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Abstract

In this paper, we review and examine indigenous knowledge on water harvesting, storage, and conservation, in the Indian context. The paper articulates indigenous technologies developed and implemented through the centuries across a wide spectrum of geographical, environmental and cultural contexts on the Indian subcontinent. The paper demonstrates that many "new" appropriate technologies in research and development could be adaptations or extensions of extant indigenous knowledge systems on water. Water problems being faced by drought prone communities can best be addressed by reviving and revitalizing older indigenous water systems already in place, but currently in disuse and disrepair. Nevertheless, these systems can be made functional and have the potential to become economically viable alternatives which will replenish depleted aquifers. These older technological systems can be revived while integrating more modern rainwater harvesting technologies; hence the paper will also demonstrate the potential for linkage and integration of IK systems with modern scientific knowledge (MSK) systems in ways that address the water problems being faced by communities. This approach has the potential to result in knowledge and technology transfer, and community capacity building, occurring in a sustainable manner. These IK systems are reviewed and examined across the Indian subcontinent, focusing on indigenous communities and their responses to water crises.

Keywords: Indigenous Knowledge, Appropriate Technology, Water, Harvesting, Storage, Conservation.

Introduction

With global climate change, the planet is seeing increasing numbers of extreme weather events, one of which is drought-like conditions being experienced by regions and communities that rarely experienced them before. Water scarcity has become a harsh reality, with communities struggling to address their water needs in an ecological and sustainable manner. Increasing use of bore wells, drilled deeper and deeper to reach a receding water table is an unsustainable approach that will lead to further depletion of the ground water and increasing water scarcity. An alternative approach is to revive, renovate and redevelop ancient indigenous knowledge (IK) and technologies on water harvesting, conservation and storage. These indigenous technologies and knowledge systems should inform the rejuvenation of appropriate technologies (AT's) for water. Appropriate Technology implementation should empower communities sustainably, which is more likely with full community engagement. Embedded in this process, and for the development intervention and technology deployment to be successful, indigenous local knowledge must be an integral part of the solution.

Indigenous Knowledge and Indigenous Knowledge Systems (IKS) are terminologies utilized by researchers and scholars to broadly capture bodies of knowledge and knowledge systems that are localized and unique to a given culture or society (Ellen and Harris, 1996;

Ahmed, 1994; Tharakan, 2012a, 2012b). Earlier papers (Tharakan, 2015a, 2015b) have provided a fuller review and analysis of IK and IKS, their defining characteristics, their undergirding philosophies, their modes of operation, and the conditionality's under which the indigenous knowledge or technology is developed, implemented and executed, either successfully or not, all within the framework of an appropriate technology approach.

In essence, IKS should be considered as the informational and knowledge base for a given society, and they are critical to the facilitation of communication and decision-making within the community. An example of an IKS on a national scale is the *panchayathi raj* system in rural India (Warren, 1991). The *panchayathi raj* system ensures that all decisions affecting a community are taken at the local level and that all community members have the opportunity to provide input and be considered before a final decisions is made. Nevertheless, given the complex nature of societies and communities, and as discussed in earlier papers (Tharakan, 2015a, 2015b), defining IK and IKS are politically "loaded" terms: being able to identify what and who is "indigenous" can be a delicate exercise in misrepresentation, underrepresentation or even over-representation of particular groups within a diverse community, with various stakeholders vying for attention.

Another important aspect of IKS is that, although they do not often have substantial "theoretical" grounding, they are still not entirely static: IK can be constantly changing, being produced, and reproduced, as communities engage in exchanges across their boundaries. Finally, it is also extremely critical to remember that IKS are situated within a broad cultural, social, and geographical context, and hence technical from non-technical knowledge and practice cannot easily or necessarily be separated (Flavier et al, 1995). Nevertheless, IKS are critical to ensure the flourishing of communities responding to diverse sets of stressors.

Appropriate Technology and the Water Situation in India

The widespread use of the term "appropriate technologies" requires articulation of what exactly it means for a technology to be deemed "appropriate". AT has always been difficult to define, and AT's development and implementation have been a source of debate in the past (Ravesteijn, 1989; Rybzynski, 1991). Over the decades, discourse and discussion on AT and what exactly characterizes it, some consensus has emerged on what AT means, but many of the received wisdoms about AT are still being questioned (Lissenden et al, 2014). Although some general received wisdom on AT suggests that it should only require small amounts of capital, emphasize the use of local materials, be relatively labor intensive and be small scale and affordable, there has been suggestions that this applies to Micro-AT, and that there should be a demarcation between micro- and macro-AT (Verharen, et al 2015). As that discussion on micro-AT and macro-AT has shown, these tenets, philosophically deriving from the "small is beautiful" ideas of Schumaker (1973), are still being questioned. Nevertheless, AT philosophy requires that it be grounded within specific communities, and that AT development and implementation engage these communities engendering capacity building and empowerment. Thus, AT's must, in general, be comprehensible, controllable and maintainable within a community. More capital intensive, "sophisticated" and imported technologies often require high levels of technical education and training for maintenance and operation, not usually resident within local communities, and the lack of which often results in the failure of an AT. Many of these factors, however, would be critical for a macro-AT intervention, such as a large-scale solar power facility, to be successfully implemented.

Thus, and perhaps most importantly, adherence to the ethic of AT requires that local communities must be included at all stages, from technology conceptualization and innovation to development and implementation. Any technology that claims the mantle of "appropriate" should also be adaptable and flexible, while eliminating – or at least minimizing - adverse environmental impacts (Darrow and Saxenian, 1986; Tharakan, 2006), with the ultimate aim of empowering the communities in which they are deployed.

Water Situation in India

Appropriate Technologies for Water Storage

The water situation in India is serious in that water access and availability is currently limited *vis a vis* the actual need. Figure 1 show the fresh water availability in India primarily from surface river waters and flows. What the graphic picture shows is that the fresh water availability picture for India's future is not particularly sanguine. The graphic shows the estimated per capita annual water availability in cubic meters (M^3) demonstrating that there is wide disparity in basin-wide water availability. Causes vary, ranging from uneven rainfall, varying population density, and differing policy responses. Given that the minimum requirement, defined by international multilateral agencies, is 1000 cu m per capita per year to be above scarcity conditions, parts of India enjoy a water surfeit, in terms of availability, at 14,057 cu m/pers/yr, while other regions thirst at 307 cu m/yr/pers. Meanwhile the per capita water availability on a national basis has declined from 2001, when it stood at 1,816 cu m/pers/yr, to about a 15% reduction by 2011, when it stood at 1,544 cu m/pers/yr. The problem in some regions is acute and critical, such as west flowing rivers of the Kutch and Saurashtra regions with water availability less than 500 cu m/pers/yr.

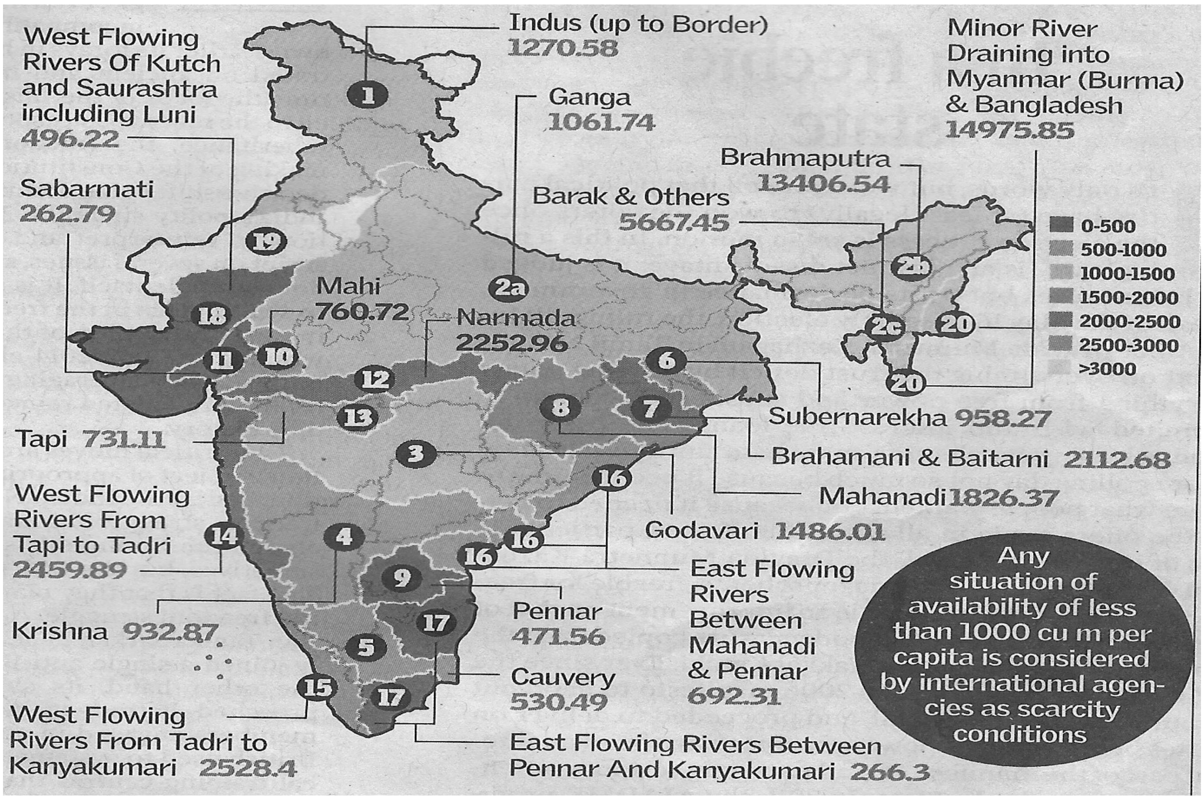

Figure 1. Estimated Per Capita Average Water Availability in Cubic Meters (*The Hindu,* Saturday May 7th, Kochi Edition; Data sourced from Central Water Commission, New Delhi, India)

The fact that parts of India suffer from water scarcity while other parts have a surfeit of water is not surprising and much is attributable to geographic and climactic variations across regions. Nevertheless, indigenous knowledge systems on water resources, water harvesting, water treatment and water storage exist from across India. There are IKS that are focused on the storage and management of water resources, which can be dated to the earliest times, including the foundational Indus Valley civilization where water storage treatment and management, including disposal of both *grey* and *black* waste waters, was an integral part of urban systems and design.

