, a shared history, a shared culture, a specific territory, and a sense of solidarity. These aspects are fundamental to an ethnic group and also fixed features of an ethnic identity formation. Once the identity is formed based on the aspects, it will last for years without any changes (Smith, 1986).

The constructivist approach postulated the notion that ethnic identity is changeable and it is not a static phenomenon. To them, the construction of ethnic identity is situational and relational and is formed and shaped by material and social aspects of a situation in a historical period of time (Comaroff, 1987; Erikson, 1993). Paul Brass is the pioneer of the constructivist school of ethnic identity and his argument is that ethnic identity formation is not a fixed aspect of a social structure, but it is a process (Brass, 1974). Another connotation of this school of thought is that the identity of an ethnic group is shaped by its social contact with other ethnic groups. Barth (1969), who proposed the concept of ethnic boundary, explained that an ethnic identity is constituted in relation to other ethnic communities, which are in social contact with it. This study sets its theoretical base on the constructivist paradigm.

RESULTS AND DISCUSSION

Brief historical outlook on socio-economic and cultural changes

Coastal Vedda communities were considered as highly accultured indigenous groups in Sri Lanka. Literature on Vedda communities prominently concentrated on vanishing indigeneity among the coastal Vedda population of the Eastern region of Sri Lanka (Seligmann & Seligmann, 1911; Wijesekera, 1964; Dart Jon, 1990; Thangarajah, 1995; De Silva & Punchihewa, 2011). Like other traditional ethnic societies in Sri Lanka, coastal Vedda communities received external forces of changes aimed at modernization in post-colonial periods. Veddas' social change is widely perceived as the structural changes in their traditional social structure and in the social organization and as the assimilation into modern cultural life that the other ethnic communities shared in common. The rate of interaction they had with other ethnic and cultural contexts was the determinant factor in bringing about changes in their traditional way of life. The more they received contacts the more they adopted other cultural values. To understand the social, economic and cultural changes in the Vedda communities, it is primarily required an understand Vedda's primitive way of life before colonial invasions in this country.

Because Veddas had a primitive lifestyle, they were underrated as the lowest status groups based on the notion of least civilized groups. However, though the Vedda people were separated and isolated from other ethnic people and lived in jungles, they could develop their own culture. Veddas' social life was more closely associated with their nature. They also originated a unique system of supernature. The cultural aspects of Veddas originated in connection with the natural environment of their habitats and the belief in supernatural beings. They had their own pantheon and rituals. They developed language, music, dance and ceremonies. They formed a unique cultural identity and established a great sense of community solidarity. They kept their social order peaceful and cohesive in relation to nature and human nature.

It is evident that Veddas' life was not considerably disturbed by colonial invasions. Veddas were treated as separate social groups under colonial administrations. Their habitats were not widely ravaged by the colonial invaders. However, it caused the migration of a number of Vedda communities under colonial rule, mainly during the British period. Changes that occurred in the hitherto existing social structure due to the colonial administrative system allowed Veddas to enjoy equal life chances and opportunities with other ethnic communities in their respective regions.

Unlike India, the British colonial regime did not consider the caste system in their administrative dealings in Sri Lanka. The 1931 universal franchise made an influential impact on the equality of treatment of all people of this country without any reservations. This political right encouraged people towards mainstream political culture. Meanwhile, equality in education and employment has also cracked the barriers of interaction between lower and high-status group people justified under the caste rules. These changes led underestimated status groups to adopt the Western way of life through British education and employment opportunities.

There were many interventions in coastal Vedda communities compelling towards modernization and westernization. There were many chances opened for coastal Vedda people, with the introduction of rights of equality in civil and political arenas, to interact and engage in public affairs with Tamil communities in their regions. Moreover, these communities were targeted for several development interventions aimed to bring about modern social and economic upliftment in their indigenous life. However, these modernisation-centred development interventions were not effectively impacted until the civil war was over since most of the coastal Vedda communities were under the Liberation Tigers of Tamil Eelam (LTTE) control areas where the intrusion of these interventions was limited due to the armed conflict situations.

However, forced migrations induced by state colonization schemes and civil war led Vedda people to closely live with Tamil or Sinhala ethnic groups. Leaving their natural forest habitats, the Vedda people had to change their mode of subsistence. Hunters became cultivators; the large number of Vedda families who relied on hunting and gathering had to engage in crop cultivation in their newly migrated localities since paddy and vegetable cultivation and cattle rearing were the main mode of livelihood in the places where no possibilities found for hunting. The change in livelihood brought about changes in the life patterns of the Vedda people. And it also facilitated the process of intermingling with Tamil people. With their engagement in agrarian livelihood, coastal Vedda people were able to ameliorate their economic status with their adjacent Tamil people who also engaged in cultivation. Further, collaborations and sharing responsibilities in the cultivation process like channelling irrigations, hiring wage labourers and forming agrarian societies expedited the merging of life with Tamil communities. There was also a social reason why Tamil communities did not resist the incorporation of Vedda people into their relationships through intermarriage and co-habitats. Most of these neighbouring Tamil communities were not belonged to high caste groups, though they engaged in cultivation. They did not follow elite ways of life. They did not pursue Sanskrit religious worship. Therefore, Vedda people could share similar life opportunities with them like school education, dispensary and other mobile health services, community-based organizations and rations and reliefs. The civil war was one of the factors that promoted the co-existence of coastal Vedda people with Tamil communities. Almost all coastal Vedda communities lived in Vaharai, Muthur, Verugal and Kiran divisions were under LTTE control territory of the Eastern region. Very few coastal Vedda communities like Valachennai and Kaluwankerney settlements lived in government-controlled areas during wartime. Tamil people in LTTE-controlled areas had to face intermittent incidents of armed violence and also had to experience the scourge of war along with the Vedda people. Besides sharing the mourning of deaths with Veddas, Tamil political elites wanted to maintain the majoritarian position in the eastern province despite the state oppression aiming to diminish the ethnic ratio of the Tamil population in the region. Therefore, they considered coastal Veddas as Tamils differentiating them from Muslims and Sinhalese people. When the conflict in the region reached its peak, LTTE wanted more recruits from the region so the coastal Vedda people were recruited by LTTE to fight against government security forces. Coastal Vedda people were also attracted towards Tamil nationalist campaigns during wartime since the Vedda villages were affected by military operations of the government security forces. Therefore, the coastal Vedda people had resentment towards the government. Further, LTTE sets a sanction on maintaining caste-based treatments and any status-based discrimination in their territory. Therefore, coastal Vedda people rarely faced resistance to intermingling with Tamil people.

Development interventions that enormously took place in the coastal Vedda villages caused further changes in life and modernization of lifestyle in coastal Vedda communities. These development projects were aimed at developing the socio-economic conditions of backward areas. Since a large number of families in coastal Vedda villages were under the poverty line, several reconstruction, social and livelihood development projects were implemented there. These development interventions were never projected to preserve the culture or nature of the indigenous people. And there were no articulations of interest in the cultural conservation of Vedda people raised by the communities. Indeed, the benefits of the projects changed the lifestyle of the beneficiaries of coastal Vedda villages in consistent with modernized Tamil communities.

Intentional intermingling than the natural assimilation

It is obvious that coastal Vedda communities were deemed to be outcast social groups for their economic backwardness and primitive social life or sedentary lifestyles in the regional social group status hierarchy. Coastal Vedda people were the marginalized social group experiencing discrimination in entertaining equal status and opportunities in relation to adjacent Tamil ethnic communities. Therefore, they tended to intentionally change their lifestyle consistent with Tamil people.

Vedda communities inhabiting scattered settlements in maritime provinces of Eastern Sri Lanka are deemed as the depressed social groups in their regional status hierarchy. Vedda people have been considered as the lowest status group by other dominant ethnic and caste groups. Though Vedda people have no affiliation in the caste categorization of Tamil or Sinhala ethnic groups, they are considered as the lowest status group than the lowest ranks of the Tamil caste group. This is because of their isolated group situation having no linear association with the Tamil ethnic group and because of their minority number. Further, the primitive lifestyle of the Vedda people postulated their backwardness in the civilization process and, when compared with other ethnic people, their economic backwardness postered them as the lowest class group. All these reasons led to stratifying them as the lowest social group in their regional status hierarchy.

This lowest-status identity entangles them to be victimized by the various forms of structural marginalization. They were restricted to entertain equal life opportunities and life chances in relation to Tamil people. They were marginalized in sharing common resources with Tamil people. They experienced limitations in engaging in public affairs. They were also enumerated as untouchable people by the dominant Tamil caste people.

It was observed that these communities have been engaging in strategies to escape from the depressed identity. Coastal Vedda people gradually started to intermingle with the Tamil ethnic group which is the dominant ethnic group located in the vicinity of their settlements. They began to adopt the Tamil cultural way of life. This trend was highly pervasive among coastal Vedda communities of the Vaharai division in Batticaloa as they have experienced a struggle to escape the indigenous identity and to intermingle with the Tamil community.

Many Vedda families have swiftly assimilated into their nearest dominant ethnic culture, leaving their traditional way of life, to get rid of marginalization based on the lowest status identity. Though their lowest status identity is manipulated in the traditional caste-based hierarchical status orientation, indeed, Vedda communities were given such status due to their economic backwardness and primitive lifestyles in comparison with other ethnic groups which drastically changed into modern or Western lifestyles in the region. Being aware of the facts of the disadvantaged status formation of their groups, Vedda communities, which were deprived of securing a reputation for their indigeneity from other ethnic groups and realized failure in doing so, began to relinquish the material aspects of their group identity and to intermingle with the greater cultural tradition of adjacent Tamil communities. It has been imperative for coastal Vedda families to ameliorate their socio-economic condition to be coterminous with Tamil communities. In such a process of status amelioration, coastal Vedda families desperately required assistance to enhance their lifestyle. Contributing to education, employment and lifestyle, it was identified that Christian missionaries served as active agents in the process of social upliftment of these marginalized indigenous groups. Christian missionaries played a catalyst role in the status amelioration of marginalized indigenous communities so as to facilitate their strategic way of changing lifestyles.

Modernization and Tamil ethnonationalism as motivating factors

Socio-economic changes that occurred in the coastal Vedda communities mainly in the post-colonial period exerted influence in transforming the indigenous life patterns of the Vedda people into the dominant ethnic culture in the region.

Since coastal Vedda people were deemed as the lowest status group due to their economic backwardness and primitive way of life, they were marginalized in the public sphere and in relation to the interaction with Tamil caste groups. It tended Vedda people to relinquish their indigenous lifestyle and to intermingle with the Tamil ethnic group. It is just not assimilation, but an intentional effort of these underrated indigenous people to escape from the marginalization and the structural violence based on their indigeneity.

State education and healthcare facilities and development projects implemented by Non-Governmental Organizations largely changed their lifestyle in a modernized way like economically well-off Tamil villagers and expedited the process of intermingling them into Tamil ethnic groups.

Tamil political elites wanted to consider coastal Veddas who speak the Tamil language as Tamil people to numerically strengthen their majoritarian stand in the region. The LTTE also recruited youths from coastal Vedda communities and fought against the so-called "Sinhala Government". And Tamil nationalist political parties which have their vote banks in coastal Vedda villages propagated their Tamil nationalist ideologies against the Sinhala nationalist government leaving aside indigenous group solidarity and consciousness. These tendencies and processes motivated the assimilation of coastal Vedda people into Tamil ethnic groups and caused the identity shift from indigenous identity to Tamil identity.

A shift towards manifest identity

The incursion of modern lifestyle brought about many changes in the culture and social structure of indigenous communities in Sri Lanka. Though the changes are generally perceived as a linear progressive advancement by others, indeed, the changes caused various cultural and psychological disturbances in their traditional way of life. Apparently, these communities became more backwards in socioeconomic standards of life due to the disruptions. Thereby indigenous communities inhabiting scattered settlements in maritime provinces of Eastern Sri Lanka are deemed as the depressed social groups in their regional status hierarchy due to their lowest economic status. This lowest economic status-based identity entangles them to be victimized by the various forms of structural marginalization. It is obvious that these communities have been engaging in strategies to escape from the depressed identity due to marginalization and to shift into a manifest identity that is deemed to be the modern or Western life.

Coastal Vedda communities of Vaharai division in Batticaloa and their struggle in escaping the indigenous identity. Many Vedda families have swiftly assimilated into their nearest dominant ethnic culture, leaving their traditional way of life, to get rid of marginalization based on the lowest status identity (Wijesekera, 1964, Dart, 1990, De Silva and Punchihewa, 2011:11). Though their lowest status identity is manipulated in the traditional caste-based hierarchical status orientation, indeed, Vedda communities were given such status due to their economic backwardness and primitive lifestyles in comparison with other ethnic groups which drastically changed into modern or western lifestyle in the region. Being aware of the facts of the disadvantaged status formation of their groups, Vedda communities, which were deprived of securing a reputation for their indigeneity from other ethnic groups and realized failure in doing so, began to relinquish the material aspects of their group identity and to intermingle with the greater cultural tradition of adjacent Tamil communities.

It is observed that Indigenous people are in an identity crisis since they cannot entirely succeed in changing or escaping their Indigenous identity. Amidst this social process of changing their indigenous identity, these communities did not leave some material aspects, religious rituals, locality, and life sustenance patterns, of their traditional way of life, which keep on reflecting their indigenous identity to others. This study focuses on the identity issue of the Vedda people caused by the disturbance of their cultural context.

Culture, ecology and religion in shaping identity

Socio-cultural integration of indigenous communities entwined with their ecological settings. The Indigenous culture of Vedda is the way of life constructed by them to live harmoniously in their environment. Indigenous cultural life includes spiritual, natural and human domains and these three realms form the worldview of the people (Burger 1990). This worldview helps Vedda people to understand their community formation and relationship in the ecological settings and to develop social consciousness and a sense of responsibility.

Vedda people in the region have experienced varying degrees of disruption with regard to their traditional lifestyle and worldview. This disruption has contributed to many social maladies that are extant in these indigenous communities today (Thangarajah, 1995). The Western worldview has placed these indigenous cultures in juxtaposing situations. These cultures, having been characterized as primitive and backward, are subjected to an endless stream of assimilative processes to bring the Vedda people into mainstream society. However, they do not leave their ecology, though they left their traditions. Adapting the modern way of life, which has no consistency with natural and spiritual settings, fluctuated their worldview. Thus, the Vedda people began to lose their identity as the perturbed worldview caused by the discontinuity of the connection between natural, human, and spiritual realms reduced their social consciousness and commitments of the Vedda people. However, they didn't fully integrate themselves into mainstream culture as they continue to maintain certain indigenous cultural aspects, which appear to them essential to their survival in the ecology. This leads to the identity dilemma for the Vedda people. There are a few basic questions to be answered to illustrate the situation in a phenomenological way; Why do Vedda people retain certain material cultural aspects while intermingling with mainstream culture? What are the external factors that perturbed the Vedda's worldview? And how did it affect furnishing the exigencies of mutual social existence and cause identity dilemma among Veddha people?

The necessity to maintain old cultural aspects amidst assimilation

It is evident that Coastal Veddas who tended to culturally intermingle with another dominant ethnicity do not lose their entire culture. There are cultural aspects of the groups that continue to survive amidst the social and cultural adaptation, since their material cultural symbols, more importantly, religious-oriented, are essentially meaningful to their social life as they reflect the core values of the community (Turner, 1968). Coastal Veddas in Eastern province gradually intermingled with Tamil caste communities and denied explicitly revealing their aboriginal identity since they experienced victimization of marginalization due to their lower status attached to their indigeneity (Thangarajah, 1995). Indeed, they took intentional measures to relinquish their aboriginal identity and thus purposefully avoid maintaining material aspects of their Vedda culture; dialects of their language, rituals, hunting and gathering in subsistence and so on while letting their community adopt elements of Tamil ethnic culture. However, they haven't given up their cultural tradition. They continued to maintain symbolic aspects in ritualistic tradition and have shown resistance towards Sanskritization and conversion to Christianity. The study found that their original cultural aspects are associated with their nature and survival of the ecology in which they grew and continue to live. From a cultural ecological perspective, since they did not change nature, they cannot entirely get rid of the cultural components of life there.

Factors that altered the worldview of the Vedda people

In anthropology, worldview is conceptually understood in relation to culture and cognitive map (Berger et al., 1974). A worldview is the acquirement of people to make sense of the world around them. Through forming a worldview, people of a community identify themselves as a unique group of people. To the Vedda people, their worldview based on the shared sense of their material and non-material culture has been perturbed due to the assimilation with modern or mainstream culture. Vedda people intentionally adapted mainstream Tamil culture to relinquish their indigenous identity to avoid the lowest status caused by their primitive way of life rather than being absorbed by Tamil "great tradition". Anyhow, their worldview has been altered by the modern worldview. This change in the worldview might have changed their perception of their identity if they could have entirely changed their traditional culture. However, Vedda communities continue to hold some aspects of their traditional culture which is essentially required and associated with their survival in the ecology. Therefore, two different confronting values of culture intercept the worldview of the Vedda people. It leads to identity confusion among them. There are cultural aspects of the groups that continue to survive amidst the social and cultural adaptation, since their material cultural symbols, more importantly, religious-oriented, are essentially meaningful to their social life as they reflect the core values of the community (Turner, 1968). Until and unless the community moves away from its location, symbols are meaningful to the community since the meanings of the symbols are derived from its cultural ecology.

CONCLUSION

Coastal Vedda people's transition towards modernization generated identity confusion among them. They initially tended to lose their indigenous identity and to intermingle with Tamil ethnic communities in the adjacent villages. However, they failed to fully integrate themselves into Tamil ethnic culture and to entirely relinquish their indigenous culture, and they tend to perpetuate some traditional cultural aspects which seems to be imperative for their social existence in their original localities. Their assimilated culture is not now consistent with the oldest view of their nature. The new values are confronted with their spiritual belief. The confronted realities between culture, nature and supernature brought about contested identities among Vedda people to their worldview.

In the course of transforming their indigenous identity, Vedda communities in the study area largely assimilated with the modern culture of adjacent Tamil communities. However, they couldn't leave certain material cultural aspects of their identity. Those cultural aspects that are in close association with their ecology seem to be inevitable for their living in their localities. This, in turn, helps to persist material social facts of their group identity and such traditional elements of their indigenous cultural tradition serve to maintain their group boundary and solidarity, separating them from adjacent Tamil caste communities. Therefore, amidst changes due to modernization and cultural assimilation because of enormous interactions with other dominant ethnic groups, certain material cultural aspects have remained intact among many indigenous communities. This empirical phenomenon can be related to the concept of worldview in describing the identity crisis of Vedda communities in the areas. When new values assimilate with the existing traditional values of culture, they should be adapted inconsistent with nature and accommodated into the realm of its supernature, since it affects the worldview of the community people who lived with the common sense of identity. If the process is not properly modified or managed by the community itself or other interventions, people have different confronted worldviews which results in an identity crisis of the community. Retaining material cultural aspects, assimilated way of life and confused worldviews brought about identity confusion among coastal Vedda people.

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Establishment of embryo splitting and demi-embryo transfer technology for goats in Sri Lanka: A preliminary study

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ABSTRACT

Embryo splitting and transfer is an advancement of reproductive biotechnology that is developing towards routine applications in the field. The objective of the experiment was to establish the technology in Sri Lanka. Proven Jamnapari nanny goats (n = 5) were superovulated using progesterone-releasing intravaginal pessaries, ovine follicular stimulating hormone, and pregnant mare serum gonadotropin hormones based on a standard protocol. With the observation of oestrous, does were administered with gonadotropin-releasing hormone and inseminated using proven bucks (n=2). Seven days post insemination, surgical embryo flushing was carried out under general anaesthesia. After washing with flushing and holding medium collected embryos were assessed for quality and classified into ‘Excellent’, ‘Good’ and ‘Poor’ categories. Excellent and Good embryos were bisected using a microsurgical cutting blade system under the splitting medium. Two demi-embryos were transferred to the uteri of each oestrous synchronized jumnapari recipient (n=5), surgically. Pregnancy diagnosis was carried out using ultrasound scanning (7.5MHz) technology at 35 days of pregnancy. Seventeen embryos were recovered with a 65.38% recovery rate while counting 26 corpora lutea in embryo donors. Harvested embryos were classified as Excellent (n = 9), Good (n = 5) and Poor (n = 3) while resulting in 10 transferrable demi-embryos at the splitting. One healthy kid was born at full term (146 days) with a birth weight of 2.35 kg. The daily weight gain was 152.3 g during the first six weeks of age. The

study revealed the feasibility of practising embryo splitting and demi-embryo transfer technology while reporting the first goat born through this technology in Sri Lanka. Further studies would be supportive of the optimisation of the technique in the country.

Keywords: Embryo, Embryo splitting, Embryo transfer, Goat, Reproductive biotechnology

INTRODUCTION

Walter Heape became the 'father of embryo transfer' with the success of rabbit embryo transfer in 1891(Selk, 2002) while reporting the first goat embryo transfer in 1942, successfully. After 1960 with the identification of different applications and benefits, the multiple ovulation and embryo transfer (MOET) was popularized and started to be used widely at commercial levels in many countries of the world (Wright, 1988). Primarily it was identified as a suitable technique for the multiplication of genetically superior animals with higher breeding efficacy (Cognie et al., 2003; Gonzalez-Bulnes et al., 2004). In addition, it is a convenient way to transport genetic material in the world at low expenses, with minimum risk of dispersal diseases (Abeygunawardena, 2002), and as a humane alternative to the stressful transportation of live animals from country to country (Duran, 2008). MOET is a valuable tool for the evaluation of fetal and maternal interactions while facilitating specific pathogen-free herds (Wright, 1988), especially for research purposes. Livestock breeders can use this technology to share their valuable germplasm nationally and internationally without depleting their gene base (Duran, 2008). Embryo transfer is considered a better technique for the conservation of endangered animal species (Senger, 1999) even using animals, which have no conceptions or fail to have conventional gestations (Noakes, 1986). Same way it is useful for the rapid screening of artificial insemination (AI) sires for genetically recessive characteristics (e.g. syndactyly) and for identification of potential AI studs through contract mating (Hinrichs, 1998).

Hans Dreich (1800s), the pioneer scientist of embryo splitting (demi embryo) technology used two-cell embryos of sea urchins for his initial studies. 'Shaking' was the first bisection method of embryos practised in his studies. In 1902 two cell embryos of Salamander were bisected with infant hair by Hans Spemman (Beckett, 2010). Presently there are several techniques for embryo splitting in different countries, such as microsurgical cutting blade system, identical needle system in combination with microsurgical blade system (Udy, 1987) and noncontact diode laser technique (Halvaei et al., 2018) etc. Bisection or splitting of embryos into identical halves by microsurgery was practised by a few commercial embryo transfer teams around the world (Hinrichs, 1998). Furthermore, various types of demi embryos have been introduced on an experimental basis in the world. Such as demi embryos with zona pellucida, without zona pellucida and demi embryos embedded in 7% gelatin without zona pellucida etc. (Warfild et al., 1987).

In the MOET process, 50% of recovered embryos are suitable for splitting (Southwell, 2010) and two cell stages to the blastocyst stage can be bisected successfully (Seidel & Seidel, 1991a) with similar survival rates (Udy, 1987). However, certain studies revealed the value of splitting 6-cell stage embryos than the low blastomeres embryos (Hamatani et al., 2006). With the amalgamation of embryo splitting, the duplication rate of the donor could be further accelerated (Southwell, 2010) and genetically identical pairs can result (Noli et al., 2017) according to the requirement of research purpose (Seidel & Seidel., 1991b; Noakes, 1986) with similar pregnancy rate. Although the size of the blastocyst can vary according to the stage of splitting (Noli et al., 2015), the size of the offspring may not be affected by the technique (Escriba' et al., 2002). In embryo transfer, twin pregnancies with different sexes have a risk of getting freemartins in goats. Transferring bisected embryos can overcome this problem by resulting in twins that are of the same sex (Hinrichs, 1998). In comparison to studies on embryo transfer in goats, studies on embryo splitting are very low in the world.

MOET technology for animals was established in 2006-2007 using goats in Sri Lanka (Perera et al., 2007, 2008 a, 2008 b, 2010). Although it has been established in certain countries (Illmensee & Levanduski, 2010), there has been no detailed research in Sri Lanka to study the applicability of embryo splitting in caprine. Therefore, the objective of the study was to investigate the feasibility of the application of embryo splitting technology for goat embryos in Sri Lanka as an initiative for the application of it for farm animal practice.

METHODOLOGY

Ethical clearance

All the experiments were carried out according to the ethical guidelines and approval (VERC-21-20) received from the Ethical Clearance Committee, Faculty of Veterinary Medicine and Animal Science, University of Peradeniya.

Location

A major part of the experiment was conducted at the 'Goat Research Facility and Animal Embryo Biotechnology Laboratory, Department of Farm Animal Production and Health, Faculty of Veterinary Medicine and Animal Science, University of Peradeniya. Natural insemination was carried out at the Veterinary Teaching Farm, Udaperadeniya Peradeniya.

Animal selection and preparation for embryo transfer

Healthy non-pregnant Jamnapari does (2^{nd} - 4^{th} parities) who have been given tetanus toxoid annually, were selected (embryo donors- 5, recipients- 8) for the study, based on the production, breeding efficacy, and pedigree. They were 2.5-4 months from their last weaning and 5-6.5 months from their last kidding with above-average body conditions. Two proven Jamnapari bucks were selected as studs of the study. All the selected goats were treated with anthelmintics (LEVAFAS® Drench) initially. They were fed with *ad-libitum* forage, 650 g of concentrates and a vitamin-mineral mixture (Minamax®) (30 g for females and 15g for males) daily for two months prior to the study and continued until the end of the study.

Superovulation of embryo donors

The embryo donors (n=05) were introduced with progesterone liberating intravaginal pessaries (45 mg, Cronolone, Intervet) on the morning of day 01 of the superovulation protocol. They were injected intramuscularly with 2.5 ml of pure oFSH; (0.88 mg/ml, NIADDK-oFSH-17-Standard, Ovagen™, New Zealand), on day 08 of the programme. Furthermore, 300 IU PMSG, (Folligon, Boxmeer-Holland) was injected into all embryo donors on the twilight of day eight. Folliculogenesis and development were further stimulated using successive administering of 1.25 ml oFSH in the morning and evening of day-09 and 10 (Gonzalez-Bulnes et al., 2004). Does were administered with 197 µg of cloprostenol sodium (PGF Veyx-fort, Schwarzenborn) in the dawn of day 09 and vaginal pessaries were taken away in the evening of day 10. On day 11, 1.25 ml of oFSH and 1 ml of GnRH (50 µl/ml, Depherelin, Schwarzenborn) were administered in the dawn and twilight, respectively.

Following the GnRH injection, the genetically superior proven Jamnapari bucks (n=2) for natural breeding until the next 48 hrs.

Preparation of embryo-collecting media

Embryo flushing medium was prepared by introducing 2 g of bovine serum albumin (BSA) (SIGMA- ALDRICH, USA) (Seidel & Seidel, 1991a) powder into the 200 ml of Lactated Ringers Solution (LRS) (B. Braun, Malaysia) tenderly at 37 ^{0}C temperature for 45 minutes until dissolved appropriately. Prior to using the medium, 2 ml of embryo-graded Penicillin Streptomycin (SIGMA-ALDRICH, USA) solution was added into the medium gently.

Embryo collection

Embryo collection was performed after withholding periods of feed (24 hr) and water (12 hr). An embryo donor was sedated under the intramuscular (IM) administering of xylacine 2% (0.2 mg/kg), (Bromazine®) (Bishop, 2001). Twenty minutes later it was anaesthetized under the Intravenous administration of ketamine hydrochloride 10% (11 mg/kg), (Ketamil®). After preparation of the surgical site, both ovaries and the uterus were exteriorized via mid-ventral laparotomy. After counting the number of corpora lutea in each ovary the utero-tubal junction of the left uterine horn was penetrated with a blunt-ended (18G) hypodermic needle. Then the tip of an embryo flushing catheter (3 ½ FR, 14cm; Sovereign™) was inserted towards the uterine horn. The uterine hone was perforated with small artery forceps at the level of the bifurcation and a two-way pediatric silicon elastomer coated foley catheter (8 Ch/Fr, 3/5 ml/cc; Unomedical Sdn., Malaysia) was inserted. After inflating the cuff, the stylet of the Foley catheter was removed. Fifty millilitres (10 ml×5) of embryo flushing medium were inserted along the flushing catheter while light tapping on the uterine horn, and it was collected into a beaker using the Foley catheter. The same technique was applied to the right horn. After the removal of catheters, pierced places at the level of bifurcation were sutured with 3/0 cat gut (Ethicon®). After applying hydrocortisone cream (Astron, Sri Lanka) the reproductive tract and the ovaries were repositioned in the celomic cavity. With the surgical correction of laparotomy, the animal was kept separately under standard post-operative care. The same procedure was applied to all the embryo donors.

Evaluation of embryos

Flushing medium with embryos was kept in an incubator (Sanyo Electric, Japan) providing 5% CO_2, 38.5 °C temperature and 85% relative humidity, until the isolation of embryos. During the isolation process, a flushing medium that contained embryos was transferred gradually into an embryo-searching dish (Nunclon™, Denmark). Under a dissection microscope, embryos were isolated using a wire trawl (Hauptstrasse 41, Germany) and transferred into a well, which contained embryo flushing medium, of a four-well plate (Nunclon™, Denmark). After the first washing, embryos were transferred into the second well, which contained embryo holding medium (ViGRO HOLDING plus, USA) of the plate. While counting the number, the quality of the embryos was assessed using the International Embryo Transfer Society (Stringfellow & Givens, 2010) and FAO (Seidel & Seidel, 1991a) guidelines with the consideration of size, physical damage, and internal appearance. In this evaluation, using an inverted light microscope (Model CK-2, Olympus, Japan) with 200 magnifications the harvested embryos were classified as excellent, good, and poor (Table 1). Throughout the evaluation process, embryos were maintained under 37 °C, using two-stage warmers (MP 300 DM, England).