In the following subsections, various indigenous water technologies are reviewed while analysing their possible contribution to addressing the water scarcity problems of that region.

Traditional Water Structures

Stepwells: One of the most typical water resource storage and management indigenous technologies from centuries ago is the stepwell, a photograph of which is shown in Figure 2. Stepwells (or *bawari*) are basically wells that are extremely wide and in which the water is accessed by going down multiple sets of steps, depending on how deep the well is. They may have been covered or protected in some way, and they are quite significant architecturally. Although step wells are found in many different parts of India, they predominate in the western and north-western regions, also including neighbouring Pakistan.

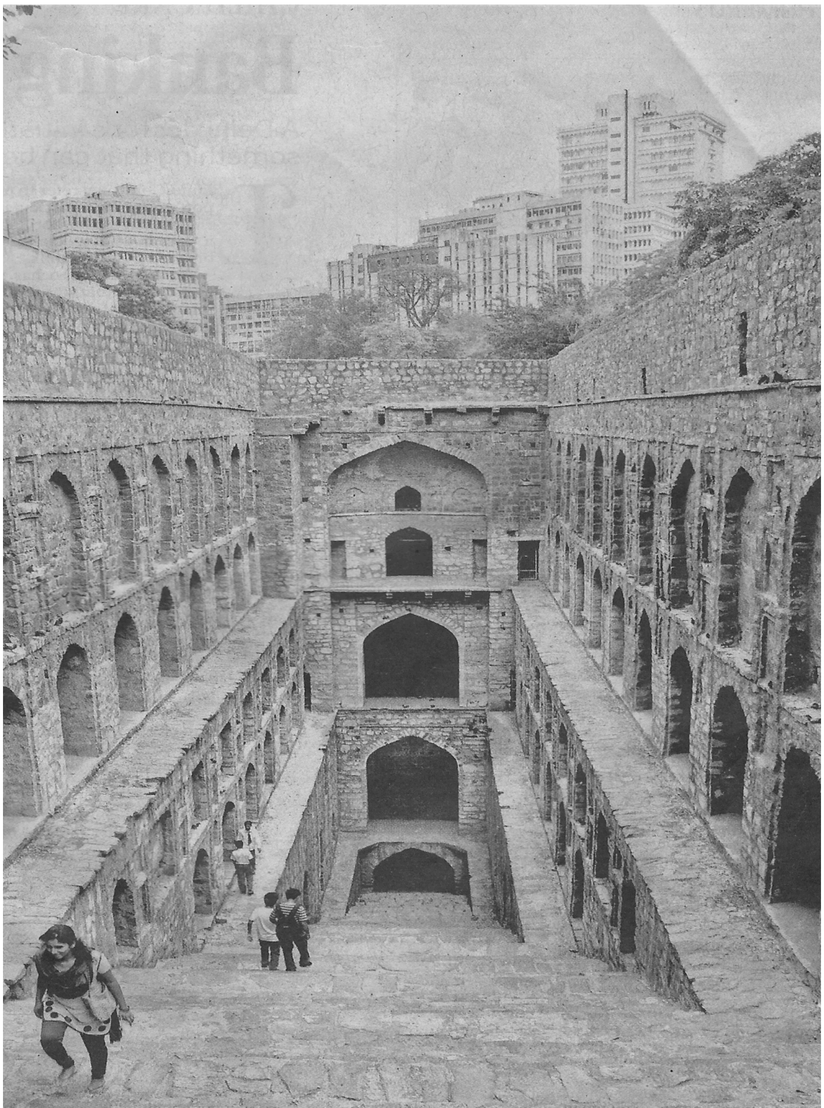

Figure 2: The *Agrasen ki Baoli* in Delhi, India, which was build in the 14th century to collect rainwater during the monsoon season. (*The Hindu*, Sunday, May 8th, 2016, Kochi, India).

Construction of stepwells was mainly utilitarian, although many stepwells include substantial and intricate architectural embellishments. From a hydrological engineering perspective, stepwells are one of the many types of storage and irrigation tanks indigenously developed in ancient India – there is some indication that both the Indus valley civilizations utilized a form of a stepwell for water storage and access. The intent of the developers and builders of the stepwells was clear: to cope with India's huge seasonal fluctuations in water availability. The main advantage of the stepwell over a simple tank or other well is that people can reach the ground water level, and the access enables maintenance and management of the well as well. Stepwell construction involved the digging of deep trenches until one reached the groundwater. The walls of the trenches were then lined with blocks of stone without the use of mortar while structuring the blocks into stairs leading down to the water. A modification on the stepwell was the incorporation of ramps (*johra* wells) that enabled cattle to reach the water. In addition, stepwells usually consist of a vertical section in the form of a shaft for the drawing of water, and then there are many subterranean passageways, chambers and steps that lead down to the water itself. It is important to note that the wells also served social functions, providing a space for relief from daytime heat, and also serving as venues for social gatherings and religious ceremonies. Hence the stepwells architectural flourishes, some with highly intricate ornamentation on many of the stepwells from the 2nd century AD onwards

The stepwell is usually situated in such a way that the hydrogeology recharges the well while the structure and positioning permit the harvesting of rainwater and its subsequent storage in the stepwell itself. Because of their positioning, design and construction, stepwells were the "everlasting source of water" within communities. Needless to say, as population density increased the ability of the well and rain water harvesting recharge to supply the growing population with water of consistent quality and at sufficient quantity to meet their needs was severely challenged. As the population grew, the solution to the water resources needed was to have treated, piped water provided to the growing population. In the case of urban India, many of these water systems became possible only through the damming and/or diversion of rivers and the building of canals to meet the intakes for the water treatment plants. A comprehensive overview of the uniquely diverse architectural splendour of the stepwells of India has been beautifully documented and provided by Lautman (2013).

Tankas: These are smaller tanks that are built either underneath the main room in the house or in the central courtyard of the house to collect rainwater. The walls of the *tankas* were usually of polished lime or the walls were lined with decorative tiles, which helped to keep the water cool. Water from *tankas* was only for drinking. If the recharge of water through the harvesting of rainwater was insufficient, water was obtained from nearby wells or tanks and then used to fill the *tankas*.

Khadin: A *khadin* is a rural construction undertaken to harvest surface runoff water for agricultural purposes (see Figure 3). The design involves a long embankment – up to 300 meters long – that is constructed of earth across the lower hill slopes, which lie below the gravelly uplands. Excess water drains off easily through integrated sluices and spillways. The idea behind the *khadin* system is that rainwater is harvested and collected from and on farmland in the rainy season for use, and subsequently the water saturated land below the *khadin* is used for the planting of next years crops.

Although the *khadin* system is Indian in origin and design, similar water management systems were developed and implemented in the Ur civilization of Mesopotamia over 4000 years ago, by the Nabateans in the Middle East and in the Negev desert. Such a technological approach was also used by the Native Americans of south western Colorado, once again demonstrating and underscoring the tremendous breath and diversity of different indigenous knowledge systems.

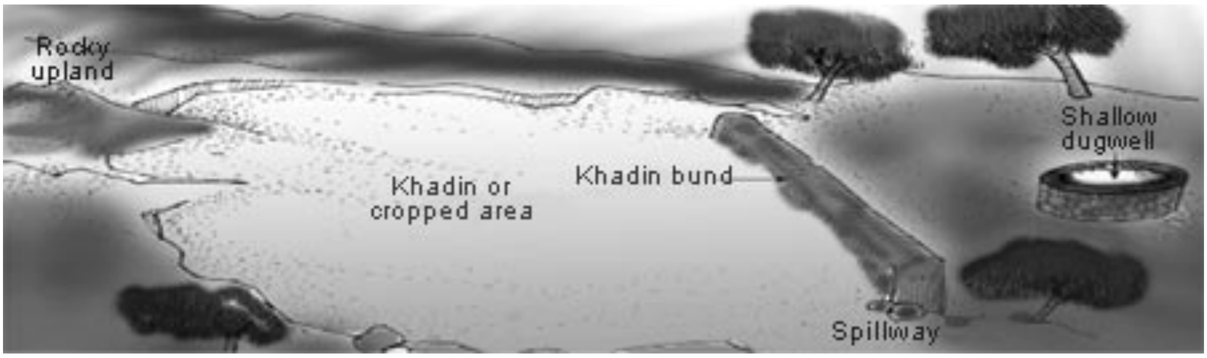

Figure 3. A diagram of the *Khadin* system of water harvesting from farmland (Agarwal et al, 2005).

Khadins and the knowledge about how, where and when to build them and how to utilize them are part of an IKS that is being forgotten as practitioners are a dying and disappearing group. These earthen bund formed water storage areas to harvest surface runoff can be implemented easily in our times, and the revival and redevelopment of this appropriate technology can provide relief to thousands of rural farming communities that have been adversely affected by the drought like conditions gripping parts of India now.

Ahar Pynes: An *ahar pynes* is a traditional system of floodwater harvesting, indigenous to the south Bihar region of India. This system design takes advantage of – or factors into it – the existing slope of 1 m/km across southern Bihar from south to north. With sandy soil, water is not retained and groundwater levels are low. However, the rivers do swell once during the monsoon and the water is swiftly carried away. To prevent this and harvest the water, an *ahar*, or a catchment basin embanked on three sides, is dug out and constructed. This results in harvesting of the flood waters when the rivers are in peak. As the water is used up and reduces over the summer period, the water storage leaves behind a wet bed. This *ahar* bed is used to grow a winter crop after the water has drained off, similar to the Khadins. The *pynes* are the artificial channels that are constructed to utilize the river water in agricultural fields.

Given the flood-drought cycle that many of India's farmlands experience, as well as the natural seasonal cycling of the monsoon and summer seasons, Ahars with appropriate *pynes* to fill them can be constructed so that water from the rainy and flood season is not lost as run-off but is harvested and stored for use during the summer dry season.

Kunds/Kundis: The *kund* or *kundi* is a circular underground well, with a saucer shaped catchment area that gently slopes towards the centre where the well is situated. The *kundi* are mainly for harvesting rainwater for drinking. In the design, a wire mesh is stretched across all water inlets to prevent any debris from falling into the well pit. The sides of the well are covered with lime and ash as a disinfectant strategy. Most *kundis* have a cover of some sort to protect the collected water, and a bucket is usually used to draw out water. *Kundis* require capital investment as well as land, so most large *kundis* are on private land and owned by wealthy farmers.

Nevertheless, Kundis and contruction of Kundi could be revived This can be tied to governmental employment schemes, such as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), that guarantee's a 100 days of paid employment for all rural residents from across India. This scheme is being utilized to provide employment to farmers during the fallow season; much of the employment is utilized by local governing bodies such as panchayats, to do public service activities such as clearing undergrowth, maintaining rural roads and clearing irrigation channels and canals. With appropriate training, rural residents can also be trained in the construction and maintenance of *Kundis*, which would provide water relief to many communities.

Jhalaras: *Jhalaras* are large human-excavated tanks used by the communities for religious rites. Their design is usually rectangular, with three sides incorporating steps to permit the community to access the water. This is a groundwater technology, designed to collect seepage from a lake located upstream. The purpose of the water is also focused on religious rites and bathing, not for drinking.

Eri: The *Eri* system of Tami Nadu provides irrigation for approximately one-third of the total irrigated area in the state. *Eri's* are tanks dug across the plains part of the state that have been critical in maintaining ecological harmony, preventing erosion, and in keeping flooding under control. The *eri's* themselves created a micro-climate through their presence and made paddy cultivation possible. *Eri's* were communally maintained with each village providing a percentage of their gross product, while also assigning land to support the village functionaries. These individuals undertook the responsibility of maintaining the eri's, which requires regular desilting, maintenance of sluices, inlets and irrigation channels. The water situation in the plains of Tamil Nadu suggest that the *eri* system needs to be revived in many places and expanded in places it's already in use

Ooranis: These are tanks found in southern Travancore. They are numerous in number but usually of a set smaller size. The smaller size in the design came about because of the location of the community, which is in the western ghat mountains, and thus large, flat and open spaces are limited.

This ancient technology has demonstrated success where modern technological interventions have failed. In the south eastern coastal parts of India, water scarcity and water quality (due to intrusion of saline or brackish water) are serious issues; the main governmental response was to increase the number of hand pumps and power pumps but the result was withdrawal of brackish water and elevation and upward movement of the saline water intrusions. A number of additional piped water schemes were implemented but they failed, primarily because there was insufficient water in the feed water sources. Given the poor performance of these modern schemes, several NGO's as well as the government decided to take a fresh look at the *oorani* option. After getting detailed accounting of the hydrogeological zones in the districts, old *ooranis* that had fallen into disuse and subject to encroachments and siltation, choked inlets structures, lack of side embankments and contamination were located and identified. Several NGO's then worked with local communities to revive the *oorani* systems, and to provide (re)training on *oorani* systems. The community also participated in desilting and in widening and deepening them to increase storage capacity, inlet and outlet structures were built on, and stone pitching and grass turfing work was initiated to prevent soil erosion. Finally, filter trenches were also constructed and connected to a draw well outside the ponds so that drinking water could also be sourced from the *ooranis*. (Vasudeo, 2005).

Bamboo Drip Irrigation: In bamboo-based drip irrigation, bamboo pipes are used to tap streams and spring waters and to irrigate plantations. With this system of water conservation, a flow of 20 liters/minute, gets transported across many hundreds of meters, finally getting reduced to a drip-irrigation flow of 1 – 5 mls/min at the plant itself. This system is indigenous to Meghalaya and about 200 years old. Here, bamboo pipes are used to divert perennial springs from the top of the hills to the lower reaches using only gravity flow. The bamboo channel sections convey the water to the plot site where it is further distributed into branches, all made from differing diameters and lengths of bamboo piping. The intake into the piping systems are controlled by manipulating the positioning and slants of the intake pipes. The system is comprised of bamboo pipes of varying diameters, which are used to lay the channels. Several tools, including an axe and a round chisel with a long handle are used to smoothen the channels as well as adjust lengths, shave angles and tie pipes and channels together. In most of the systems, at least four to five stages of distribution and reduction are involved from point of intake to the point of drip application directly to the plant.

Surangam: In the northern part of Kerala state in the Kasergod district, there are little surface waters for people to depend on (unlike in most other parts of Kerala where rivers and backwaters are plentiful). Because of the terrain, there is high discharge from rivers in the monsoon and very low discharge in the dry months. Thus, people depend on groundwater and a water harvesting structure known as *surangam*, which is a tunnel shaped horizontal well that has been excavated into hard laterite rock formations. The excavation is deep enough to reach sufficient quantity of water, which then flows out of the tunnel and it is collected in an open pit outside. *Surangams* are anywhere from 0.45 – 0.7 meters (m) wide and 1.8 to 2.0 m high, allowing a human to stand in it. The length varies, anywhere from 3 m to as long as 300m. With the deeper *surangams*, several subsidiary *surangams* of decreasing size may be excavated inside the main one. For long *surangams*, several vertical airshafts are dug into the laterite as well, which improves access and aeration or ventilation in the larger *surangams*.

Korambu: These are common across various parts of India. *Korambus* are temporary dams that stretch across the mouths of water channels, made of a wooden frame, brush, mud and grass. Construction involves the placing of a wooden beam across the water channel, touching both banks of the canal. To this beam is tied several vertical wooden beams of the appropriate desired height whose lower ends rest firmly on the ground. A close-knit coconut thatch is tied to this frame, which is then covered with mud and grass, forming a dam across the channel, and raising the water level. This raised water level enables the water to be diverted into field channels, and the height of the *korambu* can be adjusted so that fields lying on the upstream side are not submerged. In operation, water is allowed to flow from one field to the next until all the fields are irrigated. These structure are built twice a years, before the onset of the monsoon so that water can be supplied during the winter and summer season.

Bengal Inundation Channel: Bengal had an unique system of inundation canals designed to control flood waters. The floodwaters entered the fields through the inundation canals, carrying silt and fish, which swam through these canals into lakes and tanks, and fed on the mosquito larvae there, which helped to keep malaria in check. Following the British conquest of India, the irrigation system was neglected and fell into disuse. According to the historical records, these canals were broad and shallow, carrying the cresting waters of the rivers along with fine clay that was free from coarse sand. These canals were also long and continuous and irrigation was effected by making cuts in the banks of the canals, which were closed once flooding was over.

Phad: This is a community managed irrigation system that was prevalent in northwestern Maharashtra, and which probably came into existence three or four hundred years ago operating on three rivers in one basin. The system begins with a check dam (a *bandhara*) that is built across a river; from the *bandharas* a series of canals (*kalvas*) branch out to carry water to the fields. These *kalvas* range in length from two to twelve kilometres and have a uniform discharge capacity of around 450 liters/second. Distributaries (*charis*) are built to feed water from the *kalva* to different areas of the *phad*. There are *sarangs* (field channels) to carry water to individual fields.

The *phad* is a region, or set, of fields, that are cultivated or left fallow. They range in size from 10 to 200 hectares, and every year the village decides which *phad* will be left fallow. Only one type of crop is allowed on one *phad*; sugarcane may be grown in one or two *phads* while seasonal crops are grown in the other *phads*, ensuring a healthy crop rotation system.

Zings: These are water harvesting structures that are found in Ladakh. *Zings* are small tanks that collect glacial melt water. Included in this system is a network of guiding channels that brings the water from the glaciers to the tanks. As glaciers melt during the day, channels fill up with a trickle that by afternoon has turned into flowing water; this water collects in the tank over time and is used the next day.

Discussion

From this brief expose of some of the various indigenous technologies available from different regions of India, it is clear that there is sufficient indigenous knowledge on water use and conservation that already exists within the country amongst a wide diversity and cross section of communities, ranging from those at the southern tip in Kerala, to the north eastern states and across the north western regions and Pakistan. Many of these systems, despite decades, and in some cases centuries, of neglect, remain viable. Many have been abandoned and are now in disrepair and non-functional. All of these, however, could potentially be cost effective alternatives that offer the potential to rejuvenate ground water aquifers that may be reduced or depleted. Cost effectiveness will be determined using a holistic accounting approach that values preservation of community knowledge and indigenous technology, and sees them as contributing factors to community empowerment and economic development. These structures are being revived and the technologies that under lay them are being revitalized and given a re-look. The hope is that these structures can be upgraded and productively combined with rainwater harvesting and more modern water management techniques such as anicuts, percolation, injection wells and subsurface barriers. This is where modern scientific knowledge systems can contribute to not only the preservation of indigenous technologies, but also to their development and adaptation to address the water problems of today.