Table 1. The quality of embryos classified according to the International Embryo Transfer Society and FAO guidelines

Quality of embryos		
Excellent	Good	Poor
09	05	03

Embryo splitting

Selected excellent and good embryos (n=14) were transferred into an embryo searching plate which contained LRS as the splitting medium. The aggregation of embryos to the centre part of the searching plate was facilitated by rotating the plate gently. The plate was kept on a stage warmer which was 37 °C for one minute. After the adhesion of embryos to the bottom, the searching plate was kept on the stage of embryo splitting microscope (Olympus CK 2, Japan) which consists of an electronic microsurgical blade system. An embryo-holding pipette system which originally belonged to a micro-manipulating system (Leica, Germany) was coupled for a better handling of embryos. Embryo embryo-holding pipette and microsurgical blade were arranged according to the 1 and 9 o'clock positions (Figure 1-A) respectively. Embryos were immobilized with the negative pressure applied through the holding pipette on the zona pellucida of each embryo. A microsurgical blade was kept on an embryo and gentle pressure was applied. The blade was moved forward and backwards using the joystick until cutting through zona pellucida and blastomeres or embryoblast and trophoblast of morulae and blastocysts, respectively. At the use of blastocysts, special care was taken to position those to produce demi embryos with equal halves of inner cell mass (Rho et al., 1998). Immediately after production, demi embryos (Table 2) were transferred into an embryo searching dish which contained embryo holding medium and kept in a CO_2 incubator until transfer into the uteri of recipient animals.

Table 2. Number and developmental stage of embryos at different stages of the study

Embryonic stage	Number of embryos collected	Number of demi-embryos	Number of transferable demi-embryos
Morulae	09	18	08
Blastocysts	05	10	02

Data from the table revealed the possible damage to goat embryos during microsurgery with a knife-splitting system.

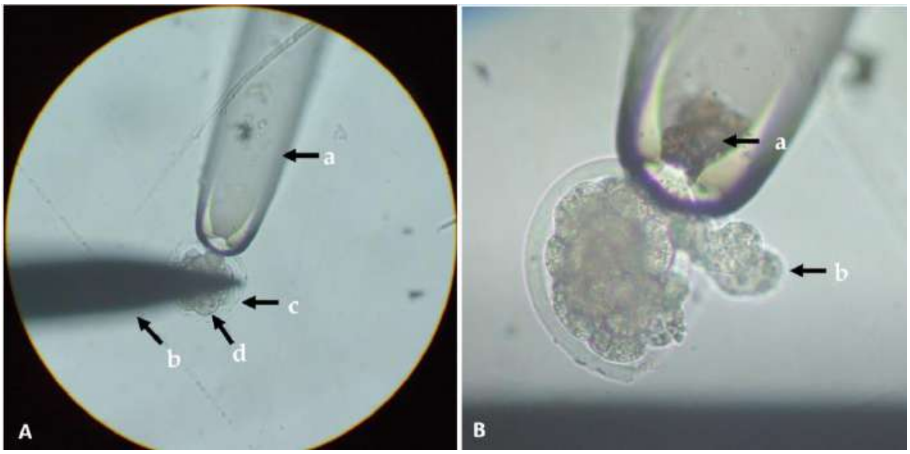

Figure 1. Bisection of the morulae stage of an embryo through basic knife method (×200) (A) At the process of microsurgery; holding pipette is used to apply negative pressure on the zona pellucida to immobilize the embryo. The tip of the knife cut mainly through intercellular junctions of blastomeres, a) Embryo holding pipette b) Embryo splitting knife c) Zona pellucida d) Blastomeres (B) A demi-embryo resulted after the microsurgery of a morula. a) Cell debris adhered to the holding pipette, b) partially detached blastomeres from the cellular mass.

Synchronization of embryo recipients

At the dawn of day 01 intravaginal progestogen pessaries (Chronogest®), were inserted into all recipients, (n= 8), and 125 µg of $PGF_{2\alpha}$ (Veyx®) was injected intramuscularly into each animal. On day 17, vaginal pessaries were taken-out, and 400 IU of PMSG; (Folligon®) were administered to each doe intramuscularly. The does were observed for signs of estrus on the subsequent day.

Surgical embryo transfer

The recipients (n=5) were positioned on a surgical cradle in dorsal recumbency under general anaesthesia like at the embryo flushing surgery. The cradle was slanted 60° with the head directing down. After preparation of the surgical site, an incision of nearly 1.5 cm was made in the skin approximately 3 cm to the left of the centerline and 5 cm anterior to the cranial border of the udder. A trocar and cannula were placed into the peritoneal cavity through the incision of the skin. The trocar was detached, and a laparoscope (6.5 mm diameter) was inserted via the cannula into the abdominal cavity. A similar incision was done on the right side and Babcock forceps were inserted. The uterine horns were observed, and the ovaries were inspected to find the ovary with large corpus luteum/corpora lutea (CLs) using the laparoscope. The end part of the ipsilateral horn was gripped, and the 01 cm part was externalized with the Babcock forceps. In the meantime, demi-embryos were inserted into the tip of the tomcat catheter using a 1cc syringe as follows at each transfer.

At first, a little volume of embryo holding medium was taken into the tip of the catheter followed by an air space, then the medium which contained embryos and the final air space. The uterine horn was pierced (close to the utero-tubal junction) with a blunt 18 G hypodermic needle. Afterwards, the tip of the catheter was introduced, and the embryos were released into the lumen of the uterine horn. Before releasing the horn into the abdominal cavity, the tom cat catheter was flushed with embryo holding medium and examined to confirm the absence of embryos remaining there. After surgical correction of the laparotomy incisions animals were kept separately under post-operative care and close observation.

Pregnancy diagnosis
Pregnancy diagnosis was conducted 35 days post ET, under trans-rectal ultrasound scanning (Land wind Medical P09, China, 7.5 MHz linear type probe) technology.

RESULTS AND DISCUSSION

Although all 5 donors responded to super ovulatory treatments, embryos could be collected only in 3 donors. In this study, an embryo donor who didn't carry embryos was reported with blind oviducts. Further, embryos may not result due to fertilization failure (Bulnez et al., 2004) in certain does. In addition, the growth stage of embryos can differ even in the same embryo donor due to synchronized ovulation and fertilization of oocytes (Cognie et al., 2004; Perera et al., 2008).

Twenty-six CLs were identified in embryo donors and 17 embryos were harvested with a 65.38% embryo recovery rate. In handling any procedure, embryos can be misplaced, and it is a common problem in this practice. Sometimes embryos can be misplaced due to floating on the surface of the medium. It can be decreased by releasing embryos from the wire troll at the bottom of the medium-filled well (Perera et al., 2008b).

Splitting embryos was a challenging task due to cellular and embryonic debris, which had adhered to the knife and the holding pipette. Debris arising from splitting in goat embryos (Figure 1, B) is extremely sticky to the manipulation equipment. In sheep and cattle, these are not much adhesive compared to the goat. A conventional splitting system with a basic knife exerted all pressure on the embryo and cut across both zona pellucida and embryonic cellular mass, resulting in very poor survival of viable demi embryos compared to the twin needle with knife splitting system (Udy, 1987). So, using this basic knife-splitting microscope was a difficult and time-consuming task.

In the present study, although there were 17 embryos, 03 were not considered due to damage at the flushing. Furthermore, out of 28 demi-embryos, only 10 demi-embryos were in the transferable stage (Table 2). The other embryos were not in the transferable stage due to damage to the blastomeres or due to detachments of blastomeres from each other (Figure 2). With similar micromanipulation conditions, goat embryos vary from their counterpart cattle and sheep embryos (Udy, 1987). It was reported that goat embryos possess many peculiar characteristics such as 1) Intercellular adhesions are not stranger in compacted morula and morula stages of goat embryos. While splitting there can easily damage inter-cellular junctions. That can cause a fall apart of the cellular mass of the embryo resulting in uneven halves. 2) Compared to cattle and sheep embryos, goat embryos bear more flexible zona pellucidae; which can cause relatively difficult and a much greater degree of embryo squashing (Udy, 1987). Under that circumstance, a set of embryos was sacrificed (Table 2) to practice and get hands-on experience with splitting in this study. Furthermore, the destruction of blastomeres (Figure 2) at splitting could be one of the primary causes for the poorer pregnancy rate following the transfer of demi embryos (Skrzyszowska, 1997).

Figure 2. Damaged demi-embryos, due to detachment of blastomeres (a) from each other at the microsurgical procedure of the experiment. b – part of the zona pellucida.

Especially in commercial applications of embryo splitting technologies, speed and gentle handling is essential for better survivability of demi embryos and efficient practice (Udy, 1987). Although goat embryos are more fragile than cattle and sheep embryos, early blastocysts to nearly hatched late blastocoels stagers are comparatively hardier for splitting. However, spitting those embryos is extremely difficult with conventional microsurgical blade systems without severely damaging or destroying the embryos (Udy, 1987).

Among embryo recipients (n=8), 6 does showed estrus signs within the expected period. One embryo recipient animal was removed from the program due to the falling of the vaginal progesterone pessary. Probably it can be due to the pulling of the strand of the pessary by crows or by other does in the shed. It can be minimized by removing or making the strand shorter. In addition to that another recipient was removed due to the absence of estrus within the expected period to synchronize the oestrous of both donors and the recipient animals. According to the limitation of demi embryos, only 5 recipients who expressed the signs of oestrous were used for the embryo transfer. Furthermore, fresh embryos can be tolerated only up to the 24-hour difference between their developmental stage and the uterine environment at conception (Standard Operations Procedures Manual, 2013). Considering these possibilities, a few additional numbers of does should have been included in the synchronization process.

Following the transplantation of demi-embryos (Figure 1-B), one doe was found to be pregnant (Figure 3). After 146 days of pregnancy period, a healthy male kid (Figure 4) was born with a 2.5 kg birth weight. In the first six weeks, the daily weight gain of the offspring was 152.3 g.

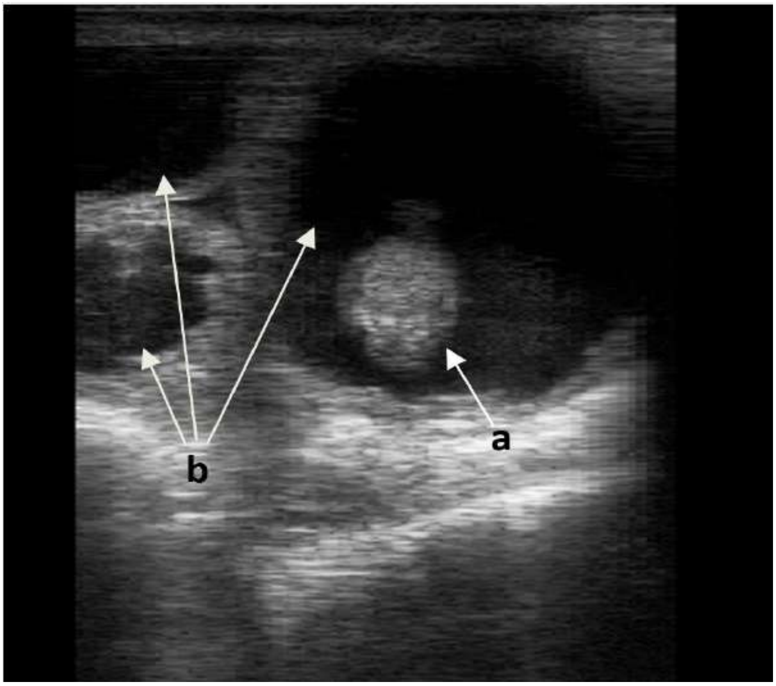

Figure 3. Ultrasound scanning image of the pregnancy indicates the fetus (a), fluid filled cross sections of the pregnant uterus (b) at 35 days post demi embryo transfer.

Figure 4. The first goat offspring (Jamnapari male), born through embryo splitting technology in Sri Lanka

CONCLUSION

The study reported the first animal (kid) born through demi-embryo technology in Sri Lanka. Microsurgical skill is a critical factor in minimizing damage to cellular mass leading to a better harvest of transferrable demi-embryos. The success of the study revealed the feasibility of application in embryo transfer technology in Sri Lanka and the probable enhancement of output with the combination of embryo splitting technology for goats. Embryo-splitting technology can be practiced under Sri Lankan conditions for goats revealing the applicability of it in farm animal practice towards the self-sufficiency in related products. Further studies are required to optimize this technique to acquire higher success rates with identical twins towards the development of science and self-sufficiency in farm animal products in the country.

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Rainwater for healthy living: Comparison of ayurveda and modern aspects

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ABSTRACT

Consumption of contaminated water has caused water-related diseases and approximately 3.4 million people, mostly children, to die. Therefore, it is the fundamental right of human beings to receive clean and safe water at an affordable cost. The aim of this study was to analyze the health benefits of using rainwater according to Ayurveda and modern science. The information was gathered from the Ayurveda authentic texts and published research articles across the databases Google Scholar, PubMed and Science Direct. The ayurveda authentic texts include *Charaka Samhita, Susruta Samhita, Ashtanga Hrdaya, Ashtanga Samgraha, Bhavapraksha, Sharangadhara Samhita* and *Kashyapa Samhita*. According to ayurveda, rainwater is considered nectar-like, of un-manifested taste, sweet in nature, satiating, sustaining, pure, pleasant, clear, refreshing, easily digestible and vitalizer in qualities and most wholesome for the body. Furthermore, it pacifies the *vata* and *kapha dosha of Tridosha*; and cures ailments caused by the vitiation of *pitta dosha* (a physiological humor), *rakta* (blood) and *visha* (poison) owing to its cold, coolant and enlivening qualities. Recent studies revealed that physio chemical properties of groundwater are above World Health Organization limits for drinking water due to contamination making it unsuitable for consumption without extensive purification. However, rainwater has proved that it has better quality than the groundwater in Sri Lanka. Accordingly, collecting and storing the freely available rainwater as mentioned in Ayurveda, which has been practiced in the last 5000 years must be encouraged among the rural population who lacks clean and safe water for healthy living.

Keywords: Ayurveda, Groundwater, Healthy living, Rainwater, Surface water

INTRODUCTION

Worldwide, millions of people are lacking access for safe drinking water, sanitation, and hygiene (WASH), which causes a wide range of water-related diseases. Every 20 years global water consumption doubles and is more than twice the rate of population increase. According to research findings, by the year 2030, more than half of the world's population will face severe water shortage (Winblad & Herbert, 2004).

Sri Lanka is demarcated into three zones based on annual rainfall and two-thirds of the country is considered as dry zone. Mainly the inhabitants in the dry zone lack access to daily safe drinking water. The national census of the year 2008 reported that this country has pipe-borne water coverage only for 34% of the population, while the rest depends on various sources like groundwater wells, tube wells with hand pumps, rainwater harvesting tanks, minor rural water supply schemes and water stored in surface including springs, streams, canals, *wewa* (surface tanks) and irrigations tanks. Water pollution from industrial contaminants, pesticides and fertilizers is believed to be the major factor for the health-related problems in the communities using this water. Incidentally, Chronic Kidney Disease (CKD) is a major health issue prevalent among the farming communities in the dry zone areas and it is a disease condition that requires immediate attention and remedial measures in order to safeguard the rural farming communities. Several research studies have presented numerous factors including fertilizers, agrochemicals and heavy metals as the causatives for chronic kidney disease (CKD), however, as of present, no conclusive evidence has been put forth to prove the real cause (Manthrithileke, 2015).

Water is a vital resource for all living beings as well as a part of a larger ecosystem (UN-Water, 2015). Due to the skillful management of the essential and limited water resources, man has been able to survive even in deserts for thousands of years. Furthermore, access to safe and clean water for the population is one of the sustainable development goals (Weerarathna et al., 2009). Therefore, the sustainability of consumable water should be ensured for the existence of living creatures on earth.