In Jodhpur, for instance, architects and environmental activists are seeking to clean up and revive the hundreds of stepwells (bawari's) that lie unused or accumulating garbage around the city. There are over 200 stepwells that date from the 6th century CE, that are part of a water infrastructure that was sophisticated and built to meet the needs of the city across widely varying water supplies. Although the city received very little rain, and only between June and September, this rain is diverted using canals built on the hilly outskirts of the city and channelled into tanks (*talabs*), from where it seeps into the ground raising the water table and recharging an intricate network of aquifers built deep with narrow steps down to the well to minimize water evaporation (Sriram, 2016). These older technologies and systems are now being revived and modern systems being constructed where none existed before since the technology is appropriate and suited to the hydrological profiles and geographical locale and setting in the city. Although renovation costs will vary widely depending on the existing condition of the stepwells, installation of new piping, borewells and water treatment systems will incur larger costs, not just in economic terms but also cultural and social terms. Reving the stepwell provides employment to local communities, builds capacity of the community to address their water resource needs and will address the defining issue of appropriate technology by empowering the community.

For these efforts to be successful, scientists and engineers from academia and government laboratories need to focus on building bridges and connections between indigenous knowledge and modern scientific knowledge. Just as Mistry and Berardi (2016) have argued that local ecological knowledge, i.e. the indigenous knowledge of communities that reside within given ecosystems, must be placed at the centre of environmental governance, it is incumbent of scientists and engineers working in the development context to acknowledge and integrate indigenous knowledge of water and water systems management in their research, planning and design and development work.

Conclusion

It is clear that the scope and breadth of indigenous knowledge systems for water is broad and comprehensive, with distinct IKS across the diverse socio-geographical landscape of India, ranging from the practices in the foothills of the Himalayas to the technologies developed in the far south to those developed in the remote northeast regions. Each of these indigenous technologies, whether through local check dams, directed channels, water diversions and collection strategies, address water resource needs, both for agricultural use as well as for personal use, including drinking, cooking and bathing. Most of these indigenous technologies fell into disuse after arrival of the British, who were not able to appreciate the effectiveness of the IKS systems and let these systems fall into disuse and hence into disrepair. As water scarcity becomes a more widespread reality for greater numbers of people, it is clear that revival of the indigenous technologies may be one clear strategy to rejuvenate water sources and to sustainably increase the availability of water.

At the same time, it is critical that professionals, practitioners, academics and researchers engage with local communities and their indigenous knowledge systems, devoting effort to understand the IKS within the context of modern scientific knowledge (MSKS) and understanding. This participatory and affirming approach to validate IKS is important and vital to not only the preservation of the IKS, but to it's development, expansion and dissemination as well. The tie-up with MSKS will provide the scientific and technological grounding and rigor to enable these water related and focused IKS to be rejuvenated and flourish again.

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Mapping of Groundwater quality in Great Kordufan states with Geochemistry and Health Aspects

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Abstract

Groundwater is the most used source of drinking water in rural area of Sudan as it represents about 45.1% of drinking water as per sources up to the year 2010. It is extremely vital especially in arid and semi-arid regions far from Nile basin. The groundwater quality is very dynamic due to natural process of rock interaction. That interaction adds beneficial minerals elements to water, the deficiency or excess of some elements will raise risk of health problems. In such context, periodic monitoring of water resources quality is essential, the practice that does not exist in most water provisioning authorities. In this paper we introduce a systematic groundwater quality data model for tracking and mapping its quality overtime. We show how the quality profiles are clustered and discuss the clustering results with the geochemical structure of the region, the associated health problems, and potential health risks. The aim of this mapping is to support decision-making about water safety for drinking, as well as to link cluster with appropriate best practice treatment and open the case for research. We take Great Kordufan States as case study with physiochemical measurement profiles collected by national and regional Water Corporation linked with spatial geo-informatics. The water qualities profile clusters in consistence with geological structure of the area shows alkaline salts, associated with ultrabasic rocks fluoride vein, and carbonates (attributed to concentration of fluoride), total dissolve salt (TDS), nitrite, and other minerals. The proposed model is scalable and can be extended to track other aspects of safe drinking water provisioning such as service coverage, equality, maintainability and sustainability toward Sustainable Development Goals (SDG) achievement.

Keywords: Fluoride; Groundwater; Kordufan; Mapping; Water quality

Introduction

Clean Water is an essential human right. However, there are 663 million people in the world without access to clean water. Water born disease contributes globally to more than 7% of mortality rates according to Joint WHO/UNICEF, more ever according to WHO about 80% of all diseases in human beings are caused by water ,(Ramakrishnaiah, Sadashivaiah, & Ranganna, 2009). Although groundwater is less exposed to biological contamination, but it needs careful and periodic monitoring since it's highly dynamic. Chemical fluctuations in shallow groundwater typically result from different cumulative effects, such as land use and associated chemical concentration in the topsoil, net vertical recharge (affected by leaching rainfall), local depth to groundwater, lateral recharge from ground or surface water sources, etc. In spite some of these effects can be measured accurately, it is impractical to measure others, i.e., those with unstructured spatial and temporal distribution (Mun, Ritter, & Li, 2005). Groundwater boreholes are costly and prone to many maintain-ability and sustainability problems. In order to better achieve Sustainable Development Goals, a high quality data about clean water provisioning is needed, which covers many aspects like coverage, quantities, distribution, water uses, operation status, and most importantly the quality. The rocks interaction with groundwater adds beneficial minerals to water, but excess or deficiency of some minerals may lead to potential health risks. Great Kordufan state is located in the western part of Sudan, far from the Nile basin and is characterized by groundwater as the main drinking water source, there are observable problems in drinking water quality related to the dynamic geological structure of domestic water supply in great Kordufan state e.g. Turbidity and salinity. The quality of water reflects directly to public health. In this paper we introduce systematic water quality model to provide comprehensive insight decision on water quality, by using clustering techniques to build water quality profile for each group, and link clusters with appropriate best practice treatment and open the case for research. This is a response to the gap on the rare availability of valuable water provisioning information in order to build a model to follow, for open data in this field, in order to guide the decision of suitable treatment.

In section 2 we give the geological structure of the studied region linked to whole Sudan groundwater map, section 3 will cover the methodology while the result will be shown in section 4, at the end conclusion on the result are given

Geological structure

The geological structure of study area varies with respect to groundwater condition due to variation in their lithology and rock type, the geological formations of great Kordofan States consist of the Basement Complex, the Nubian Sandstone, the Um Rawaba sedimentary formation and the superficial deposits of which sands are the dominant fraction. Following the formation of basement complex rocks, the region was subjected to prolonged erosion and later invaded by shallow seas depositing the Nawa Formation (Devonian- Carboniferous).The Basement rocks in the area are mainly metamorphic rocks of amphibolites that most of retrograde to green schist faces Biotitic and granitic gneisses. The Middle Miocene continental seas had covered the whole region depositing the thick horizontally bedded Nubian Sandstone formation(Ginaya, Elkrail, & Farwa, 2013). The area is underlain by high-grade gneisses and low-grade metavolcano sedimentary sequence (both are intruded by alkaline and post to anrogenic intrusions) and paleozoic sediments. The zone of the intrusions consists mainly of syenitic and granitic intrusions associated with ultra-basic rocks, fluorite vein and carbonates (Ibn Ouf, 2007), (Edmunds, W.M &Smedley, 1996). The distribution of groundwater in the Sudan is shown in the Fig1, Kordofan has three distinct groundwater aquifers salient Bara basin, Enhoud basin and Um Rwaba Basin, the late two are less saline than Bara.

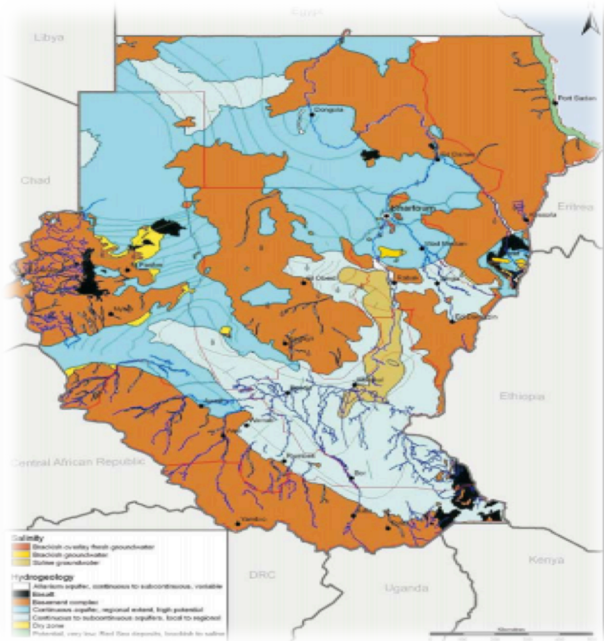

Figure 1. groundwater distribution in Sudan (Steiner, 2007)

Methodology

The samples were collected by national and regional Water Corporation, during the period between 2008 and 2010 for North Kordufan while the South Kordufan' s data was collected between 2015-2016. Samples were analyzed for 16 parameters such as pH, electrical conductivity, TDS, total hardness, Alkalinity, Chloride, Fluoride, Nitrite, Nitrate, Iron, Calcium, Magnesium, Ammonia, Sodium and potassium. These parameters are selected to be the features of the profiles. The analysis of parameters done by Standard Methods for the Examination of Water and Wastewater (Clesceri, 1998). We explore many Groundwater representation data models which contain many information(SustainableWASH, 2016). We found that geo-information with demography is more important beside quality parameters which we implemented in this paper, but also it will be valuable if the data was enriched with the operation status, service life, water quantities, depth of the well in addition to type of water uses. Such information will give insights about water provisioning, (Neis & Zielstra, 2014).

Data Clustering

The data are clustered using two methods of clustering, Hierarchal Clustering Analysis HCA, and K-means Clustering, we compared the first clustering structure with the optimum number of clusters of the second approach, in order to have inter-approaches validation. We used Silhouette diagram as graphical aid to select optimum K clusters as described in (Rousseeuw, 1987), the Silhouette value measure how far the object similar to his cluster (Cohesion) with ultimate value of +1 with comparison to separation which had -1 as edge value to indicates poor belonging to its cluster. The Cluster analysis will use similarity measure to reduce the analysis into to a few groups so that their characteristics are easy to study and searched for best practices water treatment or open the cases for the appropriate technology research. The cluster analysis combined with the decision tree for more explanation on the effect of the variation of different parameters related to water quality severity. HCA clustering shows clearly three groups which coincide with K-mean optimum clusters number depicted by Silhouette diagram in Fig 2, while the parameter variation of the cluster and water quality severity were shown in Fig2. using decision tree information gain.

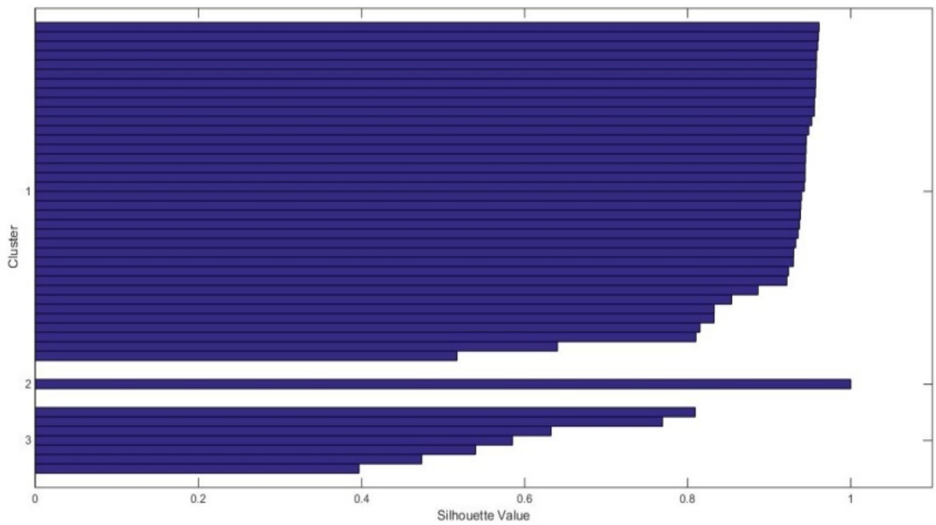

Figure 2. Silhouette Diagram for K=3 in K-Means Clustering

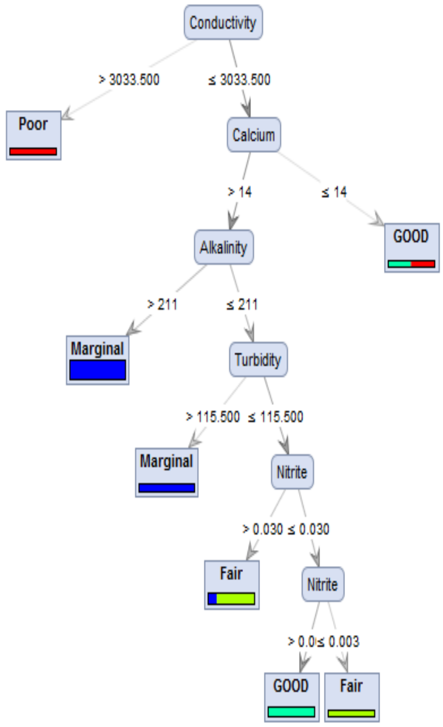

Figure 3. Decision Tree for Water Quality features

Water Quality Index (WQI)

In order to simplify the reporting of water quality data, it`s suitable to use WQI, it`s statistical summaries to report the value of water quality as a figure of merit. The index weights the summation of the composition of water referring to certain defined objectives. These objectives are related to WHO standards or another similar standard, such as European and Canadian standards. In drinking water, there is a weight assigned to each major parameter which has a critical health effects by increasing or decreasing the concentration of the resource for domestic purposes. The objectives of the study are extracted from WHO 2011 standards (Gorchev & Ozolins, 2011), for physiochemical parameters.

To calculate WQI we used the methodology of Canadian Department of Environment and Conservation (Lumb, Halliwell, & Sharma, 2006). The parameters are based on three factors. (F1) the scope factor, which represents the percent of variables that did not meet their objectives

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} * 100$$

F_2 the frequency factor, which represents the percentage of how frequent individual tests failed to meet the objectives, in our sampled data all groundwater wells are measured only once in its lifetime so that $F_1 = F_2$

$$F_2 = \frac{\text{Number of failed testes}}{\text{Total number of testes}} * 100$$

F3 the amplitude factor, which measures the amount by which failed test value don't meet their objectives it is calculated in three steps:

i- The number of times by which an individual concentration is greater than or less than, when the objective is termed an excursion.

$$\text{Excursion} = \left[\frac{\textit{Failed test value}}{\textit{Objective}}\right] - 1$$

For the cases in which the test value must not fall below the objective

Excursion = $[\frac{\text{Objective}}{\text{Failed test value}}]-1$

ii- The collective amount by which individual tests are out of compliance calculated by summing the excursion of individual tests from their objectives and dividing by the total number of testes not meeting objective this variable, referred to as the normalized sum of excursion or ***nse***

nse = $\sum_{i=1}^{n} \text{excursion} / \text{tests}$

iii- F3 is then calculated by a sympatric function that scales the normalized sum of excursion from objective (***nse***) to yield a range between 0 to 10

$F_3 = [\frac{nes}{0.1\ nes+0.01}]$

WQI is then calculated as: $[\sqrt{F^2 1 + F^2 2 + F^2 3}]/1.732$

Table1 Water Quality Index WQI ranks and its ranges

WQI Range	WQI Ranks
100-95	EXCELLENT
94-80	GOOD
79-65	FAIR
64-45	MARGINAL
44-0	POOR

Spatial Interpolation

Beside statistical summaries using simple statistics moments (Means, Median, Stdev, Min, Max), multivariate correlation analysis can reveal a lot of dependencies between parameters, in addition, to interpolate the parameters ranges with geospatial span, such spatial interpolations will give insight visual approximation to WQI and hazard parameters variations. Many similar studies argue the important of Kriging interpolation to give the best linear unbiased prediction of the intermediate values, maps of WQI, Fluorides, Nitrate …etc (Analysis & Corporation, 2013; Hassan, 2014), can easily drive to better inform which area predicted to have failed water quality objectives.

Results and discussion

Summary of Parameters statistics

Table 1 summarizes (min, max, median and average) it shows how many orders of magnitude the natural concentrations of the analyzed elements cover in this data set (deviated value indicates by **Bolds**), also compare with WHO water quality standard and other complementary standards, mainly Canadian for some parameters.

Table 2. Summary of the concentrations physo-chemical parameters of great Kordofan state from 2008 - 2016 using WHO guidelines (2011),* Nephelometric turbidity units,** Canadians Guideline 2008

Parameters	Objective Value	Mean	Min	Max	Stdv
pH	6.5-8.5	7.3	6.6	8.0	0.3
Temperature	44	31.2	18.9	41.0	8.4
Conductivity	500	**1032.8**	164.62	5482.7	980.8
TDS	500	**686.5**	90.54	3837.9	689.9
Alkalinity	400	226.5	72	610.0	141.5
T. Hardiness	100	**267.2**	20	2619.0	450.6
Chloride	250	47.6	1.4	320.0	81.5
Fluoride	0.5-1.5	0.3	0	2.7	0.5
Nitrite	3	**16.1**	0	300.0	46.3
Nitrate	50	35.5	0	220.0	46.4
Iron	0.3	0.3	0	2.6	0.6
Calcium	75	57.9	6.4	660.0	111.8
Magnesium	50	17.3	1.6	78.4	14.3
Ammonia	3	0.3	0	3.2	0.7
K + Na	50	**78.1**	0	291.8	57.6
Turbidity	5	**19.5**	0	357.0	69.1

There are some elements with concentration that exceeds the guideline limits which raises the potential health risks. The maximum value of conductivity in data set is 5482.7µs/cm which far from WHO objective, it is an evidence of solubility of minerals in this region, the conductivity shows high correlations (0.99) with TDS which also go beyond the acceptable level. This result is coinciding with the region geological structure which is dominated by sand and alkaline rock. The Nitrite concentration in ***El Beniya*** village (North Kordufan) far exceeds the acceptable range of domestic water which may be attributed to Bacteria activity since there is no large agriculture activity around the village. The K-means clustering method, cluster the data into three clusters, the variation of parameters across the cluster are depicted in Fig 3 where the overall water quality rank distribution are given in Table 2

Table 3. Water Quality Rank distribution across the clusters

Cluster	GOOD	Fair	Marginal	Poor	Total Sample In cluster
cluster_0	**0**	**0**	**6**	**1**	**7**
cluster_2	**7**	**13**	**15**	**1**	**36**
cluster_1	**0**	**0**	**0**	**1**	**1**

Fig 4 shows deviation across clusters in TDS, Conductivity, Alkalinity, Fluoride, and Nitrite. Since TDS and Conductivity show high correlation we plot other parameters against TDS to reveal how cluster scattering over the space Fig 5,6,7 depict that effects