The natural water cycle and the availability of water were balanced, but man's inference disturbed the natural water cycle in the recent past. Due to human interventions such as deforestation, pollution and wetland drainage, the balanced water cycle started to be disturbed and has, therefore, been the cause of global water related issues (Charles, 2000). Ultimately this may lead to at least one-third of the world population facing hardships due to water scarcity in the near future. Moreover, among the world's continents, Asia is alleged to be in the worst condition considering the availability of water due to the continent being home to 60% of the world's population even though the availability of consumable water from the total available water is considered only 36% (UNESCO, 2003).

In certain dry zone areas of Sri Lanka, where longer dry period exists, the communities experience a lack of clean drinking water supply and safe water for domestic purposes. Due to the growing population, climate change and diminishing water resources, the need for clean water for domestic purposes for the population is increasing (Ariyananda, 2010). These conditions are leading to finding methods to strengthen the sustainability of available consumable water. Therefore, this paper analyses the ayurveda concept of rainwater, its collection and storage for healthy living with the modern aspects of measurement of water quality to ensure the sustainability of available consumable water for the growing population at an affordable cost.

METHODOLOGY

The information related to Ayurveda, was gathered from translations and interpretations of the ancient ayurveda authentic texts including the *Susruta samhita, Charaka Samhita, Bhavaprakasha, Sharangadhara Samhita, Ashtanga Hrdaya Samhita, Ashtanga Samgraha Samhita* and *Kashyapa Samhita*. Information regarding the modern concept of water and its quality studies were collected from published journal articles across the databases PubMed, Science Direct and Google Scholar.

RESULTS AND DISCUSSION

Ayurveda aspects of water quality

Rainwater collected from the sky

According to ayurveda, rainwater is called *Antariiksha* due to its origin being from the *Antariiksha* zone, which is the intermediate zone between the Earth and the sky. It is furthermore called *Dharajala*.

In the ayurveda concept, the rain water that is steadily flowing from the sky without meeting any obstacles should be collected and filtered through a cloth to remove any macro impurities mainly and finally stored in a vessel made from gold, silver, copper, glass, crystal or earth. *Acharya Sushruta* however, had mentioned a total of 6 types of vessels made of *Swarna* (gold), *rajata* (silver), *tamra* (copper), *kansya* (bronze), *mani* (precious stones) and *mrittika* (mud) that could be utilized for the purpose of water storage (Sharma, 2013). However, the utilization of a specific type of vessel depends on the economic and financial status of the user. According to modern research, metal vessels exhibit an anti-microbial effect on the stored water due to their oligodynamic effect. The oligodynamic effect is that the metal vessels release metal ions onto the stored water, and the toxic effect of the metal ions acts on living cells, algae, fungi, spores, prokaryotic and eukaryotic microorganisms thus successfully destroying such microbes (Das et al., 2021). This oligodynamic effect of metals, which is a modern concept (Jadhav, 2016), gives the message that the people of the ancient era although having almost no knowledge of modern-day microorganisms, were still aware of drinking water qualities, water pollution and waterborne diseases.

According to modern science, copper is a heavy metal that exhibits a significant oligodynamic effect, that leads to the destruction of harmful bacteria (Jiddimani et al., 2021). Even according to ayurveda, the copper container, mentioned as the *Tamra jala patra* is considered the *uttama* (best) for storage of drinking water. Various classical authors have described the properties of *tamra*, which gives a clear concept of purity of water. Furthermore, various research work also backs up this concept of water storage in copper vessels for its beneficial qualities. Additionally, water stored in mud pots exhibits the least changes in water quality parameters and low microbial count (Jiddimani et al., 2021). Incidentally, according to ayurveda, in the absence of copper vessels, the best vessels (*hitakari*) for water storage are recommended to be the mud pot mentioned as the *mrit* patra (earthen pot).

Rainwater according to ayurveda, is considered nectar-like, sweet, satiating, sustaining, pure, pleasant, refreshing, clear, easily digestible, of un-manifested taste and a vitalizer in qualities

(Srikantha, 2012). The ancient texts of ayurveda, opine that rainwater relieves fatigue, exhaustion, narcosis, thirst, drowsiness, fainting, burning sensation and sleepiness. Additionally, it pacifies the *Vata* and *Kapha doshas;* two of the three physiological humors of the human body. The physiological humors of the body according to ayurveda are the *Tridosha*; namely *Vata*, *Pitta* and *Kapha*. *Vata* is mainly responsible for the macro and micro-level movements and sensations of the body while *Pitta* is responsible for the transformations, enzymatic reactions etc. and *Kapha* is mainly responsible for the union and stability in the human body. The imbalance of these three *doshas* in quantity, quality and action will lead to the onset of various pathologies. Furthermore, it cures disorders that occur due to the vitiation of pitta dosha, *rakta* (blood) and *visha* (poison) due to its cold, coolant and enlivening qualities. Therefore, according to ayurveda, rainwater is considered to be the most wholesome for the body.

However, these properties can only be credited to the rainwater that is collected in a clean vessel a little after the commencement of rain, which is then filtered through a thick cloth to remove impurities and stored in containers made out of gold, silver, copper or mud. According to ayurveda, the qualities of the collected water are said to be enhanced if sunlight or moonlight is present at the time of collection. Sun-charged water also called solarized water is considered a natural source of Vitamin D and beneficial in regulating the immune system, heals insomnia and depression, improves memory and brain functioning and enhances cell and tissue rejuvenation. Additionally, moonlight charged water was found to relieve hormonal imbalances, stress and anxiety according to research studies (Faiyaz, 2018). It is mentioned that people with tender bodily constitutions, kings, people of royal authority, gentle health and those who are accustomed to eating unctuous foods should drink rainwater during the autumn season (Sharma and Dash, 2014).

Rainwater fallen on the ground

Although during rainfall, the qualities of the rainwater depend on the site of the sky it has fallen from and the season of rainfall, after the rain reaches the ground the rainwater qualities are said to depend on the ground it has fallen to (Sharma and Dash, 2014). Naturally, rainwater, hail water or snow water are of un-manifested taste, however, once the specific water types reach the ground, the water acquires the properties of the specific area (Sharma & Dash, 2014). *Acharya Charaka* describes a relationship between the taste of the rainwater and the color of the soil it had rained presented in Table 1 (Sharma & Dash, 2014).

Table 1. Relationship between the taste of the rainwater and the color of the soil (Sharma, 2013).

Color of the earth rain has fallen onto	Property/ taste
White	Astringent
Yellowish white	Bitter
Brown	Alkaline
Saline soil	Saline
Mountain valley	Pungent
Black soil	Sweet

Acharya Susruta, however, opines that the mentioning of the taste of water according to the color of the soil is incorrect, since the combination and the predominance of the *panchamaha bhuta* are responsible for the various manifestations of taste. Therefore, according to *Acharya*

Susruta, the taste of the rainwater after falling, according to the predominant *mahabhuta* in that area is given in Table 2 (Sharma, 2013).

Table 2. The tastes of the rainwater after falling, according to the predominant *mahabhuta* (Sharma, 2013)

Predominant *mahabhuta* of the land	Taste of the rainwater after falling
Prithvi (earth)	Sour and salty
Ap (water)	Sweet
Tejas (fire)	Pungent and bitter
Vayu (air)	Astringent
Akasha (ether)	Unmanifest since akasha itself is unmanifest

Acharya Charaka further mentions the qualities of the rainwater according to the seasons it falls in Table 3 (Sharma, 2013).

Table 3. The qualities of rainwater according to the seasons it falls (Sharma, 2023)

Season	Qualities of the rainwater
Sisira (late winter)	Lighter than hemantha and pacifies *kapha* and *vata*
Vasantha (spring)	Astringent and sweet and un-unctuous.
Greeshma (summer)	Not greasy
Varsha (rainy season)	Heavy and greasy
Sarath (autumn)	Thin, light and non-greasy
Hemantha (early winter)	Unctuous, aphrodisiac, strength promoting and heavy

Rainwater based on seasons

Susruta samhita, *Bhavaprakasha* and *Ashtanga hrdaya samhita* further classify rainwater into 2 major types as *Ganga jala* (gangetic water) and *Samudra jala* (oceanic water). *Ganga jala* is considered the rainwater that usually comes down during the *Ashwin* month (October), while the rain that falls during the rest of the months is considered to be *Samudra jala* (Sharma, 2013). *Bhavaprakasha* has differentiated between the *ganga* and *samudra jala* as shown in Table 4 (Sharma, 2013).

Table 4. Difference between *Ganga* and *Samudra jala* (Sharma, 2023)

Ganga jala	***Samudra jala***
Clear, palatable, enhance *shukra*, does not aggravate the *dosha*.	Slightly alkaline, salty and penetrating, diminishes body strength, semen and vision, has a bad odour and increases *dosha*. It is advised not to be utilized for any purpose.

According to the ancient texts of ayurveda, *Ganga jala*, is considered to be the more beneficial type of rainwater when compared to the *Samudra jala* (Sharma, 2013). However, *Samudra jala* which occurs during the *Ashvayuja* season (month of *Ashwin* or October), is also considered suitable for drinking purposes (Tewari, 2008). The reason for this suggestion is considered to be the rise of the *Agastya nakshatra* during this time. The *Agastya nakshastra* also called the star Canopus is said to have anti-poisonous properties, which is the ability to remove poisonous aspects and purify the water (Tewari, 2008). Therefore, if *Samudra jala* rains in October it can be similar in qualities to *Ganga jala* (Sharma, 2013).

Susruta Samhita, Ashtanga samgraha samhita and *Ashtanga Hrdaya Samhita* recommend a test to be carried out to differentiate between *Ganga* and *Samudra jala.* According to the ancient authors, whether the rainwater is pure or impure can be judged with a simple test. Keep a ball of rice flour (made from unpolished rice) on a silver plate in the open and collect rainwater in it for 1 *muhurtha* (1 *muhurtha* = 48mins) or 48 minutes. If its color remains the same the water is ganga or pure and if the color changes it is samudra or impure (Sadhale, 2006; Sharma, 2013).

The best water as recommended is the *Ganga jala* fallen during the *Ashwin* (October) month and it should be water that had fallen onto a clean white cloth or on the roof of a building and collected in clean utensils and stored in a gold, silver or earthen jar (Sharma, 2013). Further, it should be of unchanged color or taste (Srikanth, 2010). In the absence of this type of rainwater, it has been advised to utilize the groundwater from areas that are predominant of *Akasha mahabhuta* (Sharma, 2013). Such areas should be clean and vast, consisting of black or white soil with enough exposure to sunlight and breeze (Srikanth, 2010).

Ashtanga Samgraha Samhita mentions rainwater collected during the *Sharad ritu*, occurring from mid-September to middle of November and from an area with a moderate climate was of the best quality for consumption (Srikantha, 2012). It was observed that the best microbiological quality was detected in rainwater collected during the Autumn and Spring seasons (Srikantha, 2012).

According to *Acharya Charaka*, the excellent water that is even fit to be used by kings is mentioned as *Aindra Jala*, which is the rainwater that falls according to *Lord Indra* and is collected in a suitable container. The best water to be used is slightly astringent and sweet in taste, very thin and non-slimy, light, soft and non-greasy. Unseasonal rainwater is contraindicated to be utilized since it aggravates all the *Tridosha* in the living beings (Sharma, 2013).

Ayurveda methods of water purification

According to *Ashtanga samgraha,* water is purified by filtering through thick cloth to remove insects and worms, heated by fire**, e**xposed to sunlight or by immersing red-hot iron balls into it, made clear by putting parnimoola, knots of lotus plants, pearls, seeds of kataka, algae, thick cloth or gomedhaka (dolomite stone). Application of perfumes of naga (*Mesua ferrea*), champaka (*Michelia champaca*), utpala (*Nymphaea nouchali*), or patala (*Stereospermum suaveolens*) flowers to get a pleasing smell (Srikantha, 2012).

Modern aspects on water quality

Groundwater quality

Groundwater is stored in three major types of aquifers in Sri Lanka and among them Miocene Limestone aquifer in Jaffna peninsula is the richest in groundwater resource (Panabokke & Perera, 2005). However, poor groundwater quality is a concern in the peninsula mainly the nitrate pollution due to intensive agricultural practices (Maheswaren & Mahlingam, 1983;

Dissanayake & Weerasuriya, 1985; Nagarajah et al., 1988). According to a study in Jaffna peninsula, nearly two-thirds of the wells tested were reported to have salinity above the permissible limit (Nagarajah et al., 1988), while Mikunthan & De Silva (2008) investigated high concentrations of Nitrate-N and elevated alkalinity in densely populated and intensive agricultural cultivation areas. De Silva & Ayomi (2004) reported high nitrate concentration in the wells near the intensive vegetable cultivation areas in Malsiripura, Kurunegala which exceeded the Sri Lankan drinking water standards. Therefore, people in the areas were instructed to refrain from using well water during the wet season as the fertilizers leached into the well water. Amarasinghe & De Silva (2006) found that fecal coliform, the thermotolerant *E. coli* was very high in wells near residential areas in Vavuniya and Anuradhapura. In certain wells, Nitrate -N was higher than the Sri Lankan drinking water standards. Various scientists have studied the health hazards of the consumption of high nitrate-contaminated drinking water which leads to diseases like methemoglobinemia, thinning of blood vessels, aggressive behavior, hypertension and gastric cancer (Kuruppuararchi, 1995). Rathnayake & De Silva (2008) studied the water quality in randomly selected wells in Hambantota and the results showed that the nitrate, sulphate and phosphate concentration were higher than the Sri Lankan drinking water standards, while Samarrakody & De Silva (2016) reported that in upcountry soils where intensive vegetable cultivation is taking place in the upcountry, total, as well as the organic forms of phosphorus, were high which may lead to groundwater pollution and pose health hazards. In Badulla district, most of the schools are primarily dependent on groundwater wells for domestic uses and its quality analysis showed pH in the range of 6.5-8.5, whereas during the wet season, some well water showed pH of 10 which is not suitable for drinking purposes. The electrical conductivity was in the range of 1000-1200 μS/cm, where the permissible limit was 1500 μS/cm. Total dissolved solids (TDS) were 300-400 mg/L which was very close to the permissible limit of 500 mg/L (De Silva & Ariyaratne, 2020a). Further, the groundwater quality studies conducted in Kilinochchi showed that some of the well's water was not suitable for drinking purposes due to a higher pH of 10 which is higher than the permissible limit of 6.5-8.5. The electrical conductivity (EC) was in the range of 2250- 9500 μS/cm which is above the permissible limit of (1500 μS/cm). TDS values were from 1170 mg/L (September 2019) to 6490 mg/L (December 2019), where the permissible limit was 500 mg/L. During the month of December (wet season), the soluble solids in soil washed off to the groundwater wells make the well water unsuitable for drinking purposes (De Silva & Ariyananda, 2020b). High values of TDS are not suitable for both irrigation and drinking purposes (Rajasooriya, 2002). There are many research evidences that suggests groundwater quality as becoming increasingly hazardous to human health due to the pollution caused by society.

Rainwater and its quality

Sri Lanka receives an annual rainfall of around 1800 mm through bi model rainfall pattern. Rainwater is considered the primary source of water, but more than 70% of total rainfall is lost to the sea as surface runoff (Weerarathna et al., 2009).