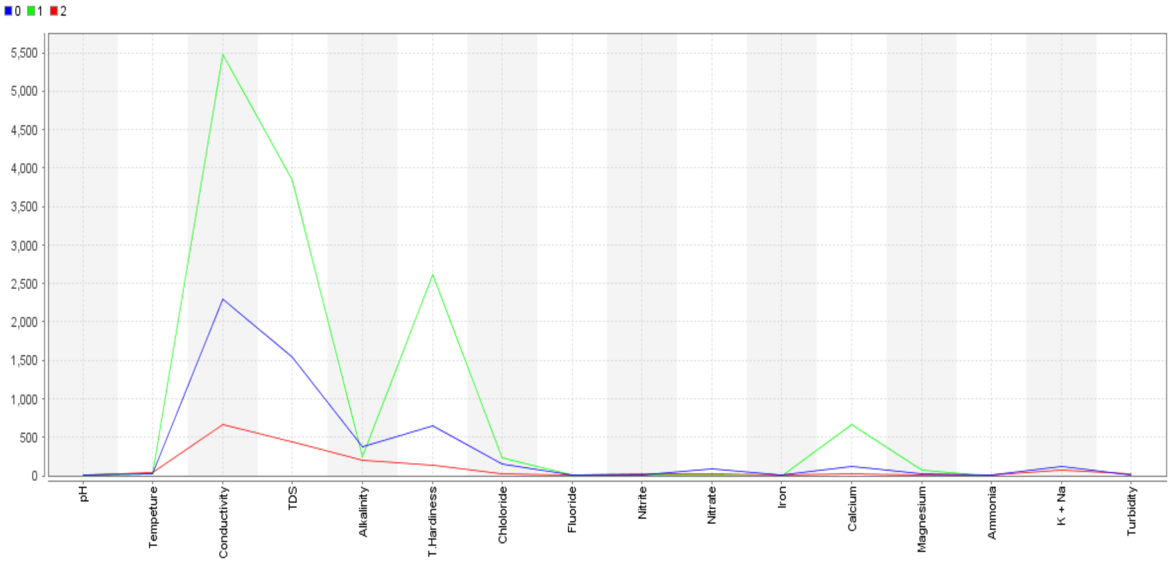

Figure 4. The Clusters and parameters variation

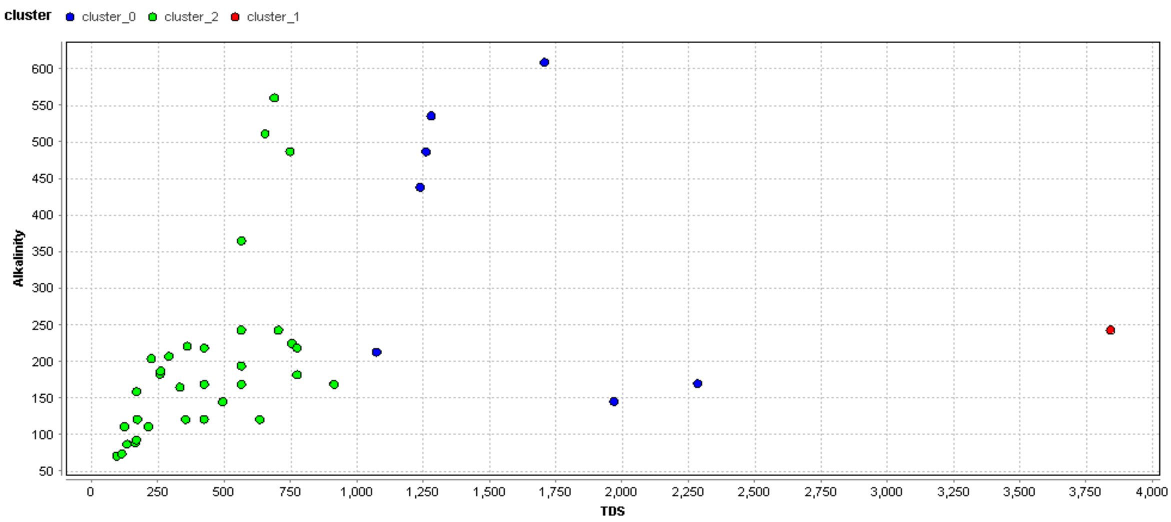

Figure 5. the distribution of cluster over Alkalinity/ TDS space (400 ppm)

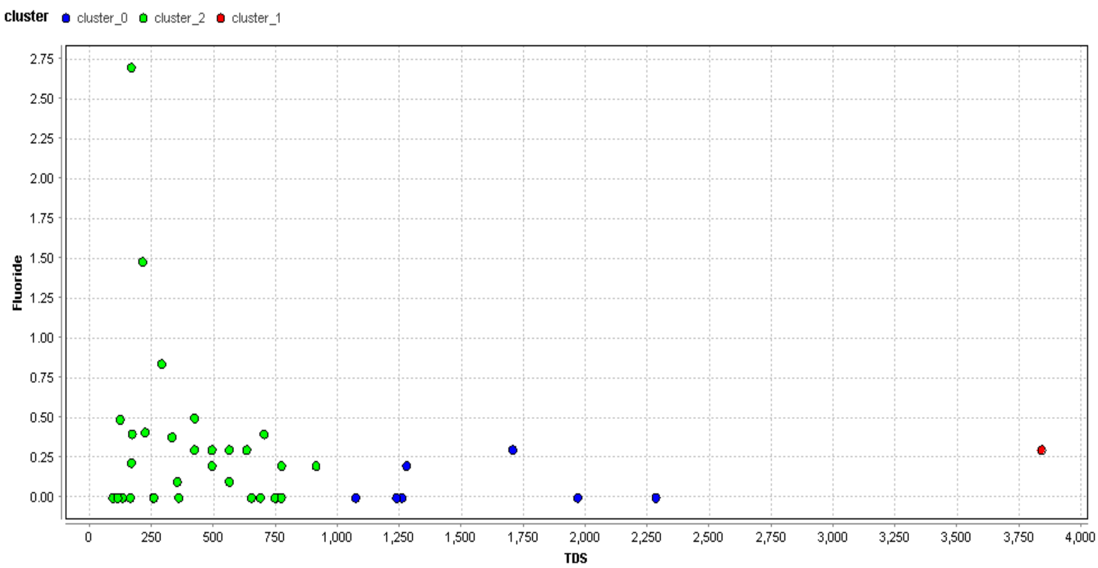

Figure 6. The distribution of cluster over Fluoride/ TDS space (1.5 ppm)

Water quality map

The water quality map shows the distribution of some parameters with spatial geo-information. The concentration distribution of this parameters start from high to moderate according to geological structure, the fluoride distribution concentrated in North-East part and the other parts more acceptable as shown in Fig 7, the rocks of the area consists of fluoride and carbonates, although high concentration of F^- will thus mostly occur in low Ca^{2+} concentration, CaF observe.

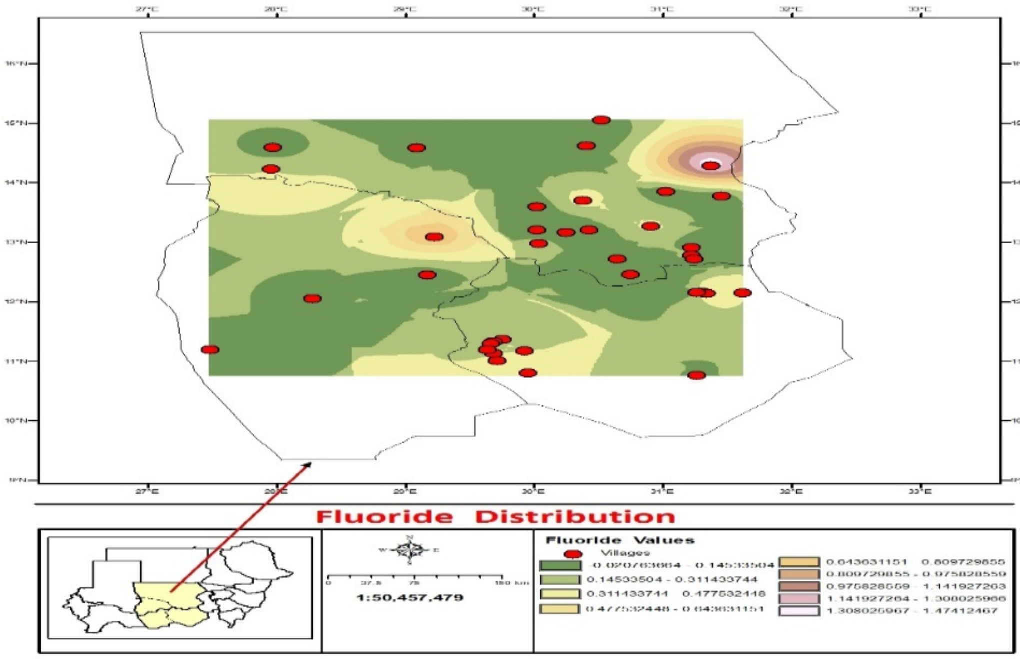

Figure 7. Fluoride distribution

The distribution of hardness occurs high in Eastern Kordofan this is a part of hydrothermal system called Umm Ruwaba basin which consists of fine sediments see Figure 8.