Therefore, the collection of rainwater on the roof using proper technology for human consumption could be an ideal and sustainable way to get rid of the issues related to safe and clean water for the rural population. Such methods of water collection and storage are called "rainwater harvesting". Rain water is highly recommended for consumption according to ayurveda since ancient time. Rainwater harvesting is an age-old technology and low-cost system which could be utilized easily with the help of family labor. Even though Sri Lanka had a long history in rainwater harvesting, such efforts had been lessened with the introduction of pipe supply and protected wells.

Currently, the government and other 16 supporting NGOs have contributed to replenishing the rainwater harvesting sector, especially, the sector has started to work with more agility since the formation of the rainwater harvesting forum in 1996 (Weerarathna et al., 2009). At present, "Lanka Rainwater Harvesting Forum" has introduced dome-shaped ferro cement tanks for household collection of rainwater with the onset of rainfall in the dry zone areas in early October.

Recent studies in collaboration with "Lanka Rainwater Harvesting Forum" and the Department of Agricultural and Plantation Engineering of the Open University of Sri Lanka on the quality of rainwater collected in rainwater harvesting tank water and groundwater wells in the Schools in Badulla district. According to the results rainwater harvested in the study area showed that pH (6.5-8.5), electrical conductivity (less than 100 µS/cm) and total dissolved solids (100 ppm) were much less than the permissible limit for Sri Lankan drinking water standards as 6.5-8.5, 1500µS/cm and 500ppm respectively. Rainwater harvesting tank water has TDS less than 100 mg/L, which is acceptable for CKDu patients in the study area (De Silva & Ariyananda, 2020a).

Water quality of the rainwater harvested and in groundwater wells in Schools and primary health centers in Kilinochchi showed that pH of the well water is within the safe limit for drinking water is 6.5 to 8.5 (SLSI, 2016). The electrical conductivity was in the range of 350 - 500 µS/cm which is also within the permissible limit of 1500 µS/cm. Total dissolved salts were 300 mg/L which is also below the permissible limit of 500 mg/L (De Silva & Ariyananda, 2020b). However, groundwater wells showed higher values than the rainwater harvested. Therefore, the quality of rainwater collected was far above the quality of the groundwater wells in the same location. Therefore, it is noticeable that the harvested rainwater quality is superior to the groundwater well quality in the study area (De Silva & Ariyananda, 2020b).

Modern methods of water purification

Modern sciences mention boiling, filtration, chlorination, coagulation, acoustic nanotube technology, LifeStraw, photocatalytic purification and microfiltration. Boiling, filtration and solarization were the common water purification methods used by local communities due to their low cost (Murugan & Ram, 2018).

CONCLUSION

According to the detailed analysis of Ayurveda text and modern research findings on water quality, it can be concluded that rainwater quality is superior to the groundwater quality. Further groundwater quality deteriorated due to intensive agricultural activities using fertilizers and pesticides which requires extensive purification before utilization for drinking purposes. Rural population in the dry and intermediate zones lacks the knowledge of purification at affordable cost. Consumption of rainwater is healthy and also at an affordable cost, but should be collected carefully and stored in containers such as copper, silver and earth and boiled before usage. Therefore, rural communities in dry and intermediate zones are encouraged to collect rainwater with the onset of the second inter-monsoon from September/ October till November and store it in containers affordable to the communities.

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Rainfall trends and implications for water resources: A case study of Rugam irrigation tank, Batticaloa, Sri Lanka

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ABSTRACT

Understanding the rainfall trends in response to changing climate is crucial to water resource planning and management. Communities in various parts of the world rely on climate-related economic activities and are affected directly and indirectly by changing rainfall patterns in the context of global climate change. Due to its location in the dry zone of Sri Lanka and the greater reliance on rainfall for its economy, the Rugam Command Area in Eravur Pattu DS Division in the Batticaloa district has been highly vulnerable to the effects of changing rainfall patterns in recent decades. This study, which assesses annual, seasonal, and monthly rainfall trends and implications for water resources across the Rugam irrigation tank area during the last two decades, is of greatest importance. This study employed various statistical tests, which include the Mann-Kendall, Sen's slope estimator and Sequential Mann-Kendall test. These tests were adopted to determine rainfall variability and long-term monotonic trends and to detect significant change points in rainfall patterns. The results reveal that the study area's annual rainfall shows no trend from 2000 to 2023. MK statistic (S) 2.2 for the annual rainfall is not statistically significant at a 95% confidence level. Regarding seasonal trends, the MK statistic for the North East Monsoon (NEM) season is -38, whereas the MK statistic for the South West Monsoon (SWM) season is 89. A negative MK for the NEM season indicates a decreasing trend, while a positive for the SWM season reflects an increasing trend. Rainfall in the NEM season that brings more rainfall to the study area exhibits a gradual decrease over time. The rainfall trend in the SWM season illustrates a statistically significant increase. The MK statistics for the First Inter Monsoon (FIM) and Second Inter Monsoon (SIM) seasons are 2.00 and 1.10, respectively, indicating an insignificant increase. The trends in monthly rainfall exhibit a marked increase from May to October, while there has been a decrease in November, December, and January. The trends in rainfall have a wide range of implications, altering the region's local climate and water resources. On the positive side, it is significant that the cultivated land under the Rugam Irrigation Scheme during the Yala season has increased over time. Negative impacts include hydrological extremes, changes in water levels and discharge patterns from Rugam Irrigation Tank, water shortages, and agricultural failures. Thus, this study suggests short-term recommendations such as monitoring and predicting rainfall trends and water levels, altering crop calendars, strengthening early warning systems and emergency response for hydrological extremes, and promoting rainwater harvesting systems. These recommendations, along with long-term initiatives, including disaster resilience, adaptive and resilient irrigation infrastructure, sustainable water management practices, crop diversification, and sustainable water resource planning, can yield significant benefits to the region. By implementing these initiatives, we can enhance the resilience of the communities and ensure their overall well-being amid changing rainfall trends in the context of climate change.

Keywords: Agriculture, Discharge, Hydrological extremes, Mann-Kendall, Rainfall, Rugam, Water resource

INTRODUCTION

Climate change, a multifaceted phenomenon, has varied effects on human society and the environment (Alam et al., 2021). The primary indications of a changing climate, including variations in precipitation patterns, severe rainfall events, storms, and sea level rise (EPA Office of Water et al., 2015), have incompatible effects on various aspects of the earth's surface water supplies. Water is intrinsically linked to the current world climate crisis (United Nations, 2019), and it is already impacting water resources worldwide (Water and Climate Coalition, 2022). The reliable delivery of many community services is at risk, even though climate change effects differ by area (EPA Office of Water et al., 2015).

Certain countries, such as Sri Lanka, confront more negative impacts than others due to their dependency on climate-related economic activities. One of the primary areas where climate change is anticipated to impact significantly is agricultural production (Woznicki et al., 2015). Because many regions of the world are predicted to experience water supply shortages and increased water demand, many sectors are particularly vulnerable to these changes. Thus, Sri Lanka has been extremely vulnerable to changing climate patterns in recent decades (Global CCS Institute, 2016). According to the Global Climate Risk Index, Sri Lanka, Puerto Rico, and Dominica were the most affected countries in 2017 (Eckstein et al., 2018). Given the historical significance of agriculture as the cornerstone of the country's economy (World Bank; CIAT, 2015), its vulnerability to climate change is exceptionally high, emphasizing the importance of this issue. Currently, the agricultural sector contributes to 7% of the nation's gross domestic product, and over 30% of the population is employed in agriculture (International Trade Administration of Department of Commerce, 2023).

Although Sri Lanka is a tropical island with plentiful water resources, rainfall distribution across various regions exhibits notable variability (Burt & Weerasinghe, 2014). The impact of climate seasons on regional climate is crucial, even though many other factors contribute to this spatial variability in rainfall. A combination of physiographic and climatic elements has caused the dry zone to endure irregular rainfall patterns based on the different climate seasons (Murray & Little, 2000). The climate of the dry zone is divided into a rainy season, which starts in October and prevails until March, and a dry season, from April to September, which is significantly influenced by the monsoons (Izumi & Hori, 2021). Since ancient times, the country's agricultural water supply has been a challenge, particularly in the dry zone of Sri Lanka.

The population in the dry zone relies significantly on irrigated agriculture (Abeywardana et al., 2018), and the demand for irrigated agriculture increased over time in line with population growth in the dry zone. The risk has risen with the current erratic rainfall pattern driven by climate change. Fluctuations in annual precipitation and temperature have received more attention globally in the climate change arena (Alam et al., 2021). Thevakaran et al. (2019) indicate that changes in rainfall cause flooding and drought in many regions of Sri Lanka. These abrupt flooding and drought conditions cause many challenges to the agricultural economy or society as a whole, which is primarily dependent on rural agricultural activity (Amarasinghe et al., 2020). Despite some efforts to ensure food security through water resource management, crop failures have increased in some parts of the dry zone.

Batticaloa district, which belongs to the dry climatic zone in the country, is particularly vulnerable to the consequences of changing rainfall patterns (Eriyagama et al., 2010). The district has a sizable agricultural workforce, with fishing being the second most prominent economic sector (District Secretariat Batticaloa, 2021). Thus, irrigation tanks are the key water source in the Batticaloa district, especially during the Yala season. Major irrigation schemes in the district include Navagiri, Thumpankerny, Unnichai, Rugam, Welikakandiya, Kitulwewa, Vahanery, Punanai Anicut Scheme, Wadamunai, and Kattumurivu (District Secretariat Batticaloa, 2021). Rugam is the third-largest irrigation tank in the Batticaloa district, following the Navagiri tank (53,500 ac ft) and the Unnichchai tank (55,020 ac ft) (District Secretariat Batticaloa, 2018). It is a vital water source for various purposes in this region, where a dry climate predominates for an extended period of the year. The demand for agricultural water is always higher in this region, and thus, farmers usually use tank water as their primary irrigation source for agriculture and animal husbandry (Sugirtharan & Rifas, 2010). Due to erratic patterns of rainfall, people have faced significant challenges from frequent flooding and dry spells in the recent past.

Thus, planning and managing water resources in this region must consider how long-term precipitation trends are changing in response to a changing climate. Accordingly, the main objective of this study is to assess the annual, seasonal, and monthly rainfall trends over the Rugam Irrigation Tank area during the last two decades (from 2000 to 2023). This study also attempts to identify the implications of rainfall trends. The local-scale analyses of hydroclimatic variables are significant because rainfall trends and their spatial implications vary spatially and emphasize the necessity of exploring the potential ecological, economic, and social impacts of rainfall variability (Barua et al., 2013; Singh et al., 2021). Thus, analysis of the temporal variations in rainfall, by annual, seasonal, and monthly, with the implications is vital in water resource and agricultural planning and decision-making process in this region.

METHODOLOGY

Study area

The Rugam Irrigation Tank is located in the southern part of Eravur Pattu DS division in Batticaloa District in Eastern Province, Sri Lanka. It belongs to the Mundeni River basin, one of the major river basins in Sri Lanka (Figure 1). Eravur Pattu DS Division is home to three important agricultural tanks: Rugam, Kithulwewa, and Weligahakandiya. Rugam is the agricultural reservoir with the largest storage area, having a water-holding capacity of 18600 ac ft. It has a catchment area of around 22399.61 acres and a surface area of 2560.37 acres (Department of Statistics, Colombo, 2017).

The Mundeni River and the Lavani River enrich the study area's water resources. The area belongs to the dry-agro-ecological zone in Sri Lanka, and its typical average annual rainfall is about 1650 mm. Despite extended dry spells, the average annual temperature continues to be 32 °C. This division has a total area of 634.16 km^2: 591.51 km^2 of land and 42.65 km^2 of water (Divisional Secretariat Eravur Pattu, 2021a).

The division has the highest number of villages (208), distributed over 39 GN divisions. There are 25,678 families and 84,131 people living in these 39 GN divisions (District Secretariat, Batticaloa, 2023). Agriculture is intended to be a significant source of income and employment for the rural population. Over half (52.9%) of the population is engaged in agriculture, the leading economic activity in 25 out of 39 GN divisions in the study area (Divisional Secretariat Eravur Pattu, 2021b). Based on the seasonal rainfall pattern, agricultural livelihoods rely on rainfed and irrigation water. The Rugam Irrigation Tank provides numerous services to the people of the Eravur Pattu DS division, and it is a vital water source for this region in many ways.

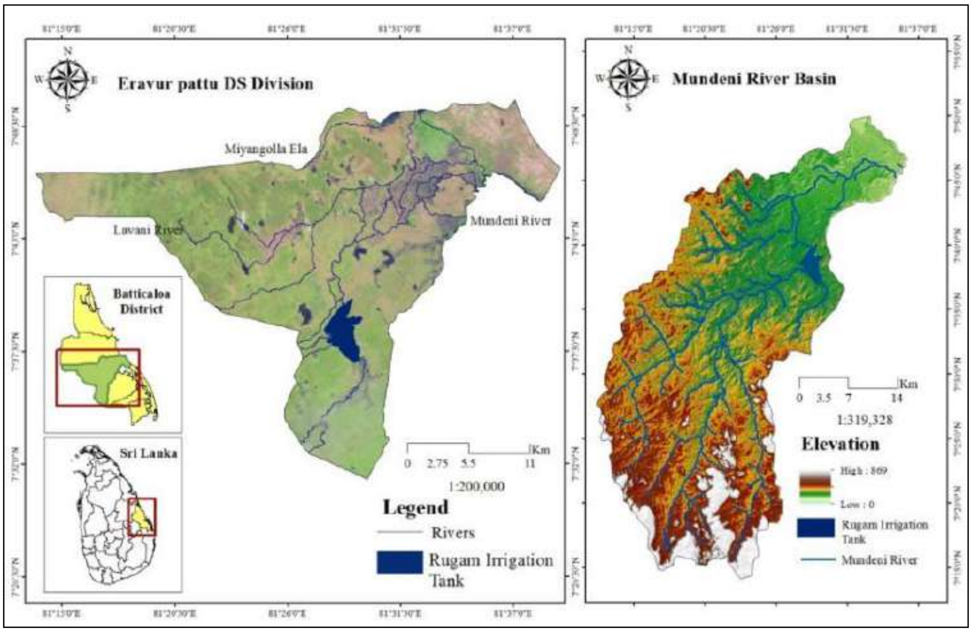

Figure 1. Location map of the study area

Data and data collection
The main objective of this study is to analyze the rainfall trends over the Rugam Irrigation Tank area using the Mann-Kendall test, Sen's Slope method, and the sequential Mann-Kendall test. Since continuous rainfall records of the Rugam rain gauge station have only been available for the last 23 years, the study is limited to data from that period. The Meteorological Department and Rugam Irrigation Office, Batticaloa, provided the rainfall data for 2000–2023. The study obtained daily rainfall data to analyze the trends in rainfall over a specified period. Based on this data, the statistical analysis detected the overall trends in annual rainfall, seasonal variation, and monthly rainfall patterns in the study area.

Additionally, the study evaluates the implications of altering rainfall patterns on the water level and discharge in the Rugam Irrigation Tank and agricultural land under this irrigation scheme. Accordingly, data relating to the water level and discharge of the Rugam tank, and the extent of the paddy lands under the Rugam scheme were gathered from multiple secondary data sources. Important data sources where data were obtained include the records from the Eravur Pattu Divisional Secretariat Division, the Department of Agrarian Services, the Census and Statistics Division, the District Secretariat, and the Office of Rugam Irrigation Tank in Batticaloa.

Analysis of data
This study has applied various statistical techniques, including the Mann-Kendall test, Sen's Slope estimator, and the Sequential Mann-Kendall test, to achieve its objective.