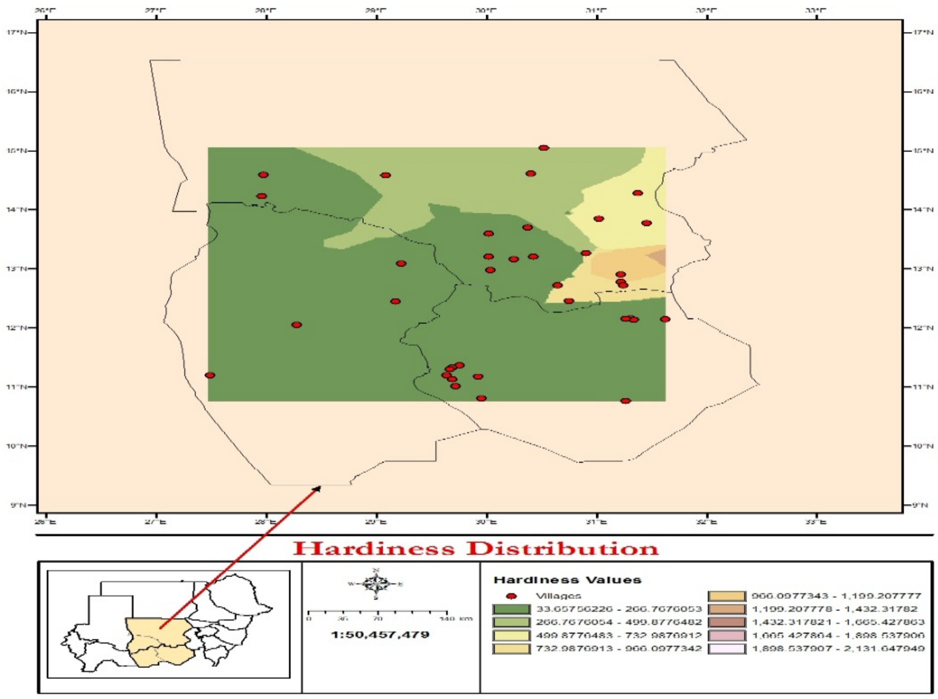

Figure 8. Hardness distribution

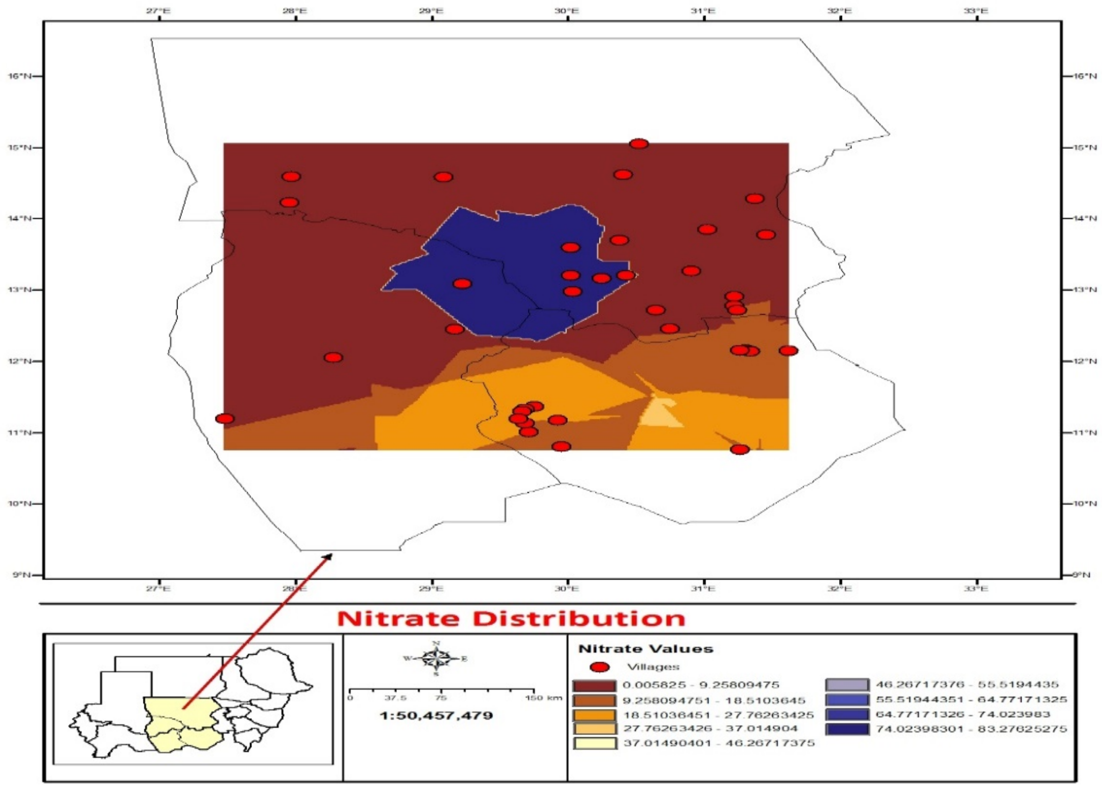

Figure 9. Nitrate distribution in ppm

Water quality index WQI of groundwater in great Kordufan state map present in Fig 10 it apparent that except in few points cases where high in TDS, Fluoride and nitrate contamination in East, North and west regions. In generally there is 7% with Poor water quality, 47% with Marginal quality, we have 45% with Fair and Good quality which are acceptable for most domestic uses. The result raised the importance of periodically checking of groundwater quality.

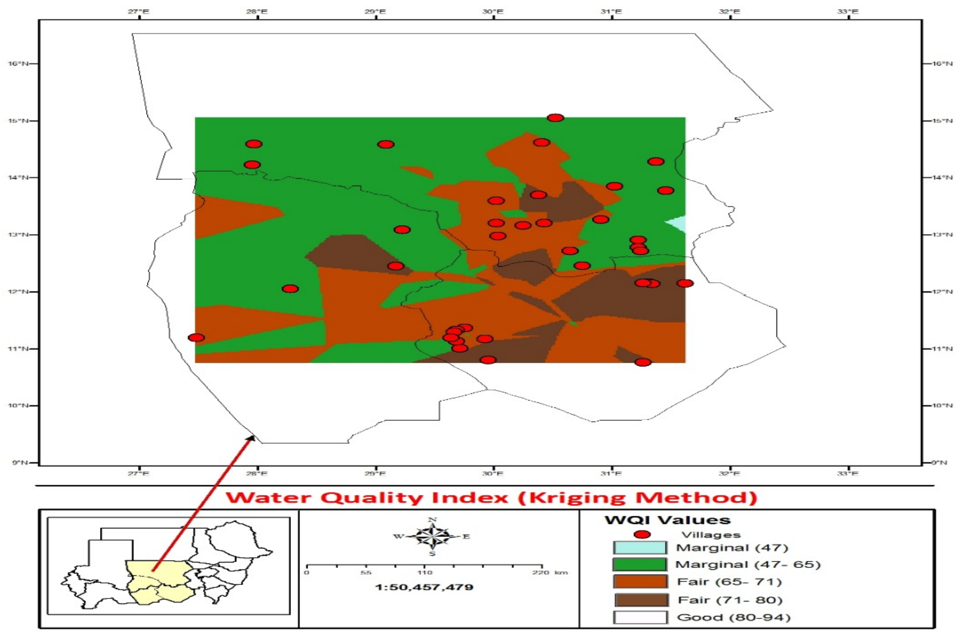

Figure 10. Distribution of water quality index WQI

Potential Health Risk for Kidney

The effect of groundwater quality on health is early observable in many studies. This study aimed to link water quality with health problems in the studied region, consistent with hardness, and calcium North Kordufan reported 3.8% of deaths according to other heart diseases, the sand stone and alkaline rock related to reported disorders of urinary of tract (3% for North Kordofan and 1% of south Kordufan) (Federal Minstery of Health Sudan, 2014). Since we have no access to integrated health's statistics, we will identify the potential risks that were well studied and covered in literature. The concentration of naturally occurring mobile elements may exceed limits of general acceptability for domestic uses. In the present study high concentrations of TDS, nitrite, iron and fluoride which attributed to geological structure of study area, however the reaction between water and bed rocks over time is give the groundwater essential minerals. There is a relationship between drinking water hardness and mortality, especially in men, from cardiovascular diseases. Nitrite oxidized rapidly to nitrate in blood and oxidation of Hb to met-Hb because it oxidize Fe^{2+} to Fe^{3+} in haem group and Fe^{3+} does not allow oxygen transport (Edmunds, W.M &Smedley, 1996; Gorchev & Ozolins, 2011), (Qua, 1998). Iron and magnesium can occur in low pH value, although water with high Mn and Fe concentration is usually unstable in terms of taste and odour. Iron bind to bacteria e.g (Thioacillusferro- oxidants, Gallionella) which is responsible for biofouling of aquifers, in some Fe rich areas it may effect in corrosion pumps and pipework in supply boreholes. Fluoride have great effect on health, it observed in potable water (TDS < 500 ppm) as fluoride ion F^-comprises over 95% of the total fluoride present as magnesium fluoride complex (MgF^-), also bind with aluminum boron, beryllium, ferric, silica, uranium and vanadium, however some fluoride compounds such as fluorosilicates incorporates into developing bone and teeth. And it has beneficial dental effects by reducing the incidence of dental carries and promotes the development of strong bones. Although fluoride have negative effect in health in high concentrations such as renal effects (kidney stone), neurological effects (especially intelligence in children when concentration > of 2 ppm see the Table below.

Table 4. Impact of fluoride in drinking water on health (Edmunds, W.M &Smedley, 1996)

Concentration of fluoride ppm	Impact on health
Nil	Limited growth and fertility
0 – 0.5	Dental caries
0.5 – 1.5	Promote dental health resulting in healthy teeth, prevents tooth decay
1.5 – 4.0	Dental fluorosis (mottling of teeth)
4.0 – 10.0	Dental fluorosis, Skelton fluorosis (pain in back and neck bones)
> 10.0	Crippling fluorosis

Conclusions

Groundwater is the most important water resource in rural areas in Sudan. While it has less exposure to biological contamination it has very dynamic characteristics due to large interaction with rocks and rainfall recharge through topsoil. In this paper we describe how systematic geo-information data can help in deriving insight decision on water provisioning quality and other development aspects. For large data sets, clustering will help a lot in reducing dimensions of analysis, the similarities nature of clustering draw explanation of certain parameters variations in addition to link certain best practices water treatment related to the deviated parameters. In studied data set, there are high concentrations records of TDS, nitrite, iron and fluoride which had a link with health risk. The model easily depicts the WQI and had simple scalability to study through GIS and data science analysis to cover a map of related health, sustainability, and equality justice distribution which will be the subject for further research.

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Design and Development of Intelligent Maternal Health Care Booster

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Abstract

Historical statistics and perspective illustrates that complications related to pregnancy and childbirth are among the leading causes of morbidity and mortality among Kenyan women. Recent estimates suggest that there are about 400 maternal deaths per 100,000 live births, representing a 1 in 25 lifetime risk of dying from a maternal-related cause .Hospital based studies suggest that the majority of these deaths are due to obstetric complications, including hemorrhage, sepsis, eclampsia and obstructed labor. Only 42 percent of women have a skilled attendant present at delivery, while 28 percent of women deliver with a traditional birth attendant (TBA). Despite the Beyond Zero campaign, an initiative by the first lady, commitment to maternal health care, Kenya continues to make slow progression due to poor actualization of the project. This comes about as a result of poor communication between the medics and the beneficiaries, and slow response from the medics. The nation hence needs quality service provision that is convenient, reliable, time-bound and affordable, an automated and well coordinated mobile clinics service that meets the pertinent needs of our mothers and infants. This research will involve a web design and development of wrist bands for the beneficiaries of the mobile clinics, a wearable technology that rides on the GPS module tracking system. The mobile clinics will have trackers, GPRS will provide the position while the GSM in the wrist band will send the information in form of a text. The website will avail information about maternal health care, where mothers and would-be-mothers will have access to some of the issues that would matter in their situation e.g. Maternal Health programs, emergency provision details, accessibility to nearest mobile clinic, New-born Health monitoring and infant check-up schedule and assignments to the mobile clinic attendants. Hence Consistency on health service provision and reduction of infant mortality rate by the Beyond Zero initiative in conjunction with this study's product.

Key Words: Maternal-related, New-born, Consistency, Beyond Zero, reduction.

Introduction

Currently the human race has been befallen by cultural change seized by manmade progeny. Amongst the many achievements by human beings, one evident accomplishment lies in wearable technology. Through the history and development of wearable computing, pioneers have attempted to enhance or extend the functionality of clothing, or to create wearables as accessories able to provide users with sousveillance1, which is the recording of an activity typically by way of small wearable or portable personal technologies. Tracking information like movement, steps and heart rate are all part of the quantified self-movement.

With all of the recent fashion-industry around the Apple Watch, Google Glass, and other cool smart bracelets and fitness trackers, it can be easy to overlook the fact that the concept of wearable technology is not actually all that new. Even before the dawn of computers, people were used to incorporating gadgets into their outfits, from early headsets and clunky portable stereos to eventually the always present Walkman. An example down history would be the abacus ring. Just as the abacus was a precursor to the modern computer, the abacus ring was the forefather of today's wearables. This marvelous 17th-century Chinese implement allowed bean counters to perform mathematical tasks without using the written word, instead moving tiny beads along nine rows - and there were no issues with battery life either. Wearables are either meant to improve what we currently have at hand or create something totally new that improves certain aspects of our lives. Wearables now largely perform two functions: tracking and communication.

Tracking: Wearables, such as Fitbit, are used to measure conditions in the body or around in the immediate environment and then track and monitor these results over time to create a map of changing events.

Communication: A wearable, such as the Apple Watch, can be used for communication by sending and receiving various types of alerts and messages either two-way or one-way.

Wearable technology is the future. It has the potential to be used as widely as mobile technology has. From business accessories to health monitoring, their influence is seen more with the passing years. However, most of these products are not designed with the global south in mind and so we can easily be forgotten in this technological leap with only the elite few participating. The portability of such devices can be of great benefit and have endless applications in our day to day life. We have a very young population and thus a huge market for such devices if they are made affordable and easy to use.

Wearable's have long been used - for example in detecting health disorders such as sleep apnea. Medical professionals such as Google Glass Surgeon even organized themselves in - WATCH Society- the Wearable Technology in Healthcare Society, in order to search for collaboration and valid use of wearable technology in healthcare. Most hospitals do not have access to the high tech equipment and some do not even electricity most of the time. In a country where healthcare is still inaccessible to most of the population innovative ways of detecting and even treating illnesses are required.

Methodology

A development methodology refers to a well-defined framework for structuring, planning, controlling the development process of an information system (Parkin, 1981). This project will involve the development of wristbands for the beneficiaries of the 32 mobile clinics in the 32 counties that have already been launched. This is a wearable technology that rides on the GPS module tracking system.The user will be required to wear a wrist band that will be housing the GPS Module and other supporting hardware ie a service button, a water proof and safety cover.

The mobile clinics will have the tracker. GPRS will provide the position while the GSM will send the information in form of a text. The clinics will also have a database of their prospective subjects. This will form a system programmed and managed by the designer.
The development of this system will employ Structured Systems Analysis and Design Method (SSADM) methodology.

SSADM is a set of standards developed for system's analysis, application design and development. SSADM uses a combination of text and diagrams throughout the whole life cycle of the system design from the initial design to the actual physical design of the application.

There are various reasons for the choice of this methodology

- SSADM is efficient in that it allows one to plan, manage and control a project well . The factors are key in delivering the product on time.
- Through SSADM important emphasis is put on the analysis of user needs. This necessitates the need for a developed and comprehensive demand analysis.
- It offers the possibility to tailor the planning of the project to the actual requirements of the business.
- There is effective use of skills as it does not require high expertise and any special skills

- SSADM also reduces error rate by defining a certain quality level in the beginning and constantly checking the system.
- It separates the logical and physical system designs so that the system does not have to be implemented again with new hardware or software

Diagrammatically the SSADM methodology can be depicted by the figure below.

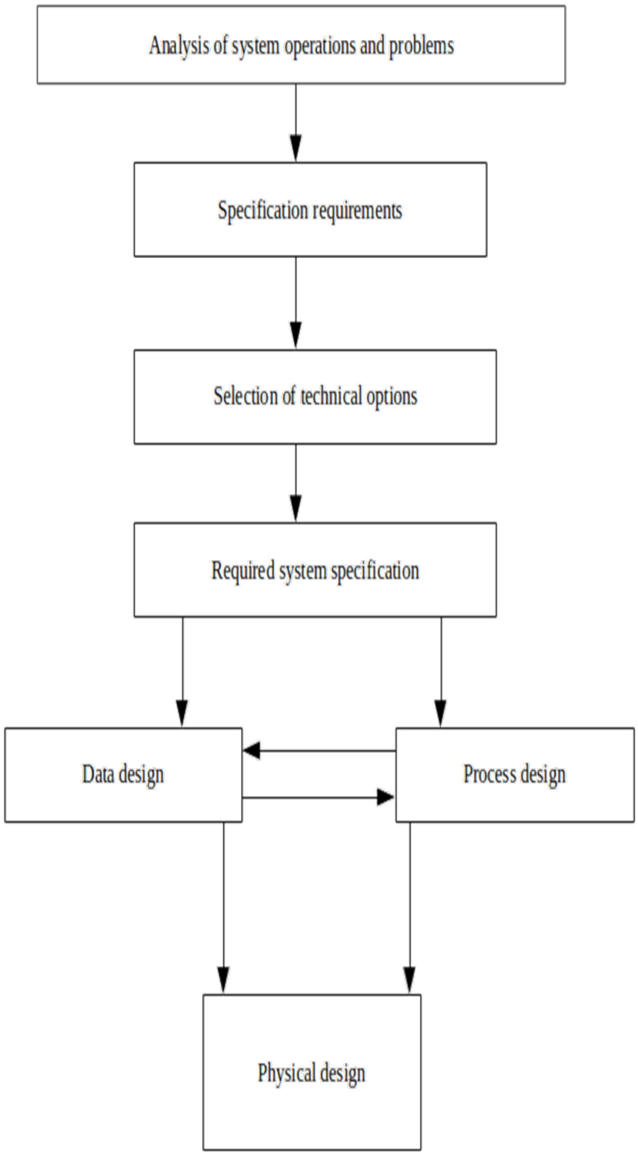

Figure 1. SSADM Methodology

Objectives

- To offer a helping hand to Beyond Zero- Providing real time location of emergency patients.
- To reach the unreachable. Most communities, especially those that live in ASAL (Arid and Semi-Arid Lands) are less populated and scattered, that is so difficult to get

to them in real time. A strategy should hence be employed to make the Beyond Zero initiative effective.

Project Pros

- Reliability and efficiency. The system improves and enhances efficiency of the mobile clinics most especially availability of drugs. When the doctors know the history of their patients from the system records, then in case of emergencies, they will be readily equipped with most likely remedies and services to be delivered, like child delivery and immunisation.
- Consistency on health service provision. With a database and a programme of patient information, the mobile clinics doctors and attendants can have a quick decisive action on diagnosis of their patients.
- Reduction of infant mortality rate. A strategic way of health service provision to the needy, expectant mothers and infant will be regularly monitored thus reducing infant mortality rates, especially in remote areas.
- Reduction of congestion in hospitals. The mobile clinics providing door-to-door services effectively through the help of the system shall reduce hospital visits significantly thus reduction in hospital congestions.

Project Cons and Possible Solutions

- Ignorance. Sensitization on vitality of the use of such wearable technology in conjunction with the Beyond Zero initiative is necessary as the subjects may not comprehend well the complementary service of the technology and the initiative.
- Awareness creation of its use. Creating awareness on existence and importance of such a system is financially and practically a challenge that requires strategic process.
- Technological know-how. The target group is majorly women and children who technologically handicapped and would need prior training.

Conclusion

This webs system stands out as both an effective link between the Beyond Zero mobile clinics initiative and a needy mother as well as convenient antenatal and postnatal information provider in developing and inaccessible parts of the country. Will also conduct alternative analysis to mitigate the constraints incurred in this system and current appropriate options to the society.

Recommendation

Measures should be put in place to ensure a high proportion of the population can use the system effectively. E.g. the government should avail the necessary incentives for the system, e.g. health records and capital, and creating awareness and using other existent initiatives like Beyond Zero Campaigns.

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