Mann-Kendall test
The Mann-Kendall test has been used as the primary analytical method to evaluate annual, seasonal and monthly rainfall trends. Many studies use the non-parametric Mann-Kendall (MK) test, which does not require a normal distribution of the data points to identify trends in hydrometeorological observations (Neha Karmeshu, 2012; Karunathilaka et al., 2017; Samarakoon et al., 2017; Gedefaw et al., 2018; Wickramaarachchi et al., 2020). Many researchers have commonly adopted this test to find trends in meteorological, agrometeorological and hydrological time series (Neha Karmeshu, 2012).

The Sen's slope test estimation, in combination with the Mann-Kendall test, as used by Samarakoon et al. (2017), is a reliable method to verify the statistical significance of trends and quantify their magnitude. This assessment, as demonstrated by Karunathilaka et al. (2017), is a dependable way to determine if a random variable's value is statistically increasing or decreasing over a certain period. Equation (1), presented below, is used to estimate the Mann-Kendall test statistic S.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(R_i - R_j) \qquad \text{Eq (1)}$$

Here, Ri means the annual value of the i^{th} year, and Rj means the annual value of the j^{th} year where i>j, as per Eq (2).

$$\mathrm{sgn}(R_i - R_j) = \begin{cases} +1 \text{ if } R_i > R_j \\ 0 \text{ if } R_i = R_j \\ -1 \text{ if } R_i < R_j \end{cases} \qquad \text{Eq (2)}$$

When a high magnitude indicates a trend that is more constant in one direction, then S will often be positive or negative depending on whether a dataset exhibits a regularly increasing or decreasing trend (Karunathilaka et al., 2017). Equation (3) provided below is used to determine the Mann-Kendall statistic's variance. When the data $n \geq 10$, the S statistic follows the normal distribution in a series with the mean of $E(S) = 0$ and the variance (Samarakoon et al., 2017).

$$\mathrm{var(S)} = \frac{1}{18}[\mathrm{n(n-1)(2n+5)}] \qquad \text{Eq (3)}$$

If there is a tie in the data, Equation (4) would give the variance of S as follows:

$$\mathrm{var(S)} = \frac{1}{18}\left[\mathrm{n(n-1)(2n+5)} - \sum_{p=1}^{a} t_p(t_p-1)(2t_p+5)\right] \qquad \text{Eq (4)}$$

where n is the total number of data points, q is the number of tied groups, and t_p is the number of data values in the p^{th} group (Karunathilaka et al., 2017). Equation (5) is used to calculate the test statistic Z.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{var(S)}}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{var(S)}}} & \text{if } S < 0 \end{cases} \qquad \text{Eq (5)}$$

The hypothesis formulated as follows to make decision

H_0: There is no trend

H_1: There is a trend

A two-sided test of the trend was used as $|Z| \leq Z1\text{-}\alpha/2$, in this case, to accept the null hypothesis (H_0) at the α level of significance (Wickramaarachchi et al., 2020). The alpha level of 0.05 is employed here. When $Z(1\text{-}\alpha/2) > 1.96$, the rainfall will increase and decrease when $Z(1\text{-}\alpha/2) < -1.96$ (Karunathilaka et al., 2017).

Sen's slope method

Sen's slope is based on a nonparametric median that calculates the magnitude of the trend (Sen, 1968). This technique is used to determine the magnitude of the trend line (Perera et al., 2020). The Sen's Slope test is an improved technique than linear regression as the test is not influenced by the number of outliers and data errors (Aditya et al., 2021a; Ray et al., 2021). The method comprises calculating slopes for all the pairs of ordinal time points through the median of these slopes to evaluate the overall slope (Karunathilaka et al., 2017b). The slope is calculated as a measurement of change per change in time, which is mentioned below in Eq (6).

$$Q = \frac{R_i - R'_i}{i - i'} \qquad \text{Eq (6)}$$

Where Q is the slope between R'i and Ri data points and the data measurements at time i' and i, respectively. The time i come before i' time.

The Sen's slope variance is estimated by Eq (7) below.

$$\mathrm{var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{a} t_p(t_p-1)(2t_p+5)\right] \quad \text{Eq (7)}$$

If there are n values xj in the time series, the number of slope estimates can be measured using N = n(n-1)/2 (Karunathilaka et al., 2017b). The N values of Qi range between the most minor and most significant, and the median of these N is the Sen's slope, as given in Equation (8).

$$Q' = \left(Q_{\frac{n+1}{2}}\right) \quad \text{if n odd} \quad \text{Eq (8)}$$

$$Q' = \frac{1}{2}\left(Q_{\frac{n}{2}} + Q_{\frac{n+2}{2}}\right) \quad \text{if n even}$$

Calculated slops are denoted as N here. Equation (9), given below, estimates the range of rankings corresponding to the defined confidence limits (Aditya et al., 2021b).

$$C_{\propto} = Z_{1-\propto/2} \times \sqrt{\mathrm{var}(S)} \quad \text{Eq (9)}$$

When the Mann-Kendall test rejects the hypothesis of no trend, Sen's Slope is used to quantify the trend.

Sequential Mann-Kendall Method

In this technique, the progressive analysis of the MK test's sequential values u(t) (prograde series) and u'(t) (retrograde series) were calculated to evaluate how the trend changed over time (Wickramaarachchi et al., 2020). Here, the standardized variable u(t) has a mean of zero and a standard deviation of one (ibid). As a result, its sequential behavior varies slightly near zero. The z values discovered from the first to last data point are the same as u(t). This test considers the relative values of each term in the time series (x1, x2..., xn). The actions listed below are carried out in that order (Wickramaarachchi et al., 2020b).

The test statistic t is then given by equation 10;

$$t_j = \sum_{1}^{j} n_j \quad \text{Eq (10)}$$

The mean and variance of the test statistic are mentioned in equation 11

$$E(t) = \frac{n(n-1)}{4} \quad \text{and}$$

$$\mathrm{Var}\ (t_{(j)} = [j(j-1)(2_j+5)]/72 \quad \text{Eq (11)}$$

The sequential values of the statistic u(t) are then calculated as Equation 12.

$$u(t) = \frac{t_j - E(t)}{\sqrt{\mathrm{Var}\ (t_j)}} \quad \text{Eq (12)}$$

Similarly, the u'(t) values are computed backwards, starting from the end of the series.

Data processing and statistical analysis were done using various software applications such as R Studio, Minitab, and Microsoft Office Excel. The statistical analysis findings were then visually depicted using charts and tables.

RESULTS AND DISCUSSION

The analysis of rainfall using different statistical tests, such as Mann-Kendall, Sen's slope, and the sequential Mann-Kendall test, illustrates some significant findings. Over time, there have been noticeable changes in the annual, seasonal, and monthly rainfall in the study area. Accordingly, understanding the local climate by identifying these trends is crucial in the decision-making process regarding water resources, agricultural practices, and disaster resilience in the study area.

Trends in annual rainfall

The annual rainfall trend is essential when analyzing a region's climate variability. Figure 2 depicts the yearly rainfall trend in the study area from 2000 to 2023. The results reveal that rainfall over the last two decades has fluctuated.

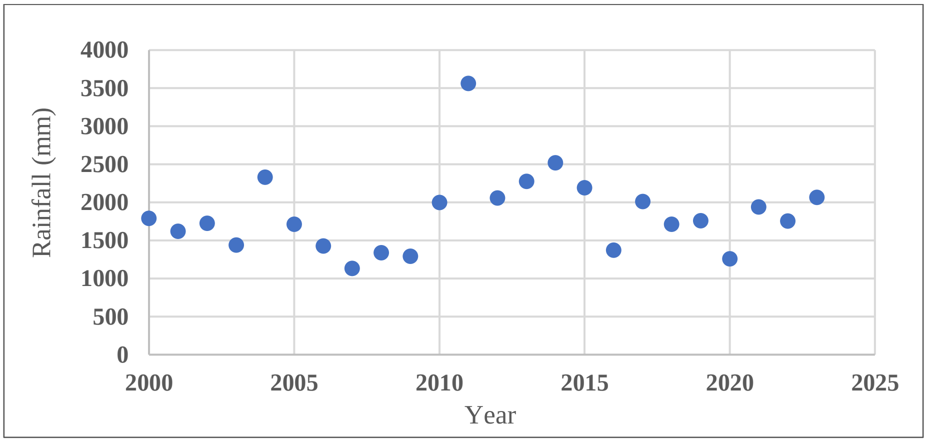

Figure 2. Annual total rainfall trend in the study area (Data Source: Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024)

According to Figure 2, there has been a decreasing trend in the beginning (2000 – 2003) of the examined period, with an increase in 2004. Following this increase, rainfall gradually decreased and reached 1133 mm rainfall in 2007; this was the year with the lowest annual rainfall ever recorded. Since 2007, rainfall has shown an increased trend. In 2011, the study area recorded its highest rainfall (3566 mm). A sharp decrease was observed in subsequent years. In 2014, the study area recorded its second-highest rainfall, 2523 mm. Since 2014, rainfall has fluctuated. During the higher rainfall years 2011 and 2014, the study area experienced severe flood disasters. In contrast, a decrease in total rainfall was recorded in years 2007, 2016, and 2020.

Mann-Kendall test was performed to estimate the annual total rainfall trend, and the test results are summarized in Table 1. The test statistic (S) 2.20 indicates an insignificant positive trend. Further, Sen's slope was estimated to demonstrate the magnitude of the trend for rainfall data. The test results show that Rugam station has an annual trend value of 6.80 mm/year. The study accepts H_0 because the p-value of 0.60 exceeds the alpha significance level (0.05). Thus, the annual total rainfall indicates an insignificant increasing trend. The studies conducted by Karunathilaka et al. (2017b) and Wickramaarachchi et al. (2020b) found a positive trend in rainfall in Sri Lanka.

Table 1. Results of the Mann-Kendall test for annual rainfall

Mann-Kendall test						
Station	Mann Kendall Statistic (S)	Kendall's Tau	Sen's Slope	P-value	Alpha	Test Interpretation
Rugam	2.20	7.97	6.80	0.60	0.05	Accept H_0
***Statistically significant at P-value≤0.05**						

Source: Data obtained from Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024

In addition, the sequential Mann-Kendall test was employed to identify change points for annual total rainfall. This test can identify the statistically significant change points over the period, according to Anie John & Brema (2018).

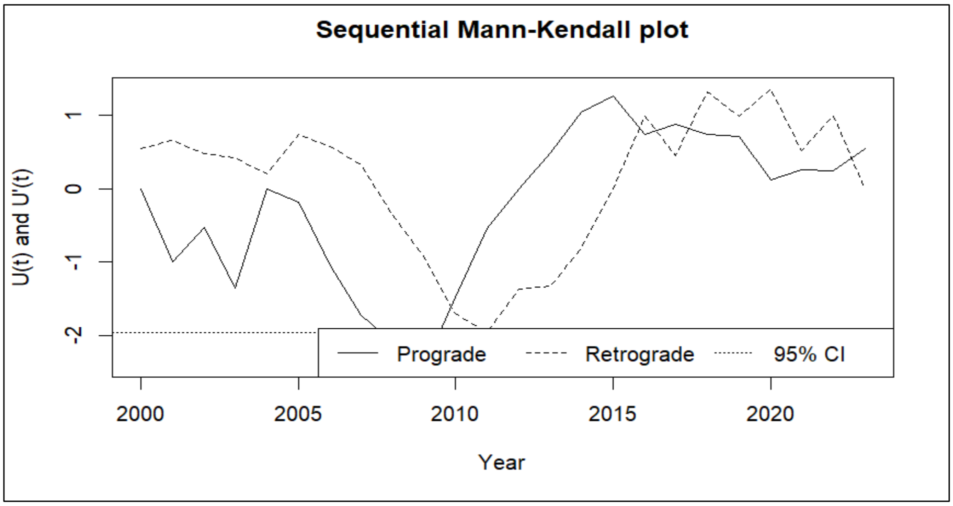

Figure 3. The curves $U(t_i)$ and $U'(t_i)$ of the Sequential Mann-Kendall plot for the annual rainfall (Data Source: Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024)

The sequential MK plot reveals some unique characteristics over the examined period. The U(ti) and U′(ti) curves for annual total rainfall indicate an apparent decreasing trend from 2000 onwards, which continues till 2010, except for an increase in 2004 (Figure 3). Subsequently, rainfall shows an upward trend from 2010 to 2015. The U(ti) and U′(ti) curves show three points of interactions in the years 2016, 2017, and 2022. No statistically significant change points were detected in annual total rainfall with an increasing trend Despite fluctuations in rainfall, the second half of the period exhibits a slight increase.

Trends in seasonal rainfall

The climatic seasons of Sri Lanka play a vital role in determining the rainfall pattern and trend of the study area. Figure 4 distinguishes the rainfall trend in four climate seasons: North East Monsoon (NEM) from December to February, South West Monsoon (SWM) from May to September, First Inter Monsoon (FIM) season from March to April, and Second Inter Monsoon (SIM) season from October to November. Depending on the locational and other geographical factors, the influence of the NEM and SIM seasons in determining the rainfall is immense. The study area receives higher rainfall from the NEM season, followed by the SIM season (Selvanayagam, 2018). Due to the influence of these two seasons, the study area receives more rainfall at the beginning and end of the year.

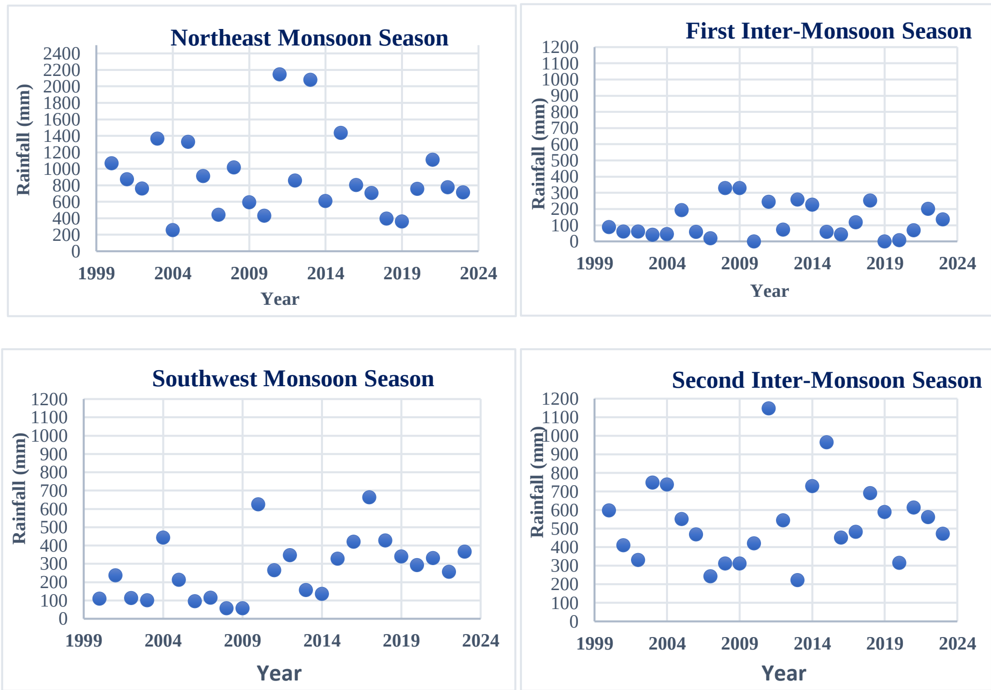

Figure 4. Seasonal rainfall trend in the study area (Data Source: Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024)

The Mann-Kendall test was performed to estimate the seasonal rainfall trend, and the test results are summarized in Table 2. The results indicate distinct trends between NEM and SWM seasons. The MK statistic (S) for NEM is -38, indicating an insignificant decreasing trend. According to (Abeysingha, 2022), however, rainfall trends in the NEM across the country show an upward trend. No such trend is manifested in the study area. In contrast, the MK statistic (S) for SWM is 89.00, which shows that the rainfall has significantly increased this season. MK statistic (S) for inter-monsoon seasons, such as FIM and SIM, are 2.00 and 1.10, respectively. These values indicate an insignificant increasing trend. As of a 95% confidence level, the p-values for NEM, FIM and SIM seasons are 0.35, 0.98, and 0.80, respectively. The p-value exceeds the alpha significance level (0.05) in these three seasons, so the study accepts H_0, indicating no statistically significant trend. If the p-value is lower than 0.05, H_0 is rejected, and the particular trend has statistical significance. Such a trend is observed in SWM, with a positive increasing trend in the rainfall.

Table 2. Results of the Mann-Kendall test for seasonal rainfall

Test Parameters	Seasons			
	NEM	FIM	SWM	SIM
MK Statistics (S)	-38.00	2.00	89.00	1.10
Kendall's tau	-0.14	7.27	0.32	3.99
p-value	0.35	0.98	***0.02**	0.80
Sen's slope	-10.73	0.06	10	0.89
Test Interpretation	Accept H_0	Accept H_0	Reject H_0	Accept H_0

***Statistically significant at p-value ≤ 0.05**

Source: Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024

Sen's slope was estimated to demonstrate the magnitude of the trend for seasonal rainfall data. According to Sen's slope results, trends differ across the four seasons. SWM shows a significant increasing trend, while FIM and SIM seasons demonstrate an insignificant increase. Conversely, NEM reveals an insignificant decreasing trend. Sen's slope value for this season is much lower (-10.73), which indicates a decreasing trend. A significant increasing trend was found only in the SWM season with a slope value of 10. Thus, results imply that rainfall significantly increases during the SWM season while the NEM season witnesses a decline over a specified period.

The MK statistic clearly explains that the annual rainfall has no trend (section 2.3 a) in the region, even though the statistic is positive (2.20) because the p-value is greater than 0.05. The hypothesis, "there is no trend", has been accepted. The MK statistic of seasons FIM (2.00) and SIM (1.10) seasons also reflect the trend of the annual pattern, but the seasons NEM and SWM show a negative and positive trend, respectively. The NEM (-38.00) season shows a negative trend, reflecting that the rainfall in the season is gradually decreasing, and the SWM (89.00) season shows a significant positive trend, suggesting that the rainfall trend is increasing rapidly. The NEM season, which usually brings more rainfall, indicates a reduction in rainfall, while the SWM season, which typically brings less rainfall, reflects an increasing trend.

The sequential Mann-Kendall test applied to detect the seasonal rainfall pattern is shown in Figure 5. Values of U(ti) and U′(ti) for the seasonal rainfall trend indicate that during the NEM, rainfall is erratic and does not follow increasing or decreasing patterns. The U(ti) and U′(ti) curves have intersected multiple times. Some specific years exhibit a statistically significant increase in rainfall, even though the overall trend for this season is not statistically significant. Notable increases in rainfall were found in 2002, 2004, 2008, 2011, 2014, and 2021, with statistically significant increases only observed in 2004 and 2014. A decrease in rainfall was found in the years 2001, 2003, 2007, 2009, 2012, 2016, and 2022. However, only 2003, 2007, and 2016 showed statistically significant decreases in rainfall.

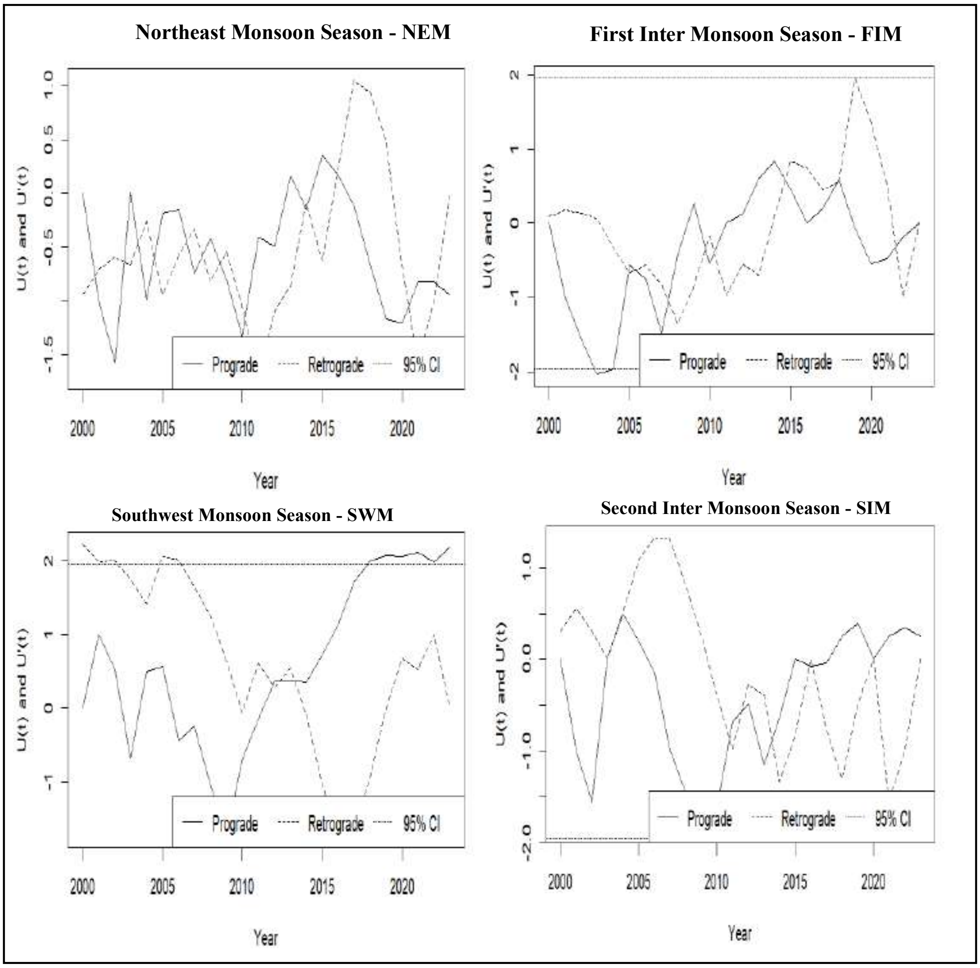

Figure 5. The curves U(ti) and U′(ti) of the Sequential Mann-Kendall test for the seasonal rainfall (Data Source: Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024)

The U(ti) and U′(ti) curves for the FIM season intersect multiple times, revealing no apparent upward or downward trend. Rainfall decreased in 2005, 2008, 2010, 2016, 2019, and 2021, with a statistically significant decrease observed only in 2008, 2010, and 2019. In contrast, an increase was observed in 2004, 2010, 2018, and 2022, with a statistically significant increase found only in 2010, 2018, and 2022. The rainfall trend for the SIM season shows a fluctuating pattern, and no definitive trend was detected from the curves of U(ti) and U′(ti). A decline in rainfall was found from 2000 to 2002. In 2004, a statistically significant increase was identified. From 2010, an upward trend was detected. However, a notable increase was found solely in 2015 and 2020.

The results of the Sequential Mann-Kendall test for the SWM season exhibited a distinct trend from the other seasons. The U(ti) and U′(ti) curves for the SWM season showed a downward trend till 2009 and an upward trend from 2010, and this increase was found to be statistically significant. The statistically significant increase in this season is expected to bring changes in the rainfall pattern in the study area. As the study area is on the leeward side during the SWM season, it usually experiences less rainfall than the windward side, and thus, it confronts various problems related to a dry climate. In this circumstance, the increase in SWM rainfall may positively affect the region.

Trends in monthly rainfall

The average monthly rainfall varies depending on the various effects of the seasons on rainfall levels (Alahacoon & Edirisinghe, 2021). Rainfall tends to be higher in the study area at the beginning and end of the year, resulting in higher monthly averages during those months (Figure 6). Accordingly, November (354.4 mm), December (451.5 mm), and January (297.5 mm) consistently rank as the top three months with the higher rainfall. Among these three months, December experienced the highest monthly average rainfall, which also coincided with a higher number of flood events in the study area (Elankumaran, 2003).

Besides, the study area experiences moderate monthly rainfall in February and October. Rainfall during these months typically ranges from 166 mm to 184 mm. The study area receives less rainfall in the middle part of the year. April, June, and July exhibit the lowest recorded average monthly rainfall, slightly contributing to the overall rainfall accumulation. In particular, June and July have received the lowest monthly average rainfall (around 37 mm) during the examined period.

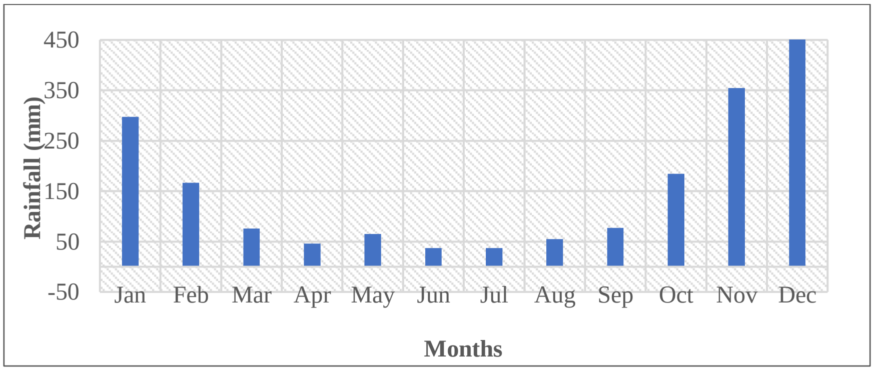

Figure 6. Monthly average rainfall in the study area (Data Source: Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024)

An approximately six-month period from March to September is defined by low rainfall (averaging below 100 mm), leading to dry spells in the region. Consequently, the effect of a dry climate is more pronounced in this period. Thus, issues concerning the availability of water resources tend to be severe around the middle of the year rather than in other months.

The results of the sequential MK test statistic for the monthly average rainfall are shown in Figure 7. The values U(ti) and U′(ti) for most months demonstrate fluctuations. When examining the monthly average rainfall pattern for each month, it is apparent that six months exhibit a noticeable increase: May, June, July, August, September, and October. The trend of increasing rainfall for June, July, August, September, and October has been reported to be statistically significant.

Notably, there is an increase in May and August, a discernible increase in rainfall recorded in these two months since 2010. In contrast, there has been a tendency towards decreasing rainfall during the NEM seasonal months, such as November, December, and January. However, this decreasing tendency is not statistically significant for any of these months. This season is marked by overall fluctuation. Moreover, the rainfall for March and April shows no statistically significant trends due to fluctuating patterns.

As discussed above, seasonal and monthly rainfall trends shape the local climate, causing challenges to the community due to the dependence on climate-reliant livelihoods. Since rainfall is the primary climatic factor that influences the regional hydrological cycle and the availability of water resources (Barua et al., 2013), rainfall variability has a wide range of implications for the environment and the socioeconomic conditions of the community in the study area. Thus, varying seasonal and monthly rainfall trends over the Rugam irrigation area have immediate and long-term effects, either positive or negative, on the region.

The erratic rainfall pattern in rainfall hit the region's agriculture, water resources, and associated human activities. Depending on the changes in seasonal trends and the fluctuating patterns in rainfall, the study area encounters some immediate effects: tank water level changes, reduction in water supply, hydrological extremes such as flood and drought, impact on harvesting schedules, damages to infrastructure and agricultural failures. Apart from these short-term effects, long-term effects such as frequent and prolonged flood hazards, changes in water availability, reduced agricultural productivity, irregular growing seasons, extended economic losses, prolonged poverty, and a shift from agricultural to other forms of economic sources were identified as important implication in the study area.

Regarding seasonal rainfall patterns, NEM is the primary season that brings more rainfall to the region. This season significantly contributes to the regional economy through rainfed agriculture as major cultivation (Maha) takes place in this season. Sangkhaphan and Shu, 2019 also indicate that rainfall provides advantages to arid, impoverished regions primarily dependent on rainfed agriculture. Thus, paddy cultivation is higher throughout the Maha season than in the Yala season in this division. In 2022/23 alone, paddy harvested area was approximately 74% (15,292.90 acres) in the Maha season and 26% (5375.68 acres) in the Yala season (District Secretariate, Batticaloa, 2023). These statistics reveal how the Maha season is essential in agricultural production in this region. However, as discussed in 3.2 and 3.3, alterations in seasonal rainfall patterns in the study area can profoundly affect paddy cultivation in the Maha season, either inadequate or excessive rainfall

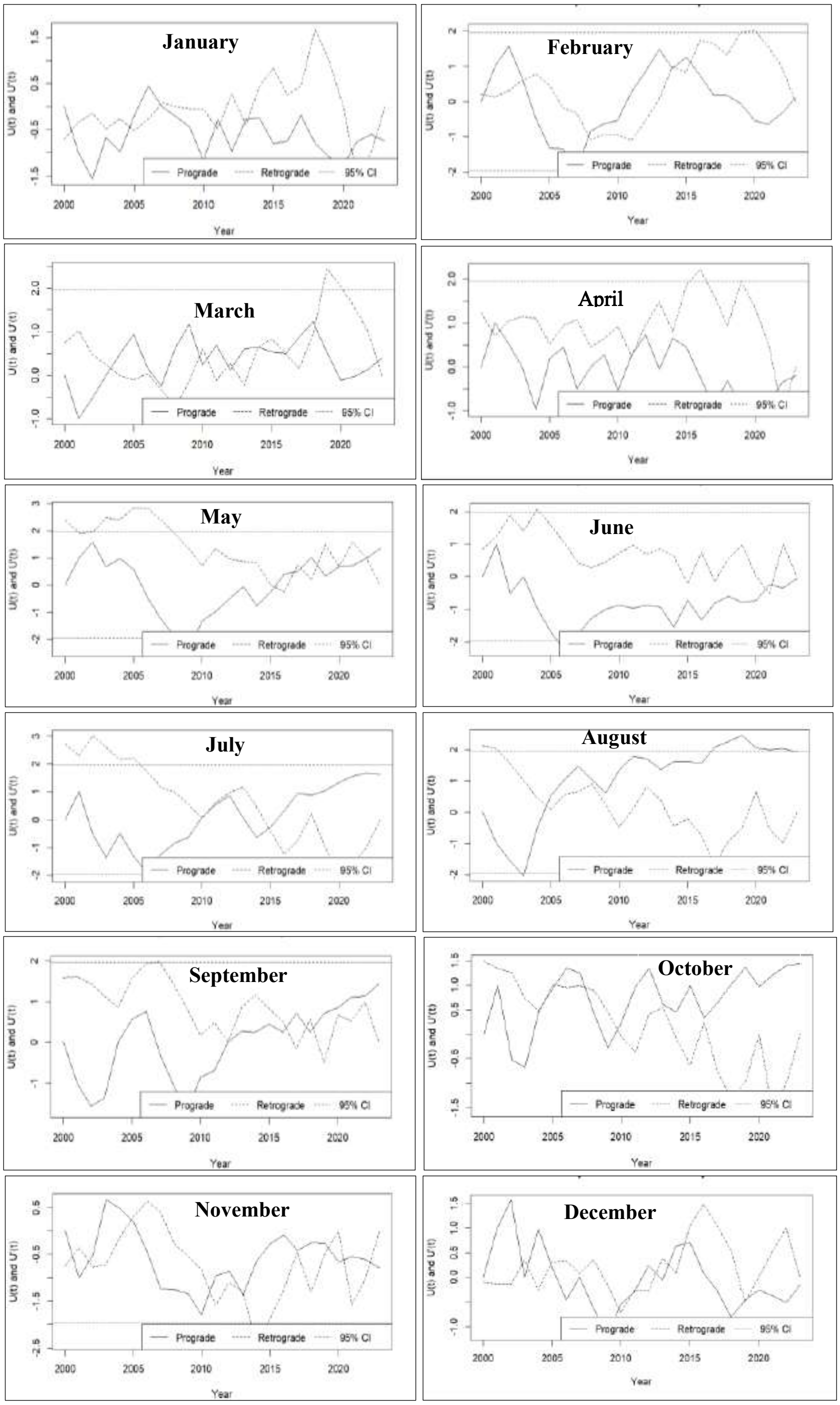

Figure 7. The curves (U(ti) and U′(ti)) of Sequential Mann-Kendall test for the monthly rainfall (Data Source: Meteorology Department, Sri Lanka and Office of Rugam Irrigation, Batticaloa, 2024)

Occurrences of extreme rainfall events increase the possibility of waterlogging, which lowers agricultural production. Conversely, insufficient and erratic rainfall patterns reduce overall productivity since paddy cultivation consistently depends on water availability. As the study area typically receives less rainfall over an extended period, irrigation water plays a vital role in accomplishing agricultural water requirements. Therefore, irrigation water demand is crucial for the Yala season and manifests by the land extent under irrigation during this season. Accordingly, the Rugam irrigation scheme plays a crucial role in the region's primary economy, including agriculture, fishing, animal husbandry, and tourism. It immensely contributes to the development of agriculture and promotes social and economic development. Figure 8 illustrates the acres of land under paddy and other food crops during the Maha and Yala seasons and crop intensity within the Rugam irrigation scheme.

According to Figure 8, the land area cultivated in both seasons has increased over time under the Rugam scheme. The standard deviation for the Maha season is 891. For the Yala season, it is 1444, indicating that the land extent in the Yala season exhibits much variability compared to the Maha season. The increase in cultivated land extent was more apparent in the Yala season. The land extent during the Maha season expanded from 5192 acres in 2006 to 7950 acres in 2023, whereas during the Yala season, it increased from 4368 acres in 2006 to 9403 acres in 2023 (Figure 8). Over the past 18 years, crop intensity has also increased despite fluctuations until 2016. The intensity was high from 2006 to 2009 but dropped to 1.72 in 2015. Subsequently, the crop intensity has risen considerably by an average value of 1.87 (Figure 8).

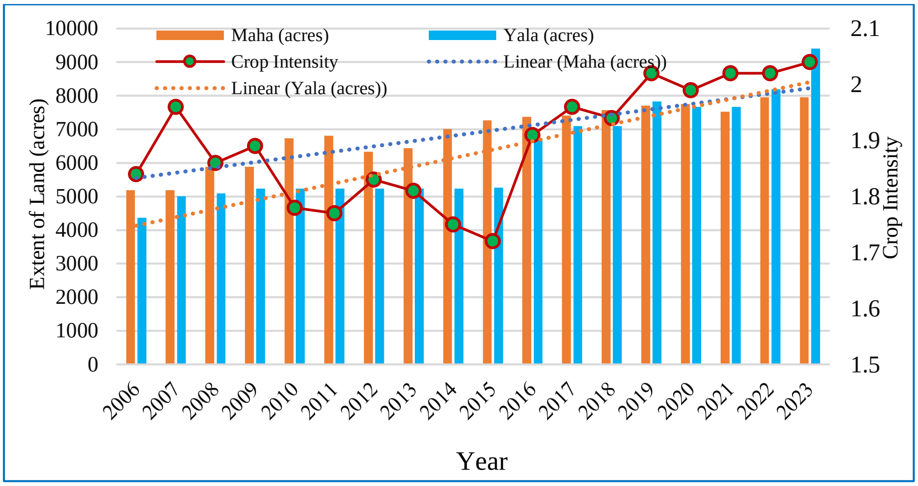

Figure 8. The land extent of paddy and other food crops in Maha and Yala seasons and crop intensity- Rugam (Data Source: Office of Rugam Irrigation, Batticaloa, 2024)

Regardless of changes in rainfall, the upward tendency might be one of the factors contributing to the expansion of land under agriculture in this division (Ranasinghe et al., 2014). This progression is vital for the agricultural advancement of the region due to the increasing population. It is noted that the population increase in the Eravur Pattu division was higher during the last decade in the entire district. The population, 73,182 in 2012, has increased to 84,131 as of 2023 (District Secretariate, Batticaloa, 2023). The increase has led to the expansion of agricultural land and increased the demand and dependence on irrigation schemes for various purposes. Thus, despite the advancement in agricultural land under the

Rugam scheme, the changing rainfall pattern in the study area has caused several adverse effects. Ranasinghe et al. (2014) highlight that shifting rainfall patterns in the study area negatively influence the communities that belong to this region.

The Mundeni River, the primary water source for the Rugam tank, plays a key role in determining the tank water levels. The amount of rainfall received by the basin's catchment area significantly influences water levels and water discharge. The annual, seasonal and monthly rainfall trends and patterns discussed in 3.1, 3.2 and 3.3 directly affect the water volume. More rainfall in the catchment area raises the tanks' water level and leads to higher discharge. Conversely, less rainfall lowers the water level and leads to reduced discharge. As indicated in Figure 9, it is evident from the rainfall data and Rugam Tank outflow data from 2012 to 2023. Throughout the period, the discharge pattern exhibited erratic changes. Total discharge peaked in 2012, 2013, and 2014, then a sharp decline was observed in the subsequent years. 2016 is recognized as the year with the lowest discharge. The drought in 2016 substantially reduced the discharge from the Rugam tank. The overall discharge has exhibited considerable fluctuations from 2016 to the present.

Water levels and water discharge from Rugam Tank are determined by the rainfall, and thus, alteration in rainfall causes different degrees of risk. Accordingly, four different conditions in the Rugam command area are discerned by the water discharge volume from reservoir: discharge between 0-1483 cusecs, estimated to be normal condition; discharge between 1483 – 17371 cusecs, considered as an alert condition; discharge between 17371-52922, categorized as danger; discharge exceeds 52922 cusecs leads to more danger condition (Rugam Irrigation Office, Batticaloa, 2024).

Thus, increased discharge associated with heavy rainfall enhances the likelihood of flood disasters. Higher rainfall in 2011 caused increased discharge and severe flooding in the study area. Similarly, discharge in the years with higher rainfall in 2012, 2013, and 2014 was 348895 ac. Ft, 384,403 ac. Ft, and 508711 ac. Ft, respectively (Rugam Irrigation Office, Batticaloa, 2024). These higher discharges, referred to as danger conditions, exacerbate adverse effects on those who reside downstream and on agricultural lands. It is clear from the declines in production under the Rugam Scheme in 2011, 2014, and 2015 that excess water has caused a negative influence on crop intensity (Figure 8).

In contrast, the reduced rainfall in 2016 and 2020 exacerbated the dry conditions, and recorded water discharge was low. In 2016, the study area received an annual rainfall of 1375.5 mm, and the total discharge was lower (16499 ac ft). In 2020, the study area experienced less rainfall (1260 mm), substantially reducing total outflow (40417 ac ft). The findings imply that the amount of rainfall in the years with higher or lesser rainfall greatly influences the discharge volume. In the context of seasonal rainfall patterns, the dry climate that predominates from June to September, particularly during the SWM season, is a serious concern in the study area. During this period, the water level of Rugam reservoir faces frequent shrinkage from its usual levels due to the irregular rainfall pattern. Lower water levels in this season in years with lower rainfall demonstrate this pattern. In October 2016, the water level was 8.00 ft, and in the same month in 2020, the water level dropped to 7.92 ft. At the end of December 2020, the water level increased to more than 16.75 ft. Ranasinghe et al. (2014) also stated that the water level in the Rugam reservoir fluctuates in response to the changing rainfall pattern.

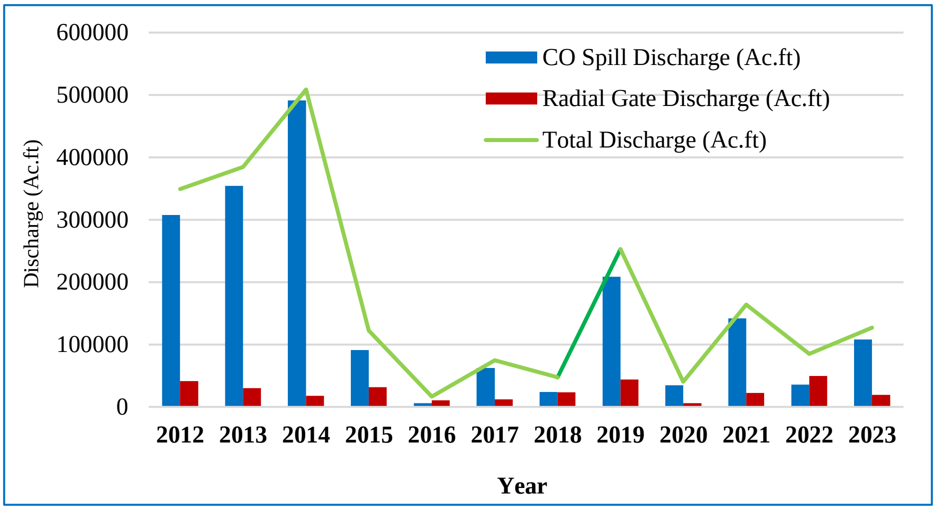

Figure 9. Outflow of Rugam tank 2012 – 2023 (Data Source: Office of Rugam Irrigation, Batticaloa, 2024)

Thus, fluctuating rainfall patterns, particularly during hydrological extremes such as droughts and floods, adversely affect the community's water requirements. The region has confronted adverse impacts in recent decades, from flood disasters to dry spells. Thus, farmers confront unforeseen challenges caused by extreme weather events resulting from flood and drought events (Ranasinghe et al., 2014). Since rural agriculture in this region depends on these water sources, the situation tends to be the most vulnerable to the effects of rainfall variability.

The dependency increases the critical role of rainfall in sustaining agriculture and livelihoods, particularly in the Yala season. During the dry spells, insufficient rainfall and irregular rainfall patterns negatively affect the farming community, and they face many struggles in meeting their water demands. Thus, they confront various challenges because of unreliable water supply for agricultural output (including the production of paddy and other crops) and other relevant economic activities. Eriyagama et al. (2010) also emphasized that the Batticaloa district frequently faces long dry spells, profoundly affecting the farming community. In this context, the changes in rainfall patterns discussed above (3.1, 3.2 and 3.3) can increase the risk and consequences of frequent agriculture failures. A study by Sugirtharan and Rifas (2010) emphasizes that water scarcity is one of the primary concerns in the Rugam command area.

In recent years, rainfall in the SWM season has increased in the region (Figure 5); the trend could potentially benefit the study area by enhancing water availability. In contrast, the reduction in rainfall in the NEM season (Table 2), the primary season in the region, is likely to affect rainfed agriculture. The scenario leads to direct and indirect consequences on agricultural livelihoods in this division. Eriyagama et al. (2010) state that while these sectors (livestock production, agriculture, and fishing) are the main contributors to the development of rural livelihoods, climate change also affects these key economic factors. Therefore, the agricultural community in this region continues to face hardship due to agricultural failures. The worst scenario is once farmers begin to rebuild their livelihoods from the shock; they are confronted with another extreme event such as flood and drought. Moreover, agricultural failures leave the farmers at increased risk of poverty. Their low income is a prime concern in terms of vulnerability level. Since the monthly income of the majority (85% of the families) falls below Rs. 40,000 (District Secretariate, Batticaloa, 2023), they face severe hardships due to financial constraints. The contemporary economic situation in the country exacerbated the challenges confronted by farmers.

As discussed above, changing rainfall patterns lead to substantial impacts in short-term and long-term in the study area, so addressing the issues confronted by farming community is crucial. Despite some progress in the management initiatives that the government and other institutions have taken, the community is nevertheless occasionally affected by adverse impacts. Accordingly, it is crucial for farmers and officials related to water resource management to understand the short and long-term consequences of irrigation demand at the local level. Relevant authorities should implement initiatives to reduce the risk and increase adaptation in response to changing rainfall pattern in the study area. Also, it is imperative to take initiatives at the community level to strengthen community capacity in addressing the challenges posed by changing rainfall patterns and extreme events in line with climate change.

CONCLUSION

This study is crucial to assess how the annual, seasonal, and monthly rainfall trends have changed over the Rugam irrigation tank area and their implications. This study adopted various statistical tests, which include the Mann-Kendall test, Sen's slope estimator, and the sequential Mann-Kendall test to assess the rainfall trends during the last two decades. The results reveal that the annual rainfall trend shows an insignificant increase. In the context of seasonal rainfall trends, except for the NEM season, all three seasons exhibit an increase in rainfall. However, the SWM season only demonstrates a significant increase. Rainfall in the NEM season, which brings considerably higher rainfall for this region, indicates an insignificant downward trend. Monthly rainfall trends show a noticeable increase in the six months from May to October. This trend would bring some positive effects to support people's livelihoods by increasing the extent of agricultural land under the Rugam scheme in the Yala season. Besides this, trends and patterns in annual, seasonal and monthly rainfall lead to multiple implications by changing the local climate and availability of water resources. The increased discharge during heavy rainfall brings adverse effects to the community in the Rugam command area, whereas the drought conditions increase problems of water shortage and crop failures. Moreover, changes in water levels and discharge from the Rugam Irrigation Tank, water shortage, and agricultural failures have become major concerns in recent years. Due to climate change, this condition is expected to increase the risk level, affecting the various aspects of the livelihoods in the region. Therefore, the study proposes actionable recommendations essential to reducing the risk of varying rainfall trends and their implications in the region on a short-term and long-term basis. Monitoring and predicting rainfall trends and water levels of the tank, altering crop calendars based on the rainfall pattern, strengthening early warning systems and emergency response for hydrological extremes such as flood and drought, and promoting rainwater harvesting systems at the local level are some of the measures which should be initiated immediately. Specifically, due to the increasing population in the study area, as the demand for water increases, it is necessary to ensure the water storage capacity and availability to meet the water demand in the future. Since the area is more vulnerable to climate change impacts, some long-term recommendations are also imperative to fight the various effects of climate change. Heightening disaster resilience, adaptive and resilient irrigation infrastructure, sustainable water management practices, crop diversification, integrated water resource policy and planning, and sustainable land use practices are some of the recommendations that must be taken seriously to ensure the overall well-being of the people in this division. Thus, it is imperative to implement such significant measures to reduce the risk of varying rainfall trends that can pave the way for a climate-resilient community.

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